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Next Generation Qualification: Guralp Systems Affinity Digitizer Evaluation

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Abstract

Sandia National Laboratories has tested and evaluated a new digitizer, the Affinity, manufactured by Guralp Systems Ltd. These digitizers are 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 power consumption, input impedance, sensitivity, full scale, self-noise, dynamic range, system noise, response, passband, and timing. The Affinity digitizer is Guralp's latest release in their digitizer product line. The Affinity is available with either 4 or 8 channels at 24 bit resolution. In addition to the 24 bit channels, 16 multiplexed low resolution channels are provided. Other features include the means to accept multiple types of timing sources (e.g. GPS, NTP and PTP) and a web page interface for command and control of the unit.

ACKNOWLEDGMENTS

The equipment was purchased and setup using funds provided by the United States Department of Defense. The evaluation and generation of the report was funded by the National Nuclear Security Administration's Office of Defense Nuclear Nonproliferation Research and Development (NA-22).

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NOMENCLATURE

BB	Broadband
dB	Decibel
DOE	Department of Energy
DWR	Digital Waveform Recorder
HNM	High Noise Model
Hz	Hertz
LNM	Low Noise Model
PSD	Power Spectral Density
PSL	Primary Standards Laboratory
SNL	Sandia National Laboratories
SP	Short-period
SPS	Sample Per Second

1 INTRODUCTION

The evaluation of the four Guralp Systems Affinity digitizers, serial numbers 4055A1, 40559A, 40559B and 4055A0, was performed to determine the performance characteristics of the instruments including sensitivity, self-noise, dynamic range, frequency response, and passband. Throughout this report these digitizers are referred to by last four digits of their serial numbers, e.g. 55A1, 559A, 559B and 55A0.

Figure 1 Affinity Digitizer (photo courtesy of Guralp Systems Ltd)

The Affinity is a 4 or 8 channel, 24-bit digitizer with variable sample rate and gain level suitable in form-factor for equipment vault style seismic monitoring system deployment.

The evaluation of the four digitizers, 55A1, 559A, 559B and 55A0, performed against the digitizer specifications below, has identified that the digitizers' performance are consistent with their manufacturer's specifications. Digitizers 55A1, 559A, 559B and 55A0 are 4 channels units, all with 24 bits of resolution. Note, only the three channels dedicated for sensor recording were evaluated. The fourth primary channel is dedicated for calibration loopback and was not evaluated.

Affinity

güralp

SPECIFICATIONS

SENSOR INPUTS	
Primary digitisation channels	Eight at 24 bits. 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	Sixteen multiplexed 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, 2x4, 2x5
Anti-alias filters	3-pole
Low pass filters	FIR (other options available)
Out-of-band rejection	140 dB
Data transmission modes	Continuous and triggered
Trigger modes	STA/LTA, level, external, software
TIMING AND CALIBRATION	
Timing source precision	<42 µs drift per hour when unsynchronised (without GPS)
Timing sources	GPS, NTP and PTP
Calibration signal generator	Amplitude/frequency adjustable, sine, step or broadband noise
OPERATION AND POWER USAGE	
Operating temperature	-25 to +60 °C
Relative humidity range	zero to 100 %
Power supply	9 - 36 V DC (9 V will power digitiser only)
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)
SOFTWARE PROTOCOLS	
Operating system	Linux
Communication technologies supported	RS232, USB, Ethernet (10BASE-T / 100BASE-T) with POE
Internet technologies supported	TCP/IP, PPP, SSH, HTTP, HTTPS (others on request)
	Firewall and routing capabilities
DATA COMMUNICATION	
Data recording formats	GCF, GDI and miniSEED
Seismic network protocols	Scream (Antelope/Earthworm), CD1.0/1.1, SEEDlink and others
Flash memory and storage	512 MB system Flash memory. Option of 16 GB or 32 GB internal Flash storage.

PHYSICAL CHARACTERISTICS	
Casing type	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	GPS antenna; 20 m GPS cable; 5 m power cable; 3 m general purpose input/output cable; 5 m ethernet cable

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DAS-AFT-0001 Issue A

Figure 2 Guralp Systems Affinity Specifications

2 TEST PLAN

2.1 Test Facility

Testing of the Guralp Systems digitizers 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, with the exception of tests performed in the temperature chamber, were performed within the FACT sites underground bunker due to the bunker's stable temperature.

Figure 3 FACT Site Bunker

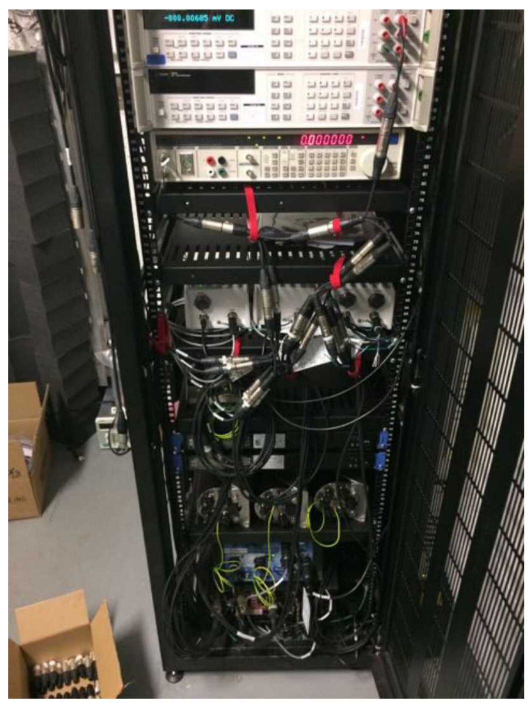

Figure 4 Partial View of Testbed in FACT Site Bunker

The temperature was maintained between 22 and 27 degrees Celsius within the bunker. The low temperature was maintained with a thermostatically controlled electric heater during the Spring months; temperatures gradually rose through the year, peaking in Summer.

A GPS re-broadcaster operates within the bunker to provide the necessary timing source for the Guralp Systems digitizers and other recording and testbed equipment present.

Figure 5 GPS Re-broadcaster

The Guralp Systems digitizers were powered off of a Protek 3005B laboratory power supply providing approximately 13.6 Volts.

Figure 6 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 Guralp Systems digitizer.

Table 1 Tests Performed

Test	Configuration
Input Impedance DC Accuracy AC Accuracy AC Full Scale AC Clip Total Harmonic Distortion Input Terminated Noise Crosstalk Common Mode Rejection Analog Bandwidth Relative Transfer Function Response Incoherent Noise Time Tag Statistics	Affinity digitizers: SN 55A1, 559A, 559B, 55A0 gain 1x, sample rate 100 sps temperature: 23° C
Input Impedance DC Accuracy AC Accuracy AC Full Scale AC Clip Total Harmonic Distortion Input Terminated Noise Crosstalk Common Mode Rejection Analog Bandwidth Relative Transfer Function Response Incoherent Noise Time Tag Statistics	Affinity SN 55A0 SB-1, Environmental Chamber gain 1x, sample rates 4, 20, 40, 100 and 200 sps gain 2x, sample rate 100 Hz gain 4x, sample rate 100 Hz temperature: 20° C
Input Impedance DC Accuracy AC Accuracy AC Full Scale AC Clip Total Harmonic Distortion Input Terminated Noise Crosstalk Common Mode Rejection Analog Bandwidth Relative Transfer Function Response Incoherent Noise Time Tag Statistics	Affinity SN 55A0 SB-1, Environmental Chamber gain 1x, sample rate 100 sps temperatures: 60° C, -25° C and -36° C

2.3 Timeline

Testing of the Guralp Systems digitizers was performed at Sandia National Laboratories between March and August 2017. Testing was performed using Affinity digitizers, serial numbers 55A1, 559A, 559B and 55A0 in the bunker. Exposure to low and high temperatures, while recording at select sample rates, was performed with Affinity 55A0.

2.4 Evaluation Frequencies

The frequency range of the measurements is from 0.01 Hz to 40 Hz. Specifically, the frequencies from the function below which generates standardized octave-band values in Hz (ANSI S1.6-1984) with F_0 = 1 Hz:

$$F(n) = F_0 \times 10^{(n/10)}$$

For measurements taken using either broadband or tonal signals, the following frequency values shall be used for n = -20, -19, …, 16, 17. The nominal center frequency values, in Hz, are:

					0.00315,	0.0040,	0.0050,	0.0063,	0.008,
0.01,	0.0125,	0.016,	0.020,	0.025,	0.0315,	0.040,	0.050,	0.063,	0.08,
0.10,	0.125,	0.16,	0.20,	0.25,	0.315,	0.40,	0.50,	0.63,	0.8,
1.0,	1.25,	1.6,	2.0,	2.5,	3.15,	4.0,	5.0,	6.3,	8.0,
10.0,	12.5,	16.0,	20.0,	25.0,	31.5,	40.0			

3 TEST EVALUATION

3.1 Power Consumption

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

3.1.1 Measurand

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

3.1.2 Configuration

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

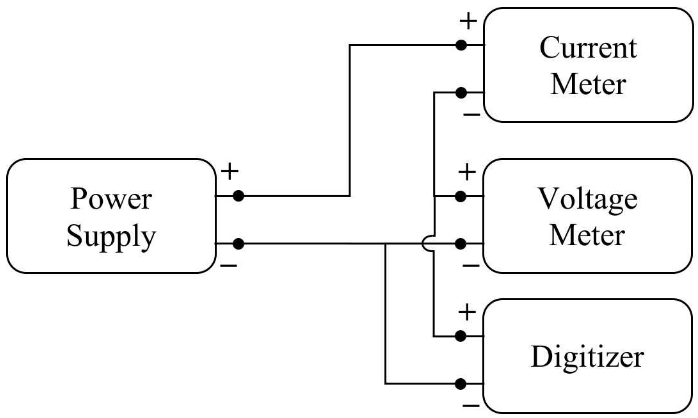

Figure 7 Power Consumption Configuration Diagram

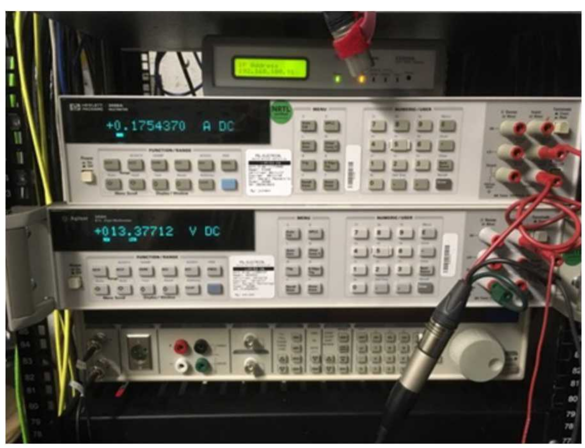

Figure 8 Power Consumption Configuration Picture

Table 2 Power Consumption Testbed Equipment

	Manufacturer / Model	Serial Number	Configuration
Power Supply	Protek 3005B	AC2074	13.5 V
Current Meter	Agilent 3458A	2823A10915	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.

3.1.3 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:

$$P = V * I$$

3.1.4 Result

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

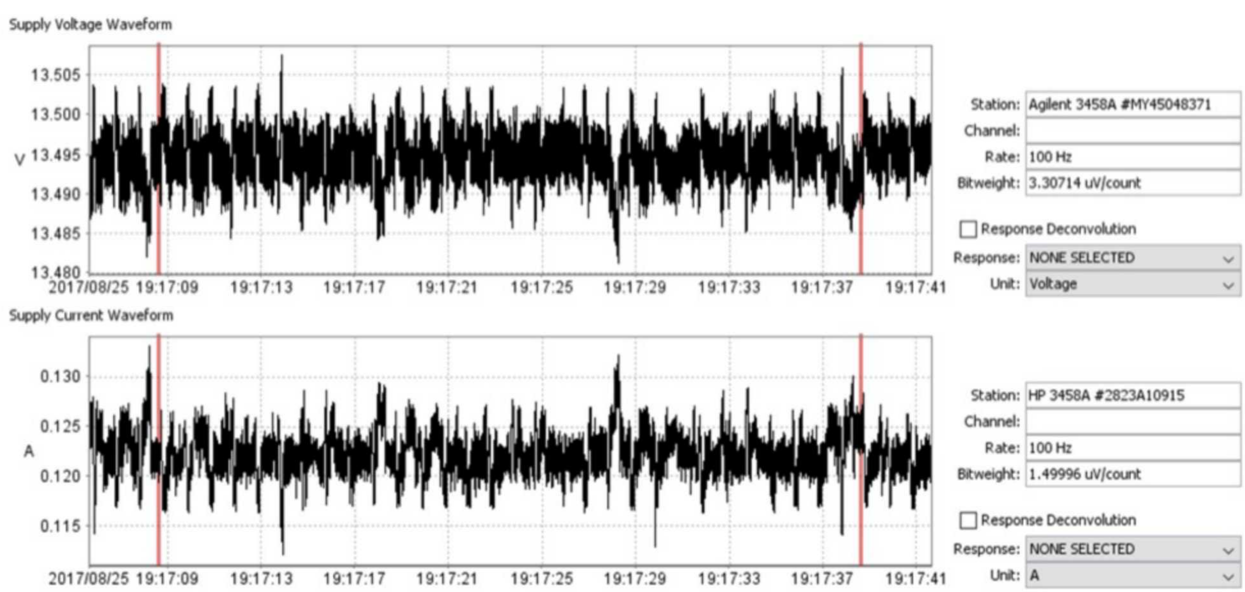

Figure 9 Voltage and Current Recorded Time Series, Affinity 55A1

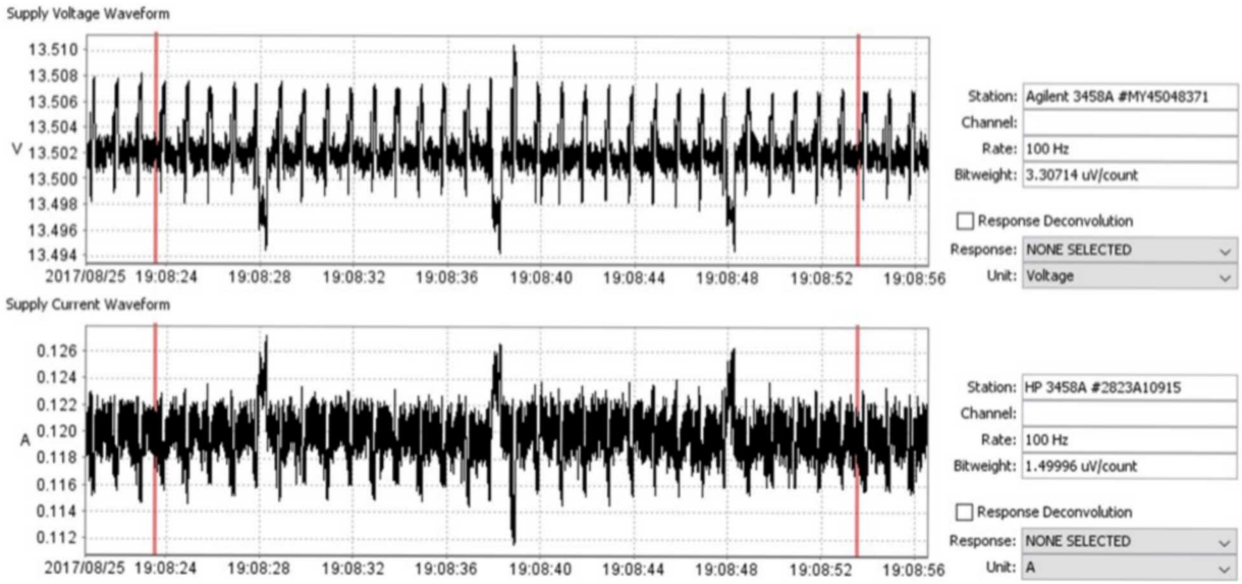

Figure 10 Voltage and Current Recorded Time Series, Affinity 559A

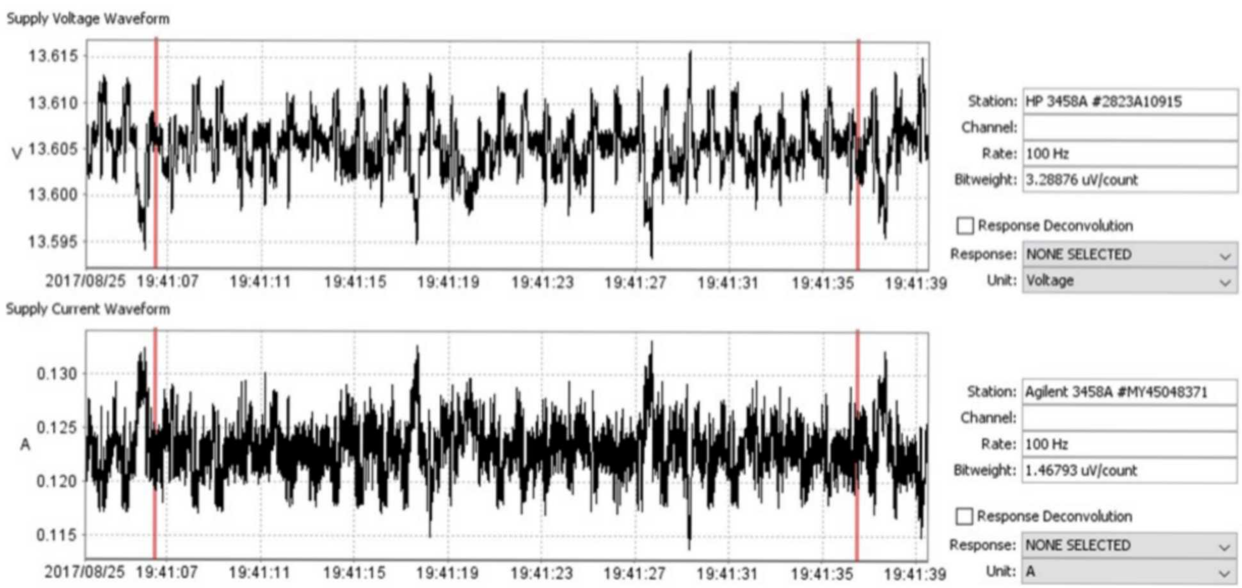

Figure 11 Voltage and Current Recorded Time Series, Affinity 559B

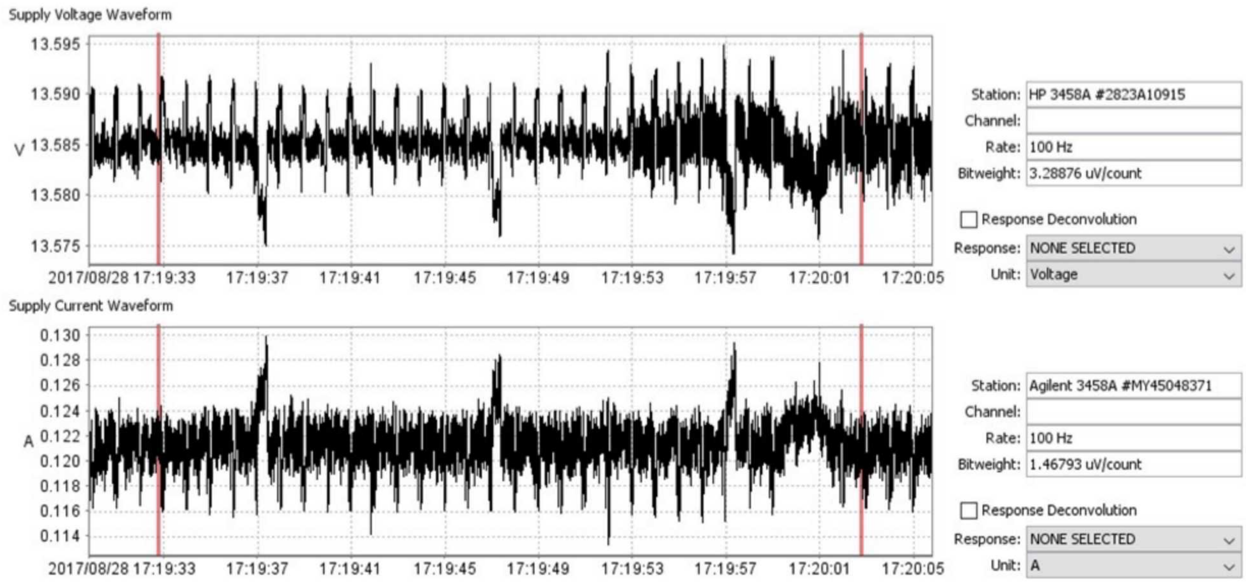

Figure 12 Voltage and Current Recorded Time Series, Affinity 55A0

Table 3 Power Consumption Results

DWR	Supply Voltage	Supply Voltage SD	Supply Current	Supply Current SD	Power Consumption	Power Consumption SD
559A	13.50 V	2.06 mV	0.1197 A	1.952 mA	1.616 W	26.64 mW
559B	13.61 V	2.93 mV	0.1232 A	2.546 mA	1.676 W	34.99 mW
55A0	13.59 V	2.72 mV	0.1214 A	2.079 mA	1.649 W	28.45 mW
55A1	13.49 V	3.68 mV	0.1222 A	2.447 mA	1.648 W	33.54 mW

The Affinity digitizers were observed to consume between 1.616 watts and 1.676 watts of power during operation. The relatively short duration time-series illustrate the variation in power required by the Affinity dataloggers; power requirements may increase momentarily beyond that shown.

The average observed power consumption of 1.65 W is reasonably consistent with the datasheet specification, as it is 6.5% greater than the 1.55 W power consumption specificied in the manufacturer's datasheet for a 4 channel system while ethernet and GPS are active.

3.2 Input Impedance

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

3.2.1 Measurand

The quantity being measured is ohms of impedance.

3.2.2 Configuration

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

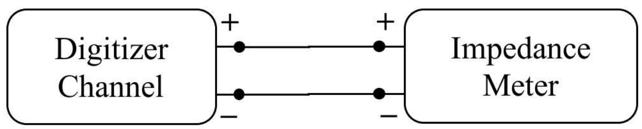

Figure 13 Input Impedance Configuration Diagram

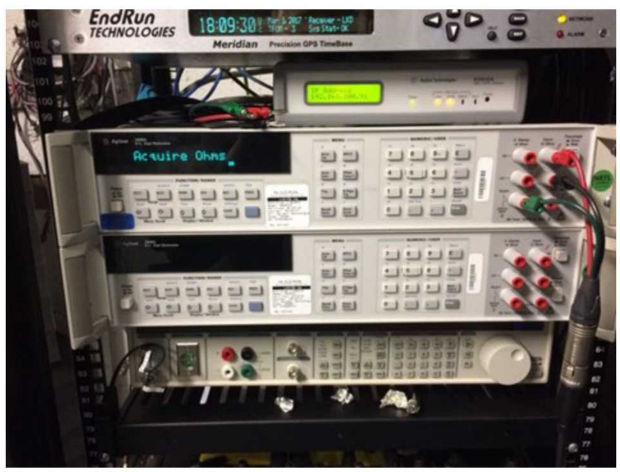

Figure 14 Input Impedance Configuration Picture

Table 4 Input Impedance Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
Impedance Meter - Bunker	Agilent 3458A	MY45048372	DC Impedance
Impedance Meter – SB1	Agilent 3458A	2823A10915	DC Impedance
Impedance Meter – SB1*	Agilent 3458A	MY45048372	DC Impedance

*Meter MY45048372 372, while installed in SB1, was used for measuring input impedance under the following conditions: gain x4 at 20° C, and gain x1 at temperatures -36° C and -25° C.

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

3.2.3 *Analysis*

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

3.2.4 *Result*

The figure below shows a representative waveform time series for the recording of input impedance made on the reference meter.

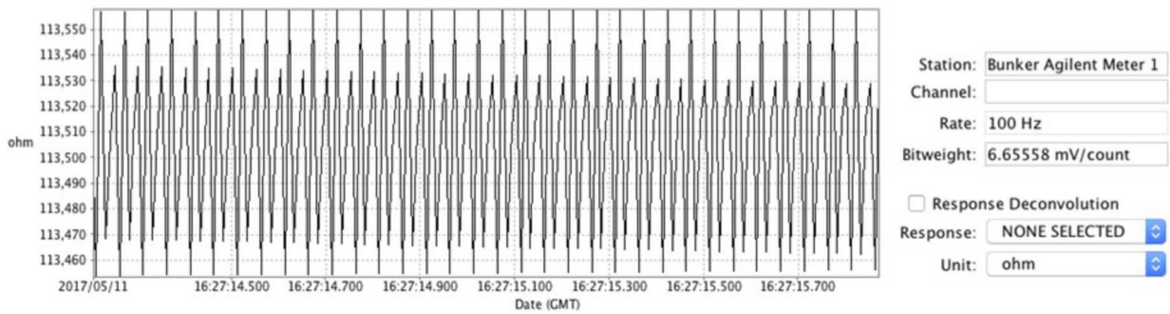

Figure 15 Impedance Time Series

The measured impedance for each of the digitizer channels while operating in a 23°C environment are shown in the table below.

Table 5 Input Impedance Results, All DWR at 23° C

DWR	Channel 1	Channel 2	Channel 3
55A1	113.5045 Kohm	113.5050 Kohm	113.5061 Kohm
559A	113.5009 Kohm	113.5011 Kohm	113.5008 Kohm
559B	113.5080 Kohm	113.5047 Kohm	113.5094 Kohm
55A0	113.5013 Kohm	113.5047 Kohm	113.5021 Kohm

The measured impedance for channels 1 thorugh 3 of digitizer 55A0 while being exposed to various temperatures from -36°C to 20°C are shown in the table below.

Table 6 Impedance of Affinity 55A0 at Select Temperatures

Temp	Channel 1	Channel 2	Channel 3
20° C	113.5027 Kohm	113.5063 Kohm	113.5043 Kohm
20° C gain 2x	113.5027 Kohm	113.5065 Kohm	113.5038 Kohm
20° C gain 4x	113.5019 Kohm	113.5054 Kohm	113.5055 Kohm
-25° C	113.5080 Kohm	113.5081 Kohm	113.50178 Kohm
-36° C	113.5077 Kohm	113.5100 Kohm	113.5101 Kohm

The measured impedance for channels 1 through 3 of digitizer 55A0 while recording at various sample rates are provided below.

Table 7 Impedance Variation with Sample Rate, Affinity 55A0, Temperature 20° C

Sample Rate	Channel 1	Channel 2	Channel 3
4 sps	113.5027 Kohm	113.5063 Kohm	113.5043 Kohm
20 sps	113.5027 Kohm	113.5063 Kohm	113.5043 Kohm
40 sps	113.5027 Kohm	113.5063 Kohm	113.5043 Kohm
100 sps	113.5027 Kohm	113.5063 Kohm	113.5043 Kohm
200 sps	113.5027 Kohm	113.5063 Kohm	113.5043 Kohm

All sample rates were recorded simultaneously, hence only one measurement of impedence for each channel was made.

All dataloggers had very consistent measured impedance values. Under all test configurations all dataloggers remained from 0.44% to 0.45% higher than the specification of 113 kOhm provided by the manufacturer.

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 DC offset in volts and the 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.

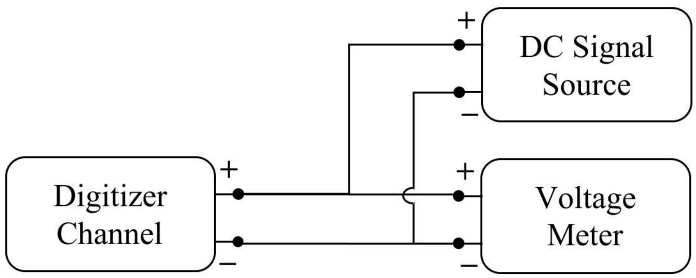

Figure 16 DC Accuracy Configuration Diagram

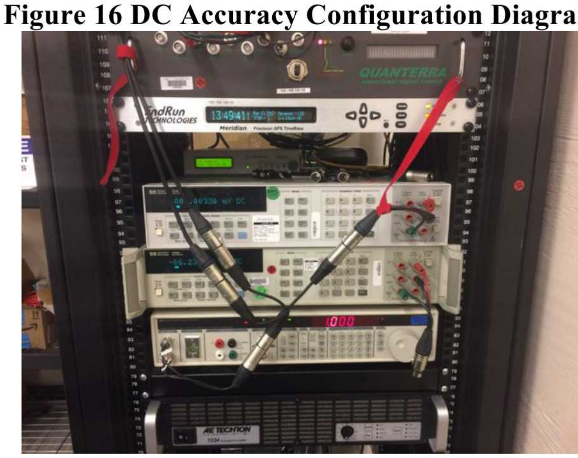

Figure 17 DC Accuracy Configuration

Table 8 DC Accuracy Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
DC Signal Source - Bunker	Stanford Research Systems DS360	123672	+1V / - 1 V
Voltage Meter - Bunker	Agilent 3458A	MY45048372	1 V full scale
Voltage Meter – Bunker*	Agilent 3458A	MY45048371	1 V full scale
DC Signal Source - SB1	Stanford Research Systems DS360	123669	+1V / - 1 V
Voltage Meter - SB1	Agilent 3458A	2823A10915	1 V full scale
Voltage Meter - SB1**	Agilent 3458A	Y45048372	1 V full scale

* Meter MY450448371, while installed in the bunker, was utilized for the DC accuracy measurements under the following conditions: all dataloggers at 23° C gain.
** Meter MY450448372, while installed in SB1, was utilized for the DC accuracy measurements under the following conditions: gain x2 and x4 at a temperature of 20° C; gain x1 at temperatures of -36° C, -25° C, 60° C.

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:

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

The digitizer DC offset is computed:

$$DC\ Offset = Bitweight * \frac{(C_{pos} + C_{neg})}{2}$$

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.

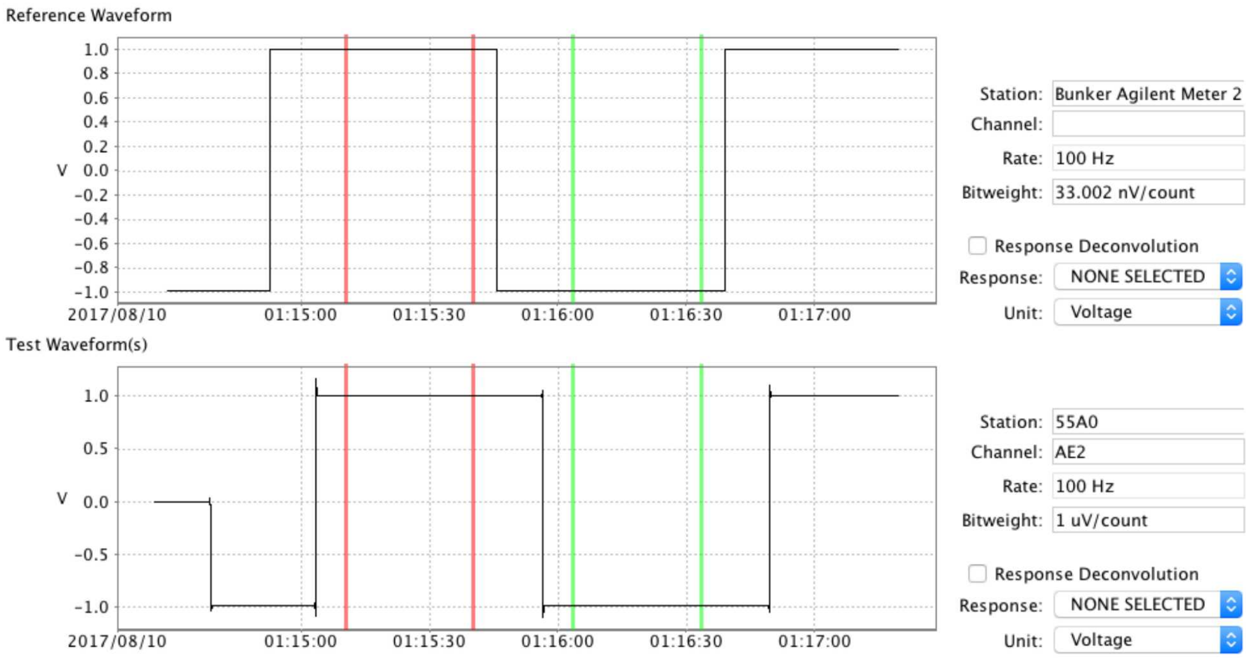

Figure 18 DC Accuracy Test Time series, Affinity 55A1, Channel AE2 (Channel 3)

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

Table 9 DC Accuracy Bitweight, All Affinity DWR at 23° C

DWR	AE2 (Channel 3)	AN2 (Channel 2)	AZ2 (Channel 1)
55A1	0.9995 uV/count	0.9995 uV/count	0.9994 uV/count
559A	0.9995 uV/count	0.9995 uV/count	0.9995 uV/count
559B	0.9996 uV/count	0.9995 uV/count	0.9996 uV/count
55A0	0.9996 uV/count	0.9996 uV/count	0.9996 uV/count

The nominal bit weights provided by Guralp Systems were specified to be 1 uV/count.

The differences between the observed bit weights at 23° C and the nominal value provided by the manufacturer are consistently from 0.04% to 0.06% lower than nominal.

Table 10 DC Accuracy Bitweight, Affinity 55A0 at Select Temperatures and Gains

Temperature	AE2 (Channel 3)	AN2 (Channel 2)	AZ2 (Channel 1)
60° C	0.9997 uV/count	0.9997 uV/count	0.9997 uV/count
20° C	0.9995 uV/count	0.9995 uV/count	0.9995 uV/count
20° C, 2x gain	0.5000 uV/count	0.5001 uV/count	0.5001 uV/count
20° C, 4x gain	0.2501 uV/count	0.2500 uV/count	0.2501 uV/count
-25° C	0.9993 uV/count	0.9993 uV/count	0.9993 uV/count
-36° C	0.9992 uV/count	0.9992 uV/count	0.9992 uV/count

Over the selected temperature range, the bitweights of Affinity 55A0, decreased with temperature, ranging from 0.03% to 0.08% below the nominal bit weight. Bitweights also varied as gain settings varied. At a gain of 1x, bitweights were below nominal by no more than 0.05% ; at 2x gain, bitweights were no more than 0.02% greater than the nominal bit weight of 0.5 uV/count; and at 4x gain, bitweights where no more than 0.04% greater than the nominal bitweight of 0.25 uV/count.

Table 11 DC Accuracy Bitweight, Affinity 55A0 at Select Sample Rates, 20° C

Sample Rate	Channel 3	Channel 2	Channel 1
4 sps	0.9995 uV/count	0.9995 uV/count	0.9995 uV/count
20 sps	0.9995 uV/count	0.9996 uV/count	0.9995 uV/count
40 sps	0.9995 uV/count	0.9996 uV/count	0.9995 uV/count
100 sps	0.9995 uV/count	0.9996 uV/count	0.9995 uV/count
200 sps	0.9995 uV/count	0.9996 uV/count	0.9995 uV/count

Across the selected sample rates, bit weights remained nearly constant, between 0.04% and 0.05% below the nominal bitweight of 1 uV/count.

Across selected sample rates, gains and temperatures, bit weights remained very stable, varying no more than 0.08% (at a temperature of -36° C) from the respective nominal bitweight.

3.4 AC Accuracy

The AC Accuracy test is used to measure the bitweight 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 bitweight in volts/count and DC offset 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.

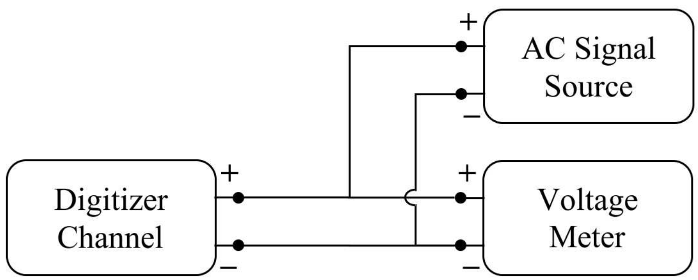

Figure 19 AC Accuracy Configuration Diagram

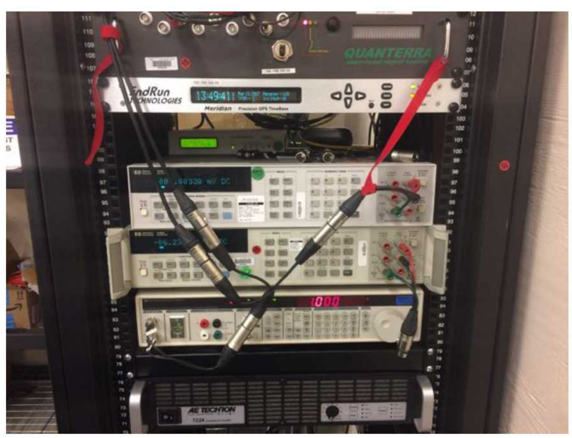

Figure 20 AC Accuracy Configuration Picture

Table 8 AC Accuracy Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
DC Signal Source - Bunker	Stanford Research Systems DS360	123672	+1V / - 1 V
Voltage Meter - Bunker	Agilent 3458A	MY45048372	1 V full scale
Voltage Meter - Bunker*	Agilent 3458A	MY45048371	1 V full scale
DC Signal Source - SB1	Stanford Research Systems DS360	123669	+1V / - 1 V
Voltage Meter - SB1	Agilent 3458A	2823A10915	1 V full scale
Voltage Meter - SB1**	Agilent 3458A	MY45048372	1 V full scale

* Meter MY450448371, while installed in the bunker, was utilized for the AC accuracy measurements under the following conditions: all dataloggers at 23° C gain.
** Meter MY450448372, while installed in SB1, was utilized for the AC accuracy measurements under the following conditions: gain x2 and x4 at a temperature of 20° C; gain x1 and temperatures at -36° C, -25° C, 60° C.

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 a 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.

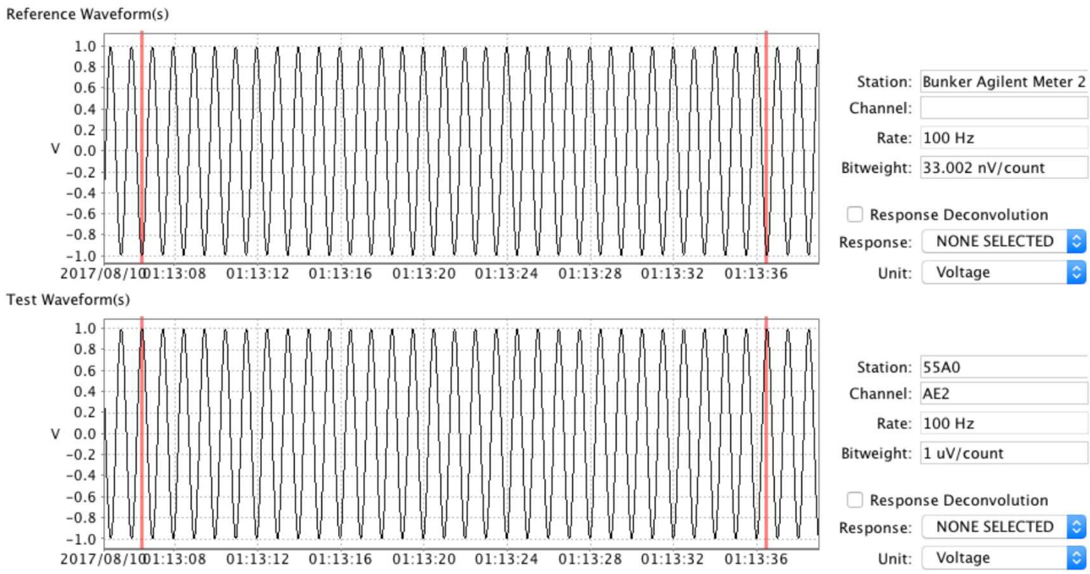

Figure 21 AC Accuracy Time Series

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

Table 9 AC Accuracy Bitweight, All Affinitys at 23° C

DWR	AE2 (Channel 3)	AN2 (Channel 2)	AZ2 (Channel 1)
55A1	0.9996 uV/count	0.9996 uV/count	0.9995 uV/count
559A	0.9996 uV/count	0.9996 uV/count	0.9996 uV/count
559B	0.9996 uV/count	0.9996 uV/count	0.9997 uV/count
55A0	0.9997 uV/count	0.9997 uV/count	0.9997 uV/count

Bit weights across dataloggers remained within 0.05% to 0.03% of the nominal bitweight of 1 uV/count.

Table 10 AC Accuracy Bitweight, Affinity 55A0, at Select Temperatures and Gains

Temperature	AE2 (Channel 3)	AN2 (Channel 2)	AZ2 (Channel 1)
60° C	0.9998 uV/count	0.9998 uV/count	0.9998 uV/count
20° C	0.9996 uV/count	0.9996 uV/count	0.9996 uV/count
20° C, gain 2x	0.5001 uV/count	0.5001 uV/count	0.5001 uV/count
20° C, gain 4x	0.2502 uV/count	0.2501 uV/count	0.2501 uV/count
-25° C	0.9994 uV/count	0.9994 uV/count	0.9994 uV/count
-36° C	0.9993 uV/count	0.9993 uV/count	0.9993 uV/count

Over the selected temperature range, the bitweights of Affinity 55A0 decreased with temperature, staying within 0.02% to 0.07% of the nominal bit weight. Bitweights also varied as gain settings varied, divergence from nominal increasing slightly with gain: at a gain of 1x, bitweights were below nominal by 0.04%, at 2x gain bitweights were above the nominal of 0.5 uV/count by 0.02% and at 4x gain bitweights where above the nominal of 0.25 uV/count by 0.04% to 0.08%.

Table 11 AC Accuracy Bitweight, Affinity 55A0, at Select Sample Rates, 20° C

Sample Rate	Channel 3	Channel 2	Channel 1
4 sps	0.9998 uV/count	0.9998 uV/count	0.9998 uV/count
20 sps	0.9998 uV/count	0.9998 uV/count	0.9998 uV/count
40 sps	0.9996 uV/count	0.9996 uV/count	0.9996 uV/count
100 sps	0.9996 uV/count	0.9996 uV/count	0.9996 uV/count
200 sps	0.9995 uV/count	0.9995 uV/count	0.9995 uV/count

As with DC Accuracy Tests, bitweights remained very near the respective nominal bitweight over the temperatures and sample rates evaluated, never diverging more than 0.08% (at a gain of 4x) of the respective nominal bitweight.

3.5 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.

3.5.1 Measurand

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

3.5.2 Configuration

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

Figure 22 Input Shorted Offset Configuration Diagram

Figure 23 Input Shorted Offset Terminators Picture

Table 12 Input Shorted Offset Testbed Equipment

Digitizer	Resistor load
Guralp Systems Affinity	200 Ohm (2x100 Ohm)

Approximately 7 hours of data are recorded for tests of all units at 23° C, while at select temperatures 1 hour duration windows are used for the analysis.

3.5.3 Analysis

The measured bitweight, 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:

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

3.5.4 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.

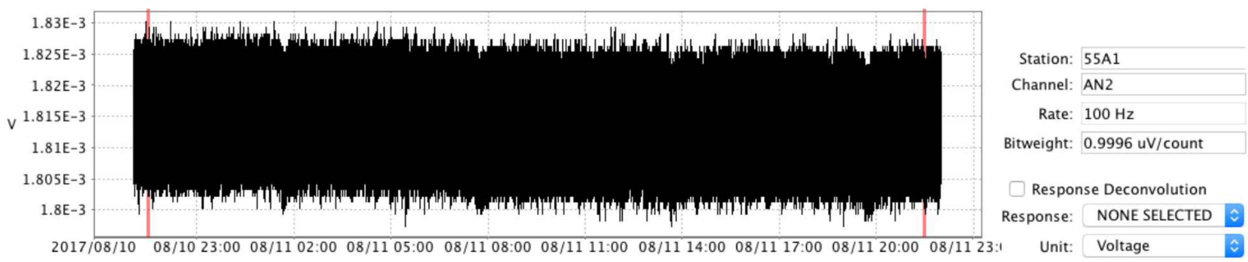

Figure 24 Input Shorted Offset Time Series

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

Table 13 Input Shorted Offset, All Affinitys, 23° C

DWR	AE2 (Channel 3)	AN2 (Channel 2)	AZ2 (Channel 1)
55A1	-1.932 mV	1.815 mV	0.2367 mV
559A	0.9204 mV	-1.798 mV	-0.3168 mV
559B	-0.03260 mV	-2.254 mV	1.275 mV
55A0	-1.2572 mV	-0.0182 mV	0.1964 mV

The maximum offset observed across dataloggers is -0.0113% of full-scale, observed on datalogger 559B, channel AN2 (channel 2).

Table 14 Input Shorted Offset, Affinity 55A0, at Select Temperatures and Gains

Temperature	AE2 (Channel 3)	AN2 (Channel 2)	AZ2 (Channel 1)
60° C	-1.933 mV	-0.6854 mV	-0.4630 mV
20° C	-1.239 mV	-0.003079 mV	0.2108 mV
20° C, gain 2x	-0.4811 mV	0.1488 mV	0.2503 mV
20° C, gain 4x	-0.2481 mV	0.08039 mV	0.1265 mV
- 25° C	0.03181 mV	1.255 mV	1.460 mV
- 36° C	0.2950 mV	1.515 mV	1.718 mV

The maximum offset of datalogger 55A0 across all evaluated temperatures is -1.933 mV, or 0.0097% of full scale, was observed at 60° C on channel 3. This offset was also the highest observed across all gain configurations evaluated.

Table 15 Input Shorted Offset Affinity 55A0 at Select Sample Rates, 20° C

Sample Rate	Channel 3	Channel 2	Channel 1
4 sps	-1.240 mV	-0.003088 mV	0.2108 mV
20 sps	-1.240 mV	-0.003089 mV	0.2108 mV
40 sps	-1.239 mV	-0.003084 mV	0.2108 mV
100 sps	-1.239 mV	-0.003079 mV	0.2108 mV
200 sps	-1.239 mV	-0.003084 mV	0.2108 mV

The maximum observed input shorted offset 1.933 mV or 0.0097% of full scale, occurred on channel 3 at 60° C. Minimum input shorted offset voltages occurred generally at mid temperatures (20° C or -25° C), rather than at either of the extremes (60° C or -36° C).

3.6 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.

3.6.1 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.

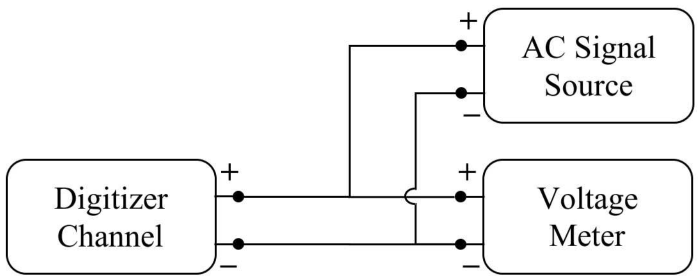

Figure 25 AC Full Scale Configuration Diagram

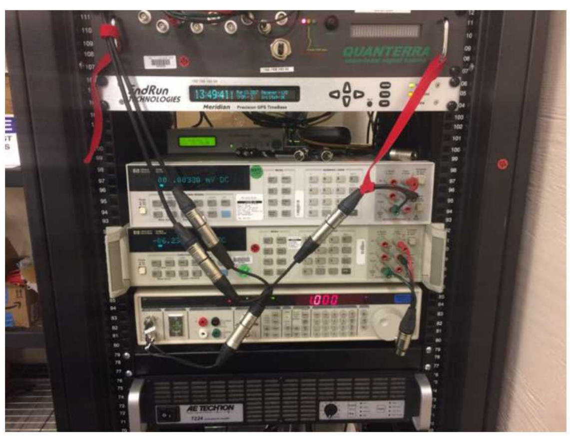

Figure 26 AC Full Scale Configuration Picture

Table 16 AC Full Scale Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
DC Signal Source - Bunker	Stanford Research Systems DS360	123672	+1V / - 1 V
Voltage Meter - Bunker	Agilent 3458A	MY45048371	1 V full scale
DC Signal Source - SB1	Stanford Research Systems DS360	123669	+1V / - 1 V
Voltage Meter - SB1	Agilent 3458A	MY45048372	1 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.

3.6.3 Analysis

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

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

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.

3.6.4 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.

