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Evaluation of Low Cost Infrasound Sensor Packages

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ABSTRACT

Sandia National Laboratories has tested and evaluated the performance of the following five models of low-cost infrasound sensors and sensor packages: Camas microphone, Gem Infrasound Logger, InfraBSU sensor, Raspberry Boom, and the Samsung S10 smartphone utilizing the Redvox app.

The purpose of this infrasound sensor evaluation is to measure the performance characteristics in such areas as power consumption, sensitivity, self-noise, dynamic range, response, passband, linearity, sensitivity variation due to changes in static pressure and temperature, and sensitivity to vertical acceleration. The infrasound monitoring community has leveraged such sensors and integrated packages in novel ways; better understanding the performance of these units serves the geophysical monitoring community.

ACKNOWLEDGEMENTS

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We would like to Daniel Bowman of Sandia National Laboratories for loan of the GEM Infrasound Loggers for this evaluation, and Jeremy Webster of Los Alamos National Laboratory for suggestions regarding the evaluation and aid with data preparation.

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ACRONYMS AND DEFINITIONS

dB	Decibel
cts	Counts
DOE	Department of Energy
DWR	Digital Waveform Recorder
GPS	Global Position System
GNSS	Global Navigation Satellite System
HNM	High Noise Model
LNM	Low Noise Model
PCB	Printed Circuit Board
PSD	Power Spectral Density
PSL	Primary Standards Laboratory
PSU	Pennsylvania State University
PVC	Polyvinyl Chloride
rms	Root Mean Square
SNL	Sandia National Laboratories
SNR	Signal-to-Noise Ratio
SUT	Sensor Under Test

1 INTRODUCTION

The evaluation of two analog voltage output sensors: the Camas microphone and InfraBSU sensor, and three integrated digital output packages: the Gem Infrasound Logger, Raspberry Boom and the Samsung S10 smartphone utilizing the Redvox app, is to determine their performance characteristics in such areas as power consumption, sensitivity, self-noise, dynamic range, response, passband, linearity, sensitivity variation due to changes in static pressure and temperature, and sensitivity to vertical acceleration. Multiple units of each of these sensors and integrated packages are being evaluated to assess their performance for a variety of potential applications.

