SANDIA REPORT
SAND2020-3031
Printed March 2020

Guralp Affinity Digitizer Evaluation

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ABSTRACT

Sandia National Laboratories has tested and evaluated a new digitizer, the Affinity, manufactured by Guralp Systems. This digitizer is used to record sensor output for seismic and infrasound monitoring applications. The purpose of the digitizer evaluation was to measure the performance characteristics in such areas as sensitivity, power, self-noise, dynamic range, system noise, relative transfer function, modified noise power ratio, analog bandwidth, harmonic distortion, common mode, cross talk, timing tag accuracy and timing drift. The Affinity provides eight, rather the typical six, channels of 24 bit high sample rate digitization, all of which may be transmitted utilizing the CD1.1 protocol, at multiple sample rates.
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ACKNOWLEDGEMENTS

This work was funded by the Defense Threat Reduction Agency (DTRA), Nuclear Arms Control Treaty (NACT) program.

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ACRONYMS AND DEFINITIONS

BB	Broadband
CTBTO	Comprehensive Nuclear Test-Ban-Treaty Organization
dB	Decibel
DOE	Department of Energy
DWR	Digital Waveform Recorder
HNM	High Noise Model
LNM	Low Noise Model
PSD	Power Spectral Density
PSL	Primary Standards Laboratory
SNL	Sandia National Laboratories
SP	Short-period

1 INTRODUCTION

Figure 1 Guralp Affinity digitizer. Photo courtesy of Guralp Systems Limited.

The evaluation of the digitizer, serial numbers 40561C, has identified that the unit's performance is consistent with the manufacturer's specifications.

Affinity

güralp

SPECIFICATIONS

SENSOR INPUTS	
Primary digitisation channels	4-channel 31-bit ADC (3 primary; 1 auxiliary)or 8-channel 31-bit ADC (6 primary; 2 auxiliary)
Input voltage	Differential input: 40 V peak-to-peak (± 20 V). Also compatible with single-ended inputs: 20 V peak-to-peak (± 10 V)
Optional environmental channels	8 multiplexed environmental channels ±10 V single-ended or 16 multiplexed environmental channels, ±10 V single-ended
Input impedence	113 kΩ
PERFORMANCE	
ADC converter type	4th-order, single-bit, low-pass Σ-Δ
Output format	32-bit
Dynamic Range	>138 dB at 100 samples per second
Absolute accuracy	0.5 %
Common-mode rejection	>80 dB
DATA PROCESSING	
Output rates available	1 to 4000 samples per second
Highest output capability	20,000 samples per second aggregate
Decimation filters	2, 4, 5.
Anti-alias filters	3-pole
Low pass filters	FIR (other options available)
Out-of-band rejection	140 dB
Data transmission modes	Continuous
Triggered data	Retrievable using event t able in the Affinity web page. User selectable pre and post event time.
Trigger modes	STA/LTA, level (threshold), external, software
TIMING AND CALIBRATION	
Timing source precision	<42 µs drift per hour when unsynchronised (without GPS) < 0.1 µs when GPS is connected
Timing sources	GNSS, PTP and NTP
Calibration signal generator	Amplitude/frequency adjustable, sine, step or broadband noise
OPERATION AND POWER USAGE	
Power supply	9 - 36 V DC*
Power consumption at 12 V DC	
4 channel	1.2 W (no GPS or ethernet)
	1.55 W (GPS with 10 Mb/s Ethernet output)
8 channel	1.5 W (no GPS or ethernet)
	1.85 W (GPS with 10 Mb/s Ethernet output)

**Power voltage for operation of this unit only. Connection to additional instrumentation or use of longer cables may result in a higher input voltage requirement.*

SOFTWARE PROTOCOLS	
Operating system	Linux
Communication technologies supported	RS232, USB, Ethernet (10BASE-T / 100BASE-T)
Internet technologies supported	TCP/IP, PPP, SSH, HTTP, HTTPS (others on request) Firewall and routing capabilities
DATA COMMUNICATION	
Data recording formats	GCF and miniSEED
Seismic network protocols	Scream! (Antelope/Earthworm), CD1.0/1.1, SEEDlink, GDI-Link and others
Data storage	Fixed 64 GB onboard storage Optional external USB storage
PHYSICAL/ENVIRONMENTAL	
Cold-start temperature range Operational temperature range	-25 to +60 °C -40 to +60 °C
Relative humidity range	zero to 100 %
Enclosure ingress protection	IP68 - protection against effects of prolonged immersion at 3 m depth for 72 hours
Enclosure/materials	Stainless steel cylinder
System weight	5.5 Kg (excluding GPS and cables)
Weight with mounting and carry bracket	6.1 Kg (excluding GPS and cables)
Dimensions - cylinder alone	274 mm × 114 Ø, excluding connectors and cables
Dimensions with mounting/ carrying bracket	304 mm × 160 mm × 130 mm, excluding connectors and cables
Standard accessories pack comprises	GNSS receiver (GPS, GLONASS, BeiDou, Galileo) with 10 m Cable (10 way to 10 way); 3 m Power Cable (4 way to Pig-tail); 5 m Ethernet Cable (6 way to Ethernet plug 8P8C); 1.8 m GPIO serial console cable (12 way-USB type A plug); RS422 to RS232 GNSS (GPS) adaptor

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In the interests of continual improvement with respect to design, reliability, function or otherwise, all product specifications and data are subject to change without prior notice.

DAS-AFT-0001 Issue D

Figure 2 Affinity Manufacturer Specifications

2 TEST PLAN

2.1 Test Facility

Testing of the Affinity digitizer was performed at Sandia National Laboratories' Facility for Acceptance, Calibration and Testing (FACT) located near Albuquerque, New Mexico, USA. The FACT site is at approximately 1830 meters in elevation.

Sandia National Laboratories (SNL), Ground-based Monitoring R&E Department has the capability of evaluating the performance of preamplifiers, digitizing waveform recorders and analog-to-digital converters/high-resolution digitizers for geophysical applications.

Tests are based on the Institute of Electrical and Electronics Engineers (IEEE) Standard 1057 for Digitizing Waveform Recorders and Standard 1241 for Analog to Digital Converters. The analyses based on these standards were performed in the frequency domain or time domain as required. When appropriate, instrumentation calibration was traceable to the National Institute for Standards Technology (NIST).

The majority of the Affinity testing were performed within the FACT sites underground bunker due to the bunker's stable temperature.

Figure 3 FACT Site Bunker

Figure 4 Affinity installed on the bunker pier.

The temperature was recorded continuously throughout the testing by a calibrated Vaisala PT300U sensor and was maintained between 22 and 23 degrees Celsius.

Figure 5 Vaisala temperature monitor within the FACT bunker

A GPS re-broadcaster operates within the bunker to provide the necessary timing source for the Affinity digitizer and other recording equipment present.

Figure 6 GPS re-broadcaster

The Affinity digitizer was powered by a Protek 3003B DC Power Supply S/N H011919 laboratory power supply providing approximately 14.0 Volts.

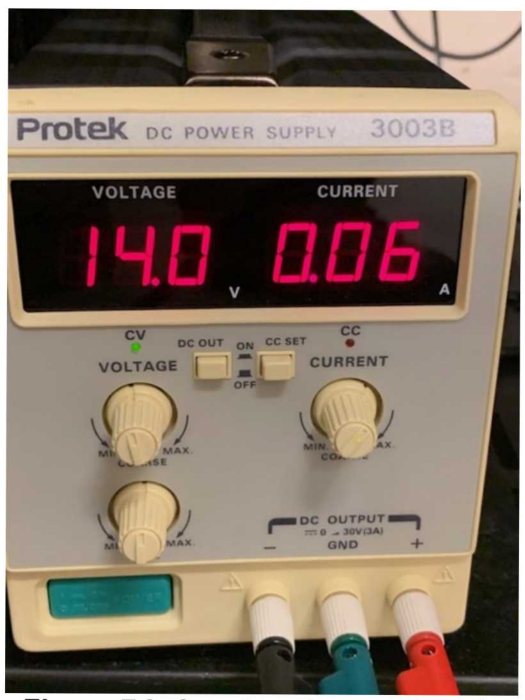

Figure 7 Laboratory Power Supply

2.2 Scope

The following table lists the tests and resulting evaluations that were performed at the various gain levels and sample rates of the Affinity digitizer.

Table 1 Tests performed

Test	Gain	Sample Rates (sps)
AC Accuracy	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
DC Accuracy	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
AC Full Scale	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
AC Over Scale	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
Input Shorted Offset	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
Self Noise	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
Self Noise (-36°C through 50°C)	1x	100, 40 and 20
Dynamic Range	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
System Noise	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
Modified Noise Power Ratio	1x, 8x	100
Response Verification	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
Relative Transfer Function	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
Analog Bandwidth	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
Total Harmonic Distortion	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
Common Mode	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
Cross Talk	1x, 2, 4x, 8x, 16x and 32x	100, 40 and 20
Timing Accuracy (GPS-based)	1x	100, 40 and 20
Timing Drift (GPS-based)	1x	100, 40 and 20
Power Consumption	1x	100, 40 and 20

Channel naming of the data streams followed that recommend by the manufacturer

Table 2 Channel Naming Convention

Port	Digitizer Channel	Channel Name		
-	-	100 sps	40 sps	20 sps
Sensor A	1	HH1	SH1	BH1
Sensor A	2	HH2	SH2	BH2
Sensor A	3	HH3	SH3	BH3
Auxiliary	4	HDF	SDF	BDF
Sensor B	5	HH5	SH5	BH5
Sensor B	6	HH6	SH6	BH6
Sensor B	7	HH7	SH7	BH7
Auxiliary	8	HH8	SH8	BH8

2.3 Timeline

Testing of the Affinity digitizer was performed at Sandia National Laboratories between March 6, 2019 and September 17, 2019.

3 TEST EVALUATION

3.1 Input Impedance

The Input Impedance test is used to measure the real DC input impedance of a digitizer recording channel during its operation.

3.1.1 Measurand

The quantity being measured is ohms of impedance.

3.1.2 Configuration

The digitizer is connected to a meter configured to measure impedance as shown in the diagram below.

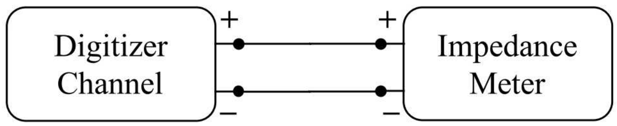

Figure 8 Input Impedance Configuration Diagram

Figure 9 Input Impedance Configuration Picture

Table 3 Input Impedance Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
Impedance Meter	Agilent 3458A	MY45048371	Ohms

The meter used to measure impedance has an active calibration from the Primary Standard Laboratory at Sandia.

3.1.3 Analysis

Measurements of the average impedance from each digitizer input channel are taken from the meter, preferably from a time-series recording:

3.1.4 Result

A representative waveform plot of impedance, acquired from the meter, is shown below. The measured impedance values for each of the digitizer channels are shown in the table below.

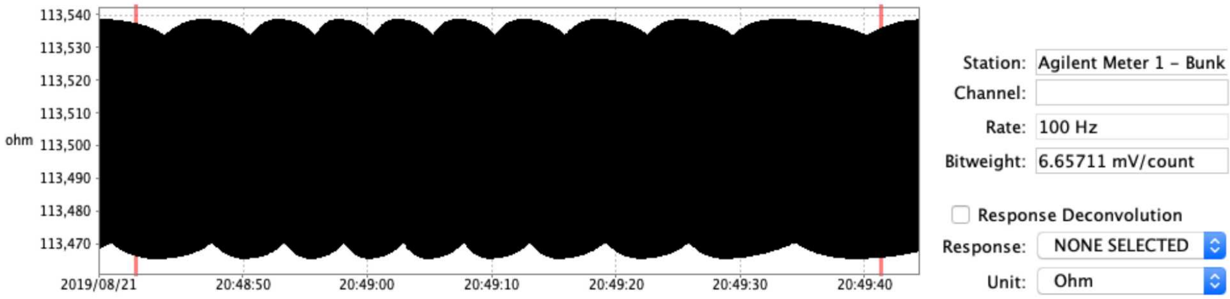

Figure 10 Impedance time series

Table 4 Impedance Results

	Channel			
Gain	1	2	3	4
1x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
2x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
4x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
8x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
16x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
32x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
	Channel			
Gain	5	6	7	8
1x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
2x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
4x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
8x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
16x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm
32x	113.5 kohm	113.5 kohm	113.5 kohm	113.5 kohm

The measured input impedance of the Affinity primary digitizer channels were all within 0.45 % of their nominal specification of 113 kohm.

3.2 Power Consumption

The Power Consumption test is used to measure the amount of power that an actively powered digitizer consumes during its operation.

3.2.1 Measurand

The quantity being measured is the average watts of power consumption via the intermediary measurements of the voltage and current.

3.2.2 Configuration

The digitizer is connected to a power supply, current meter, and voltage meter as shown in the diagram below.

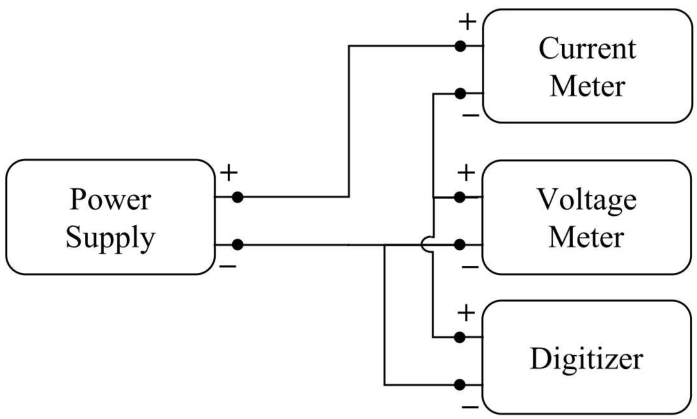

Figure 11 Power Consumption Configuration Diagram

Figure 12 Power Consumption Configuration Picture

Table 5 Power Consumption Testbed Equipment

	Manufacturer / Model	Serial Number	Configuration
Power Supply	Protek 3003B	H011919	14.0 V
Current Meter	Agilent 3458A	MY45048371	Amps
Voltage Meter	Agilent 3458A	MY45048372	100 V full scale

The meters used to measure current and voltage have active calibrations from the Primary Standard Laboratory at Sandia.

3.2.3 Analysis

Measurements of the average current and voltage from the power supply are taken from the respective meters, preferably from a time-series recording:

$$V \text{ and } I$$

The average power in watts is then calculated as the product of the current and voltage:

$$P = V * I$$

3.2.4 Result

The resulting voltage, current, and power consumption levels are shown in the figure and table below.

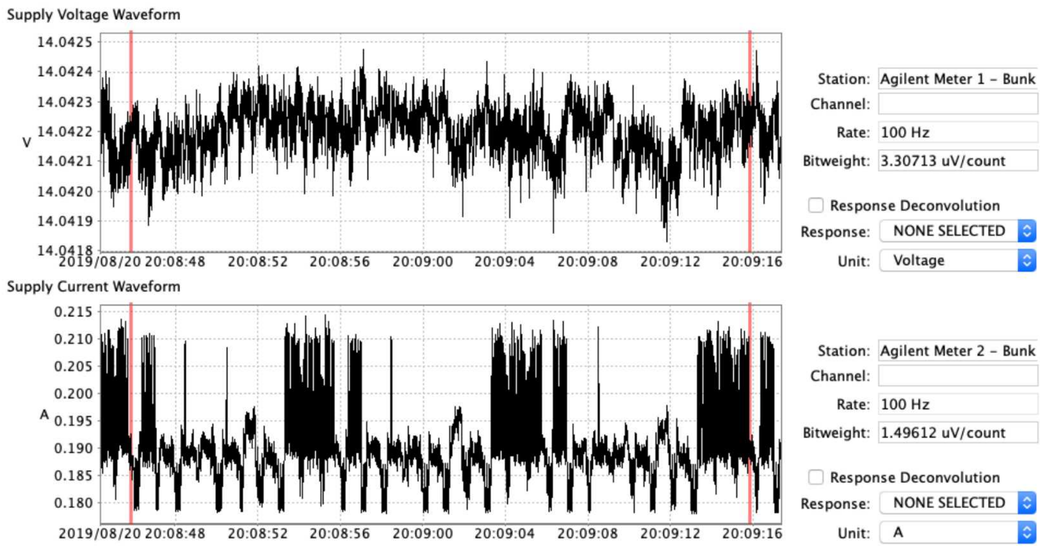

Figure 13 Voltage and Current Recorded Time Series

Table 6 Power Consumption Results

DWR	Supply Voltage	Supply Voltage SD	Supply Current	Supply Current SD	Power Consumption	Power Consumption SD
2453	14.04 V	89.5 uV	0.1906 A	7.788 mA	2.676 W	109.4 mW

The Affinity digitizer was observed to consume 2.676 watts of power while configured with a gain of 1x, recording data at 100 sps, 40 sps and 20 sps from the eight digitizer channels, authenticating and transmitting the eight data channels at the aforementioned sample rates through its ethernet port. While this power consumption is higher than the manufacturer specified (1.85 W), the manufacturer specifications do not include the task of data authentication, which would be expected to increase power consumption.

3.3 DC Accuracy

The DC Accuracy test is used to measure the bit-weight of a digitizer channel by recording a known positive and negative dc signal at a reference voltage from a precision voltage source.

3.3.1 Measurand

The quantity being measured is the digitizer input channels bit-weight in Volts/count.

3.3.2 Configuration

The digitizer is connected to a DC signal source and a meter configured to measure voltage as shown in the diagram below.

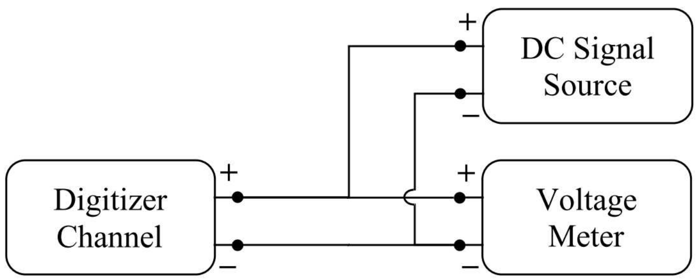

Figure 14 DC Accuracy Configuration Diagram

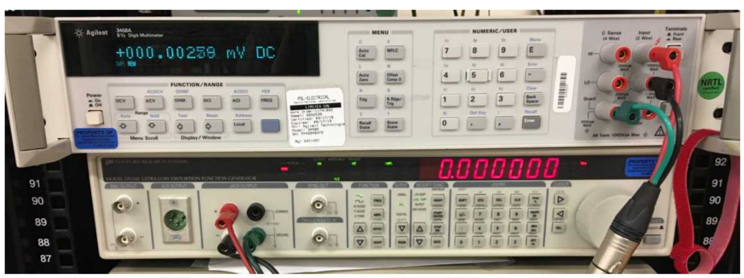

Figure 15 DC Accuracy Configuration Picture

Table 7 DC Accuracy Testbed Equipment

Type	Manufacturer / Model	Serial Number	Nominal Configuration
DC Signal Source	Stanford Research Systems, DS3360	123762	+1V / - 1 V
Voltage Meter	Agilent 3458A	MY45048371	1 V full scale

The DC Signal Source is configured to generate a DC voltage with an amplitude of approximately 10% of the digitizer input channel's full scale. One minute of data is recorded with a positive amplitude followed by one minute of data with a negative amplitude.

The meter and the digitizer channel record the described DC voltage signal simultaneously. The recording made on the meter is used as the reference for comparison against the digitizer channel. The meter is configured to record at 100 Hz.

The meter used to measure the voltage time series has an active calibration from the Primary Standard Laboratory at Sandia.

3.3.3 Analysis

A minimum of a thirty-second-time window is defined on the data for each of the positive and negative voltage signal segment.

The average of each of the positive and negative segments are computed from the reference meter in volts:

$$V_{pos} \text{ and } V_{neg}$$

The average of each of the positive and negative segments are computed from the digitizer channel in counts:

$$C_{pos} \text{ and } C_{neg}$$

The digitizer bit-weight in Volts / count is computed:

$$Bitweight = \frac{V_{pos} - V_{neg}}{C_{pos} - C_{neg}}$$

3.3.4 Result

The figure below shows a representative waveform time series for the recording made on the reference meter and a digitizer channel under test. The window regions bounded by the red and green lines indicate the segment of data used to evaluate the positive and negative regions of data, respectively.

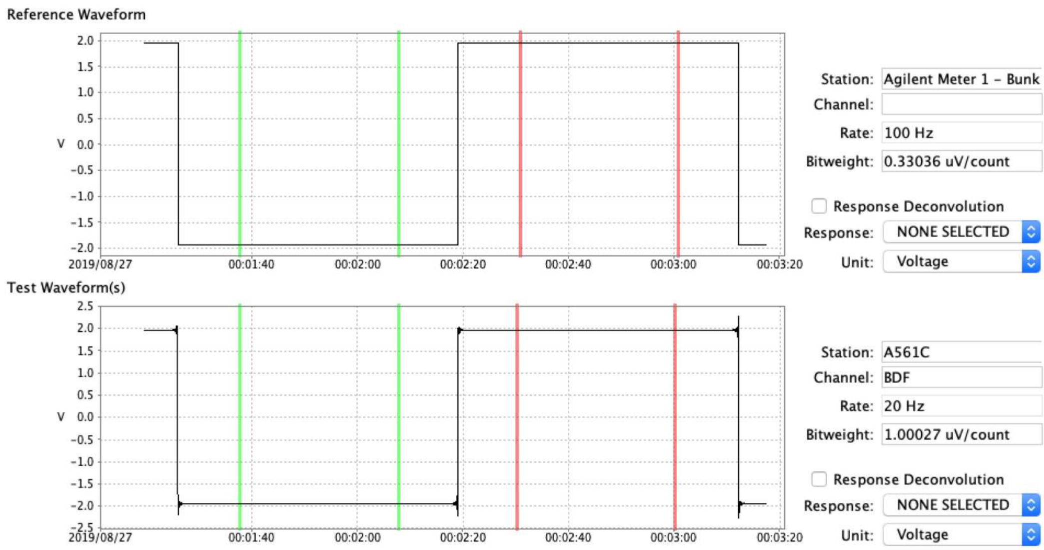

Figure 16 DC Accuracy Example Time Series

The following table contains the computed bit-weights for each of the channels, sample rates, and gain levels.

Table 8 DC Accuracy Bit-weight, 100 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	1.0000 uV/count	1.0000 uV/count	1.0000 uV/count	1.0000 uV/count	1.0001 uV/count	1.0001 uV/count	1.0001 uV/count	1.0001 uV/count
2x	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count
4x	0.2501 uV/count	0.2503 uV/count	0.2502 uV/count	0.2500 uV/count	0.2501 uV/count	0.2502 uV/count	0.2502 uV/count	0.2502 uV/count
8x	0.1250 uV/count	0.1251 uV/count	0.1251 uV/count	0.1252 uV/count	0.1252 uV/count	0.1252 uV/count	0.1251 uV/count	0.1253 uV/count
16x	62.583 nV/count	62.621 nV/count	62.724 nV/count	62.675 nV/count	62.685 nV/count	62.609 nV/count	62.703 nV/count	62.738 nV/count
32x	31.266 nV/count	31.298 nV/count	31.238 nV/count	31.252 nV/count	31.272 nV/count	31.290 nV/count	31.272 nV/count	31.307 nV/count

Table 9 DC Accuracy Bit-weight, 40 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	1.0000 uV/count	1.0000 uV/count	1.0000 uV/count	1.0000 uV/count	1.0001 uV/count	1.0001 uV/count	1.0001 uV/count	1.0001 uV/count
2x	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count
4x	0.2501 uV/count	0.2503 uV/count	0.2502 uV/count	0.2500 uV/count	0.2501 uV/count	0.2502 uV/count	0.2502 uV/count	0.2502 uV/count
8x	0.1250 uV/count	0.1251 uV/count	0.1251 uV/count	0.1252 uV/count	0.1252 uV/count	0.1252 uV/count	0.1251 uV/count	0.1253 uV/count
16x	62.583 nV/count	62.621 nV/count	62.724 nV/count	62.676 nV/count	62.685 nV/count	62.609 nV/count	62.703 nV/count	62.738 nV/count
32x	31.266 nV/count	31.298 nV/count	31.238 nV/count	31.252 nV/count	31.272 nV/count	31.290 nV/count	31.272 nV/count	31.307 nV/count

Table 10 DC Accuracy Bit-weight, 20 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	1.0000 uV/count	1.0000 uV/count	1.0000 uV/count	1.0000 uV/count	1.0001 uV/count	1.0001 uV/count	1.0001 uV/count	1.0001 uV/count
2x	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count
4x	0.2501 uV/count	0.2503 uV/count	0.2502 uV/count	0.2500 uV/count	0.2501 uV/count	0.2502 uV/count	0.2502 uV/count	0.2502 uV/count
8x	0.1250 uV/count	0.1251 uV/count	0.1251 uV/count	0.1252 uV/count	0.1252 uV/count	0.1252 uV/count	0.1251 uV/count	0.1253 uV/count
16x	62.583 nV/count	62.621 nV/count	62.724 nV/count	62.6755 nV/count	62.685 nV/count	62.609 nV/count	62.703 nV/count	62.738 nV/count
32x	31.266 nV/count	31.298 nV/count	31.238 nV/count	31.252 nV/count	31.272 nV/count	31.290 nV/count	31.272 nV/count	31.307 nV/count

Table 11 Nominal Bit-weights

Gain	Bit-weight
1x	1.0000 uV/count
2x	0.5000 uV/count
4x	0.2500 uV/count
8x	0.1250 uV/count
16x	62.50 nV/count
32x	31.25 nV/count

Observed bit-weights, at a gain of 1, varied no more than 0.009% from nominal; as gains increased through 16, maximum variation in bit-weights, from their respective nominal values, increasingly diverged as much -0.3811% at 16. At a gain of 32x though, the maximum variation from nominal across sample rates was -0.1811%.

3.4 AC Accuracy

The AC Accuracy test is used to measure the bit-weight of a digitizer channel by recording a known AC signal at a reference voltage from a precision voltage source.

3.4.1 Measurand

The quantity being measured is the digitizer input channels bit-weight in volts/.

3.4.2 Configuration

The digitizer is connected to an AC signal source and a meter configured to measure voltage as shown in the diagram below.

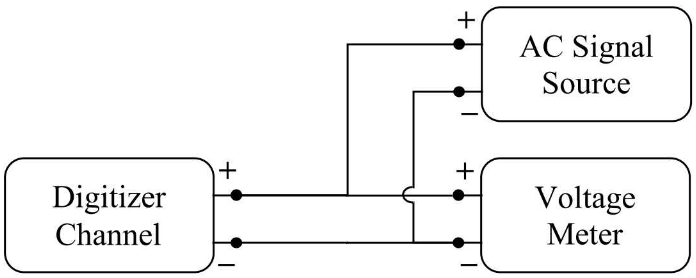

Figure 17 AC Accuracy Configuration Diagram

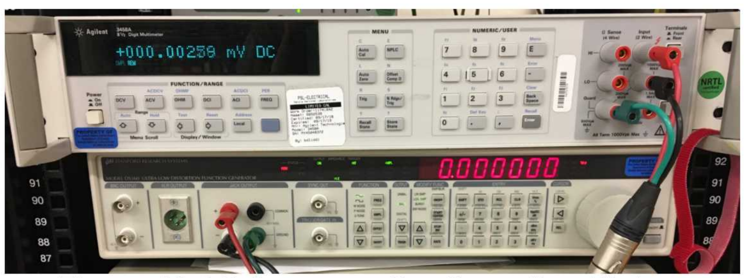

Figure 18 AC Accuracy Configuration Picture

Table 12 AC Accuracy Testbed Equipment

Type	Manufacturer / Model	Serial Number	Nominal Configuration
DC Signal Source	Stanford Research Systems, DS3360	123762	+1V / - 1 V
Voltage Meter	Agilent 3458A	MY45048371	1 V full scale

The AC Signal Source is configured to generate an AC voltage with an amplitude of approximately 10% of the digitizer input channel's full scale and a frequency equal to the calibration frequency of 1 Hz. One minute of data is recorded.

The meter and the digitizer channel record the described AC voltage signal simultaneously. The recording made on the meter is used as the reference for comparison against the digitizer channel. The meter is configured to record at 100 Hz, which is a minimum of 100 times the frequency of the signal of interest in order to reduce the Agilent 3458A Meter's response roll-off at 1 Hz to less than 0.01 %. The meter used to measure the voltage time series has an active calibration from the Primary Standard Laboratory at Sandia.

3.4.3 Analysis

A minimum of 10 cycles, or 10 seconds at 1 Hz, of data is defined on the data for the recorded signal segment.

A four parameter sine fit (Merchant, 2011; IEEE-STD1281) is applied to the time segment from the reference meter in Volts and the digitizer channel in Counts in order to determine the sinusoid's amplitude, frequency, phase, and DC offset:

$$V_{ref} \sin\left(2\, pi\, f_{ref}\, t + \theta_{ref}\right) + V_{dc}$$

$$C_{meas} \sin(2\, pi\, f_{meas}\, t + \theta_{meas}\,) + C_{dc}$$

The digitizer bit-weight in Volts / count is computed:

$$Bitweight = \frac{V_{ref}}{C_{meas}}$$

3.4.4 Result

The figure below shows a representative waveform time series for the recording made on the reference meter and a digitizer channel under test. The window regions bounded by the red lines indicate the segment of data used for analysis.

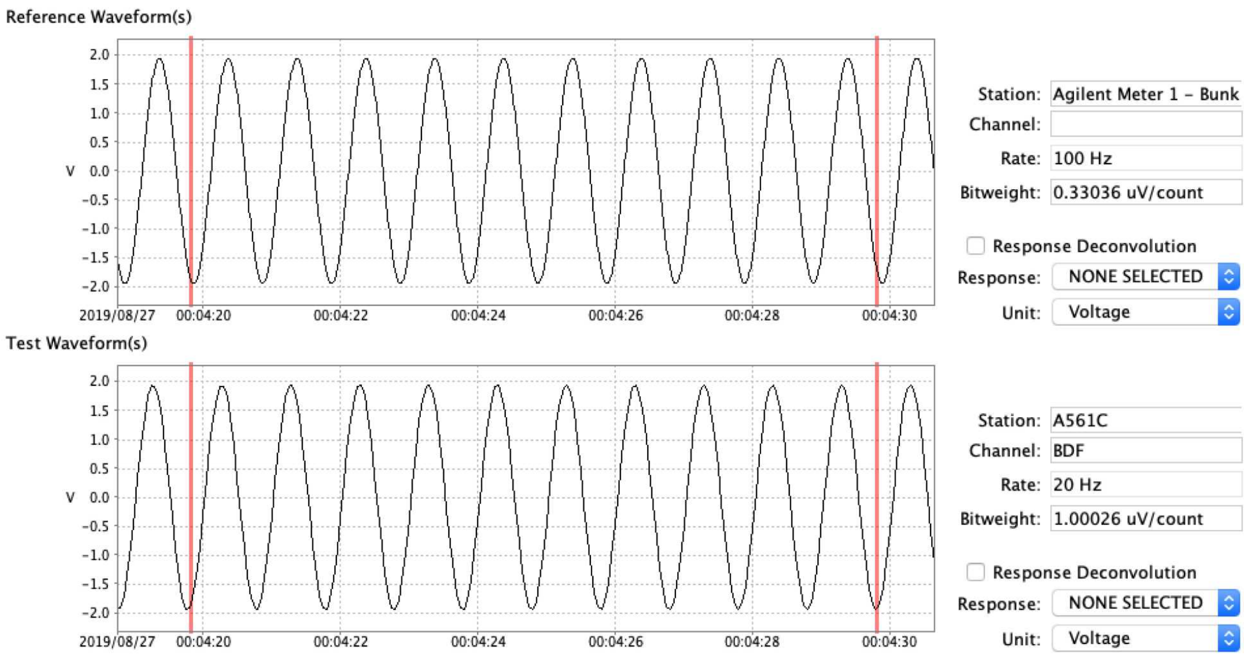

Figure 19 AC Accuracy Test Example Time Series

The following table contains the computed bit-weights for each of the channels, sample rates, and gain levels.

Table 13 AC Accuracy Bit-weight, 100 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	1.0001 uV/count	1.0001 uV/count	1.0001 uV/count	1.0001 uV/count	1.0002 uV/count	1.0002 uV/count	1.0002 uV/count	1.0002 uV/count
2x	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5003 uV/count	0.5002 uV/count	0.5003 uV/count	0.5002 uV/count
4x	0.2501 uV/count	0.2504 uV/count	0.2502 uV/count	0.2501 uV/count	0.2502 uV/count	0.2502 uV/count	0.2502 uV/count	0.2502 uV/count
8x	0.1250 uV/count	0.1251 uV/count	0.1251 uV/count	0.1252 uV/count	0.1252 uV/count	0.1252 uV/count	0.1251 uV/count	0.1253 uV/count
16x	62.588 nV/count	62.626 nV/count	62.729 nV/count	62.681 nV/count	62.690 nV/count	62.614 nV/count	62.708 nV/count	62.743 nV/count
32x	31.269 nV/count	31.301 nV/count	31.241 nV/count	31.255 nV/count	31.275 nV/count	31.293 nV/count	31.275 nV/count	31.310 nV/count

Table 14 AC Accuracy Bit-weight, 40 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	1.0000 uV/count	1.0001 uV/count	1.0000 uV/count	1.0000 uV/count	1.0001 uV/count	1.0001 uV/count	1.0001 uV/count	1.0001 uV/count
2x	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5002 uV/count	0.5003 uV/count	0.5002 uV/count
4x	0.2501 uV/count	0.2503 uV/count	0.2502 uV/count	0.2501 uV/count	0.2501 uV/count	0.2502 uV/count	0.2502 uV/count	0.2502 uV/count
8x	0.1250 uV/count	0.1251 uV/count	0.1251 uV/count	0.1252 uV/count	0.1252 uV/count	0.1252 uV/count	0.1251 uV/count	0.1253 uV/count
16x	62.586 nV/count	62.624 nV/count	62.726 nV/count	62.678 nV/count	62.688 nV/count	62.611 nV/count	62.705 nV/count	62.741 nV/count
32x	31.268 nV/count	31.300 nV/count	31.240 nV/count	31.253 nV/count	31.274 nV/count	31.291 nV/count	31.274 nV/count	31.308 nV/count

Table 15 AC Accuracy Bit-weight, 20 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	1.0003 uV/count	1.0003 uV/count	1.0003 uV/count	1.0003 uV/count	1.0003 uV/count	1.0004 uV/count	1.0004 uV/count	1.0004 uV/count
2x	0.5003 uV/count	0.5003 uV/count	0.5003 uV/count	0.5003 uV/count	0.5003 uV/count	0.5003 uV/count	0.5004 uV/count	0.5003 uV/count
4x	0.2501 uV/count	0.2504 uV/count	0.2502 uV/count	0.2501 uV/count	0.2502 uV/count	0.2503 uV/count	0.2503 uV/count	0.2502 uV/count
8x	0.1250 uV/count	0.1252 uV/count	0.1251 uV/count	0.1253 uV/count	0.1252 uV/count	0.1252 uV/count	0.1251 uV/count	0.1254 uV/count
16x	62.600 nV/count	62.638 nV/count	62.740 nV/count	62.692 nV/count	62.702 nV/count	62.625 nV/count	62.720 nV/count	62.755 nV/count
32x	31.275 nV/count	31.307 nV/count	31.247 nV/count	31.260 nV/count	31.281 nV/count	31.299 nV/count	31.281 nV/count	31.315 nV/count

The bit-weights provided by Guralp are as provided in Table 11 Nominal Bit-weights.

Similar to DC Accuracy Test results, the maximum deviation from nominal bit-weights of all sample rates increased with increase in gain, up to a gain of 16x.

Maximum deviation from nominal bit-weights across all gain settings was 0.408% for the 20 sps data at a gain of 16x. A gain of 1x provided the lowest maximum variation in gain from nominal across all channels, 0.016% for 100 sps data.

3.5 AC Full Scale

The AC Full Scale test is used to validate the nominal full scale of a digitizer channel by recording a known AC signal with a voltage equal to the manufacturer's nominal full scale.

3.5.1 Measurand

The quantity being measured is the digitizer input channels full scale in volts.

3.5.2 Configuration

The digitizer is connected to a AC signal source and a meter configured to measure voltage as shown in the diagram below.

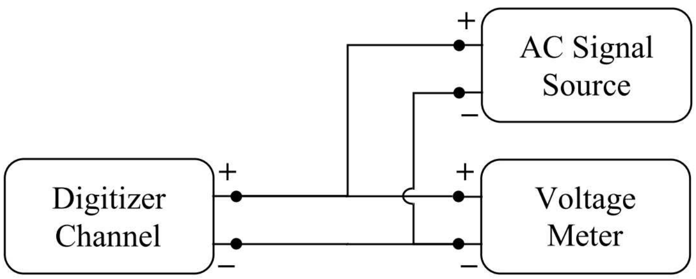

Figure 20 AC Full Scale Configuration Diagram

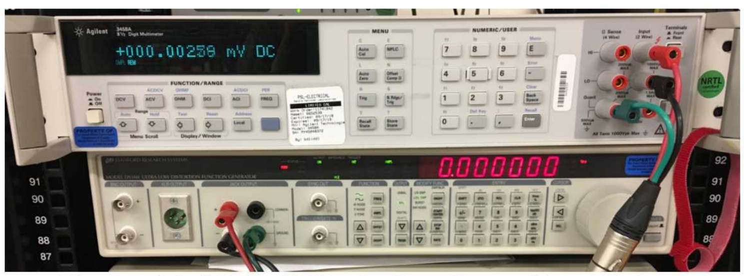

Figure 21 AC Full Scale Configuration Picture

Table 16 AC Full Scale Testbed Equipment

Type	Manufacturer / Model	Serial Number	Nominal Configuration
DC Signal Source	Stanford Research Systems, DS3360	123762	+20V / -20 V
Voltage Meter	Agilent 3458A	MY45048371	100 V full scale

The AC Signal Source is configured to generate an AC voltage with an amplitude equal to the digitizer input channel's full scale and a frequency equal to the calibration frequency of 1 Hz. One minute of data is recorded.

The meter and the digitizer channel record the described AC voltage signal simultaneously. The recording made on the meter is used as the reference for comparison against the digitizer channel. The meter is configured to record at 100 Hz, which is a minimum of 100 times the frequency of the signal of interest in order to reduce the Agilent 3458A Meter's response roll-off at 1 Hz to less than 0.01 %. The meter used to measure the voltage time series has an active calibration from the Primary Standard Laboratory at Sandia.

3.5.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n], \qquad 0 \leq n \leq N-1$$

A short window is defined on the data around one of peak of the positive and negative peaks. The value within each positive and negative window is recorded.

The time series data is compared against the reference to verify that there is no visible limiting of the values near the full scale.

3.5.4 Result

The figure below shows a representative waveform time series for the recording made on the reference meter and a digitizer channel under test. The window regions bounded by the red and green lines indicate the segment of data used to evaluate the positive and negative regions of data, respectively.

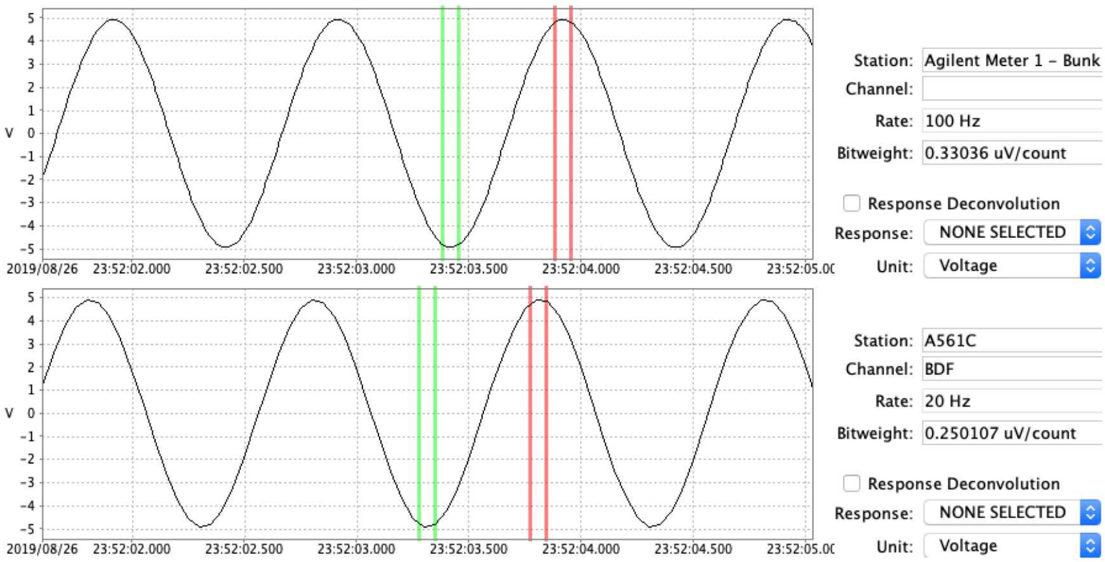

Figure 22 AC Full Scale Time Series

The following tables contain the computed positive peak, negative peak, and peak-to-peak voltages ranges for each of the channels, sample rates, and gain levels.