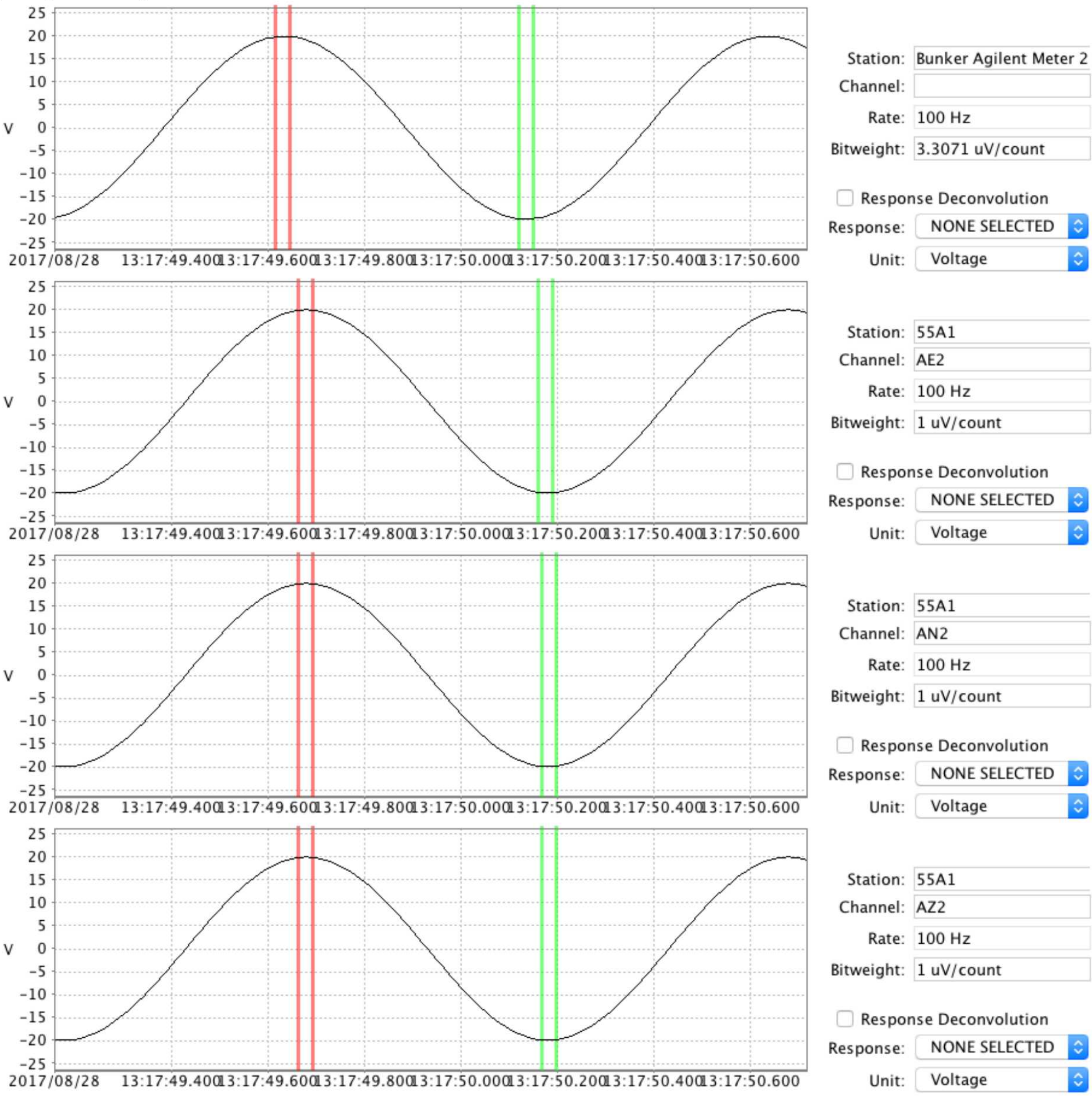

Figure 27 AC Full Scale Time Series, Affinity 55A0

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

DWR	Temperature/ Sample Rate	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
55A1	23° C	19.8952 V	19.8988 V	19.8991 V
559A	23° C	19.8898 V	19.8871 V	19.8885 V
559B	23° C	19.8876 V	19.8854 V	19.8890 V
55A0	23° C	19.8873 V	19.8887 V	19.8888 V
55A0	60° C	19.9374 V	19.9383 V	19.9388 V
55A0	20° C	19.9517 V	19.9531 V	19.9532 V
55A0	20° C (gain 2x)	9.9688 V	9.9694 V	9.9695 V
55A0	20° C (gain 4x)	4.9795 V	4.9798 V	4.9799 V
55A0	-25° C	19.9532 V	19.9553 V	19.9546 V
55A0	-36° C	19.9557 V	19.9579 V	19.9571 V
55A0	4 sps	17.4424 V	17.4437 V	17.4439 V
55A0	20 sps	19.8084 V	19.8097 V	19.8099 V
55A0	40 sps	19.9376 V	19.9388 V	19.9391 V
55A0	200 sps	19.9508 V	19.9520 V	19.9523 V

Table 18 AC Full Scale Negative Peak

DWR	Temperature/ Sample Rate	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
55A1	23° C	-19.9475 V	-19.9436 V	-19.9471 V
559A	23° C	-19.9363 V	-19.9391 V	-19.9376 V
559B	23° C	-19.9340 V	-19.9362 V	-19.9327 V
55A0	23° C	-19.9399 V	-19.9388 V	-19.9385 V
55A0	60° C	-19.9579 V	-19.9562 V	-19.9564 V
55A0	20° C	-19.9652 V	-19.9642 V	-19.9638 V
55A0	20° C (gain 2x)	-9.9889 V	-9.9882 V	-9.9881 V
55A0	20° C (gain 4x)	-5.0014 V	-5.0011 V	-5.0011 V
55A0	-25° C	-19.9680 V	-19.9677 V	-19.9666 V
55A0	-36° C	-19.9615 V	-19.9613 V	-19.9600 V
55A0	4 sps	-17.3506 V	-17.3494 V	-17.3492 V
55A0	20 sps	-19.8401 V	-19.8389 V	-19.8387 V
55A0	40 sps	-19.9466 V	-19.9453 V	19.9391 V
55A0	200 sps	-19.9644 V	-19.9631 V	-19.9630 V

Table 19 AC Full Scale Peak-to-Peak

DWR	Temperature/ Sample Rate	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
55A1	23° C	39.8427 V	39.8424 V	39.8462 V
559A	23° C	39.8261 V	39.8262 V	39.8261 V
559B	23° C	39.8216 V	39.8217 V	39.8217 V
55A0	23° C	39.8272 V	39.8274 V	39.8273 V
55A0	60° C	39.8952 V	39.8945 V	39.8952 V
55A0	20° C	39.9169 V	39.9173 V	39.9170 V
55A0	20° C (gain 2x)	19.9576 V	19.9576 V	19.9576 V
55A0	20° C (gain 4x)	9.9809 V	9.9809 V	9.9809 V
55A0	-25° C	39.9213 V	39.9229 V	39.9212 V
55A0	-36° C	39.8952 V	39.8945 V	39.8952 V
55A0	4 sps	34.7930 V	34.7931 V	34.7931 V
55A0	20 sps	39.6485 V	39.6485 V	39.6486 V
55A0	40 sps	39.8841 V	39.8842 V	39.8842 V
55A0	200 sps	39.9152 V	39.9152 V	39.9152 V

For all sample rates and gain levels, the digitizer 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.

3.7 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.

3.7.1 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.

3.7.2 Configuration

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

Figure 28 Self Noise Configuration Diagram

Figure 29 Self Noise Configuration Picture

Table 20 Self Noise Testbed Equipment

	Impedance
Resistor	200 ohm (2 x 100 Ohm)

24 hours of data are generally utilized for this test.

3.7.3 Analysis

The measured bit-weight at 1 Hz, from Section 3.4, AC Accuracy, is applied to the collected data:

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

The PSD is computed (Merchant, 2011) from the time series using a Hann window of length 4k, 8k, and 16k for the 20 Hz, 40 Hz, and 100 Hz sample rates, respectively. The window length and data duration were chosen such that there were several points below the lower limit of the evaluation pass-band of 0.01 Hz and the 90% confidence interval is less than 0.5 dB.

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

Over frequencies (in Hertz):

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

The noise level PSD in V^2/Hz are compared to the theoretical levels of quantization noise in an ideal analog to digital converter in order to determine the number of effective noise free bits:

$$Spectral\ Noise = \left(\frac{(2 * V_{FS}/2^B)^2}{12 * F_s/2}\right)$$

Where:

$Spectral\ Noise$	= Units of V^2/Hz
V_{FS}	= Digitizer peak full scale in Volts
B	= Number of ideal bits of resolution
F_s	= Sampling frequency in Hertz

In addition, the total RMS noise is calculated over an application pass-band:

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

where $f[n]$ and $f[m]$ are the passband limits, T_s is the sampling period in seconds, and L is window length.

3.7.4 Result

The figures below show the 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.

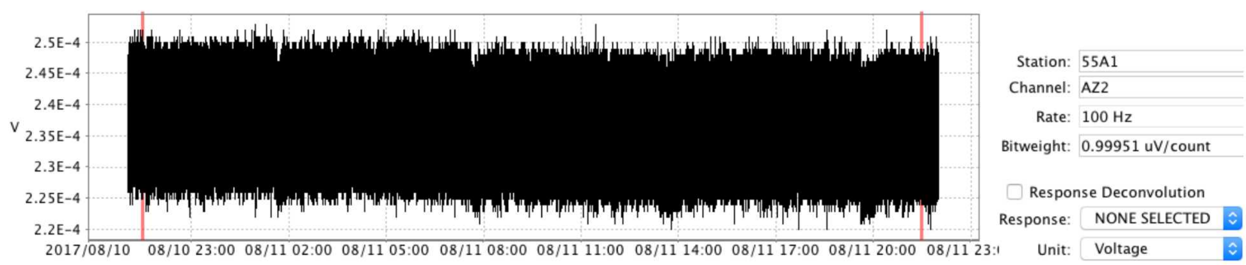

Figure 30 Self Noise Time Series Example, Affinity 55A1, AZ2 (Channel 1)

Plots of power spectra and tables of RMS noise levels are organized as follows:

- each datalogger recording at 100 sps at a temperature of 23° C.
- SN 55A0 at varying sample rates (4, 20, 40, 100 and 200) while exposed to 20° C.
- SN 55A0 recording at 100 sps, while exposed at temperatures of 60° C, 20° C, -25° C and -36° C (the lowest temperature possible with our environmental chamber.
- SN 55A0 gain set to 2x and 4x, recording at 100 Hz and exposed to 20° C.

The computed self noise of all dataloggers while exposed to 23° C follows. The data window is 24 hrs long and the computation has 90% confidence level of 0.43 dB in all cases.

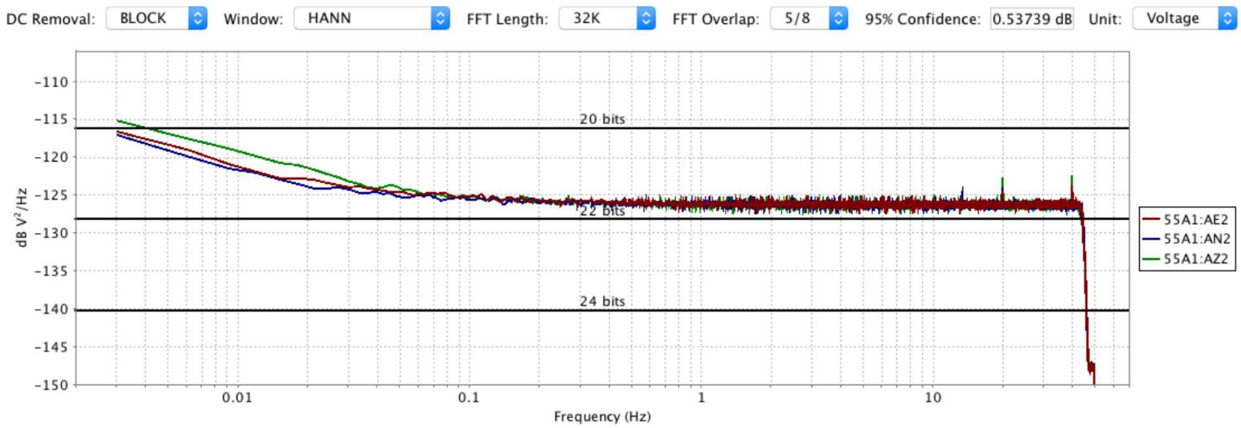

Figure 31 Self Noise Power Spectra Affinity 55A1, 100 sps, 23° C

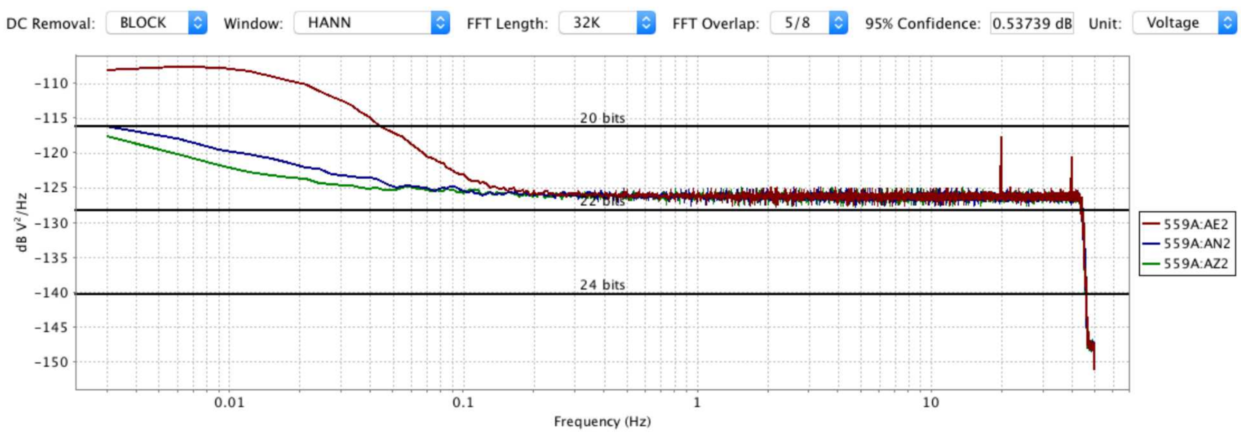

Figure 32 Self Noise Power Spectra Affinity 559A, 100 sps, 23° C

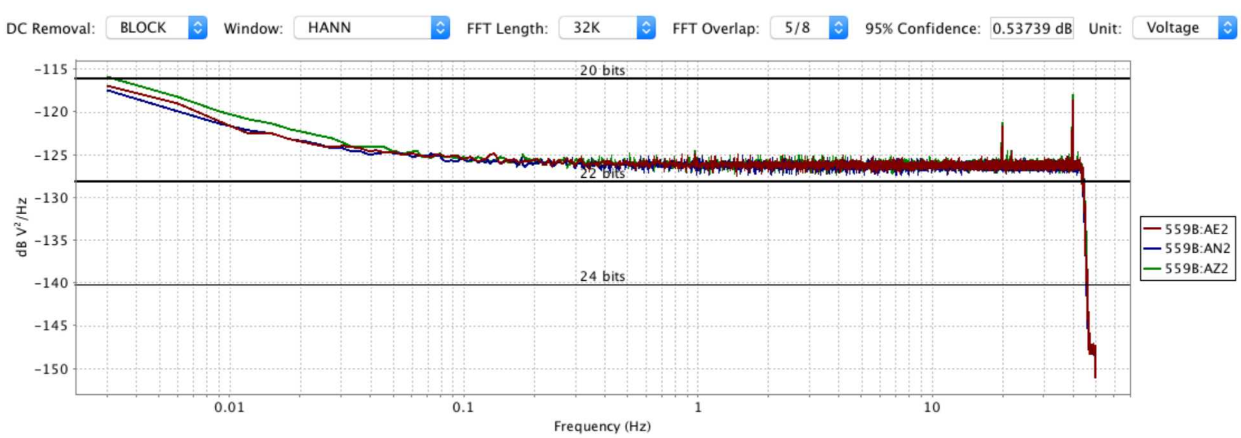

Figure 33 Self Noise Power Spectra Affinity 559B, 100 sps, 23° C

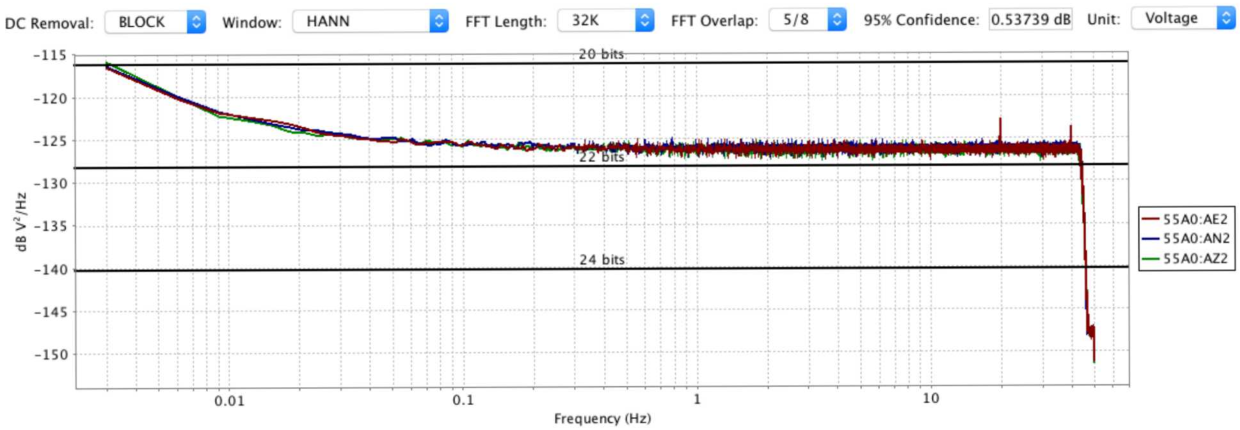

Figure 34 Self Noise Power Spectra Affinity 55A0, 100 sps, 23° C

Channel AE2 on datalogger 559A has increased noise over the other channels at lower frequencies: 2.2 dB at 0.1 Hz to has much as 8.0 dB over channel AN2 at 0.012 Hz.

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

Table 21 Self Noise RMS over 0.02 Hz – 1 Hz at 23° C, all DWR

DWR	AE2 (Channel 3)	AN2 (Channel 2)	AZ2 (Channel 1)
55A1	503.21 nV rms	494.46 nV rms	499.82 nV rms
	0.50 counts rms	0.49 counts rms	0.50 counts rms
559A	645.64 nV rms	496.89 nV rms	490.03 nV rms
	0.65 counts rms	0.50 counts rms	0.49 counts rms
559B	499.50 nV rms	489.90 nV rms	503.44 nV rms
	0.50 counts rms	0.49 counts rms	0.50 counts rms
55A0	489.34 nV rms	496.69 nV rms	487.03 nV rms
	0.49 counts rms	0.50 counts rms	0.49 counts rms

Table 22 Self Noise RMS over 0.5 Hz – 16 Hz at 23° C, all DWR

DWR	AE2 (Channel 3)	AN2 (Channel 2)	AZ2 (Channel 1)
55A1	1908.82 nV rms	1898.76 nV rms	1894.12 nV rms
	1.91 counts rms	1.90 counts rms	1.90 counts rms
559A	1898.53 nV rms	1888.47 nV rms	1882.48 nV rms
	1.90 counts rms	1.89 counts rms	1.88 counts rms
559B	1905.31 nV rms	1876.27 nV rms	1916.89 nV rms
	1.91 counts rms	1.88 counts rms	1.92 counts rms
55A0	1879.29 nV rms	1916.20 nV rms	1871.71 nV rms
	1.88 counts rms	1.92 counts rms	1.87 counts rms

Table 23 Self Noise RMS over 0.02 Hz – 16 Hz at 23° C, all DWR

DWR	AE2 (Channel 3)	AN2 (Channel 2)	AZ2 (Channel 1)
55A1	1942.92 nV rms	1931.33 nV rms	1928.20 nV rms
	1.94 counts rms	1.93 counts rms	1.93 counts rms
559A	1975.14 nV rms	1922.11 nV rms	1914.54 nV rms
	1.98 counts rms	1.92 counts rms	1.92 counts rms
559B	1938.56 nV rms	1908.56 nV rms	1950.75 nV rms
	1.94 counts rms	1.91 counts rms	1.95 counts rms
55A0	1911.56 nV rms	1948.72 nV rms	1903.80 nV rms
	1.91 counts rms	1.95 counts rms	1.90 counts rms

Average self noise over all channels at 23° C are as follows: over the low passband 508.00 nV rms (~ 0.5 counts rms), over the high passband 1894.74 nV rms (less than 2 counts rms) and over the broad passband 1931.35 nV rms (less than 2 counts rms). Self noise values remained relatively consistent within the high and broad passbands, within 1.22% and 2.27% of the average across all dataloggers and channels respectively, however channel 3 (AE2) of datalogger 559A had an elevated self noise of 645.64 nV, 27.1% above the average self noise in lower passband.

Self noise noise spectra plots and tables, containing the computed RMS noise levels in both volts and counts, follow for each of the evaluated temperatures. Passbands consistent with the requirements for seismic applications were selected.

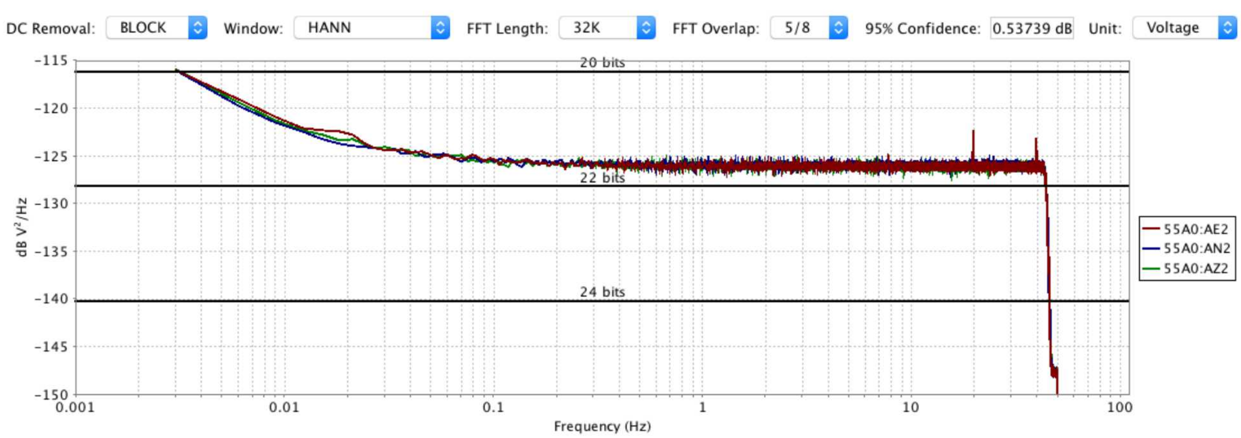

Figure 35 Self Noise Power Spectra Affinity 55A0, 100 sps, 60° C

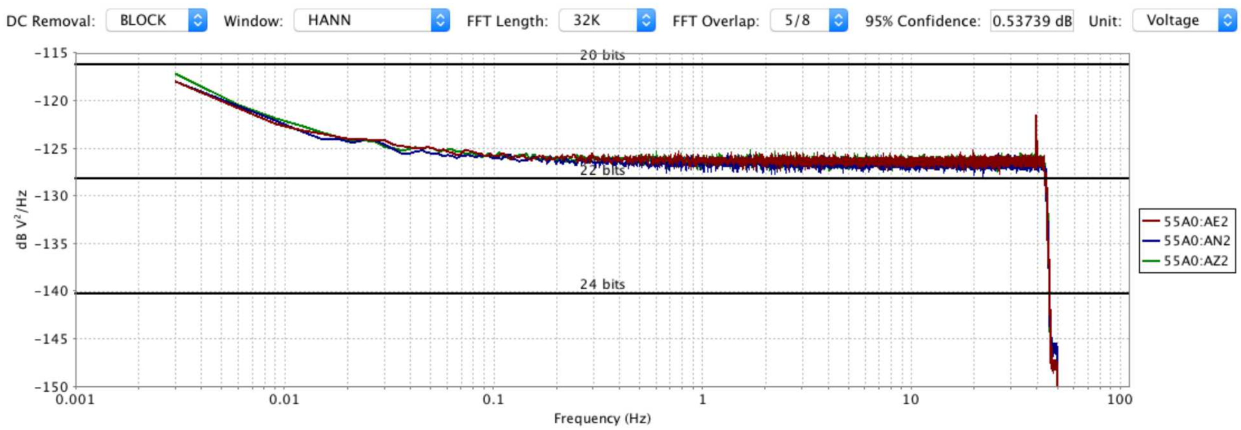

Figure 36 Self Noise Power Spectra Affinity 55A0, 100 sps, 20° C

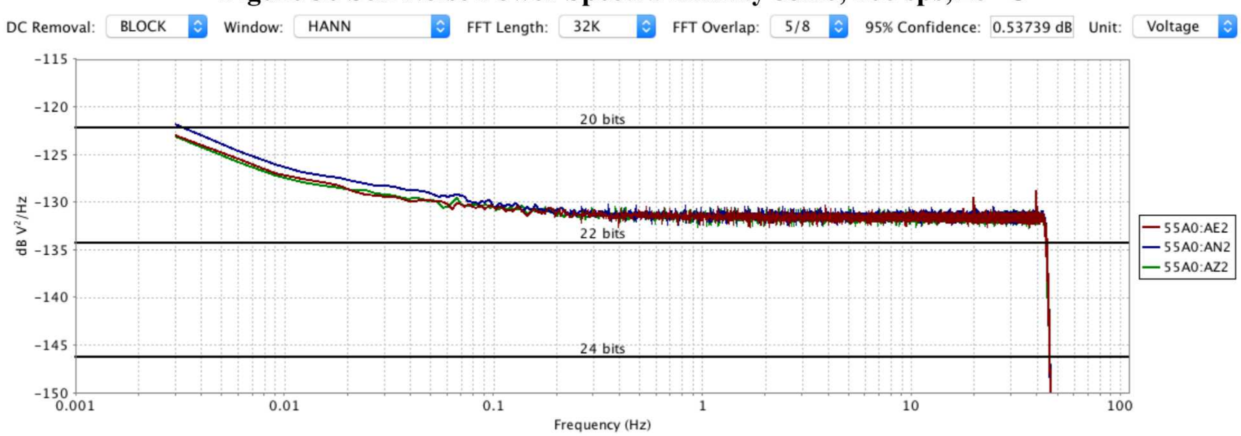

Figure 37 Self Noise Power Spectra Affinity 55A0, 100 sps, 20° C, Gain 2x

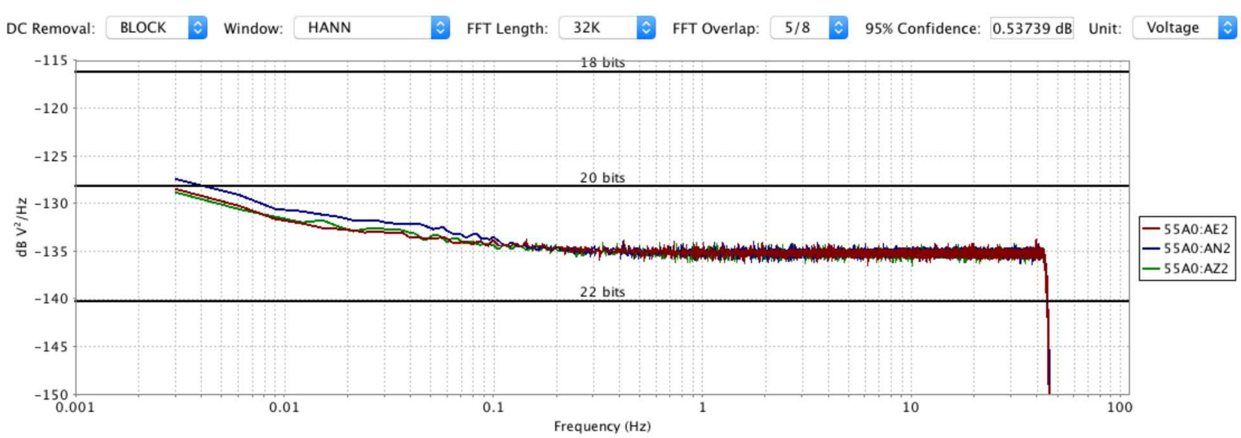

Figure 38 Self Noise Power Spectra Affinity 55A0, 100 sps, 20° C, Gain 4x

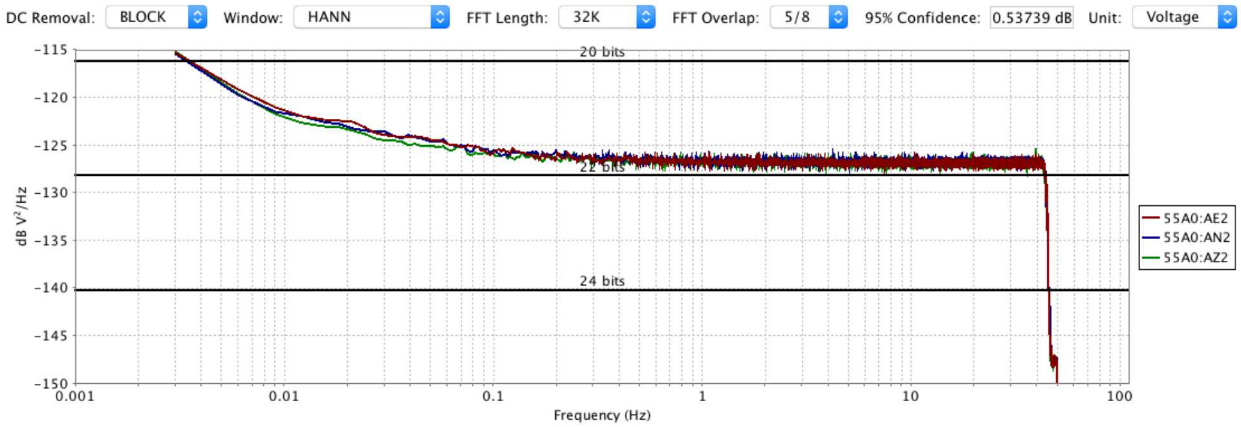

Figure 39 Self Noise Power Spectra Affinity 55A0, 100 sps, -25° C

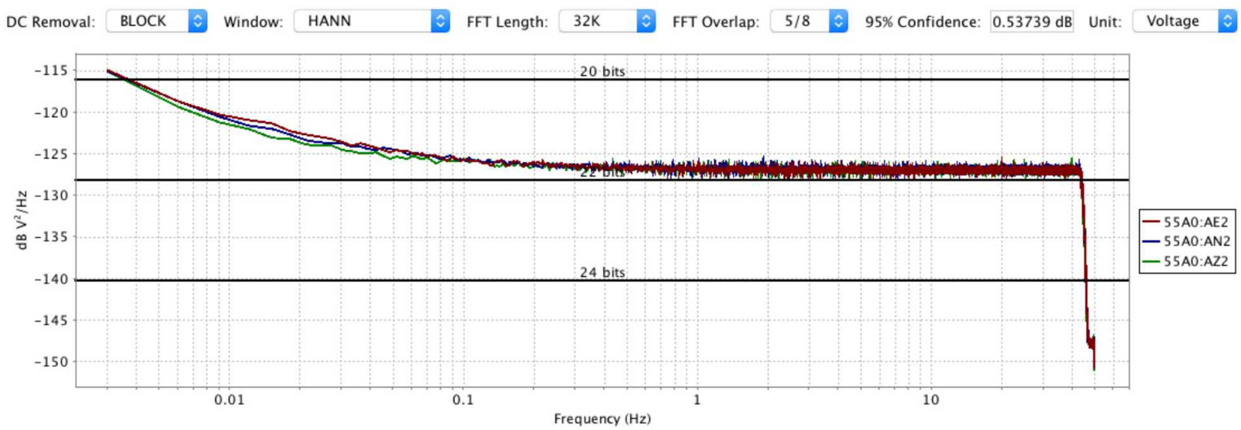

Figure 40 Self Noise Power Spectra Affinity 55A0, 100 sps, -36° C

Table 24 Self Noise RMS, Affinity 55A0, 0.02 Hz–1.0 Hz, at Select Temperatures

Temperature	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
60° C	499.52 nV rms	505.55 nV rms	498.64 nV rms
	0.50 counts rms	0.51 counts rms	0.50 counts rms
20° C	489.53 nV rms	470.25 nV rms	486.47 nV rms
	0.49 counts rms	0.47 counts rms	0.49 counts rms
20° C gain 2x	270.56 nV rms	277.85 nV rms	271.01 nV rms
	0.54 counts rms	0.56 counts rms	0.54 counts rms
20° C gain 4x	177.82 nV rms	180.50 nV rms	175.98 nV rms
	0.71 counts rms	0.72 counts rms	0.70 counts rms
-25° C	473.90 nV rms	479.60 nV rms	466.70 nV rms
	0.47 counts rms	0.48 counts rms	0.47 counts rms
-36° C	468.94 nV rms	470.57 nV rms	461.75 nV rms
	0.47 counts rms	0.47 counts rms	0.46 counts rms

Table 25 Self Noise RMS, Affinity 55A0, 0.5 Hz – 16 Hz, at Select Temperatures

Temperature	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
60° C	1930.77 nV rms	1956.59 nV rms	1926.81 nV rms
	1.93 counts rms	1.96 counts rms	1.93 counts rms
20° C	1876.03 nV rms	1812.08 nV rms	1872.55 nV rms
	1.88 counts rms	1.81 counts rms	1.87 counts rms
20° C gain 2x	1031.47 nV rms	1047.04 nV rms	1027.67 nV rms
	2.06 counts rms	2.09 counts rms	2.05 counts rms
20° C gain 4x	676.19 nV rms	681.74 nV rms	673.83 nV rms
	2.70 counts rms	2.73 counts rms	2.69 counts rms
-25° C	1770.04 nV rms	1798.05 nV rms	1768.48 nV rms
	1.77 counts rms	1.80 counts rms	1.77 counts rms
-36° C	1747.11 nV rms	1773.80 nV rms	1747.74 nV rms
	1.75 counts rms	1.77 counts rms	1.75 counts rms

Table 26 Self Noise RMS, Affinity 55A0, 0.02 Hz – 16 Hz, at Select Temperatures

Temperature	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
60° C	1963.51 nV rms	1989.33 nV rms	1959.17 nV rms
	1.96 counts rms	1.99 counts rms	1.96 counts rms
20° C	1908.15 nV rms	1842.97 nV rms	1904.52 nV rms
	1.91 counts rms	1.84 counts rms	1.91 counts rms
20° C gain 2x	1049.58 nV rms	1066.34 nV rms	1046.02 nV rms
	2.10 counts rms	2.13 counts rms	2.09 counts rms
20° C gain 4x	688.16 nV rms	694.27 nV rms	685.63 nV rms
	2.75 counts rms	2.78 counts rms	2.74 counts rms
-25° C	1803.30 nV rms	1831.37 nV rms	1800.03 nV rms
	1.80 counts rms	1.83 counts rms	1.80 counts rms
-36° C	1780.16 nV rms	1806.31 nV rms	1779.10 nV rms
	1.78 counts rms	1.81 counts rms	1.78 counts rms

Average self noise across all channels and temperatures (gain 1x) were as follows for the low, high and broad passbands: 480.95 nV rms, 1831.67 nV rms and 1863.99 nV rms. Self noise varied no more than 5.11%, 6.82% and 6.72% in the low, high and broad passbands respectively. Self noise levels decreased with temperature in all pass bands, with the exception of AN2 (channel2) in the low passband at -25° C where self noise increased slightly to 479.60 nV rms.

Next are the power spectra of the data collected at varying sample rates, from high to low sample rates, for datalogger 55A0, where: duration is 24 hours; FFT length varies with sample rate, 90% confidence values vary from 0.43 dB to 0.54 dB (4 Hz sample rate).

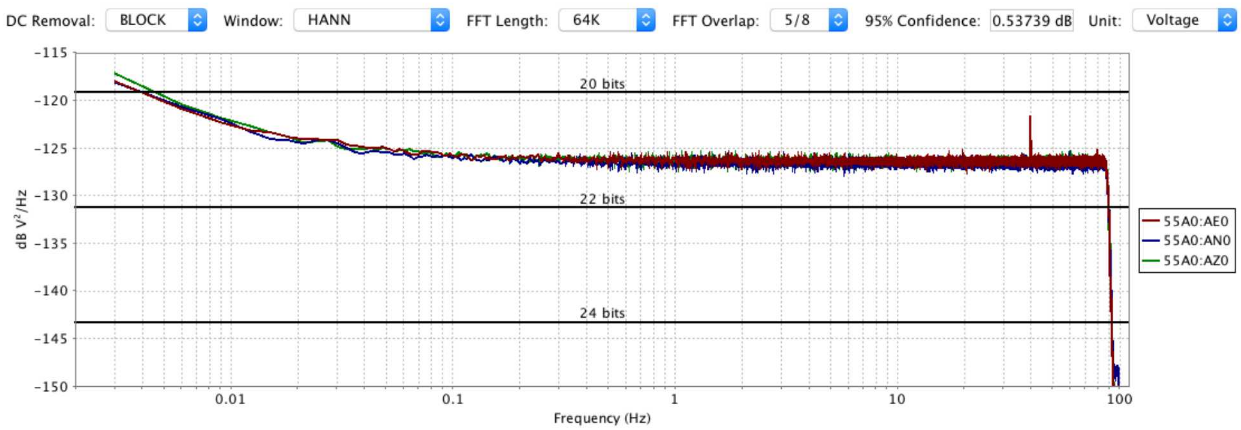

Figure 41 Self Noise Power Spectra Affinity 55A0, 200 sps, 20° C

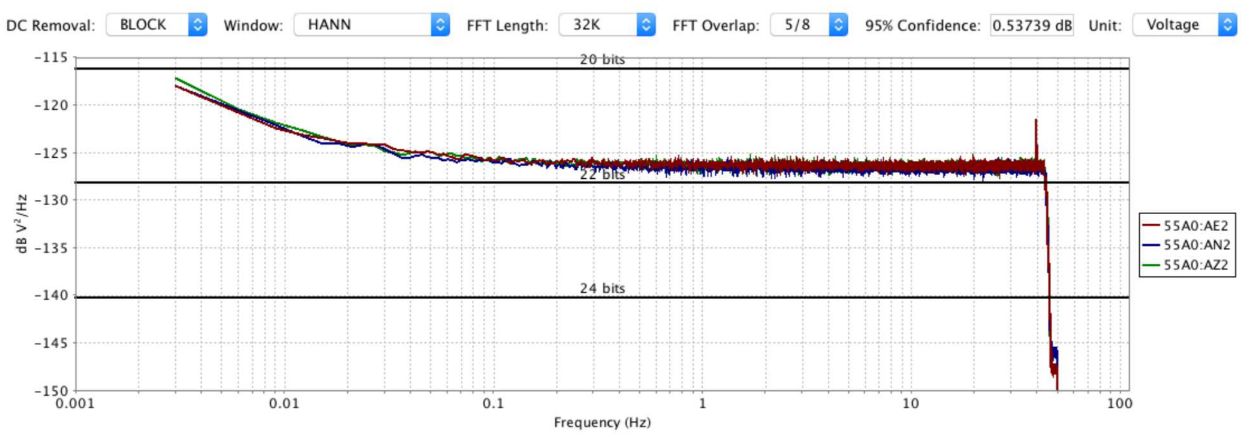

Figure 42 Self Noise Power Spectra Affinity 55A0, 100 sps, 20° C

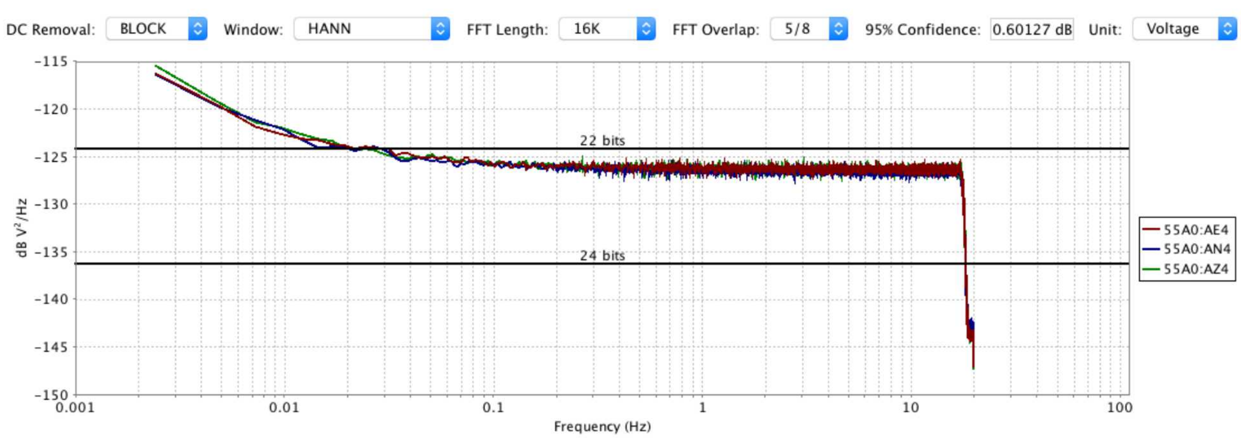

Figure 43 Self Noise Power Spectra Affinity 55A0, 40 sps, 20° C

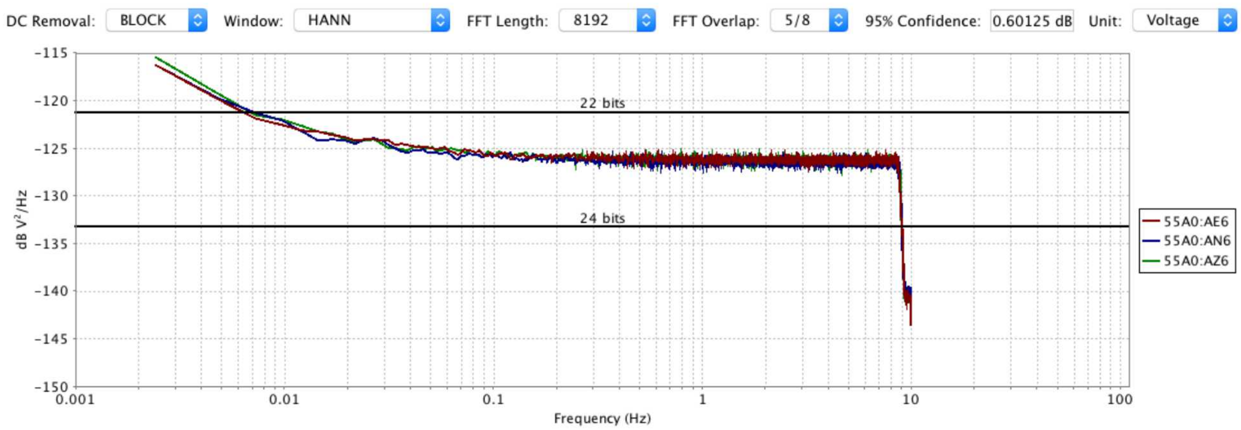

Figure 44 Self Noise Power Spectra Affinity 55A0, 20 sps, 20° C

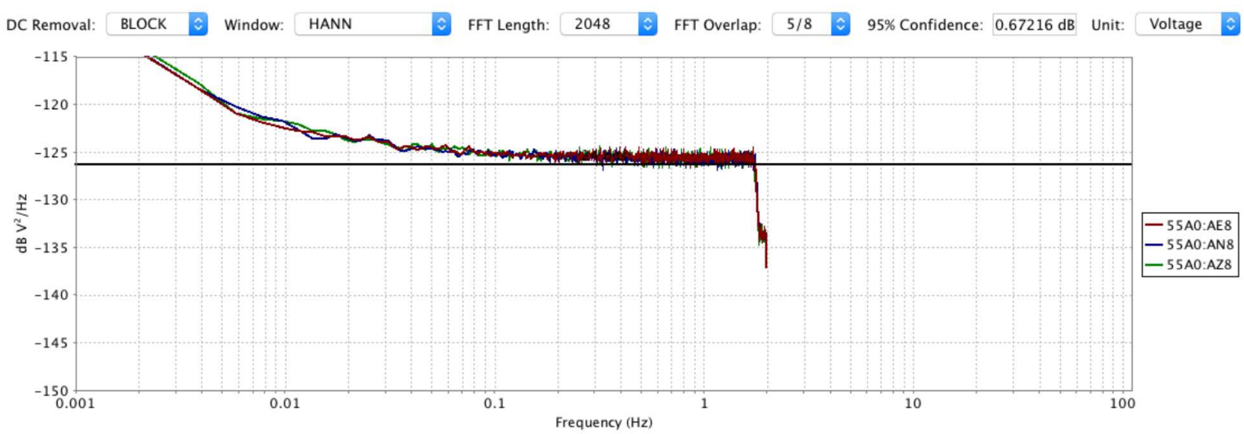

Figure 45 Self Noise Power Spectra Affinity 55A0, 4 sps, 20° C

Table 27 Self Noise RMS, Affinity 55A0, 0.02 Hz – 1 Hz, at Select Sample Rates

Sample Rate	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
4 sps	527.14 nV rms	520.01 nV rms	524.18 nV rms
	0.53 counts rms	0.52 counts rms	0.52 counts rms
20 sps	495.76 nV rms	477.51 nV rms	492.52 nV rms
	0.50 counts rms	0.48 counts rms	0.49 counts rms
40 sps	491.70 nV rms	477.06 nV rms	488.38 nV rms
	0.49 counts rms	0.48 counts rms	0.49 counts rms
100 sps	489.53 nV rms	470.25 nV rms	486.47 nV rms
	0.49 counts rms	0.47 counts rms	0.49 counts rms
200 sps	488.47 nV rms	470.33 nV rms	485.34 nV rms
	0.49 counts rms	0.47 counts rms	0.49 counts rms

Table 28 Self Noise RMS, Affinity 55A0, 0.5 Hz – 16 Hz, at Select Sample Rates

Sample Rate	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
4 sps	600.18 nV rms	591.93 nV rms	596.05 nV rms
	0.60 counts rms	0.59 counts rms	0.60 counts rms
20 sps	1410.58 nV rms	1366.23 nV rms	1405.58 nV rms
	1.41 counts rms	1.37 counts rms	1.41 counts rms
40 sps	1885.74 nV rms	1839.32 nV rms	1882.65 nV rms
	1.89 counts rms	1.84 counts rms	1.88 counts rms
100 sps	1876.03 nV rms	1812.08 nV rms	1872.55 nV rms
	1.88 counts rms	1.81 counts rms	1.87 counts rms
200 sps	1872.16 nV rms	1811.34 nV rms	1868.88 nV rms
	1.87 counts rms	1.81 counts rms	1.87 counts rms

Table 29 Self Noise RMS, Affinity 55A0, 0.02 Hz – 16 Hz, at Select Sample Rates

Sample Rate	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
4 sps	707.66 nV rms	698.16 nV rms	703.54 nV rms
	0.71 counts rms	0.70 counts rms	0.70 counts rms
20 sps	1454.01 nV rms	1408.03 nV rms	1448.74 nV rms
	1.45 counts rms	1.41 counts rms	1.45 counts rms
40 sps	1917.90 nV rms	1870.59 nV rms	1914.65 nV rms
	1.92 counts rms	1.87 counts rms	1.92 counts rms
100 sps	1908.15 nV rms	1842.97 nV rms	1904.52 nV rms
	1.91 counts rms	1.84 counts rms	1.91 counts rms
200 sps	1904.19 nV rms	1842.24 nV rms	1900.68 nV rms
	1.91 counts rms	1.84 counts rms	1.90 counts rms

Average self noise across all channels and sample rates were as follows for the low, high and broad passbands: 484.44 nV rms, 1776.39 nV rms and 1441.93 nV rms. Note, the 4 Hz self noise has been excluded from the average and variability comparisons of the self noise as the 4 sps data excludes most of the high passband and much of the broad passband, artificially lowering the calculated of self noise in the aforementioned passbands. With exclusion of the 4 sps data as previously noted, self noise varied between 7.97% and 8.81% across all sample rates and channels. Rms noise values did not exceed the equivalent of 2 count rms while operating at a gain of 1x; at gains of 2x and 4x, rms noise did not exceed the equivalent of 3 counts rms.

3.8 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.

3.8.1 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).

3.8.2 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 3.6**Error! Reference source not found.**, AC Full Scale. The value for the smallest signal comes from the evaluated digitizer channel self noise determined in section 3.5, Self Noise.

3.8.3 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.

3.8.4 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.

Table 30 Dynamic Range, 20x Gain, at 23°C, All Affinitys

DWR	Passband	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
55A1	20 mHz - 1 Hz	148.98 dB	149.13 dB	149.03 dB
	20 mHz - 16 Hz	137.24 dB	137.29 dB	137.31 dB
	0.5 Hz - 16 Hz	137.40 dB	137.44 dB	137.46 dB
559A	20 mHz - 1 Hz	146.81 dB	149.09 dB	149.21 dB
	20 mHz - 16 Hz	137.10 dB	137.33 dB	137.37 dB
	0.5 Hz - 16 Hz	137.44 dB	137.49 dB	137.52 dB
559B	20 mHz - 1 Hz	149.04 dB	149.21 dB	148.97 dB
	20 mHz - 16 Hz	137.26 dB	137.40 dB	137.21 dB
	0.5 Hz - 16 Hz	137.41 dB	137.54 dB	137.36 dB
55A0	20 mHz - 1 Hz	149.22 dB	149.09 dB	149.26 dB
	20 mHz - 16 Hz	137.38 dB	137.22 dB	137.42 dB
	0.5 Hz - 16 Hz	137.53 dB	137.36 dB	137.57 dB

The observed dynamic range values across all dataloggers and channels, recording at a gain of 1x while exposed to 23° C, were between 146.81d B and 149.26 dB over the 0.02 Hz to 1.0 Hz passband, 137.36 dB and 137.57 dB over the 0.5 Hz to 16 Hz passband and 137.10 dB and 137.42 dB over the 0.02 Hz and 16 Hz passband. Note the 2+ dB drop in dynamic range of datalogger 559A channel 3; this is due to the previously noted increased self noise observed below 2 Hz.

Dynamic range varied no more than 1.41% from the average of 148.92 dB over the low passband, 0.077% of the 137.46 dB average of the high passband and 0.14% of 137.29 dB average broad passband.