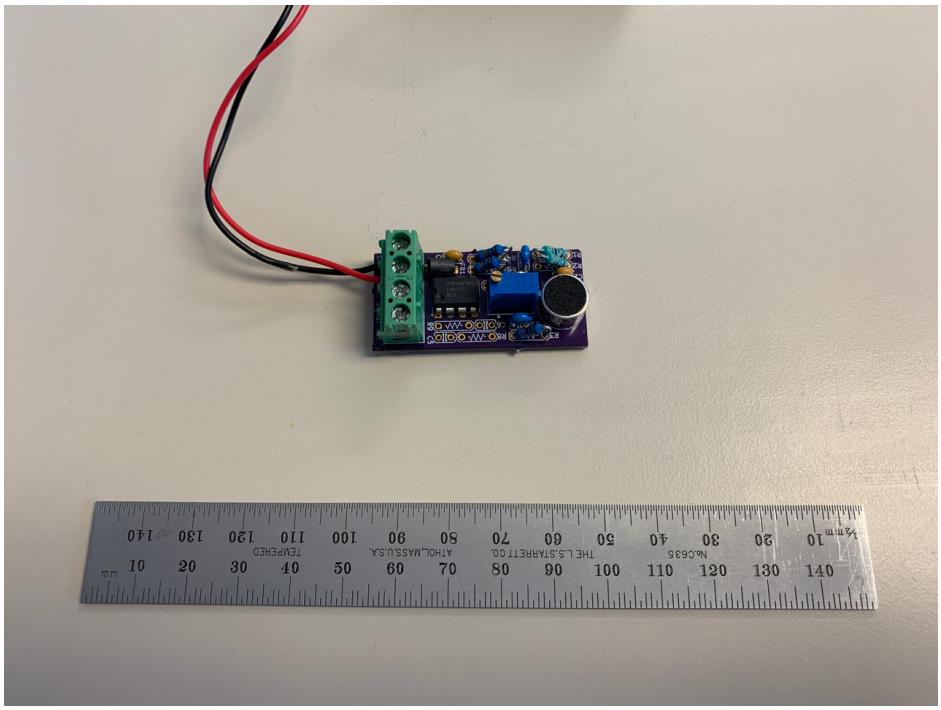

Figure 1 Camas Microphone

The Camas microphone is a relatively new sensor, produced in relatively small numbers by Jake Anderson of Boise State University. Each is powered by two AA batteries during the evaluation, as would often be the case in field applications. As these sensors do not have serial numbers associated with them, they are referred to as Camas microphones #1, #2 and #3. Specifications are not presently published for the microphones. The ruler in Figure 1, providing a sense of scale, is 15 cm long.

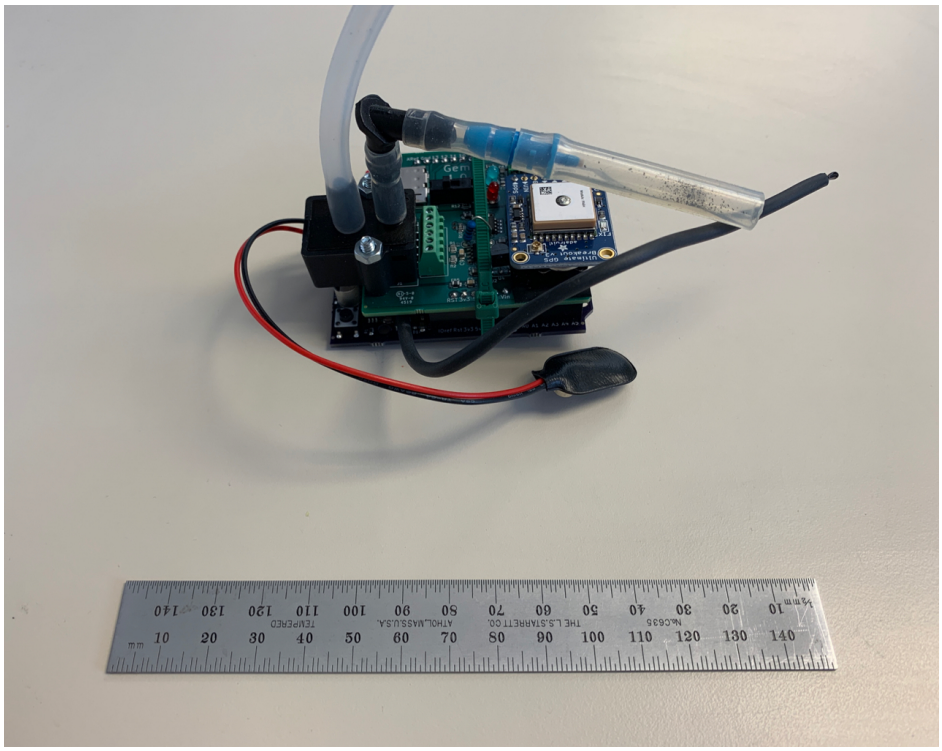

Figure 2 Gem Infrasound Logger

The Gem infrasound Logger is an integrated datalogger, GPS receiver, and infrasound sensor whose development was led by Jake Anderson and Jeffery Johnson of Boise State University. A 9 volt battery powers the Gem during the evaluation, as would be common in field applications. The serial numbers for the sensors used in this evaluation are listed below.

Table 1 Gem Infrasound Logger Serial Numbers

063
069
070
073

Difficulties with Gem packages #063, #069 and #073, including SD card write errors and recording locking up, prevented their full evaluation. Note Gem #069 was only used for a power consumption test. Specifications published by the developers are provided in Figure 3.