Table 17 AC Full Scale Positive Peak, 100 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	19.7050 V	19.7000 V	19.7000 V	19.7000 V	19.7000 V	19.7000 V	19.7000 V	19.7000 V	19.7000 V
2x	9.8531 V	9.8519 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V
4x	4.9261 V	4.9257 V	4.9256 V	4.9256 V	4.9256 V	4.9257 V	4.9257 V	4.9256 V	4.9257 V
8x	2.4871 V	2.4880 V	2.4880 V	2.4880 V	2.4880 V	2.4880 V	2.4880 V	2.4880 V	2.4880 V
16x	1.2433 V	1.2431 V	1.2431 V	1.2431 V	1.2431 V	1.2431 V	1.2431 V	1.2431 V	1.2431 V
32x	0.6215 V	0.6217 V	0.6217 V	0.6217 V	0.6216 V	0.6217 V	0.6216 V	0.6216 V	0.6217 V

Table 18 AC Full Scale Positive Peak, 40 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	19.7050 V	19.6580 V	19.6580 V	19.6580 V	19.6580 V	19.6580 V	19.6580 V	19.6580 V	19.6580 V
2x	9.8531 V	9.8519 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V
4x	4.9261 V	4.9197 V	4.9197 V	4.9197 V	4.9196 V	4.9197 V	4.9197 V	4.9197 V	4.9197 V
8x	2.4871 V	2.4856 V	2.4856 V	2.4856 V	2.4855 V	2.4855 V	2.4855 V	2.4855 V	2.4856 V
16x	1.2433 V	1.2425 V	1.2425 V	1.2425 V	1.2425 V	1.2425 V	1.2425 V	1.2425 V	1.2425 V
32x	0.6215 V	0.6217 V	0.6217 V	0.6217 V	0.6216 V	0.6217 V	0.6216 V	0.6216 V	0.6217 V

Table 19 AC Full Scale Positive Peak, 20 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	19.7050 V	19.6320 V	19.6320 V	19.6320 V	19.6320 V	19.6320 V	19.6320 V	19.6320 V	19.6320 V
2x	9.8531 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V	9.8518 V
4x	4.9261 V	4.9012 V	4.9012 V	4.9012 V	4.9011 V	4.9012 V	4.9012 V	4.9012 V	4.9012 V
8x	2.4871 V	2.4731 V	2.4731 V	2.4731 V	2.4731 V	2.4731 V	2.4731 V	2.4731 V	2.4731 V
16x	1.2433 V	1.2425 V	1.2425 V	1.2425 V	1.2425 V	1.2425 V	1.2425 V	1.2425 V	1.2425 V
32x	0.6215 V	0.6217 V	0.6217 V	0.6217 V	0.6217 V	0.6217 V	0.6217 V	0.6217 V	0.6217 V

Table 20 AC Full Scale Negative Peak, 100 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-19.7570 V	-19.7470 V	-19.7480 V	-19.7480 V	-19.7480 V	-19.7480 V	-19.7480 V	-19.7480 V	-19.7470 V
2x	-9.8782 V	-9.8760 V	-9.8761 V	-9.8760 V	-9.8760 V	-9.8760 V	-9.8760 V	-9.8760 V	-9.8760 V
4x	-4.9387 V	4.9256 V	4.9257 V	4.9256 V	4.9256 V	4.9257 V	4.9257 V	4.9256 V	4.9257 V
8x	-2.4950 V	-2.4951 V	-2.4951 V	-2.4951 V	-2.4951 V	-2.4951 V	-2.4951 V	-2.4951 V	-2.4951 V
16x	-1.2463 V	-1.2462 V	-1.2462 V	-1.2462 V	-1.2462 V	-1.2462 V	-1.2462 V	-1.2462 V	-1.2462 V
32x	-0.6232 V	-0.6234 V	-0.6233 V	-0.6234 V	-0.6233 V	-0.6234 V	-0.6234 V	-0.6234 V	-0.6233 V

Table 21 AC Full Scale Negative Peak, 40 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-19.7570 V	-19.7190 V	-19.7190 V	-19.7190 V	-19.7190 V	-19.7190 V	-19.7190 V	-19.7190 V	-19.7190 V
2x	-9.8782 V	-9.8760 V	-9.8760 V	-9.8760 V	-9.8760 V	-9.8760 V	-9.8760 V	-9.8760 V	-9.8760 V
4x	-4.9387 V	-4.9310 V	-4.9310 V	-4.9309 V	-4.9309 V	-4.9310 V	-4.9310 V	-4.9310 V	-4.9309 V
8x	-2.4950 V	-2.4921 V	-2.4921 V	-2.4921 V	-2.4921 V	-2.4921 V	-2.4921 V	-2.4921 V	-2.4921 V
16x	-1.2463 V	-1.2450 V	-1.2450 V	-1.2450 V	-1.2450 V	-1.2450 V	-1.2450 V	-1.2450 V	-1.2450 V
32x	-0.6232 V	-0.6233 V	-0.6234 V	-0.6234 V	-0.6234 V	-0.6234 V	-0.6234 V	-0.6234 V	-0.6233 V

Table 22 AC Full Scale Negative Peak, 20 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-19.7570 V	-19.6700 V	-19.6700 V	-19.6700 V	-19.6700 V	-19.6700 V	-19.6700 V	-19.6700 V	-19.6700 V
2x	-9.8782 V	-9.8760 V	-9.8760 V	-9.8760 V	-9.8782 V	-9.8760 V	-9.8760 V	-9.8760 V	-9.8760 V
4x	-4.9387 V	-4.9182 V	-4.9182 V	-4.9181 V	-4.9181 V	-4.9182 V	-4.9182 V	-4.9182 V	-4.9181 V
8x	-2.4950 V	-2.4827 V	-2.4827 V	-2.4827 V	-2.4827 V	-2.4827 V	-2.4827 V	-2.4827 V	-2.4827 V
16x	-1.2463 V	-1.2450 V	-1.2450 V	-1.2450 V	-1.2450 V	-1.2450 V	-1.2450 V	-1.2450 V	-1.2450 V
32x	-0.6232 V	-0.6234 V	-0.6234 V	-0.6234 V	-0.6234 V	-0.6234 V	-0.6234 V	-0.6234 V	-0.6234 V

For all sample rates and gain levels, all channels were able to fully resolve the sinusoid with a peak-to-peak amplitude at or near the channels claimed full scale value without any signs of flattening that would indicate that clipping is occurring.

3.6 AC Over Scale

The AC Over Scale test is used to validate the nominal full scale of a digitizer channel by recording a known AC signal with a voltage exceeds to the manufacturer's nominal full scale.

3.6.1 Measurand

The quantity being measured is the digitizer input channels full scale in volts.

3.6.2 Configuration

The digitizer is connected to a AC signal source and a meter configured to measure voltage as shown in the diagram below.

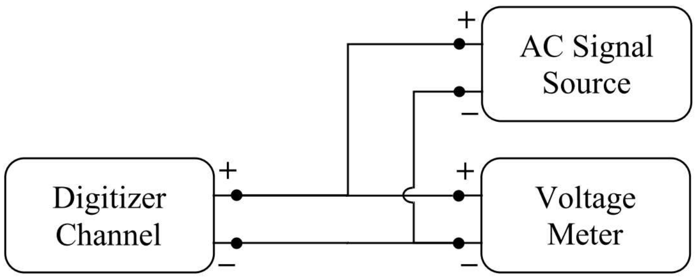

Figure 23 AC Full Scale Configuration Diagram

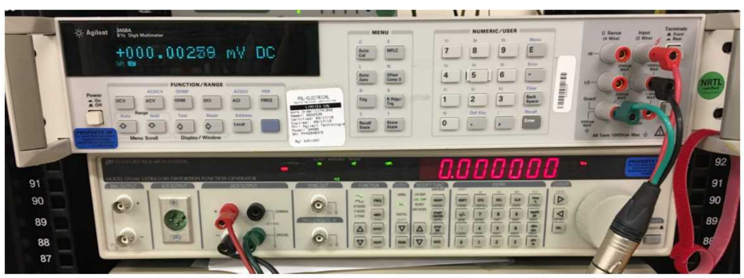

Figure 24 AC Full Scale Configuration Picture

Table 23 AC Over Scale Testbed Equipment

Type	Manufacturer / Model	Serial Number	Nominal Configuration
DC Signal Source	Stanford Research Systems, DS3360	123762	+20V / - 20 V
Voltage Meter	Agilent 3458A	MY45048371	100 V full scale

The AC Signal Source is configured to generate an AC voltage with an amplitude of approximately 110% of the digitizer input channel's full scale and a frequency equal to the calibration frequency of 1 Hz. One minute of data is recorded.

Caution is taken to ensure that the voltage amplitude does not exceed the safety limits of the recording channel and that the test is short in duration to minimize the potential for damage to the equipment.

The meter and the digitizer channel record the described AC voltage signal simultaneously. The recording made on the meter is used as the reference for comparison against the digitizer channel. The meter is configured to record at , which is a minimum of 100 times the frequency of the signal of interest in order to reduce the Agilent 3458A Meter's response roll-off at 1 Hz to less than 0.01 %.

The meter used to measure the voltage time series has an active calibration from the Primary Standard Laboratory at Sandia.

3.6.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n], \qquad 0 \leq n \leq N-1$$

A short window is defined on the data around one of peak of the positive and negative peaks. The value within each positive and negative window is recorded.

The time series data is compared against the reference to verify that there is visible limiting of the values near the full scale.

3.6.4 Result

The figure below shows a representative waveform time series for the recording made on the reference meter and a digitizer channel under test. The window regions bounded by the red and green lines indicate the segment of data used to evaluate the positive and negative regions of data, respectively.

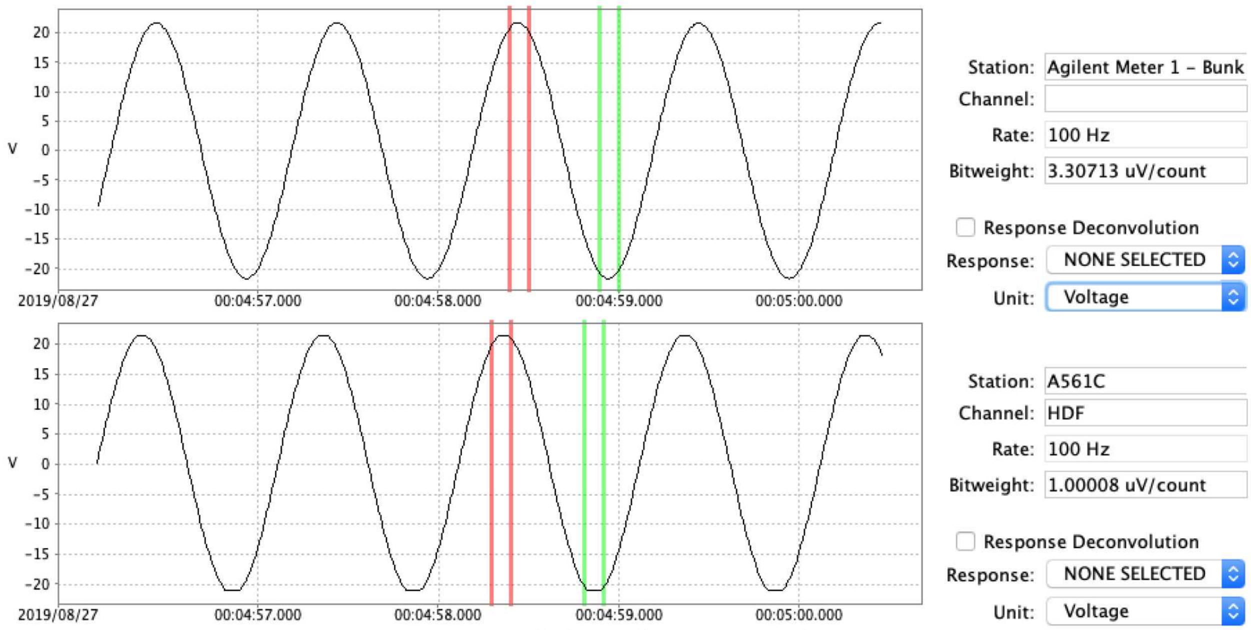

Figure 25 AC Over Scale Time Series

Table 24 AC Over Scale Positive Peak, 100 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	21.6750 V	21.4770 V	21.4970 V	21.4640 V	21.4770 V	21.4840 V	21.4890 V	21.4780 V	21.4750 V
2x	10.8370 V	10.7420 V	10.7530 V	10.7360 V	10.7430 V	10.7460 V	10.7470 V	10.7430 V	10.7390 V
4x	5.4184 V	5.3697 V	5.3815 V	5.3687 V	5.3692 V	5.3729 V	5.3753 V	5.3731 V	5.3711 V
8x	2.7382 V	2.6843 V	2.6905 V	2.6852 V	2.6904 V	2.6892 V	2.6899 V	2.6874 V	2.6920 V
16x	1.3695 V	1.3441 V	1.3463 V	1.3465 V	1.3463 V	1.3469 V	1.3454 V	1.3468 V	1.3474 V
32x	0.6837 V	0.6717 V	0.6730 V	0.6706 V	0.6714 V	0.6720 V	0.6725 V	0.6718 V	0.6724 V

Table 25 AC Over Scale Positive Peak, 40 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	21.6750 V	21.4840 V	21.5020 V	21.4720 V	21.4840 V	21.4910 V	21.4950 V	21.4850 V	21.4820 V
2x	10.8370 V	10.7490 V	10.7590 V	10.7430 V	10.7500 V	10.7530 V	10.7540 V	10.7500 V	10.7470 V
4x	5.4184 V	5.3760 V	5.3878 V	5.3750 V	5.3755 V	5.3792 V	5.3816 V	5.3794 V	5.3774 V
8x	2.7382 V	2.6850 V	2.6908 V	2.6858 V	2.6907 V	2.6895 V	2.6903 V	2.6879 V	2.6923 V
16x	1.3695 V	1.3447 V	1.3467 V	1.3469 V	1.3467 V	1.3472 V	1.3459 V	1.3472 V	1.3477 V
32x	0.6837 V	0.6719 V	0.6730 V	0.6710 V	0.6716 V	0.6722 V	0.6726 V	0.6720 V	0.6725 V

Table 26 AC Over Scale Positive Peak, 20 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	21.6750 V	21.4940 V	21.5070 V	21.4860 V	21.4940 V	21.4990 V	21.5020 V	21.4950 V	21.4920 V
2x	10.8370 V	10.7340 V	10.7410 V	10.7300 V	10.7350 V	10.7370 V	10.7370 V	10.7350 V	10.7330 V
4x	5.4184 V	5.3933 V	5.4008 V	5.3927 V	5.3930 V	5.3954 V	5.3969 V	5.3955 V	5.3942 V
8x	2.7382 V	2.6947 V	2.6998 V	2.6954 V	2.6997 V	2.6987 V	2.6993 V	2.6972 V	2.7011 V
16x	1.3695 V	1.3497 V	1.3515 V	1.3517 V	1.3515 V	1.3520 V	1.3508 V	1.3519 V	1.3524 V
32x	0.6837 V	0.6727 V	0.6738 V	0.6719 V	0.6725 V	0.6730 V	0.6734 V	0.6728 V	0.6733 V

Table 27 AC Over Scale Negative Peak, 100 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-21.7280 V	-21.1620 V	-21.1760 V	-21.1480 V	-21.1550 V	-21.1620 V	-21.1740 V	-21.1580 V	19.9350 V
2x	-10.8660 V	-10.5880 V	-10.5960 V	-10.5830 V	-10.5860 V	-10.5890 V	-10.5930 V	-10.5880 V	-10.5880 V
4x	-5.4343 V	-5.2943 V	-5.3029 V	-5.2932 V	-5.2923 V	-5.2952 V	-5.2987 V	-5.2959 V	-5.2957 V
8x	-2.7465 V	-2.6461 V	-2.6511 V	-2.6468 V	-2.6510 V	-2.6498 V	-2.6514 V	-2.6485 V	-2.6537 V
16x	-1.3740 V	-1.3250 V	-1.3265 V	-1.3269 V	-1.3264 V	-1.3269 V	-1.3260 V	-1.3270 V	-1.3280 V
32x	-0.6855 V	-0.6619 V	-0.6630 V	-0.6610 V	-0.6614 V	-0.6620 V	-0.6627 V	-0.6618 V	-0.6627 V

Table 28 AC Over Scale Negative Peak, 40 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-21.7280 V	-21.1800 V	-21.1930 V	-21.1660 V	-21.1730 V	-21.1800 V	-21.1910 V	-21.1760 V	-21.1790 V
2x	-10.8660 V	-10.5980 V	-10.6050 V	-10.5920 V	-10.5950 V	-10.5980 V	-10.6020 V	-10.5970 V	-10.5970 V
4x	-5.4343 V	-5.3009 V	-5.3086 V	-5.2998 V	-5.2989 V	-5.3018 V	-5.3050 V	-5.3025 V	-5.3023 V
8x	-2.7465 V	-2.6462 V	-2.6502 V	-2.6468 V	-2.6501 V	-2.6491 V	-2.6504 V	-2.6480 V	-2.6528 V
16x	-1.3740 V	-1.3243 V	-1.3259 V	-1.3264 V	-1.3258 V	-1.3264 V	-1.3254 V	-1.3265 V	-1.3275 V
32x	-0.6855 V	-0.6627 V	-0.6636 V	-0.6618 V	-0.6623 V	-0.6628 V	-0.6634 V	-0.6627 V	-0.6634 V

Table 29 AC Over Scale Negative Peak, 20 sps

Gain	Reference	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-21.7280 V	-21.2370 V	-21.2490 V	-21.2240 V	-21.2310 V	-21.2370 V	-21.2470 V	-21.2340 V	-21.2360 V
2x	-10.8660 V	-10.6120 V	-10.6190 V	-10.6060 V	-10.6100 V	-10.6130 V	-10.6160 V	-10.6110 V	-10.6110 V
4x	-5.4343 V	-5.3237 V	-5.3329 V	-5.3224 V	-5.3213 V	-5.3248 V	-5.3286 V	-5.3257 V	-5.3253 V
8x	-2.7465 V	-2.6552 V	-2.6602 V	-2.6559 V	-2.6601 V	-2.6590 V	-2.6605 V	-2.6576 V	-2.6629 V
16x	-1.3740 V	-1.3300 V	-1.3317 V	-1.3323 V	-1.3317 V	-1.3323 V	-1.3312 V	-1.3324 V	-1.3334 V
32x	-0.6855 V	-0.6637 V	-0.6648 V	-0.6627 V	-0.6632 V	-0.6638 V	-0.6645 V	-0.6637 V	-0.6645 V

At all sample rates, applied voltages greater than full scale were observed across all channels with obvious clipping visible in the timeseries, similar to that illustrated in Figure 25 AC Over Scale Time Series.

3.7 Input Shorted Offset
The Input Shorted Offset test measures the amount of DC offset present on a digitizer by collecting waveform data from an input channel that has been shorted. Thus, any signal present on the recorded waveform should be solely due to any internal offset of the digitizer.

3.7.1 Measurand
The quantity being measured is the digitizer input channels DC offset in volts.

3.7.2 Configuration
The digitizer input channel is connected to a shorting resistor as shown in the diagram below.

Figure 26 Input Shorted Offset Configuration Diagram

Figure 27 Input Shorted Offset Termination Resistors

Table 30 Input Shorted Offset Termination Resistors

Channels	Termination Resistor
Primary	100 ohm (50 x 2 ohm)

One hour of data are recorded.

3.7.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n], \qquad 0 \leq n \leq N-1$$

The mean value, in volts, is evaluated:

$$Offset = \frac{1}{N}\sum_{n=0}^{N-1} x[n]$$

3.7.4 Result

The figure below shows a representative waveform time series for the recording made on a digitizer channel under test. The window regions bounded by the red lines indicate the segment of data used for analysis.

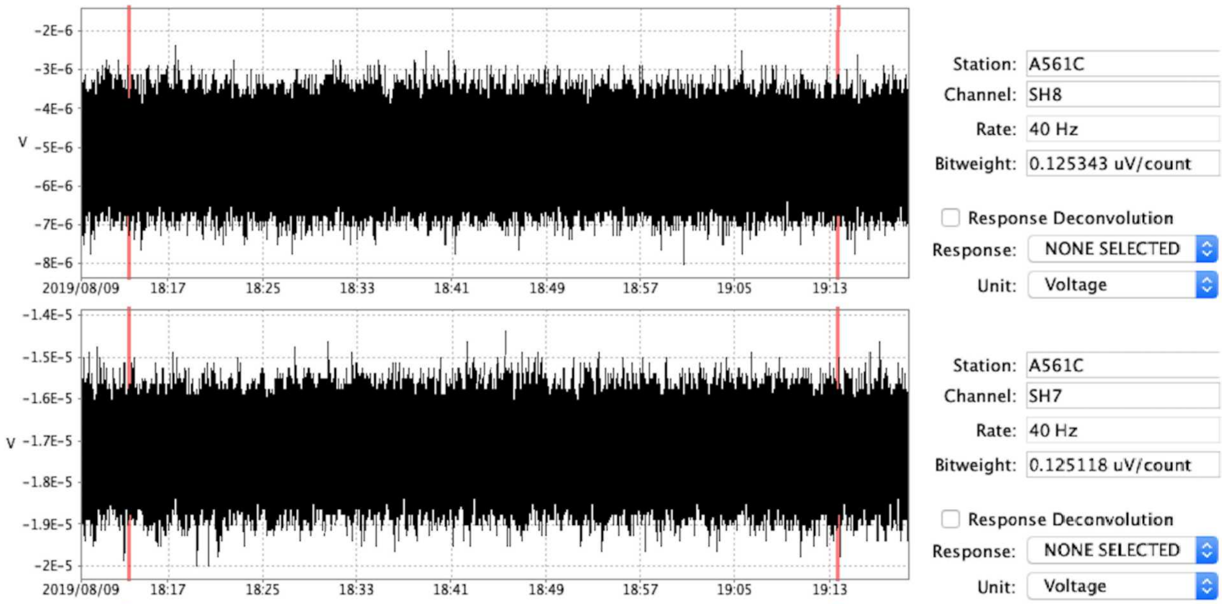

Figure 28 Input Shorted Offset Time Series

The following table contains the computed DC offsets in volts for each of the channels, sample rates, and gain levels.

Table 31 Input Shorted Offset, 100 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-109.7 uV	-103.1 uV	-100.2 uV	-104.0 uV	-	-	-	-
2x	-31.38 uV	-23.68 uV	-10.70 uV	-23.02 uV	-	-	-	-
4x	-9.12 uV	-18.67 uV	-12.95 uV	-20.67 uV	-	-	-	-
8x	-	-	-	-	-13.48 uV	-14.48 uV	-17.24 uV	-5.15 uV
16x	-	-	-	-	-10.70 uV	-12.26 uV	-15.88 uV	-2.47 uV
32x	-	-	-	-	-11.01 uV	-13.22 uV	-17.37 uV	-3.56 uV

Table 32 Input Shorted Offset, 40 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-109.7 uV	-103.1 uV	-100.2 uV	-104.0 uV	-	-	-	-
2x	-23.02 uV	-31.38 uV	-23.68 uV	-30.10 uV	-	-	-	-
4x	-9.12 uV	-18.67 uV	-12.95 uV	-20.67 uV	-	-	-	-
8x	-	-	-	-	-13.48 uV	-14.48 uV	-17.24 uV	-5.15 uV
16x	-	-	-	-	-10.70 uV	-12.26 uV	-15.88 uV	-2.47 uV
32x	-	-	-	-	-11.01 uV	-13.22 uV	-17.37 uV	-3.56 uV

Table 33 Input Shorted Offset, 20 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-109.7 uV	-103.1 uV	-100.2 mV	-104.0 uV	-	-	-	-
2x	-23.02 uV	-31.39 uV	-23.69 uV	-30.11 uV	-	-	-	-
4x	-9.13 uV	-18.67 uV	-12.95 uV	-20.67 uV	-	-	-	-
8x	-	-	-	-	-13.48 uV	-14.48 uV	-17.24 uV	-5.16 uV
16x	-	-	-	-	-10.71 uV	-12.26 uV	-15.88 uV	-2.47 uV
32x	-	-	-	-	-11.01 uV	-13.22 uV	-17.37 uV	-3.56 uV

The maximum observed input shorted offsets across all channels, with respect to nominal full scale, ranged from a minimum of 0.0003% at a gain 2x (all sample rates) to a maximum of -0.0028% at a gain of 32x (all sample rates).

3.8 Self-Noise

The Self-Noise test measures the amount of noise present on a digitizer by collecting waveform data from an input channel that has been terminated with a resistor whose impedance matches the nominal impedance of a chosen sensor at 1 Hz. Thus, any signal present on the recorded waveform should be solely due to any internal noise of the digitizer.

3.8.1 Measurand

The quantity being measured is the digitizer input channels self-noise power spectral density in dB relative to 1 V^2/Hz versus frequency and the total noise in Volts RMS over an application pass-band.

3.8.2 Configuration

The digitizer input channel is connected to a shorting resistor as shown in the diagram below.

Figure 29 Self Noise Configuration Diagram

Figure 30 Input Shorted Offset Termination Resistors

Table 34 Input Terminated Noise Termination Resistors

Channels	Termination Resistor
Primary	100 ohm (50 x 2 ohm)

12 hours of data is recorded.

3.8.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n], \qquad 0 \le n \le N-1$$

The PSD is computed from the time series (Merchant, 2011) from the time series using between a 64k-sample to 4K-sample Hann window, depending on the sample rate of data. The window length and data duration were chosen such that there were a few points below the lower limit of the evaluation pass-band of 0.02 Hz and the 95% confidence interval is less than 0.6 dB.

$$P_{xx}[k], 0 \le k \le N-1$$

Over frequencies (in Hertz):

$$f[k], 0 \le k \le N-1$$

In addition, the total RMS noise over the application pass-band of 0.02 to 4.0 Hz is computed:

$$rms = \sqrt{\frac{1}{T_s L}\sum_{k=n}^{m}|Pxx[k]|}$$

where $f[n]$ and $f[m]$ are the pass − band limits

3.8.4 Result

The figures below show the representative waveform time series and power spectra for the recording made on a digitizer channel under test. The window regions bounded by the red lines indicate the segment of data used for analysis.

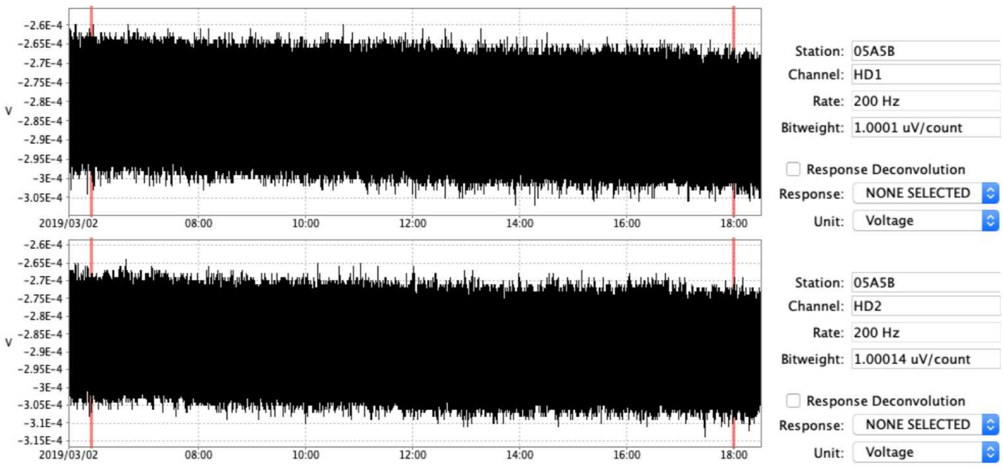

Figure 31 Self Noise Time Series

The self noise time series provided in Figure 31 Self Noise Time Series, are representative of the general character of the self noise data collected on all channels over the gains evaluated.