Table 31 Dynamic Range Affinity 55A0, at Select Temperatures

Temp	Passband	00HHE Channel 3	00HHN Channel 2	00HHZ Channel 1
60°C	20 mHz - 1 Hz	149.04 dB	148.94 dB	149.05 dB
	20 mHz - 16 Hz	137.15 dB	137.04 dB	137.17 dB
	0.5 Hz - 16 Hz	137.30 dB	137.18 dB	137.31 dB
20°C	20 mHz - 1 Hz	149.21 dB	149.56 dB	149.27 dB
	20 mHz - 16 Hz	137.40 dB	137.70 dB	137.41 dB
	0.5 Hz - 16 Hz	137.55 dB	137.85 dB	137.56 dB
100 sps 2x gain	20 mHz - 1 Hz	148.34 dB	148.11 dB	148.33 dB
	20 mHz - 16 Hz	136.57 dB	136.43 dB	136.60 dB
	0.5 Hz - 16 Hz	136.72 dB	136.59 dB	136.75 dB
100 sps 4x gain	20 mHz - 1 Hz	145.97 dB	145.84 dB	146.06 dB
	20 mHz - 16 Hz	134.22 dB	134.14 dB	134.25 dB
	0.5 Hz - 16 Hz	134.37 dB	134.30 dB	134.40 dB
-25°C	20 mHz - 1 Hz	149.50 dB	149.39 dB	149.63 dB
	20 mHz - 16 Hz	137.89 dB	137.75 dB	137.90 dB
	0.5 Hz - 16 Hz	138.05 dB	137.91 dB	138.06 dB
-36°C	20 mHz - 1 Hz	149.59 dB	149.56 dB	149.72 dB
	20 mHz - 16 Hz	138.00 dB	137.87 dB	138.01 dB
	0.5 Hz - 16 Hz	138.16 dB	138.03 dB	138.16 dB

Performance generally improves as temperatures decrease, except for the dynamic range calculated on channel 2 for the low passband where the dynamic range at -25° C drops slightly relative to the dynamic range computed at for 20° C.

In the low passband, over all temperatures, while recording at a gain of 1x, all channels remained between 0.53% of the maximum dynamic range of 149.37 dB. Similarly, in the high passband, over all temperatures, all channels remained between 0.29% of the maximum dynamic range of 137.61%; and finally in the broad passband, all channels remained within 0.29% of the maximum dynamic range of 137.76 dB.

Table 32 Dynamic Range Affinity 55A0, at Select Sample Rates

Rate	Passband	00HHE (Channel 3)	00HHN (Channel 2)	00HHZ (Channel 1)
4 sps	20 mHz - 1 Hz	148.57 dB	148.69 dB	148.62 dB
	20 mHz - 16 Hz	146.01 dB	146.13 dB	146.06 dB
	0.5 Hz - 16 Hz	147.44 dB	147.56 dB	147.50 dB
20 sps	20 mHz - 1 Hz	149.10 dB	149.43 dB	149.16 dB
	20 mHz - 16 Hz	139.76 dB	140.04 dB	139.79 dB
	0.5 Hz - 16 Hz	140.02 dB	140.30 dB	140.05 dB
40 sps	20 mHz - 1 Hz	149.18 dB	149.44 dB	149.24 dB
	20 mHz - 16 Hz	137.35 dB	137.57 dB	137.37 dB
	0.5 Hz - 16 Hz	137.50 dB	137.72 dB	137.51 dB
100 sps	20 mHz - 1 Hz	149.21 dB	149.56 dB	149.27 dB
	20 mHz - 16 Hz	137.40 dB	137.70 dB	137.41 dB
	0.5 Hz - 16 Hz	137.55 dB	137.85 dB	137.56 dB
200 sps	20 mHz - 1 Hz	149.23 dB	149.56 dB	149.29 dB
	20 mHz - 16 Hz	137.42 dB	137.70 dB	137.43 dB
	0.5 Hz - 16 Hz	137.56 dB	137.85 dB	137.58 dB

Over the sample rates at which dynamic ranges were evaluated, dynamic ranges remained relatively stable across channels. In the low passband, over all sample rates recording at a gain of 1x, all channels remained between 0.49% of the average dynamic range of 149.31 dB in the low passband. Similarly, in the high passband, over all sample rates, all channels remained within of 6.73% of 138.25 dB average dynamic range in the passband. Finally, in the broad passband, all channels, over all sample rates, remained within 5.83% of the average dynamic range of 138.08 dB over the broad passband.

Note, the 4 sps self noise has been excluded from the aforementioned average and variability comparisons of dynamic range as the 4 Hz data excludes most of the high passband and much of the broad passband, artificially lowering the calculated of self noise in the aforementioned passbands and, therefore, raising the associated dynamic range.

Dynamic ranges over all evaluated conditions and passband varied from as low 137 dB to as much as 150 dB.

3.9 System Noise

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

3.9.1 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 $(m/s)^2/Hz$ versus frequency.

3.9.2 Configuration

There is no test configuration for the dynamic range test.

The time-series data and PSD are obtained from the evaluated digitizer channel self noise determined in Section 3.7, Self Noise, 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.

3.9.3 Result

The PSD of the system noise is shown in the plots below. Where available, reference sensor and background noise models are provided for comparison.

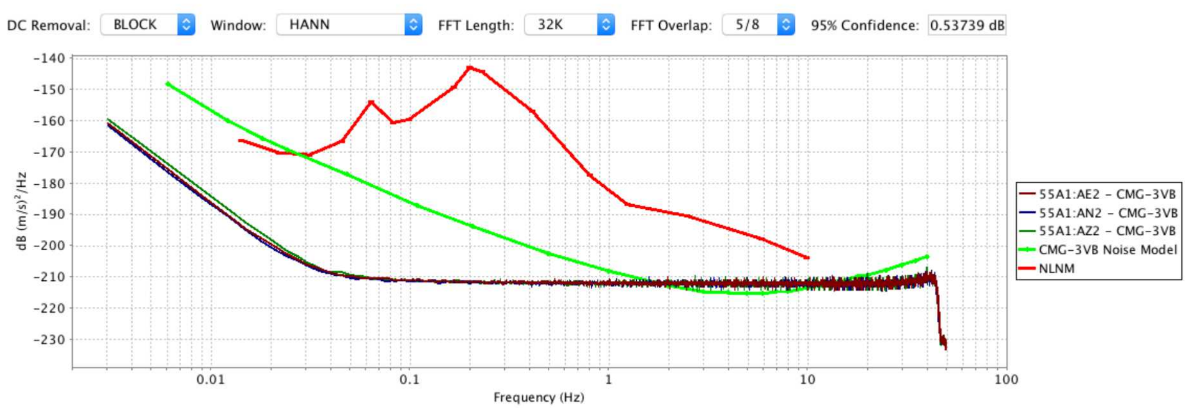

Figure 46 Seismic System Noise Affinity 55A1, 23° C

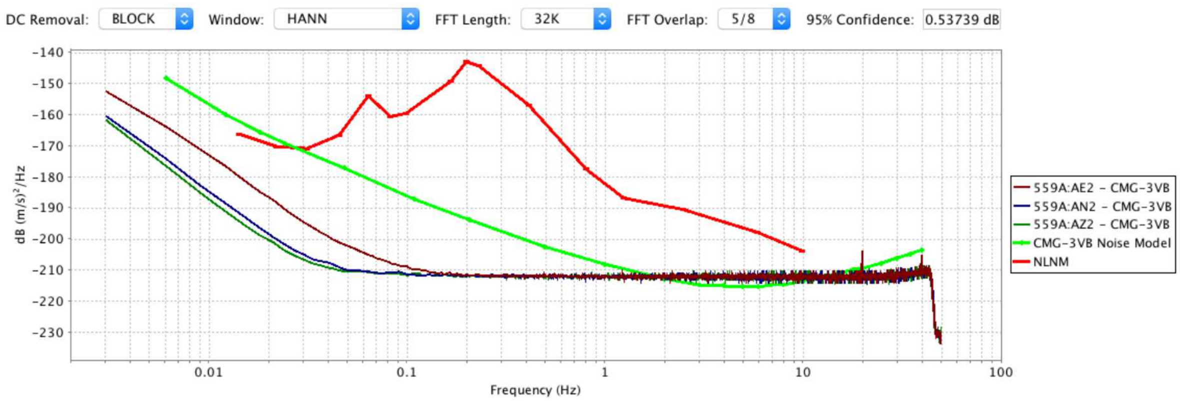

Figure 47 Seismic System Noise Affinity 559A, 23° C

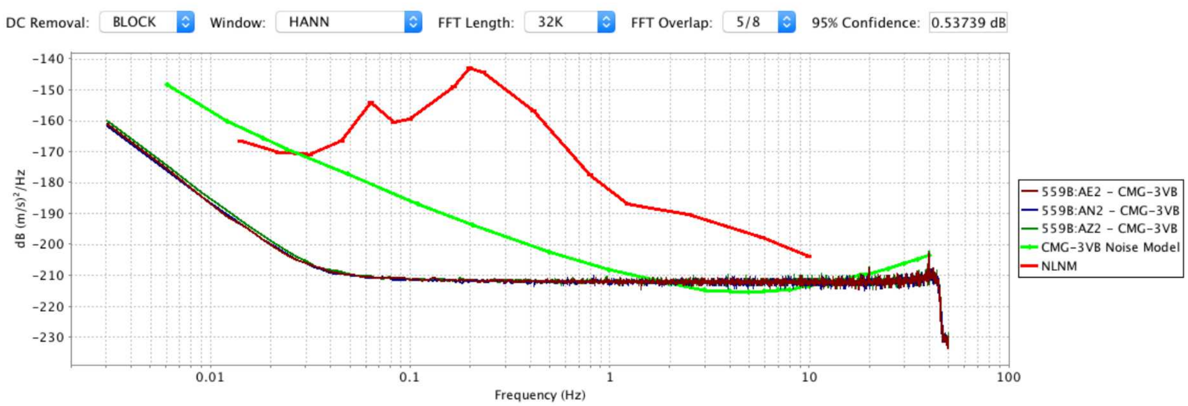

Figure 48 Seismic System Noise Affinity 559B, 23° C

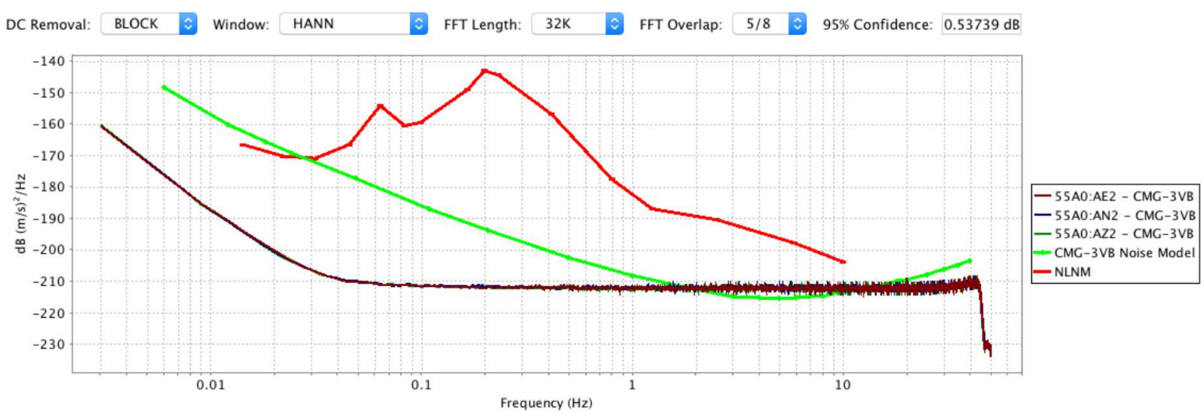

Figure 49 Seismic System Noise Affinity 55A0, 23° C

Equivalent seismic system noise of all Affinity dataloggers recording at a gain of 1x, while exposed to a 23° C environment, exceeds the self-noise models of the Guralp CMG-3VB from as low as 1.9 Hz and as high as 13.3 Hz.

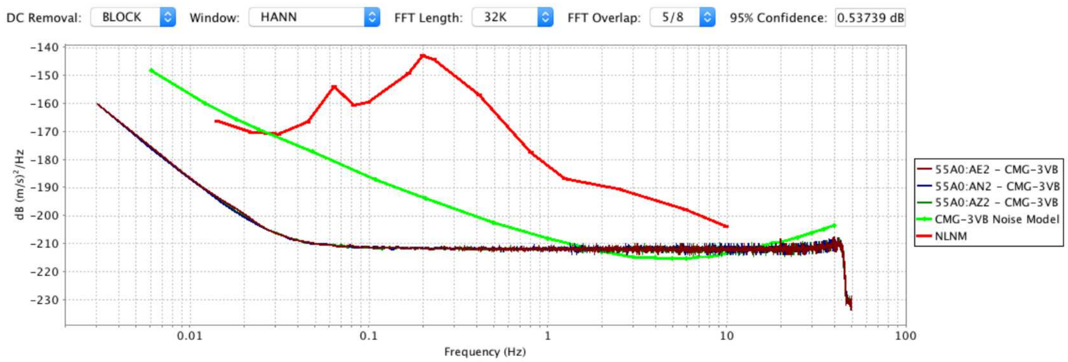

Figure 50 Seismic System Noise Affinity 55A0, 60° C

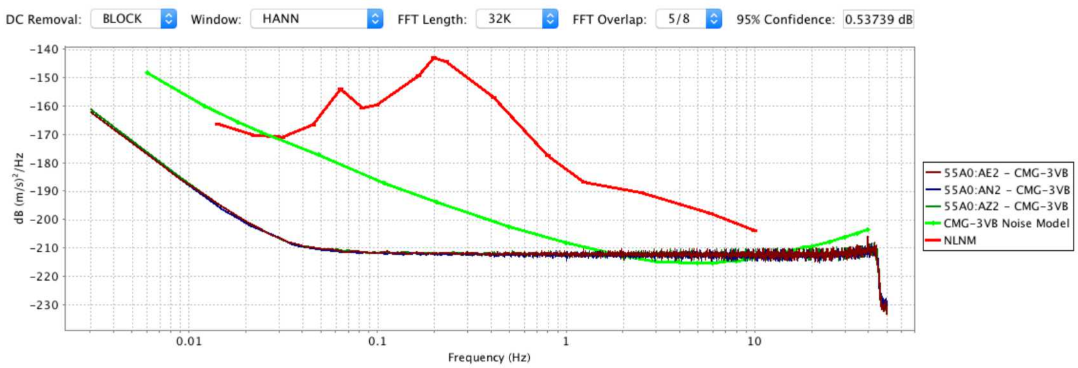

Figure 51 Seismic System Noise Affinity 55A0, 20° C

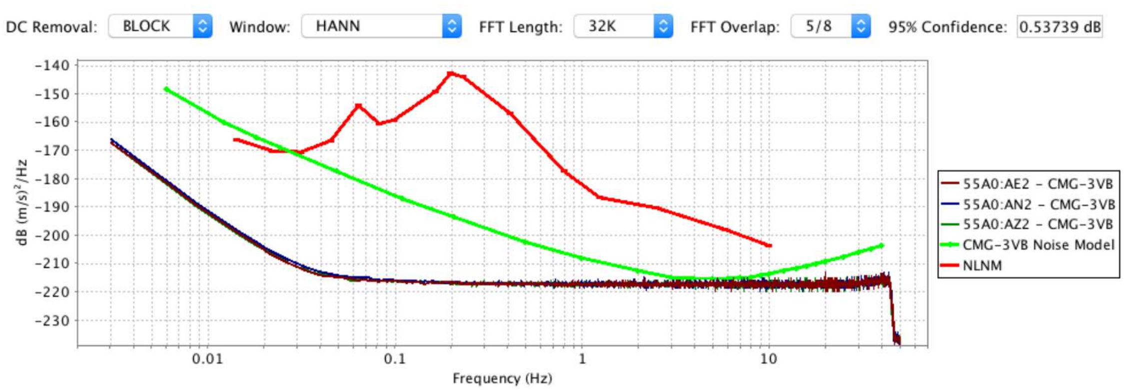

Figure 52 Seismic System Noise Affinity 55A0, 100 Hz, 2x Gain

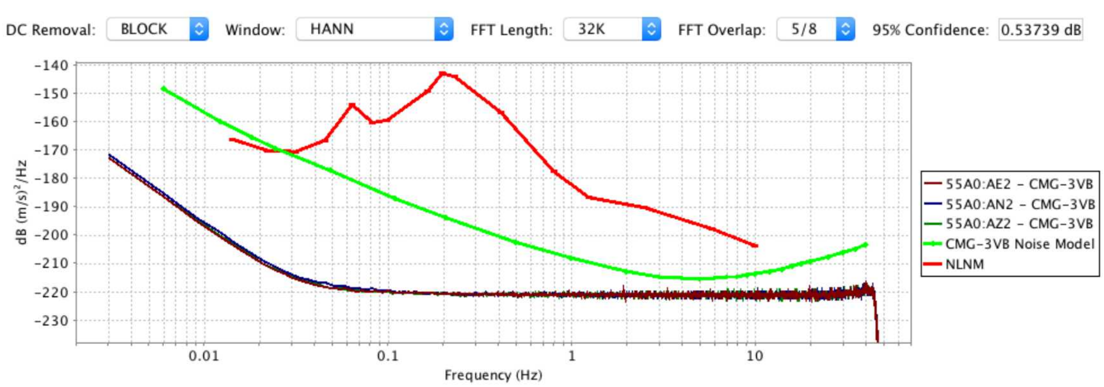

Figure 53 Seismic System Noise Affinity 55A0, 100 Hz, 4x Gain

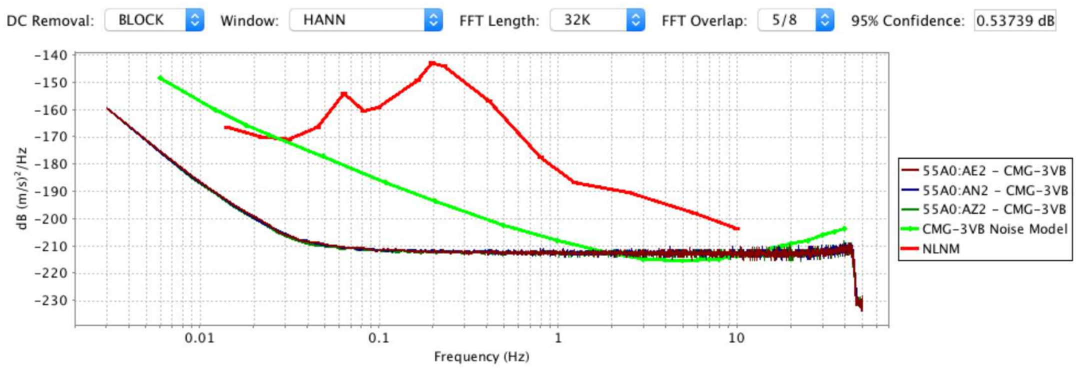

Figure 54 Seismic System Noise Affinity 55A0, -25° C

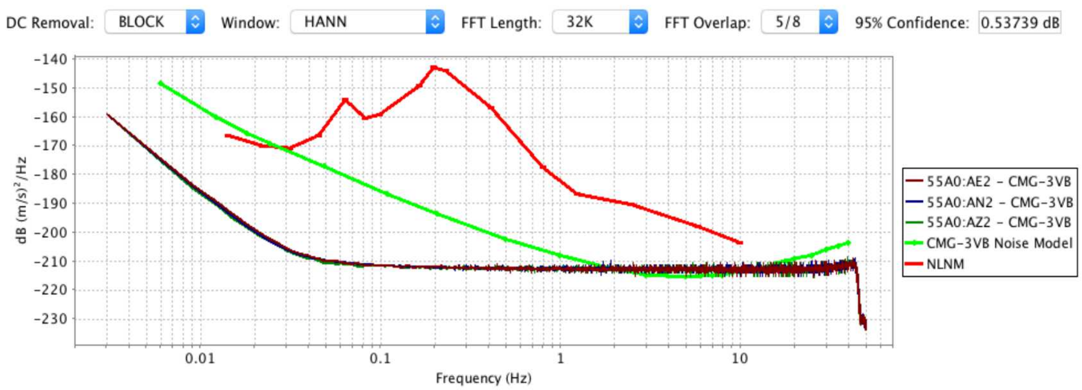

Figure 55 Seismic System Noise Affinity 55A0, -36° C

Over the temperatures to which the Affinity datalogger was exposed the seismic system noise exceed the CMG-3VB noise model, over a significant portion of the higher passband of interest (0.5 to 16 Hz). At the -36° C seismic system noise of the Affinity exceeded the self noise model between 2.1 Hz and 11.3 Hz (up to 11.6 Hz for the North channel); at 60°C system noise exceed the self noise model between 2.1 Hz and 13.4 Hz (13.7 Hz for the North channel).

With the datalogger gain set to 2x, average computed system noise remains below the Low Noise Model, from 56.5 dB to 56.8 dB lower at 0.1 Hz and from 13.6 dB to 13.7 db at 10 Hz. Similarly, computed system noise is below the noise model of the Guralp Systems CMG-3VB sensor: between 30.1 dB to 30.4 dB lower at 0.1 Hz and 3.8 dB to 3.9 dB lower at 10 Hz. As expected, at a datalogger gain of 4x self noise drops further below the noise models. With respect to the low noise model values range from 60.0 dB to 60.6 dB lower at 0.1 Hz and 17.3 dB to 17.4 dB lower at 10 Hz; with respect to the sensor self noise model of the CMB-3VB, system noise ranges 33.6 dB to 34.2 dB lower at 0.1 Hz and 7.5 dB to 7.6 dB lower at 10 Hz.

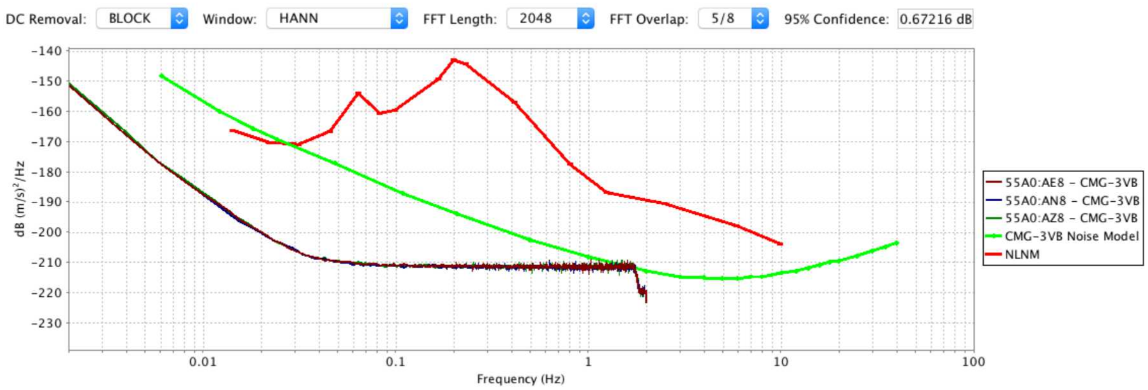

Figure 56 Seismic System Noise Affinity 55A0, 4 Hz

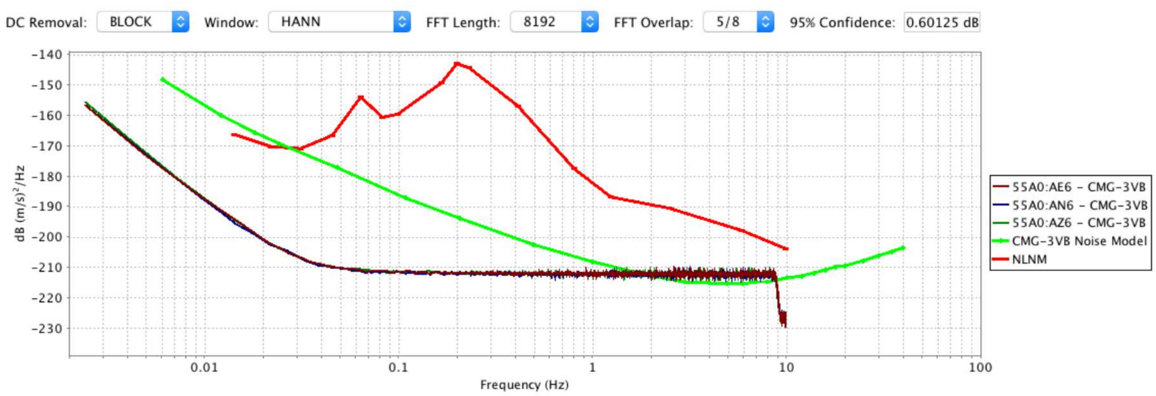

Figure 57 Seismic System Noise Affinity 55A0, 20 Hz

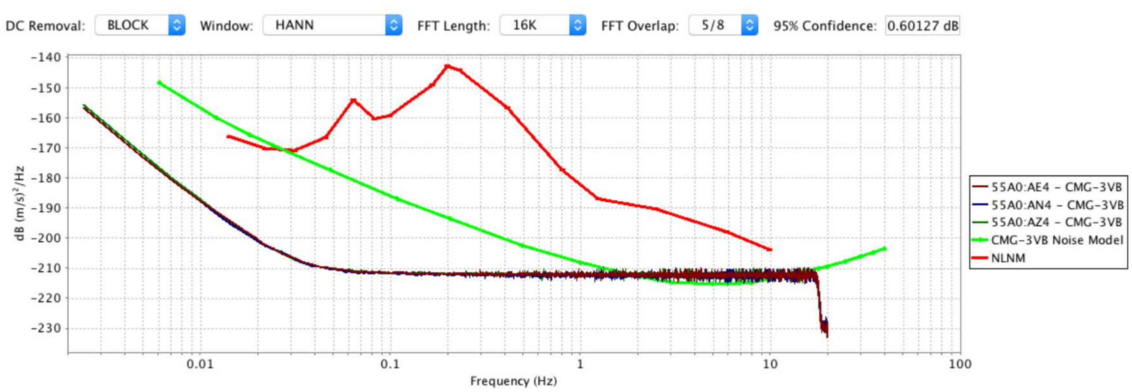

Figure 58 Seismic System Noise Affinity 55A0, 40 Hz

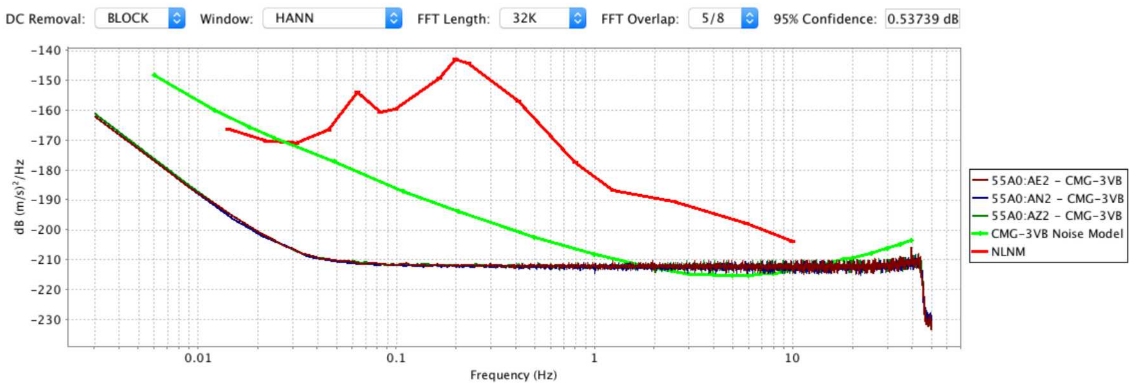

Figure 59 Seismic System Noise Affinity 55A0, 100 Hz

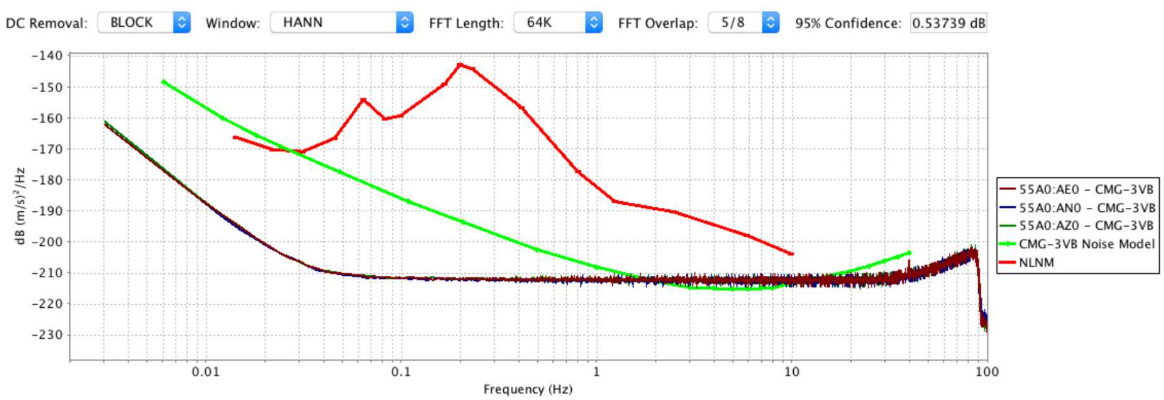

Figure 60 Seismic System Noise Affinity 55A0, 200 Hz

Over the sample rates evaluated, at a gain of 1x, seismic system noise exceeded the CMG-3VB noise model from as low as 1.9 Hz to 2.0 Hz (North channel) to as high as 12.0 Hz (North channel) to 12.9 Hz.

3.10 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.

3.10.1 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.

3.10.2 Configuration

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

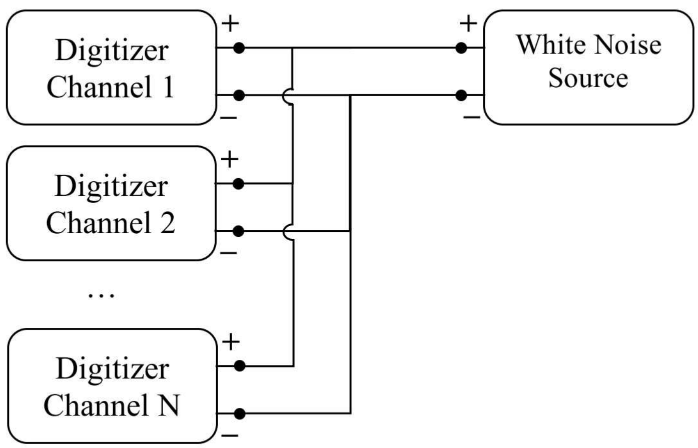

Figure 61 Response Verification Configuration Diagram

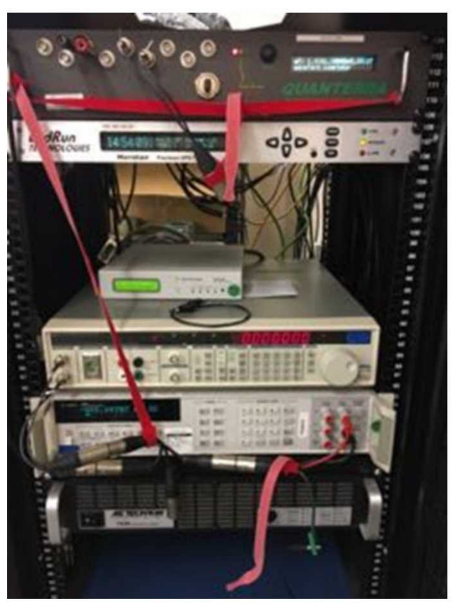

Figure 62 Response Verification Configuration Picture

Table 33 Response Verification Testbed Equipment

	Manufacturer / Model	Serial Number	Configuration
White Noise Source Bunker	Stanford Research Systems DS360	123672	+1V / - 1 V
White Noise Source SB1	Stanford Research Systems DS360	123669	+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.

3.10.3 Analysis

The measured bitweight, 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:

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

3.10.4 Result

The coherence and relative amplitude and phase response were computed between channel 1 and the remaining two channels for all of the evaluated sample rate and gain configurations utilizing a 7 hour window of data.

The first group of plots shows coherence between channel 1 and the remaining channels for each datalogger under test.

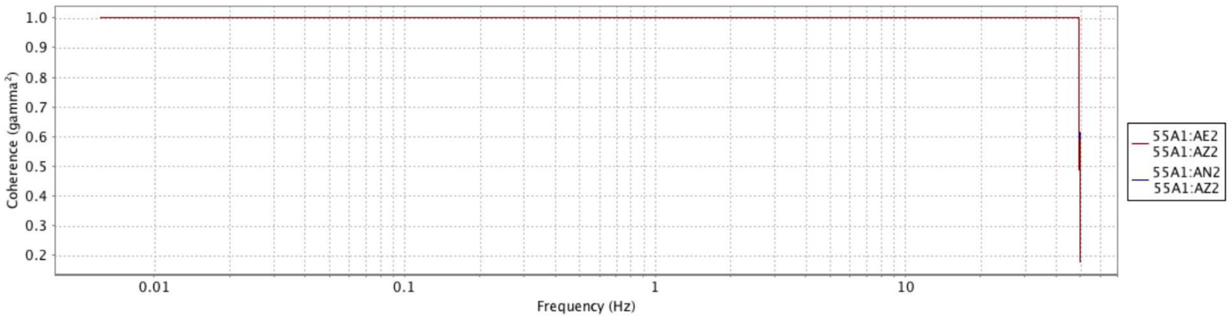

Figure 63 White Noise Coherence Affinity 55A1, 23° C

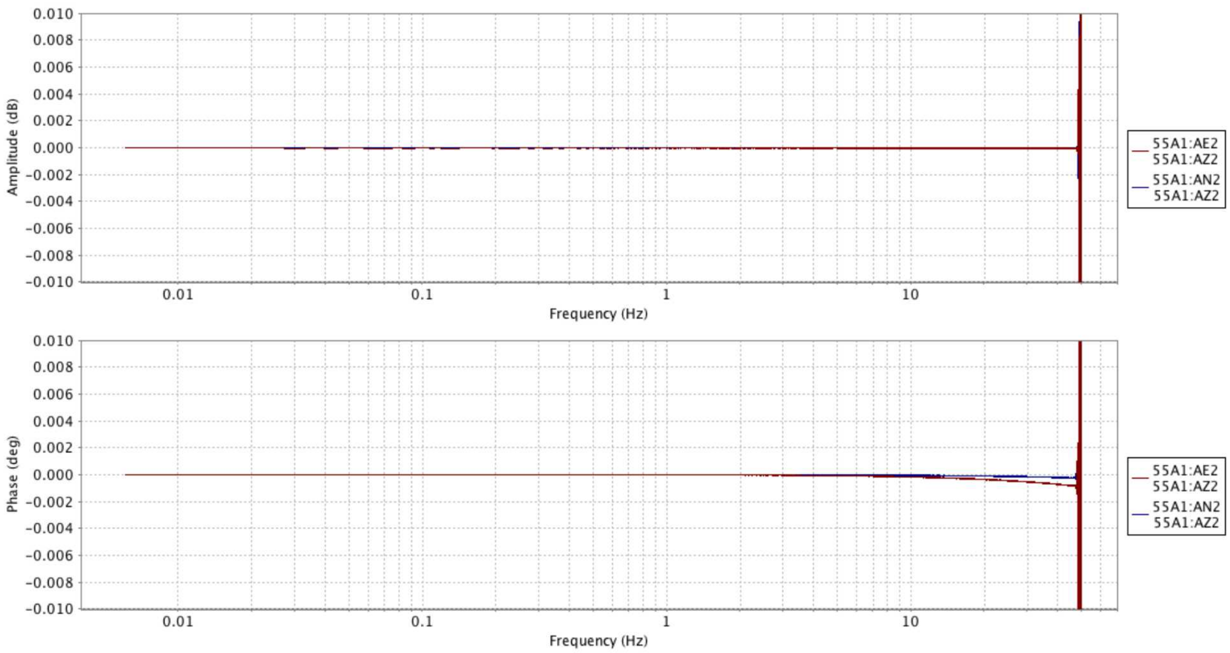

Figure 64 Relative Magnitude and Phase Affinity 55A1, 23° C

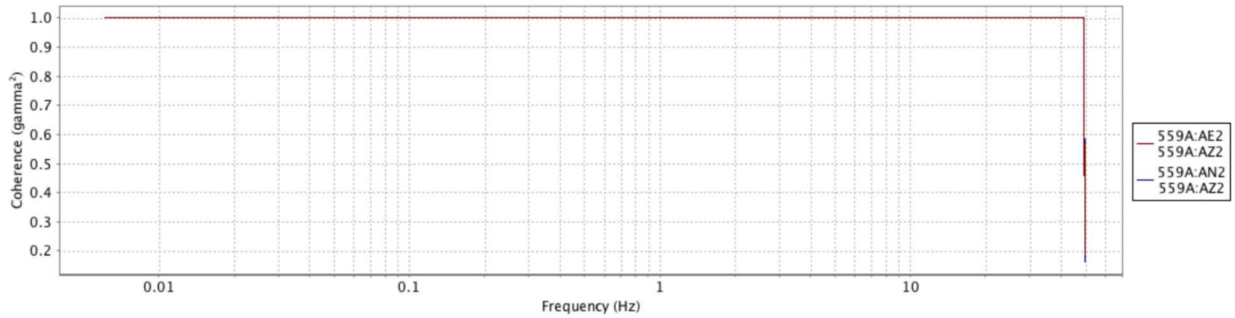

Figure 65 White Noise Coherence Affinity 559A, 23° C

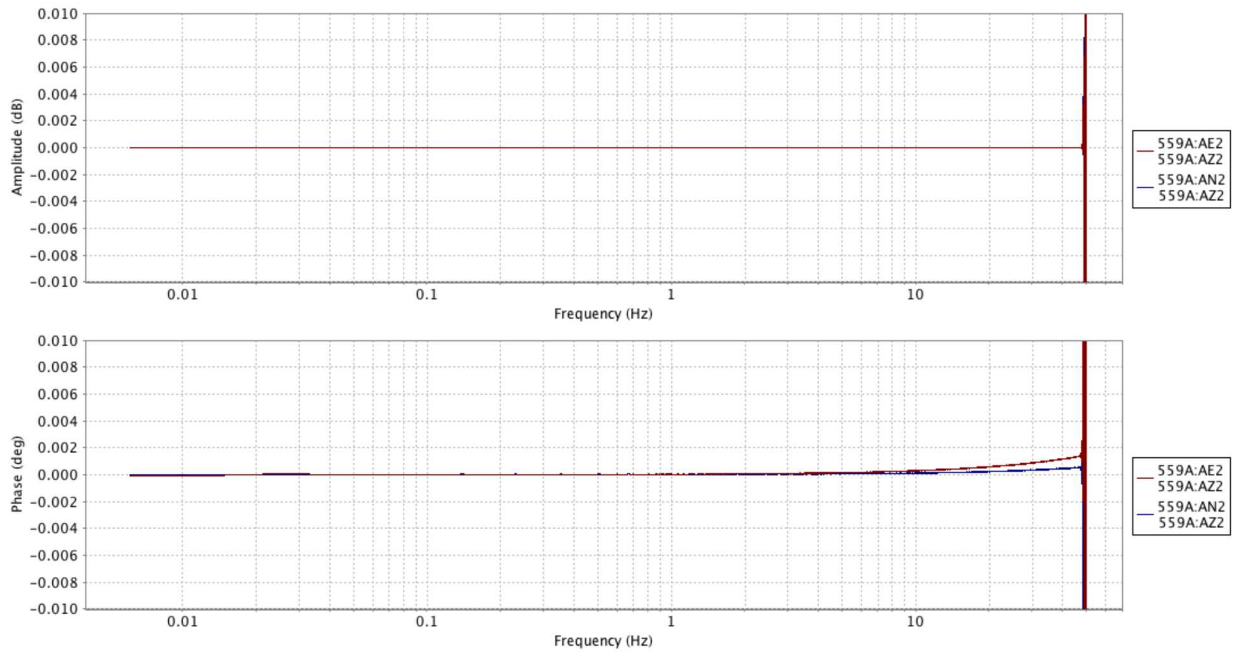

Figure 66 Relative Magnitude and Phase Affinity 559A, 23° C

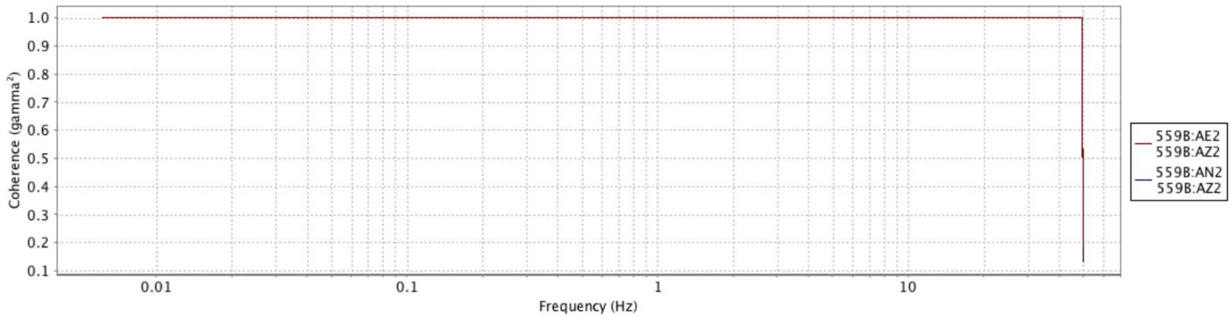

Figure 67 White Noise Coherence Affinity 559B, 23° C

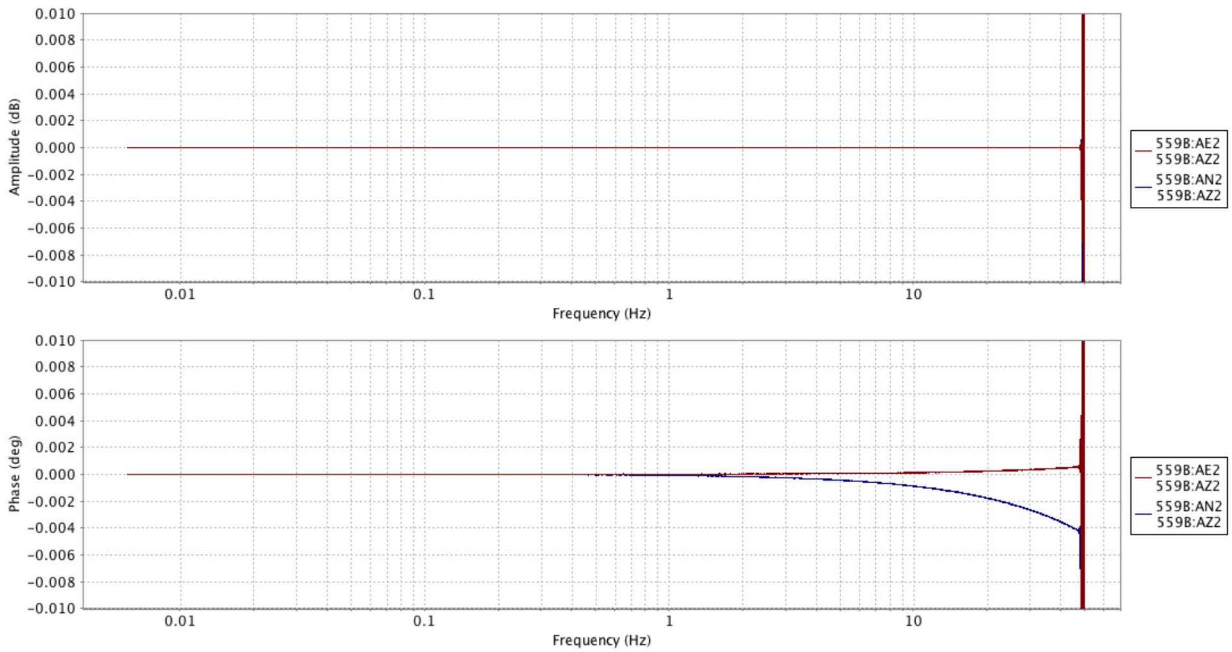

Figure 68 Relative Magnitude and Phase Affinity 559B, 23° C

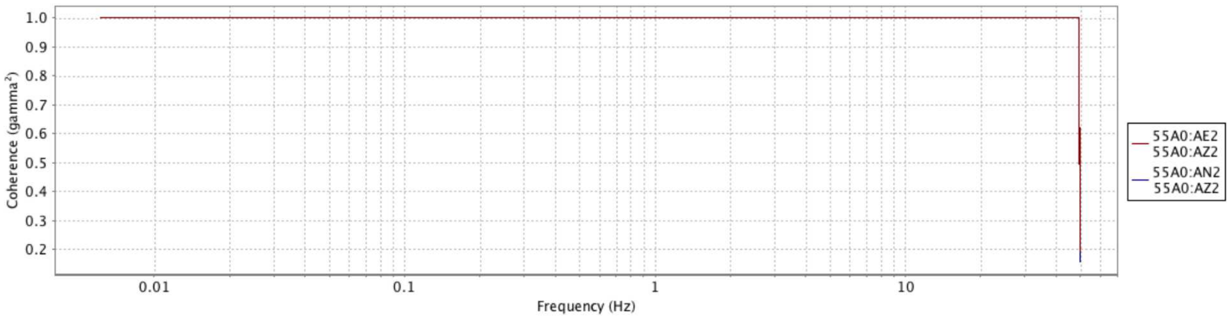

Figure 69 White Noise Coherence Affinity 55A0, 23° C

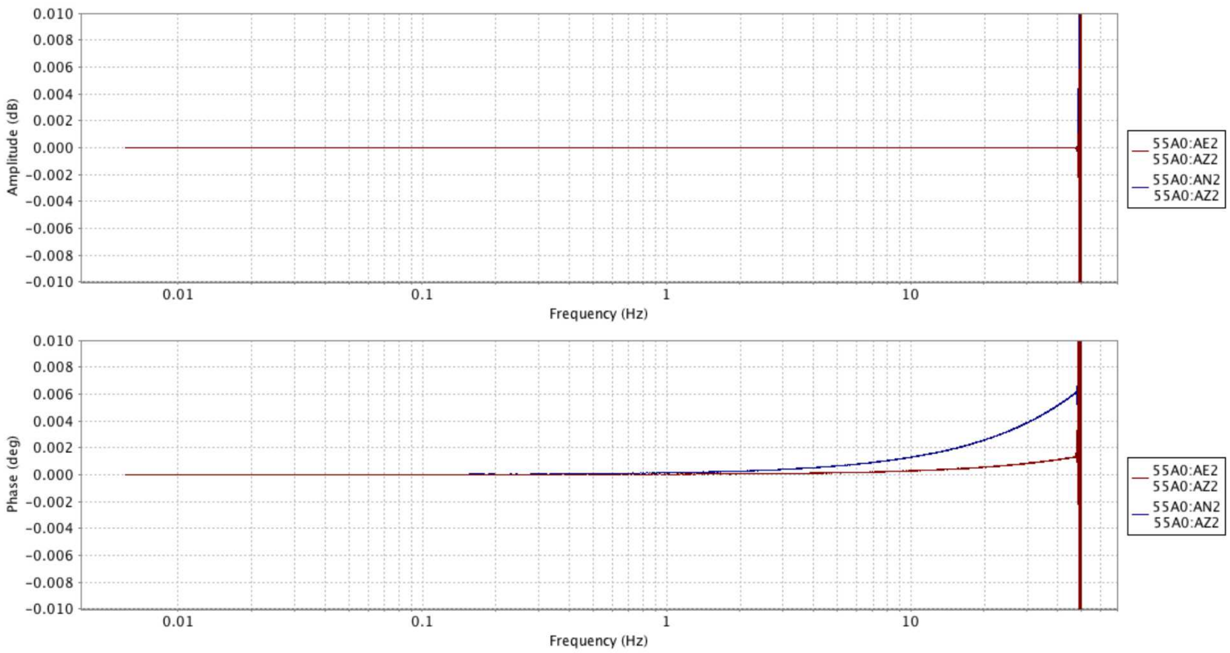

Figure 70 Relative Magnitude and Phase Affinity 55A0, 23° C

The coherence was identically 1.0 across the pass-band. Phase differences were very small, with some variation in the amount of the roll-off between channels. This roll-off in phase may be attributed to slight differences in timing, which will be investigated further in the Relative Transfer Function section.

The next group of plots shows coherence, relative magnitude and relative phase between channel 1 and channels 2-3 for datalogger 55A0 at temperatures of 60° C, 20° C (and gains at 2x and 4x), -25° C and -36° C, utilizing a 1 hour window of data. Coherence, from the lowest frequencies available while utilizing a 1 hour time window to that approaching the Nyquist, is essentially 1.0 gamma^2, therefore only coherence for a temperature of 60° C is shown below.