Specifications for the Gem Data Logger		
Parameter	**Value**	**Unit**
Resolution	16.3*	mPa/count
Full scale	±536*	Pa
Sample rate	100	Samples per second
Bandwidth	0.05*–25	Hz
Noise (0.05 Hz < f < 25 Hz)	15.1	mPa
Noise (0.5 Hz < f < 5 Hz)	7.2	mPa
Power (finding GPS fix)	124	mW
Power (with GPS fix)	107	mW
Power (GPS standby)	36	mW
Average power	40.5†	mW
Internal temperature range	–35 to 50	°C
Supply voltage range	3.4–16	V

These values apply to the most common implementation of Gem v.0.9.

*User adjustable: Dynamic range is adjusted by changing the value of the amplifier's gain-setting resistor or the pressure transducer model, and the low corner frequency is adjusted by changing the parameters of the pneumatic filter. For example, while attempting to record shock waves near the vent at Tungurahua (Ecuador), a high-pressure transducer and low amplifier gain resulted in a resolution of 0.961 Pa and a full-scale range of ±31.5 kPa.

†This value assumes a time to first fix of 30 s. When Global Positioning System (GPS) signal strength is low, more time will be spent finding a fix, and overall power draw will be higher.

Figure 3 Gem Infrasound Logger Specifications

Figure 4 InfraBSU sensors

The InfraBSU sensor, developed by Jeffery Johnson of Boise State University, is a follow-on to the InfraNMT sensor, and is based upon a micromachined piezoresistive differential pressure transducer and mechanical filter. The photo in Figure 4 shows the sensor in its plastic/PVC case (as tested) and outside of its sensor case. The sensor is powered by a 9 volt battery during this evaluation, as it is commonly used in field applications. Three InfraBSU sensors were tested during this evaluation. Their serial numbers and specifications published by the developer are provided below.

Table 2 InfraBSU Serial Numbers

400
422
424

Table 3 InfraBSU Published Specifications

Parameter	Value	Units
Sensitivity	45.13 ± 0.23	μV Pa^{-1}
Nominal linear range	±124.5	Pa
Noise		mPa rms
0.5–2 Hz	2.02	
0.1–20 Hz	5.47	
0.05–20 Hz	5.62	
Power consumption (using a 9-V source)	27	mW
Sensor voltage range (SVR)	$8 \leq \text{SVR} \leq 40$	V
Current (using a 9-V source)	3	mA

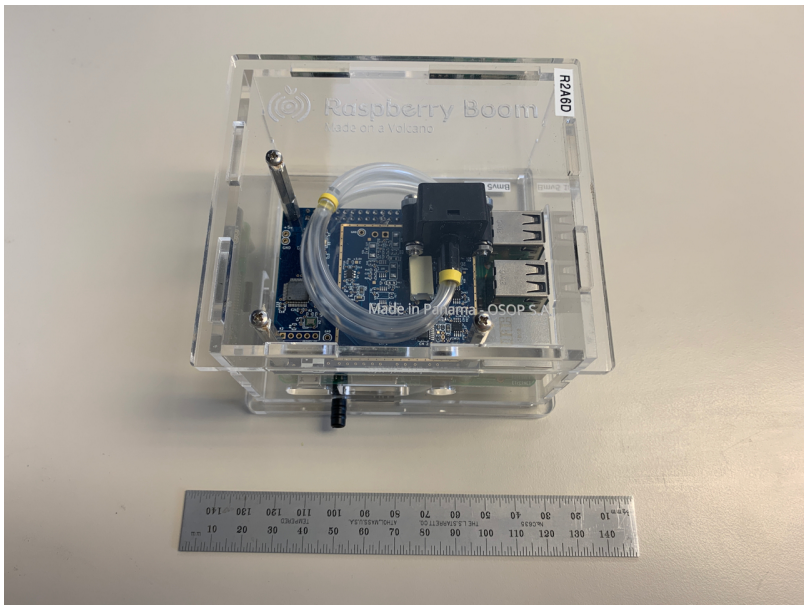

Figure 5 Raspberry Boom Integrated Sensor/Datalogger Package

The Raspberry Boom, as the name implies, leverages a Raspberry PI computer, into which a digitizer, GPS receiver and infrasound sensor are integrated. Raspberry Shake, S.A, of Chiriqui, Panama (raspberryshake.org) produces the unit. Power is provided via a micro-USB port, which was powered at 5.3 VDC via a laboratory power supply. The Raspberry Boom comes with two mechanical filter options, a 1 second or 20 second high pass filter. The evaluation occurred with the 20 second mechanical filter installed.