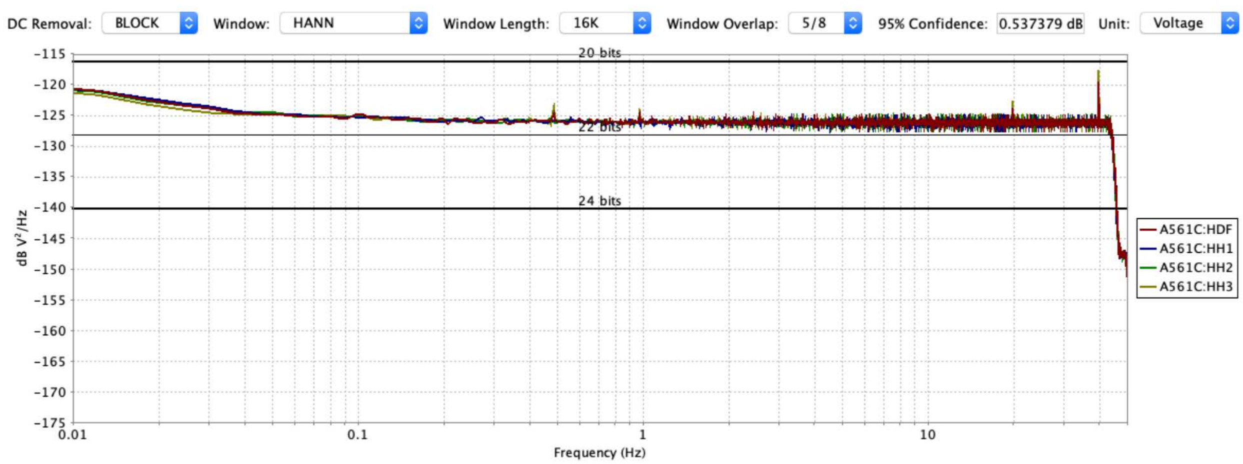

Figure 32 Self Noise Power Spectra, 1x Gain, 100 sps

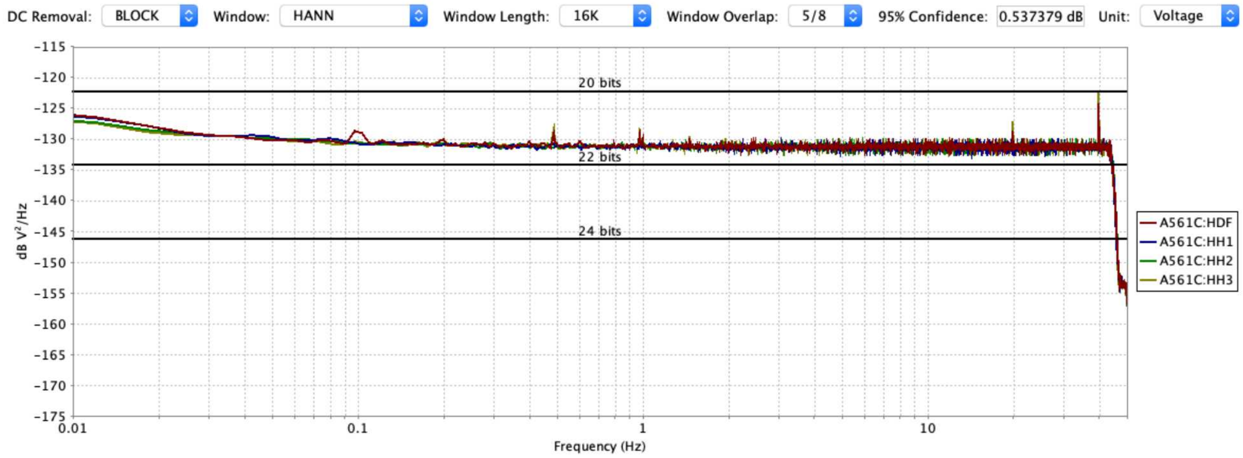

Figure 33 Self Noise Power Spectra, 2x gain, 100 sps

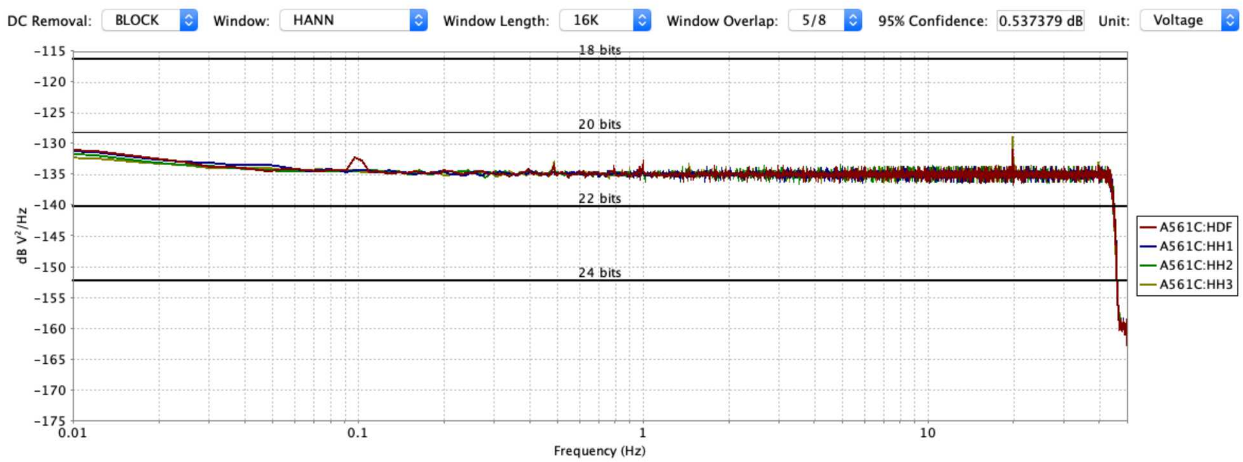

Figure 34 Self Noise Power Spectra, 4x gain, 100 sps

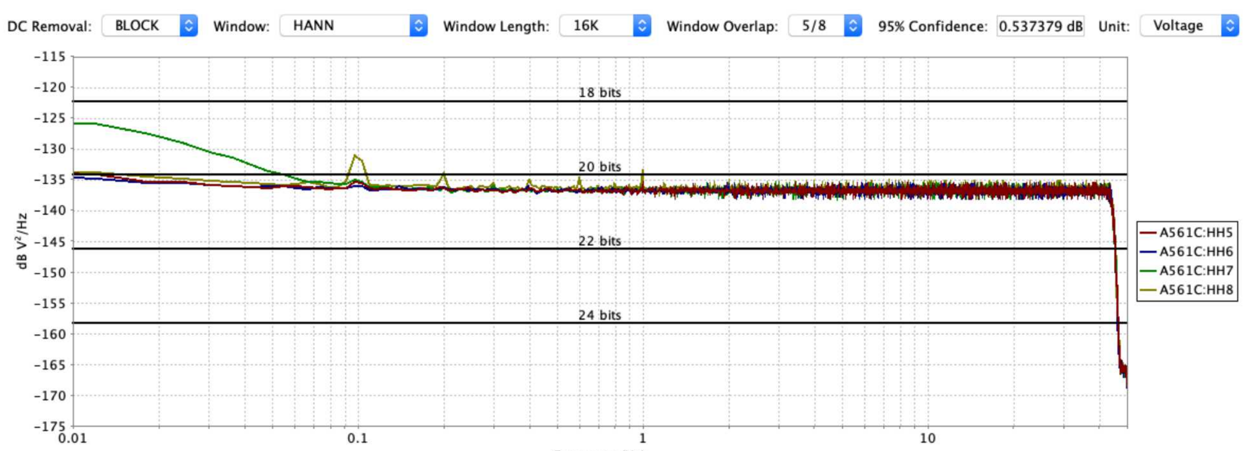

Figure 35 Self Noise Power Spectra, 8x gain, 100 sps

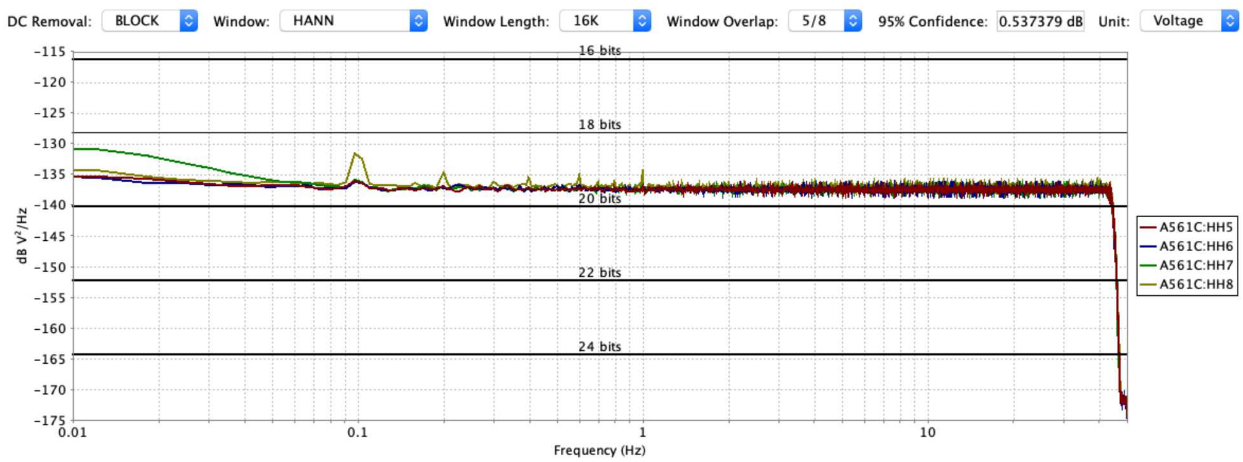

Figure 36 Self Noise Power Spectra, 16x gain, 100 sps

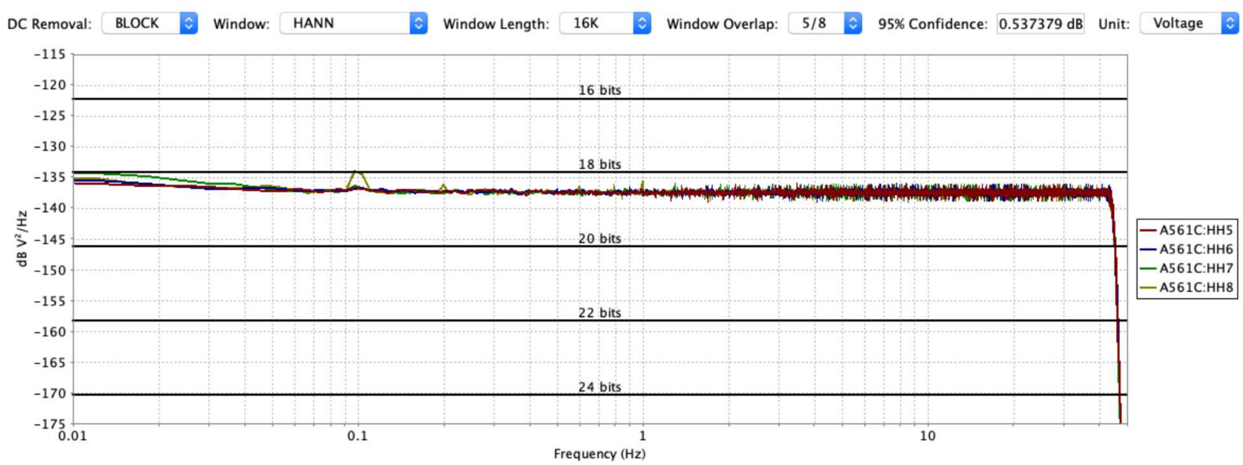

Figure 37 Self Noise Power Spectra, 32x gain, 100 sps

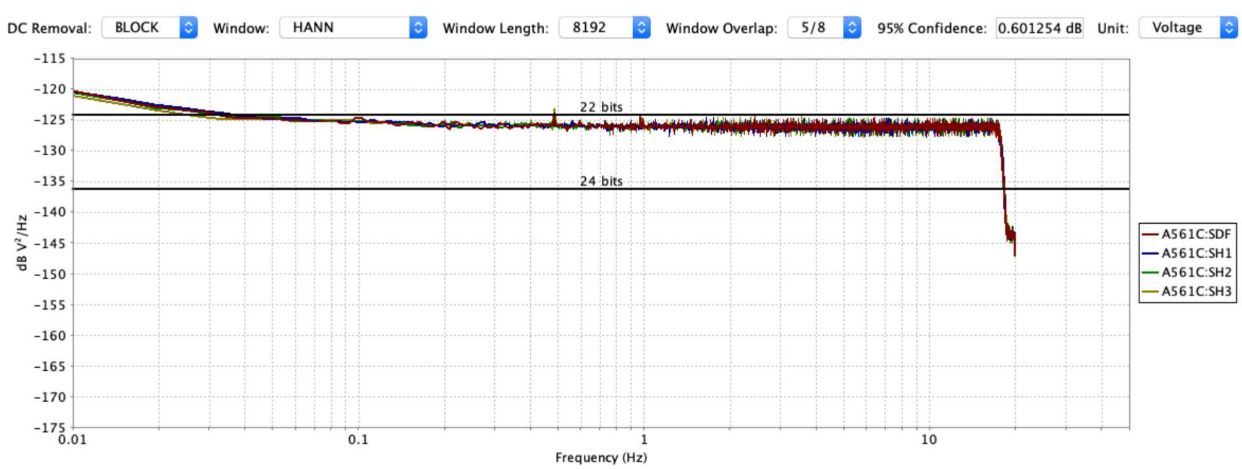

Figure 38 Self Noise Power Spectra, 1x gain, 40 sps

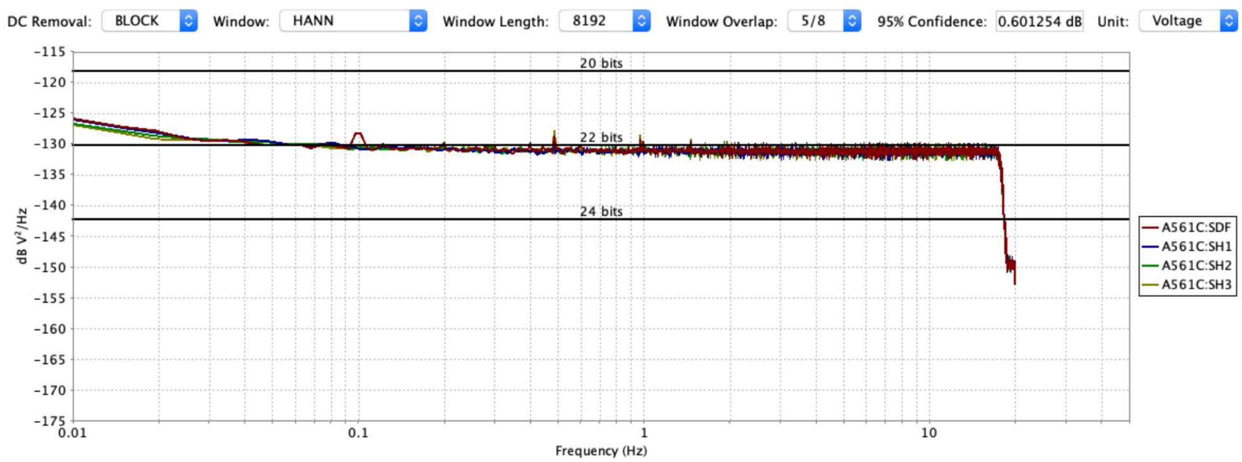

Figure 39 Self Noise Power Spectra, 2x gain, 40 sps

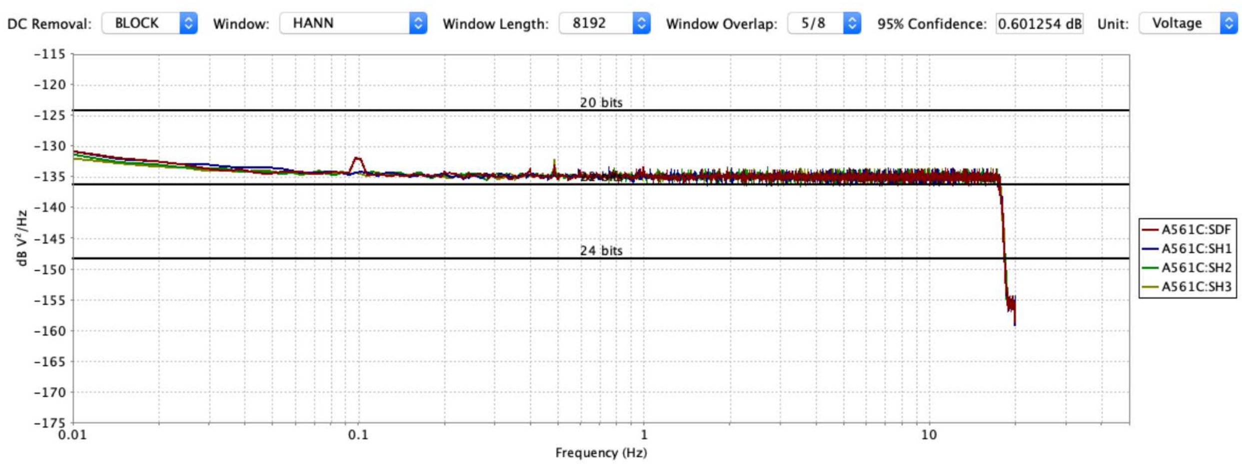

Figure 40 Self Noise Power Spectra, 4x gain, 40 sps

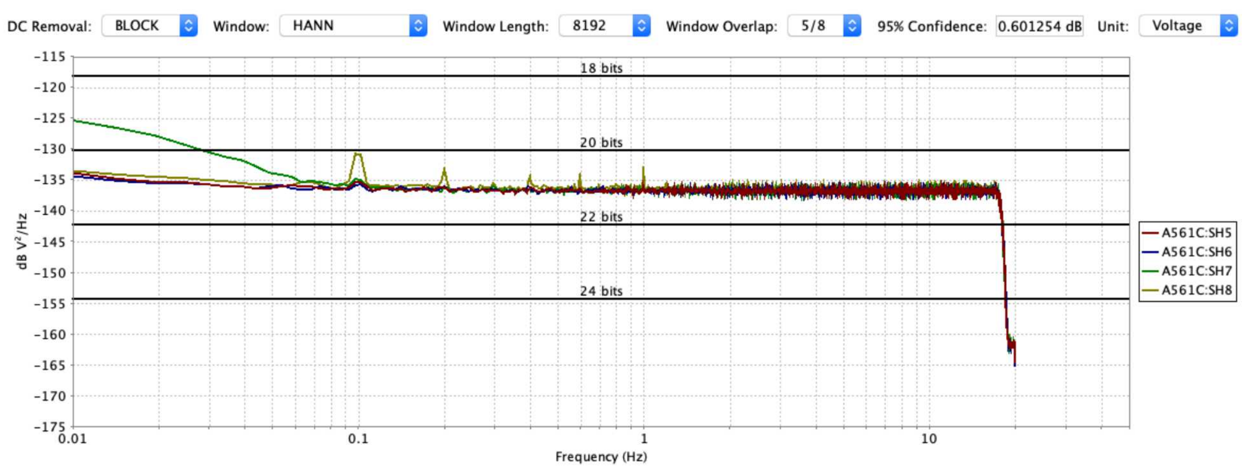

Figure 41 Self Noise Power Spectra, 8x gain, 40 sps

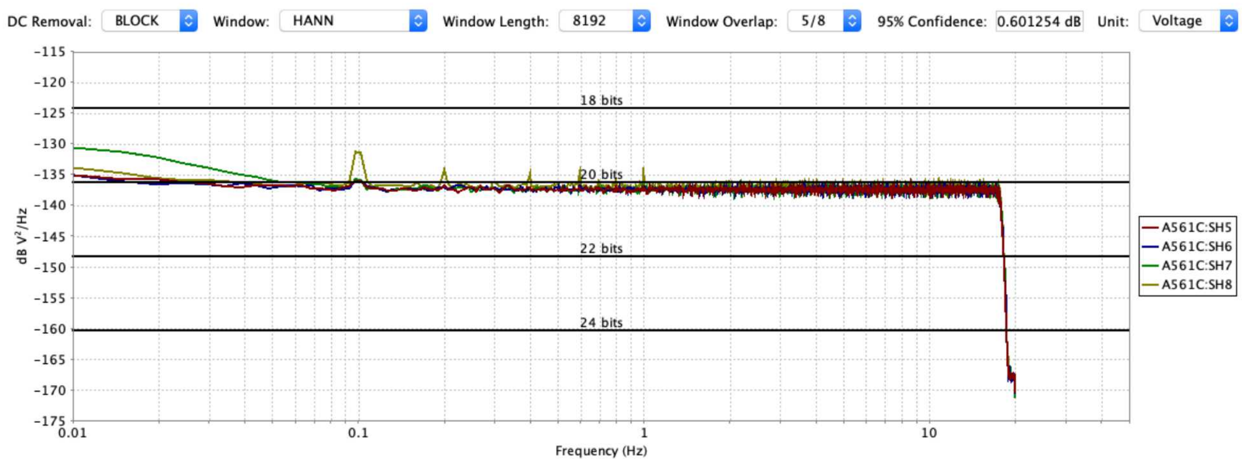

Figure 42 Self Noise Power Spectra, 16x gain, 40 sps

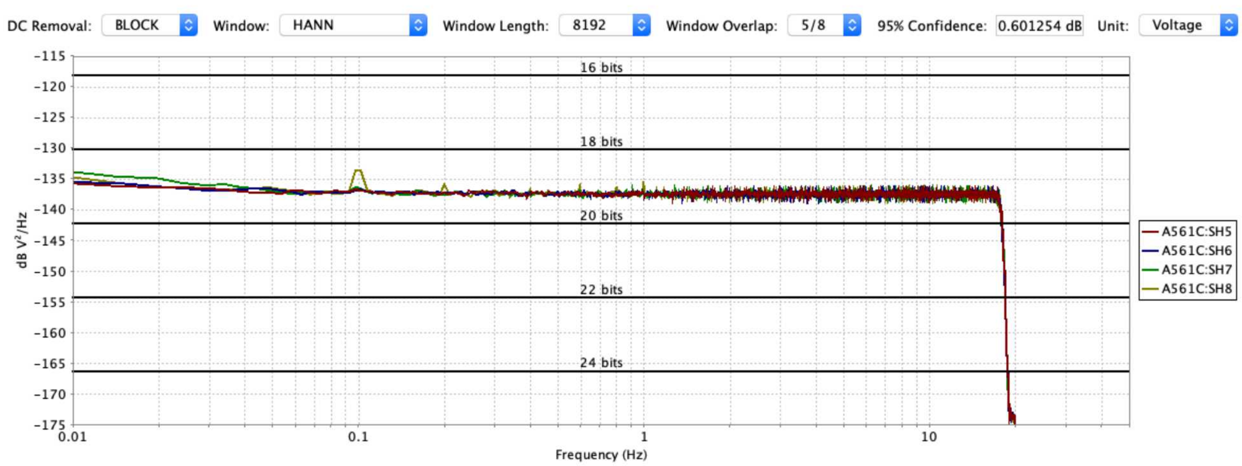

Figure 43 Self Noise Power Spectra, 32x gain, 40 sps

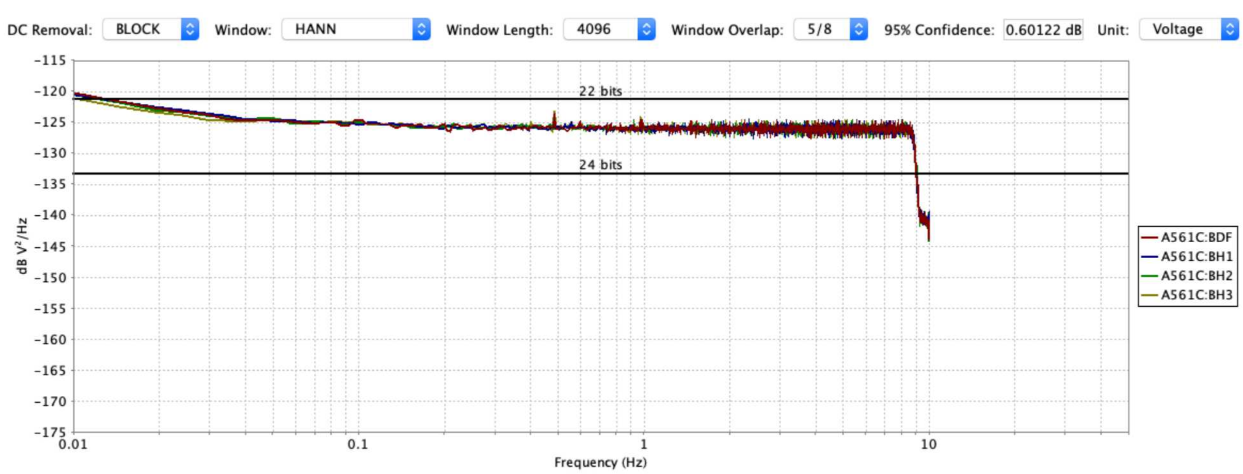

Figure 44 Self Noise Power Spectra, 1x gain, 20 sps

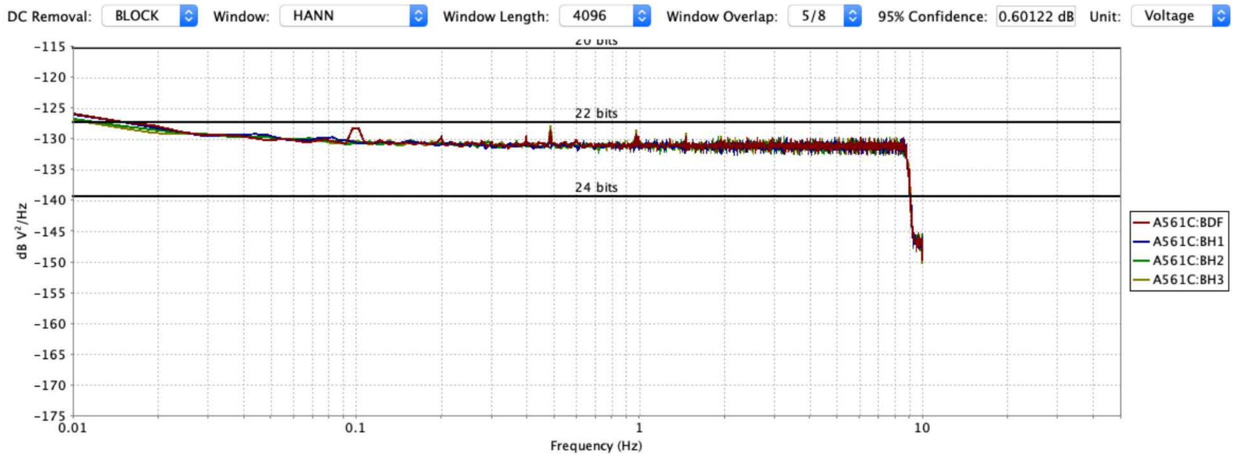

Figure 45 Self Noise Power Spectra, 2x gain, 20 sps

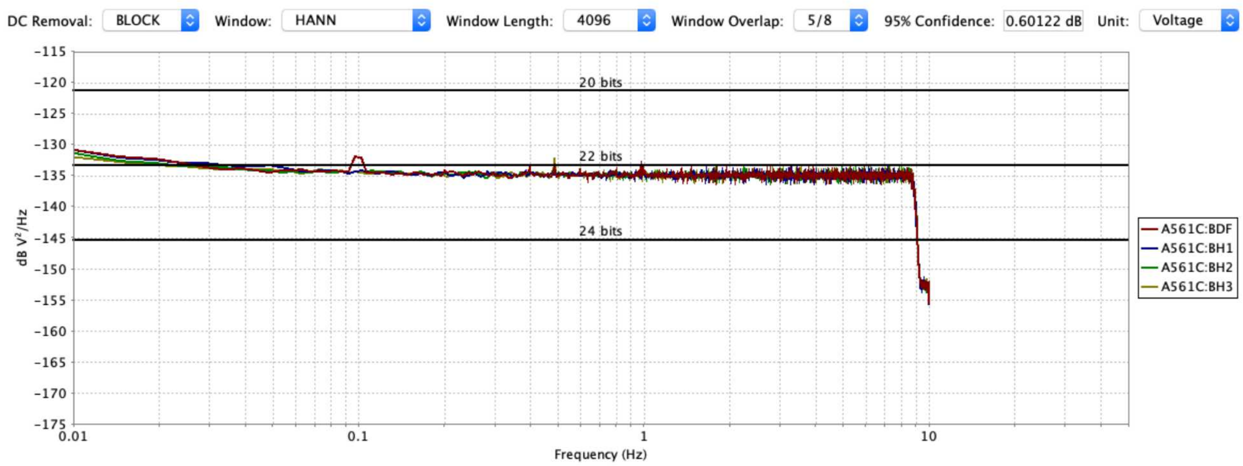

Figure 46 Self Noise Power Spectra, 4x gain, 20 sps

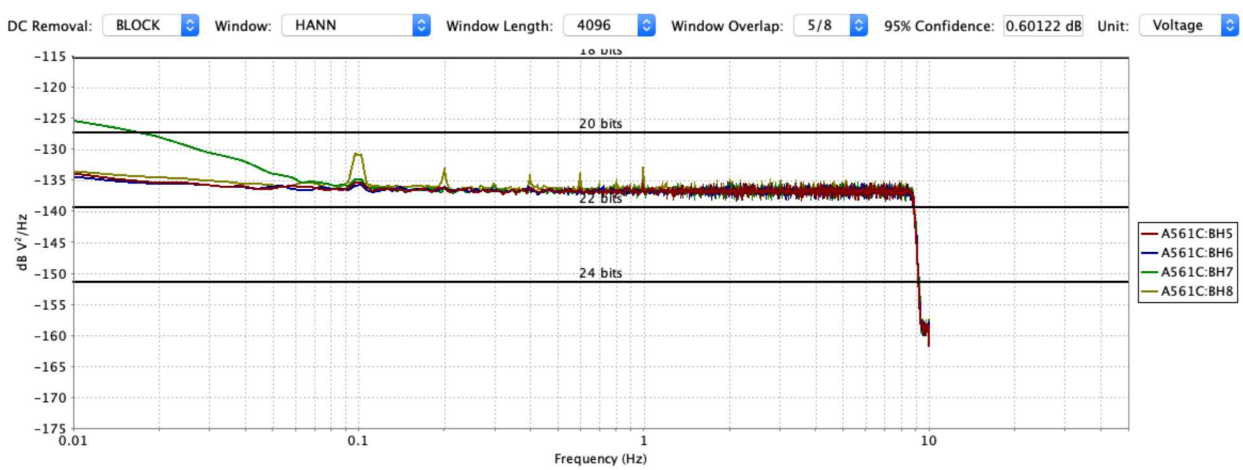

Figure 47 Self Noise Power Spectra, 8x gain, 20 sps

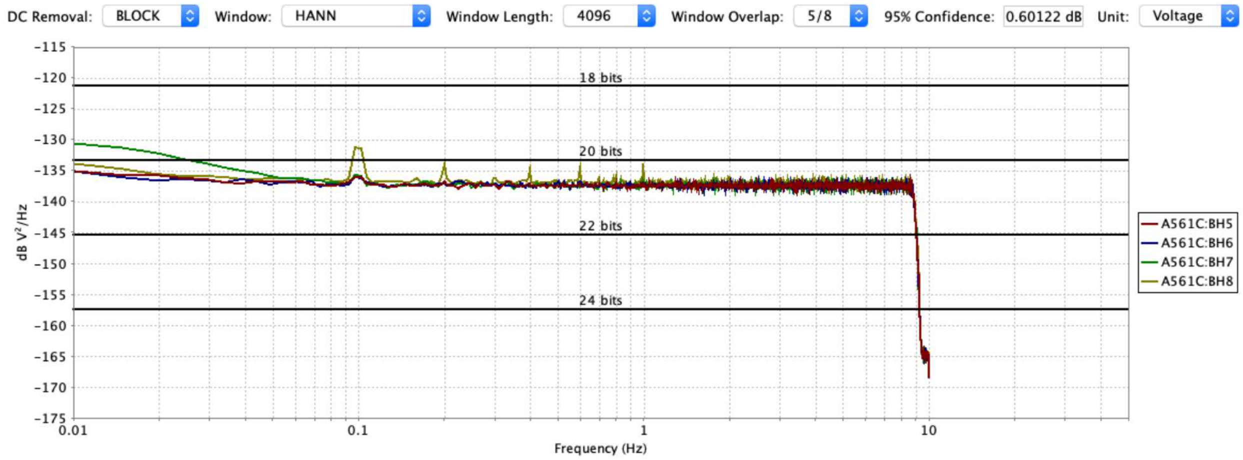

Figure 48 Self Noise Power Spectra, 16x gain, 20 sps

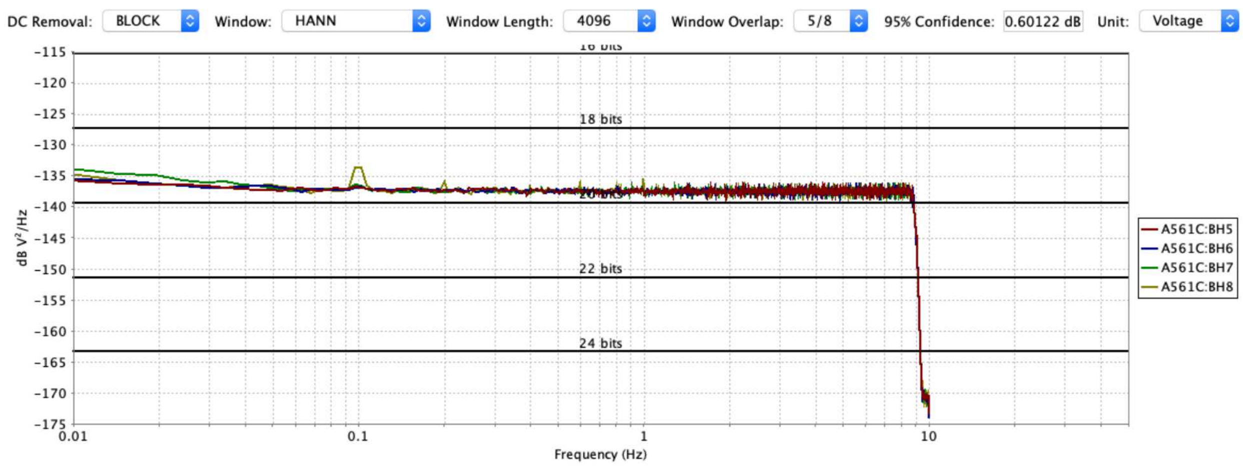

Figure 49 Self Noise Power Spectra, 32x gain, 20 sps

The Figure 32 through Figure 49 illustrate the observed self noise is relatively flat across the across the from approximately 0.10 Hz up to the Nyquist, with 2 db to 8 db amplitude spectral spikes between 0.098 Hz and 0.10 Hz (channel 4 (HDF)) and at 0.49 Hz, 0.98 Hz, 20 Hz and 40 Hz (channels 3 and 4). At gains of 8x through 32x, channel 7 shows spectral spiking between 0.098 Hz and 0.10 Hz, at 0.20 Hz, 0.4 Hz, 0.06 Hz and 0.99 Hz. Channel 7 also exhibits increasing self noise as frequency decreases, below approximately 0.06 Hz. This increased self noise on channel 7 did not change character after the input cables and terminated resistors were interchanged between the Sensor A and Sensor B ports of the digitizer.

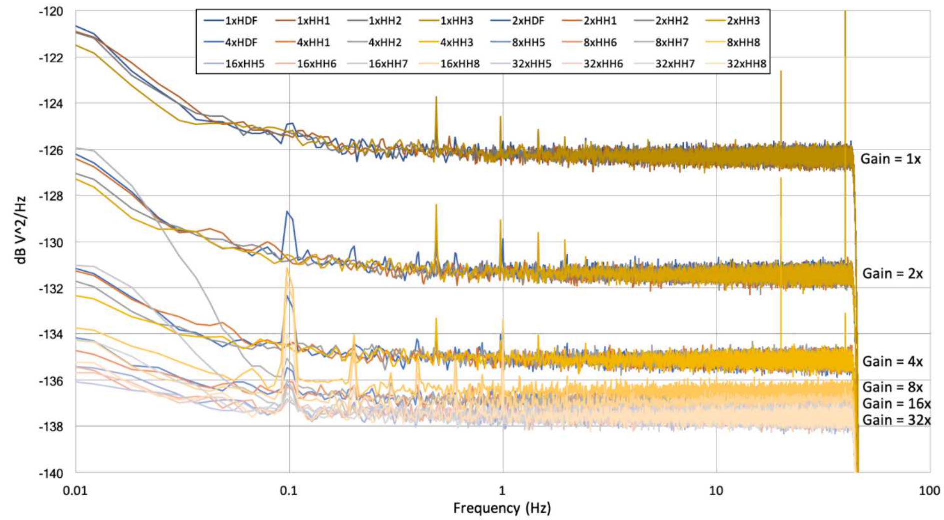

Figure 50 Summary of Self Noise Power: Gains: 1x, 2x, 4x, 8x, 16x and 32x, 100 sps

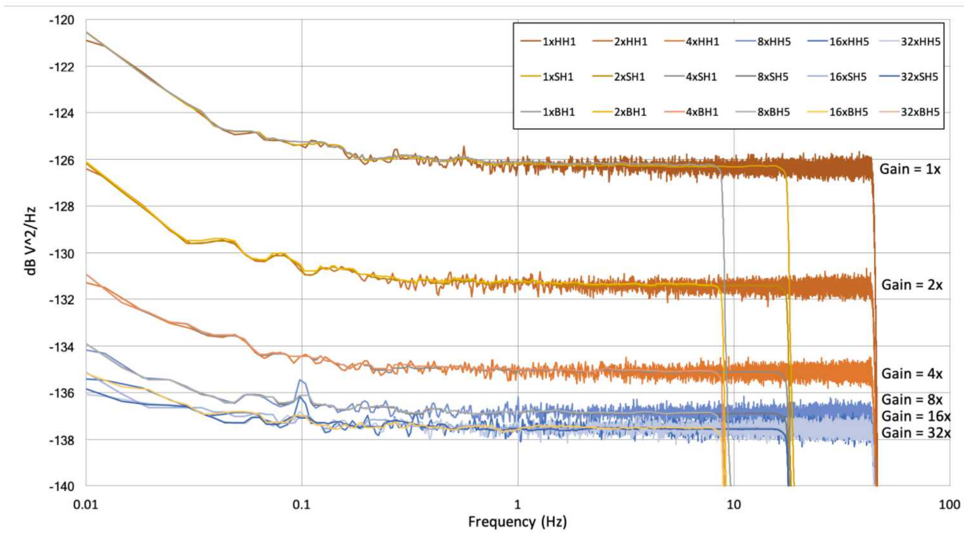

Figure 51 Comparison of Self Noise as Recorded at 100 sps, 40 sps and 20 sps

Figure 50 and Figure 51 illustrate while self noise improves with increasing gain, the rate of self noise improvement with gain decreases. Self noise remains consistent across sample rates, as is shown in Figure 50.

The following tables contains the computed RMS noise levels in both volts and counts for each of the evaluated sample rates and gain settings. A frequency pass-band consistent with the application requirements for each of the seismic and infrasound applications were selected.

Digitizer self-noise values are reported in units of dB relative to 1 V^2/Hz at the defined third-octave frequencies. The 90% uncertainty of the provided estimates are +/- 0.54 dB, +/- 0.60 dB and +/- 0.60 dB, at 100 sps, 40 sps and 20 sps respectively.

Table 35 Terminated Noise, Gains 1x and 2x, 100 sps

Frequency (Hz)	Gain = 1x				Gain = 2x			
	Channel HH1	Channel HH2	Channel HH3	Channel HDF	Channel HH1	Channel HH2	Channel HH3	Channel HDF
0.01	-121.15 dB	-121.20 dB	-121.84 dB	-121.00 dB	-126.76 dB	-127.32 dB	-127.64 dB	-126.59 dB
0.0125	-121.15 dB	-121.20 dB	-121.84 dB	-121.00 dB	-126.76 dB	-127.32 dB	-127.64 dB	-126.59 dB
0.016	-122.27 dB	-122.81 dB	-123.24 dB	-122.62 dB	-127.96 dB	-128.56 dB	-128.99 dB	-127.86 dB
0.02	-122.27 dB	-122.81 dB	-123.24 dB	-122.62 dB	-127.96 dB	-128.56 dB	-128.99 dB	-127.86 dB
0.025	-123.15 dB	-123.50 dB	-124.11 dB	-123.43 dB	-129.03 dB	-129.13 dB	-129.46 dB	-128.96 dB
0.0315	-123.15 dB	-123.50 dB	-124.11 dB	-123.43 dB	-129.03 dB	-129.13 dB	-129.46 dB	-128.96 dB
0.04	-124.73 dB	-124.56 dB	-124.87 dB	-124.79 dB	-129.56 dB	-129.89 dB	-130.01 dB	-130.01 dB
0.05	-124.89 dB	-124.57 dB	-124.87 dB	-124.82 dB	-129.64 dB	-129.91 dB	-130.29 dB	-130.27 dB
0.063	-124.89 dB	-125.08 dB	-124.97 dB	-125.22 dB	-130.35 dB	-130.15 dB	-130.43 dB	-130.32 dB
0.08	-125.18 dB	-125.29 dB	-125.07 dB	-125.31 dB	-130.17 dB	-130.49 dB	-130.74 dB	-130.37 dB
0.1	-125.38 dB	-125.29 dB	-125.19 dB	-125.45 dB	-130.73 dB	-130.79 dB	-130.82 dB	-130.58 dB
0.125	-125.29 dB	-125.49 dB	-125.71 dB	-125.45 dB	-130.69 dB	-130.88 dB	-130.78 dB	-130.80 dB
0.16	-125.75 dB	-125.99 dB	-125.83 dB	-125.73 dB	-130.74 dB	-130.93 dB	-130.92 dB	-130.97 dB
0.2	-126.08 dB	-125.87 dB	-125.89 dB	-125.97 dB	-131.00 dB	-130.93 dB	-130.97 dB	-130.91 dB
0.25	-125.96 dB	-125.88 dB	-126.03 dB	-126.04 dB	-131.15 dB	-131.16 dB	-130.96 dB	-131.00 dB
0.315	-125.94 dB	-126.09 dB	-125.91 dB	-126.30 dB	-131.28 dB	-131.23 dB	-131.08 dB	-131.26 dB
0.4	-126.09 dB	-125.92 dB	-126.05 dB	-126.03 dB	-131.33 dB	-131.27 dB	-131.16 dB	-131.06 dB
0.5	-126.10 dB	-126.03 dB	-126.00 dB	-126.03 dB	-131.19 dB	-131.26 dB	-131.35 dB	-130.99 dB
0.63	-126.17 dB	-126.15 dB	-126.08 dB	-126.11 dB	-131.25 dB	-131.27 dB	-131.36 dB	-131.22 dB
0.8	-126.25 dB	-126.26 dB	-126.15 dB	-126.22 dB	-131.36 dB	-131.27 dB	-131.33 dB	-131.28 dB
1	-126.24 dB	-126.12 dB	-126.29 dB	-126.19 dB	-131.31 dB	-131.29 dB	-131.29 dB	-131.23 dB
1.25	-126.23 dB	-126.21 dB	-126.14 dB	-126.21 dB	-131.35 dB	-131.35 dB	-131.34 dB	-131.29 dB
1.6	-126.32 dB	-126.12 dB	-126.30 dB	-126.20 dB	-131.41 dB	-131.43 dB	-131.35 dB	-131.36 dB
2	-126.33 dB	-126.27 dB	-126.26 dB	-126.24 dB	-131.46 dB	-131.35 dB	-131.32 dB	-131.27 dB
2.5	-126.27 dB	-126.23 dB	-126.27 dB	-126.26 dB	-131.43 dB	-131.36 dB	-131.41 dB	-131.28 dB
3.15	-126.27 dB	-126.26 dB	-126.23 dB	-126.28 dB	-131.41 dB	-131.36 dB	-131.39 dB	-131.37 dB
4	-126.32 dB	-126.25 dB	-126.27 dB	-126.25 dB	-131.47 dB	-131.38 dB	-131.45 dB	-131.35 dB
5	-126.36 dB	-126.30 dB	-126.31 dB	-126.31 dB	-131.41 dB	-131.39 dB	-131.45 dB	-131.35 dB
6.3	-126.34 dB	-126.30 dB	-126.28 dB	-126.28 dB	-131.46 dB	-131.42 dB	-131.41 dB	-131.35 dB
8	-126.35 dB	-126.28 dB	-126.31 dB	-126.30 dB	-131.47 dB	-131.41 dB	-131.44 dB	-131.34 dB
10	-126.36 dB	-126.28 dB	-126.32 dB	-126.31 dB	-131.47 dB	-131.41 dB	-131.43 dB	-131.34 dB
12.5	-126.34 dB	-126.30 dB	-126.30 dB	-126.31 dB	-131.44 dB	-131.42 dB	-131.46 dB	-131.34 dB
16	-126.34 dB	-126.31 dB	-126.29 dB	-126.32 dB	-131.46 dB	-131.42 dB	-131.44 dB	-131.36 dB
20	-126.33 dB	-126.29 dB	-126.31 dB	-126.30 dB	-131.47 dB	-131.43 dB	-131.43 dB	-131.34 dB
25	-126.36 dB	-126.29 dB	-126.32 dB	-126.31 dB	-131.46 dB	-131.43 dB	-131.45 dB	-131.34 dB
31.5	-126.36 dB	-126.30 dB	-126.31 dB	-126.31 dB	-131.46 dB	-131.43 dB	-131.44 dB	-131.34 dB
40	-126.38 dB	-126.32 dB	-126.33 dB	-126.34 dB	-131.50 dB	-131.46 dB	-131.47 dB	-131.37 dB

Table 36 Terminated Noise, Gains 4x and 8x, 100 sps

Frequency (Hz)	Gain = 4x				Gain = 8x			
	Channel HH1	Channel HH2	Channel HH3	Channel HDF	Channel HH5	Channel HH6	Channel HH7	Channel HH8
0.01	-131.48 dB	-131.97 dB	-132.49 dB	-131.40 dB	-134.31 dB	-134.90 dB	-126.07 dB	-133.85 dB
0.0125	-131.48 dB	-131.97 dB	-132.49 dB	-131.40 dB	-134.31 dB	-134.90 dB	-126.07 dB	-133.85 dB
0.016	-132.50 dB	-133.02 dB	-133.26 dB	-132.43 dB	-135.37 dB	-135.54 dB	-127.57 dB	-134.53 dB
0.02	-132.50 dB	-133.02 dB	-133.26 dB	-132.43 dB	-135.37 dB	-135.54 dB	-127.57 dB	-134.53 dB
0.025	-133.01 dB	-133.57 dB	-133.57 dB	-133.06 dB	-135.45 dB	-135.65 dB	-129.19 dB	-134.85 dB
0.0315	-133.01 dB	-133.57 dB	-133.57 dB	-133.06 dB	-135.45 dB	-135.65 dB	-129.19 dB	-134.85 dB
0.04	-133.57 dB	-134.26 dB	-134.11 dB	-134.23 dB	-136.31 dB	-136.21 dB	-132.64 dB	-135.69 dB
0.05	-133.64 dB	-134.36 dB	-134.14 dB	-134.30 dB	-136.31 dB	-136.18 dB	-133.78 dB	-135.78 dB
0.063	-134.30 dB	-134.59 dB	-134.50 dB	-134.30 dB	-136.09 dB	-136.51 dB	-134.99 dB	-135.71 dB
0.08	-134.33 dB	-134.59 dB	-134.37 dB	-134.40 dB	-136.52 dB	-136.42 dB	-135.64 dB	-136.21 dB
0.1	-134.48 dB	-134.54 dB	-134.47 dB	-134.36 dB	-136.39 dB	-136.50 dB	-135.84 dB	-135.27 dB
0.125	-134.60 dB	-134.54 dB	-134.64 dB	-134.74 dB	-136.53 dB	-136.67 dB	-136.34 dB	-136.03 dB
0.16	-134.88 dB	-134.71 dB	-134.88 dB	-134.84 dB	-136.75 dB	-136.56 dB	-136.61 dB	-136.03 dB
0.2	-134.95 dB	-134.92 dB	-135.15 dB	-134.71 dB	-136.62 dB	-136.71 dB	-136.72 dB	-136.13 dB
0.25	-135.09 dB	-134.66 dB	-134.80 dB	-134.86 dB	-136.63 dB	-136.71 dB	-136.74 dB	-136.29 dB
0.315	-134.91 dB	-134.86 dB	-135.12 dB	-135.14 dB	-136.86 dB	-136.72 dB	-136.67 dB	-136.42 dB
0.4	-134.93 dB	-134.80 dB	-135.01 dB	-135.00 dB	-136.81 dB	-136.84 dB	-136.85 dB	-136.34 dB
0.5	-134.97 dB	-134.87 dB	-135.05 dB	-134.92 dB	-136.86 dB	-136.79 dB	-136.83 dB	-136.36 dB
0.63	-134.94 dB	-135.04 dB	-134.94 dB	-135.00 dB	-136.93 dB	-136.92 dB	-136.86 dB	-136.47 dB
0.8	-134.99 dB	-135.03 dB	-135.02 dB	-134.96 dB	-136.84 dB	-136.80 dB	-136.86 dB	-136.36 dB
1	-135.15 dB	-135.05 dB	-135.03 dB	-135.05 dB	-136.83 dB	-136.88 dB	-136.85 dB	-136.50 dB
1.25	-135.07 dB	-135.04 dB	-135.08 dB	-135.20 dB	-136.83 dB	-136.93 dB	-136.88 dB	-136.48 dB
1.6	-135.05 dB	-135.09 dB	-135.05 dB	-135.09 dB	-136.83 dB	-136.88 dB	-136.87 dB	-136.51 dB
2	-135.14 dB	-135.05 dB	-135.17 dB	-135.05 dB	-136.89 dB	-136.84 dB	-136.98 dB	-136.47 dB
2.5	-135.02 dB	-135.09 dB	-135.13 dB	-135.14 dB	-136.86 dB	-136.87 dB	-136.95 dB	-136.50 dB
3.15	-135.10 dB	-135.11 dB	-135.13 dB	-135.13 dB	-136.90 dB	-136.87 dB	-136.93 dB	-136.49 dB
4	-135.13 dB	-135.12 dB	-135.15 dB	-135.12 dB	-136.86 dB	-136.93 dB	-136.91 dB	-136.51 dB
5	-135.15 dB	-135.09 dB	-135.07 dB	-135.13 dB	-136.94 dB	-136.92 dB	-136.91 dB	-136.50 dB
6.3	-135.13 dB	-135.12 dB	-135.13 dB	-135.10 dB	-136.88 dB	-136.91 dB	-136.93 dB	-136.53 dB
8	-135.13 dB	-135.11 dB	-135.12 dB	-135.17 dB	-136.89 dB	-136.89 dB	-136.92 dB	-136.51 dB
10	-135.14 dB	-135.09 dB	-135.12 dB	-135.12 dB	-136.90 dB	-136.94 dB	-136.92 dB	-136.47 dB
12.5	-135.12 dB	-135.10 dB	-135.14 dB	-135.15 dB	-136.89 dB	-136.92 dB	-136.92 dB	-136.52 dB
16	-135.16 dB	-135.11 dB	-135.13 dB	-135.11 dB	-136.90 dB	-136.91 dB	-136.94 dB	-136.52 dB
20	-135.12 dB	-135.12 dB	-135.13 dB	-135.12 dB	-136.93 dB	-136.94 dB	-136.91 dB	-136.52 dB
25	-135.13 dB	-135.11 dB	-135.12 dB	-135.13 dB	-136.91 dB	-136.92 dB	-136.94 dB	-136.52 dB
31.5	-135.16 dB	-135.12 dB	-135.12 dB	-135.13 dB	-136.90 dB	-136.92 dB	-136.94 dB	-136.51 dB
40	-135.17 dB	-135.15 dB	-135.17 dB	-135.16 dB	-136.93 dB	-136.94 dB	-136.96 dB	-136.55 dB

Table 37 Terminated Noise, Gains 16x and 32x, 100 sps

Frequency (Hz)	Gain = 16x				Gain = 32x			
	Channel HH5	Channel HH6	Channel HH7	Channel HH8	Channel HH5	Channel HH6	Channel HH7	Channel HH8
0.01	-135.48 dB	-135.58 dB	-131.07 dB	-134.35 dB	-136.16 dB	-135.70 dB	-134.33 dB	-135.25 dB
0.0125	-135.48 dB	-135.58 dB	-131.07 dB	-134.35 dB	-136.16 dB	-135.70 dB	-134.33 dB	-135.25 dB
0.016	-135.82 dB	-136.45 dB	-131.97 dB	-135.40 dB	-136.45 dB	-136.11 dB	-134.98 dB	-136.22 dB
0.02	-135.82 dB	-136.45 dB	-131.97 dB	-135.40 dB	-136.45 dB	-136.11 dB	-134.98 dB	-136.22 dB
0.025	-136.30 dB	-136.55 dB	-133.18 dB	-135.92 dB	-136.55 dB	-136.61 dB	-135.64 dB	-136.70 dB
0.0315	-136.30 dB	-136.55 dB	-133.18 dB	-135.92 dB	-136.55 dB	-136.61 dB	-135.64 dB	-136.70 dB
0.04	-136.93 dB	-136.75 dB	-135.44 dB	-136.38 dB	-137.22 dB	-136.76 dB	-136.67 dB	-136.63 dB
0.05	-136.86 dB	-136.98 dB	-135.92 dB	-136.35 dB	-137.32 dB	-136.76 dB	-136.99 dB	-136.63 dB
0.063	-136.89 dB	-136.91 dB	-136.33 dB	-136.43 dB	-137.22 dB	-137.32 dB	-137.34 dB	-137.19 dB
0.08	-137.38 dB	-137.40 dB	-136.96 dB	-136.69 dB	-137.24 dB	-137.33 dB	-137.22 dB	-137.37 dB
0.1	-137.02 dB	-137.09 dB	-136.99 dB	-136.35 dB	-137.03 dB	-137.20 dB	-137.20 dB	-136.96 dB
0.125	-137.38 dB	-137.59 dB	-137.51 dB	-136.83 dB	-137.34 dB	-137.20 dB	-137.34 dB	-137.55 dB
0.16	-137.40 dB	-137.42 dB	-137.34 dB	-136.92 dB	-137.29 dB	-137.35 dB	-137.47 dB	-137.27 dB
0.2	-137.49 dB	-137.27 dB	-137.33 dB	-136.93 dB	-137.40 dB	-137.36 dB	-137.58 dB	-137.44 dB
0.25	-137.41 dB	-137.29 dB	-137.25 dB	-136.85 dB	-137.32 dB	-137.45 dB	-137.43 dB	-137.51 dB
0.315	-137.34 dB	-137.39 dB	-137.36 dB	-136.86 dB	-137.35 dB	-137.44 dB	-137.50 dB	-137.43 dB
0.4	-137.50 dB	-137.54 dB	-137.52 dB	-136.83 dB	-137.38 dB	-137.43 dB	-137.48 dB	-137.47 dB
0.5	-137.53 dB	-137.41 dB	-137.40 dB	-136.96 dB	-137.58 dB	-137.54 dB	-137.50 dB	-137.53 dB
0.63	-137.46 dB	-137.41 dB	-137.52 dB	-136.96 dB	-137.56 dB	-137.54 dB	-137.66 dB	-137.47 dB
0.8	-137.55 dB	-137.53 dB	-137.53 dB	-136.95 dB	-137.62 dB	-137.61 dB	-137.56 dB	-137.50 dB
1	-137.59 dB	-137.50 dB	-137.52 dB	-137.05 dB	-137.58 dB	-137.49 dB	-137.59 dB	-137.54 dB
1.25	-137.44 dB	-137.56 dB	-137.55 dB	-137.07 dB	-137.57 dB	-137.56 dB	-137.54 dB	-137.54 dB
1.6	-137.44 dB	-137.54 dB	-137.49 dB	-137.11 dB	-137.62 dB	-137.46 dB	-137.60 dB	-137.58 dB
2	-137.48 dB	-137.53 dB	-137.50 dB	-137.05 dB	-137.60 dB	-137.60 dB	-137.57 dB	-137.56 dB
2.5	-137.54 dB	-137.53 dB	-137.55 dB	-137.07 dB	-137.51 dB	-137.52 dB	-137.54 dB	-137.53 dB
3.15	-137.55 dB	-137.57 dB	-137.59 dB	-137.08 dB	-137.54 dB	-137.60 dB	-137.55 dB	-137.54 dB
4	-137.50 dB	-137.52 dB	-137.52 dB	-137.05 dB	-137.49 dB	-137.60 dB	-137.54 dB	-137.62 dB
5	-137.50 dB	-137.56 dB	-137.60 dB	-137.14 dB	-137.56 dB	-137.54 dB	-137.59 dB	-137.62 dB
6.3	-137.52 dB	-137.54 dB	-137.56 dB	-137.09 dB	-137.55 dB	-137.58 dB	-137.55 dB	-137.60 dB
8	-137.51 dB	-137.55 dB	-137.53 dB	-137.08 dB	-137.57 dB	-137.55 dB	-137.55 dB	-137.57 dB
10	-137.52 dB	-137.54 dB	-137.54 dB	-137.04 dB	-137.57 dB	-137.54 dB	-137.55 dB	-137.58 dB
12.5	-137.53 dB	-137.51 dB	-137.56 dB	-137.08 dB	-137.56 dB	-137.57 dB	-137.58 dB	-137.57 dB
16	-137.53 dB	-137.54 dB	-137.55 dB	-137.10 dB	-137.57 dB	-137.57 dB	-137.58 dB	-137.58 dB
20	-137.56 dB	-137.51 dB	-137.56 dB	-137.07 dB	-137.56 dB	-137.56 dB	-137.59 dB	-137.58 dB
25	-137.53 dB	-137.52 dB	-137.57 dB	-137.09 dB	-137.58 dB	-137.57 dB	-137.59 dB	-137.59 dB
31.5	-137.54 dB	-137.53 dB	-137.54 dB	-137.09 dB	-137.56 dB	-137.57 dB	-137.59 dB	-137.58 dB
40	-137.57 dB	-137.56 dB	-137.59 dB	-137.12 dB	-137.60 dB	-137.60 dB	-137.61 dB	-137.63 dB