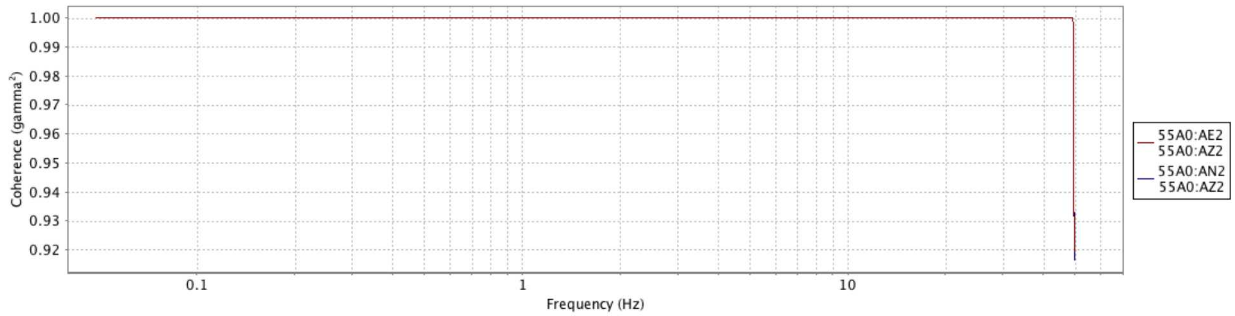

Figure 71 Coherence Affinity 55A0, 60° C

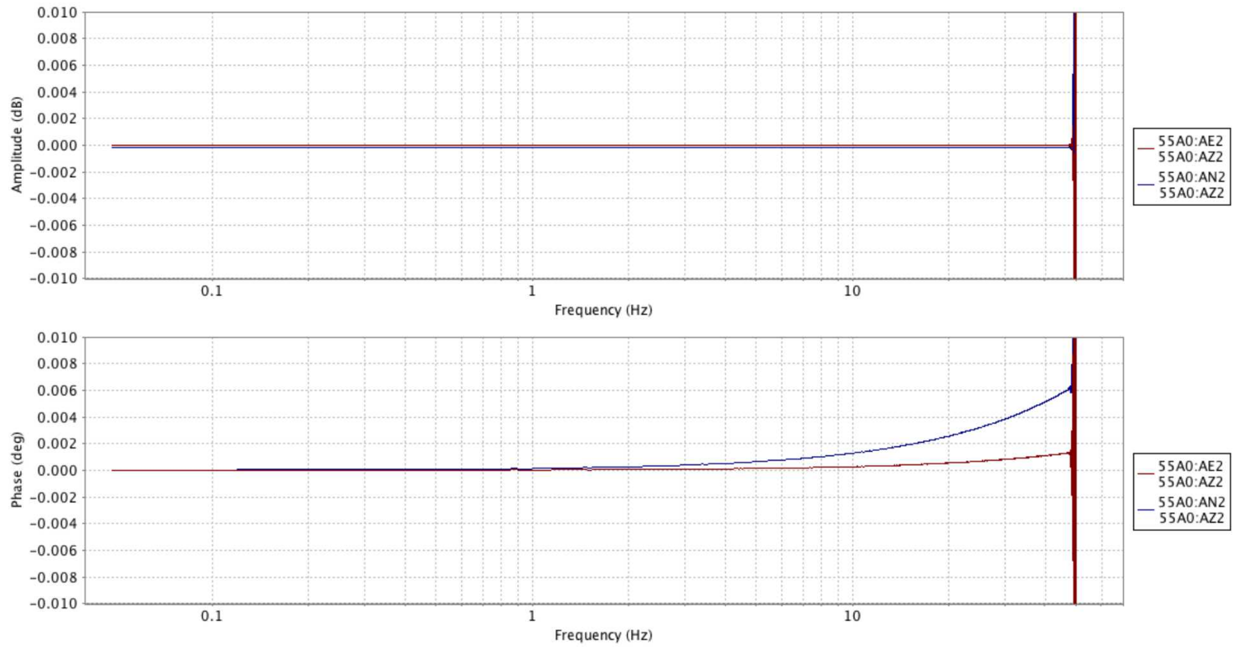

Figure 72 Relative Magnitude and Phase Affinity 55A0, 60° C

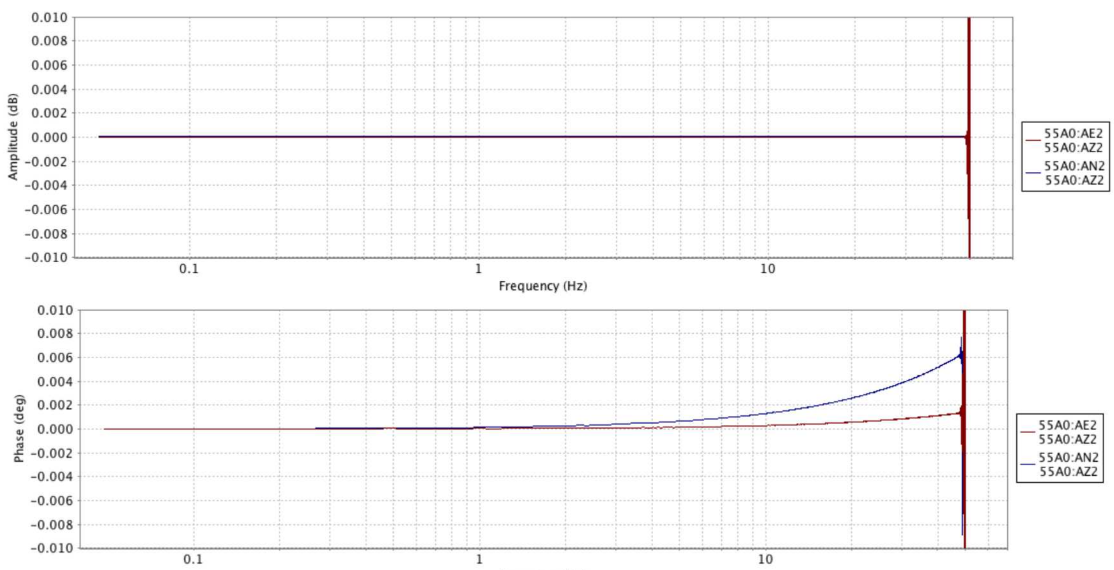

Figure 73 Relative Magnitude and Phase Affinity 55A0, 20° C

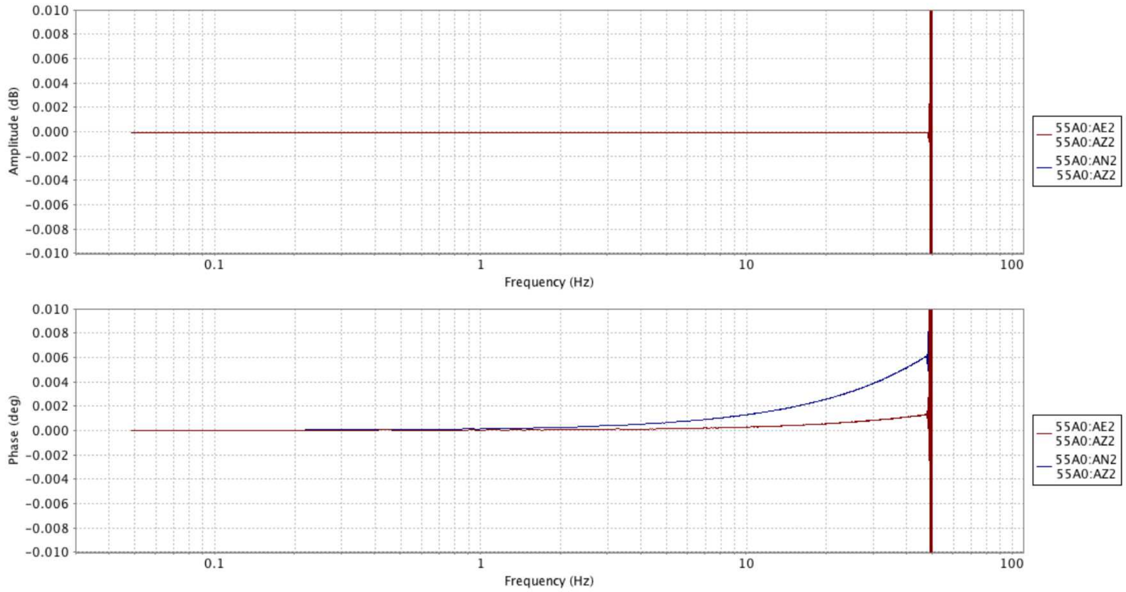

Figure 74 Relative Magnitude and Phase Affinity 55A0, 100 sps, Gain 2x

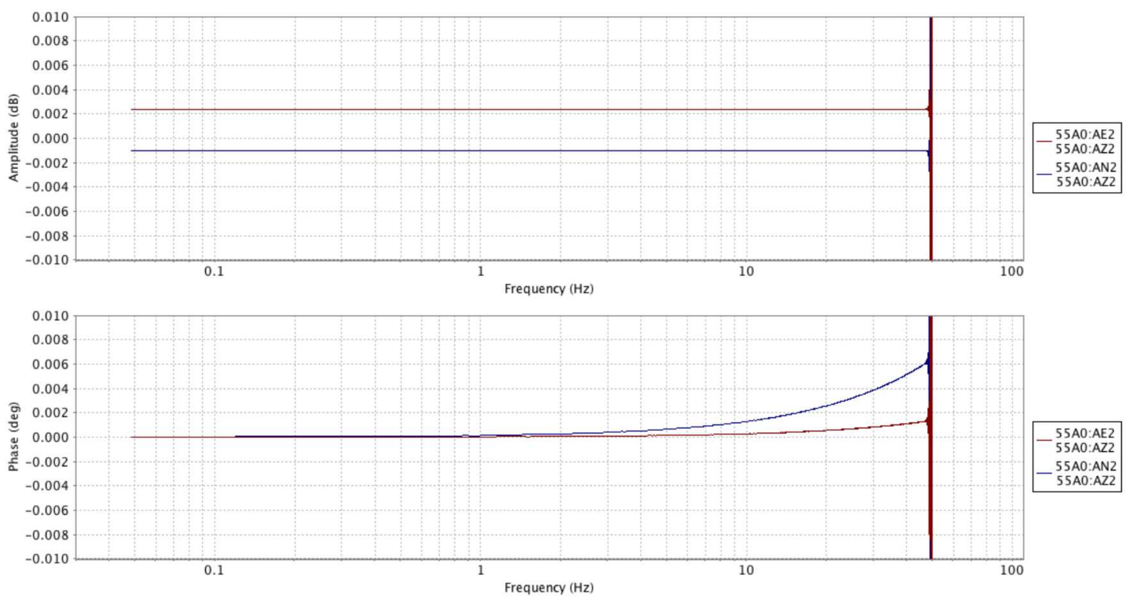

Figure 75 Relative Magnitude and Phase Affinity 55A0, 100 sps, Gain 4x

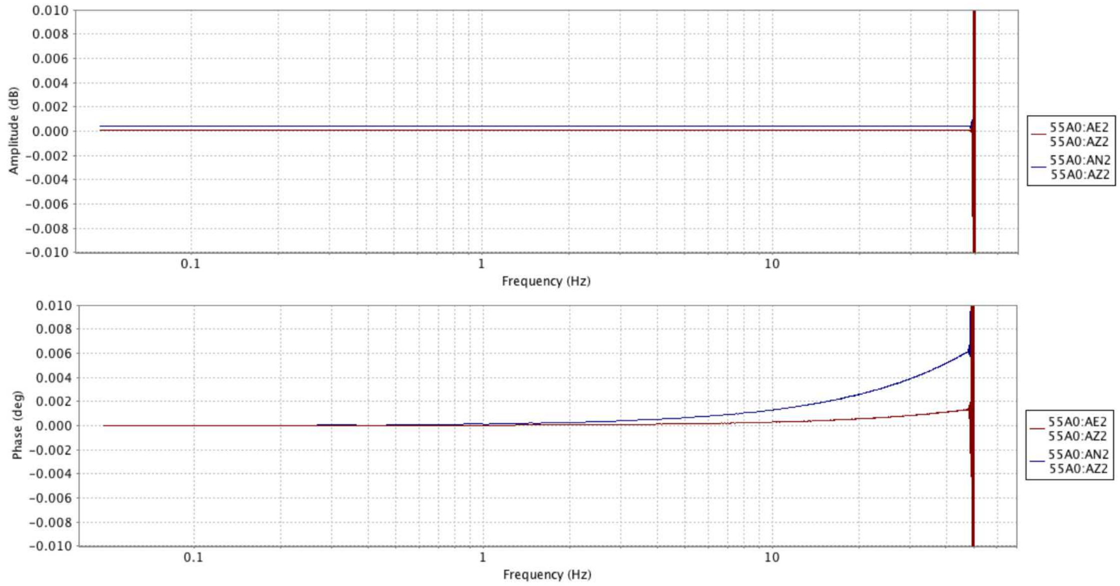

Figure 76 Relative Magnitude and Phase Affinity 55A0, -25° C

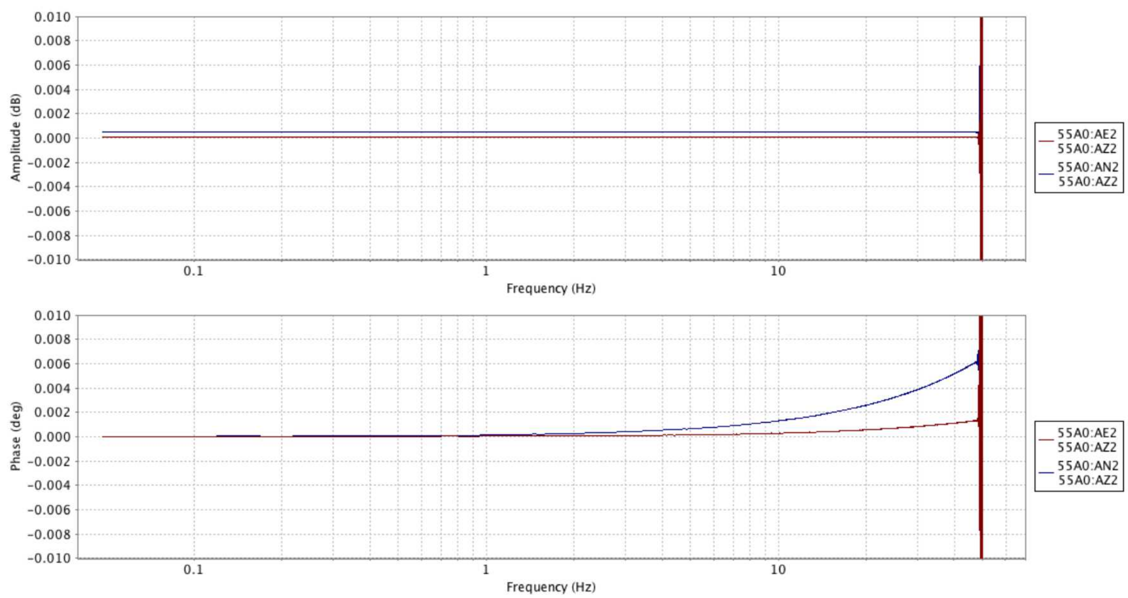

Figure 77 Relative Magnitude and Phase Affinity 55A0, -36° C

At the evaluated temperatures, the relative amplitudes were effectively zero. This indicates that there were no differences in response between the digitizer channels of any individual datalogger. Phase differences were very small, with a slight roll-off, varying between channels. This roll-off in phase may be attributed to slight differences in timing, which will be investigated further in the Relative Transfer Function section.

The relative magnitude measurement made while datalogger 55A0 was configured with a gain of 4x shows a uniform offset over frequency indicating a slight difference between channel sensitivities (as much as 0.028% across channels) during this test and those measured in the AC accuracy test, which provided the sensitivities utilized for computations for this test.

The following group of plots shows relative magnitude and relative phase between channel 1 and channels 2 and 3 for datalogger 55A0 at sample rates of 4 sps, 20 sps, 40 sps, 100 sps and 200 sps, utilizing a 1 hour window of data. Coherence, from the lowest frequencies available while utilizing a 1 hour time window to that approaching the Nyquist, is essentially 1.0 $gamma^2$, given this consistency, plots of coherence are omitted.

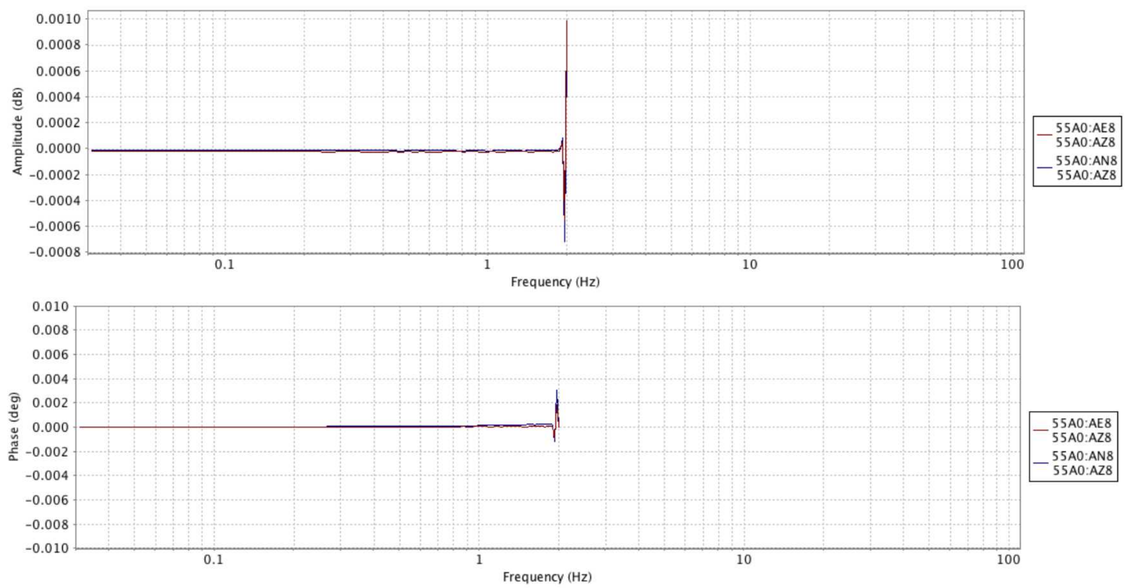

Figure 78 Relative Magnitude and Phase Affinity 55A0, 4 sps

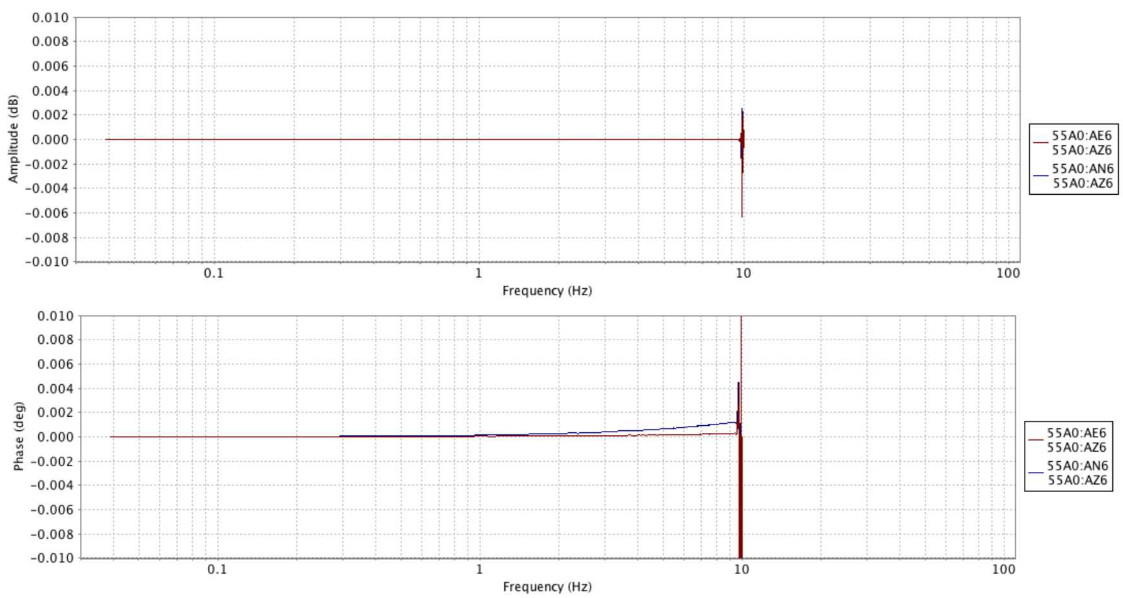

Figure 79 Relative Magnitude and Phase Affinity 55A0, 20 sps

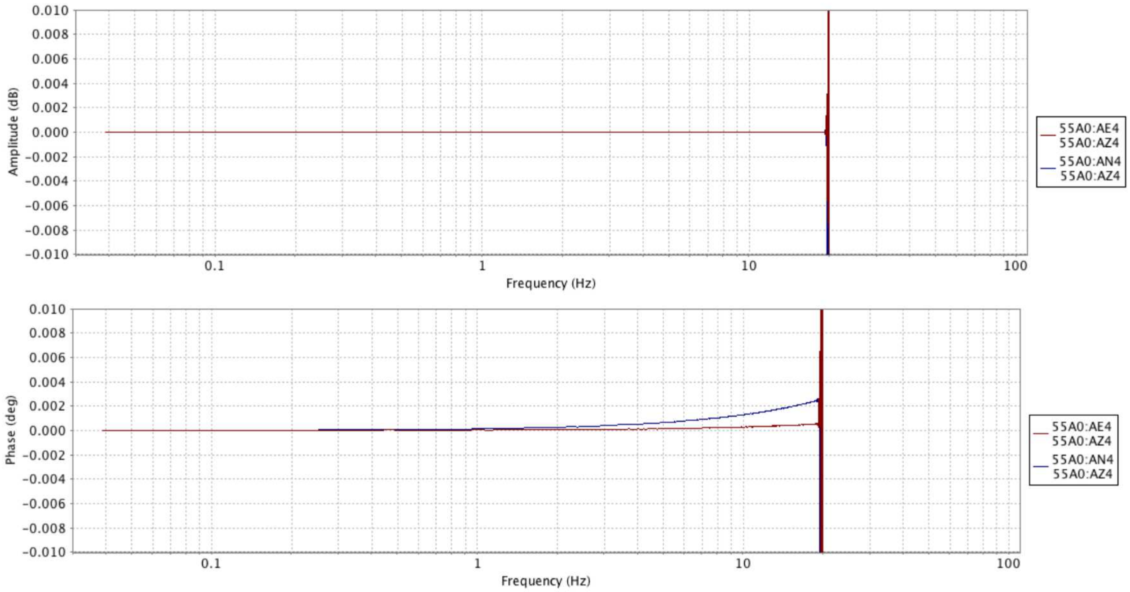

Figure 80 Relative Magnitude and Phase Affinity 55A0, 40 sps

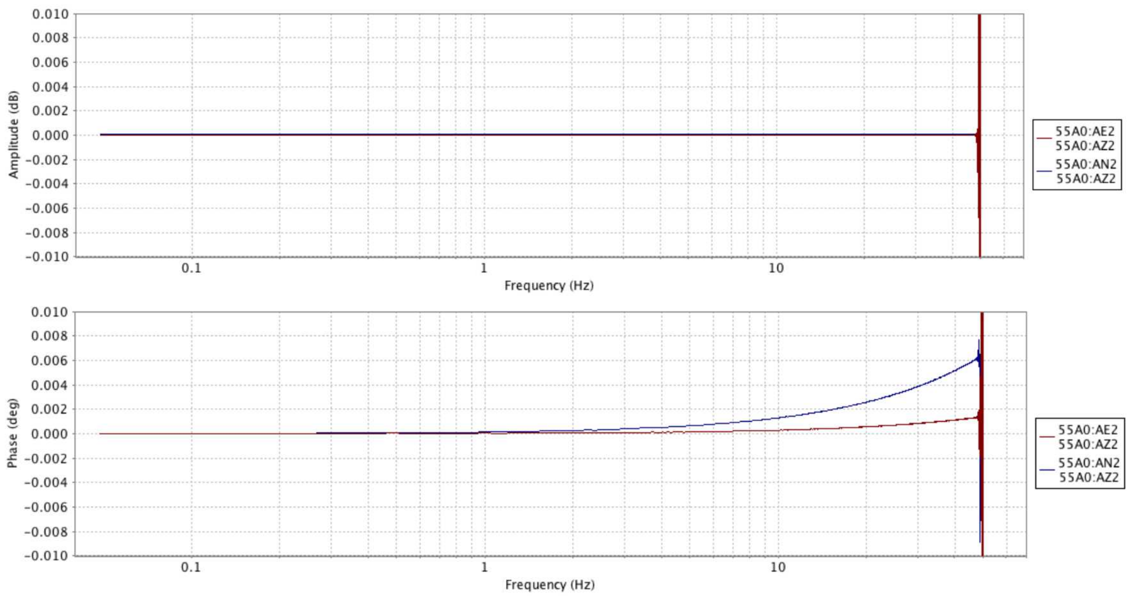

Figure 81 Relative Magnitude and Phase Affinity 55A0, 100 sps

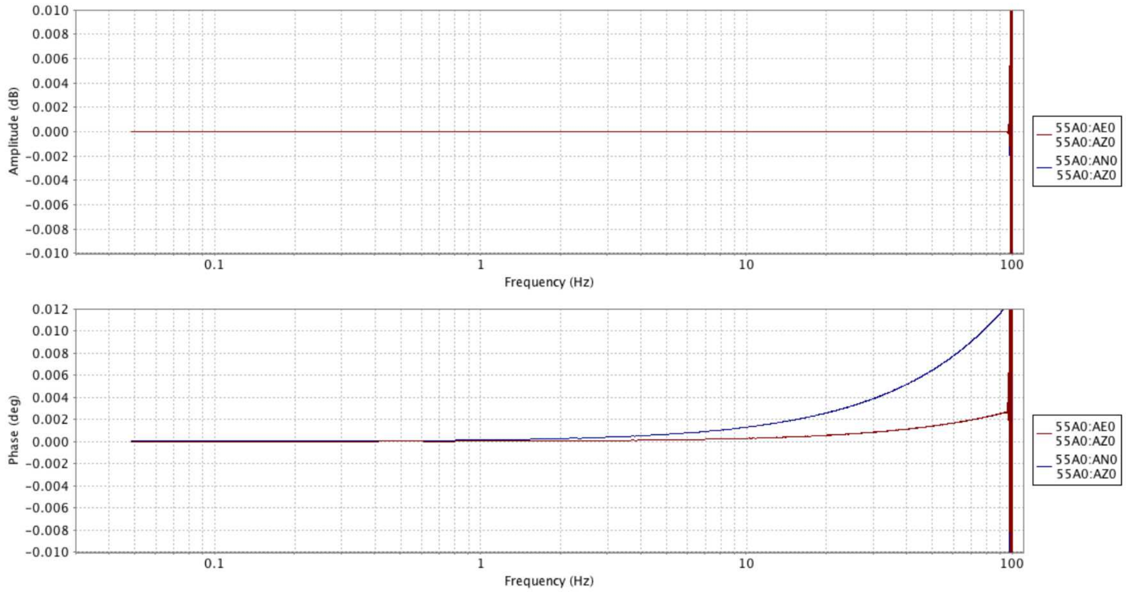

Figure 82 Relative Magnitude and Phase Affinity 55A0, 200 sps

Similar to the results at 23° C, over the temperatures and sample rates evaluated, magnitude and phase varied little. Roll-off in the relative phase plots is apparent in the 20 sps, 40 sps, 100 sps and 200 sps data, consistent with a slight timing offset between channels.

3.11 Relative Transfer Function

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

3.11.1 Measurand

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

3.11.2 Configuration

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

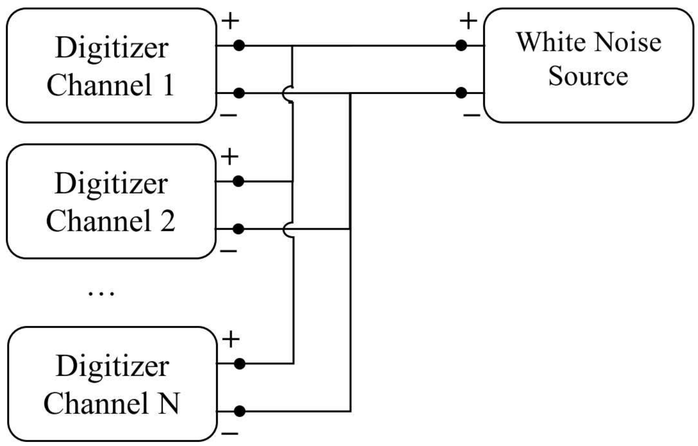

Figure 83 Relative Transfer Function Configuration Diagram

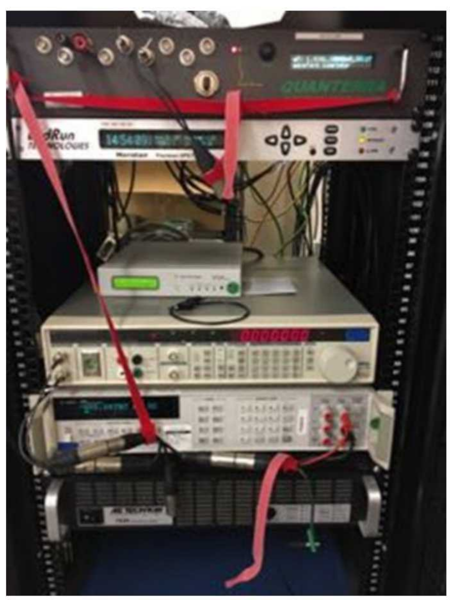

Figure 84 Relative Transfer Function Configuration Picture

Table 34 Relative Transfer Function Testbed Equipment

	Manufacturer / Model	Serial Number	Configuration
White Noise Source - Bunker	Stanford Research Systems DS360	123672	+1V / - 1 V
White Noise Source - SB1	Stanford Research Systems DS360	123669	+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.

3.11.3 Analysis

The measured bitweight, 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:

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

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

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

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:

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

3.11.4 Result

The phase delay versus frequency is shown for all of the evaluated sample rates and gains in the plots below. To the extent that the delay is a constant time offset, the phase delay is observed to be linear with respect to frequency.

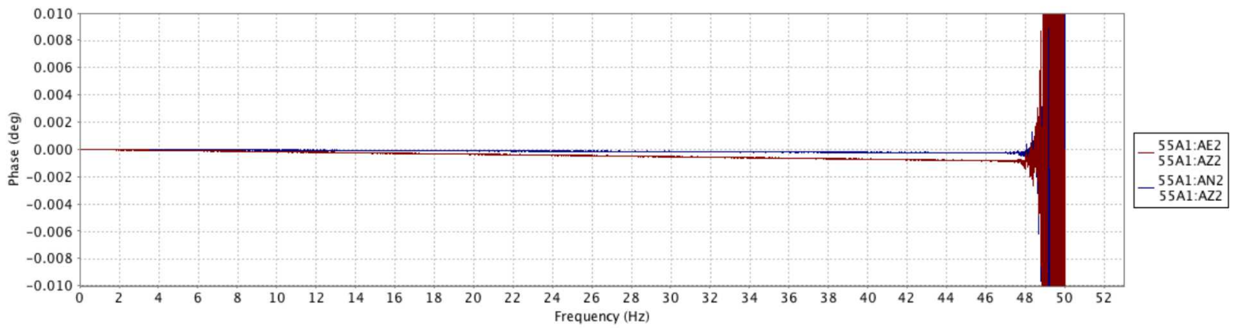

Figure 85 Relative Transfer Function, Affinity 55A1 , 23°C

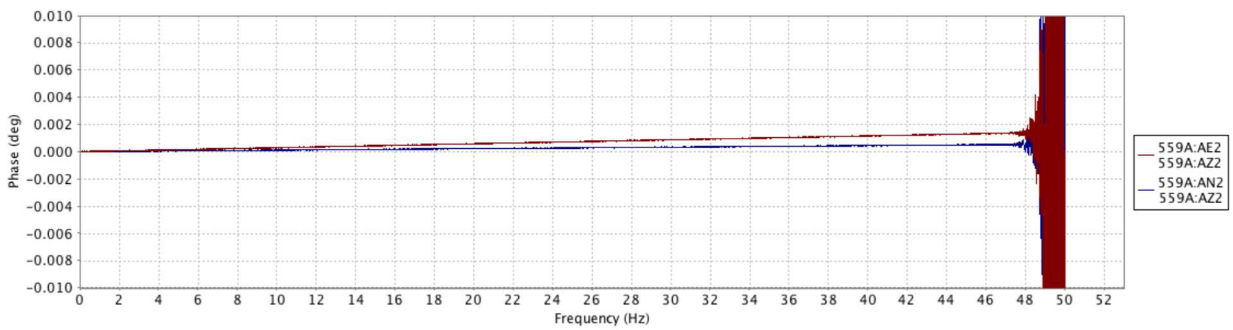

Figure 86 Relative Transfer Function, Affinity 559A, 23°C

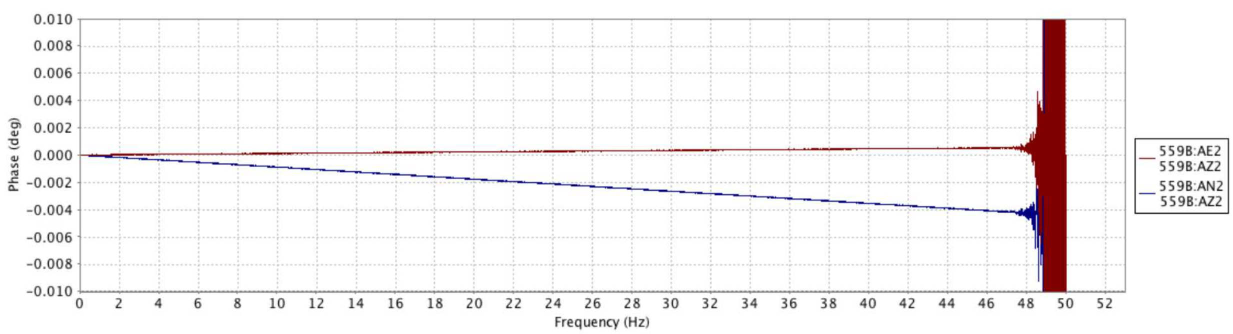

Figure 87 Relative Transfer Function, Affinity 559B, 23°C

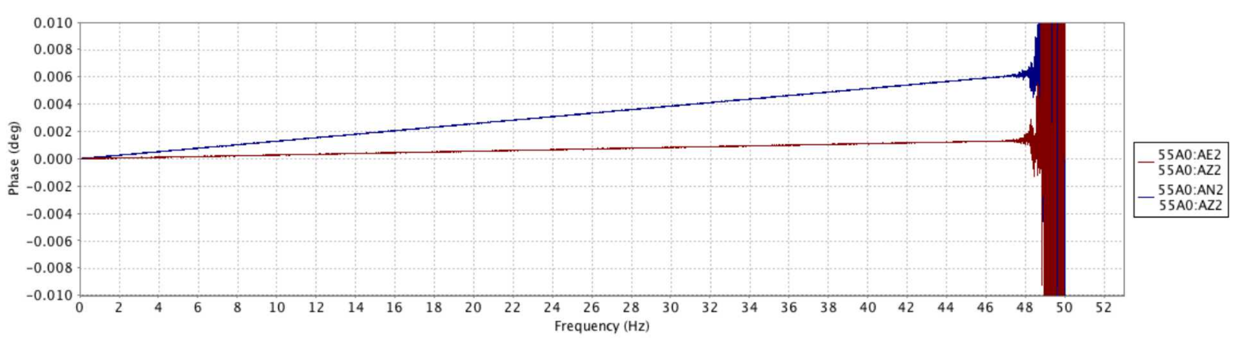

Figure 88 Relative Transfer Function, Affinity 55A0, 23°C

Phase delays are linear with respect to frequency for all dataloggers 559A, 559B, 55A0 and 55A1. The constant channel-to-channel timing skew corresponding to these phase delays is shown in the tables below.

Table 35 Relative Transfer Function Timing Skew

DWR	AE2 (channel 3)	AN2 (channel 2)
55A1	-00.05 us	-00.02 us
559A	00.08 us	00.08 us
559B	00.03 us	-00.25 us
55A0	00.08 us	00.36 us

All of the channels were observed to have a timing skew that was within half a microsecond of one another.

The following plots show the relative transfer function for Affinity 55A0 across variations in temperature and gain setting.

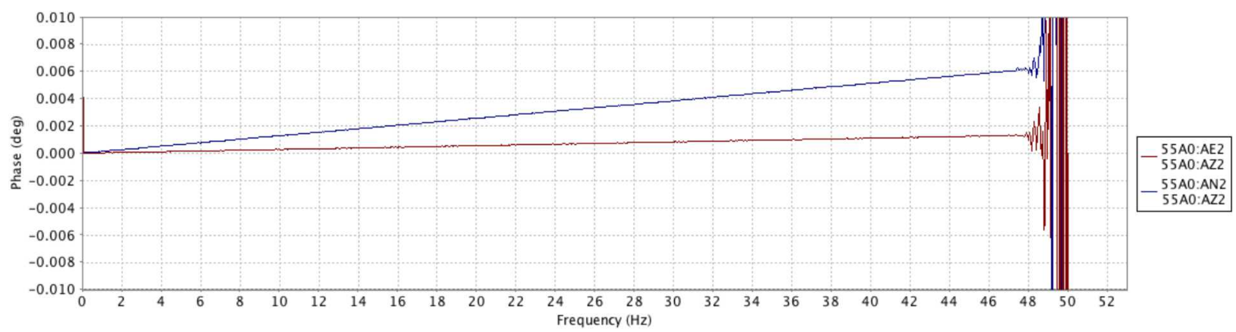

Figure 89 Relative Transfer Function, Affinity 55A0, 60° C

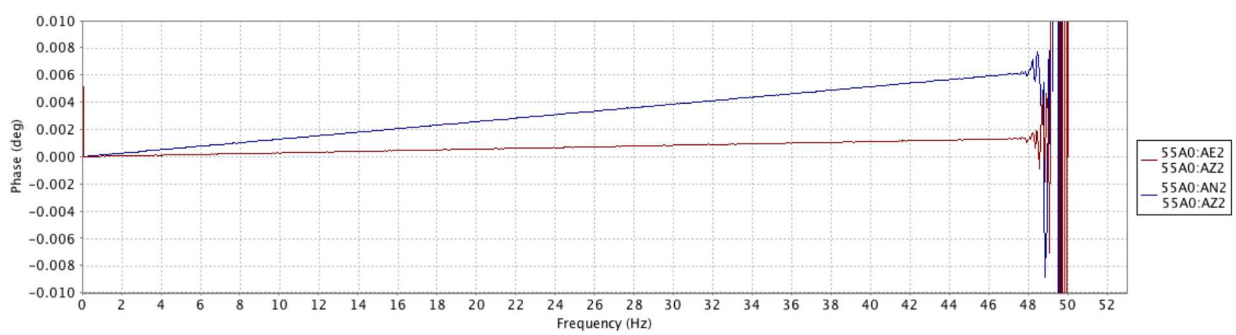

Figure 90 Relative Transfer Function, Affinity 55A0, 20° C

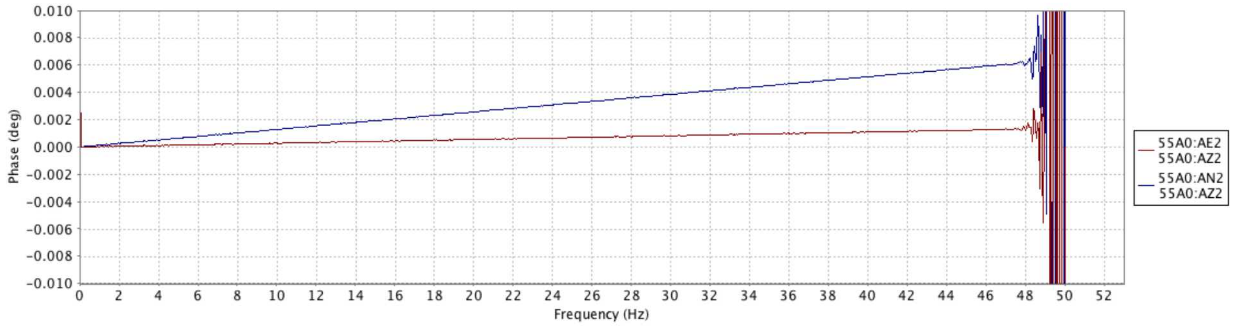

Figure 91 Relative Transfer Function, Affinity 55A0, 20° C, 2x Gain

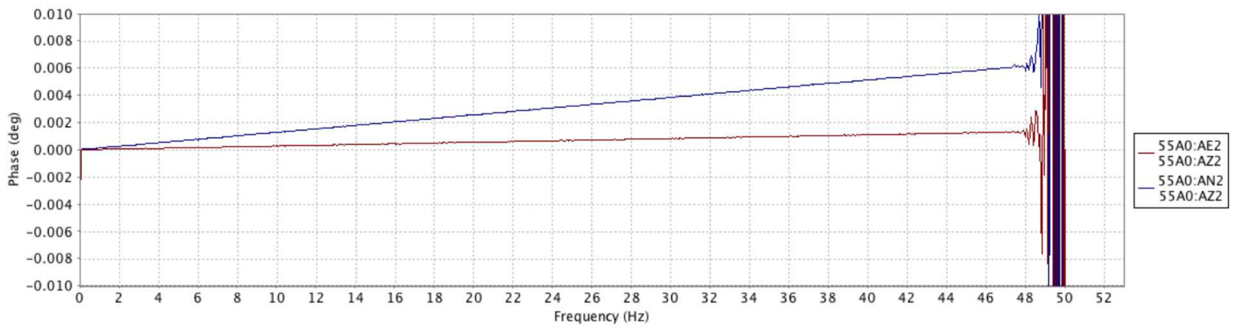

Figure 92 Relative Transfer Function, Affinity 55A0, 20° C, 4x Gain

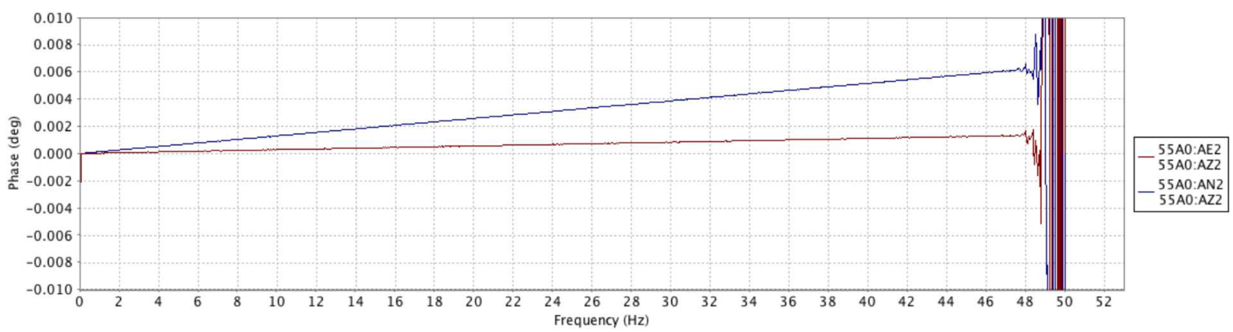

Figure 93 Relative Transfer Function, Affinity 55A0, -25° C

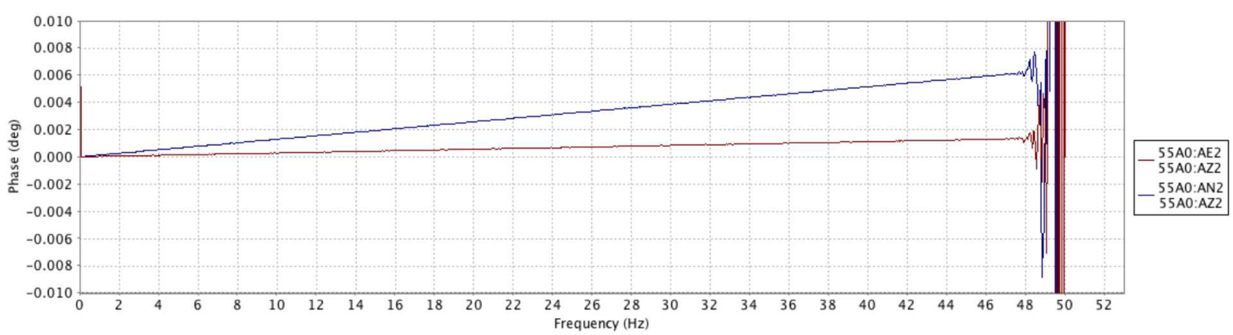

Figure 94 Relative Transfer Function, Affinity 55A0, -36° C

Phase delays are linear with respect to frequency and are very consistent across the temperature to which the dataloggers were exposed and across configured gain settings.

Table 36 Relative Transfer Function Timing Skew, Affinity 55A0 at Select Temperatures

Temperature	AE2 (channel 3)	AN2 (channel 2)
60° C	00.08 us	00.36 us
20° C	00.08 us	00.36 us
20° C gain 2x	00.08 us	00.36 us
20° C gain 4x	00.08 us	00.36 us
-25° C	00.08 us	00.36 us
-36° C	00.08 us	00.36 us

Timing skews observed of datalogger 55A0 are stable, with no measureable difference across the temperatures to which the datalogger was exposed, nor with the gain setting varying between 1x, 2x and 4x.

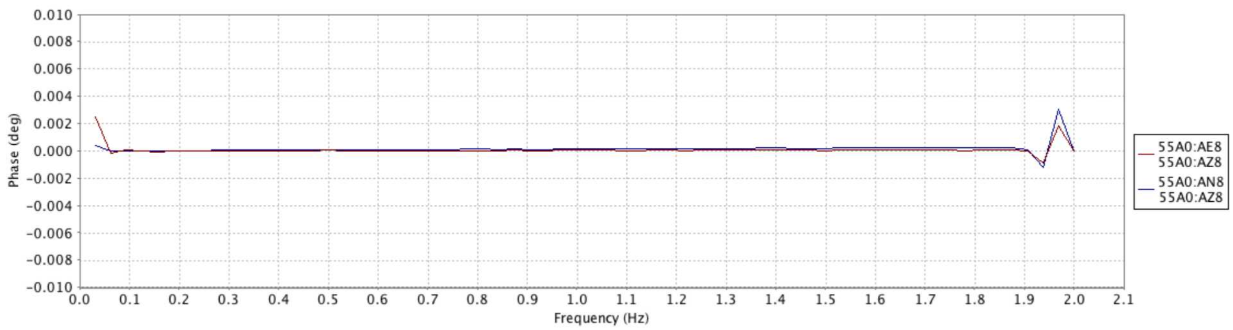

Figure 95 Relative Transfer Function, Affinity 55A0, 4 sps

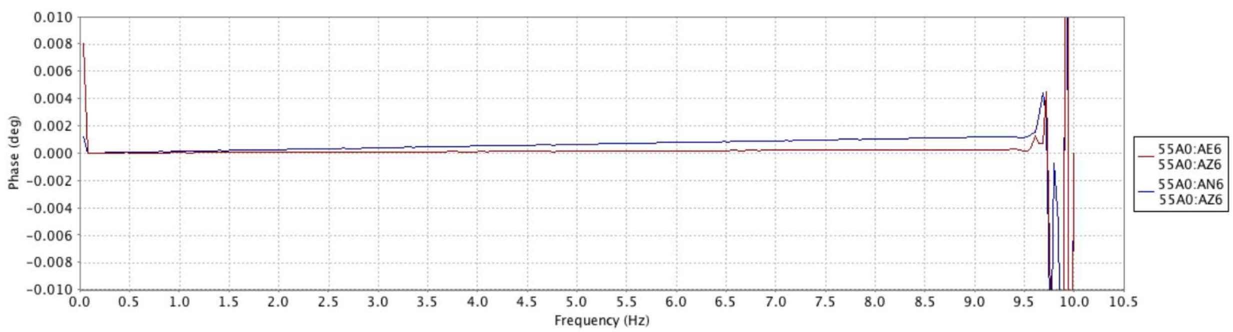

Figure 96 Relative Transfer Function, Affinity 55A0, 20 sps

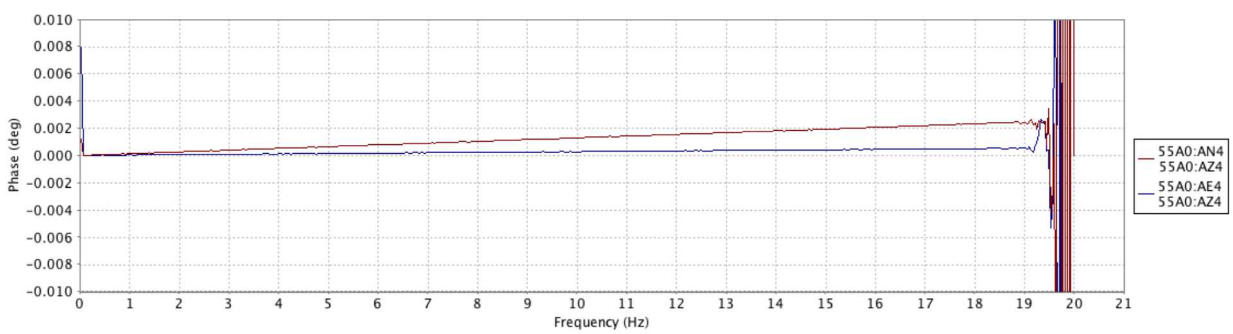

Figure 97 Relative Transfer Function, Affinity 55A0, 40 sps

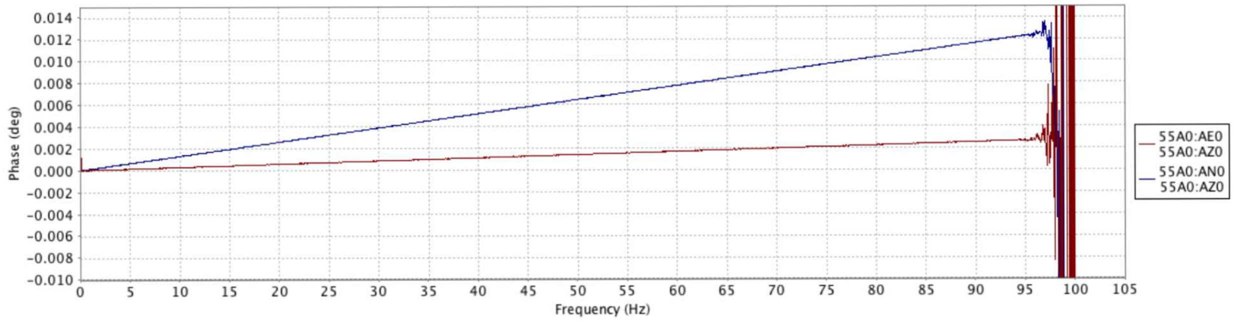

Figure 98 Relative Transfer Function, Affinity 55A0, 200 sps

Phase delays are observed at 5 sps and 20 sps are negligible. Phase delays appear to be linear and are more appreciable at higher sample rates (>= 40 sps).