Three units were tested during this evaluation; their serial numbers follow in Table 4. Note that the characters in parenthesis are used to refer to these units in this report. Manufacturer-supplied specifications may be found in Table 5.

Table 4 Raspberry Boom Serial Numbers

1016 (R2A6D)
1033 (RF958)
1034 (R1C9F)

Table 5 Raspberry Boom Manufacturer-Provided Infrasound Specifications

Parameter	Value
Type	MEMS temperature compensated differential pressure transducer
Samples per second	*100*
Data packet transmission rate	Data packets shipped across serial port at a rate of 4 packets/ second (250 ms/ packet)
Bandwidth (estimate)	-3dB points at 1 Hertz (1 seconds) to 44 Hertz (for 1s mechanical filter, default). -3dB points at 0.08 Hertz (13 seconds) to 44 Hertz (for 20s mechanical filter). Rolloff past low frequency corners: 2 poles or 40dB/decade
Poles (estimate, radians/ second)	There is a hardware single-pole high-pass filter with a -3 dB point around 0.05 Hz. With 1s mechanical filter attached: -0.312 (20 seconds, single pole high pass filter, from hardware) -6.289 (1 Hz, single pole high pass filter, from mechanical filter) With 20s mechanical filter attached: -0.312 (20 seconds, single pole high-pass filter, from hardware) -0.312 (20 seconds, single pole high pass filter, from mechanical filter)
Zeros (estimate, radians/ second)	0,0
Sensitivity (estimate)	56,000 counts/ Pascal +/- 10% precision
Clip Level (estimate)	+/- 8,388,608 counts (24-bits) 0.5 inches of water, corresponding to +/- 125 Pa
Digitizer Dynamic range	24-bit ADC Sigma-Delta **ΣΔ** 144 dB (24 bits)
Effective bits (estimate)	21 bits (126 dB) from 1 to 20 Hz @ 100 sps (for the entire analog to digital hardware chain). *Note: Whereas most manufacturers report this for their digitizer only, we are reporting it for the entire sensor + ADC hardware chain. The effective bits of the digitizer itself are necessarily better.* This parameter is also commonly known as “Dynamic Range”; “RMS to RMS noise"; or "noise free bits".
Linearity of the pressure measurement (included in total error band measurement)	<0.5%
Gain Calibration	Automatic
Mechanical filter High Pass filter options	1s, 20s (all units ship with both)