Table 38 Self Noise RMS over 0.01 Hz to 10 Hz

Gain	Sample Rate	Channel HH1	Channel HH2	Channel HH3	Channel HDF
1x	100 sps	1.536 uV rms	1.545 uV rms	1.542 uV rms	1.543 uV rms
		1.536 counts rms	1.545 counts rms	1.542 counts rms	1.543 counts rms
	40 sps	1.543 uV rms	1.552 uV rms	1.549 uV rms	1.550 uV rms
		1.543 counts rms	1.552 counts rms	1.548 counts rms	1.550 counts rms
	20 sps	1.476 uV rms	1.485 uV rms	1.482 uV rms	1.482 uV rms
		1.475 counts rms	1.484 counts rms	1.481 counts rms	1.482 counts rms
		Channel HH1	Channel HH2	Channel HH3	Channel HDF
2x	100 sps	851.0 nV rms	855.0 nV rms	853.5 nV rms	862.9 nV rms
		1.701 counts rms	1.709 counts rms	1.706 counts rms	1.725 counts rms
	40 sps	854.0 nV rms	858.3 nV rms	856.7 nV rms	865.5 nV rms
		1.707 counts rms	1.716 counts rms	1.713 counts rms	1.730 counts rms
	20 sps	815.1 nV rms	819.0 nV rms	817.6 nV rms	826.3 nV rms
		1.629 counts rms	1.637 counts rms	1.634 counts rms	1.651 counts rms
		Channel HH1	Channel HH2	Channel HH3	Channel HDF
4x	100 sps	556.6 nV rms	557.9 nV rms	556.0 nV rms	556.7 nV rms
		2.226 counts rms	2.229 counts rms	2.222 counts rms	2.226 counts rms
	40 sps	557.6 nV rms	559.0 nV rms	557.1 nV rms	557.8 nV rms
		2.230 counts rms	2.233 counts rms	2.227 counts rms	2.231 counts rms
	20 sps	530.1 nV rms	531.4 nV rms	529.6 nV rms	530.3 nV rms
		2.119 counts rms	2.122 counts rms	2.117 counts rms	2.120 counts rms
		Channel HH5	Channel HH6	Channel HH7	Channel HH8
8x	100 sps	453.5 nV rms	453.0 nV rms	456.7 nV rms	476.0 nV rms
		3.624 counts rms	3.619 counts rms	3.650 counts rms	3.798 counts rms
	40 sps	453.7 nV rms	453.2 nV rms	455.9 nV rms	476.2 nV rms
		3.625 counts rms	3.621 counts rms	3.644 counts rms	3.799 counts rms
	20 sps	430.0 nV rms	429.6 nV rms	432.6 nV rms	451.2 nV rms
		3.435 counts rms	3.432 counts rms	3.456 counts rms	3.599 counts rms
		Channel HH5	Channel HH6	Channel HH7	Channel HH8
16x	100 sps	421.4 nV rms	420.9 nV rms	421.5 nV rms	445.1 nV rms
		6.722 counts rms	6.722 counts rms	6.722 counts rms	7.094 counts rms
	40 sps	421.3 nV rms	420.7 nV rms	421.2 nV rms	445.2 nV rms
		6.720 counts rms	6.719 counts rms	6.717 counts rms	7.096 counts rms
	20 sps	398.6 nV rms	398.0 nV rms	398.5 nV rms	421.2 nV rms
		6.357 counts rms	6.356 counts rms	6.354 counts rms	6.712 counts rms
		Channel HH5	Channel HH6	Channel HH7	Channel HH8
32x	100 sps	419.8 nV rms	419.7 nV rms	419.3 nV rms	419.2 nV rms
		13.424 counts rms	13.413 counts rms	13.408 counts rms	13.390 counts rms
	40 sps	419.6 nV rms	419.5 nV rms	419.1 nV rms	419.0 nV rms
		13.417 counts rms	13.405 counts rms	13.400 counts rms	13.383 counts rms
	20 sps	397.0 nV rms	396.7 nV rms	396.4 nV rms	396.3 nV rms
		12.691 counts rms	12.676 counts rms	12.672 counts rms	12.657 counts rms

Table 39 Self Noise RMS over 0.01 Hz to 40 Hz

Gain	Sample Rate	Channel HH1	Channel HH2	Channel HH3	Channel H HDF
1x	100 sps	3.052 uV rms	3.070 uV rms	3.070 uV rms	3.068 uV rms
		3.051 counts rms	3.069 counts rms	3.070 counts rms	3.068 counts rms
	40 sps	2.059 uV rms	2.070 uV rms	2.067 uV rms	2.067 uV rms
		2.059 counts rms	2.070 counts rms	2.067 counts rms	2.067 counts rms
	20 sps	1.476 uV rms	1.485 uV rms	1.482 uV rms	1.482 uV rms
		1.475 counts rms	1.484 counts rms	1.481 counts rms	1.482 counts rms
		Channel HH1	Channel HH2	Channel HH3	Channel H HDF
2x	100 sps	1.693 uV rms	1.701 uV rms	1.699 uV rms	1.717 uV rms
		3.386 counts rms	3.400 counts rms	3.397 counts rms	3.433 counts rms
	40 sps	1.140 uV rms	1.145 uV rms	1.143 uV rms	1.155 uV rms
		2.280 counts rms	2.290 counts rms	2.285 counts rms	2.310 counts rms
	20 sps	815.1 nV rms	819.0 nV rms	817.6 nV rms	826.3 nV rms
		1.629 counts rms	1.637 counts rms	1.634 counts rms	1.651 counts rms
		Channel HH1	Channel HH2	Channel HH3	Channel HDF
4x	100 sps	1.109 uV rms	1.112 uV rms	1.110 uV rms	1.109 uV rms
		4.433 counts rms	4.442 counts rms	4.436 counts rms	4.436 counts rms
	40 sps	744.5 nV rms	746.7 nV rms	744.1 nV rms	745.0 nV rms
		2.977 counts rms	2.983 counts rms	2.974 counts rms	2.979 counts rms
	20 sps	530.1 nV rms	531.4 nV rms	529.6 nV rms	530.3 nV rms
		2.119 counts rms	2.122 counts rms	2.117 counts rms	2.120 counts rms
		Channel HH5	Channel HH6	Channel HH7	Channel HH8
8x	100 sps	904.1 nV rms	903.0 nV rms	904.2 nV rms	946.5 nV rms
		7.224 counts rms	7.214 counts rms	7.226 counts rms	7.551 counts rms
	40 sps	605.9 nV rms	605.2 nV rms	606.9 nV rms	635.0 nV rms
		4.841 counts rms	4.835 counts rms	4.851 counts rms	5.066 counts rms
	20 sps	430.0 nV rms	429.6 nV rms	432.6 nV rms	451.2 nV rms
		3.435 counts rms	3.432 counts rms	3.456 counts rms	3.599 counts rms
		Channel HH5	Channel HH6	Channel HH7	Channel HH8
16x	100 sps	840.7 nV rms	841.2 nV rms	839.6 nV rms	886.2 nV rms
		13.411 counts rms	13.434 counts rms	13.389 counts rms	14.125 counts rms
	40 sps	563.0 nV rms	562.2 nV rms	562.4 nV rms	594.1 nV rms
		8.981 counts rms	8.979 counts rms	8.968 counts rms	9.469 counts rms
	20 sps	398.6 nV rms	398.0 nV rms	398.5 nV rms	421.2 nV rms
		6.357 counts rms	6.356 counts rms	6.354 counts rms	6.712 counts rms
		Channel HH5	Channel HH6	Channel HH7	Channel HH8
32x	100 sps	837.8 nV rms	837.7 nV rms	836.4 nV rms	835.9 nV rms
		26.789 counts rms	26.770 counts rms	26.743 counts rms	26.698 counts rms
	40 sps	560.3 nV rms	560.5 nV rms	559.8 nV rms	559.5 nV rms
		17.917 counts rms	17.911 counts rms	17.899 counts rms	17.870 counts rms
	20 sps	397.0 nV rms	396.7 nV rms	396.4 nV rms	396.3 nV rms
		12.691 counts rms	12.676 counts rms	12.672 counts rms	12.657 counts rms

Average self noise of 100 sps channels the over the 0.01 Hz – 10 Hz passband, ranged from as much as 1.541 uV rms for the gain of 1x to as low as 419.5 nV rms at a gain of 32x. No rms noise value varied more than 4.19% (at gain 16x) from their respective average rms noise values. Rms noise values did not exceed the equivalent of 2 counts rms while operating at a gain of 1x or 2x and 14 counts rms at gain 32x.

Average self noise over the passband 0.01 Hz – 0.10 Hz evaluated at 20 and 40 sps varied no more than 4.24% (20 sps at a gain of 16x) from their respective average rms noise values. Similarly, rms noise values did not exceed the equivalent of 2 counts rms while operating at a gain of 1x or 2x and 14 counts rms at gain 32x.

Over the frequency range of 0.01 Hz to 40 Hz, we limit our comments to the 100 sps data as the limits in frequency content of the 40 sps and 20 sps data obviously lower the rms noise computed over this frequency range. Average self noise of 100 sps channels over the passband, ranged from as much as 3.065 uV rms for the gain of 1x to as low as 837.0 nV rms at a gain of 32x. No rms noise value varied more than 4.03% (at gain 16x) from their respective average rms noise values. Rms noise values did not exceed the equivalent of 4 counts rms while operating at a gain of 1x and 27 counts rms at a gain 32x.

3.9 Dynamic Range

Dynamic range is defined to be the ratio between the power of the largest and smallest signals that may be measured on the digitizer channel.

3.9.1 Measurand

The Dynamic Range is measured as dB of the ratio between the power in the largest and smallest signals. The largest signal is defined to be a sinusoid with amplitude equal to the full scale input of the digitizer channel. The smallest signal is defined to have power equal to the self-noise of the digitizer channel. This definition of dynamic range is consistent with the definition of signal-to-noise and distortion ratio (SINAD) for digitizers (IEEE Std 1241-2010 section 9.2).

3.9.2 Configuration

There is no test configuration for the dynamic range test.

The full scale value used for the largest signal comes from the manufacturer's nominal specifications, validated in section 3.4 AC Full Scale. The value for the smallest signal comes from the evaluated digitizer channel self noise determined in section 3.7 Self Noise.

3.9.3 Analysis

The dynamic range over a given pass-band is:

$$Dynamic\ Range = 10 \cdot \log_{10}\left(\frac{signal\ power}{noise\ power}\right)$$

Where

$$signal\ power = \left(fullscale/\sqrt{2}\right)^2$$

$$noise\ power = (RMS\ Noise)^2$$

The application pass-band over which the noise is integrated should be selected to be consistent with the application pass-band.

3.9.4 Result

The following tables contain the peak-to-peak full scales, noise levels, and dynamic ranges that were identified in the evaluations of the sample rates and gain levels over the frequency range 0.01 Hz to 10 Hz and 0.01 Hz to 40 Hz.

Table 40 Dynamic Range, 0.01 Hz to 10 Hz, 100 sps

Gain	Channel HH1	Channel HH2	Channel HH3	Channel HDF	Channel HH5	Channel HH6	Channel HH7	Channel HH8
1x	139.28 dB	139.23 dB	139.25 dB	139.24 dB	-	-	-	-
2x	138.39 dB	138.35 dB	138.37 dB	138.27 dB	-	-	-	-
4x	136.06 dB	136.04 dB	136.07 dB	136.06 dB	-	-	-	-
8x	-	-	-	-	131.82 dB	131.83 dB	131.76 dB	131.40 dB
16x	-	-	-	-	126.43 dB	126.45 dB	126.43 dB	125.96 dB
32x	-	-	-	-	120.45 dB	120.45 dB	120.46 dB	120.46 dB

Table 41 Dynamic Range, 0.01 Hz to 10 Hz, 40 sps

Gain	Channel SH1	Channel SH2	Channel SH3	Channel SDF	Channel SH5	Channel SH6	Channel SH7	Channel SH8
1x	139.24 dB	139.19 dB	139.21 dB	139.21 dB	-	-	-	-
2x	138.36 dB	138.32 dB	138.33 dB	138.24 dB	-	-	-	-
4x	136.04 dB	136.02 dB	136.05 dB	136.04 dB	-	-	-	-
8x	-	-	-	-	131.81 dB	131.82 dB	131.77 dB	131.39 dB
16x	-	-	-	-	126.44 dB	126.45 dB	126.44 dB	125.96 dB
32x	-	-	-	-	117.94 dB	117.94 dB	117.95 dB	117.95 dB

Table 42 Dynamic Range, 0.01 Hz to 10 Hz, 20 sps

Gain	Channel BH1	Channel BH2	Channel BH3	Channel BDF	Channel BH5	Channel BH6	Channel BH7	Channel BH8
1x	139.63 dB	139.58 dB	139.60 dB	139.59 dB	-	-	-	-
2x	138.77 dB	138.72 dB	138.74 dB	138.65 dB	-	-	-	-
4x	136.48 dB	136.46 dB	136.49 dB	136.48 dB	-	-	-	-
8x	-	-	-	-	132.28 dB	132.29 dB	132.23 dB	131.86 dB
16x	-	-	-	-	126.92 dB	126.93 dB	126.92 dB	126.44 dB
32x	-	-	-	-	120.93 dB	120.94 dB	120.95 dB	120.95 dB

Table 43 Dynamic Range, 0.01 Hz to 40 Hz, 100 sps

Gain	Channel HH1	Channel HH2	Channel HH3	Channel HDF	Channel HH5	Channel HH6	Channel HH7	Channel HH8
1x	133.32 dB	133.27 dB	133.27 dB	133.27 dB	-	-	-	-
2x	132.41 dB	132.38 dB	132.38 dB	132.29 dB	-	-	-	-
4x	130.07 dB	130.05 dB	130.06 dB	130.07 dB	-	-	-	-
8x	-	-	-	-	125.82 dB	125.84 dB	125.82 dB	125.43 dB
16x	-	-	-	-	120.44 dB	120.43 dB	120.45 dB	119.98 dB
32x	-	-	-	-	114.44 dB	114.45 dB	114.46 dB	114.46 dB

The observed dynamic range values over the 0.01 Hz and 10 Hz passband varied across all sample rates from 139.23 dB (100 sps) to 139.63 dB (40 sps) at a gain of 1x, while at a gain of 32x observed dynamic ranges varied from 117.94 dB (40 sps) to 120.95 dB (20 sps).

Over the frequency range of 0.01 Hz to 40 Hz, we limit our comments to the 100 sps data as the limits in frequency content of the 40 sps and 20 sps data obviously raise the dynamic range as signal above their respective Nyquist Frequency is absent. Dynamic ranges varied from as little as 114.44 dB, at a gain of 32x to as high as 133.32 dB at a gain of 1x.

3.10 System Noise

The System Noise test determines the amount of digitizer self-noise expressed in units of a sensor.

3.10.1 Measurand

The quantity being measured is the digitizer input channels self-noise power spectral density, corrected by a sensor's response to some geophysical unit, in dB relative to 1 $(dB)^2$/Hz versus frequency.

3.10.2 Configuration

There is no test configuration for the dynamic range test.

3.10.3 Analysis

The time-series data and PSD computed in section 3.7 are corrected for a desired sensor's amplitude response model. The resulting PSD in the sensor's geophysical unit is then compared against an application requirement or background noise model to determine whether the resulting system noise meets the requirement.

3.10.4 Result

The PSD of the system noise is shown in the plots below. A representative channel's data, from the isolation noise tests, has the response and sensitivity of a selection of sensors applied to determine equivalent infrasound and seismic system noise

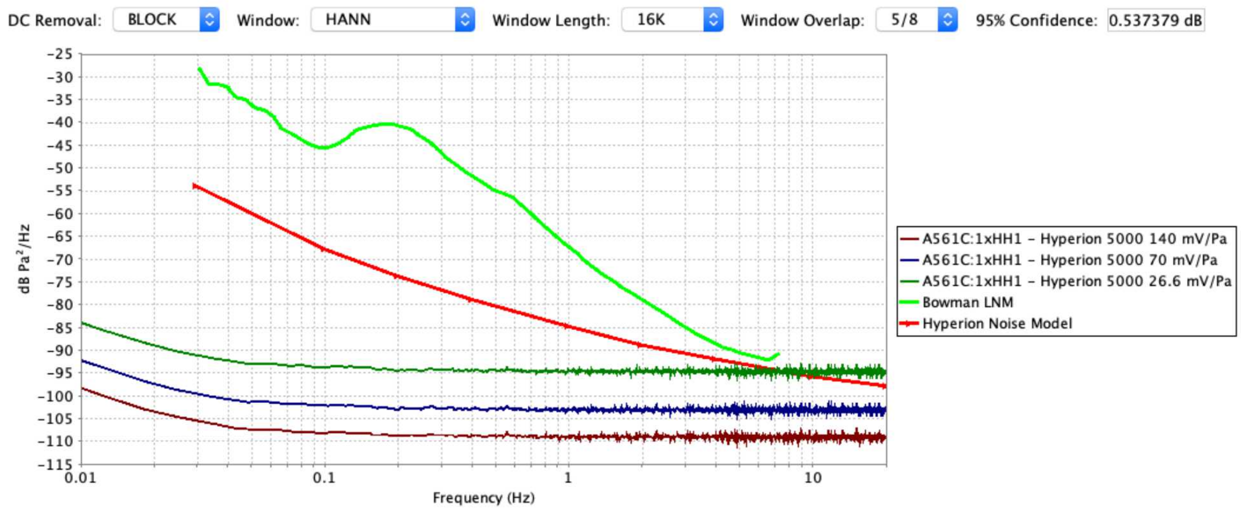

Figure 52 System Noise, Hyperion Series Response, 140 mV/Pa, 70 mV/Pa, 26.6 mV/Pa

System noise of the Affinity with the Hyperion 5000 series response (26.6 mV/Pa) rises above the self noise of the Hyperion sensor, while the higher sensitivity units' self noise remains below the sensors noise model.

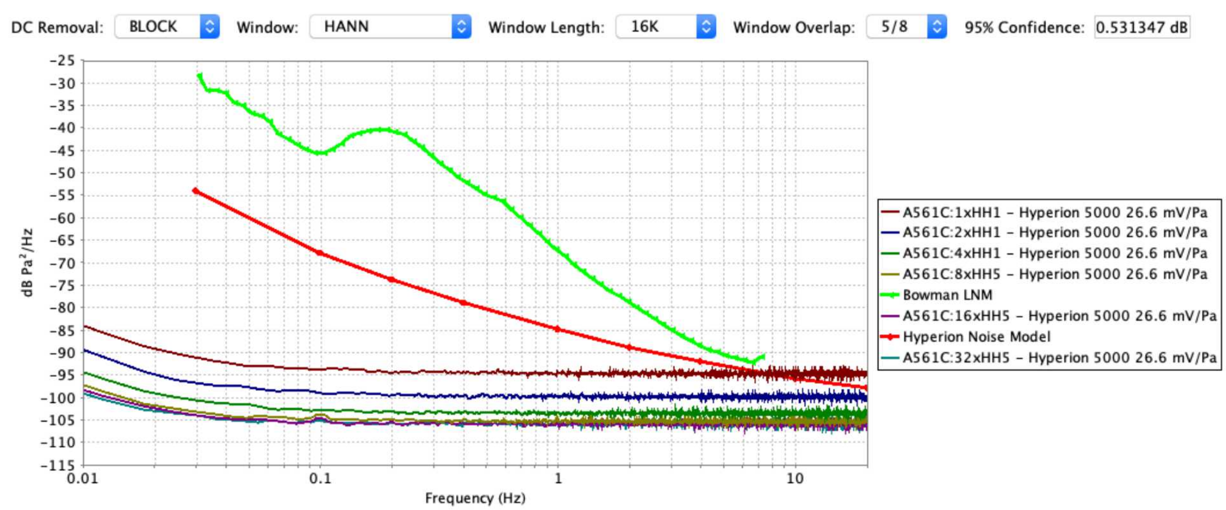

Figure 53 System Noise, Hyperion Series Response, 1x, 2x, 4x, 8x, 16x, 32x Gains

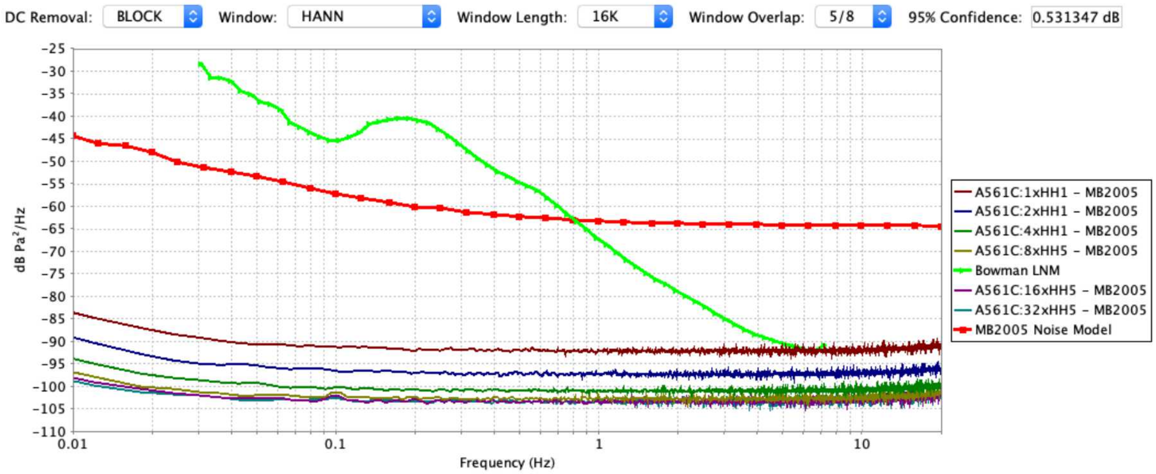

Figure 54 System Noise, MB2005 Response, 1x, 2x, 4x, 8x, 16x, 32x Gains

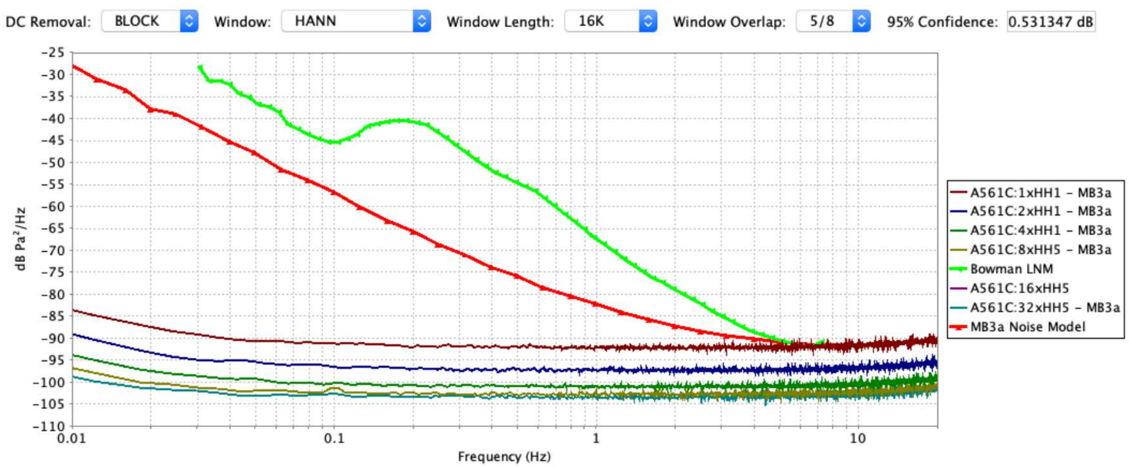

Figure 55 System Noise, MB3a Response, 1x, 2x, 4x, 8x, 16x, 32x Gains

System noise of Affinity with the Hyperion 5000 series (140 mV/Pa) or MB2005 (20 mV/Pa) response applied is well below the self noise of the respective sensor, even at a gain of 1x. When system noise has the response of the MB3a (20 mV/Pa) applied, as shown in Figure 55, the system noise curves clearly illustrates the need to operate the Affinity at gain settings greater than 1x, as the system noise at a gain of 1x is above the MB3a self noise at and above 7.0 Hz.

Seismic system noise, utilizing seismometer responses for the Guralp CMG3T (1500 Vs/m), Geotech GS-13 (2000 Vs/m), Streckheisen STS-2 (1500 Vs/m) and STS-5a (1500 Vs/m) and Nanometrics T-120 (1200 Vs/m) are plotted below.

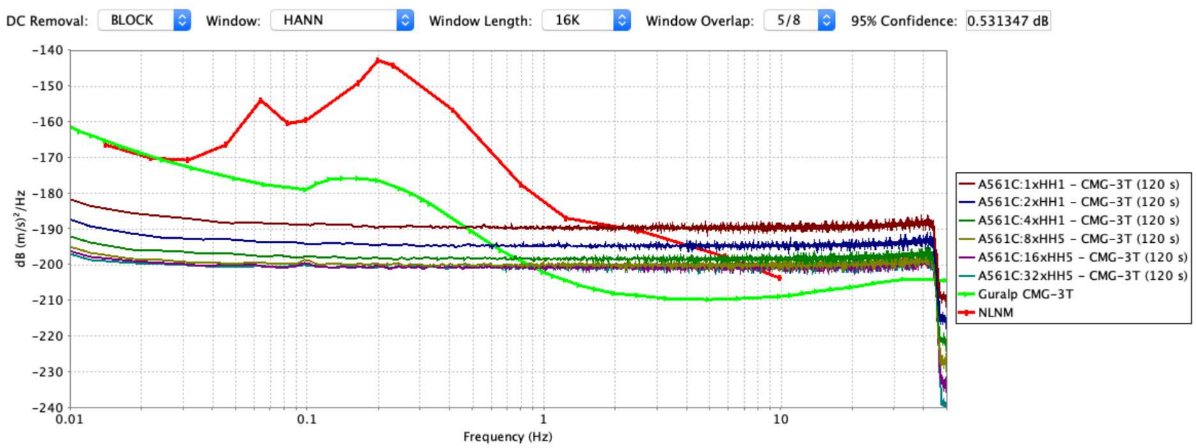

Figure 56 System Noise, CMG-3T Response, 1x, 2x, 4x, 8x, 16x and 32x Gain

System noise in CMG3-T equivalent units exceed that of the CMG-3T noise model, above 0.47 Hz, 0.62 Hz, 0.76 Hz, 0.87 Hz, 0.92 Hz and 0.93 Hz, at gains of 1x, 2x, 4x, 8x, 16x and 32x respectively.

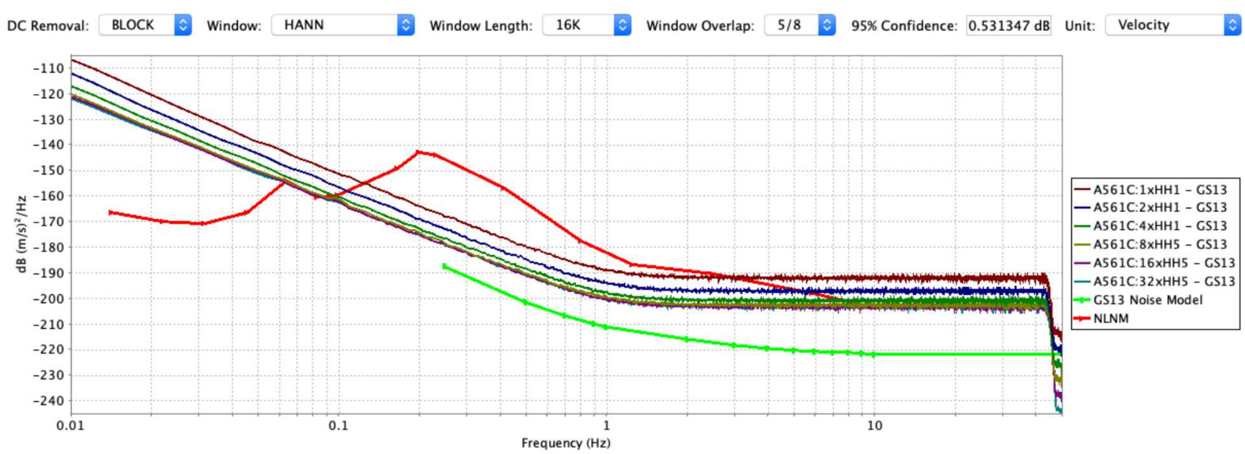

Figure 57 System Noise, GS-13 Response, 1x, 2x, 4x, 8x, 16x and 32x Gains

When expressed in GS-13 equivalent units, system noise is well above that of the GS-13 noise model at all gains evaluated, from 0.25 Hz, the lowest frequency of the GS-13 noise model to effectively the Nyquist frequency.

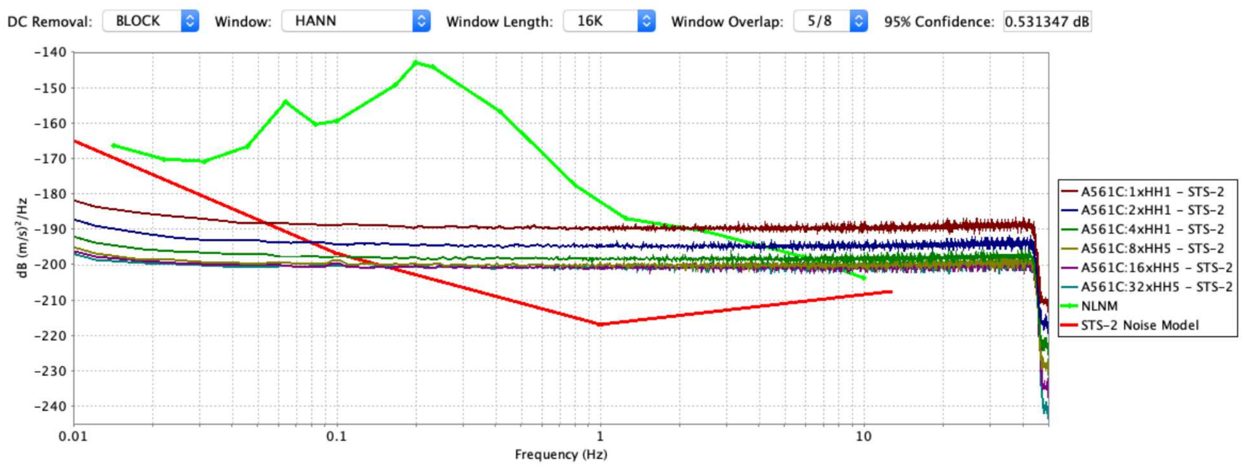

Figure 58 System Noise, STS-2 Response, 1x, 2x, 4x, 8x, 16x and 32x Gains

At all gains evaluated the Affinity's system noise, expressed in units of an STS-2, exceeds the self noise of the STS-2 over some portion of the frequency range evaluated: above 0.055 Hz, 0.79 Hz, 0.12 Hz, 0.15 Hz, 0.16 Hz and 0.16 Hz, at gains of 1x, 2x, 4x, 8x, 16x and 32x respectively.

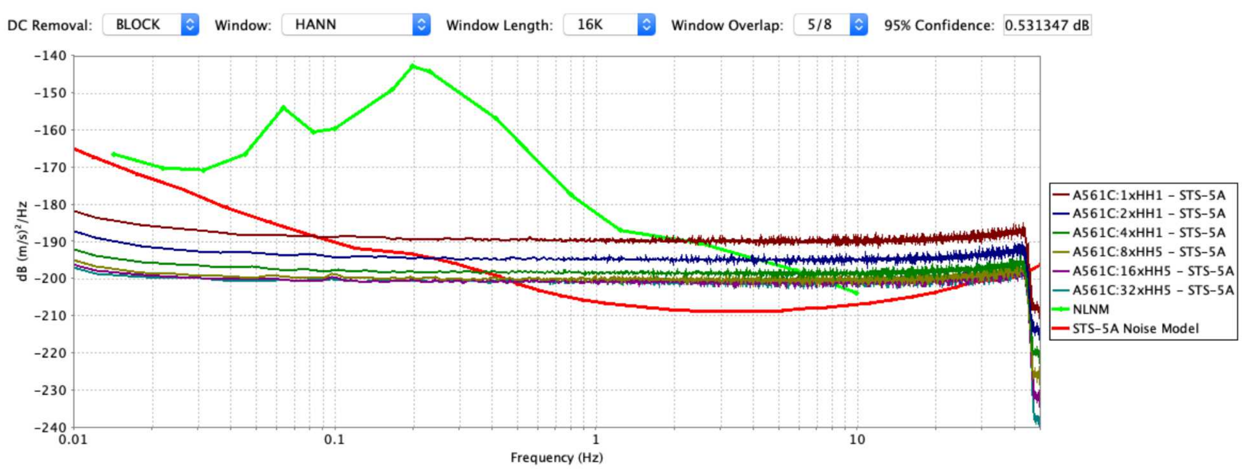

Figure 59 System Noise, STS-5a Response, 1x, 2x, 4x, 8x, 16x and 32x Gains

System noise of the Affinity expressed in units of STS-5a response, exceeds the self noise of the sensor above the following frequencies: 0.085 Hz, 0.25 Hz, 0.38 Hz, 0.48 Hz and 0.88 Hz at gains of 1x, 2x, 4x, 8x, 16x and 32x, respectively.

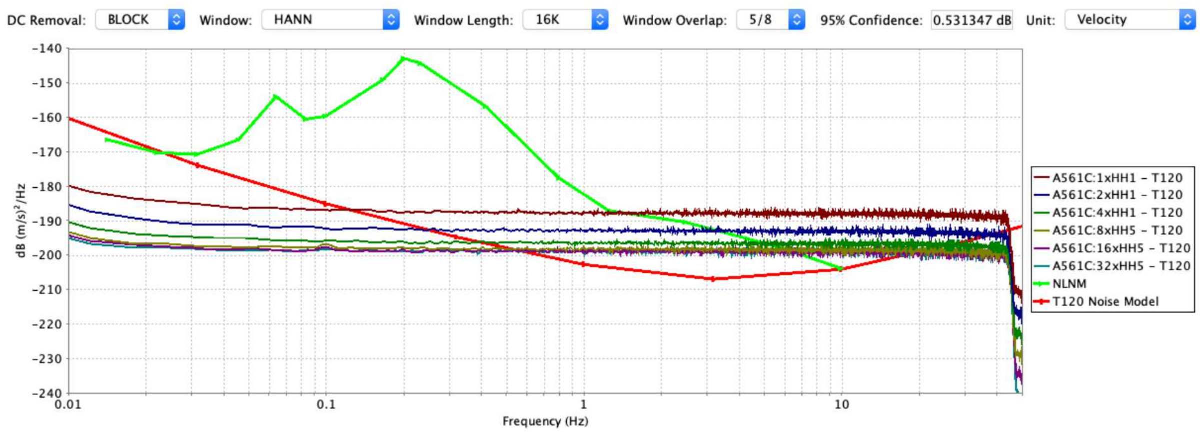

Figure 60 System Noise, T-120 Response, 1x, 2x, 4x, 8x, 16x and 32x Gains

When system noise is expressed in T-120 units, the Affinity exceeds the self noise of the T-120 above 0.13 Hz; as the gain increases the frequency range over which its system noise exceeds the self noise of the sensor narrows: from 0.25 Hz to 38 Hz at a gain of 2x, 0.42 Hz to 28 Hz at 4x, 0.54 Hz to 23 Hz at 8x, 0.60 Hz to 20 Hz at gains of 16x and 32x.

Seismic system noise plots, for all sensors, illustrate the need to operate the Affinity at high gain settings to minimize the frequency band over which the digitizer self noise exceeds that of selected seismic sensor.

3.11 Temperature Self-Noise

The Temperature Self-Noise test measures the amount of noise present on a digitizer by collecting waveform data from an input channel that has been terminated with a resistor whose impedance matches the nominal impedance of a chosen sensor at 1 Hz while the digitizer is being maintained at a specific temperature.

3.11.1 Measurand

The quantity being measured is the digitizer input channels self-noise power spectral density in dB relative to 1 V^2/Hz versus frequency and the total noise in Volts RMS over an application pass-band.

3.11.2 Configuration

The digitizer input channel is connected to a shorting resistor as shown in the diagram below.

Figure 61 Self Noise Configuration Diagram

Figure 62 Input Shorted Offset Temperature Test, Affinity in the Middle

Table 44 Input Terminated Noise Termination Resistors

Channels	Termination Resistor
Primary	100 ohm (50 x 2 ohm)

Approximately 8 hours of data is recorded beginning hours after the digitizer has acclimatized to the new temperature setting.

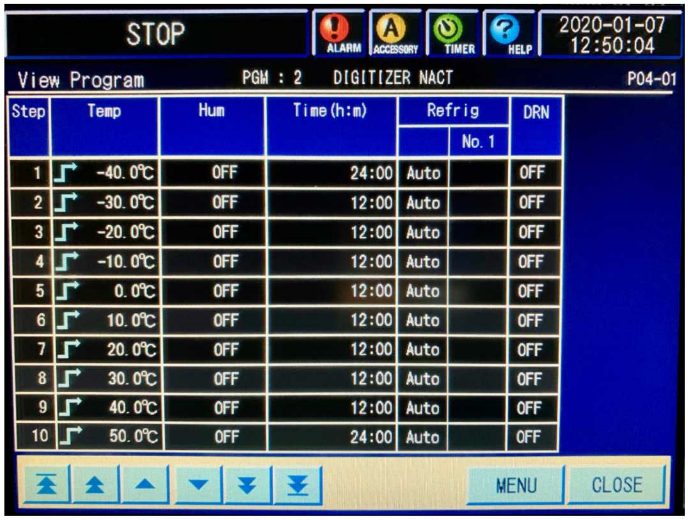

Figure 63 Environmental Chamber Temperature Schedule

3.11.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n], \qquad 0 \leq n \leq N-1$$

The PSD is computed from the time series (Merchant, 2011) from the time series using between a 32K-sample Hann window. The window length and data duration were chosen such that there were a few points below the lower limit of the evaluation pass-band of 0.01 Hz and the 90% confidence interval is less than 0.94 dB.

$$P_{xx}[k], 0 \leq k \leq N-1$$

Over frequencies (in Hertz):

$$f[k], 0 \leq k \leq N-1$$

In addition, the total RMS noise over the application pass-band of 0.02 to 4.0 Hz is computed:

$$rms = \sqrt{\frac{1}{T_s L} \sum_{k=n}^{m} |Pxx[k]|}$$

where $f[n]$ and $f[m]$ are the pass − band limits

3.11.4 Result

The time series plot over the time over the temperature testing time period are shown below. Only the data from 100 Hz is shown as the other sample rates are otherwise identical. Note, the narrow offsets on the left and right of the plot are data drop-outs.

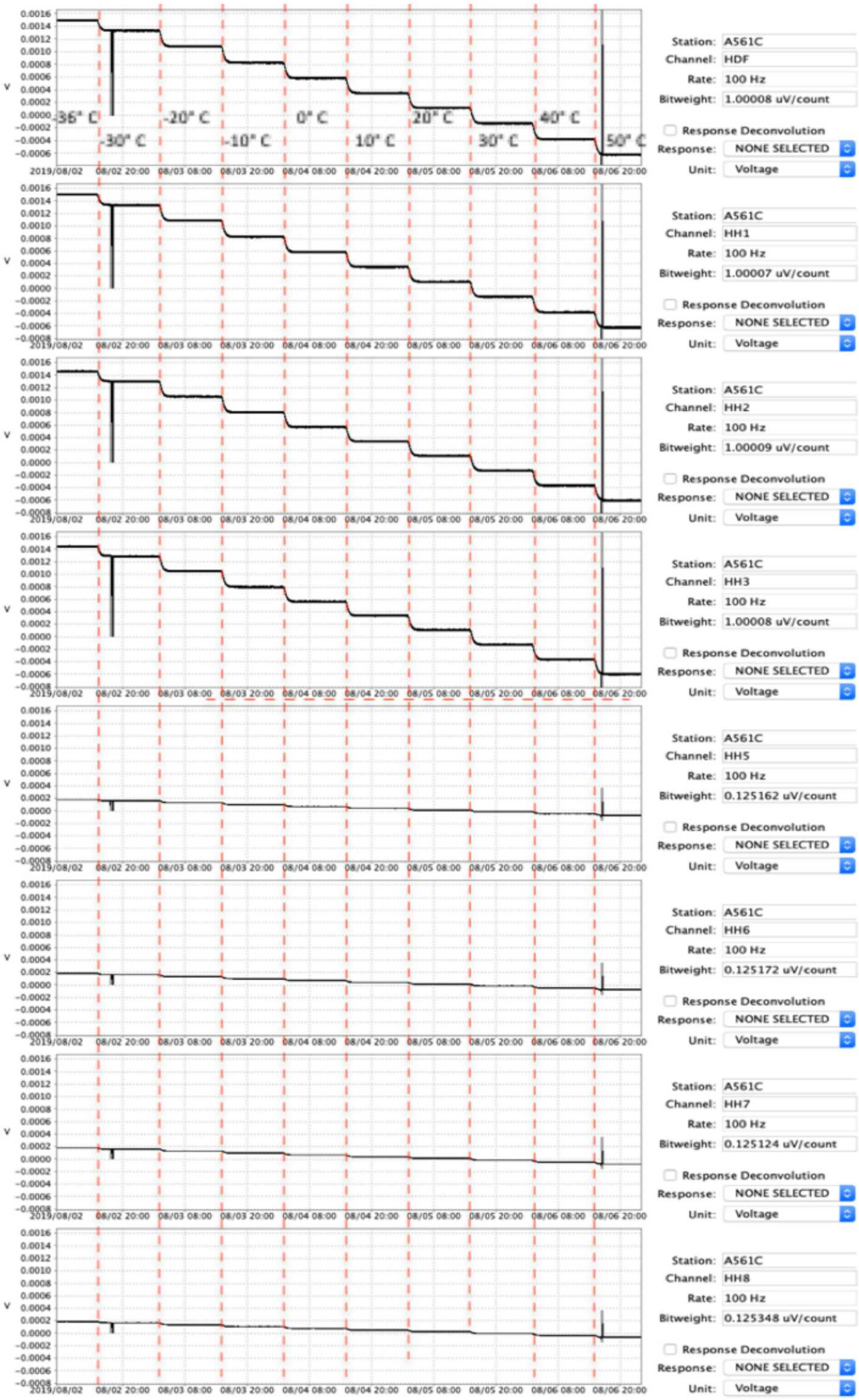

Figure 64 Self Noise Time Series over -36° C to 50° C

The offset of the voltage illustrated in the plot are shown in the following table.