Table 37 Relative Transfer Function Timing Skew, Affinity 55A0 at Select Sample Rates

Sample Rate	Channel 3	Channel 2
4 sps	00.09 us	00.36 us
20 sps	00.08 us	00.36 us
40 sps	00.08 us	00.36 us
100 sps	00.08 us	00.36 us
200 sps	00.08 us	00.36 us

Timing skews observed at selected sample rates, are very stable, ranging from 0.08 us to 0.09 us for channel 3 and 0.36 us for channel 2.

3.12 Analog Bandwidth

The Analog Bandwidth test measures the bandwidth of the digitizer's analog and digital filter.

3.12.1 Measurand

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

3.12.2 Configuration

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

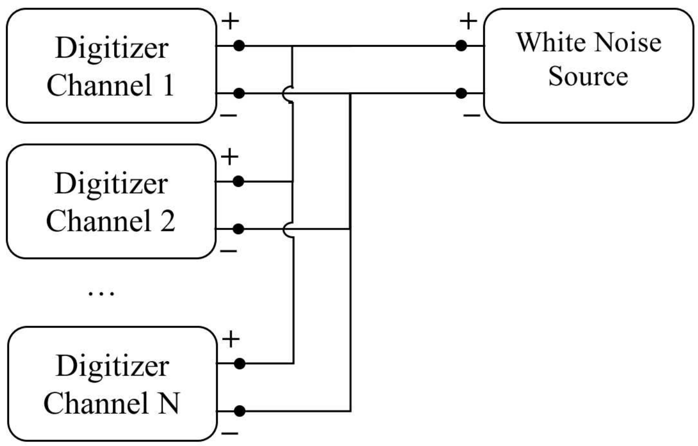

Figure 99 Analog Bandwidth Configuration Diagram

Table 38 Analog Bandwidth Testbed Equipment

	Manufacturer / Model	Serial Number	Configuration
White Noise Source - Bunker	Stanford Research Systems DS360	123672	+1V / - 1 V
White Noise Source - SB1	Stanford Research Systems DS360	123669	+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. Seven and one hour data recordings were utilized for the evaluation across all dataloggers and for evaluations at select temperatures, gains and sample rates, respectively.

3.12.3 Analysis

The measured bitweight, 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 and the 3 dB point in the power spectra is measured.

3.12.4 Result

The power spectra of the white noise signal recorded on the Affinity digitizer channels are shown in the plots below.

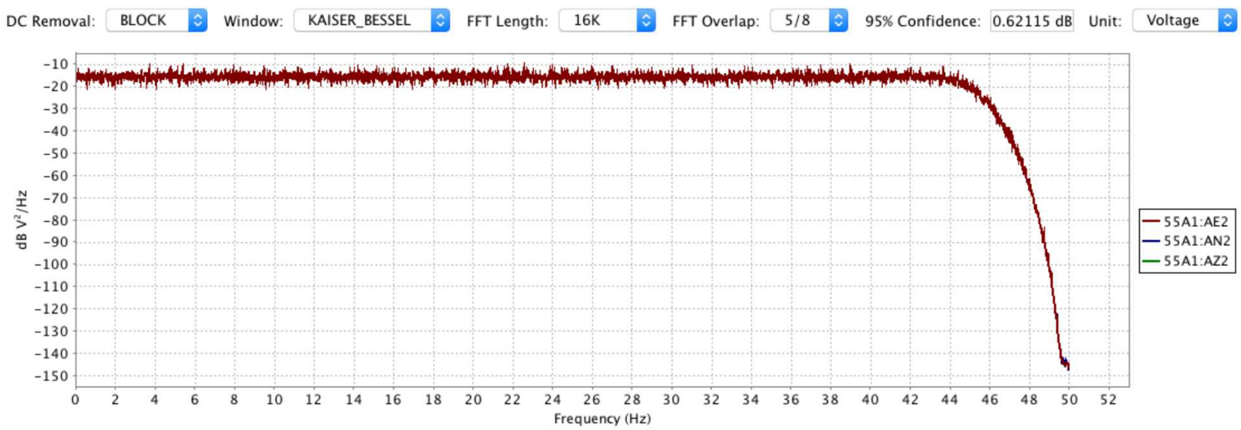

Figure 100 Analog Bandwidth Affinity 55A1, 23° C

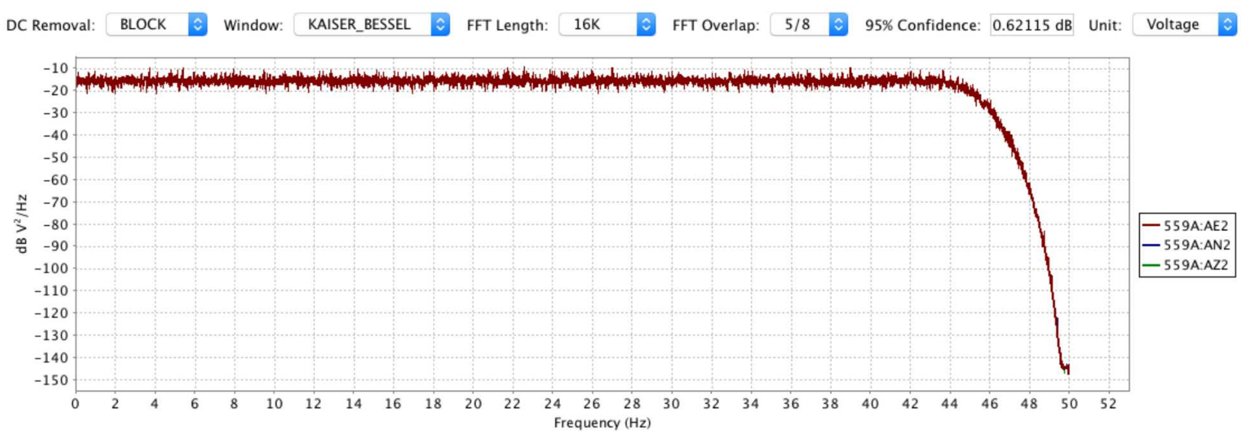

Figure 101 Analog Bandwidth Affinity 559A, 23° C

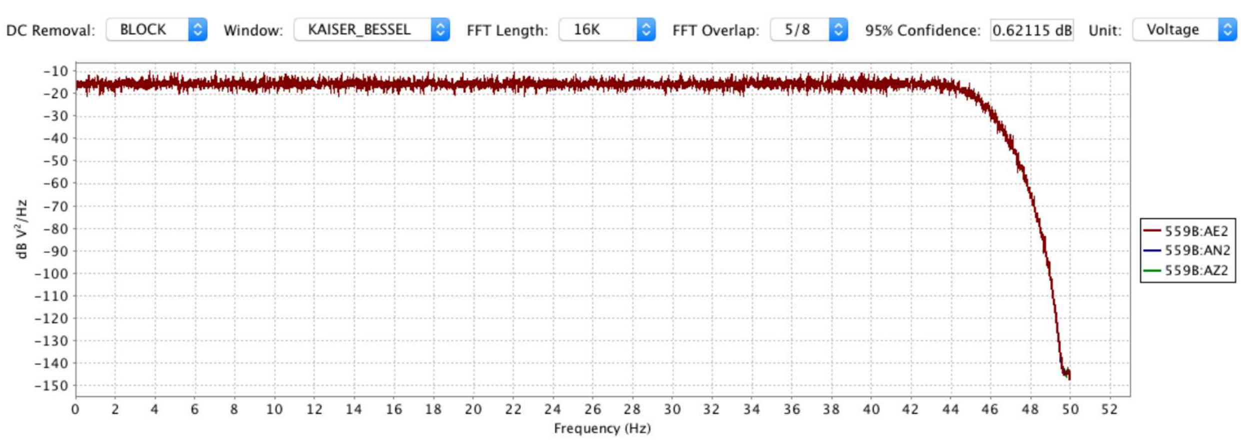

Figure 102 Analog Bandwidth Affinity 559B, 23° C

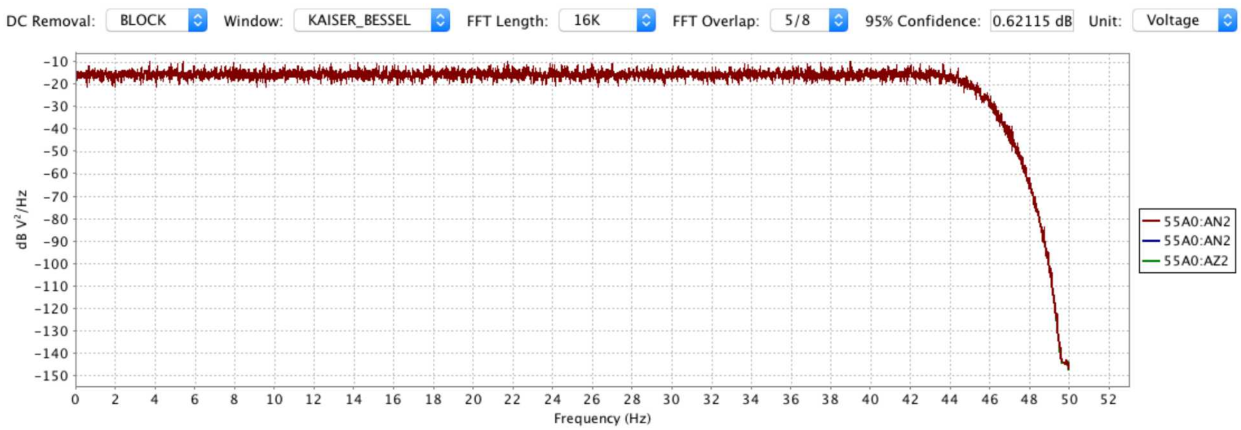

Figure 103 Analog Bandwidth Affinity 55A0, 23° C

Table 39 Analog Bandwidth, All Affinitys, 23° C

DWR	AE2 (channel 3)	AN2 (channel 6)	AZ2 (channel 1)	% Nyquist Frequency
55A1	44.940 Hz	44.940 Hz	44.940 Hz	89.88 %
559A	44.678 Hz	44.678 Hz	44.678 Hz	89.36 %
559B	44.666 Hz	44.666 Hz	44.666 Hz	89.33 %
55A0	44.885 Hz	44.885 Hz	44.885 Hz	89.77 %

The observed pass-band limit of all the dataloggers while recording 100 sps, with a 1x gain, while exposed to 20° C remained between 89.33% and 89.88% of the 50 Hz Nyquist Frequency.

The following plots contain the bandwidth across variations in temperature, gain, and sample rate for Affinity 55A0.

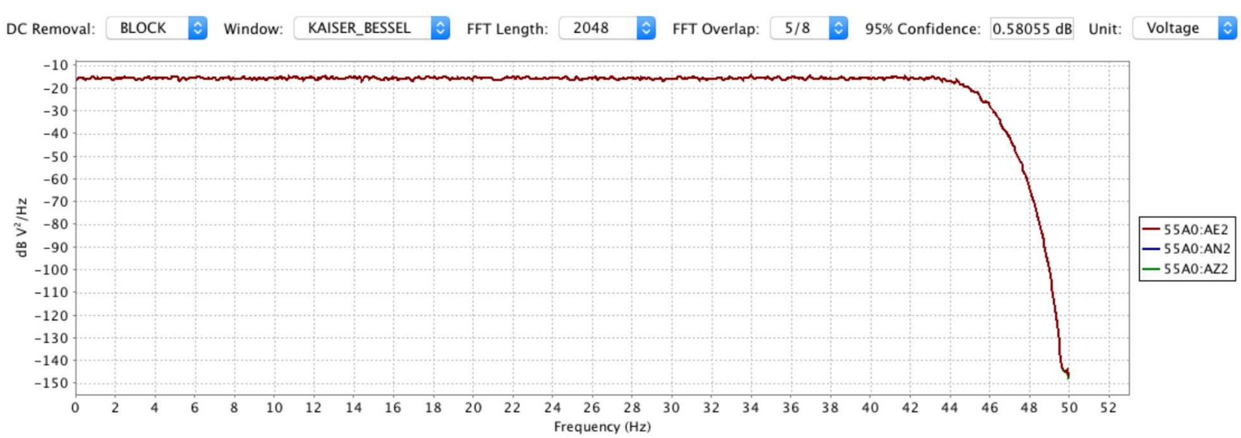

Figure 104 Analog Bandwidth Affinity 55A0, 60° C

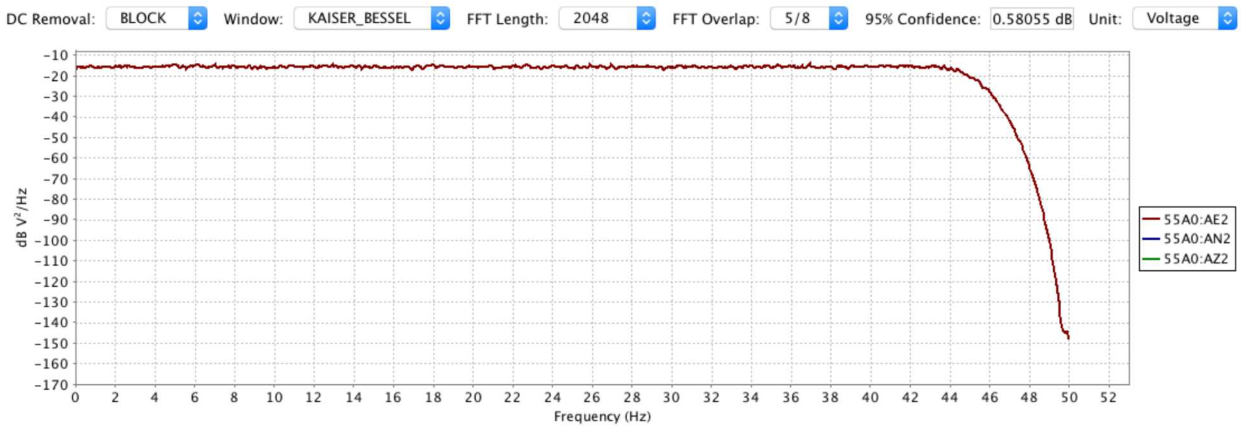

Figure 105 Analog Bandwidth Affinity 55A0, 20° C

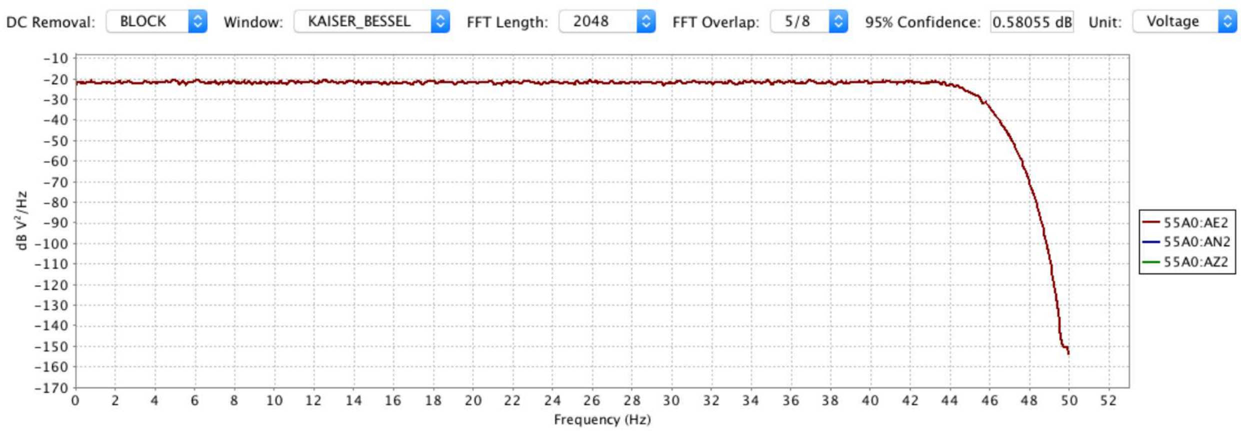

Figure 106 Analog Bandwidth Affinity 55A0, 20° C, 2x Gain

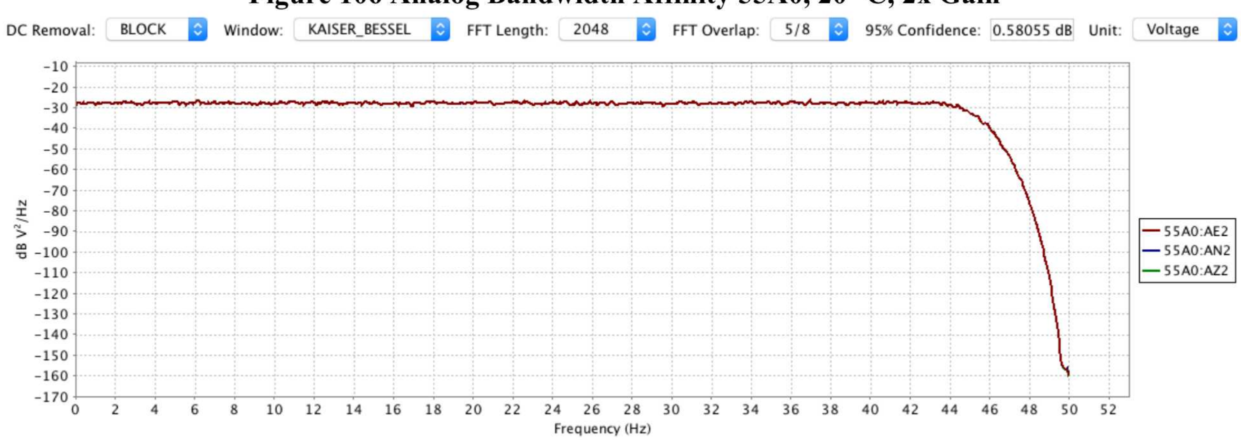

Figure 107 Analog Bandwidth Affinity 55A0, 20° C, 4x Gain

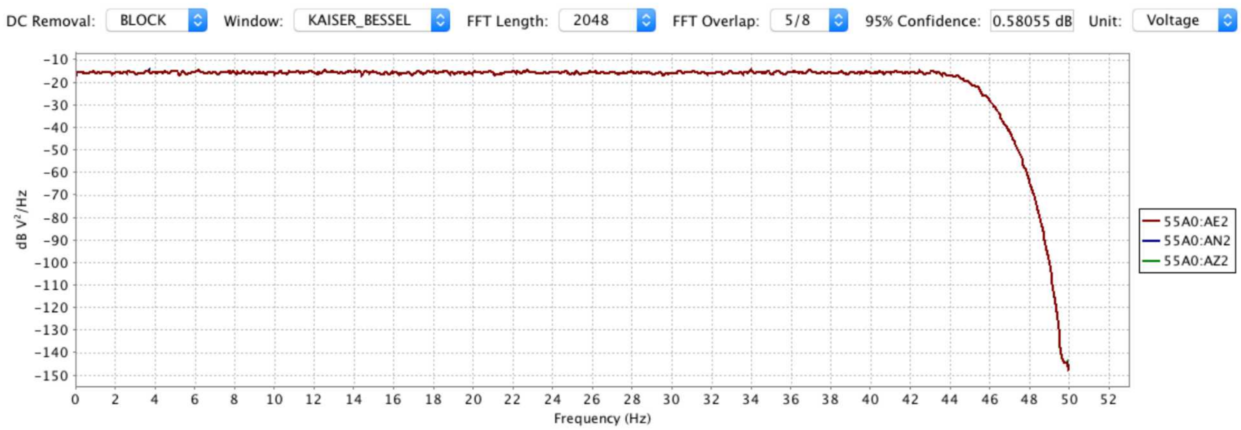

Figure 108 Analog Bandwidth Affinity 55A0, -25° C

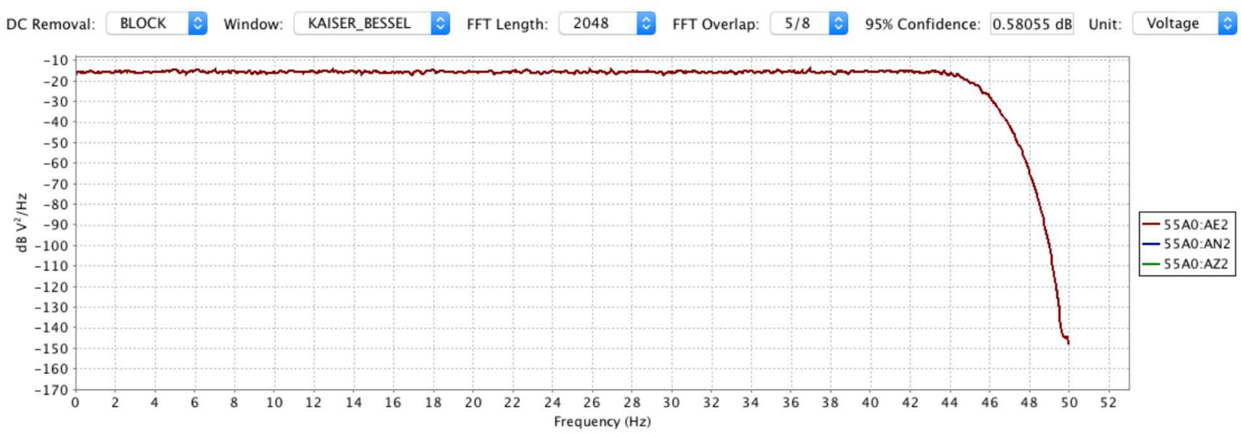

Figure 109 Analog Bandwidth Affinity 55A0, -36° C

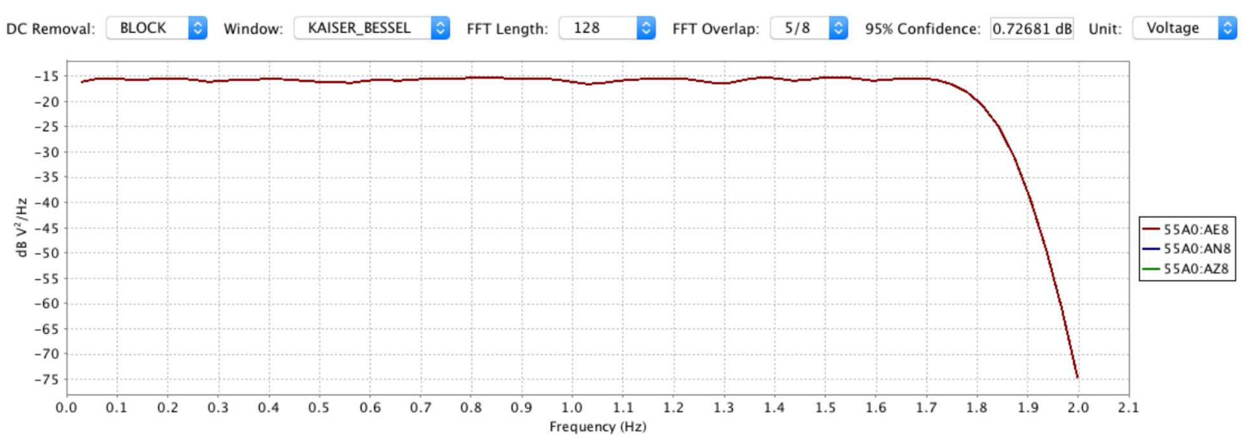

Figure 110 Analog Bandwidth Affinity 55A0, 4 sps

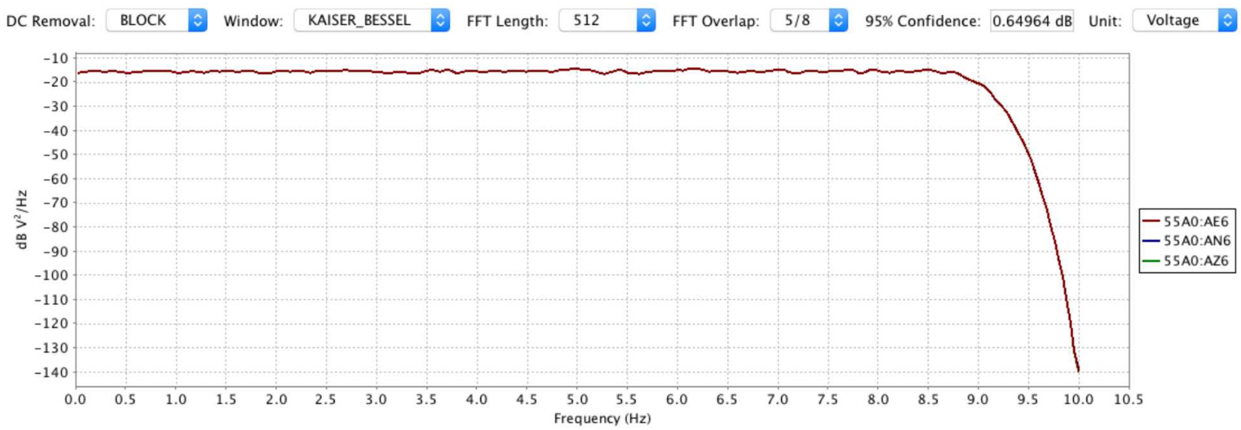

Figure 111 Analog Bandwidth Affinity 55A0, 20 sps

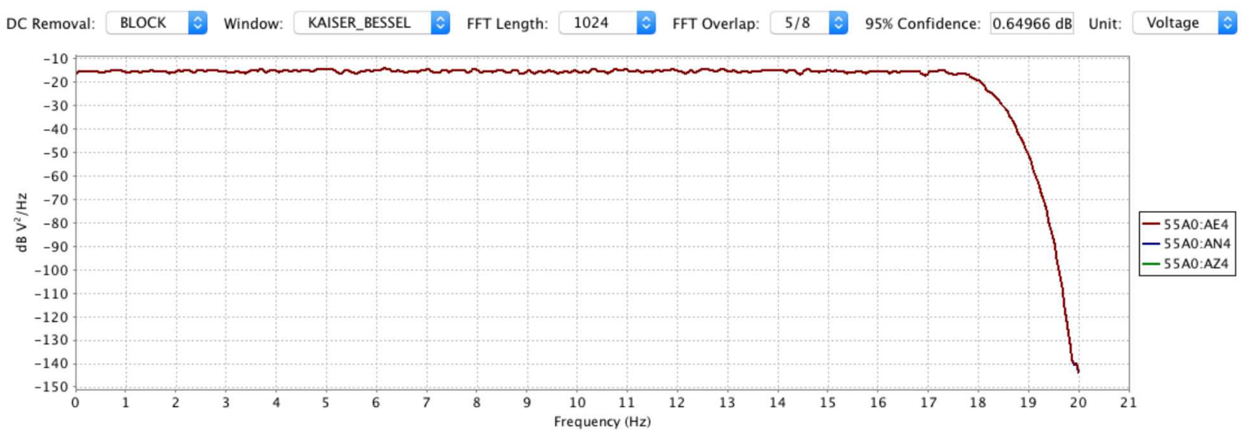

Figure 112 Analog Bandwidth Affinity 55A0, 40 sps

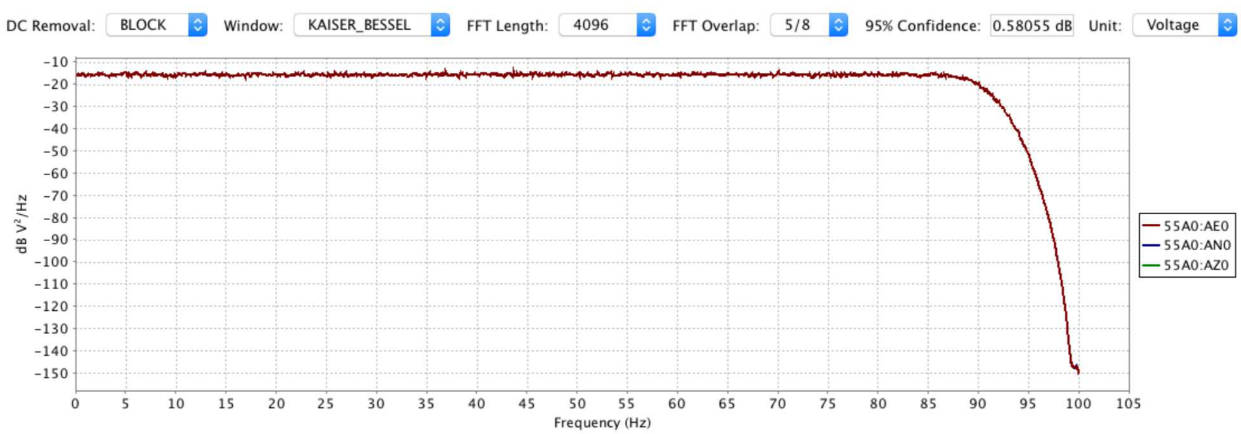

Figure 113 Analog Bandwidth Affinity 55A0, 200 sps

Table 40 Analog Bandwidth, Affinity 55A0, at Select Temperatures and Sample Rates

Temperature, Sample Rate	Channel 3	Channel 2	Channel 1	% Nyquist Frequency
60 C, 100 sps	44.824 Hz	44.824 Hz	44.824 Hz	89.65%
20 C 100 sps	44.775 Hz	44.775 Hz	44.775 Hz	89.55%
20 C, 100 sps gain 2x	44.727 Hz	44.727 Hz	44.727 Hz	89.45%
20 C, 100 sps gain 4x	44.824 Hz	44.824 Hz	44.824 Hz	89.65%
-25 C, 100 sps	43.775Hz	43.775 Hz	43.775 Hz	89.55%
-36 C, 100 sps	44.775 Hz	44.775 Hz	44.775 Hz	89.55%
20 C, 4 sps	1.781 Hz	1.781 Hz	1.781 Hz	89.05%
20 C, 20 sps	8.867 Hz	8.867 Hz	8.867 Hz	88.67%
20 C, 40 sps	17.93 Hz	17.93 Hz	17.93 Hz	89.65%
20 C, 200 sps	89.502 Hz	89.502 Hz	89.502 Hz	89.50%

The passband limits of datalogger 55A0 are tightly clustered across the temperatures at which observations were made, between 89.55% and 89.65% of the Nyquist frequency. Across the range of sample rates, analogy bandwidth, expressed as a percentage of the Nyquist frequency, varied slightly more than over the temperature ranges tested, from 88.67% to 89.65%.

Across all tests, analog bandwidth remained at least 88.67% of the Nyquist Frequency.

3.13 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.

3.13.1 Measurand

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

3.13.2 Configuration

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

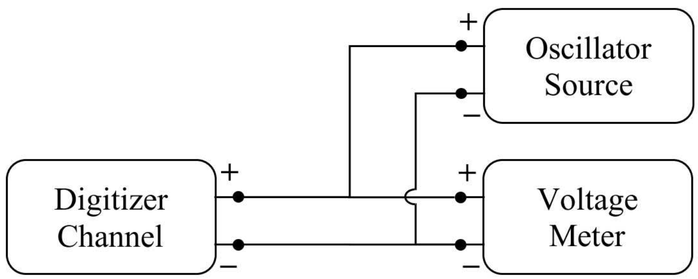

Figure 114 THD Configuration Diagram

Figure 115 Total Harmonic Distortion Configuration

Table 41 Total Harmonic Distortion Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
Oscillator Source - Bunker	End Run Technologies/Meridian GPS 3025-0101 Quanterra/Supertonal Signal Source	12010020 021202	+5 V / -5 V
Voltage Meter - Bunker	Agilent 3458A	MY45048372	10 V full scale
Voltage Meter – Bunker #2	Agilent 3458A	MY45048371	10 V full scale
Oscillator Source – SB1	End Run Technologies/Meridian GPS 3025-0101 Quanterra/Supertonal Signal Source	12010021 021204	+5 V / -5 V
Voltage Meter – SB1*	Agilent 3458A	MY45048372	10 V full scale

* Meter MY450448372, while installed in SB1, was utilized for measuring THD while under the following conditions: gain x2 and x4 at a temperature of 20° C; gain x1 and temperatures at -36° C, 20° C, -25° C and 60° C.

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 noise from digital electronics containing a pulse-per-second timing.

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.

3.13.3 Analysis

The measured bitweight, 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 a Kaiser-Bessel window varying in length from 4k to 16k window dependent upon on the sample rate of the data recorded. 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 90% confidence interval ideally 0.5 db or below, though in practice the 90% confidence interval ranged between 0.39 dB and 0.89 dB; at the lowest sample rate the 90% confidence interval increases to has high as 1.43 dB.

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

Over frequencies (in Hertz):

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

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.

3.13.4 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.

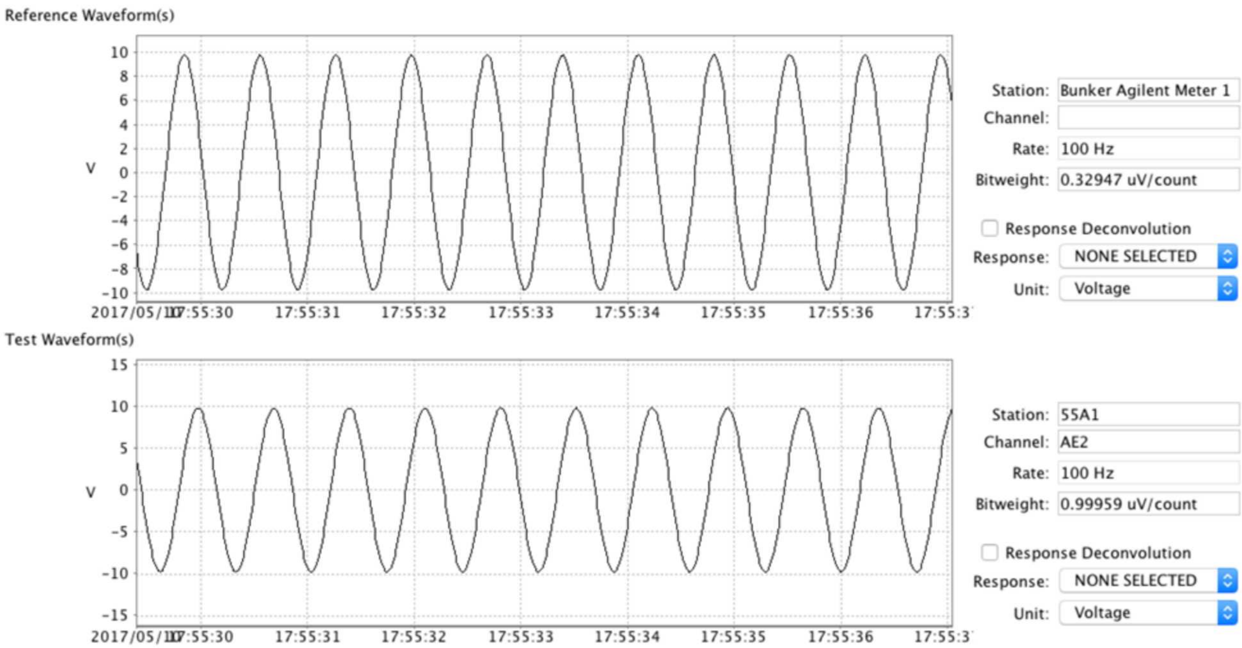

Figure 116 THD Time Series

The figures below show the power spectra of the THD for each of the digitizers evaluated.

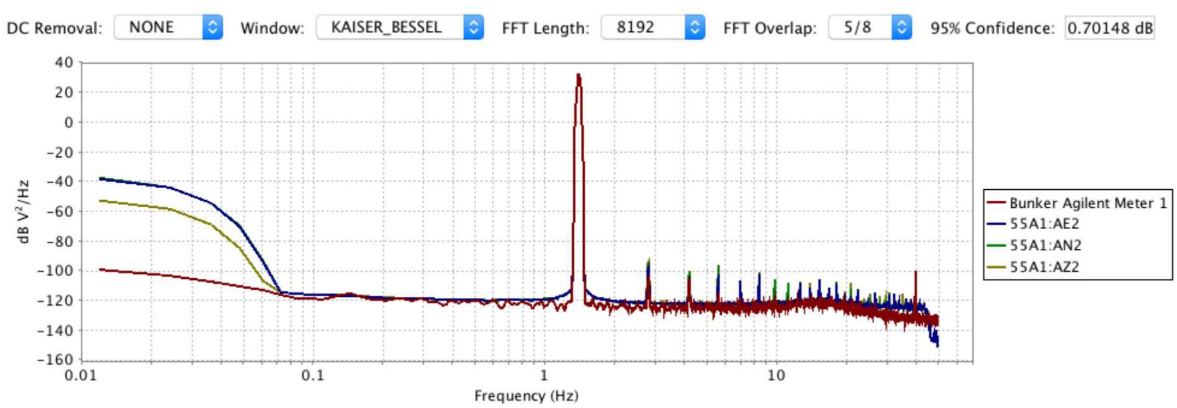

Figure 117 THD Power Spectra Affinity 55A1, 100 sps

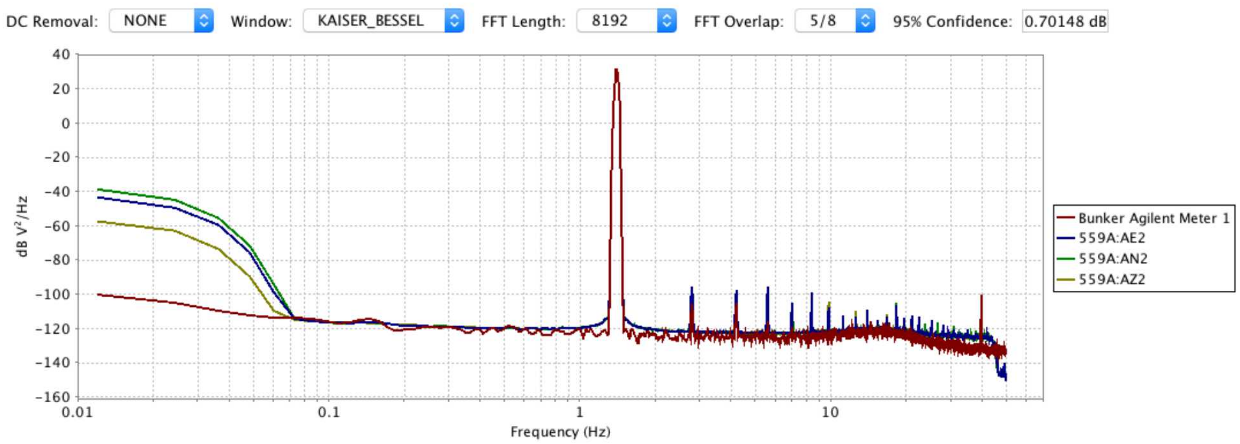

Figure 118 THD Power Spectra Affinity 559A, 100 sps

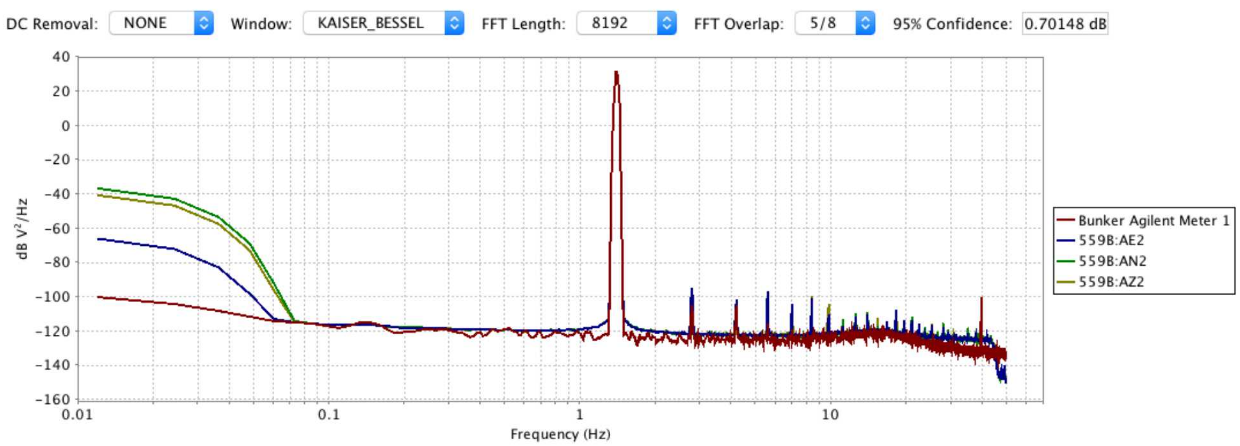

Figure 119 THD Power Spectra Affinity 559B, 100 sps

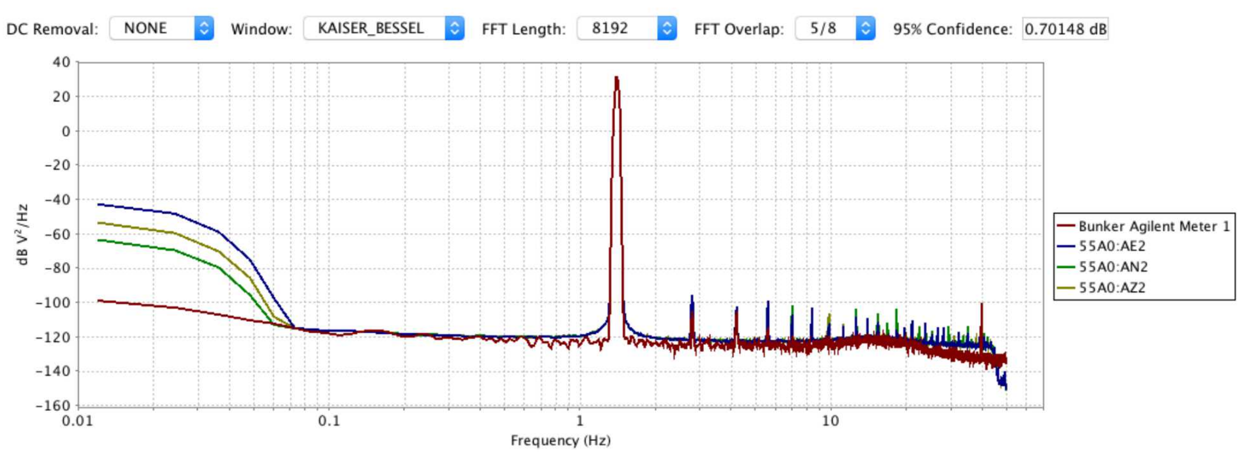

Figure 120 THD Power Spectra Affinity 55A0, 100 sps

Table 42 Total Harmonic Distortion, All Dataloggers, 23° C

DWR	Reference Meter	00HHE (chan 3)	00HHN (chan 2)	00HHZ (chan 1)
55A1	-132.97 dB	-126.01 dB	-123.61 dB	-122.54 dB
559A	-133.23 dB	-122.16 dB	-126.10 dB	-124.80 dB
559B	-133.29 dB	-123.29 dB	-124.34 dB	-124.30 dB
55A0	-133.10 dB	-124.25 dB	-126.33 dB	-126.01 dB

In all cases, the reference measurement of the signal generated by the low distortion oscillator exceeded the measurement made on the digitizer channel indicating that the distortion observed is due to the digitizer. The observed harmonic distortion ranged between -122.16 dB and -126.33 dB.

The figures below show the power spectra of the THD for Affinity 55A0 across a range of temperature exposures and gain levels.

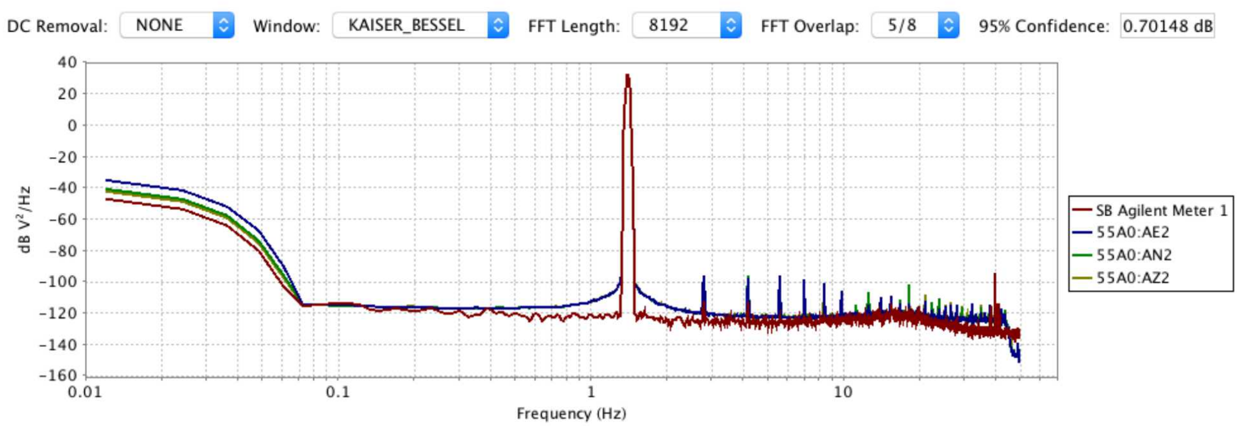

Figure 121 THD Power Spectra Affinity 55A0, 60° C

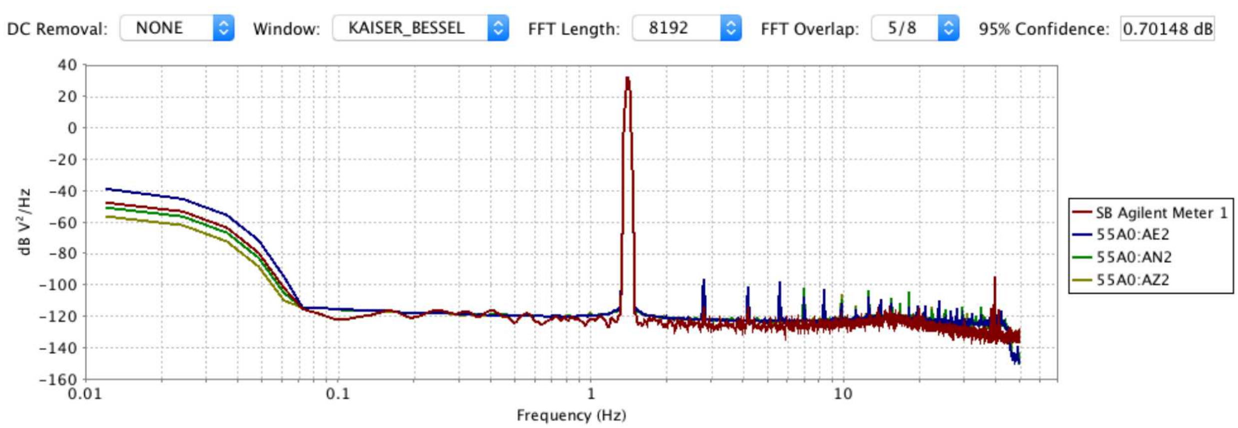

Figure 122 THD Power Spectra Affinity 55A0, 20° C

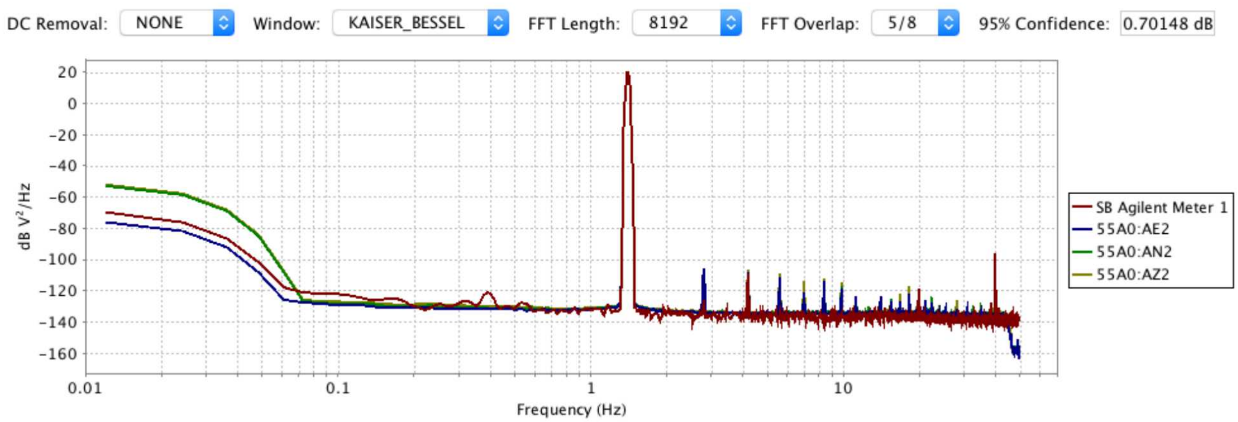

Figure 123 THD Power Spectra Affinity 55A0, 20° C, 4x Gain

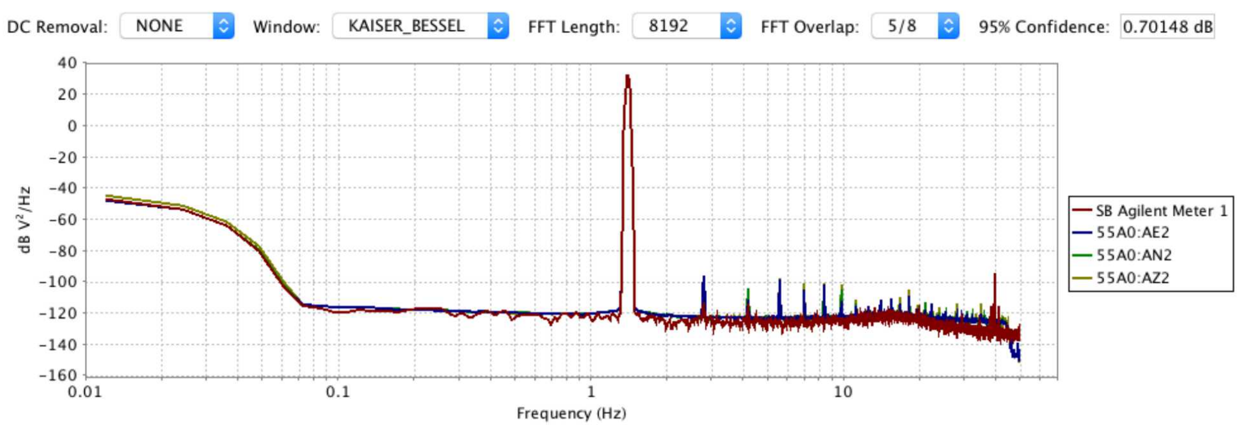

Figure 124 THD Power Spectra Affinity 55A0, -25° C

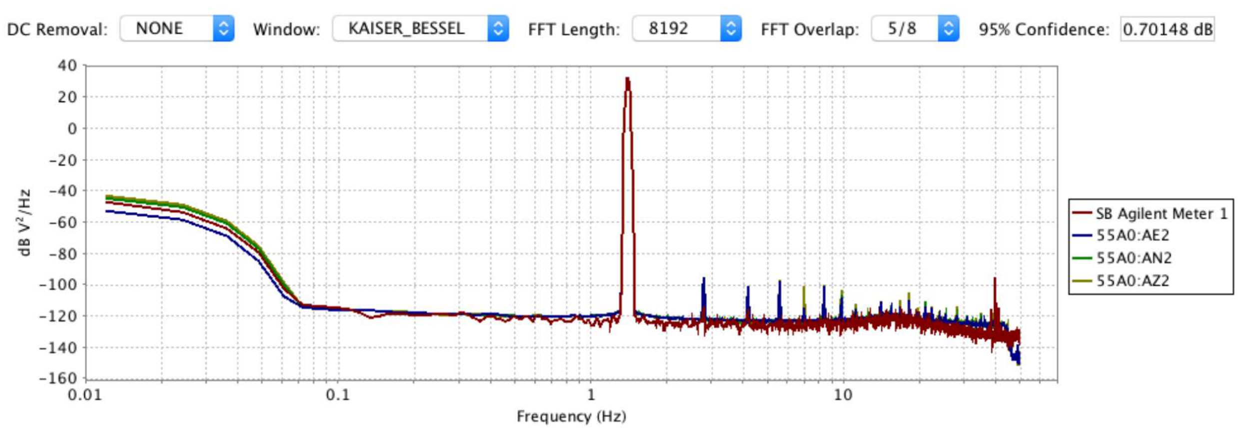

Figure 125 THD Power Spectra Affinity 55A0, -36° C

Table 43 Total Harmonic Distortion at Select Temperatures

Temp	Reference Meter	00HHE (chan 3)	00HHN (chan 2)	00HHZ (chan 1)
60° C	-139.55 dB	-122.38 dB	-125.33 dB	-124.74 dB
20° C	-142.12 dB	-124.47 dB	-126.55 dB	-125.99 dB
20° C, gain 4x	-128.49 dB	-122.51 dB	-123.63 dB	-122.07 dB
-25° C	-141.56 dB	-124.96 dB	-125.63 dB	-124.38 dB
-36° C	-140.93 dB	-124.09 dB	-124.98 dB	-123.92 dB

Total Harmonic Distortion varied, though no relationship between THD with temperature is present. Channels 1 and 2 had their best THD values at 20° C while recording at a gain of 1x; channel 3 at -25° C. Channel 2 had the most stable THD over the temperatures tested, varying no more than 1.24% when exposed to -36° C. The maximum variation of THD over temperatures was 2.07%, which was observed on channel 3 while exposed to 60° C.