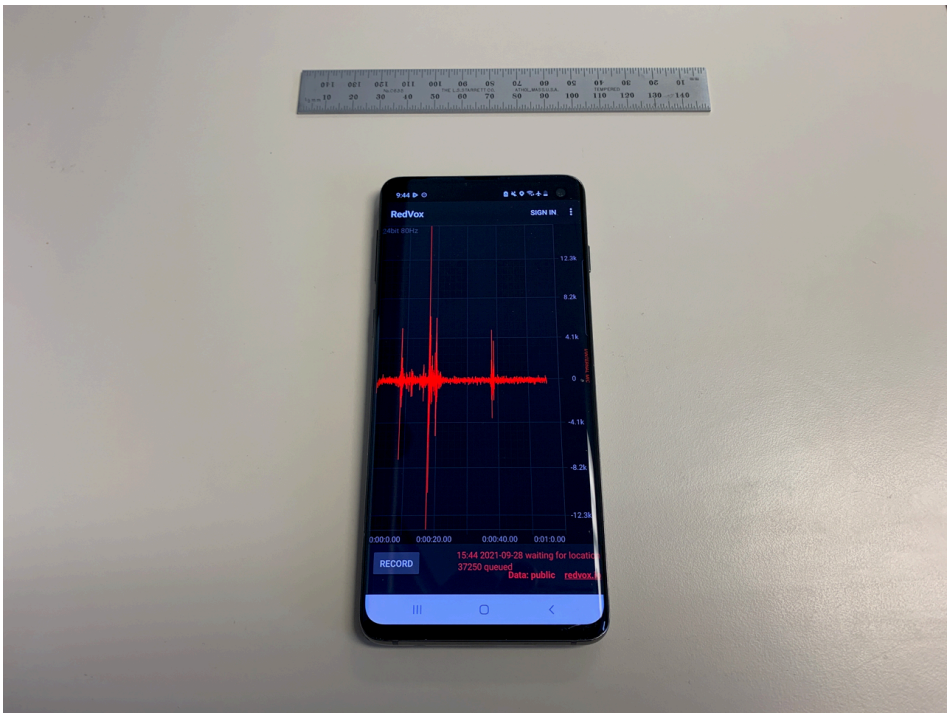

Figure 6 Samsung S10 with Redvox Application

The Samsung S10 smartphone is an Andriod-based smartphone, which runs Redvox, version 2.6.20. Redvox is an infrasound recording application, developed by Milton Garces (www.redvoxsound.com/blog/synesthesia). As with the other packages and sensors, three units were evaluated; their serial numbers follow in the table below.

Table 6 Samsung S10 Serial Numbers

RF8N5202H6W
RF8N5202WAP
RF8N63DKYSE

For brevity, the Samsung smartphones will be referenced throughout this report by the last character of their serial number, e.g. E, P or W. Technical specifications are not provided for the S10 as they are not readily available. The smartphones were evaluated while powered with their internal lithium-ion batteries, as would commonly be the case during normal use.

2 TEST PLAN

2.1 Test Facility

Testing 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), Geophysics Department has the capability of evaluating the performance of seismometers, infrasound sensors, preamplifiers, digitizing waveform recorders, and analog-to-digital converters/high-resolution digitizers for geophysical applications.

Tests are developed for consistency with 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 and Technology (NIST).

Testing was performed utilizing the FACT Site's 1400L infrasound test chamber, Spektra CS-18P Seismic Calibration System, and ESPEC EPL-2H Thermal Chamber.