Table 45 DC Offset and Rate of Change of DC Offset with Temperature

Temp.	HH1	HH2	HH3	HDF	HH5	HH6	HH7	HH8
	Gain = 1x				Gain = 8x			
	DC Offset							
	DC Offset Rate of Change							
-36° C	1.4990 mV	1.4568 mV	1.4440 mV	1.4946 mV	0.1771 mV	0.1828 mV	0.1783 mV	0.1862 mV
	0.027 mV/°C	0.027 mV/°C	0.026 mV/°C	0.027 mV/°C	0.0032 mV/°C	0.0033 mV/°C	0.0033 mV/°C	0.0033 mV/°C
-30° C	1.3348 mV	1.2975 mV	1.2862 mV	1.3315 mV	0.1576 mV	0.1627 mV	0.1584 mV	0.1666 mV
	0.025 mV/°C	0.024 mV/°C	0.024 mV/°C	0.025 mV/°C	0.0030 mV/°C	0.0031 mV/°C	0.0030 mV/°C	0.0030 mV/°C
-20° C	1.0853 mV	1.0552 mV	1.0466 mV	1.0833 mV	0.1281 mV	0.1321 mV	0.1279 mV	0.1366 mV
	0.026 mV/°C	0.025 mV/°C	0.025 mV/°C	0.026 mV/°C	0.0031 mV/°C	0.0032 mV/°C	0.0032 mV/°C	0.0031 mV/°C
-10° C	0.8245 mV	0.8023 mV	0.7963 mV	0.8245 mV	0.0972 mV	0.1002 mV	0.0962 mV	0.1053 mV
	0.026 mV/°C	0.025 mV/°C	0.025 mV/°C	0.026 mV/°C	0.0031 mV/°C	0.0032 mV/°C	0.0032 mV/°C	0.0031 mV/°C
0° C	0.5813 mV	0.5667 mV	0.5628 mV	0.5829 mV	0.0685 mV	0.0704 mV	0.0666 mV	0.0762 mV
	0.024 mV/°C	0.023 mV/°C	0.023 mV/°C	0.024 mV/°C	0.0028 mV/°C	0.0029 mV/°C	0.0029 mV/°C	0.0028 mV/°C
10° C	0.3433 mV	0.3359 mV	0.3343 mV	0.3466 mV	0.0403 mV	0.0412 mV	0.0375 mV	0.0478 mV
	0.024 mV/°C	0.023 mV/°C	0.023 mV/°C	0.024 mV/°C	0.0028 mV/°C	0.0029 mV/°C	0.0029 mV/°C	0.0028 mV/°C
20° C	0.1071 mV	0.1068 mV	0.1074 mV	0.1119 mV	0.0123 mV	0.0122 mV	0.0088 mV	0.0198 mV
	0.024 mV/°C	0.024 mV/°C	0.023 mV/°C	0.024 mV/°C	0.0029 mV/°C	0.0030 mV/°C	0.0029 mV/°C	0.0028 mV/°C
30° C	-0.1355 mV	-0.1281 mV	-0.1261 mV	-0.1306 mV	-0.0165 mV	-0.0178 mV	-0.0204 mV	-0.0082 mV
	0.025 mV/°C	0.024 mV/°C	0.024 mV/°C	0.025 mV/°C	0.0030 mV/°C	0.0031 mV/°C	0.0029 mV/°C	0.0027 mV/°C
40° C	-0.3836 mV	-0.3686 mV	-0.3655 mV	-0.3807 mV	-0.0462 mV	-0.0490 mV	-0.0499 mV	-0.0353 mV
	0.024 mV/°C	0.024 mV/°C	0.024 mV/°C	0.024 mV/°C	0.0028 mV/°C	0.0029 mV/°C	0.0031 mV/°C	0.0031 mV/°C
50° C	-0.6278 mV	-0.6057 mV	-0.6013 mV	-0.6232 mV	-0.0738 mV	-0.0785 mV	-0.0805 mV	-0.0661 mV
Average Rate of Change - Entire Temperature Range								
	0.025 mV/°C	0.024 mV/°C	0.024 mV/°C	0.025 mV/°C	0.0029 mV/°C	0.0030 mV/°C	0.0030 mV/°C	0.0029 mV/°C

The plots in Figure 64 Self Noise Time Series over -36° C to 50° C clearly illustrate the linear relationship between the input shorted offset voltage and temperature. Table 45 provides the rate of DC offset change between temperatures and the rate of change over the temperature extremes. DC offset were relatively small and the observed rate of change in DC offset with temperature remains relatively constant over the temperatures over which DC offset was evaluated.

The power spectra for the data collected at each gain level and temperature are shown in the following plots.

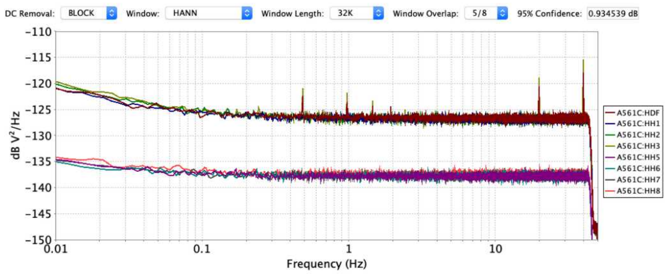

Figure 65 Self Noise, -36° C

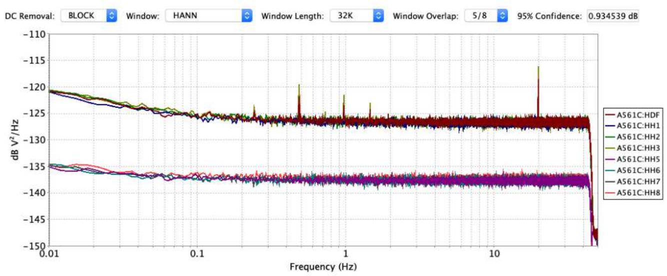

Figure 66 Self Noise, -30° C

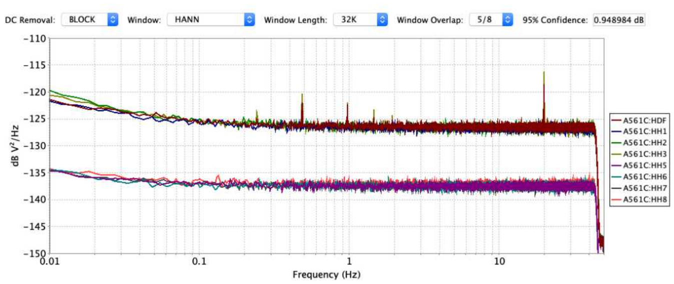

Figure 67 Self Noise, -20° C

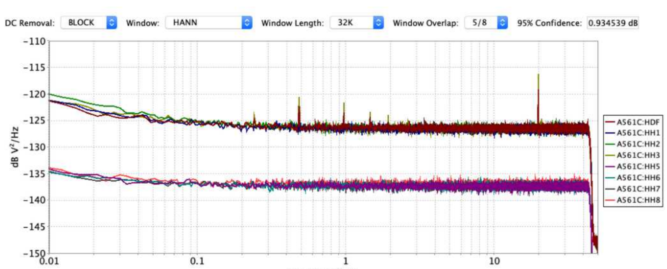

Figure 68 Self Noise, -10° C

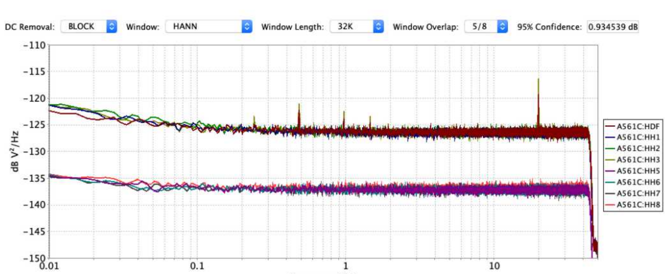

Figure 69 Self Noise, 0° C

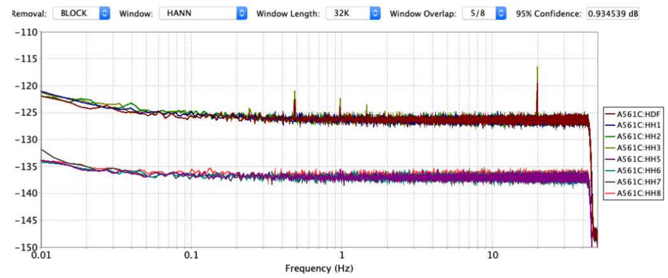

Figure 70 Self Noise, 10° C

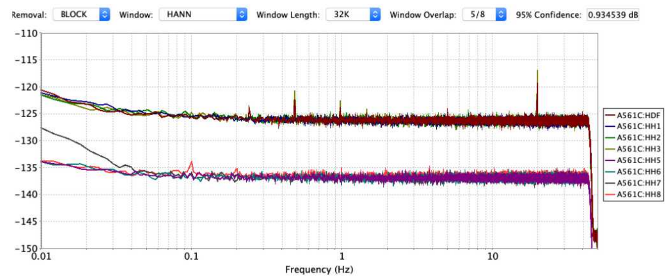

Figure 71 Self Noise, 20° C

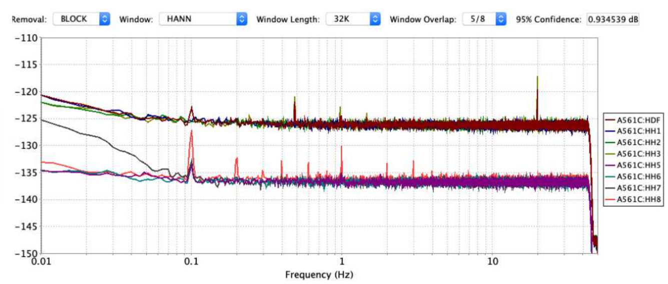

Figure 72 Self Noise, 30° C

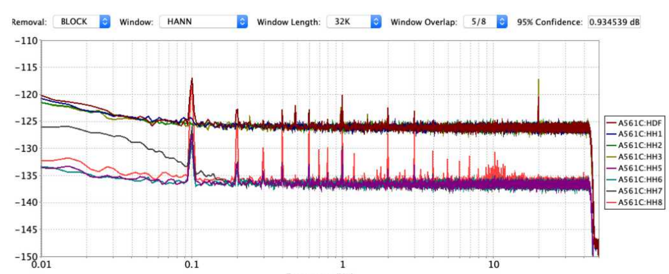

Figure 73 Self Noise, 40° C

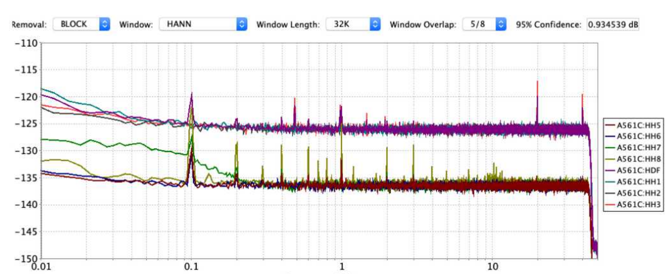

Figure 74 Self Noise, 50° C

The above plots illustrate that the self noise of all channels increases slightly, approximately 1 dB (essentially equivalent 95% confidence limit) at gains x1 and 2 dB at a gain of 8x. More noteworthy however, are spectral noise spikes at 0.1 Hz through 1.3 Hz visible in the 8x gain channels (HH5 - HH8), and the increase in noise near 10 Hz illustrated in the 50° C which are nearly absent in the -36° C data. The increase in self noise of channel HH7 at and below 0.2 Hz first becomes evident at 0° C, and gradually increases in the data through 50° C. As mentioned previously in section 3.7, subsequent to this evaluation of self noise, digitizer test cables and terminating resistors were interchanged, between the Sensor A and Sensor B ports of the digitizer; the anomalously higher self noise of channel HH7 at higher temperatures remained on HH7, rather than moving to channel HH3 as would be expected if the cause of the elevated self noise had been the result of a cabling or terminating resistor.

3.12 Response Verification

The Response Verification test measures the amplitude and phase response versus frequency that is present on the digitizer channels, relative to a reference channel.

3.12.1 Measurand

The quantity being measured is the unit-less relative amplitude and relative phase in degrees versus frequency for each digitizer channel relative to the first channel.

3.12.2 Configuration

Multiple digitizer channels are connected to a white noise signal source as shown in the diagram below.

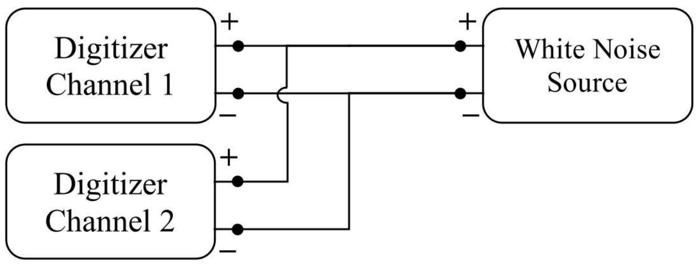

Figure 75 Response Verification Configuration Diagram

Figure 76 Relative Transfer Function Configuration Picture

Table 46 Response Verification Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
White Noise Source	Stanford Research Systems, DS3360	123762	+1V / - 1 V

The White Noise Source is configured to generate a band-width limited white noise voltage with an amplitude equal to approximately 10% of the digitizer input channel's full scale. One hour of data is recorded.

3.12.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n], \qquad 0 \leq n \leq N-1$$

The relative transfer function, both amplitude and phase, is computed between the two digitizer channels (Merchant, 2011) from the power spectral density:

$$H[k], \qquad 0 \leq k \leq N-1$$

3.12.4 Result

The coherence and relative amplitude and phase response were computed between channel 1 and the remaining three channels for all of the evaluated sample rate and gain configurations. In all cases, the coherence was identically 1.0 across the entire pass-band. The coherence, relative amplitude, and relative phase are shown in the plots below. Coherence is consistently very high at all gain and sample rates, hence only the first coherence plot is provided. Furthermore, only 100 sps relative amplitude and phase are provided as the relative amplitude and phase of the 40 sps and 20 sps, at their respective gains, are identical to the 100 sps and serve no purpose pf presented herein.

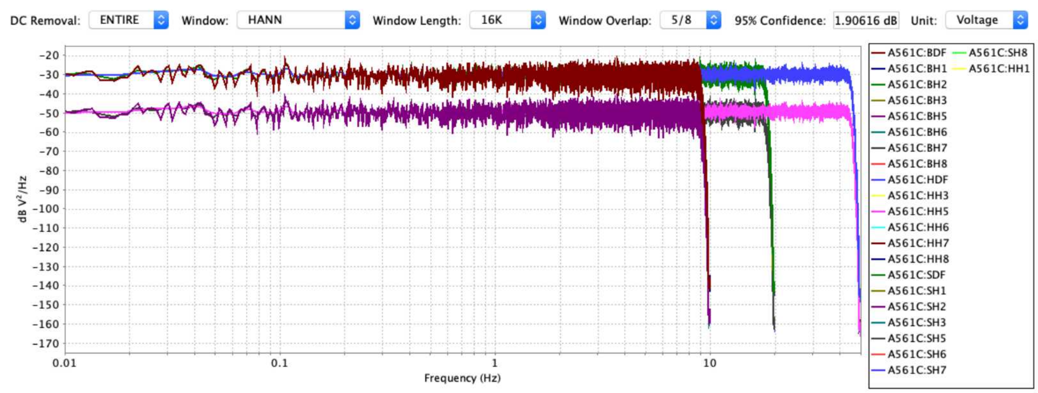

Figure 77 Power Spectra, Gains 1x and 8x, 100 sps, 40 sps and 20 sps

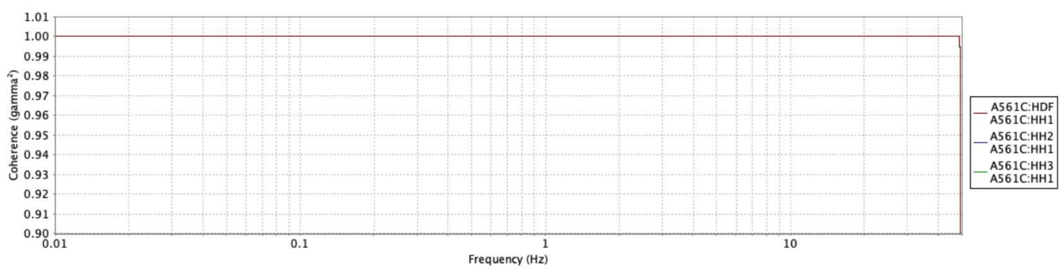

Figure 78 White Noise Coherence, Gain 1x, 100 sps

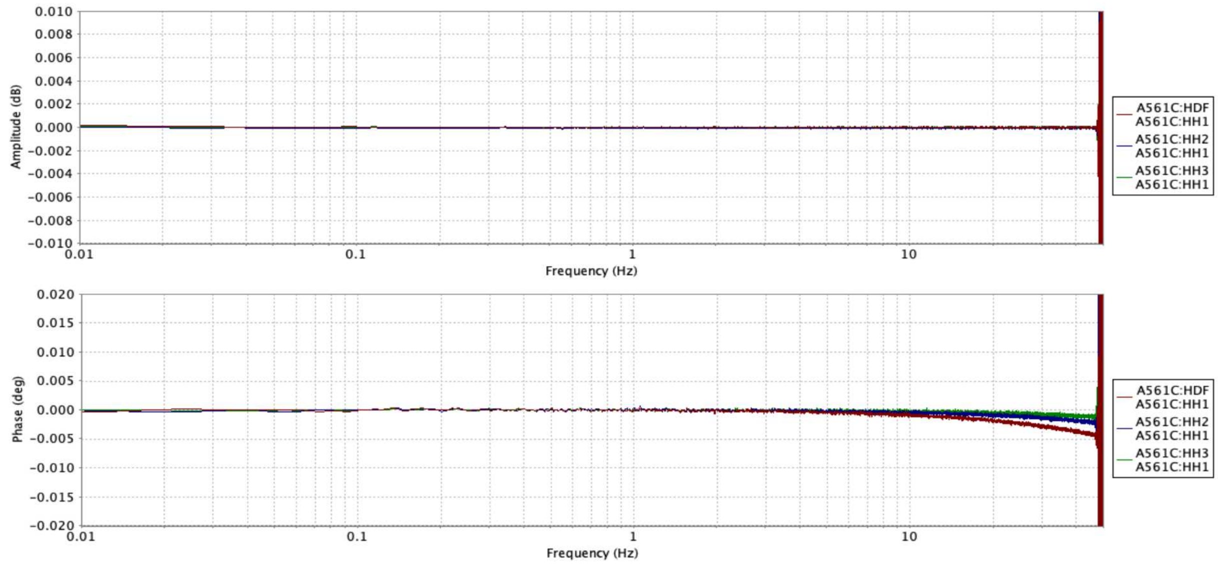

Figure 79 Relative Amplitude and Phase, Gain 1x, 100 sps

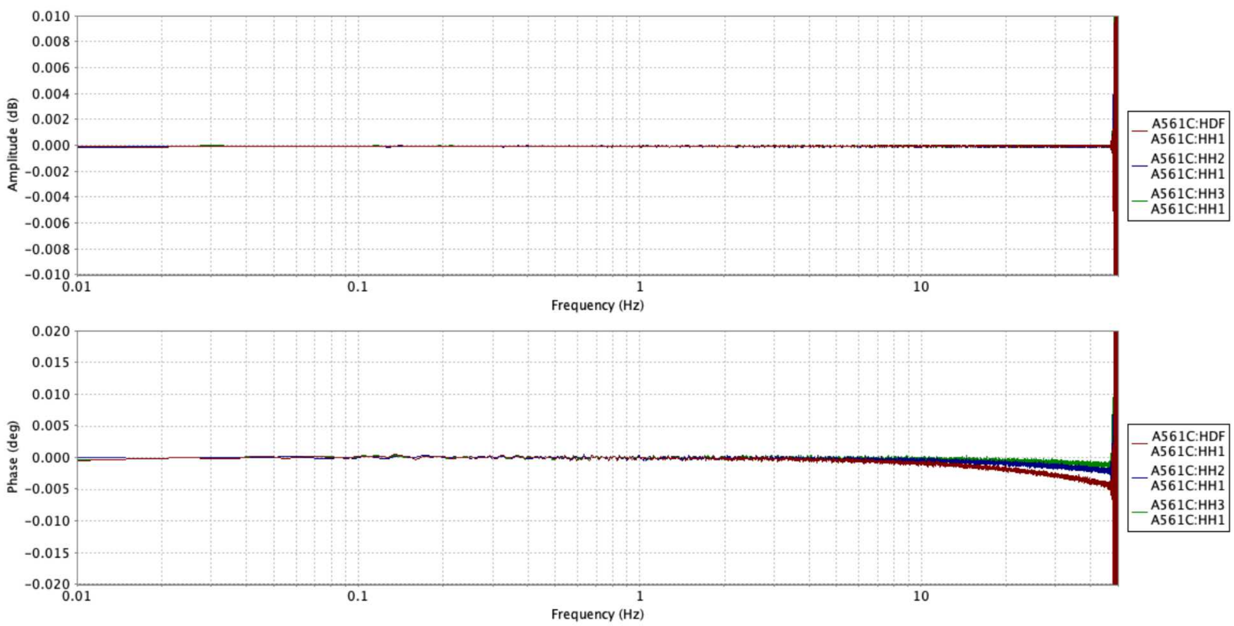

Figure 80 Relative Amplitude and Phase, Gain 2x, 100 sps

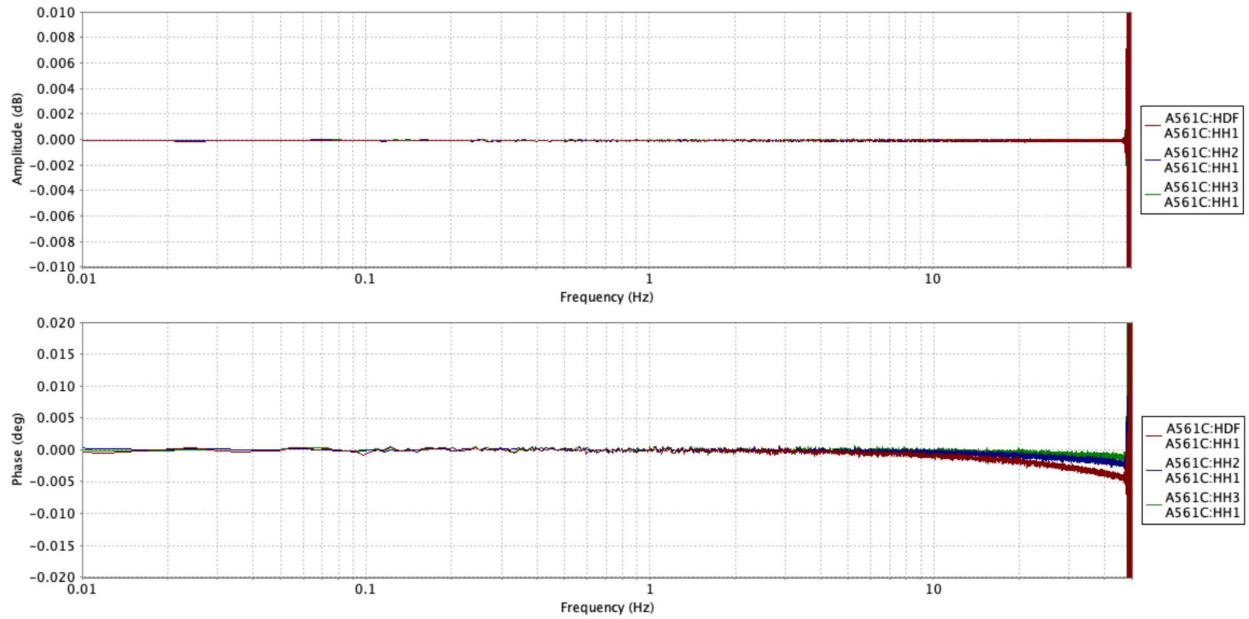

Figure 81 Relative Amplitude and Phase, Gain 4x,100 sps

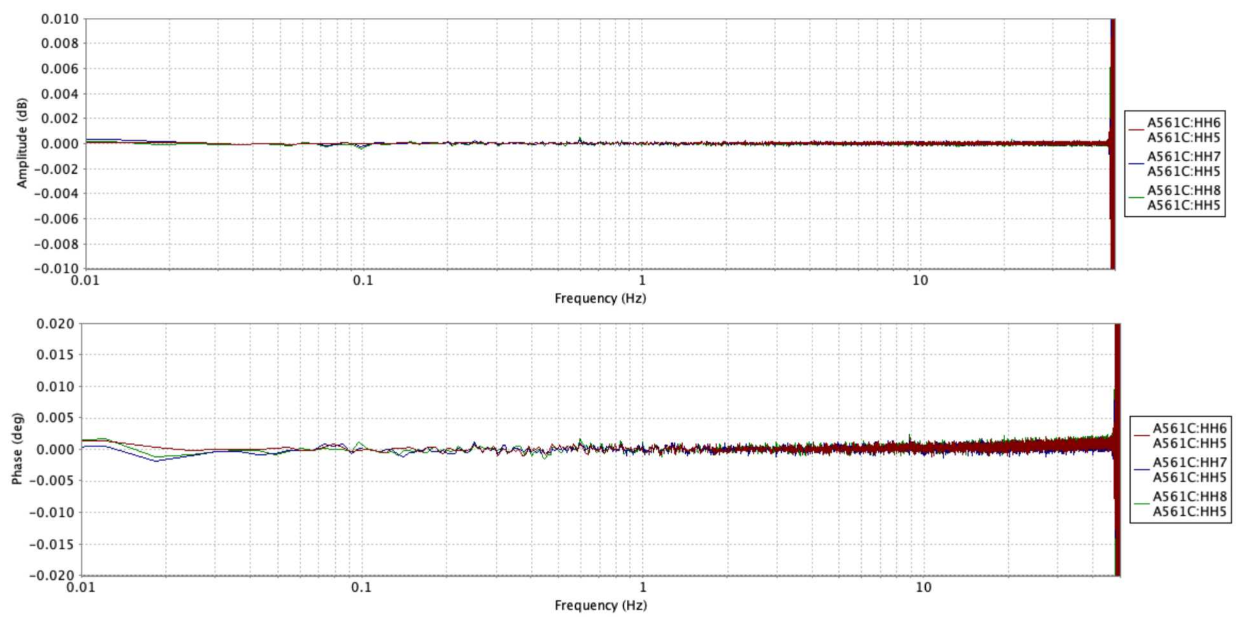

Figure 82 Relative Amplitude and Phase, Gain 8x, 100 sps

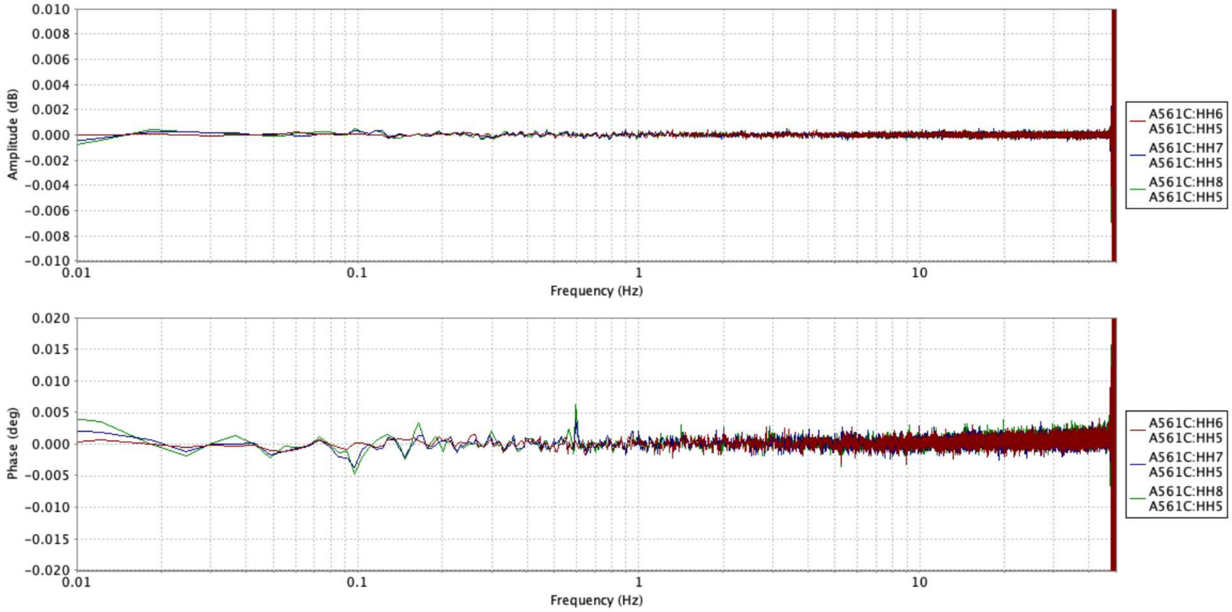

Figure 83 Relative Amplitude and Phase, Gain 16x, 100 sps

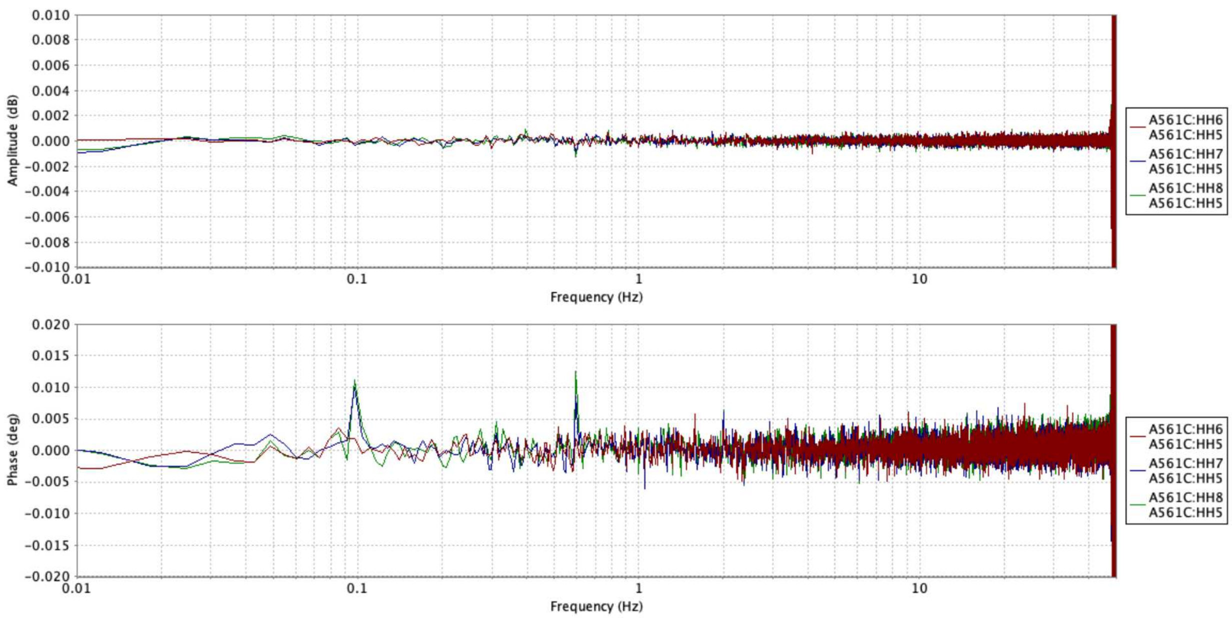

Figure 84 Relative Amplitude and Phase, Gain 32x, 100 sps

In all cases, the relative amplitudes were effectively zero across the pass-band. This indicates that there were no differences in response between the digitizer channels. There were some slight roll-off in the phase responses, as much as 0.005 degrees in the 100 sps data at all gains evaluated. This roll-off in phase may be attributed to slight differences in timing, which will be investigated further in the Relative Transfer Function section.

3.13 Relative Transfer Function

The Relative Transfer Function test measures the amount of channel-to-channel timing skew present on a digitizer.

3.13.1 Measurand

The quantity being measured is the timing skew in seconds between the digitizer input channels.

3.13.2 Configuration

Multiple digitizer channels are connected to a white noise signal source as shown in the diagram below.

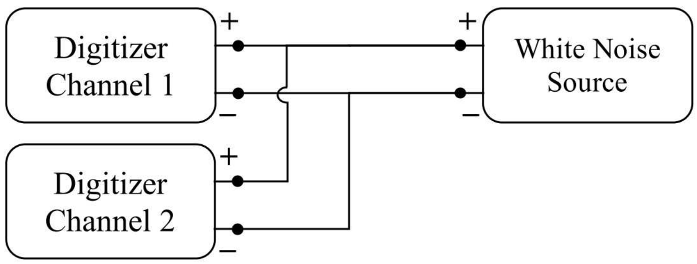

Figure 85 Relative Transfer Function Configuration Diagram

Figure 86 Relative Transfer Function Configuration Picture

Table 47 Relative Transfer Function Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
White Noise Source	Stanford Research Systems, DS3360	123762	+1V / - 1 V

The White Noise Source is configured to generate a band-width limited white noise voltage with an amplitude equal to approximately 10% of the digitizer input channel's full scale. At least one hour of data is recorded.

3.13.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n], \qquad 0 \le n \le N-1$$

The relative transfer function, both amplitude and phase, is computed between the two digitizer channels:

$$H[k], \qquad 0 \le k \le N-1$$

The tester defines a frequency range over which to measure the skew:

$$f[k], \qquad 0 \le k \le N-1$$

The amount of timing skew, in seconds, is computed by averaging the relative phase delay between the two channels over a frequency band from f[n] to f[m] over which the relative phase delay is observed to be linear:

$$skew = \frac{1}{m-n+1} \sum_{k=n}^{m} \frac{\measuredangle(H[k])}{2\pi\, f[k]}$$

3.13.4 Result

Phase delays were observed to be consistent at each sample across all gain settings. A phase delay versus frequency plot for channels HH1 - HH3, HDF at a gain of 1x is shown below; it is representative of relative transfer function plots for all evaluated sample rates and at gains 1x, 2x and 4x. Channels HH5 - HH8, were evaluated at the higher gain settings. These channels at gains 8x, 16x and 32x exhibit near zero slope phase delay. Plots of 100 sps at gains of 8x, 16x and 32x and 20 sps at a gain of 32x are provided as representative of the aforementioned near zero slope, and scatter evident, at the high gains common to all evaluated sample rates at these gain settings. To the extent that the delay is a constant time offset, the phase delay is observed to be linear with respect to frequency for each channel grouping and gain setting evaluated.

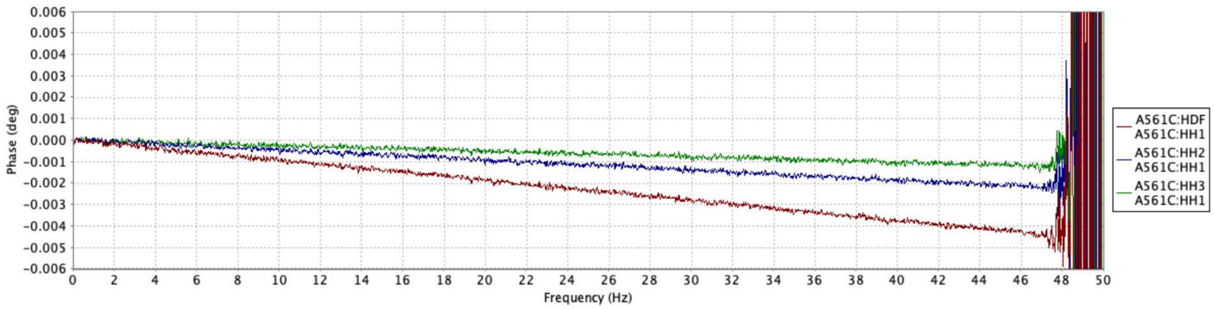

Figure 87 Relative Transfer Function Relative Phase, HH1 – HH3 and HDF, Gain 1x, 100 sps

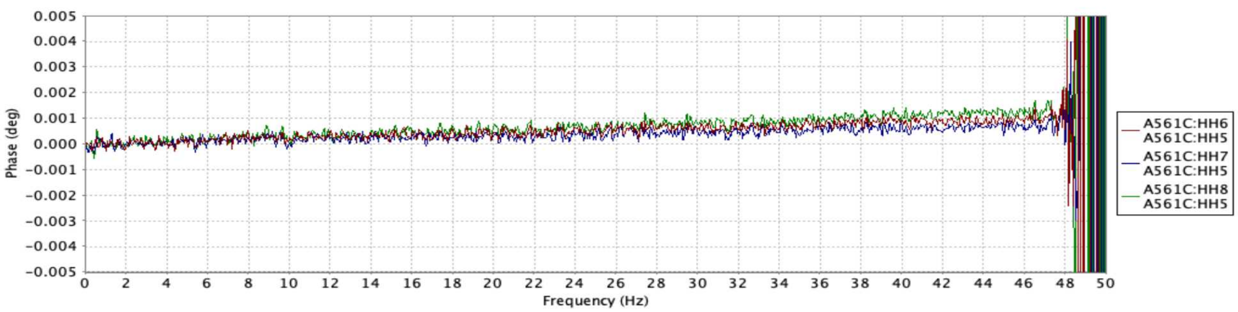

Figure 88 Relative Transfer Function Relative Phase, HH5 – HH8, Gain 8x, 100 sps

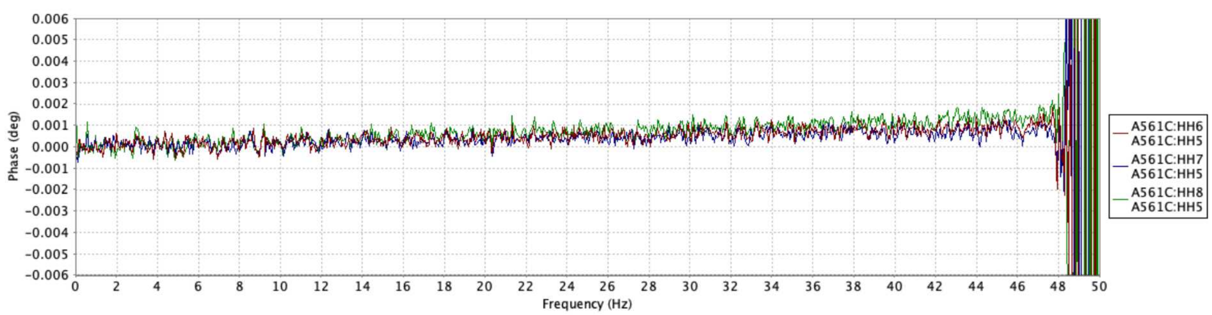

Figure 89 Relative Transfer Function Relative Phase, HH5 – HH16, Gain 16x, 100 sps

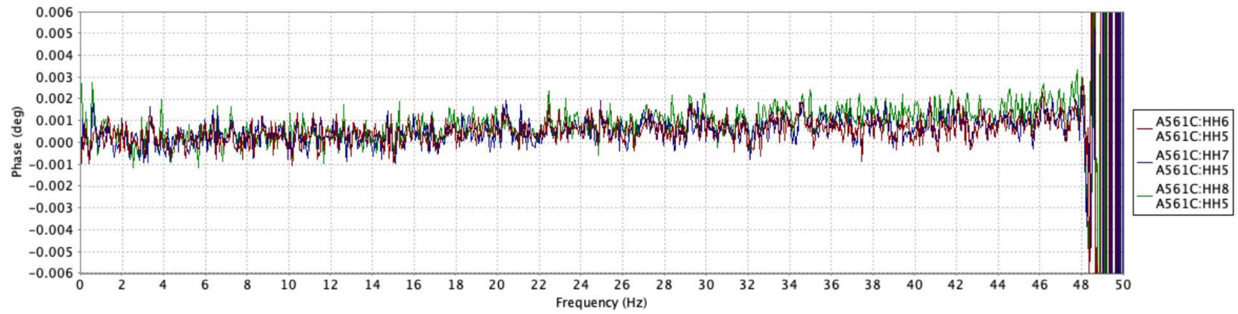

Figure 90 Relative Transfer Function Relative Phase, HH5 – HH16, Gain 32x, 100 sps

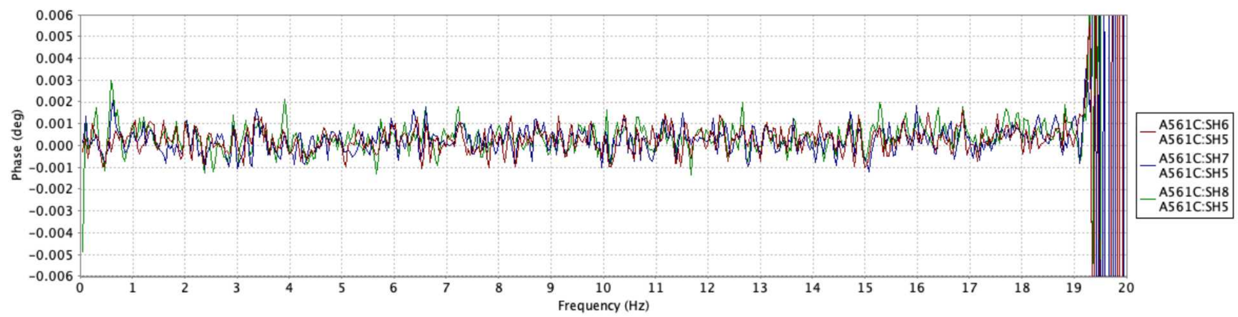

Figure 91 Relative Transfer Function Relative Phase, HH5 – HH16, Gain 32x, 20 sps

All of the phase delays are indeed linear with respect to frequency. The constant channel-to-channel timing skew corresponding to these phase delays is shown in the table below.

Table 48 Relative Transfer Function Timing Skew relative to Channel 1

Gain	Sample Rate	Channel 2	Channel 3	Channel 4
1x	100 sps	-0.1271 us	-0.0722 us	-0.2597 us
2x	100 sps	-0.1301 us	-0.0717 us	-0.2616 us
4x	100 sps	-0.1283 us	-0.0676 us	-0.2585 us
1x	40 sps	-0.1245 us	-0.0748 us	-0.2599 us
2x	40 sps	-0.1296 us	-0.0715 us	-0.2626 us
4x	40 sps	-0.1271 us	-0.0639 us	-0.2587 us
1x	20 sps	-0.1195 us	-0.0785 us	-0.2598 us
2x	20 sps	-0.1323 us	-0.0772 us	-0.2669 us
4x	20 sps	-0.1257 us	-0.0564 us	-0.2593 us

Table 49 Relative Transfer Function Timing Skew relative to Channel 5

Gain	Sample Rate	Channel 5	Channel 7	Channel 8
8x	100 sps	0.0555 us	0.0398 us	0.0729 us
16x	100 sps	0.0555 us	0.0483 us	0.0767 us
32x	100 sps	0.0844 us	0.0679 us	0.1163 us
8x	40 sps	0.0513 us	0.0372 us	0.0708 us
16x	40 sps	0.0531 us	0.0517 us	0.0696 us
32x	40 sps	0.1190 us	0.0790 us	0.1470 us
8x	20 sps	0.0351 us	0.0270 us	0.0585 us
16x	20 sps	0.0489 us	0.0608 us	0.0664 us
32x	20 sps	0.1799 us	0.0967 us	0.2268 us

Timing skews varied across gain settings as shown in Table 48 and Table 49. Channels 1 through 4 maintained consistent timing skews at each sample rate and gain evaluated, varying no more than 0.2669 microseconds (channels 1 vs channel 4, 20 sps, gain 2x). Channels 4 through 8 timing skews were less than channels 1 through 4, rising to no more than 0.2268 microseconds (channels 4 vs 8, 20 sps, gain 32x).