The following figures show the power spectra of the THD for Affinity 55A0 across a range of sample rates.

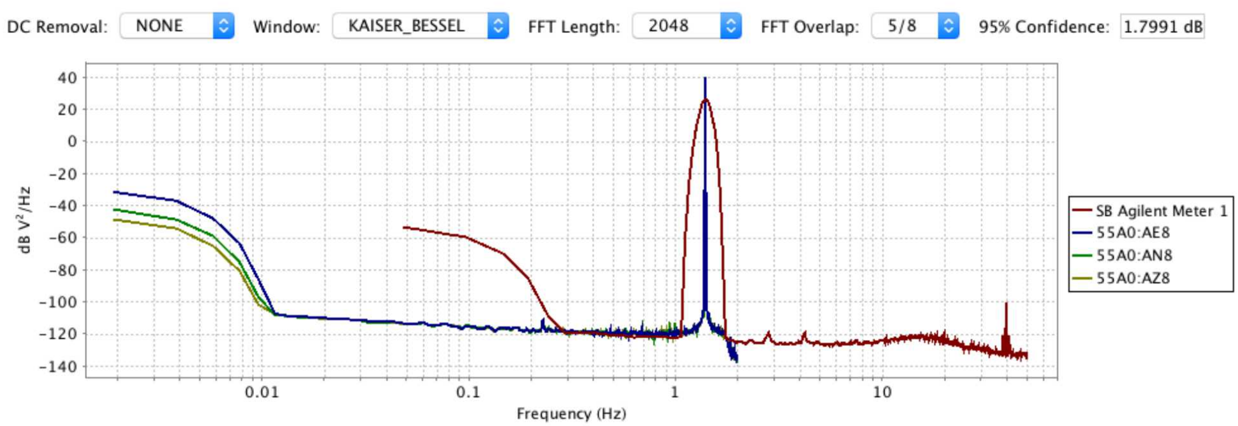

Figure 126 THD Power Spectra Affinity 55A0, 4 sps

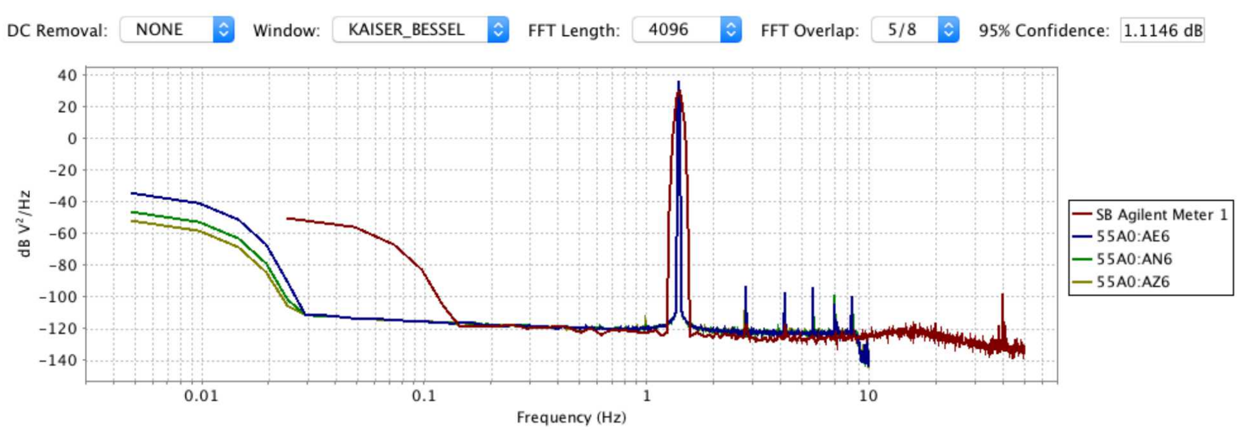

Figure 127 THD Power Spectra Affinity 55A0, 20 sps

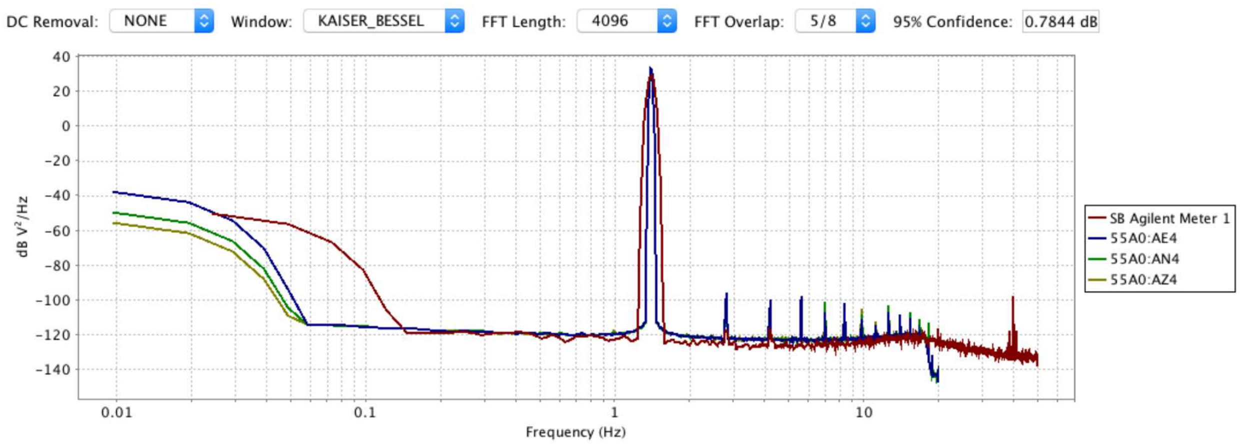

Figure 128 THD Power Spectra Affinity 55A0, 40 sps

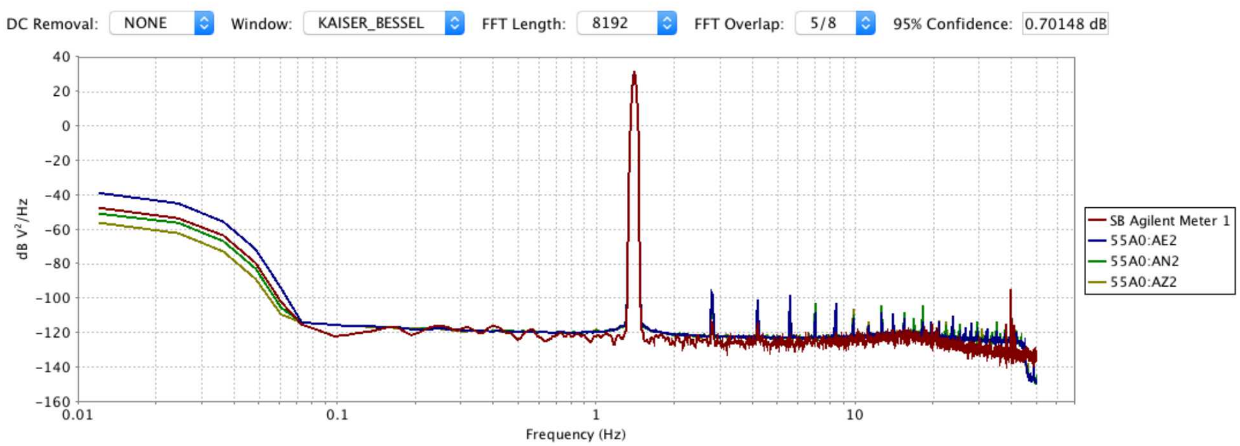

Figure 129 THD Power Spectra Affinity 55A0, 100 sps

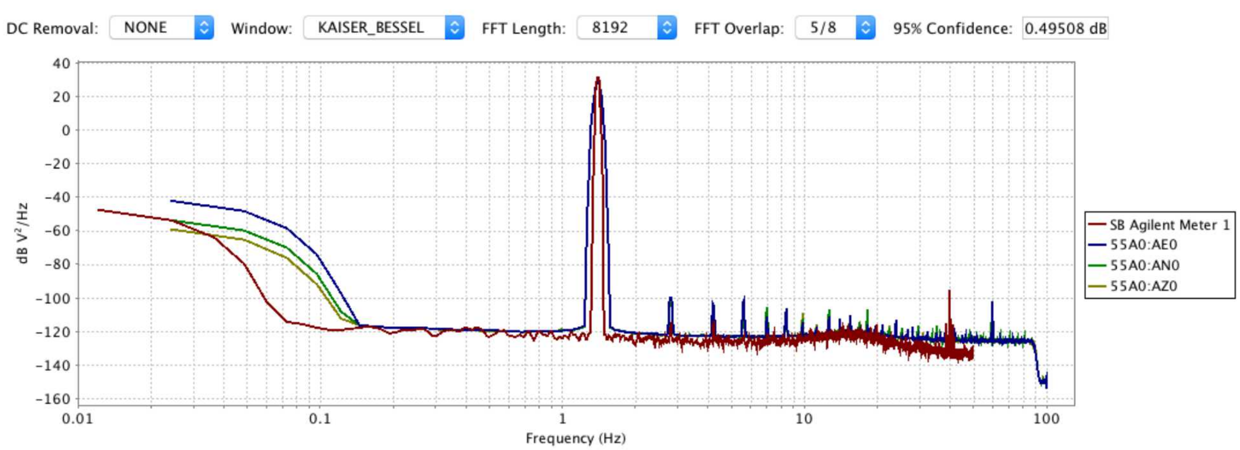

Figure 130 THD Power Spectra Affinity 55A0, 200 sps

Table 44 Total Harmonic Distortion at Select Sample Rates

Sample Rate	Reference Meter	Channel 3	Channel 2	Channel 1
4 sps	-137.06 dB	-180.06 dB	-181.14 dB	-181.50 dB
20 sps	-141.55 dB	-125.01 dB	-127.76 dB	-126.67 dB
40 sps	-141.28 dB	-124.54 dB	-126.58 dB	-126.08 dB
100 sps	-142.12 dB	-124.47 dB	-126.55 dB	-125.99 dB
200 sps	-140.56 dB	-124.31 dB	-126.22 dB	-125.78 dB

Total Harmonic Distortion varies several dB (discounting the very low THD calculated at 4 sps in this analysis due to the limited number of harmonics present). When compared to the lowest THD, which occurred, for all channels, at a sample rate of 20 sps, Channel 3 (AE6) varied the least from its best THD, -125.01 by only 0.56% at 200 sps sample rate. The largest varying THD occurred on Channel 2, where it varied as much as 1.20% at 200 sps from -127.76 dB, its best THD calculated.

THD over all test conditions (at 1x gain) varied from -122.16 dB (100 sps sample rate) at 23°C to -127.76 db at 20 sps sample rate (discounting the calculated THD at 4 sps).

3.14 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.

3.14.1 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.

3.14.2 Configuration

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

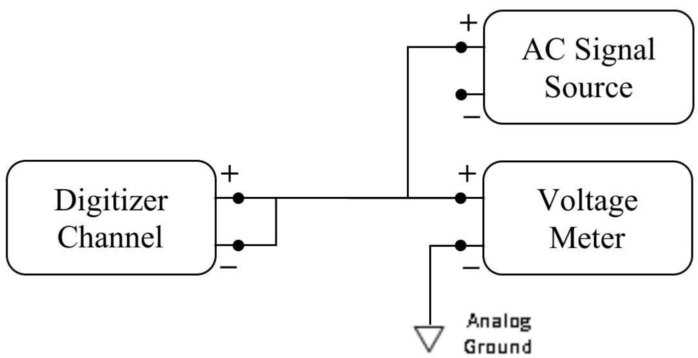

Figure 131 Common Mode Rejection Configuration Diagram

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.

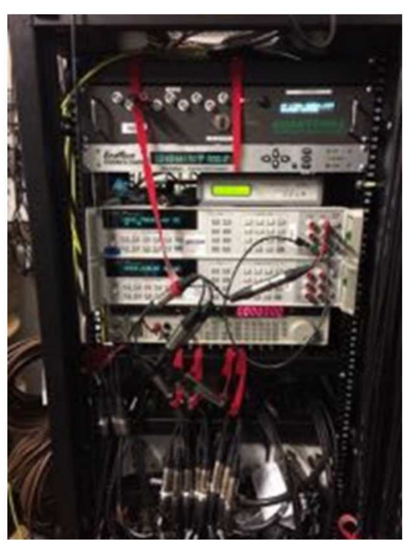

Figure 132 Common Mode Rejection Configuration

Table 45 Common Mode Rejection Testbed Equipment

	Manufacturer / Model	Serial Number	Configuration
DC Signal Source - Bunker	Stanford Research Systems DS360	123672	+1V / - 1 V
Voltage Meter - Bunker	Agilent 3458A	MY45048372	1 V full scale
DC Signal Source - SB1	Stanford Research Systems DS360	123669	+1V / - 1 V
Voltage Meter - SB1	Agilent 3458A	MY45048372	1 V full scale

The AC Signal Source is configured to generate an 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. 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.

3.14.3 Analysis

A minimum of a 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:

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

3.14.4 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.

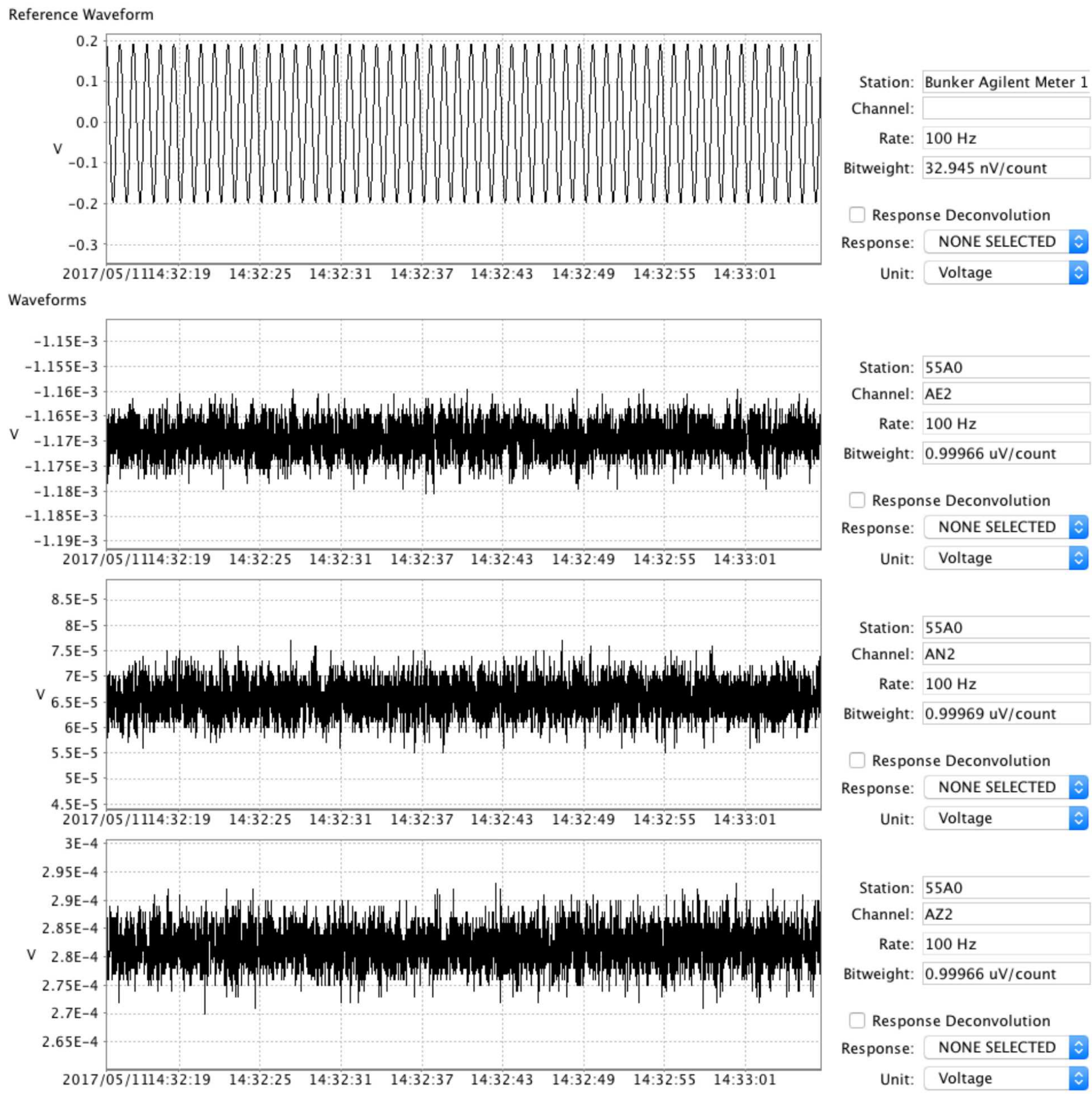

Figure 133 Common Mode Rejection Time Series

The following table contains the computed common mode noise and rejection ratio.

Table 46 Common Mode Rejection Ratio, All Dataloggers, 23° C

DWR		AE2 (chan 3)	AN2 (chan 2)	AZ2 (chan 1)
55A1	Amplitude	0.09 uV	0.06 uV	0.12 uV
	Rejection Gain	126.66 dB	130.87 dB	124.52 dB
559A	Amplitude	0.12 uV	0.21 uV	0.23 uV
	Rejection Gain	123.83 dB	119.42 dB	118.59 dB
559B	Amplitude	0.13 uV	0.80 uV	0.04 uV
	Rejection Gain	123.43 dB	107.71 dB	133.00 dB
55A0	Amplitude	0.11 uV	0.46 uV	0.54 uV
	Rejection Gain	124.62 dB	112.54 dB	111.13 dB

The observed common mode rejection across dataloggers ranged from 107.71 dB to 130.87 dB.

Table 47 Common Mode Rejection: 55A0, at Select Temperatures and Sample Rates

Temperature, Sample Rate		Channel 3	Channel 2	Channel 1
60° C, 100 sps	Amplitude	0.23 uV	1.30 uV	1.69 uV
	Rejection Gain	132.64 dB	117.67 dB	115.36 dB
20° C, 100 sps	Amplitude	0.06 uV	1.66 uV	2.22 uV
	Rejection Gain	144.18 dB	115.50 dB	112.99 dB
20° C, 100 sps 2x gain	Amplitude	0.06 uV	0.87 uV	1.09 uV
	Rejection Gain	143.99 dB	121.18 dB	119.19 dB
20° C, 100 sps 4x gain	Amplitude	0.07 uV	0.43 uV	0.54 uV
	Rejection Gain	131.35 dB	115.28 dB	113.16 dB
-25° C, 100 sps	Amplitude	0.51 uV	2.41 uV	4.09 uV
	Rejection Gain	125.86 dB	112.30 dB	107.70 dB
-36° C, 100 sps	Amplitude	0.80 uV	3.41 uV	6.02 uV
	Rejection Gain	121.87 dB	109.28 dB	104.33 dB
20° C, 4 sps	Amplitude	0.14 uV	1.62 uV	2.21 uV
	Rejection Gain	137.09 dB	115.75 dB	113.02 dB
20° C, 20 sps	Amplitude	0.10 uV	1.66 uV	2.24 uV
	Rejection Gain	140.13 dB	115.51 dB	112.93 dB
20° C, 40 sps	Amplitude	0.10 uV	1.67 uV	2.21 uV
	Rejection Gain	139.97 dB	115.46 dB	113.05 dB
20° C, 200 sps	Amplitude	0.07 uV	1.67 uV	2.22 uV
	Rejection Gain	143.29 dB	115.48 dB	113.00 dB

The observed common mode rejection with datalogger 55A0 while the is gain set to 1x, ranged between 104.33 dB (channel 1, -36° C) and 144.18 dB (channel 3, 20° C) over the temperatures evaluated. Across sample rates evaluated, the observed common mode rejection ranged between 112.93 dB (channel 1, 20 sps) and 144.18 dB (channel 3, 100 sps). Over temperatures and sample rates channel 1 (vertical) consistently had the lowest rejection gain and channel 3 (east) the highest rejection gain.

Common mode rejection ranged between 104.33 dB to 144.18 dB over all test conditions.

3.15 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.

3.15.1 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.

3.15.2 Configuration

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

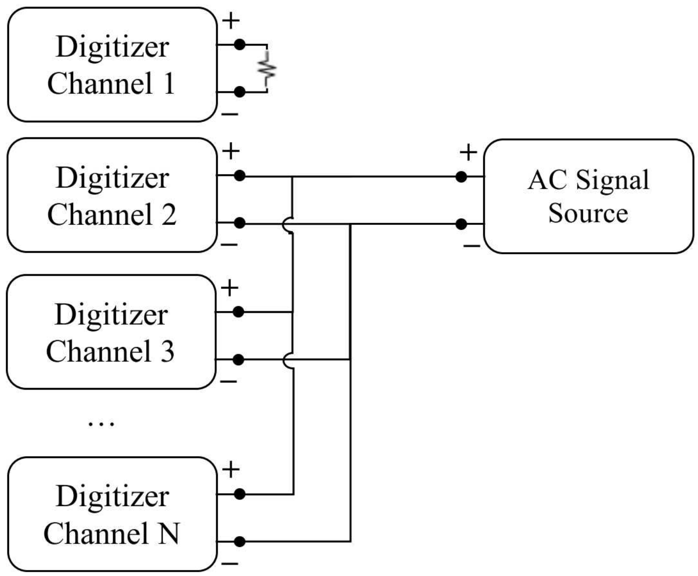

Figure 134 Crosstalk Configuration Diagram

Figure 135 Crosstalk Configuration

Table 48 Crosstalk Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
AC Signal Source Bunker	Stanford Research Systems DS360	123672	+1V / - 1 V
AC Signal Source SB1	Stanford Research Systems DS360	123669	+1V / - 1 V

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 1.2 minutes of data are recorded.

3.15.3 Analysis

The measured bitweight, 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 2k-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:

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

3.15.4 Result

The figure below 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.

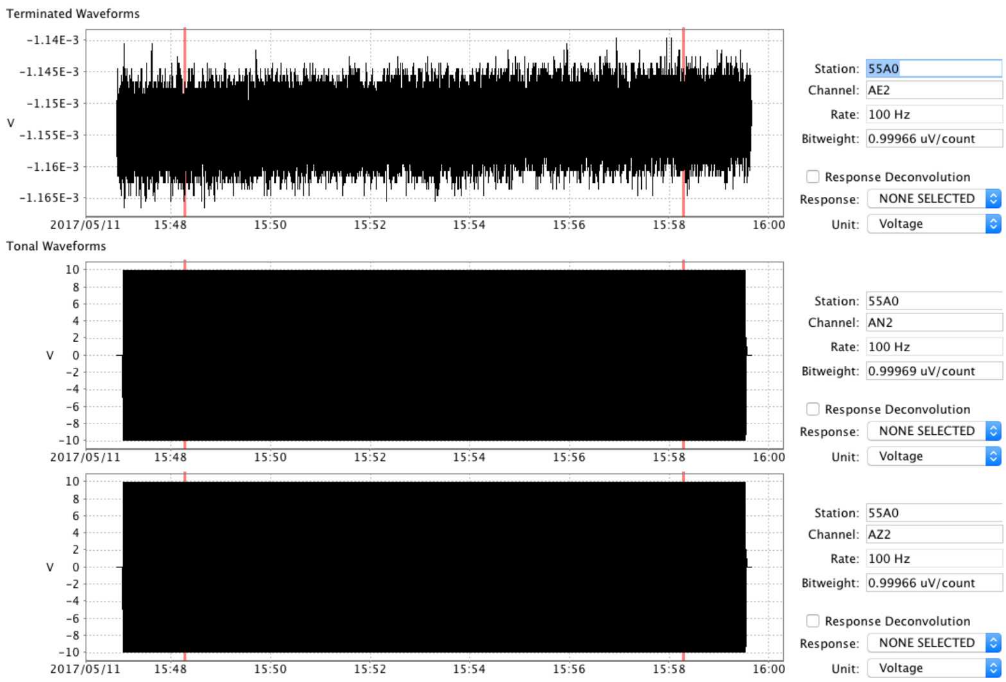

Figure 136 Crosstalk Time Series Example, Affinity 55A0

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

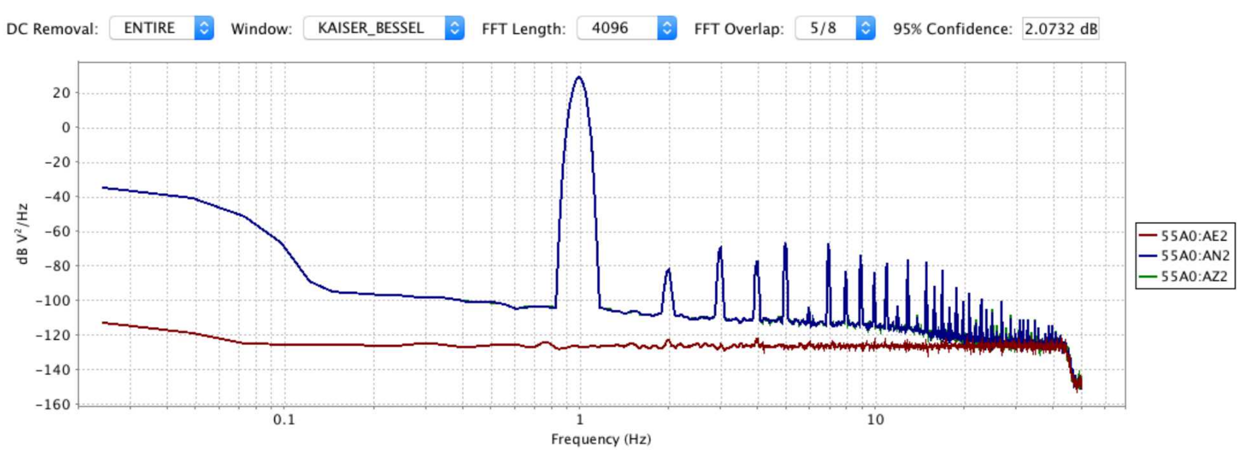

Figure 137 Crosstalk Power Spectra

The following table contains the computed crosstalk ratios for all digitizers measured in the bunker at 23 C. Notice the lack of an observable peak in the terminated channel's power spectra.

Table 49 Crosstalk*, All Dataloggers, 100 Hz, 23 C

DWR	AE2 (chan 3)	AN2 (chan 2)	AZ2 (chan 1)
55A1	-153.11 dB	-153.25 dB	-152.58 dB
559A	-153.73 dB	-153.88 dB	-153.27 dB
559B	-153.56 dB	-146.63 dB	-152.85 dB
55A0	-153.79 dB	-153.43 dB	-153.76 dB

No peak is observable in the terminated channel's power spectra, therefore the values represent the maximum possible observable crosstalk*. The maximum possible observable levels of crosstalk were all between -142.63 and -153.88 dB

The following table contains the computed crosstalk ratios for 55A0 measured across temperature and gain levels.

Table 50 Crosstalk*, Datalogger 55A0 at Select Temperatures

Temperature	AE2 (chan 3)	AN2 (chan 2)	AZ2 (chan 1)
60° C	-152.54 dB	-153.19 dB	-152.45 dB
20° C	-150.92 dB	-151.31 dB	-151.13 dB
20° C, Gain 2x	-148.80 dB	-149.56 dB	-151.02 dB
20° C, Gain 4x	-147.90 dB	-146.55 dB	-145.66 dB
-25° C	-151.03 dB	-151.02 dB	-152.08 dB
-36° C	-152.34 dB	-150.46 dB	-150.99 dB

No peak is observable in the terminated channel's power spectra, therefore the values represent the maximum possible observable crosstalk*. The maximum possible observable levels of crosstalk (1x gain) calculated over the temperatures selected for evaluation varied from as little as -150.46 dB as -153.19 dB. No significant trend with respect to temperature is noted.

The following table contains the computed crosstalk ratios for 55A0 measured across sample rates.

Table 51 Crosstalk*, Datalogger 55A0 at Select Sample Rates, 20° C

Sample Rate	Channel 3	Channel 2	Channel 1
4 sps	-149.19 dB	-149.57 dB	-147.95 dB
20 sps	-151.58 dB	-149.47 dB	-149.16 dB
40 sps	-149.09 dB	-148.66 dB	-149.28 dB
100 sps	-150.92 dB	-151.31 dB	-151.13 dB
200 sps	-151.69 dB	-151.12 dB	-151.33 dB

No peak is observable in the terminated channel's power spectra, therefore the values represent the maximum possible observable crosstalk*. No correlations are present between maximum possible observable crosstalk (1x gain) and changes in sample rates or temperatures; values range from -147.95 dB to as much as -151.69 dB.

3.16 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.

3.16.1 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.

3.16.2 Configuration

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

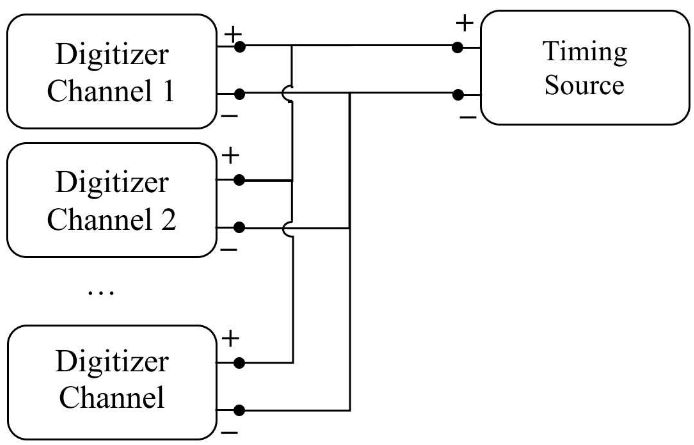

Figure 138 Time Tag Configuration Diagram

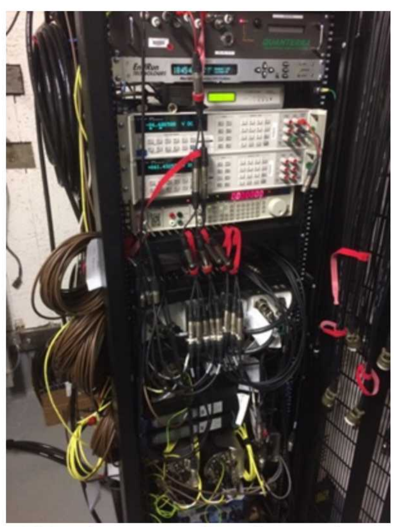

Figure 139 Time Tag Configuration Picture

Table 52 Time Tag Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
SB1	End Run Technologies/Meridian GPS 3025-0101 Quanterra/Supertonal Signal Source	12010021 021204	GPS PPM Output
Bunker	End Run Technologies/Meridian GPS 3025-0101 Quanterra/Supertonal Signal Source	12010020 021202	GPS PPM Output

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

3.16.3 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.

3.16.4 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.

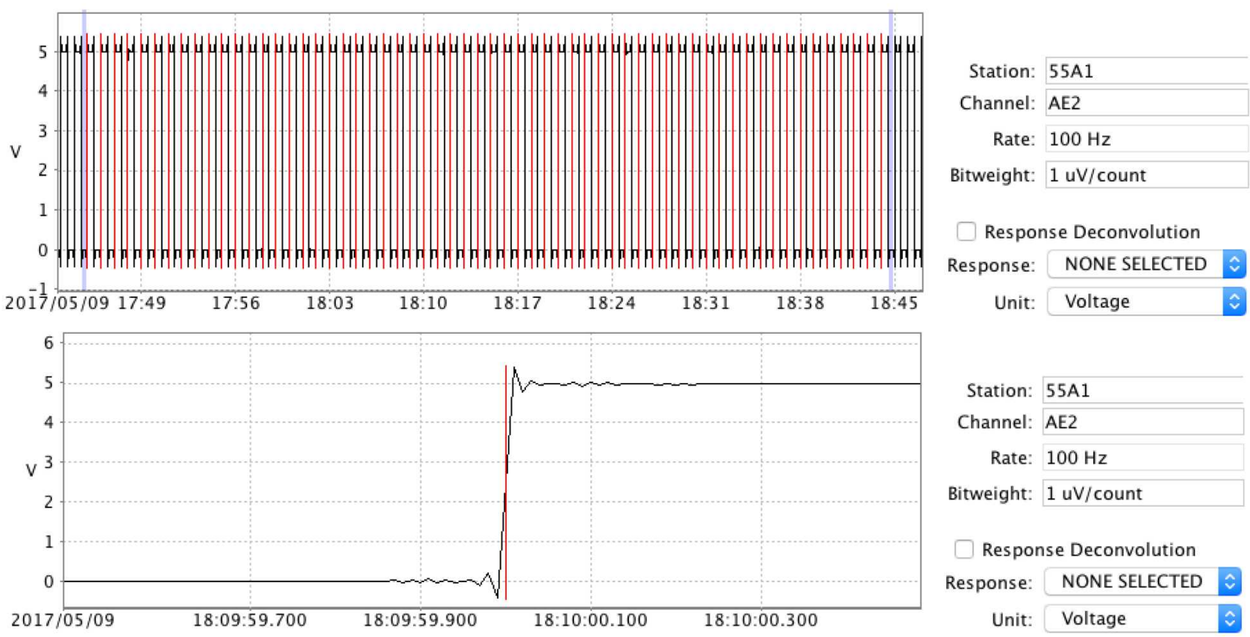

Figure 140 Time Tag Accuracy PPM Time Series

The following table contains the computed timing offsets as measured from the testing configuration as shown in Figure 138, where all input channels are connected in parallel to the timing source, not isolated as the Guralp engineers suggested, as the equipment under test was no longer available when the suggestion of the alternative test configuration was made.

Table 53 Time Tag Accuracy, All Affinitys, 23° C

DWR	AE2 (chan 3)	AN2 (chan 2)	AZ2 (chan 1)
55A1	-25.51 us	-25.75 us	-25.75 us
559A	-25.27 us	-25.27 us	-25.03 us
559B	-25.51 us	-25.27 us	-25.51 us
55A0	-25.51 us	-25.75 us	-25.51 us

Table 54 Time Tag Accuracy, Affinity 55A0, 100 Hz, Select Temperatures

Temperature	AE2 (chan 3)	AN2 (chan 2)	AZ2 (chan 1)
60° C	-39.10 us	-39.10 us	-38.86 us
20° C	-38.86 us	-39.10 us	-38.86 us
100 Hz, gain 2x	-31.95 us	-31.95 us	-31.71 us
100 Hz, gain 4x	-31.47 us	-31.95 us	-31.47 us
-25° C	-38.86 us	-39.34 us	-38.86 us
-36° C	-39.58 us	-39.82 us	-39.58 us

Table 55 Time Tag Accuracy, Affinity 55A0, Select Sample Rates

Sample Rate	Chanel 3	Channel 2	Channel 1
4 Hz	-34.81 us	-35.05 us	-35.05 us
20 Hz	-33.86 us	-34.33 us	-34.09 us
40 Hz	-35.52 us	-35.76 us	-35.52 us
100 Hz	-38.86 us	-39.10 us	-38.86 us
200 Hz	-41.25 us	-41.48 us	-41.01 us

Over all test configurations and conditions, timing offsets varied from -25 us to -41 us, with no correlation of offset with temperature or sample rate.

3.17 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.

3.17.1 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.

3.17.2 Configuration

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

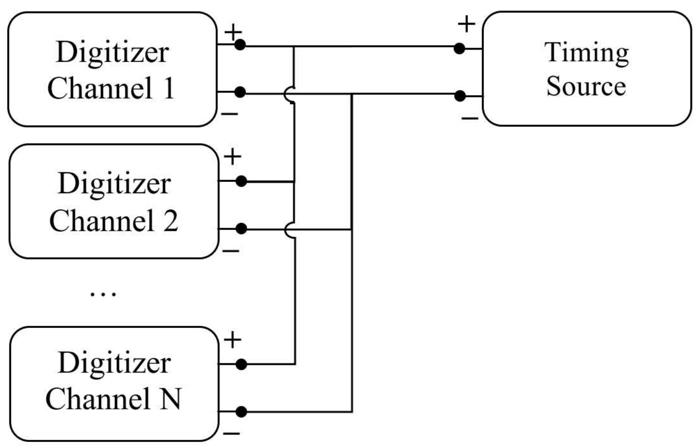

Figure 141 Timing Drift Configuration Diagram

Table 56 Timing Drift Testbed Equipment

Location	Manufacturer / Model	Serial Number	Nominal Configuration
SB1	End Run Technologies/Meridian GPS 3025-0101 Quanterra/Supertonal Signal Source	12010021 021204	GPS PPM Output
Bunker	End Run Technologies/Meridian GPS 3025-0101 Quanterra/Supertonal Signal Source	12010020 021202	GPS PPM Output

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 covered, which results in the digitizer losing timing lock. The digitizer is allowed to drift before the GPS antenna uncovered and then regains its timing lock and corrects for drift.

3.17.3 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.