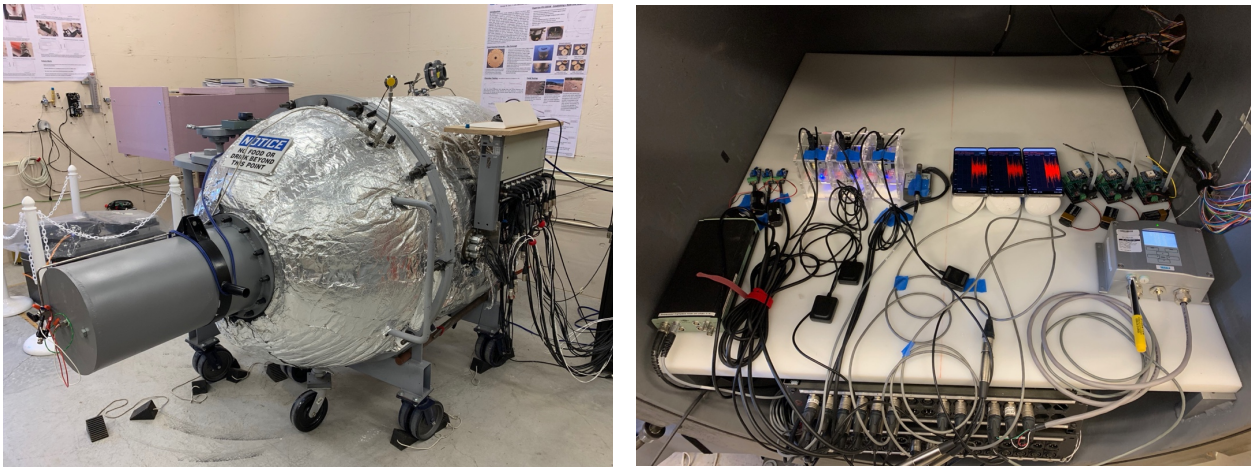

Figure 7 Exterior and Interior of the SNL 1400L Infrasound Chamber

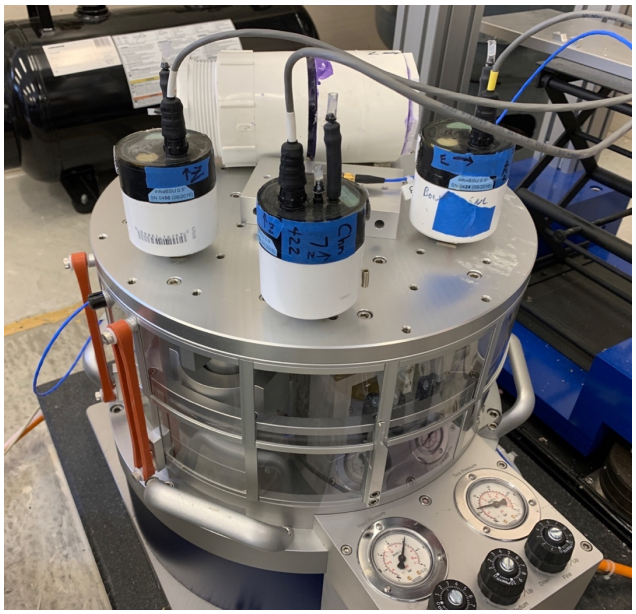

Figure 8 SNL Spektra Vertical Calibration Table

Figure 9 SNL ESPEC Thermal Chamber

The temperature, pressure, and relative humidity was recorded continuously throughout the testing within the testing environment by several calibrated Vaisala PTU-300 units. The test bed datalogger, Vaisala units and Raspberry Booms were powered by laboratory power supplies.

Figure 10 Vaisala PTU300

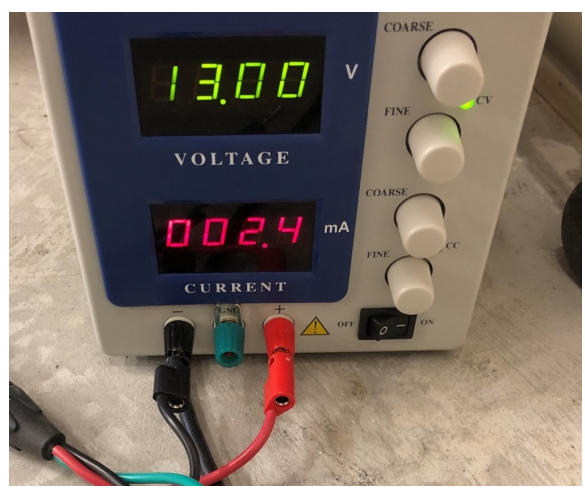

Figure 11 Lab Power Supply

2.2 Scope

The following table lists the tests and resulting evaluations that were performed. The laboratory infrasound portions of the test sequence were performed at controlled conditions at either an ambient barometric pressure 820 hPa or 1000 hPa and 23 C temperature. Extended measurements of variability to environmental conditions were made over 600 to 1000 hPa and -35 to 50 C.