3.14 Analog Bandwidth

The Analog Bandwidth test measures the bandwidth of the digitizers analog and digital filter.

3.14.1 Measurand

The quantity being measured is the upper limit of the frequency pass-band in Hertz.

3.14.2 Configuration

Multiple digitizer channels are connected to a white noise signal source as shown in the diagram below.

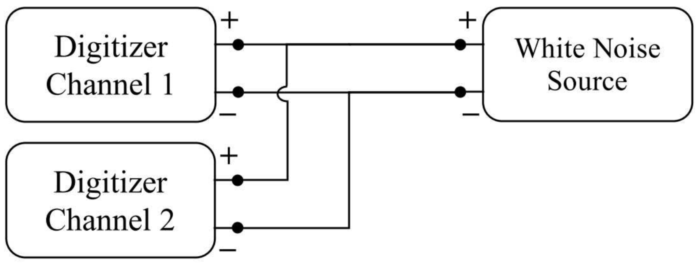

Figure 92 Analog Bandwidth Configuration Diagram

Table 50 Analog Bandwidth Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
White Noise Source	Stanford Research Systems, DS3360	123762	+1V / - 1 V

The White Noise Source is configured to generate a band-width limited white noise voltage with an amplitude equal to approximately 10% of the digitizer input channel's full scale. One minute of data is recorded.

3.14.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n], \qquad 0 \le n \le N-1$$

The PSD is computed from the time series (Merchant, 2011) from the time series and the 3 dB point in the power spectra is measured.

3.14.4 Result

The power spectra of the white noise signal recorded on the Affinity digitizer channels was consistent across gain settings at each sample rate, therefore representative power spectra are shown in the plots below.

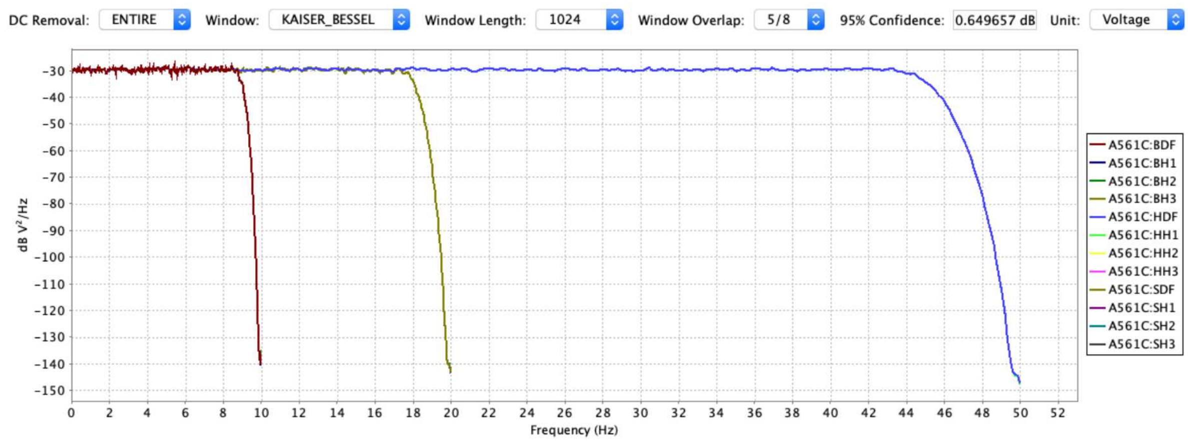

Figure 93 Analog Bandwidth, Gain 1x, 100 sps, 40 sps and 20 sps

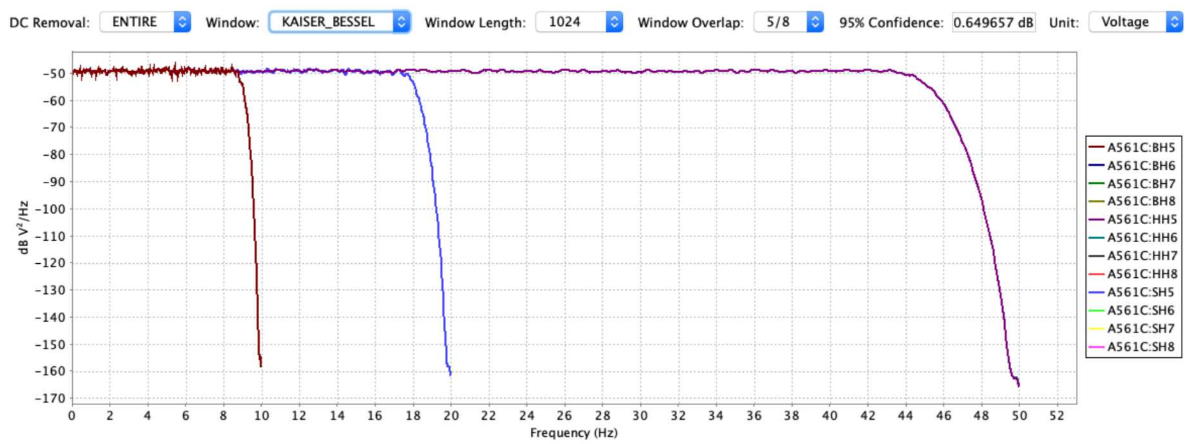

Figure 94 Analog Bandwidth, Gain 8x, 100 sps, 40 sps and 20 sps

Table 51 Analog Bandwidth, 100 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	44.70 Hz	44.70 Hz	44.70 Hz	44.70 Hz	-	-	-	-
2x	44.80 Hz	44.80 Hz	44.80 Hz	44.80 Hz	-	-	-	-
4x	44.80 Hz	44.80 Hz	44.80 Hz	44.80 Hz	-	-	-	-
8x	-	-	-	-	44.70 Hz	44.70 Hz	44.70 Hz	44.70 Hz
16x	-	-	-	-	44.80 Hz	44.80 Hz	44.80 Hz	44.80 Hz
32x	-	-	-	-	44.80 Hz	44.80 Hz	44.80 Hz	44.80 Hz

Table 52 Analog Bandwidth, 40 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	17.90 Hz	17.90 Hz	17.90 Hz	17.90 Hz	-	-	-	-
2x	17.90 Hz	17.90 Hz	17.90 Hz	17.90 Hz	-	-	-	-
4x	17.90 Hz	17.90 Hz	17.90 Hz	17.90 Hz	-	-	-	-
8x	-	-	-	-	17.90 Hz	17.90 Hz	17.90 Hz	17.90 Hz
16x	-	-	-	-	17.90 Hz	17.90 Hz	17.90 Hz	17.90 Hz
32x	-	-	-	-	17.90 Hz	17.90 Hz	17.90 Hz	17.90 Hz

Table 53 Analog Bandwidth, 20 sps

Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	8.85 Hz	8.85 Hz	8.85 Hz	8.85 Hz	-	-	-	-
2x	8.85 Hz	8.85 Hz	8.85 Hz	8.85 Hz	-	-	-	-
4x	8.85 Hz	8.85 Hz	8.85 Hz	8.85 Hz	-	-	-	-
8x	-	-	-	-	8.85 Hz	8.85 Hz	8.85 Hz	8.85 Hz
16x	-	-	-	-	8.85 Hz	8.85 Hz	8.85 Hz	8.85 Hz
32x	-	-	-	-	8.85 Hz	8.85 Hz	8.85 Hz	8.85 Hz

All of the channels were observed to have similar high frequency pass-band limit for common gain settings. Across all sample rates and gains evaluated, as a percentage of the sampling rate's Nyquist Frequency, the high frequency pass-band limit varies from 89.40% (100 sps, gains 1x and 8x) to 89.6% (100 sps gains 4x, 16x and 32x).

3.15 Total Harmonic Distortion

The Total Harmonic Distortion test is used to measure the linearity of a digitizer channel by recording a known AC signal at a reference voltage from an ultra-low distortion oscillator.

3.15.1 Measurand

The quantity being measured is the digitizer input channels linearity expressed in decibels.

3.15.2 Configuration

The digitizer is connected to an ultra-low distortion oscillator and a meter configured to measure voltage as shown in the diagram below.

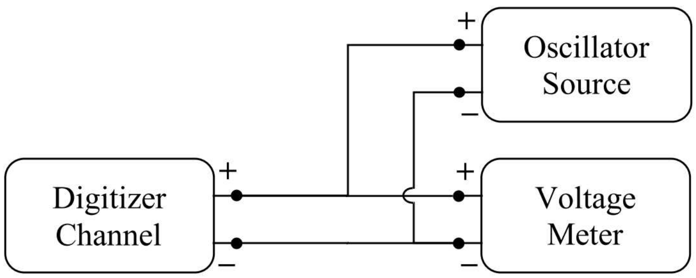

Figure 95 Total Harmonic Distortion Configuration Diagram

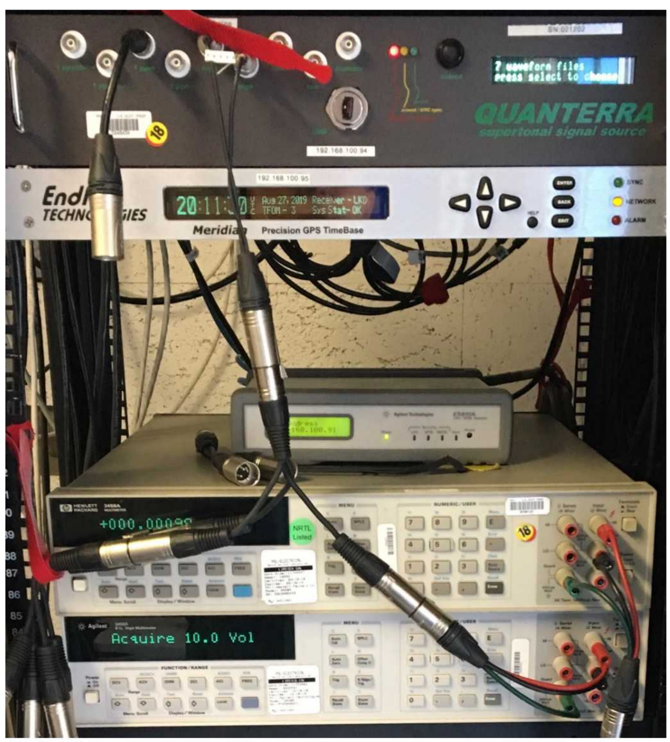

Figure 96 Total Harmonic Distortion Configuration Picture

Table 54 Total Harmonic Distortion Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
Oscillator	End Run Technologies/Meridian GPS 3025-0101 Quanterra/Supertonal Signal Source	12010020 021202	+0.64 V / -0.64 V
Voltage Meter	Agilent 3458A	MY45048371	1 V full scale

The oscillator is configured to generate an AC signal with an amplitude of approximately 50% of the digitizer input channel's full scale and a frequency equal to 1.41 Hz. This frequency was chosen as it is near the calibration frequency of 1 Hz and neither this frequency or any of its nearby harmonics coincide with integer valued frequencies which are typically are often corrupted with

The meter and the digitizer channel record the described AC voltage signal simultaneously. The recording made on the meter is used as the reference for comparison against the digitizer channel. The meter is configured to record at 100 Hz, which is a minimum of 100 times the frequency of the signal of interest in order to reduce the Agilent 3458A Meter's response roll-off at 1 Hz to less than 0.01 %.

Both the chosen oscillator and reference meter have signal characteristics that exceed that of the digitizer under test. Therefore, any distortion observed in the signal recorded on the digitizer channel may be inferred to be due to the digitizer.

A minimum of 1 hour of data is recorded.

The meter used to measure the voltage time series has an active calibration from the Primary Standard Laboratory at Sandia.

3.15.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n], \qquad 0 \leq n \leq N-1$$

The PSD is computed from the time series (Merchant, 2011) from the time series using a 4k-sample Kaiser-Bessel window. A Kaiser-Bessel window is used to minimize the width of the main lobe and the amplitude of side-lobes. The window length and data duration were chosen to provide sufficient frequency resolution around the primary harmonic and to ensure that the 95% confidence interval is less than approximately 1 dB. The resulting 95% confidence interval was determined to be 1.31 db.

$$P_{xx}[k], 0 \leq k \leq N-1$$

Over frequencies (in Hertz):

$$f[k], 0 \leq k \leq N-1$$

A peak-detection algorithm is applied to identify peaks that occur at the location of expected harmonics within the power spectra and the RMS power is computed for each of the peaks that are present (Merchant, 2011).

The THD is then computed as the ratio power in the harmonics to the power in the fundamental:

$$THD_{dB} = 10\log_{10}\left(\frac{\sqrt{\sum_{l=1}^{M-1}(rms[l])^2}}{rms[0]}\right)^2$$

The THD of the signal recorded on the reference meter is computed as well. The reference meter THD provides a baseline for the quality of the signal that was introduced to the digitizer. Any increase in signal distortion may be inferred to be due to the digitizer.

3.15.4 Result

The figure below shows a short segment of a representative waveform time series recorded on both the reference meter and a digitizer channel under test of the sinusoid that was used to measure harmonic distortion.

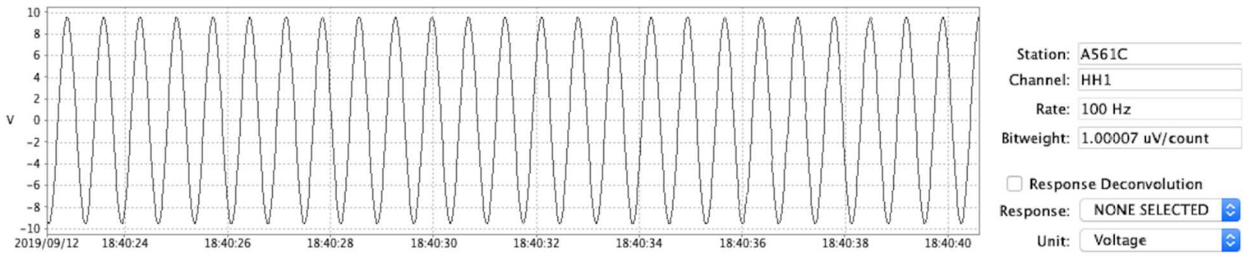

Figure 97 Total Harmonic Distortion Time Series

The figures below show the power spectra of the THD for each of the sample rates and gains evaluated.

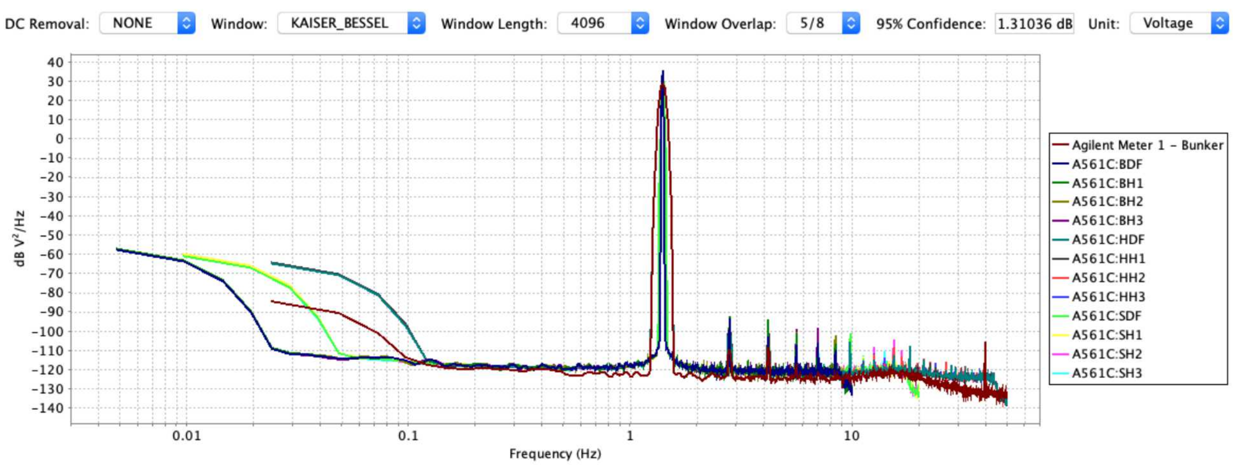

Figure 98 THD Power Spectra, Gain 1x

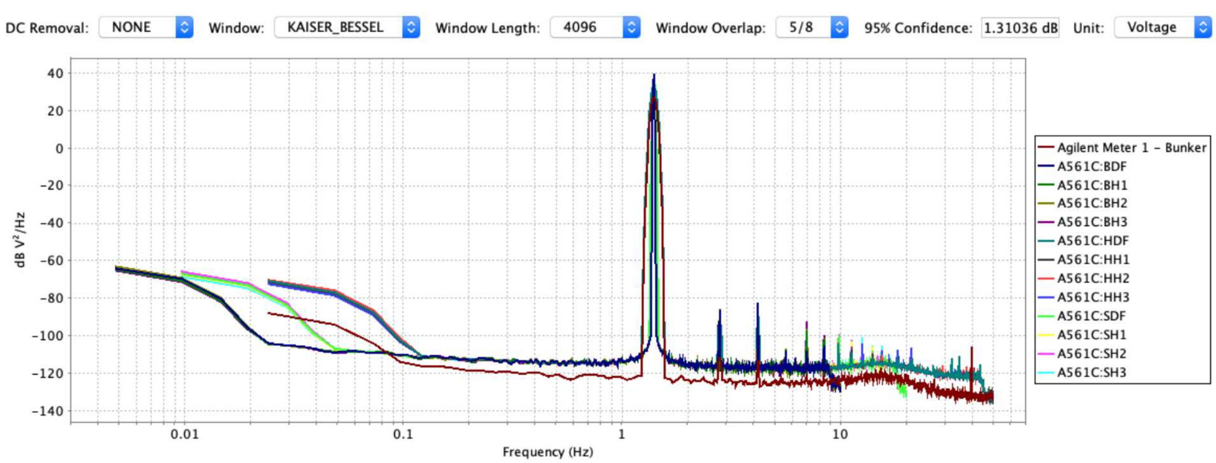

Figure 99 THD Power Spectra, Gain 2x

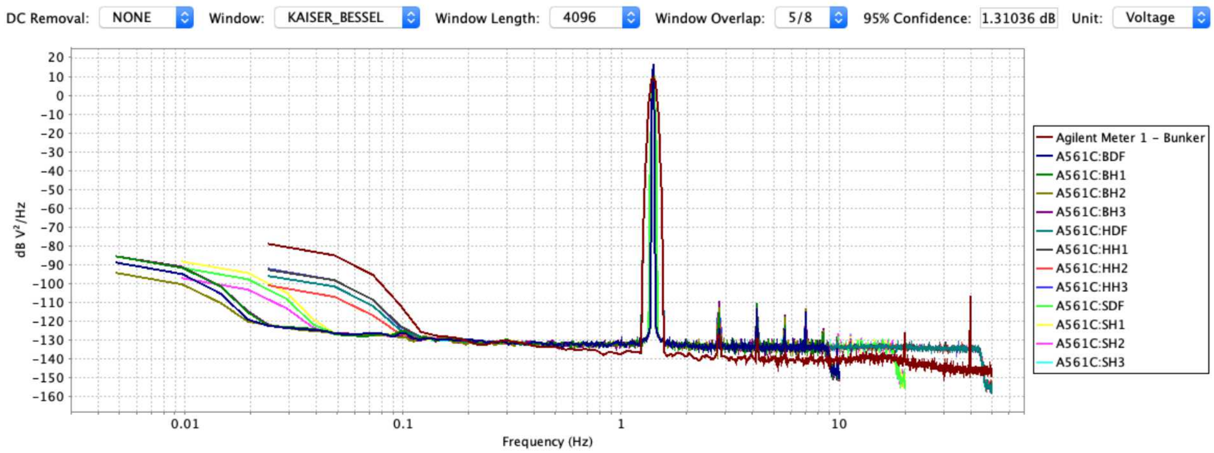

Figure 100 THD Power Spectra, Gain 4x

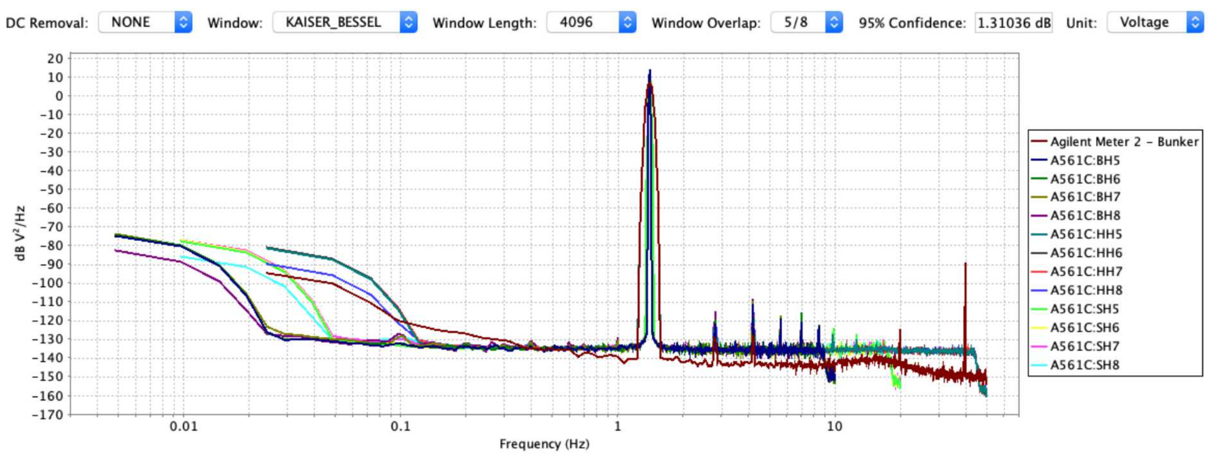

Figure 101 THD Power Spectra, Gain 8x

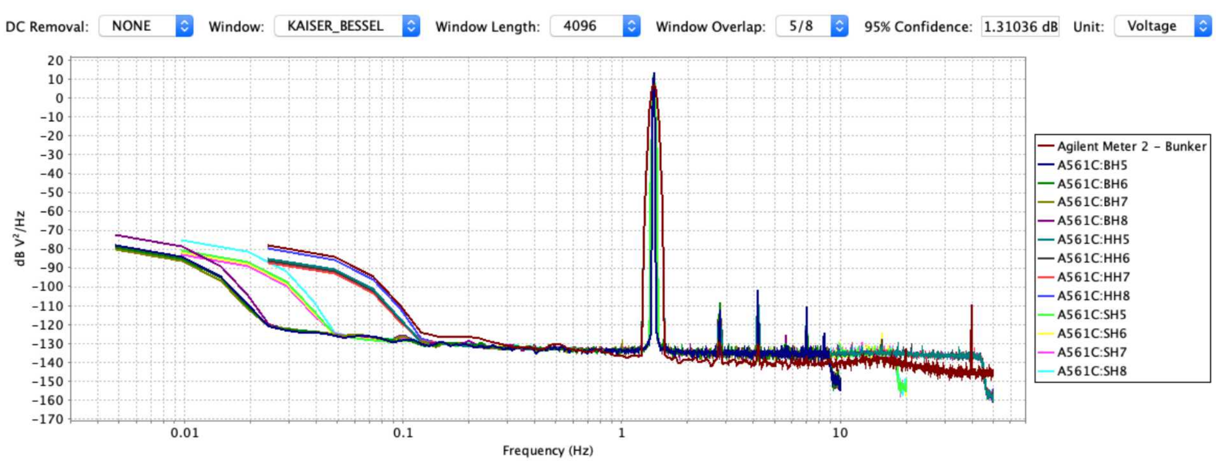

Figure 102 THD Power Spectra, Gain 16x

Table 55 Total Harmonic Distortion, 100 sps

Gain	Reference Meter	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-133.96 dB	-124.03 dB	-125.00 dB	-125.30 dB	-126.12 dB	-	-	-	-
2x	-134.72 dB	-123.83 dB	-123.35 dB	-122.93 dB	-120.18 dB	-	-	-	-
4x	-132.69 dB	-122.94 dB	-122.33 dB	-121.56 dB	-124.59 dB	-	-	-	-
8x	-132.66 dB	-	-	-	-	-121.95 dB	-122.03 dB	-121.29 dB	-120.43 dB
16x	-131.47 dB	-	-	-	-	-114.64 dB	-116.88 dB	-116.13 dB	-115.78 dB

Table 56 Total Harmonic Distortion, 40 sps

Gain	Reference Meter	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-133.96 dB	-124.34 dB	-125.21 dB	-125.59 dB	-126.52 dB	-	-	-	-
2x	-134.72 dB	-124.09 dB	-123.68 dB	-123.19 dB	-120.37 dB	-	-	-	-
4x	-132.69 dB	-123.76 dB	-122.89 dB	-122.23 dB	-125.61 dB	-	-	-	-
8x	-132.66 dB	-	-	-	-	-122.90 dB	-123.12 dB	-121.92 dB	-120.93 dB
16x	-131.47 dB	-	-	-	-	-114.87 dB	-117.17 dB	-116.39 dB	-116.00 dB

Table 57 Total Harmonic Distortion, 20 sps

Gain	Reference Meter	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
1x	-133.96 dB	-124.79 dB	-126.07 dB	-126.29 dB	-127.90 dB	-	-	-	-
2x	-134.72 dB	-124.60 dB	-124.18 dB	-123.70 dB	-120.50 dB	-	-	-	-
4x	-132.69 dB	-124.33 dB	-123.55 dB	-122.68 dB	-126.52 dB	-	-	-	-
8x	-132.66 dB	-	-	-	-	-123.77 dB	-123.57 dB	-122.31 dB	-121.22 dB
16x	-131.47 dB	-	-	-	-	-114.96 dB	-117.38 dB	-116.51 dB	-116.16 dB

At a gain of 32x the Agilent meter noise exceeds that of the Quanterra ULDO therefore a measurement of THD at gain of 32x is not possible. However, for gains 1x through 16x, there was sufficient difference in observed distortion between that of the reference and the data channels to determine the THD measured is that of the digitizer.

The observed harmonic distortion of the 100 sps channels ranged between -114.64 dB and -126.12 dB across all gains; across the 40 sps channels, at all gains, observed harmonic distortion ranged between -114.87 dB to -126.52 dB; and finally, across the 20 sps channels, observed harmonic distortion ranged from -114.96 dB to -127.90 dB. The general improvement in THD as sample rate decreases is likely due to the omission of harmonics above the lower sample rates' Nyquist frequency, thereby artificially increasing the respective THD calculated, over that of the THD observed at 100 sps.

3.16 Modified Noise Power Ratio

The Modified Noise Power Ratio test measures the linearity of the digitizer channels across a range of amplitudes.

3.16.1 Measurand

The quantity being measured is the ratio between signal power and incoherent noise across a range of input amplitudes.

3.16.2 Configuration

Multiple channels are connected to a white noise signal source as shown in the diagram below.

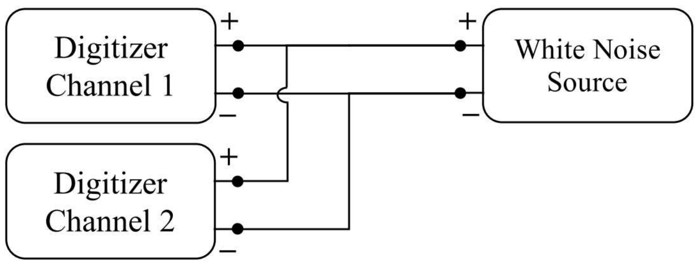

Figure 103 Analog Bandwidth Configuration Diagram

Table 58 Modified Noise Power Ratio Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
White Noise Source	Stanford Research Systems, DS3360	123762	+1V / - 1 V

The White Noise Source is configured to generate band-width limited white noise voltages with amplitudes spanning the full scale of the channel. Thirty minutes of data is recorded at each amplitude level.

3.16.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n], \qquad 0 \leq n \leq N-1$$

The ratio between the signal power and the noise power is computed at each of the amplitude levels and plotted on a scale with nominal reference lines (Merchant, 2011; McDonald 1994).

3.16.4 Result

A representative waveform time series plot is shown below channels HH1 and HH2 sampled at 100 Hz.

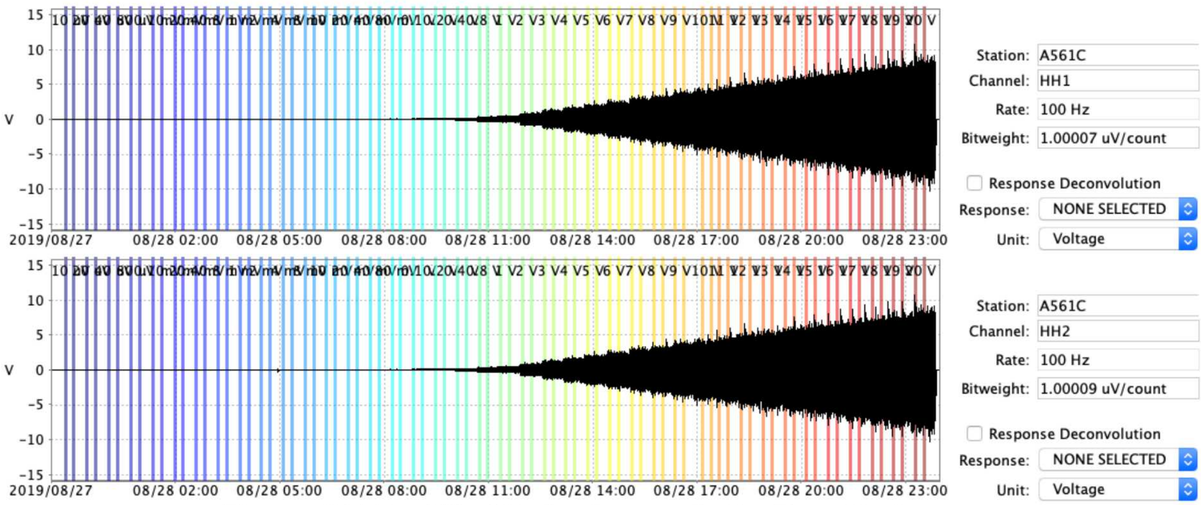

Figure 104 Modified Noise Power Ratio Time Series

The Modified Noise Power Ratio is computed at a sample rate of 100 Hz and at a gain of 1x and 8x, for channels HH1 vs HH2, HH3 and HD4 and HH5 vs HH6 – HH8, respectively. The amplitude and noise of the power spectra are integrated over 0.01 – 50 Hz. The figures and plot are shown below.

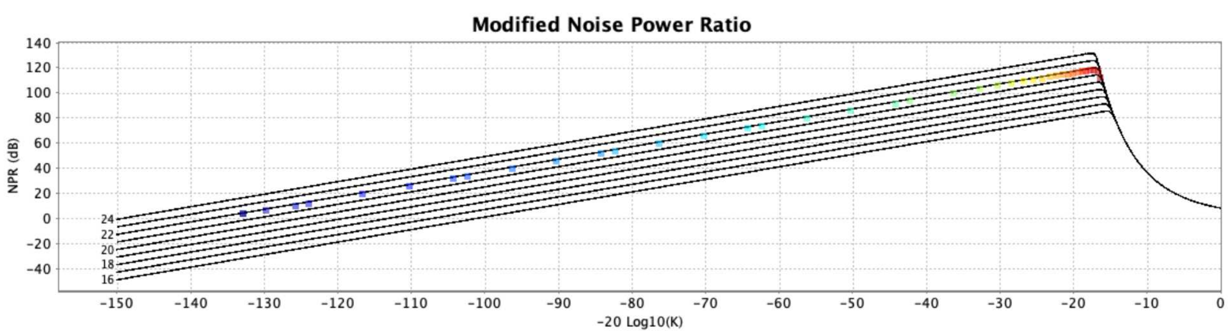

Figure 105 Modified Noise Power Ratio, Channels 1 and 2, Gain 1x

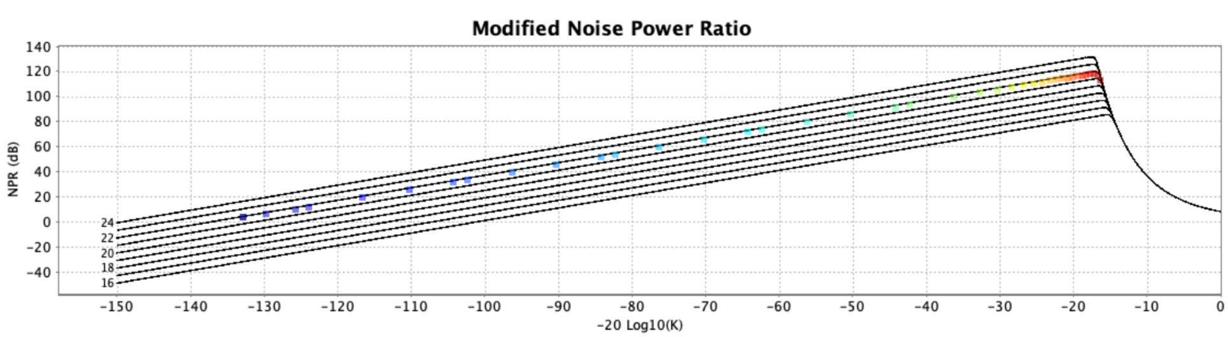

Figure 106 Modified Noise Power Ratio, Channels 1 and 3, Gain 1x

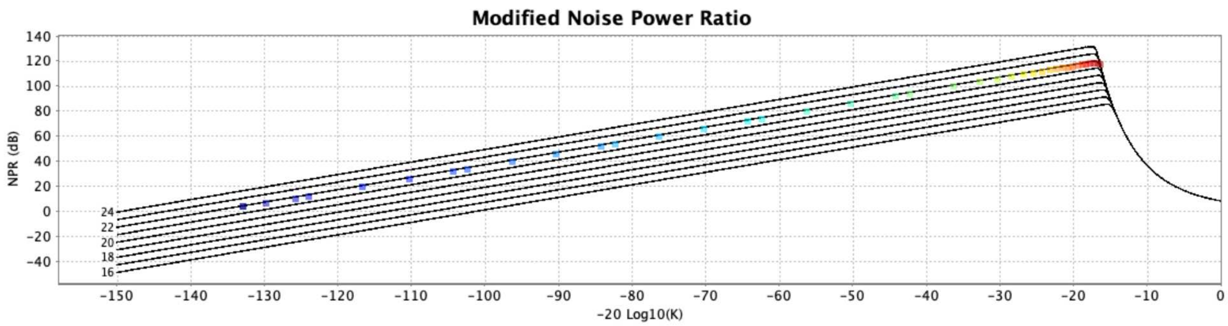

Figure 107 Modified Noise Power Ratio, Channels 1 and 4, Gain 1x

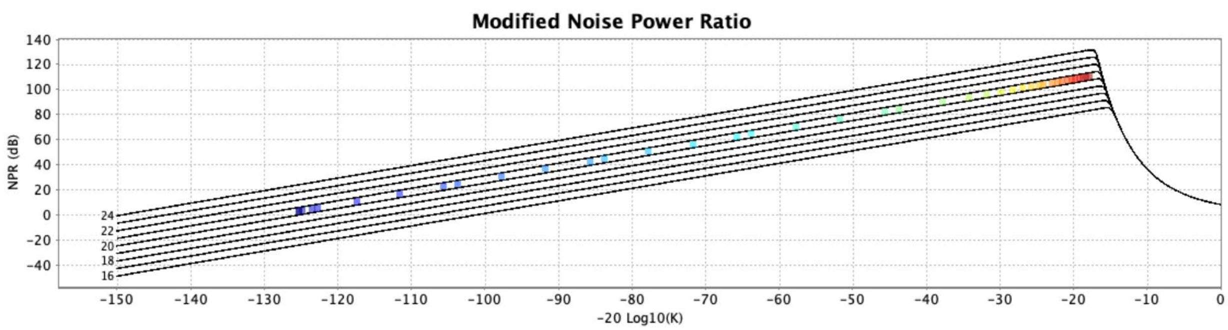

Figure 108 Modified Noise Power Ratio, Channels 5 and 6, Gain 8x

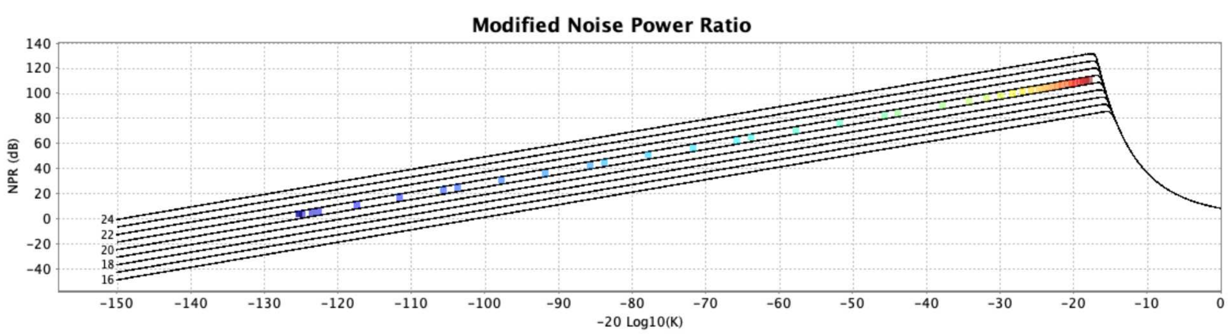

Figure 109 Modified Noise Power Ratio, Channels 5 and 7, Gain 8x

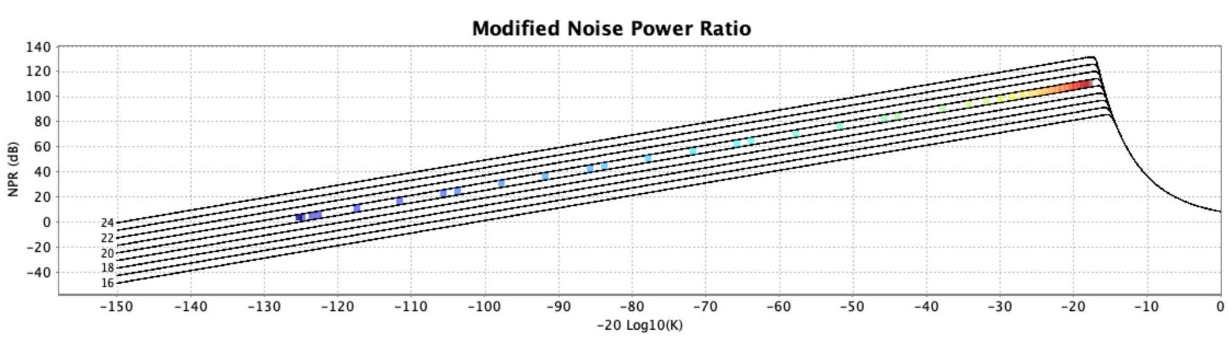

Figure 110 Modified Noise Power Ratio, Channels 5 and 8, Gain 8x

At a gain of 1x, the Affinity consistently, across the channels evaluated, has slightly less than22 bits of performance across the amplitude range. At a gain of 8x, across the channels evaluated, there was a slight reduction in performance, slightly less than 21 bits, across the amplitude range.