3.17.4 Result

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

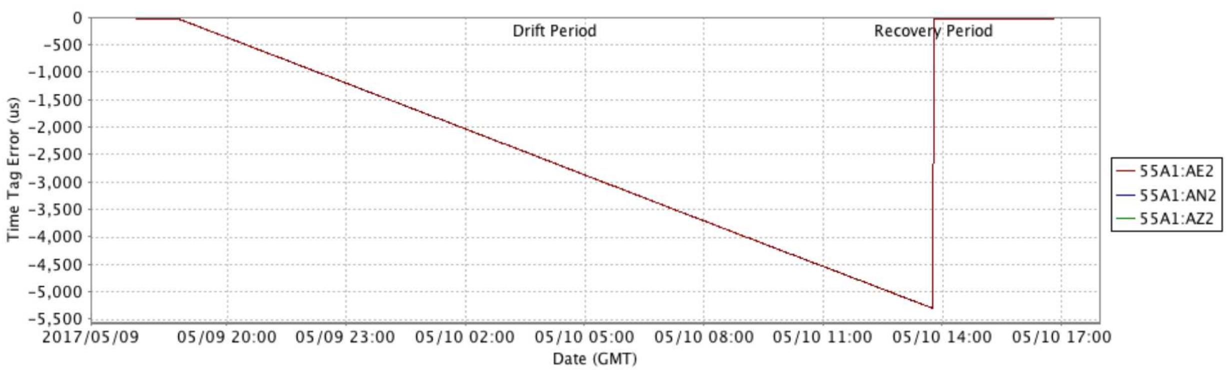

Figure 142 Time Tag Drift, Affinity 55A1, 23° C

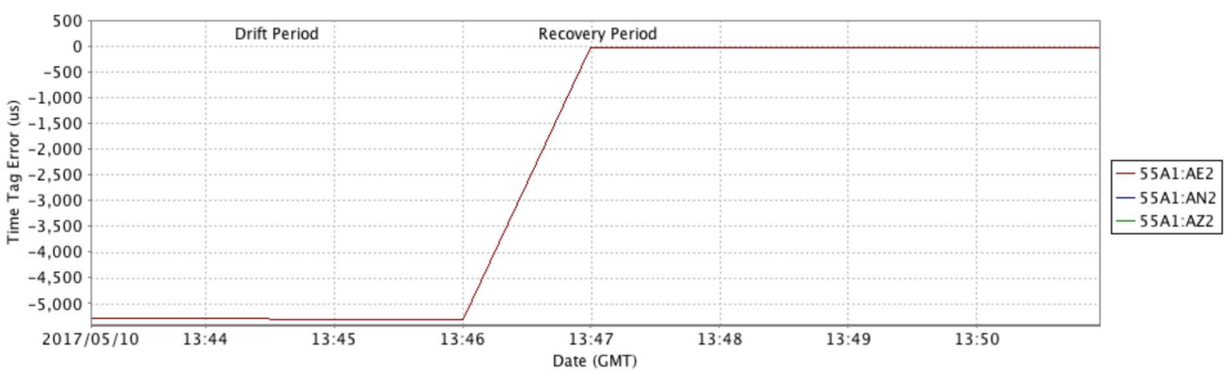

Figure 143 Time Tag Recovery Affinity 55A1, 23° C

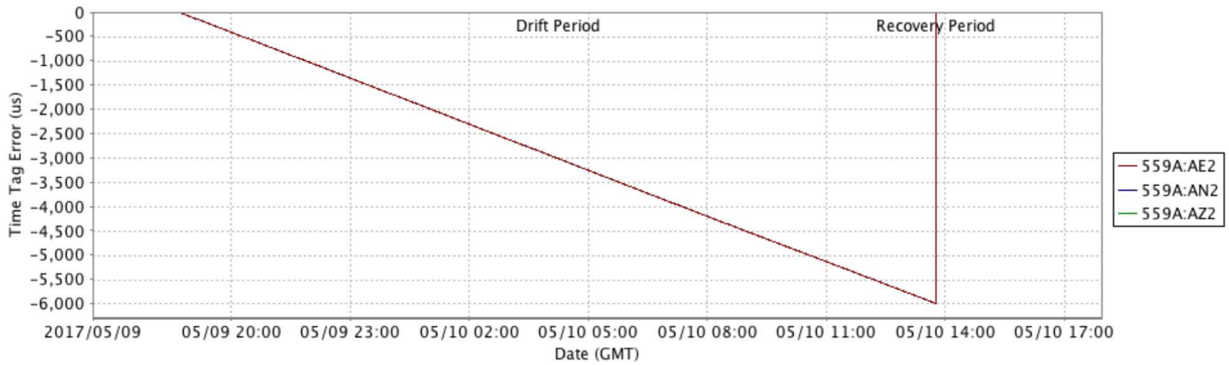

Figure 144 Time Tag Drift, Affinity 559A, 23° C

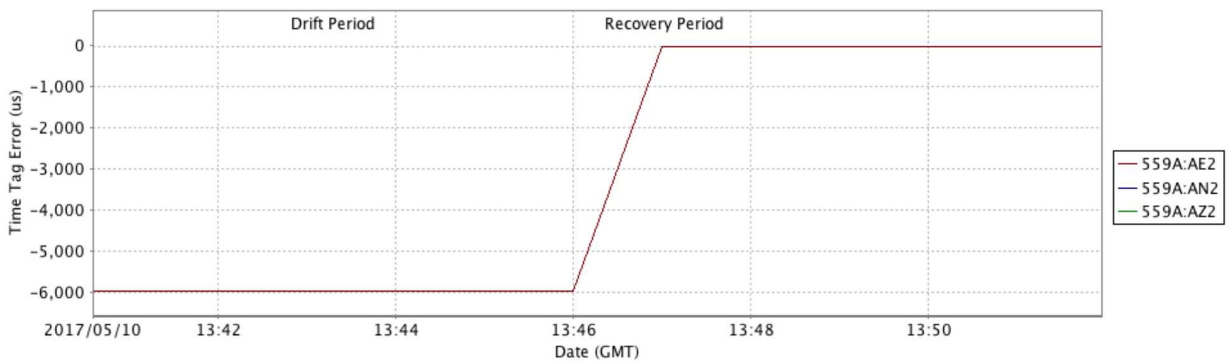

Figure 145 Time Tag Recovery, Affinity 559A, 23° C

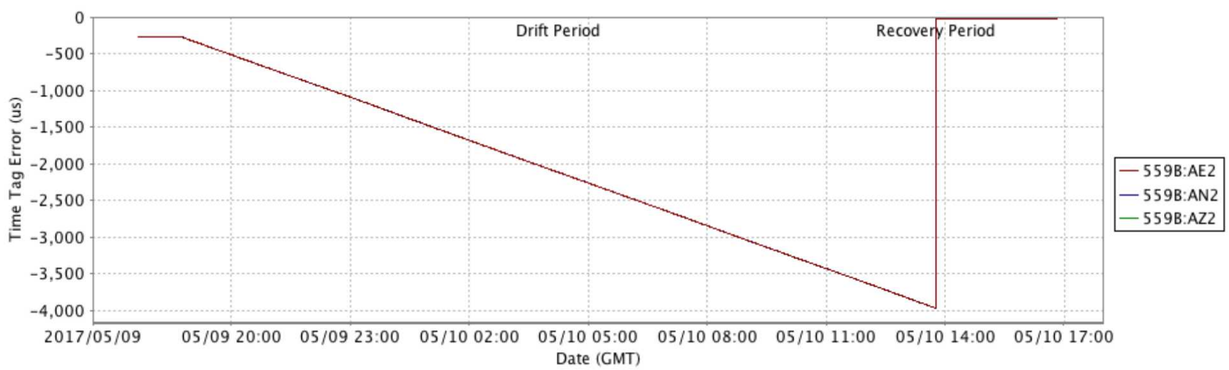

Figure 146 Time Tag Drift, Affinity 559B, 23° C

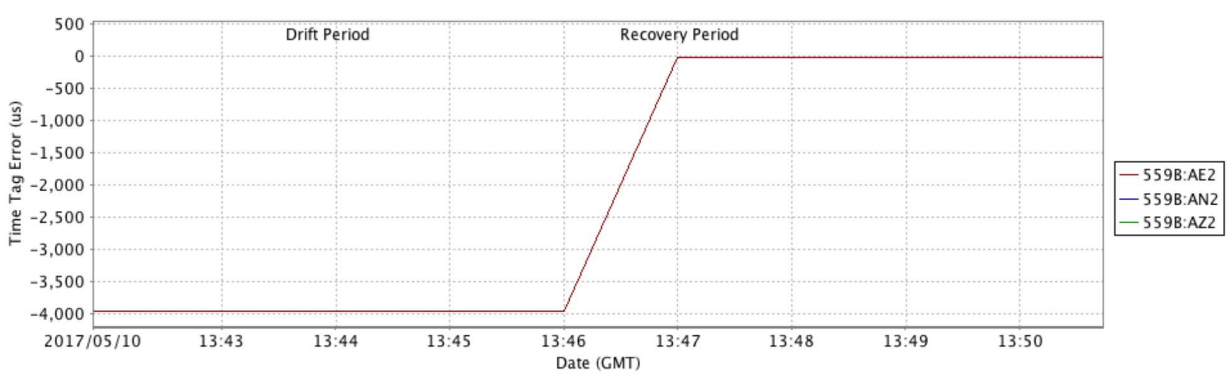

Figure 147 Time Tag Recovery, Affinity 559B, 23° C

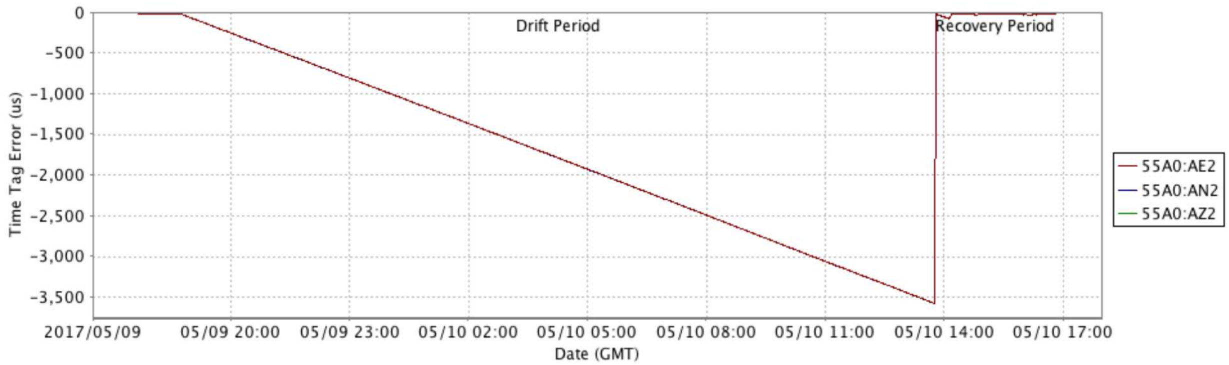

Figure 148 Time Tag Drift, Affinity 55A0, 23° C

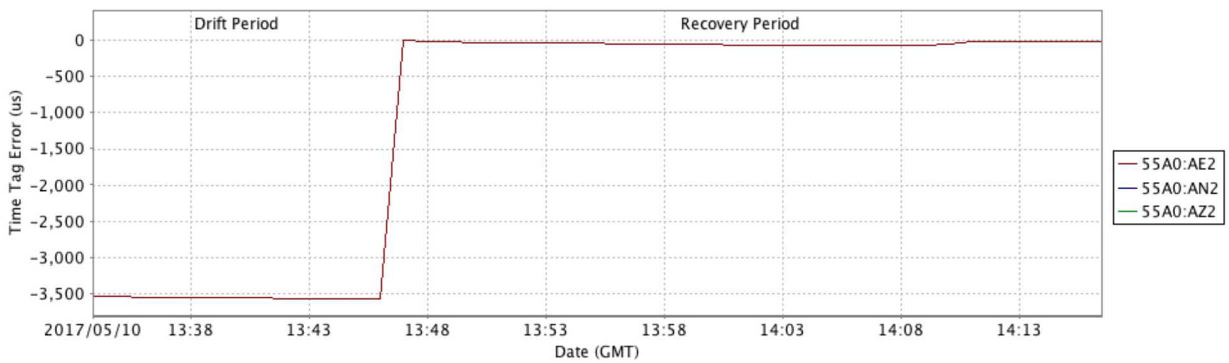

Figure 149 Time Tag Recovery, Affinity 55A0, 23° C

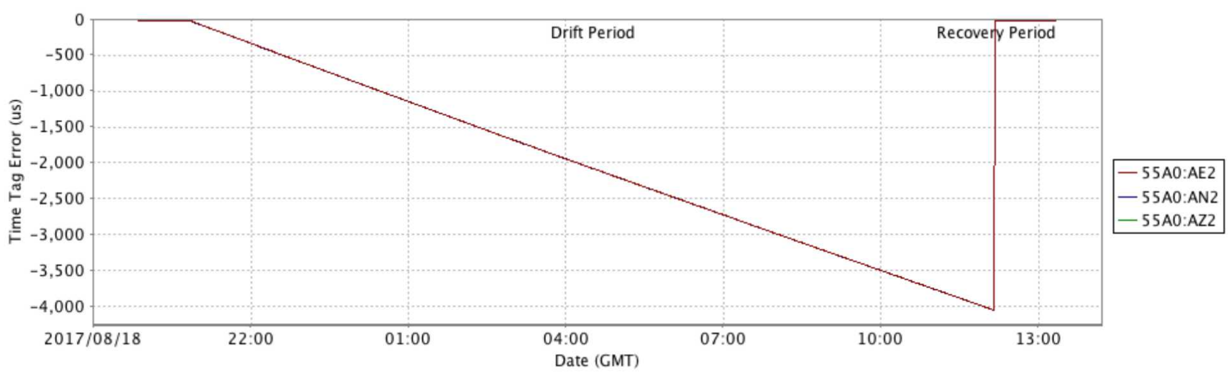

Figure 150 Time Tag Drift, Affinity 55A0, 60° C

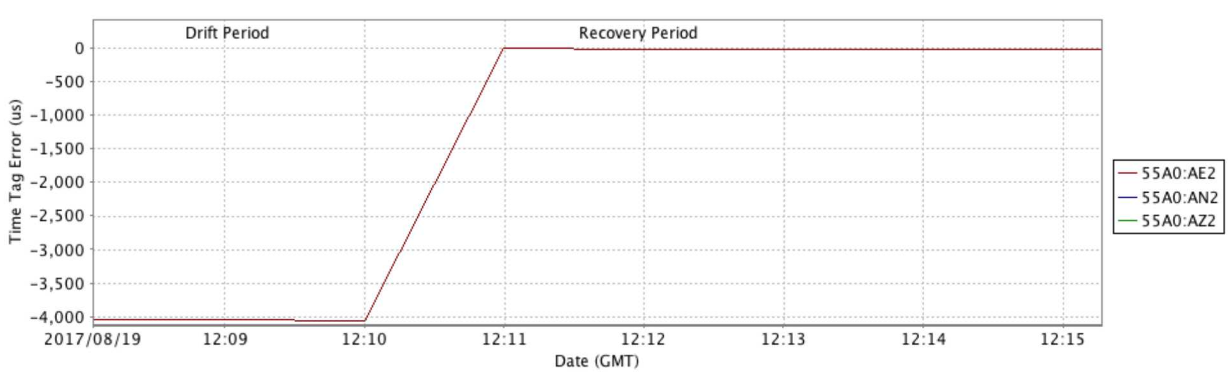

Figure 151 Time Tag Recovery, Affinity 55A0, 60° C

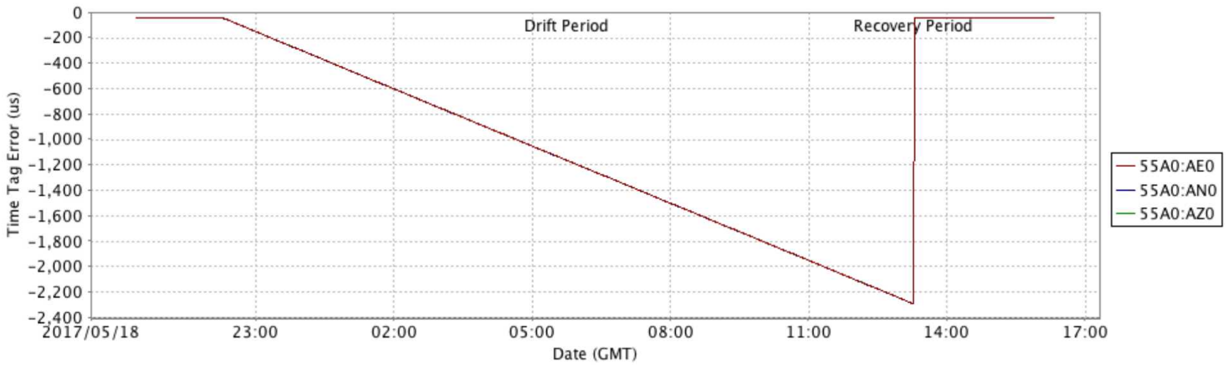

Figure 152 Time Tag Drift, Affinity 55A0, 20° C

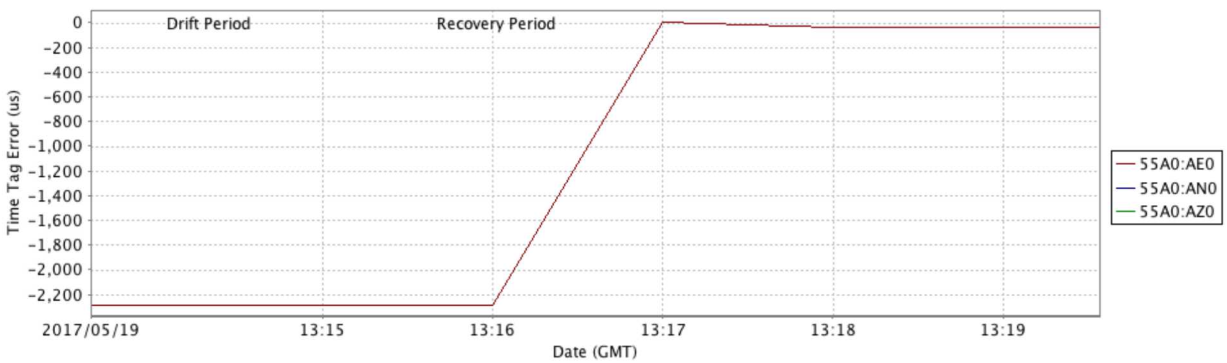

Figure 153 Time Tag Recovery, Affinity 55A0, 20° C

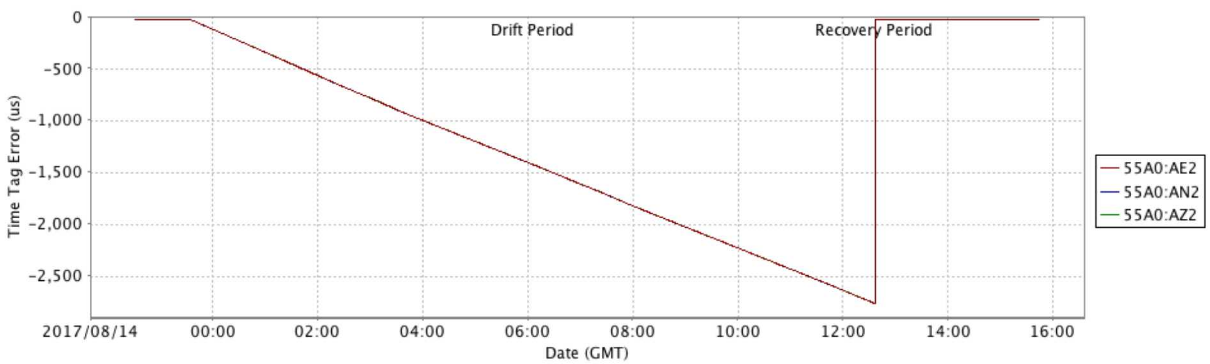

Figure 154 Time Tag Drift, Affinity 55A0, 20° C, 2x Gain

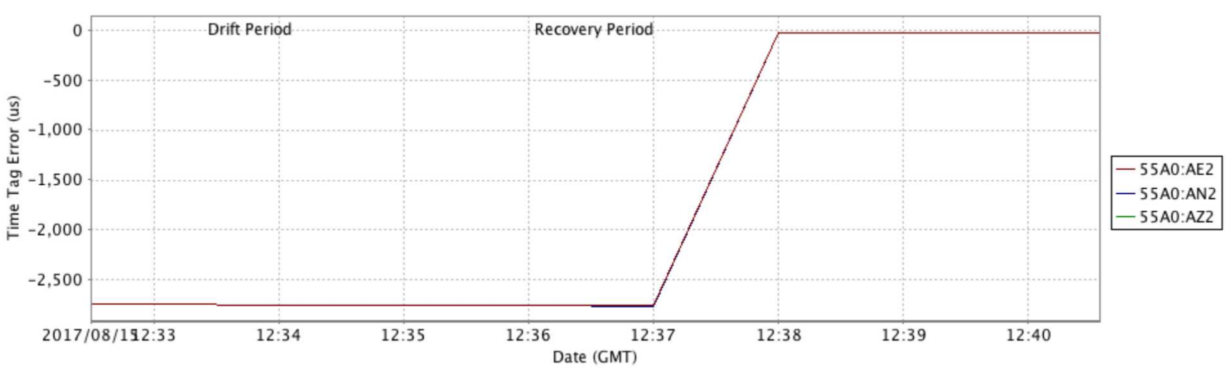

Figure 155 Time Tag Recovery Affinity 55A0, 20° C, 2x Gain

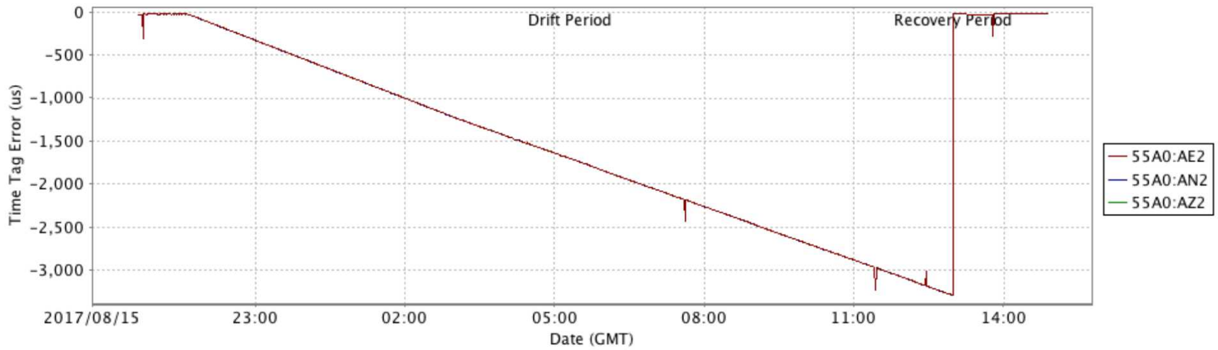

Figure 156 Time Tag Drift, Affinity 55A0, 20° C, 4x Gain

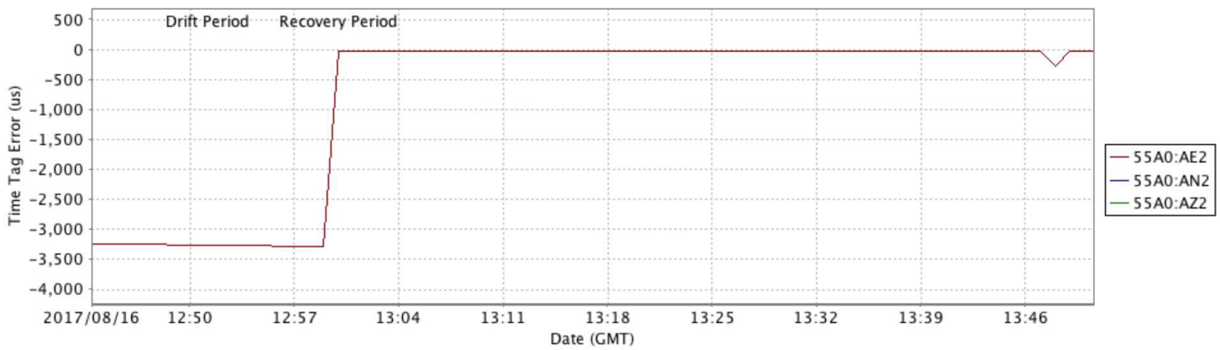

Figure 157 Time Tag Recovery Affinity 55A0, 20° C, 4x Gain

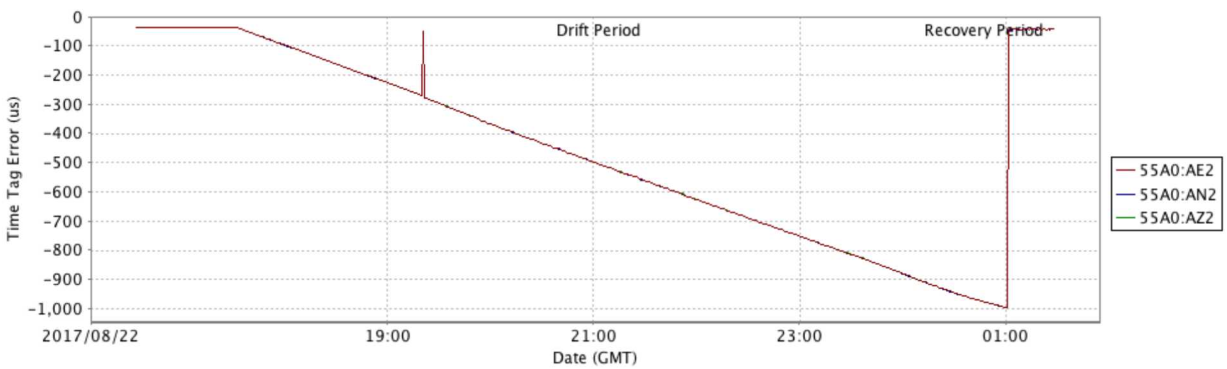

Figure 158 Time Tag Drift, Affinity 55A0, -25° C

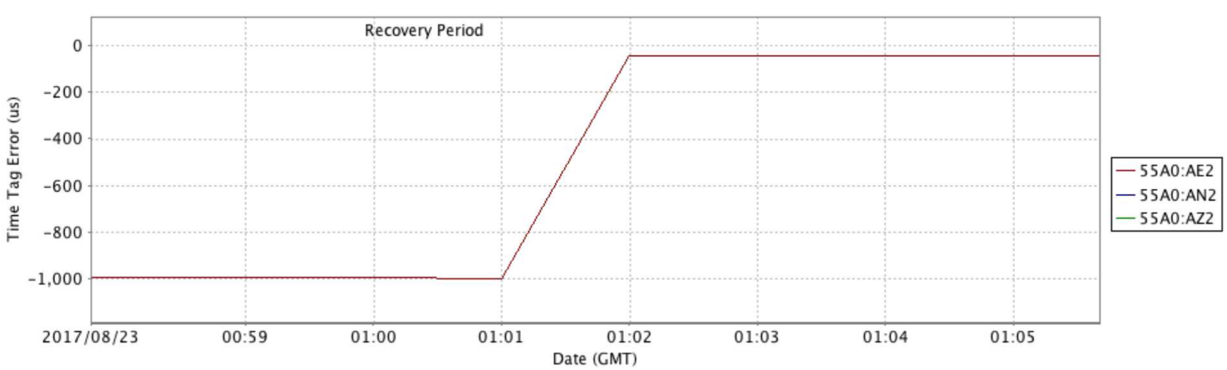

Figure 159 Time Tag Recovery, Affinity 55A0, -25° C

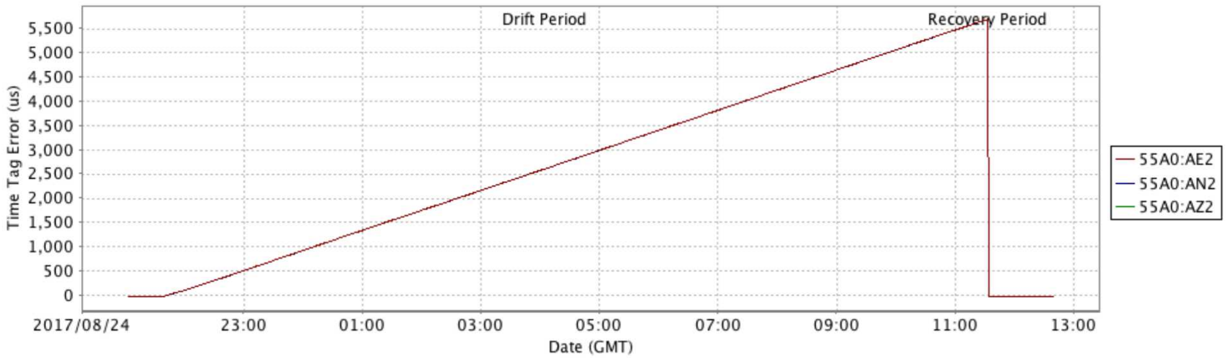

Figure 160 Time Tag Drift, Affinity 55A0, -36° C

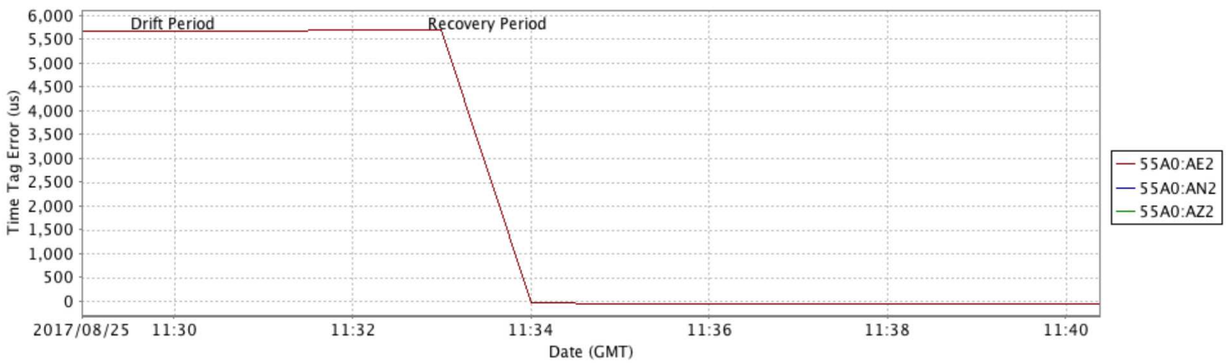

Figure 161 Time Tag Recovery, Affinity 55A0, -36° C

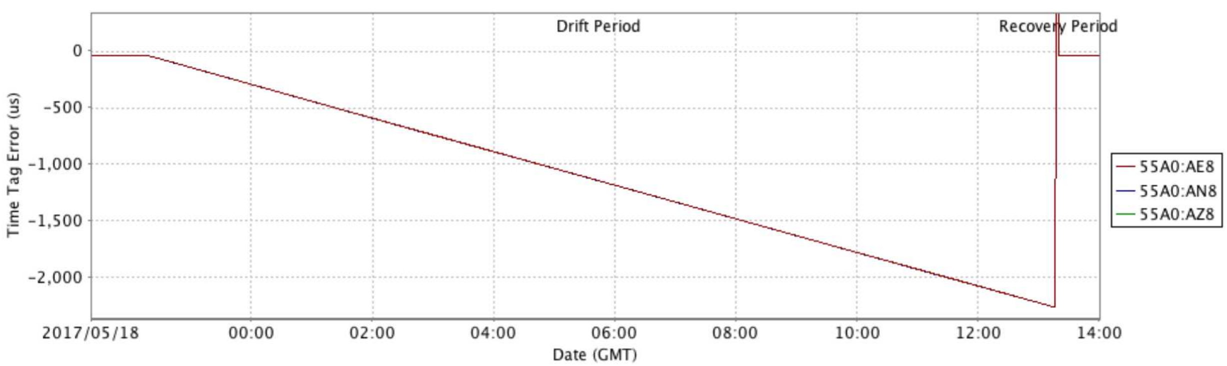

Figure 162 Time Tag Drift, Affinity 55A0, 20° C, 4 sps

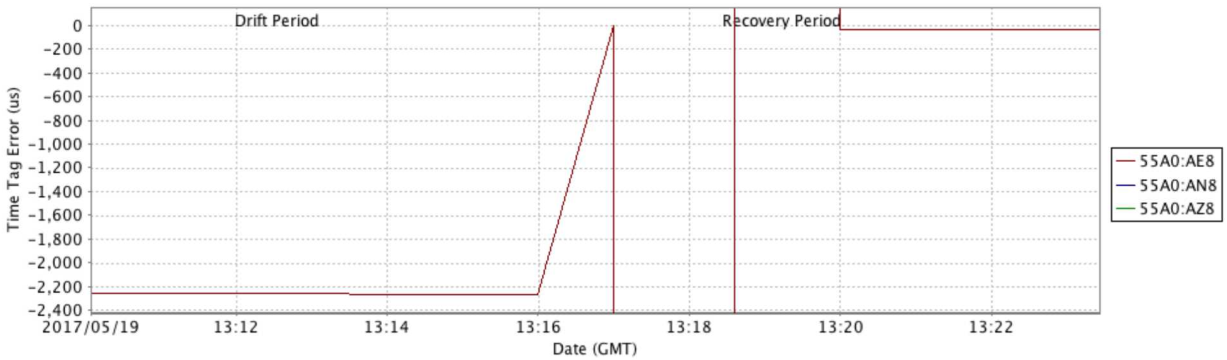

Figure 163 Time Tag Recovery, Affinity 55A0, 20° C, 4 sps

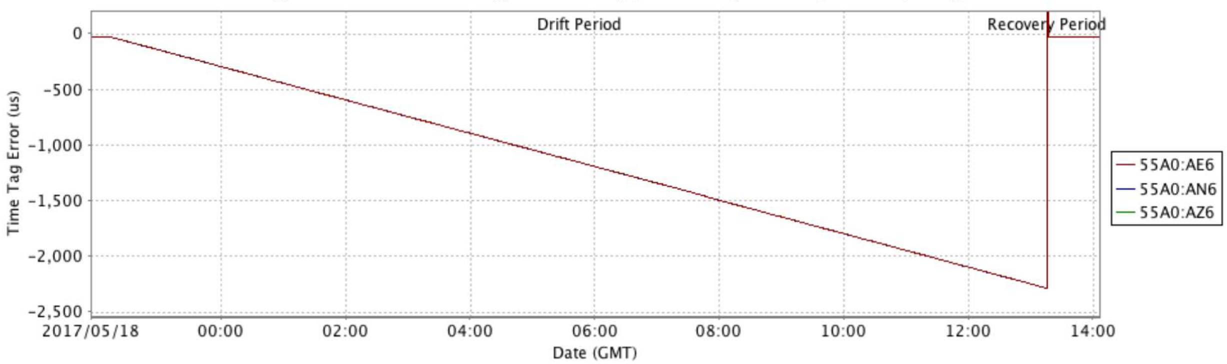

Figure 164 Time Tag Drift, Affinity 55A0, 20° C, 20 sps

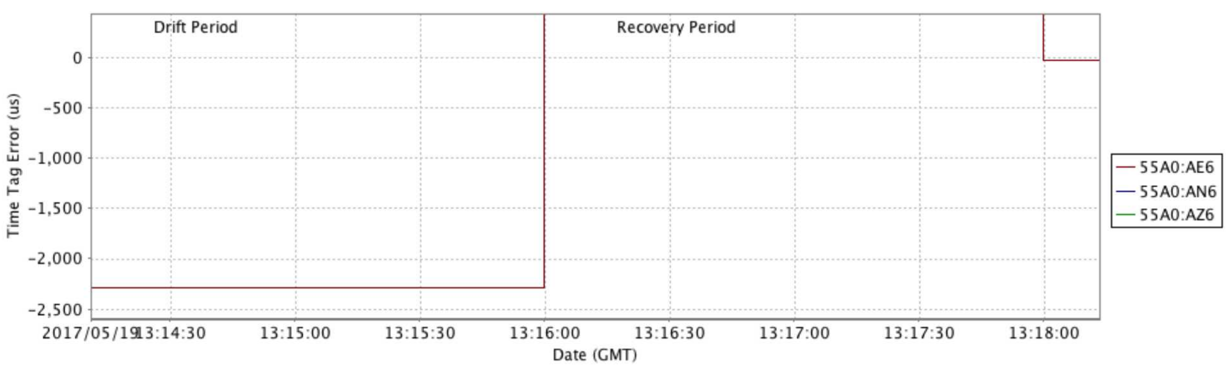

Figure 165 Time Tag Recovery, Affinity 55A0, 20° C, 20 sps

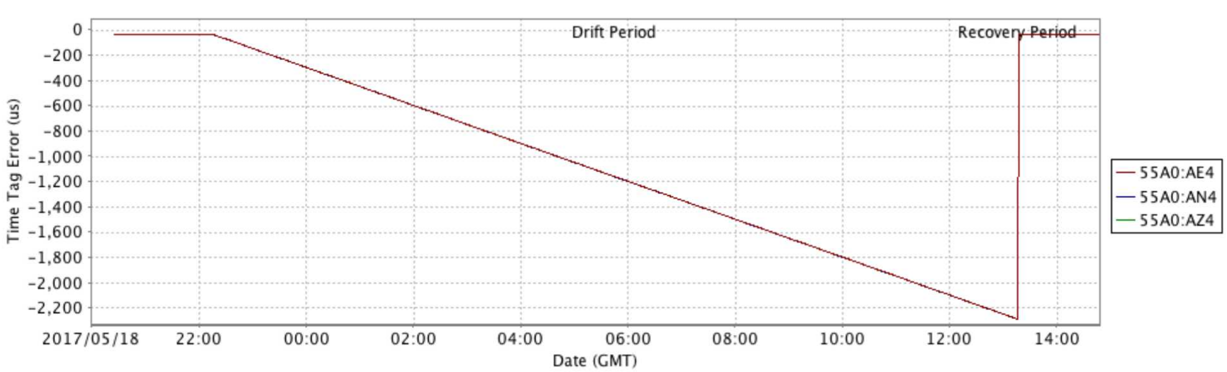

Figure 166 Time Tag Drift, Affinity 55A0, 20° C, 40 sps

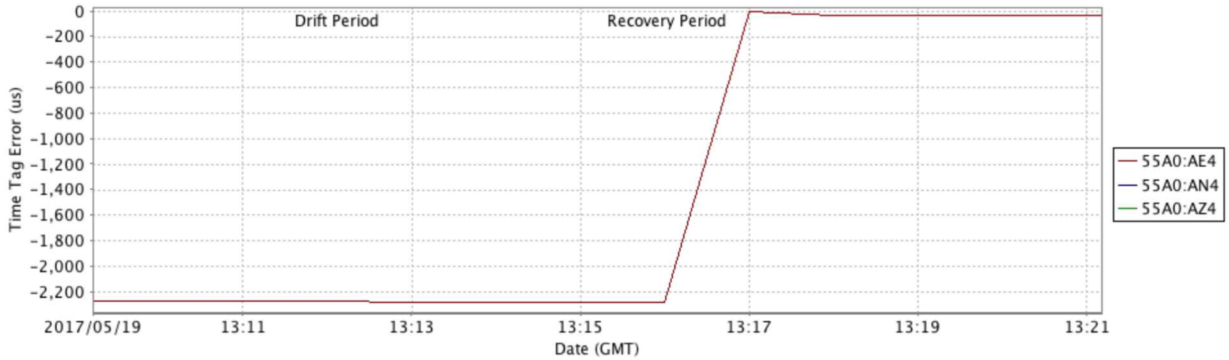

Figure 167 Time Tag Recovery, Affinity 55A0, 20° C, 40 sps

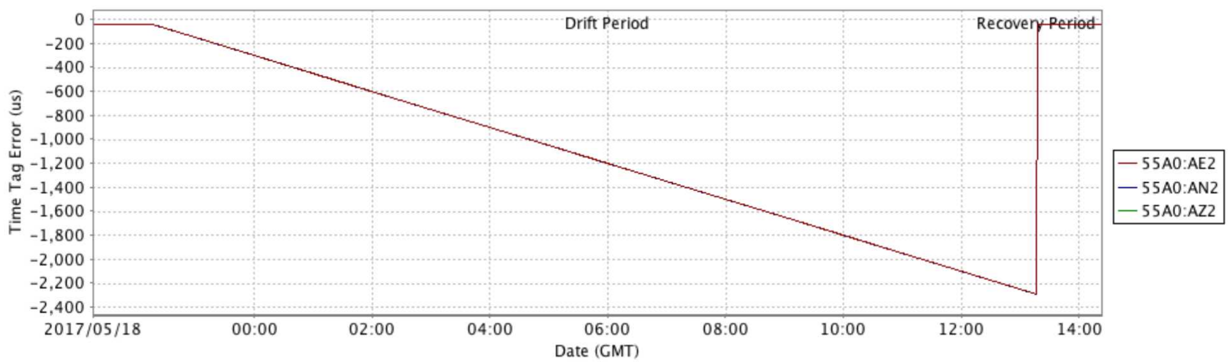

Figure 168 Time Tag Drift, Affinity 55A0, 20° C, 200 sps

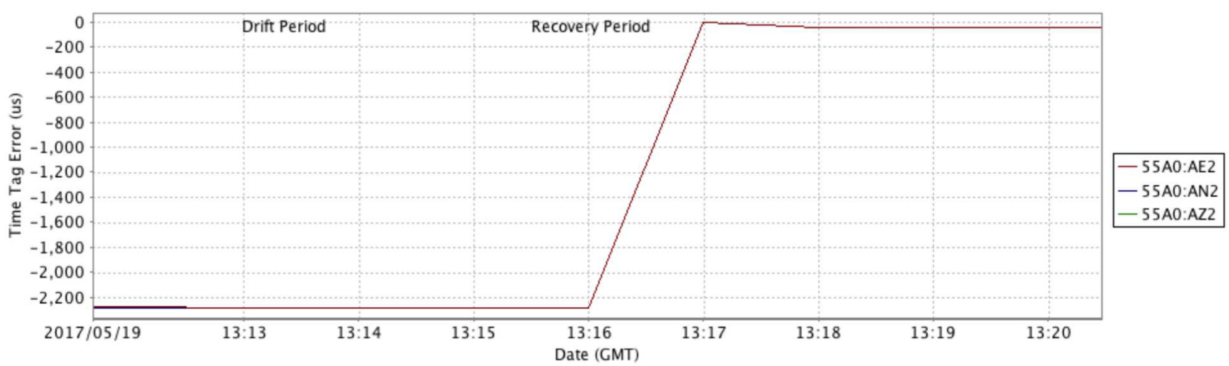

Figure 169 Time Tag Recovery, Affinity 55A0, 20° C, 200 sps

The following table contains the computed timing offsets when locked and the estimated rate at which the digitizer was observed to drift prior to recovering GPS lock.

Table 57 Time Tag Drift and Recovery

Digitizer	Config/Conditions	Timing Offset	Drift Rate
55A1	100 sps, 23° C	-5305 ms	278 us/h
559A	100 sps, 23° C	-5995 ms	314 us/h
559B	100 sps, 23° C	-3972 us	194 us/h
55A0	100 sps, 23° C	-3579 us	187 us/h
55A0	100 sps, 60° C	-4055 us	262us/h

55A0	100 Hz, 20° C	-2292 us	150 us/h
55A0	100 sps, 20° C, gain 2x	-2764 us	208 us/h
55A0	100 sps, 20° C, gain 4x	-3290 us	211 us/h
55A0	100 sps, -25° C	-997 us*	130 us/h
55A0	100 sps, -36° C	5686 us	-411 us/h
55A0	4 sps, 20° C	-2268 us	148 us/h
55A0	20 sps, 20° C	-2288 us	150 us/h
55A0	40 sps, 20° C	-2288 us	150 us/h
55A0	200 sps, 20° C	-2290 us	150 us/h

*Drift window was less than 12 hours.

Drift rates varied widely across dataloggers, from as little as 187 us/h to as much as -411 us/h. Positive drift rates equate to timing advancing ahead of the actual time. Drift rates of datalogger 55A0 decreased as temperature decreased; eventually, at the lowest temperature to which 55A0 was exposed, the drift direction reversed, e.g. the timing slowed to a rate slower than actual time. Over the suite of sample rates evaluated, drift rates maintained relatively steady, between 148 us/h to 150 us/h.

In every instance of the GPS receivers regaining lock and timing was corrected, to essentially the same measured timing offset as that prior to the drift test, within just a few minutes.

4 SUMMARY

Power Consumption
The average observed power consumption of 1.65 W is reasonably consistent with the datasheet specification, as it is 6.5% greater than the 1.55 W power consumption specificied in the manufacturer's datasheet for a 4 channel system while ethernet and GPS are active.

Input Impedance
All dataloggers had very consistent measured impedance values. Under all test configurations all dataloggers remained from 0.44% to 0.45% higher than the specification of 113 kOhm provided by the manufacturer.

DC Accuracy
Across selected sample rates, gains and temperatures, bit weights remained very stable, varying no more than 0.08% (at a temperature of -36° C) from the respective nominal bitweight.

AC Accuracy
As with DC Accuracy Tests, bitweights remained very near the respective nominal bitweight over the temperatures and sample rates evaluated, never diverging more than 0.08% (at a gain of 4x) of the respective nominal bitweight.

Input Shorted Offset
The maximum observed input shorted offset 1.933 mV or 0.0097% of full scale, occurred on channel 3 at 60° C. Minimum input shorted offset voltages occurred generally at mid temperatures (20° C or -25° C), rather than at either of the extremes (60° C or -36° C).

AC Full Scale
For all sample rates and gain levels, the digitizer 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.

Self-Noise
Rms noise values did not exceed the equivalent of 2 counts rms while operating at a gain of 1x; at gains of 2x and 4x, rms noise did not exceed the equivalent of 3 counts rms. Self noise levels decreased with temperature in all pass bands, with the exception of AN2 (channel2) in the low passband at -25° C where self noise increased slightly to 479.60 nV rms.

Dynamic Range
Dynamic Ranges over all evaluated conditions and passband varied from as low 137 dB to as much as 150 dB.

System Noise
Over the sample rates evaluated, at a gain of 1x, seismic system noise exceeded the CMG-3VB noise model from as low as 1.9 Hz to 2.0 Hz (north channels) to as high as 12.0 Hz (north channels) to 12.9 Hz.

Response Verification
Over the temperatures and sample rates evaluated, magnitude and phase varied little. Roll-off in the relative phase is apparent in the data consistent with slight timing offsets between channels.

Relative Transfer Function
All of the channels were observed to have a timing skew that was within half a microsecond of one another.

Analog Bandwidth
In all cases analog bandwidth was at least 88.67% or better of the Nyquist Frequency.

Total Harmonic Distortion
THD over all test conditions (at 1x gain) varied from -122.16 dB (100 sps sample rate) at 23°C, to -127.76 db (20 sps sample rate) discounting the calculated THD at 4 Hz.

Common Mode Rejection
Common mode rejection ranged between 104.33 dB to 144.18 dB over all test conditions.

Crosstalk
No peak is observable in the terminated channel's power spectra, therefore the values represent the maximum possible observable crosstalk. The maximum possible observable levels of crosstalk were all between -142.63 and -153.88 dB.

Time Tag Accuracy
Over all test configurations and conditions, timing offsets varied from -25 us to -41 us, with no correlation of offset with temperature or sample rate.

Time Tag Drift
Drift rates varied widely across dataloggers, from as little as 187 us/h to as much as -411 us/h. In every instance of connecting the GPS antenna to the receiver, GPS receivers locked and timing was corrected, to essentially the same measured timing offset as that prior to the drift test, within just a few minutes.

REFERENCES

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5. McDonald, Timothy S. (1994), *Modified Noise Power Ratio Testing of High Resolution digitizers*, SAND94-0221.

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: SELF-NOISE

Digitizer self-noise values are reported in units of dB relative to 1 V^2/Hz at the defined octave-band frequencies. The 90% uncertainty of the provided estimates are 0.43 dB for all gain settings.

Table 58 Affinity Digitizer Noise Model, 1x Gain

Frequency (Hz)	AE2 (chan 3)	AN2 (chan 2)	AZ2 (chan 1)
0.00315	-118.0 dB	-118.1 dB	-117.3 dB
0.004	-118.0 dB	-118.1 dB	-117.3 dB
0.005	-120.8 dB	-120.6 dB	-120.5 dB
0.0063	-120.8 dB	-120.6 dB	-120.5 dB
0.008	-122.5 dB	-122.1 dB	-122.0 dB
0.01	-122.5 dB	-122.1 dB	-122.0 dB
0.0125	-123.2 dB	-123.4 dB	-122.8 dB
0.016	-123.2 dB	-123.4 dB	-122.8 dB
0.02	-124.1 dB	-124.2 dB	-124.2 dB
0.025	-124.1 dB	-124.2 dB	-124.4 dB
0.0315	-124.3 dB	-124.7 dB	-124.9 dB
0.04	-124.9 dB	-125.6 dB	-125.2 dB
0.05	-125.1 dB	-125.5 dB	-125.0 dB
0.063	-125.6 dB	-125.9 dB	-125.3 dB
0.08	-125.5 dB	-125.9 dB	-125.7 dB
0.1	-125.9 dB	-126.1 dB	-125.8 dB
0.125	-126.0 dB	-126.2 dB	-125.8 dB
0.16	-126.1 dB	-126.2 dB	-126.0 dB
0.2	-126.1 dB	-126.4 dB	-126.1 dB
0.25	-126.0 dB	-126.4 dB	-126.2 dB
0.315	-126.2 dB	-126.5 dB	-126.2 dB
0.4	-126.2 dB	-126.6 dB	-126.2 dB
0.5	-126.2 dB	-126.6 dB	-126.4 dB
0.63	-126.3 dB	-126.6 dB	-126.4 dB
0.8	-126.3 dB	-126.7 dB	-126.4 dB
1	-126.4 dB	-126.7 dB	-126.5 dB
1.25	-126.4 dB	-126.7 dB	-126.4 dB
1.6	-126.4 dB	-126.7 dB	-126.5 dB
2	-126.3 dB	-126.7 dB	-126.4 dB
2.5	-126.4 dB	-126.7 dB	-126.4 dB
3.15	-126.5 dB	-126.7 dB	-126.5 dB
4	-126.4 dB	-126.7 dB	-126.5 dB
5	-126.5 dB	-126.7 dB	-126.5 dB
6.3	-126.5 dB	-126.8 dB	-126.5 dB
8	-126.5 dB	-126.8 dB	-126.5 dB
10	-126.5 dB	-126.7 dB	-126.5 dB
12.5	-126.5 dB	-126.8 dB	-126.4 dB
16	-126.5 dB	-126.8 dB	-126.5 dB
20	-126.5 dB	-126.7 dB	-126.5 dB
25	-126.5 dB	-126.8 dB	-126.5 dB
31.5	-126.5 dB	-126.8 dB	-126.5 dB
40	-126.5 dB	-126.8 dB	-126.5 dB

Table 59 Affinity Digitizer Noise Model, 2x Gain

Frequency (Hz)	AE2 (chan 3)	AN2 (chan 2)	AZ2 (chan 1)
0.00315	-123.0 dB	-121.9 dB	-123.2 dB
0.004	-123.0 dB	-121.9 dB	-123.2 dB
0.005	-125.5 dB	-124.7 dB	-125.9 dB
0.0063	-125.5 dB	-124.7 dB	-125.9 dB
0.008	-127.0 dB	-126.1 dB	-127.3 dB
0.01	-127.0 dB	-126.1 dB	-127.3 dB
0.0125	-127.6 dB	-126.9 dB	-127.9 dB
0.016	-127.6 dB	-126.9 dB	-127.9 dB
0.02	-128.9 dB	-127.8 dB	-128.8 dB
0.025	-129.3 dB	-128.1 dB	-128.8 dB
0.0315	-129.5 dB	-128.3 dB	-129.2 dB
0.04	-129.9 dB	-128.7 dB	-129.6 dB
0.05	-129.9 dB	-129.1 dB	-129.8 dB
0.063	-130.3 dB	-129.4 dB	-130.3 dB
0.08	-130.5 dB	-130.0 dB	-130.4 dB
0.1	-130.5 dB	-130.2 dB	-130.5 dB
0.125	-130.8 dB	-130.4 dB	-130.8 dB
0.16	-131.1 dB	-130.7 dB	-130.9 dB
0.2	-130.9 dB	-130.9 dB	-131.2 dB
0.25	-131.4 dB	-131.1 dB	-131.3 dB
0.315	-131.4 dB	-131.3 dB	-131.4 dB
0.4	-131.5 dB	-131.3 dB	-131.4 dB
0.5	-131.4 dB	-131.3 dB	-131.4 dB
0.63	-131.5 dB	-131.4 dB	-131.5 dB
0.8	-131.5 dB	-131.5 dB	-131.6 dB
1	-131.5 dB	-131.4 dB	-131.6 dB
1.25	-131.6 dB	-131.4 dB	-131.6 dB
1.6	-131.6 dB	-131.5 dB	-131.7 dB
2	-131.6 dB	-131.5 dB	-131.7 dB
2.5	-131.6 dB	-131.5 dB	-131.6 dB
3.15	-131.6 dB	-131.5 dB	-131.7 dB
4	-131.7 dB	-131.5 dB	-131.7 dB
5	-131.7 dB	-131.5 dB	-131.7 dB
6.3	-131.6 dB	-131.5 dB	-131.7 dB
8	-131.6 dB	-131.5 dB	-131.7 dB
10	-131.6 dB	-131.5 dB	-131.7 dB
12.5	-131.7 dB	-131.5 dB	-131.7 dB
16	-131.7 dB	-131.5 dB	-131.7 dB
20	-131.7 dB	-131.5 dB	-131.7 dB
25	-131.7 dB	-131.5 dB	-131.7 dB
31.5	-131.7 dB	-131.5 dB	-131.7 dB
40	-131.7 dB	-131.6 dB	-131.7 dB

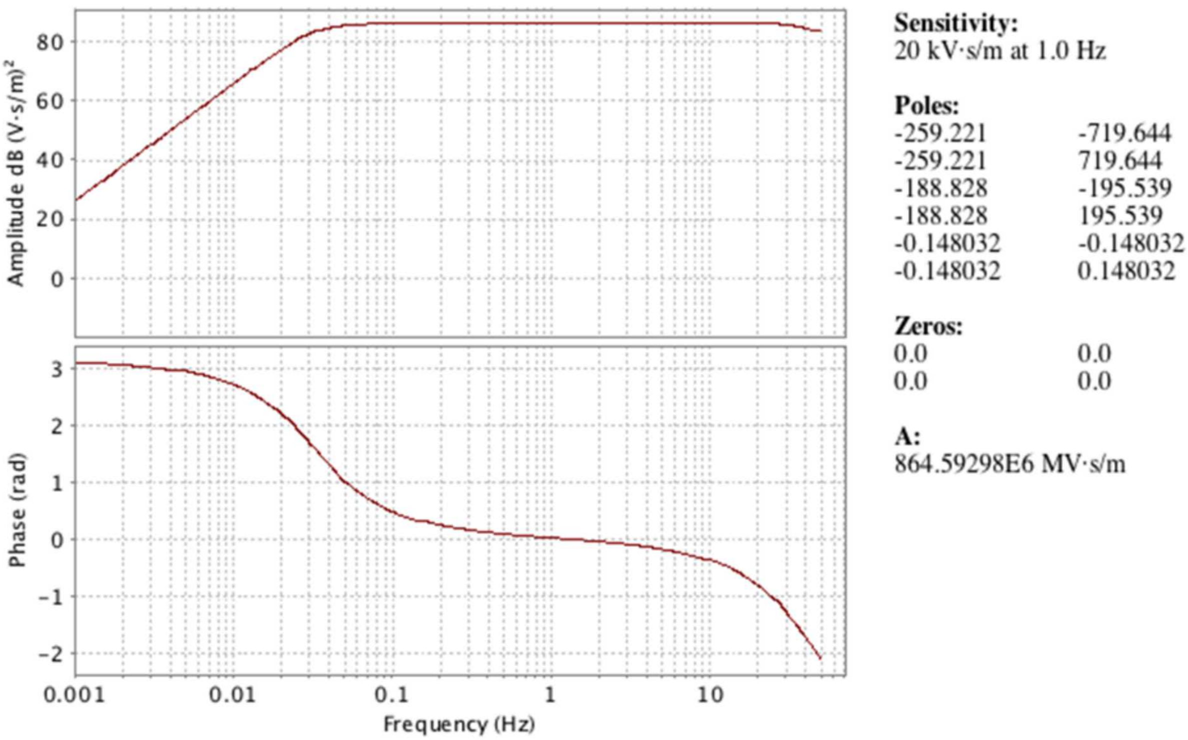
Table 60 Affinity Digitizer Noise Model, 4x Gain

Frequency (Hz)	AE2 (chan 3)	AN2 (chan 2)	AZ2 (chan 1)
0.00315	-128.5 dB	-127.6 dB	-128.9 dB
0.004	-128.5 dB	-127.6 dB	-128.9 dB
0.005	-130.4 dB	-129.1 dB	-130.6 dB
0.0063	-130.4 dB	-129.1 dB	-130.6 dB
0.008	-131.7 dB	-130.7 dB	-131.5 dB
0.01	-131.7 dB	-130.7 dB	-131.5 dB
0.0125	-132.1 dB	-130.9 dB	-132.0 dB
0.016	-132.1 dB	-130.9 dB	-131.8 dB
0.02	-132.8 dB	-131.8 dB	-132.7 dB
0.025	-133.0 dB	-131.8 dB	-132.7 dB
0.0315	-133.1 dB	-132.0 dB	-132.8 dB
0.04	-133.6 dB	-132.2 dB	-133.1 dB
0.05	-133.6 dB	-132.5 dB	-133.4 dB
0.063	-134.1 dB	-133.2 dB	-133.8 dB
0.08	-134.1 dB	-133.5 dB	-134.2 dB
0.1	-134.3 dB	-133.8 dB	-134.4 dB
0.125	-134.4 dB	-134.4 dB	-134.6 dB
0.16	-134.6 dB	-134.7 dB	-134.9 dB
0.2	-134.8 dB	-134.8 dB	-135.0 dB
0.25	-134.9 dB	-135.0 dB	-135.2 dB
0.315	-135.1 dB	-135.0 dB	-135.1 dB
0.4	-135.0 dB	-135.0 dB	-135.1 dB
0.5	-135.1 dB	-135.1 dB	-135.2 dB
0.63	-135.1 dB	-135.2 dB	-135.3 dB
0.8	-135.2 dB	-135.1 dB	-135.3 dB
1	-135.3 dB	-135.2 dB	-135.3 dB
1.25	-135.2 dB	-135.2 dB	-135.3 dB
1.6	-135.3 dB	-135.2 dB	-135.3 dB
2	-135.2 dB	-135.3 dB	-135.3 dB
2.5	-135.3 dB	-135.3 dB	-135.3 dB
3.15	-135.3 dB	-135.3 dB	-135.3 dB
4	-135.3 dB	-135.3 dB	-135.3 dB
5	-135.3 dB	-135.3 dB	-135.4 dB
6.3	-135.3 dB	-135.2 dB	-135.4 dB
8	-135.3 dB	-135.2 dB	-135.4 dB
10	-135.3 dB	-135.2 dB	-135.4 dB
12.5	-135.3 dB	-135.2 dB	-135.3 dB
16	-135.3 dB	-135.2 dB	-135.3 dB
20	-135.3 dB	-135.2 dB	-135.3 dB
25	-135.3 dB	-135.2 dB	-135.3 dB
31.5	-135.3 dB	-135.2 dB	-135.3 dB
40	-135.4 dB	-135.3 dB	-135.4 dB

APPENDIX B: RESPONSE MODELS

4.1 Guralp Systems CMG-3VB Response

Guralp Systems Model ENG-3VB-JSV500300203L seismometer amplitude and phase response.