Table 59 Modified Noise Power Ratio, Channels HH1-HH3 and HD4, Gain 1x

			Noise Power Ratio		
Amplitude	RMS Amplitude	-20 log K	1 vs 2	1 vs 3	1 vs 4
10 uV	0.000003235 V rms	-132.81	3.54 dB	3.54 dB	3.57 dB
20 uV	0.000003230 V rms	-132.83	3.54 dB	3.51 dB	3.56 dB
40 uV	0.000004623 V rms	-129.71	6.20 dB	6.17 dB	6.16 dB
80 uV	0.000007309 V rms	-125.73	10.13 dB	10.12 dB	10.15 dB
0.1 mV	0.000008925 V rms	-124.00	11.88 dB	11.84 dB	11.84 dB
0.2 mV	0.00002085 V rms	-116.63	19.19 dB	19.22 dB	19.24 dB
0.4 mV	0.00004352 V rms	-110.24	25.65 dB	25.62 dB	25.66 dB
0.8 mV	0.00008665 V rms	-104.26	31.61 dB	31.59 dB	31.62 dB
1 mV	0.0001084 V rms	-102.31	33.54 dB	33.53 dB	33.55 dB
2 mV	0.0002167 V rms	-96.29	39.59 dB	39.59 dB	39.57 dB
4 mV	0.0004328 V rms	-90.28	45.59 dB	45.57 dB	45.62 dB
8 mV	0.0008662 V rms	-84.26	51.60 dB	51.62 dB	51.62 dB
10 mV	0.001083 V rms	-82.32	53.59 dB	53.52 dB	53.54 dB
20 mV	0.002166 V rms	-76.30	59.62 dB	59.54 dB	59.60 dB
40 mV	0.004343 V rms	-70.25	65.61 dB	65.60 dB	65.62 dB
80 mV	0.008663 V rms	-64.26	71.60 dB	71.59 dB	71.62 dB
0.1 V	0.01082 V rms	-62.33	73.54 dB	73.55 dB	73.53 dB
0.2 V	0.02168 V rms	-56.29	79.59 dB	79.57 dB	79.60 dB
0.4 V	0.04334 V rms	-50.27	85.64 dB	85.57 dB	85.62 dB
0.8 V	0.08661 V rms	-44.26	91.56 dB	91.56 dB	91.63 dB
1 V	0.1082 V rms	-42.33	93.51 dB	93.51 dB	93.53 dB
2 V	0.2168 V rms	-36.29	99.58 dB	99.54 dB	99.59 dB
3 V	0.3247 V rms	-32.78	103.07 dB	103.04 dB	103.11 dB
4 V	0.4328 V rms	-30.28	105.55 dB	105.52 dB	105.53 dB
5 V	0.5409 V rms	-28.35	107.50 dB	107.47 dB	107.52 dB
6 V	0.6507 V rms	-26.74	109.06 dB	109.05 dB	109.10 dB
7 V	0.7573 V rms	-25.42	110.39 dB	110.41 dB	110.41 dB
8 V	0.8658 V rms	-24.26	111.57 dB	111.55 dB	111.58 dB
9 V	0.9732 V rms	-23.25	112.57 dB	112.57 dB	112.57 dB
10 V	1.082 V rms	-22.33	113.46 dB	113.43 dB	113.50 dB
11 V	1.191 V rms	-21.49	114.32 dB	114.29 dB	114.33 dB
12 V	1.298 V rms	-20.74	115.02 dB	114.95 dB	115.00 dB
13 V	1.408 V rms	-20.04	115.73 dB	115.67 dB	115.71 dB
14 V	1.517 V rms	-19.39	116.39 dB	116.28 dB	116.31 dB
15 V	1.627 V rms	-18.78	116.98 dB	116.87 dB	116.89 dB
16 V	1.731 V rms	-18.25	117.51 dB	117.40 dB	117.33 dB
17 V	1.842 V rms	-17.71	118.03 dB	117.93 dB	117.81 dB
18 V	1.948 V rms	-17.22	118.07 dB	118.23 dB	118.26 dB
19 V	2.059 V rms	-16.74	117.23 dB	116.97 dB	118.09 dB
20 V	2.165 V rms	-16.30	111.83 dB	112.72 dB	116.93 dB

Table 60 Modified Noise Power Ratio, Channels HH5 – HH8, Gain 8x

			Noise Power Ratio		
Amplitude	RMS Amplitude	-20 log K	5 vs 6	5 vs 7	5 vs 8
0.00000125 V	0.000000956 V rms	-125.34	3.38 dB	3.56 dB	3.56 dB
0.0000025 V	0.000000956 V rms	-125.34	3.38 dB	3.55 dB	3.55 dB
0.000005 V	0.000001018 V rms	-124.79	3.67 dB	3.74 dB	3.74 dB
0.00001 V	0.000001178 V rms	-123.53	4.89 dB	4.91 dB	4.92 dB
0.0000125 V	0.000001298 V rms	-122.68	5.68 dB	5.71 dB	5.69 dB
0.000025 V	0.000002372 V rms	-117.44	10.91 dB	10.93 dB	10.88 dB
0.00005 V	0.000004668 V rms	-111.57	16.83 dB	16.85 dB	16.79 dB
0.0001 V	0.000009173 V rms	-105.70	22.68 dB	22.64 dB	22.66 dB
0.000125 V	0.00001145 V rms	-103.77	24.63 dB	24.63 dB	24.62 dB
0.00025 V	0.00002280 V rms	-97.79	30.59 dB	30.57 dB	30.58 dB
0.0005 V	0.00004558 V rms	-91.77	36.61 dB	36.52 dB	36.54 dB
0.001 V	0.00009111 V rms	-85.76	42.63 dB	42.62 dB	42.62 dB
0.00125 V	0.0001140 V rms	-83.81	44.55 dB	44.56 dB	44.56 dB
0.0025 V	0.0002281 V rms	-77.78	50.59 dB	50.58 dB	50.58 dB
0.005 V	0.0004563 V rms	-71.76	56.61 dB	56.63 dB	56.62 dB
0.01 V	0.0009118 V rms	-65.75	62.61 dB	62.65 dB	62.60 dB
0.0125 V	0.001139 V rms	-63.82	64.55 dB	64.57 dB	64.57 dB
0.025 V	0.002279 V rms	-57.79	70.56 dB	70.55 dB	70.58 dB
0.05 V	0.004559 V rms	-51.77	76.59 dB	76.61 dB	76.62 dB
0.1 V	0.009115 V rms	-45.75	82.62 dB	82.64 dB	82.63 dB
0.125 V	0.01139 V rms	-43.82	84.54 dB	84.56 dB	84.55 dB
0.25 V	0.02282 V rms	-37.78	90.56 dB	90.59 dB	90.58 dB
0.375 V	0.03419 V rms	-34.27	94.09 dB	94.08 dB	94.07 dB
0.5 V	0.04557 V rms	-31.77	96.60 dB	96.58 dB	96.58 dB
0.625 V	0.05696 V rms	-29.84	98.53 dB	98.50 dB	98.52 dB
0.75 V	0.06842 V rms	-28.24	100.13 dB	100.04 dB	100.01 dB
0.875 V	0.07976 V rms	-26.91	101.47 dB	101.41 dB	101.45 dB
1 V	0.09111 V rms	-25.76	102.62 dB	102.64 dB	102.61 dB
1.125 V	0.1025 V rms	-24.73	103.61 dB	103.61 dB	103.64 dB
1.25 V	0.1104 V rms	-24.09	104.46 dB	104.54 dB	104.52 dB
1.375 V	0.1254 V rms	-22.98	105.36 dB	105.38 dB	105.34 dB
1.5 V	0.1368 V rms	-22.23	106.13 dB	106.13 dB	106.13 dB
1.625 V	0.1481 V rms	-21.54	106.84 dB	106.85 dB	106.80 dB
1.75 V	0.1596 V rms	-20.89	107.45 dB	107.43 dB	107.36 dB
1.875 V	0.1710 V rms	-20.29	108.07 dB	108.08 dB	108.04 dB
2 V	0.1822 V rms	-19.74	108.62 dB	108.61 dB	108.57 dB
2.125 V	0.1938 V rms	-19.20	109.14 dB	109.14 dB	109.10 dB
2.25 V	0.2051 V rms	-18.71	109.60 dB	109.61 dB	109.59 dB
2.375 V	0.2166 V rms	-18.24	110.07 dB	110.11 dB	110.09 dB
2.5 V	0.2278 V rms	-17.80	110.52 dB	112.72 dB	116.93 dB

3.17 Common Mode Rejection

The Common Mode Rejection test measures the ability of a digitizer to reject a common mode signal on a differential input channel.

3.17.1 Measurand

The quantity being measured is the ratio of the common mode signal amplitude to the observed amplitude on the digitizer input channels in dB.

3.17.2 Configuration

The digitizer is connected to a AC signal source and a meter configured to measure voltage as shown in the diagram below.

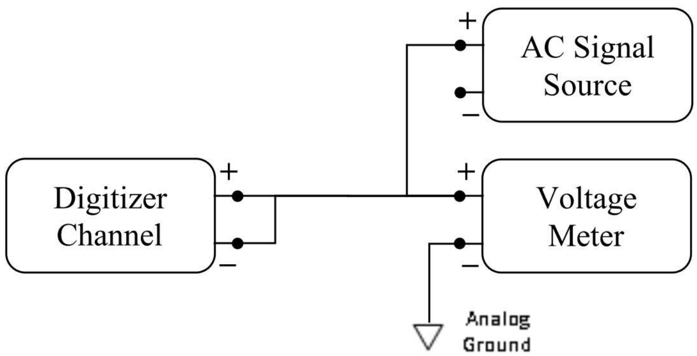

Figure 111 Common Mode Rejection Configuration Diagram

Since the digitizer input channels are differential and are shorted together, the digitizer should not be recording any signal. However, some amount of common mode signal will still be present on the digitizer input channel.

Figure 112 Common Mode Rejection Configuration Picture

Table 61 Common Mode Rejection Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
AC Signal Source	DC Signal Source	Stanford Research Systems, DS3360	123762
Voltage Meter	Voltage Meter	Agilent 3458A	MY45048371

The AC Signal Source is configured to generate a AC voltage with an amplitude of approximately 10% of the digitizer input channel's full scale and a frequency equal to the calibration frequency of 1 Hz. One minute of data is recorded.

The meter and the digitizer channel record the described AC voltage signal simultaneously. The recording made on the meter is used as the reference for comparison against the digitizer channel. The meter is configured to record at 100 Hz, which is a minimum of 100 times the frequency of the signal of interest in order to reduce the Agilent 3458A Meter's response roll-off at 1 Hz to less than 0.01 %.

The meter used to measure the voltage time series has an active calibration from the Primary Standard Laboratory at Sandia.

3.17.3 Analysis

A minimum of 10 cycles, or 10 seconds at 1 Hz, of data is defined on the data for the recorded signal segment.

A four parameter sine fit (Merchant, 2011; IEEE-STD1281) is applied to the time segment from the reference meter in Volts in order to determine the sinusoid's amplitude, frequency, phase, and DC offset:

$$V_{ref} \sin(2\pi f_0 t_n + \theta) + V_{dc}$$

A similar sine-fit is performed on the data recorded on the digitizer:

$$V_{meas} \sin(2\pi f_0 t_n + \theta) + V_{dc}$$

The Common Mode Rejection is then computed as the ratio between the reference and measured amplitudes:

$$CMR_{dB} = 10 * \log_{10}\left(\frac{V_{ref}}{V_{meas}}\right)^2$$

3.17.4 Result

The figures below show the waveform time series for the recording made on the digitizer channels under test. The window regions bounded by the red lines indicate the segment of data used for analysis.

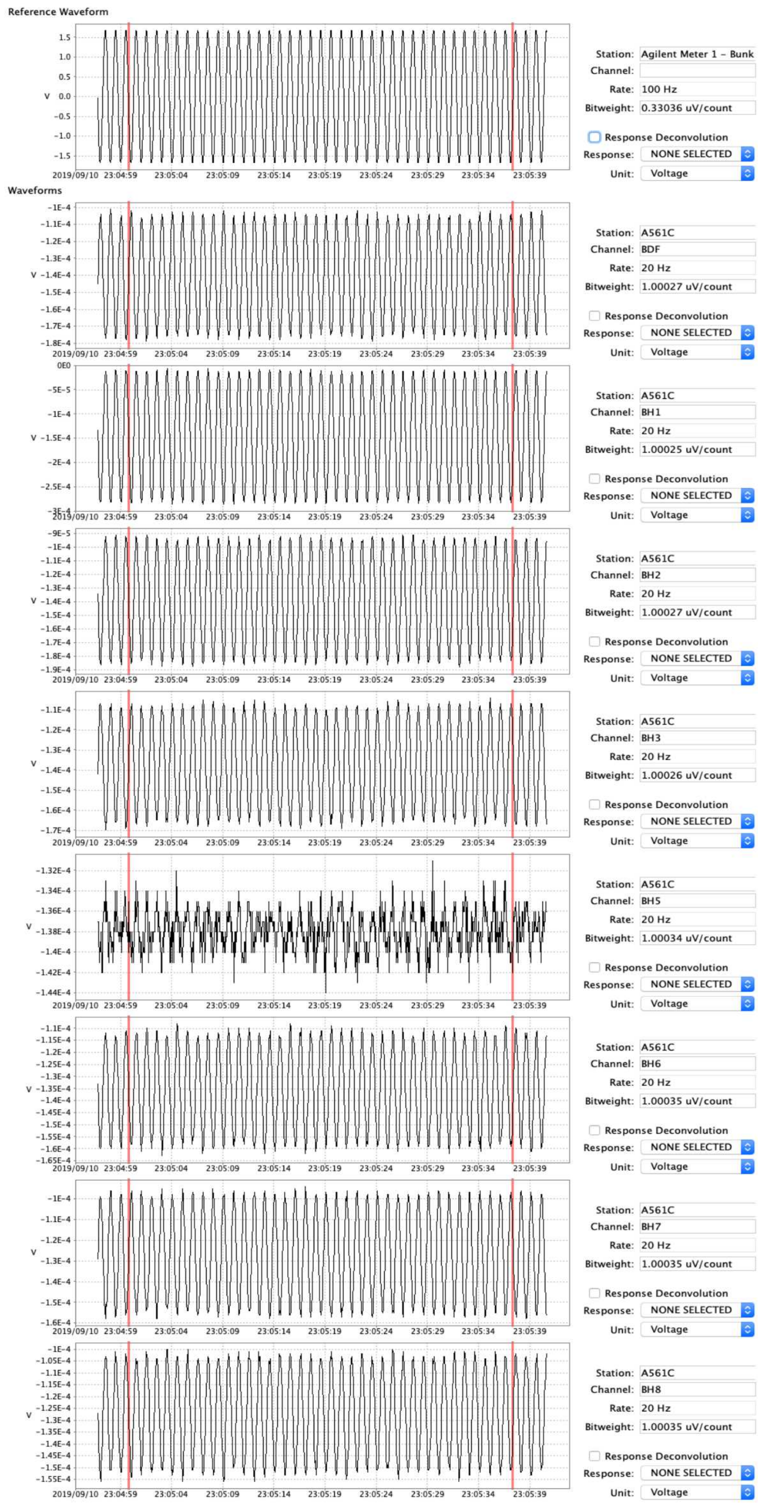

Figure 113 Common Mode Rejection Time Series, Gain 1x

The following table contains the computed common mode rejection ratio.

Table 62 Common Mode Rejection Ratio

Sample Rate	Gain	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
100 sps	1x	81.77 dB	91.23 dB	95.07 dB	93.34 dB	118.52 dB	96.87 dB	95.17 dB	96.57 dB
	2x	75.70 dB	84.97 dB	89.96 dB	87.96 dB	108.36 dB	90.65 dB	89.37 dB	91.00 dB
	4x	69.68 dB	78.85 dB	84.19 dB	82.12 dB	102.74 dB	84.68 dB	83.28 dB	85.33 dB
	8x	64.12 dB	74.40 dB	76.03 dB	74.38 dB	94.20 dB	81.87 dB	75.20 dB	83.26 dB
	16x	58.17 dB	68.88 dB	69.70 dB	67.96 dB	87.27 dB	76.49 dB	68.86 dB	78.69 dB
	32x	52.17 dB	62.96 dB	63.95 dB	62.08 dB	78.94 dB	70.48 dB	62.60 dB	73.52 dB
40 sps	1x	81.77 dB	91.23 dB	95.07 dB	93.34 dB	118.60 dB	96.88 dB	95.17 dB	96.57 dB
	2x	75.70 dB	84.96 dB	89.96 dB	87.96 dB	108.42 dB	90.64 dB	89.37 dB	91.01 dB
	4x	69.68 dB	78.85 dB	84.19 dB	82.12 dB	102.80 dB	84.68 dB	83.28 dB	85.33 dB
	8x	64.12 dB	74.41 dB	76.04 dB	74.38 dB	94.18 dB	81.86 dB	75.20 dB	83.27 dB
	16x	58.16 dB	68.87 dB	69.70 dB	67.97 dB	87.23 dB	76.49 dB	68.86 dB	78.69 dB
	32x	58.16 dB	68.87 dB	69.70 dB	67.97 dB	87.23 dB	76.49 dB	68.86 dB	78.69 dB
20 sps	1x	81.77 dB	91.22 dB	95.07 dB	93.34 dB	118.48 dB	96.87 dB	95.17 dB	96.56 dB
	2x	75.70 dB	84.96 dB	89.96 dB	87.96 dB	108.44 dB	90.65 dB	89.38 dB	91.01 dB
	4x	69.68 dB	78.85 dB	84.19 dB	82.12 dB	102.76 dB	84.68 dB	83.27 dB	85.34 dB
	8x	64.12 dB	74.41 dB	76.03 dB	74.38 dB	94.19 dB	81.87 dB	75.20 dB	83.25 dB
	16x	58.17 dB	68.87 dB	69.71 dB	67.96 dB	87.24 dB	76.50 dB	68.86 dB	78.69 dB
	32x	52.17 dB	62.95 dB	63.95 dB	62.07 dB	78.92 dB	70.48 dB	62.60 dB	73.53 dB

The observed common mode rejection ranged from 52.17 dB (gain 32x) to 118.60 dB (gain 1x).

3.18 Crosstalk

The Crosstalk test measures how much of a signal recorded on one channel of a digitizer is also present on another channel as noise.

3.18.1 Measurand

The quantity being measured is the ratio of the signal power present in one or more other channels to the observed signal power on another channel in dB.

3.18.2 Configuration

The digitizer is connected to a AC signal source and a meter configured to measure voltage as shown in the diagram below.

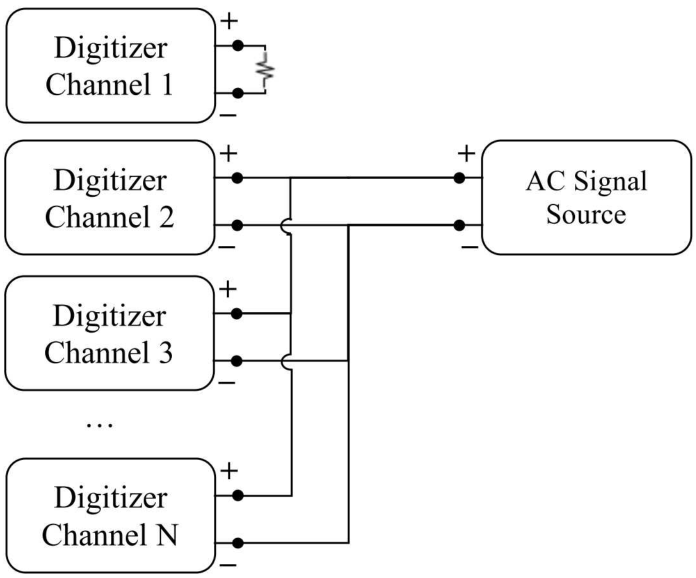

Figure 114 Crosstalk Configuration Diagram

Figure 115 Crosstalk Configuration Picture

Table 63 Crosstalk Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
AC Signal Source	DC Signal Source	Stanford Research Systems, DS3360	123762

The AC Signal Source is configured to generate a AC voltage with an amplitude of approximately 50% of the digitizer input channel's full scale and a frequency equal to the calibration frequency of 1 Hz. Approximately 10 minutes of data is recorded.

3.18.3 Analysis

The measured bit-weight, from the AC Accuracy at 1 Hz, is applied to the collected data:

$$x[n]$$

The PSD is computed from the time series (Merchant, 2011) from the time series using a 1k-sample Hann window and 5/8 overlap of the input terminated channel and all of the tonal channels:

$$P_i[k], \qquad 1 \leq i \leq N$$

For the purposes of convention, the input terminated channel is assumed to be the first channel and the tonal channels are 2 through N. The RMS value of the maximum peak in each of the power spectra are identified and computed:

$$V_{rms\ i}, \qquad 1 \leq i \leq N$$

The mean crosstalk value is also computed between the terminated channel and each of the tonal channels is computed:

$$Mean\ Crosstalk = 10\ \log_{10}\left[\frac{1}{N-1}\sum_{i=2}^{N}\frac{V_{rms\ 1}}{V_{rms\ i}}\right]^2$$

3.18.4 Result

The following figure shows a representative waveform time series for the recording made on the digitizer channels under test. All of the results were similar to the waveforms shown below. The window regions bounded by the red lines indicate the segment of data used for analysis.

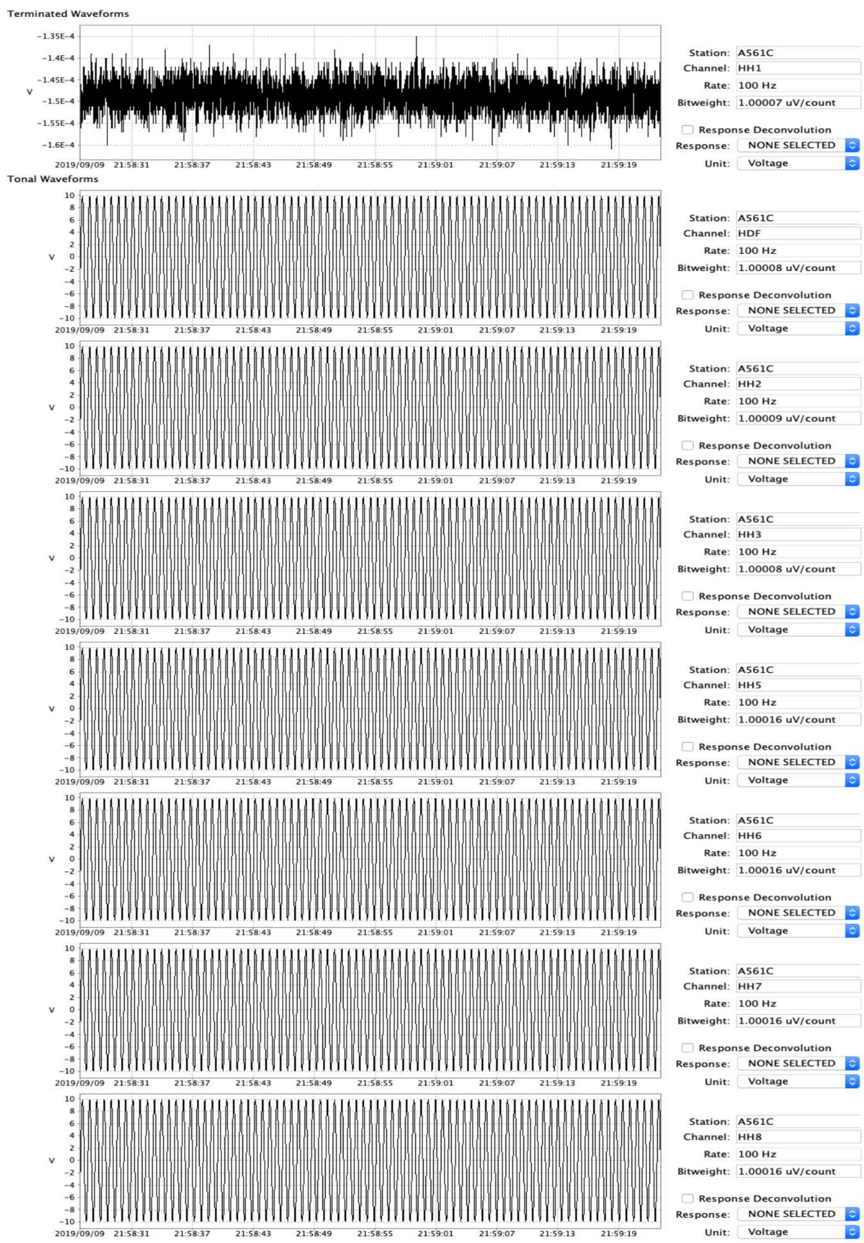

Figure 116 Crosstalk Time Series

The figures below show a representative power spectra of the terminated and tonal channels for each of the three sample rates for which crosstalk was evaluated. All of the results were similar to the power spectra shown below.

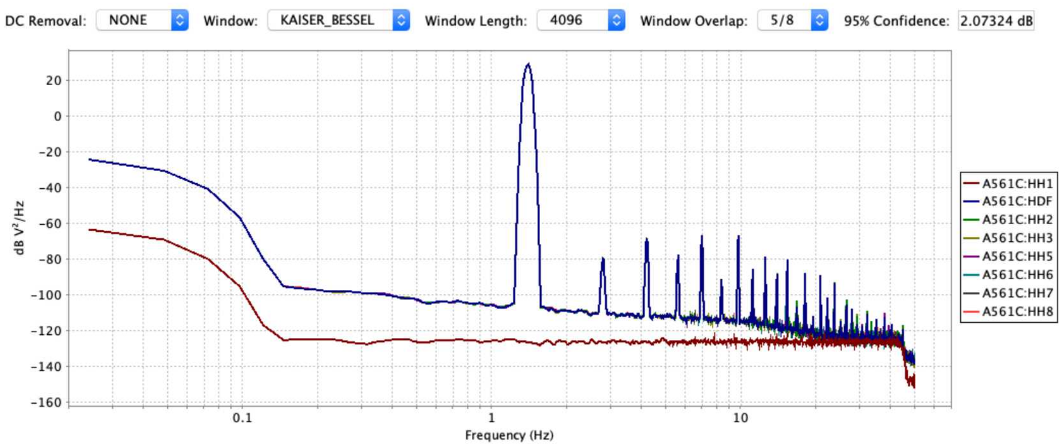

Figure 117 Crosstalk Power Spectra

The following table contains the computed crosstalk ratios.

Table 64 Crosstalk

Sample rate	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
100 sps	-153.61 dB	-153.61 dB	-152.99 dB	-153.92 dB	-153.27 dB	-152.68 dB	-152.53 dB	-153.02 dB
40 sps	-153.78 dB	-155.11 dB	-153.99 dB	-154.02 dB	-154.19 dB	-153.24 dB	-154.10 dB	-154.24 dB
20 sps	-154.01 dB	-154.99 dB	-150.21 dB	-153.88 dB	-154.75 dB	-153.08 dB	-153.98 dB	-154.36 dB

No peak is observable in the terminated sensor channel's power spectra, therefore the values represent the maximum possible observable crosstalk. The maximum possible observable levels of crosstalk of the sensor channels were all between -155.11 dB and -152.53 dB.

3.19 Time Tag Accuracy

The Time Tag Accuracy test measures the digitizer's timing accuracy under stable conditions in which the digitizer is clock is locked and stable.

3.19.1 Measurand

The quantity being measured is the error in the time tag of specific time-series sample in seconds. Error is defined to be the observed time-stamp minus the expected time-stamp.

3.19.2 Configuration

The digitizer is connected to a timing source as shown in the diagram below.

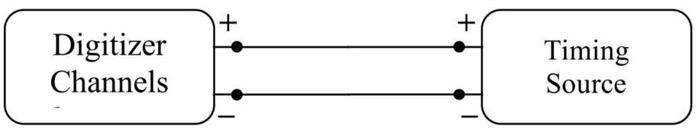

Figure 118 Timing Configuration Diagram

Figure 119 Time Tag Accuracy Configuration Picture

Table 65 Time Tag Accuracy Testbed Equipment

Manufacturer / Model	Serial Number	Nominal Configuration
End Run Technologies/Meridian GPS 3025-0101 Quanterra/Supertonal Signal Source	12010020 021202	+/- 5V PPM

The Timing Source may be configured to generate a time-synchronized pulse-per-minute, pulse-per-hour, or sinusoid. In each case, there is an observable signal characteristic.

3.19.3 Analysis

The difference between the digitizers actual and expected time stamps are measured by evaluating the unique characteristics of the signal being recorded (Merchant, 2011). The average time tag error is computed over a minimum of an hour.

3.19.4 Result

The figure below shows a representative waveform time series of a Pulse-per-minute (PPM) for the recording made on a digitizer channel under test.

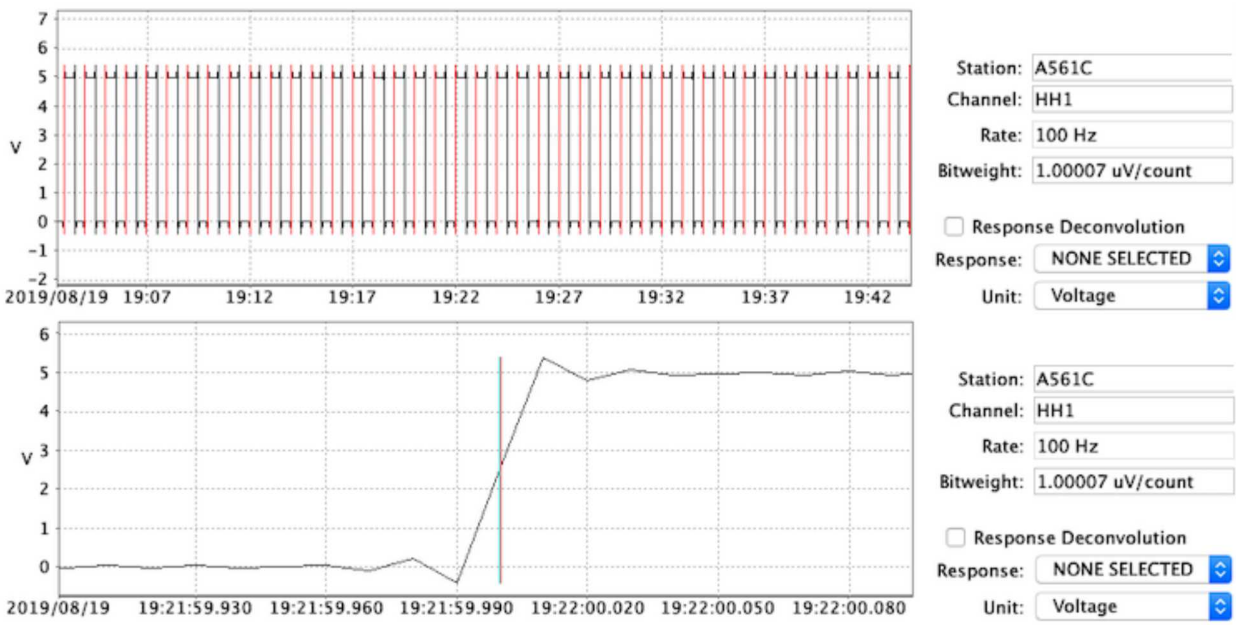

Figure 120 Time Tag Accuracy PPM Time Series

The following table contains the computed timing offsets.

Table 66 Time Tag Accuracy

Sensor Channel	100 sps	40 sps	20 sps
1	5.0267 us	5.0306 us	5.0346 us

The measured time tag accuracy values were consistent for all of the recording channels and less than 6 us. The manufacturer specifications suggesting timing accuracy of less that 1 us. Measurement of the GPS Time Tag Accuracy was performed by splitting the time synchronized PPM signal source simultaneously to all 8 channels at once. The combined loading of multiple channels on the timing source may slightly decrease time tag accuracy.

3.20 Timing Drift

The Time Tag Drift test measures how the digitizer's timing accuracy drifts when the digitizer's clock is not locked and recovers once lock is restored.

3.20.1 Measurand

The quantity being measured is the error in the time tag of specific time-series sample in seconds and the rate at which the error changes with time. Error is defined to be the observed time-stamp minus the expected time-stamp.

3.20.2 Configuration

The digitizer is connected to a timing source as shown in the diagram below.

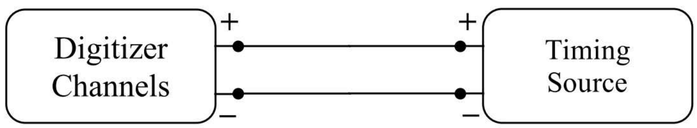

Figure 121 Timing Configuration Diagram

Table 67 Timing Drift Accuracy Testbed Equipment

Manufacturer / Model	Serial Number	Nominal Configuration
End Run Technologies/Meridian GPS 3025-0101 Quanterra/Supertonal Signal Source	12010020 021202	+/- 5V PPM

The timing source may be configured to generate a time-synchronized pulse-per-minute, pulse-per-hour, or sinusoid. In each case, there is an observable signal characteristic

The digitizer clock is allowed to stabilize before the GPS antenna is disconnected resulting in the digitizer to lose timing lock. The digitizer is allowed to drift before it is re-connected to the GPS antenna and allowed to regain its timing lock.

3.20.3 Analysis

The difference between the digitizers actual and expected time stamps are measured by evaluating the unique characteristics of the signal being recorded (Merchant, 2011).

The levels of timing error and rates of change are observed while the digitizer has GPS lock, while it is drifting without GPS lock, and while it is recovering once GPS lock is resumed.

3.20.4 Result

The figures below show the timing offsets over time as the digitizer channels drift and recovery.

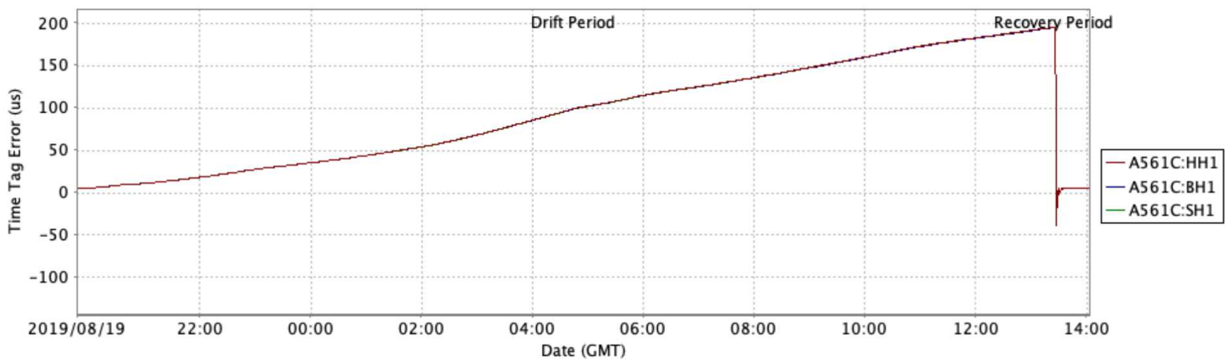

Figure 122 Observed Timing Drift and Recovery Period

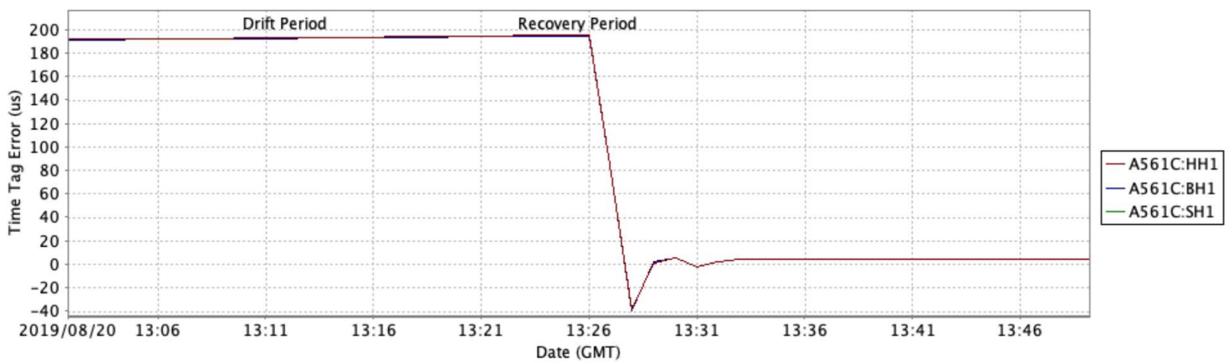

Figure 123 Moment of Timing Recovery

The following table contains the computed timing offsets when locked, drifting, and recovering and the estimated rate at which the digitizer was observed to drift and recover.

Table 68 Time Tag Drift and Recovery, Gain 1x

	100 sps	40 Hz	20 Hz
Stabilized offset – pre-drift	5.0267 us	5.0306 us	5.0346 us
Initial Drift Rate	-11.893 us/h	-11.865 us/h	-11.857 us/h
Recovery Rate	-1,973.6 us/h	-1,971 us/h	-1,971 us/h
Stabilized offset – post-drift	4.7684 us	4.7684 us	4.5419 us

Drift rate while the GPS antenna was covered was relatively consistent at -11.9 us/hr. When the antenna was uncovered, the Affinity regained lock and recovered to a stabilized offset within 7 minutes. Total drift was 190 us, during the 17 hour period during which the GPS antenna was covered.

4 SUMMARY

Input Impedance
The measured input impedance of the Affinity primary digitizer channels were all within 0.5 % of their nominal specification of 113 kohm.

Power Consumption
The Affinity digitizer was observed to consume 2.676 watts of power. While this power consumption is higher than the manufacturer specified (1.85 W), the manufacturer specifications do not include the task of data authentication, which would be expected to increase power consumption.

DC Accuracy
Observed bit-weights, at a gain of 1, varied no more than 0.009% from nominal; as gains increased through 16, maximum variation in bit-weights, from their respective nominal values, increasingly diverged as much -0.3811% at 16. At a gain of 32x though, the maximum variation from nominal across sample rates was -0.1811%.

AC Accuracy
Maximum deviation from nominal bit-weights across all gain settings was 0.408% for the 20 sps data at a gain of 16x. A gain of 1x provided the lowest maximum variation in gain from nominal across all channels, 0.016% for 100 sps data.

AC Full Scale
For all sample rates and gain levels, all channels were able to fully resolve the sinusoid with a peak-to-peak amplitude at or near the channels claimed full scale value without any signs of flattening that would indicate that clipping is occurring.

AC Over Scale
At all sample rates, applied voltages greater than full scale were observed across all channels with obvious clipping visible in the time series.

Input Shorted Offset
The maximum observed input shorted offsets across all channels, with respect to nominal full scale, ranged from a minimum of 0.0003% at a gain 2x (all sample rates) to a maximum of -0.0028% at a gain of 32x (all sample rates).

Self-Noise
Average self noise of 100 sps channels the over the 0.01 Hz – 10 Hz passband, ranged from as much as 1.541 uV rms for the gain of 1x to as low as 419.5 nV rms at a gain of 32x. No rms noise value varied more than 4.19% (at gain 16x) from their respective average rms noise values. Rms noise values did not exceed the equivalent of 2 counts rms while operating at a gain of 1x or 2x and 14 counts rms at a gain 32x.

Temperature Self Noise
Self noise of all channels increases slightly, by approximately 1 dB (essentially equivalent 95% confidence limit) at gains x1 and 2 dB at a gain of 8x. The increase in self noise of channel HH7 at and below 0.2 Hz first becomes evident at 0° C, and gradually increases in the data through 50° C.

Dynamic Range
The observed dynamic range values over the 0.01 Hz and 10 Hz passband varied across all sample rates from 139.23 dB (100 sps) to 139.63 dB (40 sps) at a gain of 1x, while at a gain of 32x observed dynamic ranges varied from 117.94 dB (40 sps) to 120.95 dB (20 sps).

System Noise
System noise, expressed in equivalent units for the Hyperion sensor (26.6 mV/Pa sensitivity), the Affinity must be operated at a gain of 2x or greater to ensure its self noise is below that of the sensor. The MB3a requires the Affinity to be operated at a gain of at least 2x to ensure its self noise remains below that of the sensor, while the MB2005 sensor, at gain 1x, the self noise remains well below that of each sensor.

Seismic system noise plots, for all sensors, illustrate the need to operate the Affinity at high gain settings to minimize the frequency band over which the digitizer self noise exceeds that of selected seismic sensor.

Response Verification
In all cases, the relative amplitudes were effectively zero across the pass-band. This indicates that there were no differences in response between the digitizer channels. There were some slight roll-off in the phase responses, consistent with small amounts of timing skew between channels.

Relative Transfer Function
The largest timing skews observed across channels was 0.2669 microseconds.

Analog Bandwidth
Across all sample rates and gains evaluated, as a percentage of the sampling rate's Nyquist Frequency, the high frequency pass-band limit varies from 89.40% (100 sps, gains 1x and 8x) to 89.6% (100 sps gains 4x, 16x and 32x).

Total Harmonic Distortion
The observed harmonic distortion of the 100 sps channels ranged between -114.64 dB and -126.12 dB across all gains.

Modified Noise Power Ratio
At a gain of 1x and 8x, the Affinity consistently, across the channels evaluated, has slightly 22 bits and 21 bits, respectively, of performance across the amplitude range.

Common Mode
The observed common mode rejection ranged from 52.17 dB (gain 32x) to 118.60 dB (gain 1x).

Cross Talk
The maximum possible observable levels of crosstalk of the sensor channels were all between -155.11 dB and -152.53 dB.

Time Tag Accuracy
The measured time tag accuracy values were consistent for all of the recording channels and less than 6 us.

Time Tag Drift
Drift rate while the GPS antenna was covered was relatively consistent at -11.9 us/hr. When the antenna was uncovered, the Affinity regained lock and recovered to a stabilized offset within 7 minutes. Total drift was 190 us, during the 17 hour period during which the GPS antenna was covered.

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

3. IEEE Standard for Analog to Digital Converters, IEEE Std. 1241-2010.

4. Kromer, Richard P., Hart, Darren M. and J. Mark Harris (2007), *Test Definition for the Evaluation of Digital Waveform Recorders Version 1.0*, SAND2007-5037.

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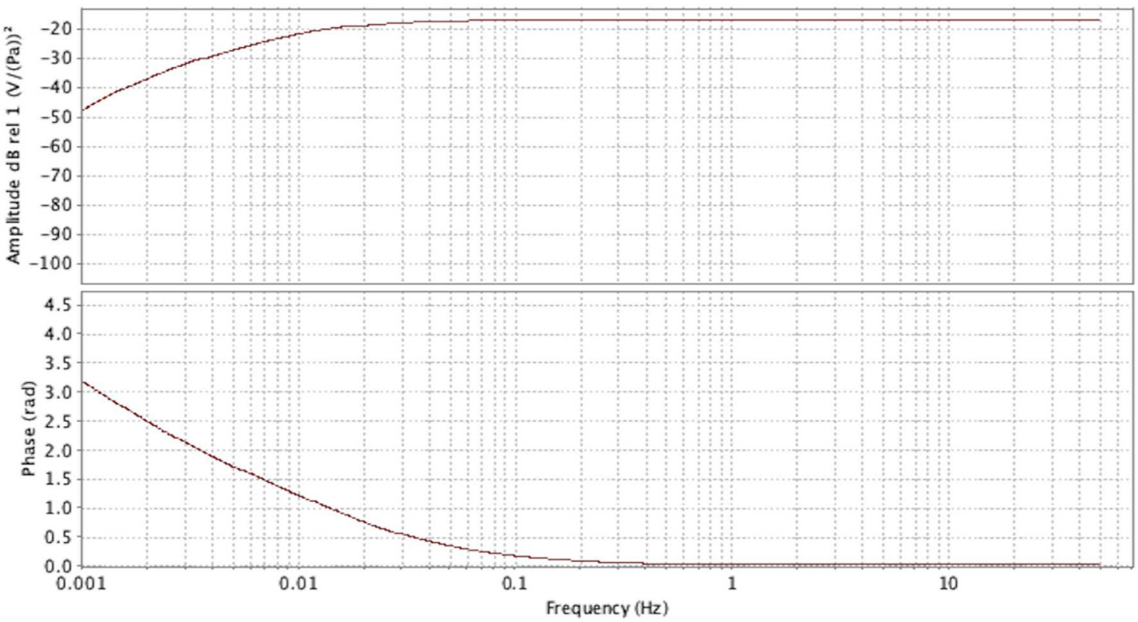
6. Merchant, B. John, and Darren M. Hart (2011), *Component Evaluation Testing and Analysis Algorithms*, SAND2011-8265.