APPENDIX C: TESTBED CALIBRATIONS

Agilent 3458A # 2823A10915

PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Limited Calibration Certificate

Document #: 41628_11719482

Item Identification

Asset Number	41628
Description	Meter,Multifunction
Model	3458A
Serial #	2823A10915
Manufacturer	Hewlett Packard Co
Customer Asset Id	N/A
Purchase Order	N/A
Customer	Ground-Based Monitoring R&E 06752
Custodian	Slad, George William
Location	SNLNM/TA1/758/1029
Date of Receipt	July 27, 2017
Dates Tested (Start – End)	August 09, 2017 - August 09, 2017
Date Approved	August 11, 2017
Calibration Expiration Date	August 11, 2018

Calibration Description

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

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41628_11719482

PRIMARY STANDARDS
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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:	HP 3458A Multimeter	Test Result:	**PASS**
Asset Number:	41628	Test Type:	FOUND-LEFT
Serial Number:	2823A10915	Calibration Date:	8/9/2017
Procedure Name:	HP 3458A	Temperature:	23 °C
Revision:	4.2	Humidity:	40 %
Calibrated By:	Jason Chance		

- 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	5/10/2018
20174	Fluke 5725A Amplifier	8/10/2017
20563	FLUKE 5790A CALIBRATOR	9/19/2017
6651332	Agilent 33250A Funtion/Arbitrary Waveform Generato	2/15/2018
6664631	Fluke 5730A Multifunction Calibrator	9/8/2017

Test Results

```
Test Description                         True Value
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
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.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

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	99.99976	100.00188	mV	2.26#	13	
-100.00000 mV		-100.00188	-99.99974	-99.99812	mV	2.26#	14	
1.00000000 V		0.99998965	0.99999895	1.00001035	V	2.97#	10	
-1.00000000 V		-1.00001035	-0.99999926	-0.99998965	V	2.97#	7	
-10.0000000 V		-10.0000987	-9.9999912	-9.9999013	V	3.92#	9	
-5.0000000 V		-5.0000501	-4.9999960	-4.9999499	V	3.71#	8	
-2.0000000 V		-2.0000209	-1.9999976	-1.9999791	V	3.24#	12	
2.0000000 V		1.9999791	1.9999967	2.0000209	V	3.24#	16	
5.0000000 V		4.9999499	4.9999953	5.0000501	V	3.71#	9	
10.0000000 V		9.9999013	9.9999894	10.0000987	V	3.92#	11	
100.000000 V		99.998821	99.999960	100.001179	V	3.51#	3	

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Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
1000.00000 V		999.98900	999.99738	1000.01100	V	2.42#	24	
DC Current								
100.000 nA		91.597	99.976	108.403	nA	1.85#	0	
1.000000 µA		0.969900	0.999960	1.030100	µA	5.5	0	
10.000000 µA		9.969900	9.999844	10.030100	µA	5.2	1	
100.00000 µA		99.95000	99.99882	100.05000	µA	5.7	2	
1.0000000 mA		0.9997500	0.9999961	1.0002500	mA	7.6	2	
10.000000 mA		9.997500	9.999991	10.002500	mA	8.1	0	
100.00000 mA		99.97500	100.00062	100.02500	mA	6.1	2	
1.0000000 A		0.9995000	1.0000213	1.0005000	A	7.6	4	
Resistance								
10.00000 Ohm	10.000270	9.99917	10.00021	10.00137	Ohm	5.8	6	
100.00000 Ohm	100.003620	99.99812	100.00318	100.00912	Ohm	6.5	8	
1.0000000 kOhm	0.99998460	0.9999336	0.9999831	1.0000356	kOhm	7.3	3	
10.000000 kOhm	9.9998320	9.999322	9.999830	10.000342	kOhm	7.3	0	
100.00000 kOhm	100.000630	99.99553	100.00075	100.00573	kOhm	6.0	2	
1.0000000 MOhm	0.99996060	0.9998586	0.9999609	1.0000626	MOhm	7.3	0	
10.000000 MOhm	9.9982380	9.996138	9.998227	10.000338	MOhm	7.2	1	
100.00000 MOhm	100.008520	99.95752	100.01760	100.05952	MOhm	6.0	18	
1.00192000 GOhm		0.9818716	1.0024808	1.0219684	GOhm	>10	3	
AC Current								
100.0000 µA @ 20 Hz		99.8300	99.9346	100.1700	µA	7.4	39	
100.0000 µA @ 45 Hz		99.8300	99.9808	100.1700	µA	9.4	11	
100.0000 µA @ 1 kHz		99.8300	99.9828	100.1700	µA	9.4	10	
1.000000 mA @ 20 Hz		0.998300	0.999488	1.001700	mA	10.0	30	
1.000000 mA @ 45 Hz		0.998300	0.999938	1.001700	mA	>10	4	
1.000000 mA @ 5 kHz		0.998300	1.000172	1.001700	mA	6.3	10	
1.000000 mA @ 10 kHz		0.995013	1.000288	1.004987	mA	3.47#	6	
10.00000 mA @ 20 Hz		9.98300	9.99494	10.01700	mA	10.0	30	
10.00000 mA @ 45 Hz		9.98300	9.99944	10.01700	mA	>10	3	
10.00000 mA @ 5 kHz		9.98300	10.00133	10.01700	mA	7.7	8	
10.00000 mA @ 10 kHz		9.94970	10.00200	10.05030	mA	4.0	4	
100.0000 mA @ 20 Hz		99.8300	99.9528	100.1700	mA	10.0	28	
100.0000 mA @ 45 Hz		99.8300	99.9995	100.1700	mA	>10	0	
100.0000 mA @ 5 kHz		99.8300	100.0300	100.1700	mA	8.5	18	
100.0000 mA @ 10 kHz		99.4800	100.0495	100.5200	mA	5.5	10	
1.000000 A @ 40 Hz		0.998300	0.999896	1.001700	A	6.5	6	
1.000000 A @ 5 kHz		0.998357	1.001093	1.001643	A	3.95#	67	
AC Volts								
10.00000 mV @ 10 Hz	10.006200	9.98599	9.99880	10.02641	mV	7.2	37	
10.00000 mV @ 40 Hz	9.998000	9.99358	9.99825	10.00242	mV	2.94#	6	
10.00000 mV @ 20 kHz	9.997000	9.99258	9.99788	10.00142	mV	2.94#	20	
10.00000 mV @ 50 kHz	9.997600	9.98650	9.99413	10.00870	mV	4.1	31	
10.00000 mV @ 100 kHz		9.94890	9.98216	10.05110	mV	>10	35	
10.00000 mV @ 300 kHz	9.997300	9.59541	9.84587	10.39919	mV	>10	38	
100.0000 mV @ 10 Hz	100.07170	99.8696	99.9998	100.2738	mV	>10	36	
100.0000 mV @ 40 Hz	99.99470	99.9477	99.9957	100.0417	mV	>10	2	
100.0000 mV @ 20 kHz	99.97850	99.9315	99.9969	100.0255	mV	>10	39	
100.0000 mV @ 50 kHz	99.98210	99.8801	99.9912	100.0841	mV	>10	9	
100.0000 mV @ 100 kHz	99.98540	99.7834	99.9719	100.1874	mV	>10	7	
100.0000 mV @ 300 kHz	99.98800	98.9781	99.8645	100.9979	mV	>10	12	
1.000000 V @ 10 Hz	0.9999928	0.997973	1.000036	1.002013	V	>10	2	
1.000000 V @ 40 Hz	0.9999930	0.999523	1.000025	1.000463	V	>10	7	
1.000000 V @ 20 kHz	0.9999961	0.999526	0.999969	1.000466	V	>10	6	
1.000000 V @ 50 kHz	1.0000142	0.998994	0.999998	1.001034	V	>10	2	
1.000000 V @ 100 kHz	1.0000316	0.998012	1.000109	1.002052	V	>10	4	
1.000000 V @ 300 kHz	1.0003600	0.990256	1.001526	1.010464	V	>10	12	
10.00000 V @ 10 Hz	10.000022	9.97982	10.00055	10.02022	V	>10	3	
10.00000 V @ 40 Hz	9.999997	9.99530	10.00036	10.00470	V	>10	8	
10.00000 V @ 20 kHz	10.000074	9.99537	9.99981	10.00477	V	>10	6	
10.00000 V @ 50 kHz	10.000247	9.99005	9.99966	10.01045	V	>10	6	

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Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
10.00000 V @ 100 kHz	10.000629	9.98043	9.99770	10.02083	V	>10	15	
10.00000 V @ 300 kHz	10.003385	9.90235	9.98995	10.10442	V	>10	13	
100.0000 V @ 10 Hz	99.99904	99.7970	100.0037	100.2010	V	>10	2	
100.0000 V @ 40 Hz	100.00010	99.9531	100.0019	100.0471	V	>10	4	
100.0000 V @ 20 kHz	100.00217	99.9552	100.0041	100.0492	V	>10	4	
100.0000 V @ 50 kHz	100.00724	99.9052	100.0091	100.1092	V	>10	2	
100.0000 V @ 100 kHz	100.01276	99.8107	100.0074	100.2148	V	>10	3	
100.0000 V @ 200 kHz	100.06317	99.0525	100.0525	101.0738	V	>10	1	
700.0000 V @ 40 Hz	700.01700	699.4370	699.9785	700.5970	V	>10	7	
700.0000 V @ 20 kHz	700.03180	699.4518	699.9037	700.6118	V	>10	22	
FREQUENCY								
10.00000 Hz @ 1 V		9.995000	10.000040	10.005000	Hz	>10	1	
40.00000 Hz @ 1 V		39.996000	39.999966	40.004000	Hz	>10	1	
100.00000 Hz @ 1 V		99.990000	99.999887	100.010000	Hz	>10	1	
1000.0000 Hz @ 1 V		999.90000	1000.00029	1000.10000	Hz	>10	0	
10000.0000 Hz @ 1 V		9999.00000	10000.00382	10001.00000	Hz	>10	0	
20000.0000 Hz @ 1 V		19998.00000	20000.00573	20002.00000	Hz	>10	0	
50000.0000 Hz @ 1 V		49995.00000	50000.01907	50005.00000	Hz	>10	0	
100.00000 kHz @ 1 V		99.990000	100.000038	100.010000	kHz	>10	0	
500.00000 kHz @ 1 V		499.950000	500.000191	500.050000	kHz	>10	0	
1.000000 MHz @ 1 V		0.9999000	1.0000004	1.0001000	MHz	>10	0	
2.000000 MHz @ 1 V		1.9998000	2.0000006	2.0002000	MHz	>10	0	
4.000000 MHz @ 1 V		3.9996000	4.0000013	4.0004000	MHz	>10	0	
6.000000 MHz @ 1 V		5.9994000	6.0000021	6.0006000	MHz	>10	0	
8.000000 MHz @ 1 V		7.9992000	8.0000032	8.0008000	MHz	>10	0	
10.000000 MHz @ 1 V		9.9990000	10.0000038	10.0010000	MHz	>10	0	

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

PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

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
6651332	Generator,Function	33250A	February 16, 2018
20563	Standard,Measurement,AC	5790A	September 19, 2017
20174	Amplifier	5725A	August 10, 2017
6664631	Calibrator,Multifunction	5730A	April 25, 2018
11123	Resistor,Standard	5155-9	May 10, 2018

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

Traceability

Values and the associated uncertainties supplied by the Primary Standards Lab (PSL) are traceable to the SI through one or more of the following:

1. Reference standards whose values are disseminated by the National Institute of Standards and Technology (United States of America) or, where appropriate, to the national metrological institute of another nation participating in the CIPM MRA;
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 by the PSL 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 Primary Standards Lab at Sandia National Laboratories.

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 presence of names and titles under "Authorization" are properly authenticated electronic signatures conforming to the equivalent identification signatory requirements of ISO 17025:2005 5.10.2.j.

Authorization

Calibrated By:

Chance, Jason
Metrologist

Approved By:

Aragon, Steven J.
Metrologist

End-of-Document

Agilent 3458A # MY45048371

PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Limited Calibration Certificate

Document #: 6652541_11682157

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 05752
Custodian	Slad, George William
Location	SNLNM/TA1/758/1044
Date of Receipt	September 13, 2016
Dates Tested (Start – End)	September 30, 2016 - September 30, 2016
Date Approved	October 12, 2016
Calibration Expiration Date	October 12, 2017

Calibration Description

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

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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

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PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

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:	FOUND-LEFT
Serial Number:	MY45048371	Calibration Date:	9/30/2016
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
  - Guardbanded limits are smaller than the specification limits
  - Guardbanding performed according to the Primary Standards Laboratory Operations Procedure (PSL-PRO-001)
- 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	5/10/2018
20174	Fluke 5725A Amplifier	8/10/2017
6651332	Agilent 33250A Funtion/Arbitrary Waveform Generato	2/17/2017
6664631	Fluke 5730A Multifunction Calibrator	5/9/2017
6668991	Fluke 5790B AC Measurement Standard	6/29/2017

Test Results

```
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.
------------------------------------------------------------

The internal temperature of the 3458A is 36.2 deg.C
DC Volts
```

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
100.00000 mV		99.99820	100.00007	100.00180	mV	1.91#	4	
-100.00000 mV		-100.00180	-100.00000	-99.99820	mV	1.91#	0	
1.00000000 V		0.99999035	1.00000018	1.00000965	V	2.08#	2	
-1.00000000 V		-1.00000965	-1.00000044	-0.99999035	V	2.08#	5	
-10.0000000 V		-10.0000964	-10.0000107	-9.9999036	V	3.09#	11	
-5.0000000 V		-5.0000488	-5.0000059	-4.9999512	V	2.89#	12	
-2.0000000 V		-2.0000196	-2.0000012	-1.9999804	V	2.22#	6	
2.0000000 V		1.9999804	2.0000015	2.0000196	V	2.22#	7	

Agilent 3458A Asset # 6652541
Calibration Date: 9/30/2016 10:32:19

Primary Electrical Lab TUR Report version 03/30/16

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PRIMARY STANDARDS LABORATORY

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Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
5.0000000 V		4.9999512	5.0000046	5.0000488	V	2.89#	10	
10.0000000 V		9.9999036	10.0000082	10.0000964	V	3.09#	8	
100.000000 V		99.998878	100.000131	100.001122	V	2.46#	12	
1000.00000 V		999.98987	1000.00176	1000.01013	V	1.83#	17	
DC Current								
100.000 nA		91.597	99.981	108.403	nA	1.85#	0	
1.000000 µA		0.969900	0.999973	1.030100	µA	5.5	0	
10.000000 µA		9.969900	9.999795	10.030100	µA	5.2	1	
100.00000 µA		99.95000	99.99837	100.05000	µA	5.4	3	
1.0000000 mA		0.9997500	0.9999940	1.0002500	mA	6.8	2	
10.000000 mA		9.997500	9.999940	10.002500	mA	7.1	2	
100.00000 mA		99.97500	100.00013	100.02500	mA	5.6	1	
1.0000000 A		0.9995000	1.0000079	1.0005000	A	6.2	2	
Resistance								
10.00000 Ohm	10.000281	9.99918	10.00027	10.00138	Ohm	5.2	1	
100.00000 Ohm	100.003660	99.99816	100.00374	100.00916	Ohm	5.9	1	
1.0000000 kOhm	0.99998410	0.9999331	0.9999872	1.0000351	kOhm	8.2	6	
10.000000 kOhm	9.9998320	9.999322	9.999884	10.000342	kOhm	8.2	10	
100.00000 kOhm	100.000690	99.99559	100.00133	100.00579	kOhm	6.5	13	
1.0000000 MOhm	0.99996080	0.9998588	0.9999692	1.0000628	MOhm	8.5	8	
10.000000 MOhm	9.9982260	9.996126	9.998293	10.000326	MOhm	5.8	3	
100.00000 MOhm	100.010650	99.95964	99.99522	100.06166	MOhm	5.5	30	
1.00192000 GOhm		0.9818716	1.0005328	1.0219684	GOhm	>10	7	
AC Current								
100.0000 µA @ 20 Hz		99.8300	99.9431	100.1700	µA	6.8	34	
100.0000 µA @ 45 Hz		99.8300	99.9865	100.1700	µA	10.0	8	
100.0000 µA @ 1 kHz		99.8300	99.9852	100.1700	µA	10.0	9	
1.000000 mA @ 20 Hz		0.998300	0.999530	1.001700	mA	8.9	28	
1.000000 mA @ 45 Hz		0.998300	0.999976	1.001700	mA	>10	1	
1.000000 mA @ 5 kHz		0.998300	1.000252	1.001700	mA	5.9	15	
1.000000 mA @ 10 kHz		0.995062	1.000536	1.004938	mA	3.25#	11	
10.00000 mA @ 20 Hz		9.98300	9.99535	10.01700	mA	8.9	27	
10.00000 mA @ 45 Hz		9.98300	9.99981	10.01700	mA	>10	1	
10.00000 mA @ 5 kHz		9.98300	10.00160	10.01700	mA	7.1	9	
10.00000 mA @ 10 kHz		9.95013	10.00277	10.04987	mA	3.47#	6	
100.0000 mA @ 20 Hz		99.8300	99.9560	100.1700	mA	8.9	26	
100.0000 mA @ 45 Hz		99.8300	100.0021	100.1700	mA	>10	1	
100.0000 mA @ 5 kHz		99.8300	100.0331	100.1700	mA	7.7	20	
100.0000 mA @ 10 kHz		99.4800	100.0596	100.5200	mA	4.7	12	
1.000000 A @ 40 Hz		0.998300	0.999931	1.001700	A	6.5	4	
1.000000 A @ 5 kHz		0.998365	1.001058	1.001635	A	3.62#	65	
AC Volts								
10.00000 mV @ 10 Hz	9.997600	9.97740	9.99811	10.01780	mV	7.2	3	
10.00000 mV @ 40 Hz	9.997700	9.99328	9.99840	10.00212	mV	2.94#	16	
10.00000 mV @ 20 kHz	9.998300	9.99388	9.99918	10.00272	mV	2.94#	20	
10.00000 mV @ 50 kHz	9.999000	9.98790	9.99777	10.01010	mV	4.1	11	
10.00000 mV @ 100 kHz	10.001400	9.95029	9.98886	10.05251	mV	>10	25	
10.00000 mV @ 300 kHz	9.998300	9.59637	9.88230	10.40023	mV	>10	29	
100.0000 mV @ 10 Hz	99.99500	99.7930	99.9984	100.1970	mV	>10	2	
100.0000 mV @ 40 Hz	99.99530	99.9483	99.9955	100.0423	mV	>10	1	
100.0000 mV @ 20 kHz	99.99520	99.9482	99.9907	100.0422	mV	>10	10	
100.0000 mV @ 50 kHz	99.99520	99.8932	99.9943	100.0972	mV	>10	1	
100.0000 mV @ 100 kHz	99.99690	99.7949	99.9842	100.1989	mV	>10	6	
100.0000 mV @ 300 kHz	99.99400	98.9841	99.9211	101.0039	mV	>10	7	
1.000000 V @ 10 Hz	1.0000237	0.998004	1.000022	1.002044	V	>10	0	
1.000000 V @ 40 Hz	1.0000196	0.999550	1.000034	1.000490	V	>10	3	
1.000000 V @ 20 kHz	1.0000224	0.999552	0.999957	1.000492	V	>10	14	
1.000000 V @ 50 kHz	1.0000291	0.999009	1.000049	1.001049	V	>10	2	
1.000000 V @ 100 kHz	1.0000269	0.998007	1.000153	1.002047	V	>10	6	
1.000000 V @ 300 kHz	1.0001011	0.990000	1.001503	1.010202	V	>10	14	
10.00000 V @ 10 Hz	10.000326	9.98013	10.00062	10.02053	V	>10	1	

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 @ 40 Hz	10.000220	9.99552	10.00043	10.00492	V	>10	4	
10.00000 V @ 20 kHz	10.000190	9.99549	9.99959	10.00489	V	>10	13	
10.00000 V @ 50 kHz	10.000207	9.99001	10.00030	10.01041	V	>10	1	
10.00000 V @ 100 kHz	9.999795	9.97960	9.99935	10.01999	V	>10	2	
10.00000 V @ 300 kHz	10.001654	9.90064	9.99885	10.10267	V	>10	3	
100.0000 V @ 10 Hz	100.00266	99.8007	100.0055	100.2047	V	>10	1	
100.0000 V @ 40 Hz	100.00218	99.9552	100.0044	100.0492	V	>10	5	
100.0000 V @ 20 kHz	100.00295	99.9559	100.0059	100.0500	V	>10	6	
100.0000 V @ 50 kHz	100.00901	99.9070	100.0129	100.1110	V	>10	4	
100.0000 V @ 100 kHz	100.01336	99.8113	100.0098	100.2154	V	>10	2	
100.0000 V @ 200 kHz	100.08044	99.0498	100.0800	101.0710	V	>10	3	
700.0000 V @ 40 Hz	700.01590	699.4359	700.0061	700.5959	V	>10	2	
700.0000 V @ 20 kHz	700.02470	699.4447	699.7809	700.6047	V	>10	42	
FREQUENCY								
10.00000 Hz @ 1 V		9.995000	10.000099	10.005000	Hz	>10	2	
40.00000 Hz @ 1 V		39.996000	40.000415	40.004000	Hz	>10	10	
100.00000 Hz @ 1 V		99.990000	100.000600	100.010000	Hz	>10	6	
1000.0000 Hz @ 1 V		999.90000	1000.00696	1000.10000	Hz	>10	7	
10000.0000 Hz @ 1 V		9999.00000	10000.06962	10001.00000	Hz	>10	7	
20000.0000 Hz @ 1 V		19998.00000	20000.13923	20002.00000	Hz	>10	7	
50000.0000 Hz @ 1 V		49995.00000	50000.35285	50005.00000	Hz	>10	7	
100.00000 kHz @ 1 V		99.990000	100.000696	100.010000	kHz	>10	7	
500.00000 kHz @ 1 V		499.950000	500.003401	500.050000	kHz	>10	7	
1.000000 MHz @ 1 V		0.9999000	1.0000071	1.0001000	MHz	>10	7	
2.000000 MHz @ 1 V		1.9998000	2.0000139	2.0002000	MHz	>10	7	
4.000000 MHz @ 1 V		3.9996000	4.0000279	4.0004000	MHz	>10	7	
6.000000 MHz @ 1 V		5.9994000	6.0000422	6.0006000	MHz	>10	7	
8.000000 MHz @ 1 V		7.9992000	8.0000588	8.0008000	MHz	>10	7	
10.000000 MHz @ 1 V		9.9990000	10.0000696	10.0010000	MHz	>10	7	

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

PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

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
6668991	Standard,Measurement	5790B	June 29, 2017
6664631	Calibrator,Multifunction	5730A	April 25, 2017
6651332	Generator,Function	33250A	February 18, 2017
20174	Amplifier	5725A	August 10, 2017
11123	Resistor,Standard	5155-9	May 10, 2018

PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

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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 by the PSL in special cases and where warranted, such as consensus standards where no national or international standards exist;

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Note 2: For National Voluntary Laboratory Accreditation Program (NVLAP) accredited capabilities, the PSL at Sandia National Laboratories is accredited by NVLAP for the specific scope of accreditation under Laboratory Code 105002-0. This certificate or report shall not be used by the customer to claim product endorsement by NVLAP, the Primary Standards Laboratory, Sandia National Laboratories or any agency of the U. S. Government.

Note 3: 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 4: The presence of names and titles under "Authorization" are properly authenticated electronic signatures conforming to the equivalent identification signatory requirements of ISO 17025:2005 5.10.2.j.

Authorization

Calibrated By:	Approved By:
Liddle, Brian David Metrologist	Aragon, Steven J. Metrologist

End-of-Document

Agilent 3458A # MY45048372

PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Limited Calibration Certificate

Document #: 6652539_11669844

Item Identification

Asset Number	6652539
Description	Multimeter,Digital
Model	3458A
Serial #	MY45048372
Manufacturer	Agilent Technologies
Customer Asset Id	N/A
Purchase Order	N/A
Customer	Ground-Based Monitoring R&E 05752
Custodian	Merchant, Bion J.
Location	SNLNM/TA1/758/1042
Date of Receipt	May 05, 2016
Dates Tested (Start – End)	May 24, 2016 - May 24, 2016
Date Approved	May 24, 2016
Calibration Expiration Date	May 24, 2017

Calibration Description

Calibration Lab	PSL-ELECTRICAL
Calibration Procedure, rev.	HP 3458A, 4.1
Temperature	23 deg C
Humidity	40 %RH
Barometric Pressure	N/A mmHg
As Found Condition	PASS
As Left Condition	PASS
Software Used	MET/CAL 8.3.2.3
Tamper Seal	Yes

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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

PRIMARY STANDARDS
LABORATORY

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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

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Calibration Data Report

Primary Electrical Lab

Unit Under Test: Agilent 3458A Digital Multimeter	Test Result: **PASS**
Asset Number: 6652539	Test Type: FOUND-LEFT
Serial Number: MY45048372	Calibration Date: 5/24/2016
Procedure Name: HP 3458A	Temperature: 23 °C
Revision: 4.1	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
  - Guardbanded limits are smaller than the specification limits
  - Guardbanding performed according to the Primary Standards Laboratory Operations Procedure (PSL-PRO-001)
- 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	5/10/2018
20563	FLUKE 5790A CALIBRATOR	6/11/2016
44972	Fluke 5725A Amplifier	12/15/2016
6651332	Agilent 33250A Funtion/Arbitrary Waveform Generato	2/17/2017
6664631	Fluke 5730A Multifunction Calibrator	4/25/2017

Test Results

Test Description — **True Value** — **Lower Limit** — **Measured Value** — **Upper Limit** — **Units** — **TUR** — **% Tol** — **Status**

```
-------------------------------------------------------
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.
-------------------------------------------------------

The internal temperature of the 3458A is 36.2 deg.C
DC Volts
```

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
100.00000 mV		99.99820	99.99965	100.00180	mV	1.91#	20	
-100.00000 mV		-100.00180	-99.99960	-99.99820	mV	1.91#	22	
1.00000000 V		0.99999035	0.99999661	1.00000965	V	2.08#	35	
-1.00000000 V		-1.00000965	-0.99999695	-0.99999035	V	2.08#	32	
-10.0000000 V		-10.0000964	-9.9999728	-9.9999036	V	3.09#	28	
-5.0000000 V		-5.0000488	-4.9999869	-4.9999512	V	2.89#	27	
-2.0000000 V		-2.0000196	-1.9999937	-1.9999804	V	2.22#	32	
2.0000000 V		1.9999804	1.9999937	2.0000196	V	2.22#	32	

PRIMARY STANDARDS LABORATORY

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Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
5.0000000 V		4.9999512	4.9999871	5.0000488	V	2.89#	26	
10.0000000 V		9.9999036	9.9999715	10.0000964	V	3.09#	30	
100.000000 V		99.998878	99.999755	100.001122	V	2.46#	22	
1000.00000 V		999.98987	999.99754	1000.01013	V	1.83#	24	
DC Current								
100.000 nA		91.597	100.101	108.403	nA	1.85#	1	
1.000000 µA		0.969900	1.000068	1.030100	µA	5.5	0	
10.000000 µA		9.969900	9.999933	10.030100	µA	5.2	0	
100.00000 µA		99.95000	99.99859	100.05000	µA	5.4	3	
1.0000000 mA		0.9997500	0.9999936	1.0002500	mA	6.8	3	
10.000000 mA		9.997500	9.999938	10.002500	mA	7.1	2	
100.00000 mA		99.97500	100.00034	100.02500	mA	5.6	1	
1.0000000 A		0.9995000	1.0000220	1.0005000	A	6.2	4	
Resistance								
10.00000 Ohm	10.000281	9.99918	10.00025	10.00138	Ohm	5.2	3	
100.00000 Ohm	100.003660	99.99816	100.00378	100.00916	Ohm	5.9	2	
1.0000000 kOhm	0.99998410	0.9999331	0.9999845	1.0000351	kOhm	8.2	1	
10.000000 kOhm	9.9998320	9.999322	9.999852	10.000342	kOhm	8.2	4	
100.00000 kOhm	100.000690	99.99559	100.00099	100.00579	kOhm	6.5	6	
1.0000000 MOhm	0.99996080	0.9998588	0.9999674	1.0000628	MOhm	8.5	7	
10.000000 MOhm	9.9982260	9.996126	9.998412	10.000326	MOhm	5.8	9	
100.00000 MOhm	100.010650	99.95964	100.02127	100.06166	MOhm	5.5	21	
1.00192000 GOhm		0.9818716	1.0025255	1.0219684	GOhm	>10	3	
AC Current								
100.0000 µA @ 20 Hz		99.8300	99.9362	100.1700	µA	6.8	38	
100.0000 µA @ 45 Hz		99.8300	99.9819	100.1700	µA	10.0	11	
100.0000 µA @ 1 kHz		99.8300	99.9814	100.1700	µA	10.0	11	
1.000000 mA @ 20 Hz		0.998300	0.999483	1.001700	mA	8.9	30	
1.000000 mA @ 45 Hz		0.998300	0.999950	1.001700	mA	>10	3	
1.000000 mA @ 5 kHz		0.998300	1.000239	1.001700	mA	5.9	14	
1.000000 mA @ 10 kHz		0.995062	1.000505	1.004938	mA	3.25#	10	
10.00000 mA @ 20 Hz		9.98300	9.99484	10.01700	mA	8.9	30	
10.00000 mA @ 45 Hz		9.98300	9.99954	10.01700	mA	>10	3	
10.00000 mA @ 5 kHz		9.98300	10.00141	10.01700	mA	7.1	8	
10.00000 mA @ 10 kHz		9.95013	10.00250	10.04987	mA	3.47#	5	
100.0000 mA @ 20 Hz		99.8300	99.9517	100.1700	mA	8.9	28	
100.0000 mA @ 45 Hz		99.8300	99.9993	100.1700	mA	>10	0	
100.0000 mA @ 5 kHz		99.8300	100.0313	100.1700	mA	7.7	18	
100.0000 mA @ 10 kHz		99.4800	100.0569	100.5200	mA	4.7	11	
1.000000 A @ 40 Hz		0.998300	0.999882	1.001700	A	6.5	7	
1.000000 A @ 5 kHz		0.998365	1.000787	1.001635	A	3.62#	48	
AC Volts								
10.00000 mV @ 10 Hz	10.009400	9.98918	9.99806	10.02962	mV	7.2	56	
10.00000 mV @ 40 Hz	10.001600	9.99718	9.99822	10.00602	mV	2.94#	77	
10.00000 mV @ 20 kHz	10.000500	9.99608	9.99885	10.00492	mV	2.94#	37	
10.00000 mV @ 50 kHz	10.001000	9.98990	9.99627	10.01210	mV	4.1	43	
10.00000 mV @ 100 kHz	10.003500	9.95238	9.98557	10.05462	mV	>10	35	
10.00000 mV @ 300 kHz	9.999400	9.59742	9.85994	10.40138	mV	>10	35	
100.0000 mV @ 10 Hz	100.07420	99.8721	99.9986	100.2763	mV	>10	37	
100.0000 mV @ 40 Hz	99.99530	99.9483	99.9977	100.0423	mV	>10	5	
100.0000 mV @ 20 kHz	99.97920	99.9322	99.9906	100.0262	mV	>10	24	
100.0000 mV @ 50 kHz	99.98200	99.8800	99.9917	100.0840	mV	>10	10	
100.0000 mV @ 100 kHz	99.98440	99.7824	99.9790	100.1864	mV	>10	3	
100.0000 mV @ 300 kHz	99.96950	98.9598	99.9037	100.9792	mV	>10	7	
1.000000 V @ 10 Hz	0.9999851	0.997965	1.000062	1.002005	V	>10	4	
1.000000 V @ 40 Hz	0.9999934	0.999523	1.000040	1.000463	V	>10	10	
1.000000 V @ 20 kHz	0.9999986	0.999529	0.999954	1.000469	V	>10	9	
1.000000 V @ 50 kHz	1.0000081	0.998988	1.000033	1.001028	V	>10	2	
1.000000 V @ 100 kHz	1.0000056	0.997986	1.000094	1.002026	V	>10	4	
1.000000 V @ 300 kHz	1.0000952	0.989994	1.001301	1.010196	V	>10	12	
10.00000 V @ 10 Hz	9.999958	9.97976	10.00060	10.02016	V	>10	3	

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Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
10.00000 V @ 40 Hz	9.999940	9.99524	10.00044	10.00464	V	>10	11	
10.00000 V @ 20 kHz	10.000035	9.99533	9.99981	10.00474	V	>10	5	
10.00000 V @ 50 kHz	10.000073	9.98987	10.00033	10.01027	V	>10	3	
10.00000 V @ 100 kHz	10.000197	9.98000	9.99859	10.02040	V	>10	8	
10.00000 V @ 300 kHz	10.000297	9.89929	9.99356	10.10130	V	>10	7	
100.0000 V @ 10 Hz	99.99889	99.7969	100.0082	100.2009	V	>10	5	
100.0000 V @ 40 Hz	99.99940	99.9524	100.0070	100.0464	V	>10	16	
100.0000 V @ 20 kHz	100.00103	99.9540	100.0023	100.0480	V	>10	3	
100.0000 V @ 50 kHz	100.00567	99.9037	100.0131	100.1077	V	>10	7	
100.0000 V @ 100 kHz	100.00786	99.8058	100.0063	100.2099	V	>10	0	
100.0000 V @ 200 kHz	100.04847	99.0380	100.0279	101.0590	V	>10	2	
700.0000 V @ 40 Hz	700.01380	699.4220	699.9477	700.5930	V	>10	11	
700.0000 V @ 20 kHz	700.03500	699.4550	699.6812	700.6150	V	>10	61	
FREQUENCY								
10.00000 Hz @ 1 V		9.995000	10.000029	10.005000	Hz	>10	1	
40.00000 Hz @ 1 V		39.996000	40.000000	40.004000	Hz	>10	0	
100.00000 Hz @ 1 V		99.990000	100.000085	100.010000	Hz	>10	1	
1000.0000 Hz @ 1 V		999.90000	1000.00152	1000.10000	Hz	>10	2	
10000.0000 Hz @ 1 V		9999.00000	10000.01335	10001.00000	Hz	>10	1	
20000.0000 Hz @ 1 V		19998.00000	20000.02479	20002.00000	Hz	>10	1	
50000.0000 Hz @ 1 V		49995.00000	50000.06675	50005.00000	Hz	>10	1	
100.00000 kHz @ 1 V		99.990000	100.000133	100.010000	kHz	>10	1	
500.00000 kHz @ 1 V		499.950000	500.000668	500.050000	kHz	>10	1	
1.000000 MHz @ 1 V		0.9999000	1.0000012	1.0001000	MHz	>10	1	
2.000000 MHz @ 1 V		1.9998000	2.0000027	2.0002000	MHz	>10	1	
4.000000 MHz @ 1 V		3.9996000	4.0000053	4.0004000	MHz	>10	1	
6.000000 MHz @ 1 V		5.9994000	6.0000078	6.0006000	MHz	>10	1	
8.000000 MHz @ 1 V		7.9992000	8.0000101	8.0008000	MHz	>10	1	
10.000000 MHz @ 1 V		9.9990000	10.0000134	10.0010000	MHz	>10	1	

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

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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
6664631	Calibrator,Multifunction	5730A	April 25, 2017
6651332	Generator,Function	33250A	February 18, 2017
44972	Amplifier	5725A	December 15, 2016
20563	Standard,Measurement,AC	5790A	June 11, 2016
11123	Resistor,Standard	5155-9	May 10, 2018

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Traceability

Values and the associated uncertainties supplied by the Primary Standards Lab (PSL) are traceable to the SI through one or more of the following:

1. Reference standards whose values are disseminated by the National Institute of Standards and Technology (United States of America) or, where appropriate, to the national metrological institute of another nation participating in the CIPM MRA;
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 by the PSL in special cases and where warranted, such as consensus standards where no national or international standards exist;

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Note 2: For National Voluntary Laboratory Accreditation Program (NVLAP) accredited capabilities, the PSL at Sandia National Laboratories is accredited by NVLAP for the specific scope of accreditation under Laboratory Code 105002-0. This certificate or report shall not be used by the customer to claim product endorsement by NVLAP, the Primary Standards Laboratory, Sandia National Laboratories or any agency of the U. S. Government.

Note 3: 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 4: The presence of names and titles under "Authorization" are properly authenticated electronic signatures conforming to the equivalent identification signatory requirements of ISO 17025:2005 5.10.2.j.

Authorization

Calibrated By:

Liddle, Brian David
Metrologist

Approved By:

Diana Kothmann
QA Representative

End-of-Document

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6652539_11669844

PRIMARY STANDARDS
LABORATORY

Sandia National Laboratories, Albuquerque, New Mexico 87185-0665

Limited Calibration Certificate

Document #: 6652539_11715460

Item Identification

Asset Number	6652539
Description	Multimeter,Digital
Model	3458A
Serial #	MY45048372
Manufacturer	Agilent Technologies
Customer Asset Id	N/A
Purchase Order	N/A
Customer	Ground-Based Monitoring R&E 06752
Custodian	Merchant, Bion J.
Location	SNLNM/TA1/758/1042
Date of Receipt	June 20, 2017
Dates Tested (Start – End)	June 27, 2017 - June 27, 2017
Date Approved	June 29, 2017
Calibration Expiration Date	June 29, 2018

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
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: 6652539	Test Type: FOUND-LEFT
Serial Number: MY45048372	Calibration Date: 6/27/2017
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
  - Guardbanded limits are smaller than the specification limits
  - Guardbanding performed according to the Primary Standards Laboratory Operations Procedure (PSL-PRO-001)
- 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	5/10/2018
20174	Fluke 5725A Amplifier	8/10/2017
6651332	Agilent 33250A Funtion/Arbitrary Waveform Generato	2/15/2018
6664631	Fluke 5730A Multifunction Calibrator	9/8/2017
6668991	Fluke 5790B AC Measurement Standard	6/29/2017

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.
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

The internal temperature of the 3458A is 35.4 deg.C
DC Volts
```

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
100.00000 mV		99.99812	99.99985	100.00188	mV	2.26#	8	
-100.00000 mV		-100.00188	-99.99981	-99.99812	mV	2.26#	10	
1.00000000 V		0.99998965	1.00000028	1.00001035	V	2.97#	3	
-1.00000000 V		-1.00001035	-1.00000058	-0.99998965	V	2.97#	6	
-10.0000000 V		-10.0000987	-10.0000089	-9.9999013	V	3.92#	9	
-5.0000000 V		-5.0000501	-5.0000048	-4.9999499	V	3.71#	10	
-2.0000000 V		-2.0000209	-2.0000006	-1.9999791	V	3.24#	3	
2.0000000 V		1.9999791	2.0000011	2.0000209	V	3.24#	5	

Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
5.0000000 V		4.9999499	5.0000048	5.0000501	V	3.71#	10	
10.0000000 V		9.9999013	10.0000079	10.0000987	V	3.92#	8	
100.000000 V		99.998821	100.000319	100.001179	V	3.51#	27	
1000.00000 V		999.98900	1000.00336	1000.01100	V	2.42#	31	
DC Current								
100.000 nA		91.597	99.923	108.403	nA	1.85#	1	
1.000000 µA		0.969900	0.999917	1.030100	µA	5.5	0	
10.000000 µA		9.969900	9.999806	10.030100	µA	5.2	1	
100.00000 µA		99.95000	99.99894	100.05000	µA	5.7	2	
1.0000000 mA		0.9997500	0.9999959	1.0002500	mA	7.6	2	
10.000000 mA		9.997500	9.999998	10.002500	mA	8.1	0	
100.00000 mA		99.97500	100.00088	100.02500	mA	6.1	4	
1.0000000 A		0.9995000	1.0000031	1.0005000	A	7.6	1	
Resistance								
10.00000 Ohm	10.000270	9.99917	10.00025	10.00137	Ohm	5.8	2	
100.00000 Ohm	100.003620	99.99812	100.00375	100.00912	Ohm	6.5	2	
1.0000000 kOhm	0.99998460	0.9999336	0.9999835	1.0000356	kOhm	9.1	2	
10.000000 kOhm	9.9998320	9.999322	9.999839	10.000342	kOhm	9.4	1	
100.00000 kOhm	100.000630	99.99553	100.00083	100.00573	kOhm	8.2	4	
1.0000000 MOhm	0.99996060	0.9998586	0.9999657	1.0000626	MOhm	9.3	5	
10.000000 MOhm	9.9982380	9.996138	9.998409	10.000338	MOhm	7.2	8	
100.00000 MOhm	100.008520	99.95752	100.02156	100.05952	MOhm	6.0	26	
1.00192000 GOhm		0.9818716	1.0013050	1.0219684	GOhm	>10	3	
AC Current								
100.0000 µA @ 20 Hz		99.8300	99.9380	100.1700	µA	7.4	37	
100.0000 µA @ 45 Hz		99.8300	99.9850	100.1700	µA	10.0	9	
100.0000 µA @ 1 kHz		99.8300	99.9838	100.1700	µA	10.0	10	
1.000000 mA @ 20 Hz		0.998300	0.999483	1.001700	mA	10.0	30	
1.000000 mA @ 45 Hz		0.998300	0.999956	1.001700	mA	>10	3	
1.000000 mA @ 5 kHz		0.998300	1.000252	1.001700	mA	6.3	15	
1.000000 mA @ 10 kHz		0.995013	1.000531	1.004987	mA	3.47#	11	
10.00000 mA @ 20 Hz		9.98300	9.99485	10.01700	mA	10.0	30	
10.00000 mA @ 45 Hz		9.98300	9.99963	10.01700	mA	>10	2	
10.00000 mA @ 5 kHz		9.98300	10.00159	10.01700	mA	7.7	9	
10.00000 mA @ 10 kHz		9.94970	10.00284	10.05030	mA	4.0	6	
100.0000 mA @ 20 Hz		99.8300	99.9512	100.1700	mA	10.0	29	
100.0000 mA @ 45 Hz		99.8300	100.0005	100.1700	mA	>10	0	
100.0000 mA @ 5 kHz		99.8300	100.0334	100.1700	mA	8.5	20	
100.0000 mA @ 10 kHz		99.4800	100.0615	100.5200	mA	5.5	12	
1.000000 A @ 40 Hz		0.998300	0.999871	1.001700	A	6.8	8	
1.000000 A @ 5 kHz		0.998357	1.000928	1.001643	A	3.95#	57	
AC Volts								
10.00000 mV @ 10 Hz	9.997500	9.97730	9.99829	10.01769	mV	7.2	4	
10.00000 mV @ 40 Hz	9.997600	9.99318	9.99808	10.00202	mV	2.94#	11	
10.00000 mV @ 20 kHz	9.998400	9.99398	9.99939	10.00282	mV	2.94#	22	
10.00000 mV @ 50 kHz	9.998900	9.98780	9.99672	10.01000	mV	4.1	20	
10.00000 mV @ 100 kHz	10.001500	9.95039	9.98671	10.05261	mV	>10	29	
10.00000 mV @ 300 kHz	9.998800	9.59685	9.86304	10.40075	mV	>10	34	
100.0000 mV @ 10 Hz	99.99330	99.7913	100.0001	100.1953	mV	>10	3	
100.0000 mV @ 40 Hz	99.99450	99.9475	100.0002	100.0415	mV	>10	12	
100.0000 mV @ 20 kHz	99.99500	99.9480	99.9922	100.0420	mV	>10	6	
100.0000 mV @ 50 kHz	99.99480	99.8928	99.9944	100.0968	mV	>10	0	
100.0000 mV @ 100 kHz	99.99690	99.7949	99.9824	100.1989	mV	>10	7	
100.0000 mV @ 300 kHz	99.99290	98.9830	99.9141	101.0028	mV	>10	8	
1.000000 V @ 10 Hz	1.0000181	0.997998	1.000063	1.002038	V	>10	2	
1.000000 V @ 40 Hz	1.0000172	0.999547	1.000045	1.000487	V	>10	6	
1.000000 V @ 20 kHz	1.0000173	0.999547	0.999938	1.000487	V	>10	17	
1.000000 V @ 50 kHz	1.0000320	0.999012	1.000005	1.001052	V	>10	3	
1.000000 V @ 100 kHz	1.0000237	0.998004	1.000072	1.002044	V	>10	2	
1.000000 V @ 300 kHz	1.0001382	0.990037	1.001300	1.010240	V	>10	12	
10.00000 V @ 10 Hz	10.000250	9.98005	10.00071	10.02045	V	>10	2	

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Test Results

Test Description	True Value	Lower Limit	Measured Value	Upper Limit	Units	TUR	% Tol	Status
10.00000 V @ 40 Hz	10.000221	9.99552	10.00050	10.00492	V	>10	6	
10.00000 V @ 20 kHz	10.000154	9.99545	9.99983	10.00485	V	>10	7	
10.00000 V @ 50 kHz	10.000260	9.99006	10.00042	10.01046	V	>10	2	
10.00000 V @ 100 kHz	9.999942	9.97974	9.99865	10.02014	V	>10	6	
10.00000 V @ 300 kHz	10.001953	9.90093	9.99372	10.10297	V	>10	8	
100.0000 V @ 10 Hz	100.00196	99.8000	100.0063	100.2040	V	>10	2	
100.0000 V @ 40 Hz	100.00209	99.9551	100.0053	100.0491	V	>10	7	
100.0000 V @ 20 kHz	100.00333	99.9563	99.9998	100.0503	V	>10	8	
100.0000 V @ 50 kHz	100.00953	99.9075	100.0102	100.1115	V	>10	1	
100.0000 V @ 100 kHz	100.01541	99.8134	100.0069	100.2174	V	>10	4	
100.0000 V @ 200 kHz	100.06695	99.0563	100.0300	101.0776	V	>10	4	
700.0000 V @ 40 Hz	700.02110	699.4411	699.9362	700.6011	V	>10	15	
700.0000 V @ 20 kHz	700.02830	699.4483	699.6416	700.6083	V	>10	67	
FREQUENCY								
10.00000 Hz @ 1 V		9.995000	10.000086	10.005000	Hz	>10	2	
40.00000 Hz @ 1 V		39.996000	40.000213	40.004000	Hz	>10	5	
100.00000 Hz @ 1 V		99.990000	100.000457	100.010000	Hz	>10	5	
1000.0000 Hz @ 1 V		999.90000	1000.00305	1000.10000	Hz	>10	3	
10000.0000 Hz @ 1 V		9999.00000	10000.02861	10001.00000	Hz	>10	3	
20000.0000 Hz @ 1 V		19998.00000	20000.05913	20002.00000	Hz	>10	3	
50000.0000 Hz @ 1 V		49995.00000	50000.14782	50005.00000	Hz	>10	3	
100.00000 kHz @ 1 V		99.990000	100.000296	100.010000	kHz	>10	3	
500.00000 kHz @ 1 V		499.950000	500.001478	500.050000	kHz	>10	3	
1.000000 MHz @ 1 V		0.9999000	1.0000029	1.0001000	MHz	>10	3	
2.000000 MHz @ 1 V		1.9998000	2.0000059	2.0002000	MHz	>10	3	
4.000000 MHz @ 1 V		3.9996000	4.0000116	4.0004000	MHz	>10	3	
6.000000 MHz @ 1 V		5.9994000	6.0000174	6.0006000	MHz	>10	3	
8.000000 MHz @ 1 V		7.9992000	8.0000233	8.0008000	MHz	>10	3	
10.000000 MHz @ 1 V		9.9990000	10.0000296	10.0010000	MHz	>10	3	

***** 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
6668991	Standard,Measurement	5790B	June 29, 2017
6664631	Calibrator,Multifunction	5730A	April 25, 2018
6651332	Generator,Function	33250A	February 16, 2018
20174	Amplifier	5725A	August 10, 2017
11123	Resistor,Standard	5155-9	May 10, 2018

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Authorization

Calibrated By:	Approved By:
Liddle, Brian David Metrologist	Aragon, Steven J. Metrologist

End-of-Document

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