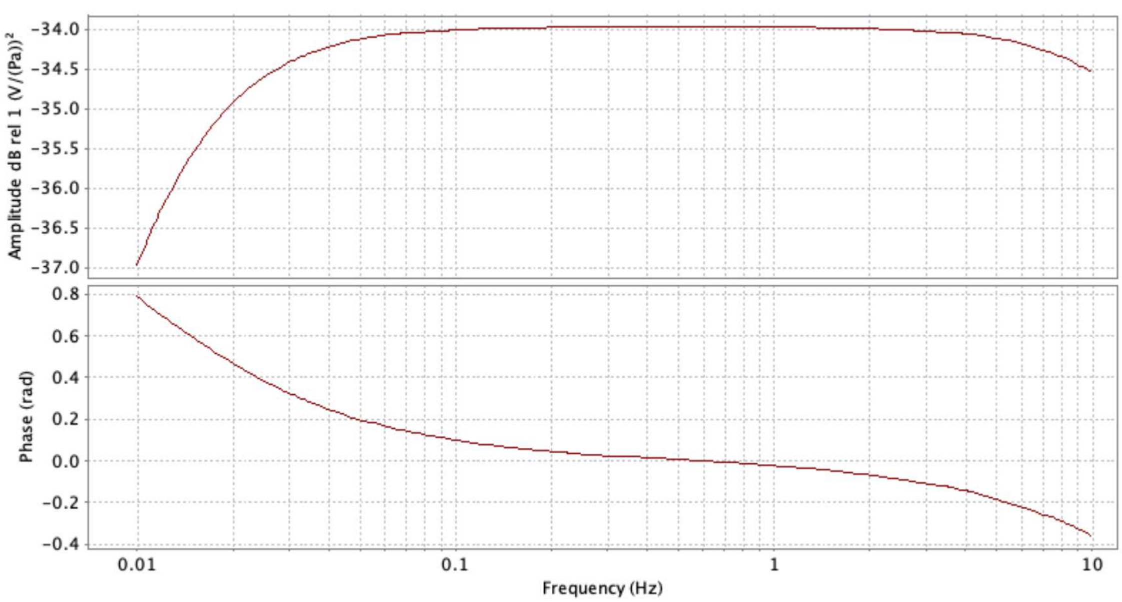
7. Sleeman, R., Wettum, A., Trampert, J. (2006), *Three-Channel Correlation Analysis: A New Technique to Measure Instrumental Noise of Digitizers and Seismic Sensors*, Bulletin of the Seismological Society of America, Vol. 96, No. 1, pp. 258-271, February 2006.Appendix A: Amplitude and Phase Response

APPENDIX A: RESPONSE MODELS

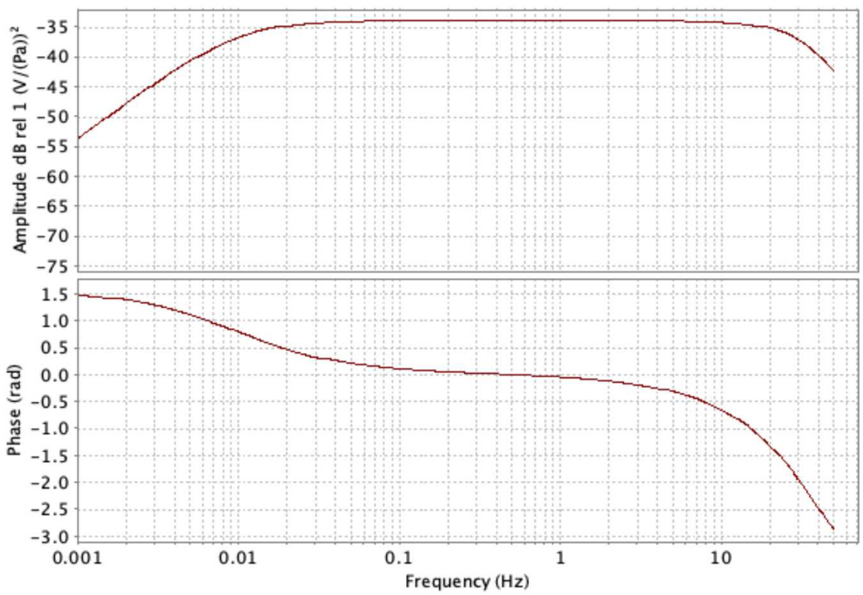
4.1 Hyperion IFS-5013 Response



4.2 Seismowave MB3a Response



4.3 Seismowave MB2005 Response



Sensitivity:
20 mV/Pa at 1.0 Hz

Poles:

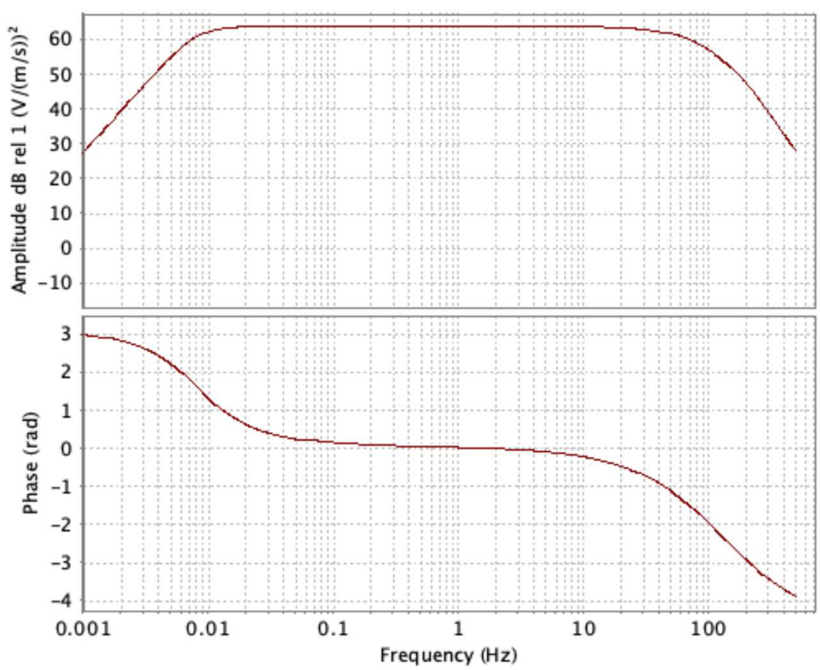
-206.69	0.0
-177.7	177.8
-177.7	-177.8
-4.3	819.6
-4.3	-819.6
-4.0	1116.7
-4.0	-1116.7
-0.0628	0.0

Zeros:

-468820.0	0.0
0.0	0.0

A:
466,950 MV/Pa

4.4 CMG-3T Response



Sensitivity:
1,500 V·s/m at 1.0 Hz

Poles:

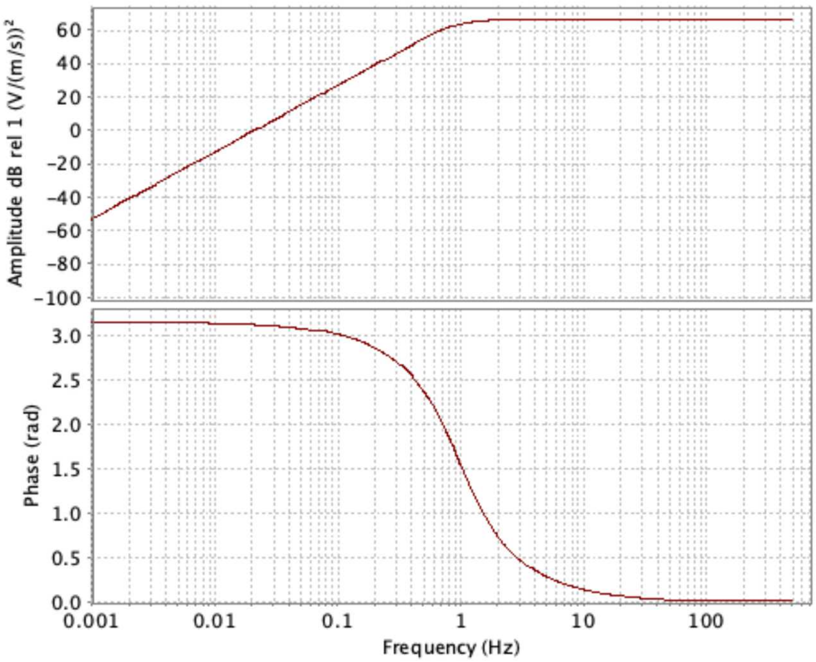
-1130.0	0.0
-1010.0	0.0
-503.0	0.0
-0.037	0.037
-0.037	-0.037

Zeros:

0.0	0.0
0.0	0.0

A:
861,208 MV·s/m

4.5 GS-13 Response



Sensitivity:
2,000 V·s/m at 5.0 Hz

Poles:

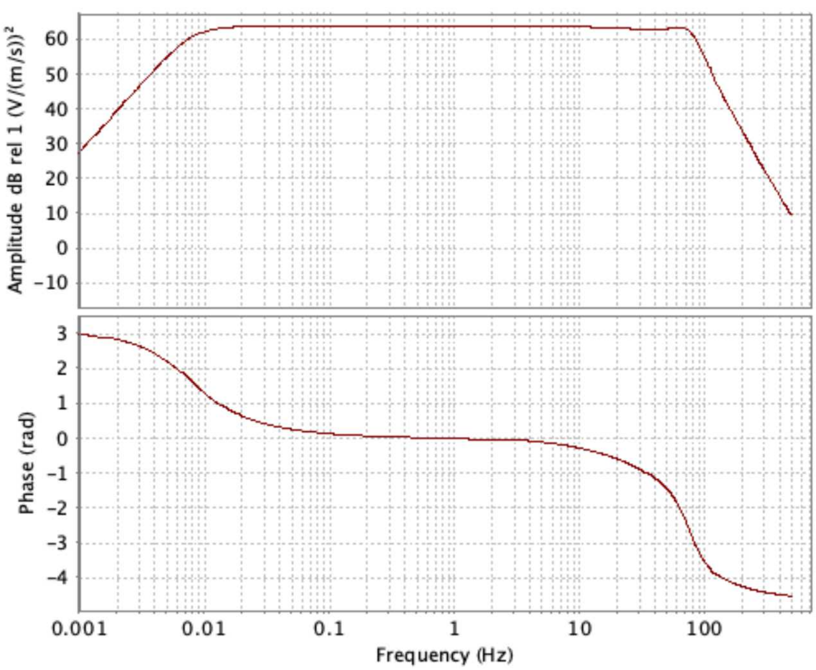
-4.443	4.443
-4.443	-4.443

Zeros:

0.0	0.0
0.0	0.0

A:
2,001.6 V·s/m

4.6 STS-2 Response



Sensitivity:
1,500 V·s/m at 1.0 Hz

Poles:

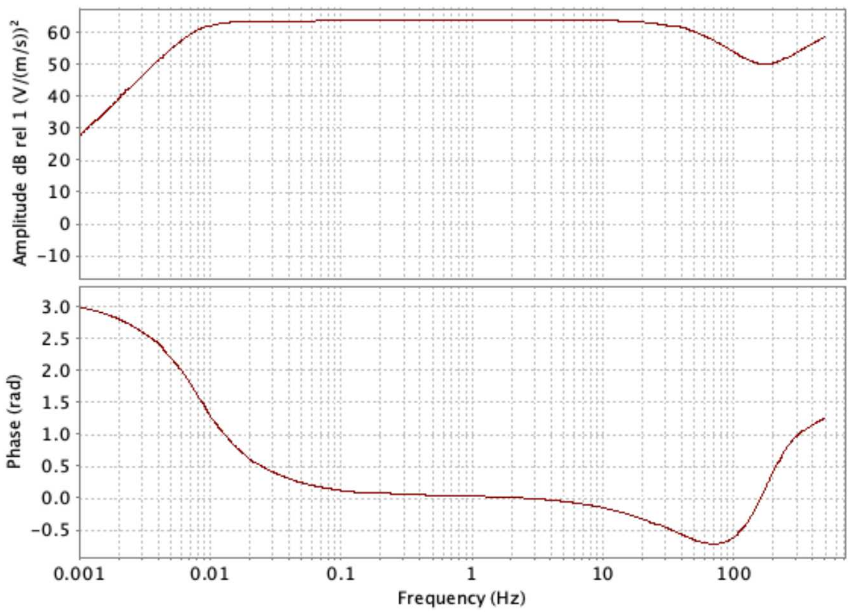
-251.0	0.0
-131.0	467.0
-131.0	-467.0
-0.037	0.037
-0.037	-0.037

Zeros:

0.0	0.0
0.0	0.0

A:
88,586.7 MV·s/m

4.7 STS-5a Response



Sensitivity:
1,500 V·s/m at 1.0 Hz

Poles:

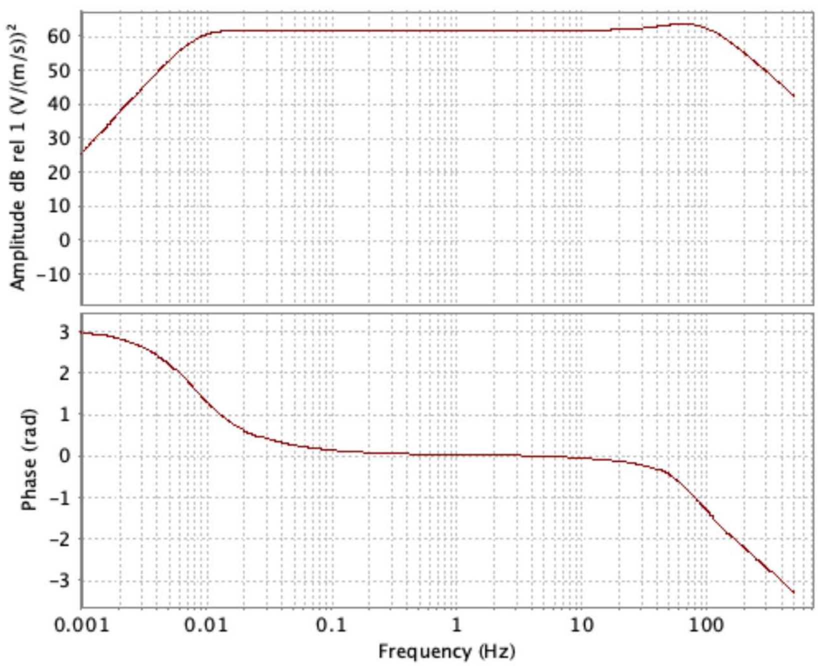
-961.0	0.0
-339.0	116.0
-339.0	-116.0
-16.0	0.0
-16.0	0.0
-0.037	-0.037
-0.037	0.037

Zeros:

-961.0	0.0
-605.0	0.0
-522.0	961.0
-522.0	-961.0
-15.7	0.0
-15.7	0.0
0.0	0.0
0.0	0.0

A:
0.275035 V·s/m

4.8 T-120 Response



Sensitivity:
1,200 V·s/m at 1.0 Hz

Poles:

-7100.0	1700.0
-7100.0	-1700.0
-4900.0	5204.0
-4900.0	-5204.0
-1260.0	0.0
-364.0	404.0
-364.0	-404.0
-142.0	0.0
-32.55	0.0
-0.036614	0.037059
-0.036614	-0.037059

Zeros:

-3177.0	0.0
-350.0	0.0
-160.0	0.0
-31.63	0.0
0.0	0.0
0.0	0.0

A:
999.05912E12 MV·s/m

APPENDIX B: TESTBED CALIBRATIONS

Agilent 3458A # MY45048371

PRIMARY STANDARDS
LABORATORY
Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Limited Calibration Certificate
Document #: 6652541_11753062

Item Identification

Asset Number	6652541
Description	Multimeter,Digital
Model	3458A
Serial #	MY45048371
Manufacturer	Agilent Technologies
Customer Asset Id	N/A
Purchase Order	N/A
Customer	Ground-Based Monitoring R&E 06752
Custodian	Slad, George William
Location	SNLNM/TA1/758/1044
Date of Receipt	November 28, 2018
Dates Tested (Start – End)	December 13, 2018 - December 17, 2018
Date Approved	December 18, 2018
Calibration Expiration Date	December 18, 2019

Calibration Description

Calibration Lab	PSL-ELECTRICAL
Calibration Procedure, rev.	HP 3458A, 4.2
Temperature	23 ± 2 deg C
Humidity	40 ± 20 %RH
Barometric Pressure	N/A mmHg
As Found Condition	PASS
As Left Condition	PASS-ADJ
Software Used	MET/CAL 8.3.2.37
Tamper Seal	None

PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Calibration Specifications and Results

This instrument (Agilent/HP 3458A) was tested using the SNL Primary Standards Laboratory's Multimeter/ Multifunction Station MMS #9300 and is certified to be within the following LIMITED specifications:

DC Volts:
± (11 ppm of reading + 10 ppm of range) 100 mV range
± (10 ppm of reading + 1 ppm of range) 1 V range
± (10 ppm of reading + 0.2 ppm of range) 10 V range
± (12 ppm of reading + 0.3 ppm of range) 100 V range
± (12 ppm of reading + 0.1 ppm of range) 1000 V range

AC Volts:
10 Hz to 40 Hz ± (0.2% of reading + 0.002% of range) 10 mV to 100 V ranges
40 Hz to 20 kHz ± (0.045% of reading + 0.002% of range) 10 mV to 100 V ranges
40 Hz to 20 kHz ± (0.08% of reading + 0.002% of range) 1000 V range
20 kHz to 50 kHz ± (0.1% of reading + 0.011% of range) 10 mV range
20 kHz to 50 kHz ± (0.1% of reading + 0.002% of range) 100 mV to 100 V ranges
50 kHz to 100 kHz ± (0.5% of reading + 0.011% of range) 10 mV range
50 kHz to 100 kHz ± (0.2% of reading + 0.002% of range) 100 mV to 100 V ranges
100 kHz to 300 kHz ± (4% of reading + 0.02% of range) 10 mV range
100 kHz to 300 kHz ± (1% of reading + 0.01% of range) 100 mV to 10 V ranges
100 kHz to 200 kHz ± (1% of reading + 0.01% of range) 100 V range

NOTE: 700 V RMS maximum on 1000 VAC range

4-wire Ohms:
± (100 ppm of reading + 10 ppm of range) 10 Ω range
± (50 ppm of reading + 5 ppm of range) 100 Ω range
± (50 ppm of reading + 1 ppm of range) 1 KΩ to 100 KΩ ranges
± (100 ppm of reading + 2 ppm of range) 1 MΩ range
± (200 ppm of reading + 10 ppm of range) 10 MΩ range
± (500 ppm of reading + 10 ppm of range) 100 MΩ range
± (2% of reading + 10 ppm of range) 1 GΩ range

DC Current
± (10% of reading + 0.01% of range) 100 nA range
± (3.0% of reading + 0.01% of range) 1 µA range
± (0.3% of reading + 0.001% of range) 10 µA
± (0.04% of reading + 0.01% of range) 100 µA and 1 A ranges
± (0.02% of reading + 0.005% of range) 1 mA, 10 mA, and 100 mA ranges

AC Current:
20 Hz to 1 kHz ± (0.15% of reading + 0.02% of range) 100 µA range
20 Hz to 5 kHz ± (0.15% of reading + 0.02% of range) 1 mA to 100 mA ranges
40 Hz to 5 kHz ± (0.15% of reading + 0.02% of range) 1 A range
5 kHz to 10 kHz ± (0.5% of reading + 0.02% of range) 1 mA to 100 mA ranges

Frequency:
10 Hz to 40 Hz ± 0.05% of reading
40 Hz to 10 MHz ± 0.01% of reading

Note 1: Measurement setup configuration is defined in manufacturer's accuracy statement footnotes.
Note 2: Additional errors due to deviations in setup configuration shall be added by the user to the specifications in this certificate.
Note 3: Contact the Primary Standards Laboratory for assistance with uncertainty calculations as needed.

PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Calibration Data Report

Primary Electrical Lab

Unit Under Test:	Agilent 3458A Digital Multimeter	Test Result:	**PASS**
Asset Number:	6652541	Test Type:	AS-FOUND
Serial Number:	MY45048371	Calibration Date:	12/13/2018
Procedure Name:	HP 3458A	Temperature:	23 °C
Revision:	4.2	Humidity:	40 %
Calibrated By:	Brian Liddle		

- Test Type is defined as follows:
  - AS-FOUND Data collected prior to adjustment and/or repair
  - AS-LEFT Data collected after adjustment and/or repair
  - FOUND-LEFT Data collected without adjustment and/or repair
- Test Uncertainty Ratio (TUR) is defined as:
  - TUR = Specification Limit / Uncertainty of the Measurement
- A hash (#) appended to the TUR indicates a guardbanded measurement
- An asterisk (*) appended to the TUR indicates use of a Test Accuracy Ratio (TAR) instead of a TUR
  - TAR = Specification Limit / Accuracy of the Standard

COMMENTS:

Standards Used

Asset #	Description	Due Date
11123	Keithley 5155-9 1 Gohm resistor	5/17/2020
44972	Fluke 5725A Amplifier	12/18/2018
6651332	Agilent 33250A Funtion/Arbitrary Waveform Generato	2/19/2019
6664630	Fluke 5730A Multifunction Calibrator	3/5/2019
6678754	Fluke 5790A-5 AC Measurement Standard	7/12/2019

Test Results

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MMS: 9300

SOFTWARE USED: Met/Cal Version 8.3.2

CALIBRATION MANUAL:
   Agilent Technologies 3458A Multimeter
   Calbration Manual, Edition 6, October 2013
   PN 03458-90017

LIMITED CALIBRATION:
   PSL specifications are larger than manufacturer's
   specifications reported in Factory User Manual.
   This is a limitation of the PSL.
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The internal temperature of the 3458A is 35.8 deg.C
DC Volts
```

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
100.00000 mV		99.99812	100.00082	100.00188	mV	2.26#	43	
-100.00000 mV		-100.00188	-100.00069	-99.99812	mV	2.26#	37	
1.00000000 V		0.99998965	1.00000724	1.00001035	V	2.97#	70	
-1.00000000 V		-1.00001035	-1.00000633	-0.99998965	V	2.97#	61	
-10.0000000 V		-10.0000987	-10.0000748	-9.9999013	V	3.92#	76	
-5.0000000 V		-5.0000501	-5.0000381	-4.9999499	V	3.71#	76	
-2.0000000 V		-2.0000209	-2.0000130	-1.9999791	V	3.24#	62	
2.0000000 V		1.9999791	2.0000150	2.0000209	V	3.24#	72	
5.0000000 V		4.9999499	5.0000393	5.0000501	V	3.71#	79	Mar
10.0000000 V		9.9999013	10.0000761	10.0000987	V	3.92#	77	
100.000000 V		99.998821	100.000851	100.001179	V	3.51#	72	

PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
1000.00000 V		999.98900	1000.01031	1000.01100	V	2.42#	94	Mar
DC Current								
100.000 nA		91.597	99.958	108.403	nA	1.85#	0	
1.000000 µA		0.969900	0.999967	1.030100	µA	5.5	0	
10.000000 µA		9.969900	9.999918	10.030100	µA	5.2	0	
100.00000 µA		99.95000	99.99923	100.05000	µA	5.7	2	
1.0000000 mA		0.9997500	0.9999938	1.0002500	mA	7.6	3	
10.000000 mA		9.997500	9.999971	10.002500	mA	8.1	1	
100.00000 mA		99.97500	100.00111	100.02500	mA	6.1	4	
1.0000000 A		0.9995000	1.0000210	1.0005000	A	7.6	4	
Resistance								
10.00000 Ohm	10.000528	9.99943	10.00061	10.00163	Ohm	5.8	8	
100.00000 Ohm	100.005370	99.99987	100.00629	100.01087	Ohm	6.5	17	
1.0000000 kOhm	0.99999750	0.9999465	1.0000057	1.0000485	kOhm	9.1	16	
10.000000 kOhm	9.9998170	9.999307	9.999903	10.000327	kOhm	9.4	17	
100.00000 kOhm	99.998110	99.99301	99.99898	100.00321	kOhm	8.2	17	
1.0000000 MOhm	0.99994470	0.9998427	0.9999551	1.0000467	MOhm	9.3	10	
10.000000 MOhm	9.9979120	9.995812	9.998052	10.000012	MOhm	7.2	7	
100.00000 MOhm	100.012100	99.96109	100.01220	100.06311	MOhm	6.0	0	
1.00117000 GOhm		0.9811366	1.0020674	1.0212034	GOhm	>10	4	
AC Current								
100.0000 µA @ 20 Hz		99.8300	99.9381	100.1700	µA	7.4	36	
100.0000 µA @ 45 Hz		99.8300	99.9836	100.1700	µA	10.0	10	
100.0000 µA @ 1 kHz		99.8300	99.9824	100.1700	µA	10.0	10	
1.000000 mA @ 20 Hz		0.998300	0.999485	1.001700	mA	10.0	30	
1.000000 mA @ 45 Hz		0.998300	0.999943	1.001700	mA	>10	3	
1.000000 mA @ 5 kHz		0.998300	1.000221	1.001700	mA	6.3	13	
1.000000 mA @ 10 kHz		0.995013	1.000508	1.004987	mA	3.47#	10	
10.00000 mA @ 20 Hz		9.98300	9.99492	10.01700	mA	10.0	30	
10.00000 mA @ 45 Hz		9.98300	9.99945	10.01700	mA	>10	3	
10.00000 mA @ 5 kHz		9.98300	10.00114	10.01700	mA	7.7	7	
10.00000 mA @ 10 kHz		9.94970	10.00223	10.05030	mA	4.0	4	
100.0000 mA @ 20 Hz		99.8300	99.9541	100.1700	mA	10.0	27	
100.0000 mA @ 45 Hz		99.8300	99.9994	100.1700	mA	>10	0	
100.0000 mA @ 5 kHz		99.8300	100.0274	100.1700	mA	8.5	16	
100.0000 mA @ 10 kHz		99.4800	100.0514	100.5200	mA	5.5	10	
1.000000 A @ 40 Hz		0.998300	0.999912	1.001700	A	6.8	5	
1.000000 A @ 5 kHz		0.998357	1.000873	1.001643	A	3.95#	53	
AC Volts								
10.00000 mV @ 10 Hz	9.997600	9.97740	9.99865	10.01780	mV	7.2	5	
10.00000 mV @ 40 Hz	9.997400	9.99298	9.99824	10.00182	mV	2.94#	19	
10.00000 mV @ 20 kHz	9.998200	9.99378	9.99926	10.00262	mV	2.94#	24	
10.00000 mV @ 50 kHz	9.998700	9.98760	9.99743	10.00980	mV	4.1	11	
10.00000 mV @ 100 kHz	10.002100	9.95099	9.98921	10.05321	mV	>10	25	
10.00000 mV @ 300 kHz	10.002200	9.60011	9.88661	10.40429	mV	>10	29	
100.0000 mV @ 10 Hz	99.99460	99.7926	99.9972	100.1966	mV	>10	1	
100.0000 mV @ 40 Hz	99.99370	99.9467	99.9988	100.0407	mV	>10	11	
100.0000 mV @ 20 kHz	99.99610	99.9491	99.9898	100.0431	mV	>10	13	
100.0000 mV @ 50 kHz	99.99640	99.8944	99.9923	100.0984	mV	>10	4	
100.0000 mV @ 100 kHz	100.00050	99.7985	99.9849	100.2025	mV	>10	8	
100.0000 mV @ 300 kHz	100.01540	99.0052	99.9458	101.0256	mV	>10	7	
1.000000 V @ 10 Hz	1.0000704	0.998050	1.000026	1.002091	V	>10	2	
1.000000 V @ 40 Hz	1.0000150	0.999545	1.000032	1.000485	V	>10	4	
1.000000 V @ 20 kHz	1.0000142	0.999544	0.999944	1.000484	V	>10	15	
1.000000 V @ 50 kHz	1.0000213	0.999001	1.000022	1.001041	V	>10	0	
1.000000 V @ 100 kHz	1.0000411	0.998021	1.000099	1.002061	V	>10	3	
1.000000 V @ 300 kHz	1.0002413	0.990139	1.001570	1.010344	V	>10	13	
10.00000 V @ 10 Hz	10.000805	9.98060	10.00055	10.02101	V	>10	1	
10.00000 V @ 40 Hz	10.000198	9.99550	10.00038	10.00490	V	>10	4	
10.00000 V @ 20 kHz	10.000233	9.99553	9.99996	10.00493	V	>10	6	
10.00000 V @ 50 kHz	10.000474	9.99027	10.00076	10.01067	V	>10	3	

Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
10.00000 V @ 100 kHz	10.000967	9.98077	9.99982	10.02117	V	>10	6	
10.00000 V @ 300 kHz	10.002521	9.90150	10.00006	10.10355	V	>10	2	
100.0000 V @ 10 Hz	100.00787	99.8059	100.0039	100.2099	V	>10	2	
100.0000 V @ 40 Hz	100.00162	99.9546	100.0027	100.0486	V	>10	2	
100.0000 V @ 20 kHz	100.00324	99.9562	99.9992	100.0502	V	>10	9	
100.0000 V @ 50 kHz	100.00659	99.9046	100.0090	100.1086	V	>10	2	
100.0000 V @ 100 kHz	100.00878	99.8068	100.0027	100.2108	V	>10	3	
100.0000 V @ 200 kHz	100.03653	99.0262	100.0015	101.0469	V	>10	3	
700.0000 V @ 40 Hz	700.02420	699.4442	699.9892	700.6042	V	>10	6	
700.0000 V @ 20 kHz	700.01940	699.4394	699.7545	700.5994	V	>10	46	
FREQUENCY								
10.00000 Hz @ 1 V		9.995000	10.000064	10.005000	Hz	>10	1	
40.00000 Hz @ 1 V		39.996000	40.000514	40.004000	Hz	>10	13	
100.00000 Hz @ 1 V		99.990000	100.001171	100.010000	Hz	>10	12	
1000.0000 Hz @ 1 V		999.90000	1000.00953	1000.10000	Hz	>10	10	
10000.0000 Hz @ 1 V		9999.00000	10000.09823	10001.00000	Hz	>10	10	
20000.0000 Hz @ 1 V		19998.00000	20000.19836	20002.00000	Hz	>10	10	
50000.0000 Hz @ 1 V		49995.00000	50000.49114	50005.00000	Hz	>10	10	
100.00000 kHz @ 1 V		99.990000	100.000982	100.010000	kHz	>10	10	
500.00000 kHz @ 1 V		499.950000	500.004911	500.050000	kHz	>10	10	
1.000000 MHz @ 1 V		0.9999000	1.0000098	1.0001000	MHz	>10	10	
2.000000 MHz @ 1 V		1.9998000	2.0000196	2.0002000	MHz	>10	10	
4.000000 MHz @ 1 V		3.9996000	4.0000393	4.0004000	MHz	>10	10	
6.000000 MHz @ 1 V		5.9994000	6.0000587	6.0006000	MHz	>10	10	
8.000000 MHz @ 1 V		7.9992000	8.0000788	8.0008000	MHz	>10	10	
10.000000 MHz @ 1 V		9.9990000	10.0000992	10.0010000	MHz	>10	10	

***** End of Test Results *****

PRIMARY STANDARDS LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Calibration Data Report

Primary Electrical Lab

Unit Under Test:	Agilent 3458A Digital Multimeter	Test Result:	**PASS**
Asset Number:	6652541	Test Type:	AS-LEFT
Serial Number:	MY45048371	Calibration Date:	12/17/2018
Procedure Name:	HP 3458A	Temperature:	23 °C
Revision:	4.2	Humidity:	40 %
Calibrated By:	Brian Liddle		

- Test Type is defined as follows:
  - AS-FOUND Data collected prior to adjustment and/or repair
  - AS-LEFT Data collected after adjustment and/or repair
  - FOUND-LEFT Data collected without adjustment and/or repair
- Test Uncertainty Ratio (TUR) is defined as:
  - TUR = Specification Limit / Uncertainty of the Measurement
- A hash (#) appended to the TUR indicates a guardbanded measurement
- An asterisk (*) appended to the TUR indicates use of a Test Accuracy Ratio (TAR) instead of a TUR
  - TAR = Specification Limit / Accuracy of the Standard

COMMENTS:

Standards Used

Asset #	Description	Due Date
11123	Keithley 5155-9 1 Gohm resistor	5/17/2020
44972	Fluke 5725A Amplifier	12/18/2018
6651332	Agilent 33250A Funtion/Arbitrary Waveform Generato	2/19/2019
6664630	Fluke 5730A Multifunction Calibrator	3/5/2019
6678754	Fluke 5790A-5 AC Measurement Standard	7/12/2019

Test Results

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MMS: 9300

SOFTWARE USED: Met/Cal Version 8.3.2

CALIBRATION MANUAL:
Agilent Technologies 3458A Multimeter
Calbration Manual, Edition 6, October 2013
PN 03458-90017

LIMITED CALIBRATION:
PSL specifications are larger than manufacturer's
specifications reported in Factory User Manual.
This is a limitation of the PSL.

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The internal temperature of the 3458A is 36.1 deg.C

DC Volts

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
100.00000 mV		99.99812	100.00009	100.00188	mV	2.26#	5	
-100.00000 mV		-100.00188	-100.00005	-99.99812	mV	2.26#	3	
1.00000000 V		0.99998965	0.99999925	1.00001035	V	2.97#	7	
-1.00000000 V		-1.00001035	-0.99999881	-0.99998965	V	2.97#	12	
-10.0000000 V		-10.0000987	-9.9999992	-9.9999013	V	3.92#	1	
-5.0000000 V		-5.0000501	-4.9999997	-4.9999499	V	3.71#	1	
-2.0000000 V		-2.0000209	-1.9999980	-1.9999791	V	3.24#	10	
2.0000000 V		1.9999791	1.9999996	2.0000209	V	3.24#	2	
5.0000000 V		4.9999499	5.0000005	5.0000501	V	3.71#	1	
10.0000000 V		9.9999013	9.9999985	10.0000987	V	3.92#	2	
100.000000 V		99.998821	100.000049	100.001179	V	3.51#	4	

Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
1000.00000 V		999.98900	1000.00265	1000.01100	V	2.42#	24	
DC Current								
100.000 nA		91.597	99.978	108.403	nA	1.85#	0	
1.000000 µA		0.969900	0.999950	1.030100	µA	5.5	0	
10.000000 µA		9.969900	9.999910	10.030100	µA	5.2	0	
100.00000 µA		99.95000	99.99977	100.05000	µA	5.7	0	
1.0000000 mA		0.9997500	0.9999974	1.0002500	mA	7.6	1	
10.000000 mA		9.997500	9.999987	10.002500	mA	8.1	1	
100.00000 mA		99.97500	100.00113	100.02500	mA	6.1	5	
1.0000000 A		0.9995000	1.0000283	1.0005000	A	7.6	6	
Resistance								
10.00000 Ohm	10.000528	9.99943	10.00054	10.00163	Ohm	5.8	1	
100.00000 Ohm	100.005370	99.99987	100.00564	100.01087	Ohm	6.5	5	
1.0000000 kOhm	0.99999750	0.9999465	0.9999962	1.0000485	kOhm	9.1	3	
10.000000 kOhm	9.9998170	9.999307	9.999813	10.000327	kOhm	9.4	1	
100.00000 kOhm	99.998110	99.99301	99.99808	100.00321	kOhm	8.2	1	
1.0000000 MOhm	0.99994470	0.9998427	0.9999461	1.0000467	MOhm	9.3	1	
10.000000 MOhm	9.9979120	9.995812	9.998001	10.000012	MOhm	7.2	4	
100.00000 MOhm	100.012100	99.96109	100.00726	100.06311	MOhm	6.0	10	
1.00117000 GOhm		0.9811366	1.0011724	1.0212034	GOhm	>10	0	
AC Current								
100.0000 µA @ 20 Hz		99.8300	99.9443	100.1700	µA	7.4	33	
100.0000 µA @ 45 Hz		99.8300	99.9880	100.1700	µA	10.0	7	
100.0000 µA @ 1 kHz		99.8300	99.9874	100.1700	µA	10.0	7	
1.000000 mA @ 20 Hz		0.998300	0.999521	1.001700	mA	10.0	28	
1.000000 mA @ 45 Hz		0.998300	0.999978	1.001700	mA	>10	1	
1.000000 mA @ 5 kHz		0.998300	1.000267	1.001700	mA	6.3	16	
1.000000 mA @ 10 kHz		0.995013	1.000557	1.004987	mA	3.47#	11	
10.00000 mA @ 20 Hz		9.98300	9.99536	10.01700	mA	10.0	27	
10.00000 mA @ 45 Hz		9.98300	9.99982	10.01700	mA	>10	1	
10.00000 mA @ 5 kHz		9.98300	10.00171	10.01700	mA	7.7	10	
10.00000 mA @ 10 kHz		9.94970	10.00294	10.05030	mA	4.0	6	
100.0000 mA @ 20 Hz		99.8300	99.9566	100.1700	mA	10.0	26	
100.0000 mA @ 45 Hz		99.8300	100.0027	100.1700	mA	>10	2	
100.0000 mA @ 5 kHz		99.8300	100.0354	100.1700	mA	8.5	21	
100.0000 mA @ 10 kHz		99.4800	100.0650	100.5200	mA	5.5	13	
1.000000 A @ 40 Hz		0.998300	0.999955	1.001700	A	6.8	3	
1.000000 A @ 5 kHz		0.998357	1.000978	1.001643	A	3.95#	60	
AC Volts								
10.00000 mV @ 10 Hz	9.997500	9.97730	9.99891	10.01769	mV	7.2	7	
10.00000 mV @ 40 Hz	9.997400	9.99298	9.99825	10.00182	mV	2.94#	19	
10.00000 mV @ 20 kHz	9.998300	9.99388	9.99923	10.00272	mV	2.94#	21	
10.00000 mV @ 50 kHz	9.998800	9.98770	9.99735	10.00990	mV	4.1	13	
10.00000 mV @ 100 kHz	10.002200	9.95109	9.98909	10.05331	mV	>10	26	
10.00000 mV @ 300 kHz	10.002300	9.60021	9.88552	10.40439	mV	>10	29	
100.0000 mV @ 10 Hz	99.99400	99.7920	99.9980	100.1960	mV	>10	2	
100.0000 mV @ 40 Hz	99.99410	99.9471	99.9966	100.0411	mV	>10	5	
100.0000 mV @ 20 kHz	99.99630	99.9493	99.9898	100.0433	mV	>10	14	
100.0000 mV @ 50 kHz	99.99650	99.8945	99.9929	100.0985	mV	>10	3	
100.0000 mV @ 100 kHz	100.00110	99.7991	99.9826	100.2031	mV	>10	9	
100.0000 mV @ 300 kHz	100.01570	99.0055	99.9411	101.0259	mV	>10	7	
1.000000 V @ 10 Hz	1.0000714	0.998051	1.000073	1.002092	V	>10	0	
1.000000 V @ 40 Hz	1.0000144	0.999544	1.000038	1.000484	V	>10	5	
1.000000 V @ 20 kHz	1.0000161	0.999546	0.999924	1.000486	V	>10	20	
1.000000 V @ 50 kHz	1.0000224	0.999002	1.000001	1.001042	V	>10	2	
1.000000 V @ 100 kHz	1.0000400	0.998020	1.000131	1.002060	V	>10	4	
1.000000 V @ 300 kHz	1.0002407	0.990138	1.001517	1.010343	V	>10	13	
10.00000 V @ 10 Hz	10.000778	9.98058	10.00051	10.02098	V	>10	1	
10.00000 V @ 40 Hz	10.000202	9.99550	10.00038	10.00490	V	>10	4	
10.00000 V @ 20 kHz	10.000220	9.99552	9.99997	10.00492	V	>10	5	
10.00000 V @ 50 kHz	10.000472	9.99027	10.00085	10.01067	V	>10	4	

PRIMARY STANDARDS LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
10.00000 V @ 100 kHz	10.000988	9.98079	10.00019	10.02119	V	>10	4	
10.00000 V @ 300 kHz	10.002562	9.90154	10.00012	10.10359	V	>10	2	
100.0000 V @ 10 Hz	100.00636	99.8043	100.0037	100.2084	V	>10	1	
100.0000 V @ 40 Hz	100.00182	99.9548	100.0020	100.0488	V	>10	0	
100.0000 V @ 20 kHz	100.00325	99.9562	99.9978	100.0503	V	>10	12	
100.0000 V @ 50 kHz	100.00681	99.9048	100.0077	100.1088	V	>10	1	
100.0000 V @ 100 kHz	100.00938	99.8074	100.0005	100.2114	V	>10	4	
100.0000 V @ 200 kHz	100.03625	99.0259	100.0052	101.0466	V	>10	3	
700.0000 V @ 40 Hz	700.02260	699.4426	699.9753	700.6026	V	>10	8	
700.0000 V @ 20 kHz	700.01930	699.4393	699.7303	700.5993	V	>10	50	
FREQUENCY								
10.00000 Hz @ 1 V		9.995000	10.000052	10.005000	Hz	>10	1	
40.00000 Hz @ 1 V		39.996000	40.000453	40.004000	Hz	>10	11	
100.00000 Hz @ 1 V		99.990000	100.000885	100.010000	Hz	>10	9	
1000.0000 Hz @ 1 V		999.90000	1000.00991	1000.10000	Hz	>10	10	
10000.0000 Hz @ 1 V		9999.00000	10000.09823	10001.00000	Hz	>10	10	
20000.0000 Hz @ 1 V		19998.00000	20000.19455	20002.00000	Hz	>10	10	
50000.0000 Hz @ 1 V		49995.00000	50000.48637	50005.00000	Hz	>10	10	
100.00000 kHz @ 1 V		99.990000	100.000982	100.010000	kHz	>10	10	
500.00000 kHz @ 1 V		499.950000	500.004911	500.050000	kHz	>10	10	
1.000000 MHz @ 1 V		0.9999000	1.0000098	1.0001000	MHz	>10	10	
2.000000 MHz @ 1 V		1.9998000	2.0000196	2.0002000	MHz	>10	10	
4.000000 MHz @ 1 V		3.9996000	4.0000391	4.0004000	MHz	>10	10	
6.000000 MHz @ 1 V		5.9994000	6.0000587	6.0006000	MHz	>10	10	
8.000000 MHz @ 1 V		7.9992000	8.0000786	8.0008000	MHz	>10	10	
10.000000 MHz @ 1 V		9.9990000	10.0000973	10.0010000	MHz	>10	10	

***** End of Test Results *****

Limitations

PSL specifications are larger than manufacturer's specifications reported in Factory User Manual. This is a limitation of the PSL.

Equipment (Standard) Used

Asset #	Description	Model #	Expires
6678754	Standard,Measurement	5790B-5	July 12, 2019
6664630	Calibrator,Multifunction	5730A/05	August 20, 2020
6651332	Generator,Function	33250A	February 20, 2019
44972	Amplifier	5725A	December 19, 2018
11123	Resistor,Standard	5155-9	May 17, 2020

PRIMARY STANDARDS
LABORATORY
Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Traceability

Values and the associated uncertainties reported are traceable to the SI through one of more of the following:

1. Reference standards whose values are disseminated by the PSL and are traceable to the SI;
2. Reference standards whose values are disseminated by a laboratory that has demonstrated competence, measurement capability, and traceability for those values;
3. The accepted value(s) of fundamental physical phenomena (intrinsic standards);
4. Ratio(s) or other non-maintained standards established by either a self-calibration and/or a direct calibration technique;
5. Standards maintained and disseminated in special cases and where warranted, such as consensus standards where no national or international standards exist.

NOTE 1: This certificate or report shall not be reproduced except in full, without the advance written approval of the laboratory.

NOTE 2: The as received condition of the standard, set of standards, or measurement equipment described herein was as expected, unless otherwise noted in the body of the certificate or report.

NOTE 3: The results reported above relate only to the items tested or calibrated.

NOTE 4: The Decision Rule for the As-Found condition is Simple Acceptance, where the measured value is within the previous certification limits.

Authorization

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End-of-Document

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