Table 7 Tests Performed

Test
Power Consumption
Sensitivity
Sensitivity vs Input Amplitude
Self-Noise
Dynamic Range
Frequency Response (Tonal, 0.01 – 20 Hz)
Pass-band
Static Pressure Response Variation
Static Temperature Response Variation
Response to Vertical Acceleration

2.3 Evaluation Frequencies

The frequency range of the measurements is from 0.01 Hz to 20 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, 10. The nominal center frequency values, in Hz, are:

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,	20						

3 TEST EVALUATION

3.1 Power Consumption

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

3.1.1 Measurand

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

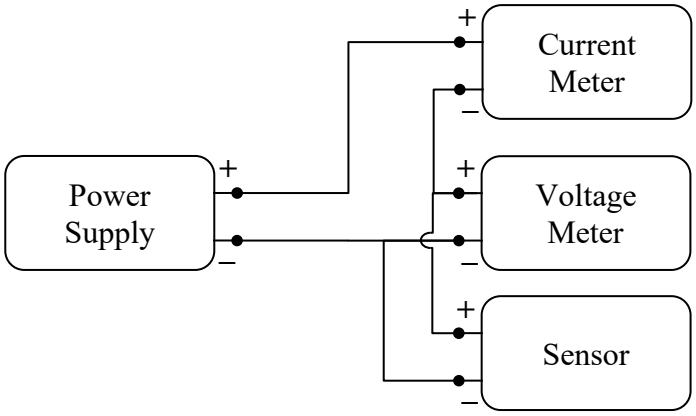

Figure 12 Power Consumption Configuration Diagram

Figure 13 Power Consumption Configuration Picture

In the case of the Samsung S10 smartphones, the power from the power supply to maintain a fully charged phone as charged was measured.

Table 8 Power Consumption Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
Power Supply	Protek DC Power Supply 3003B	N/A	12 V
Voltage Meter	Agilent 3458A	MY45048371	DC Voltage Mode
Current Meter	Agilent 3458A	MY45048372	DC Current Mode

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

3.1.3 Analysis

Measurements of the average current and voltage from the power supply are taken from the respective meters:

$$V \text{ and } I$$

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

$$P = V * I$$

3.1.4 Result

The figures below show representative waveform time series for the recordings of voltage and current made on the reference meters. The red windowed regions indicate the segments of data used to evaluate the voltage and current.

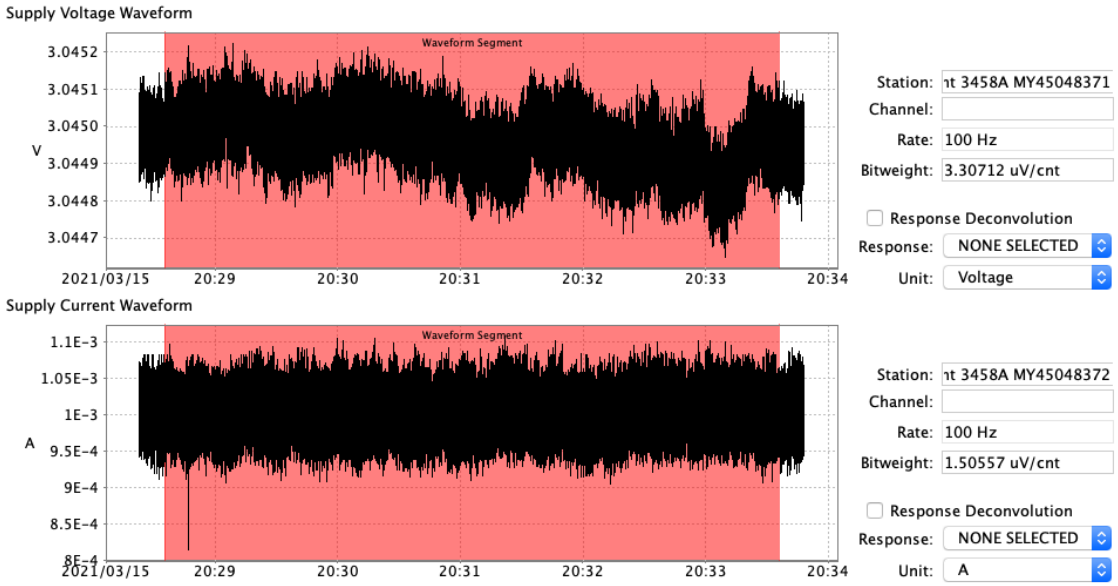

Figure 14 Power Consumption Voltage and Current Time Series: Camas Microphone

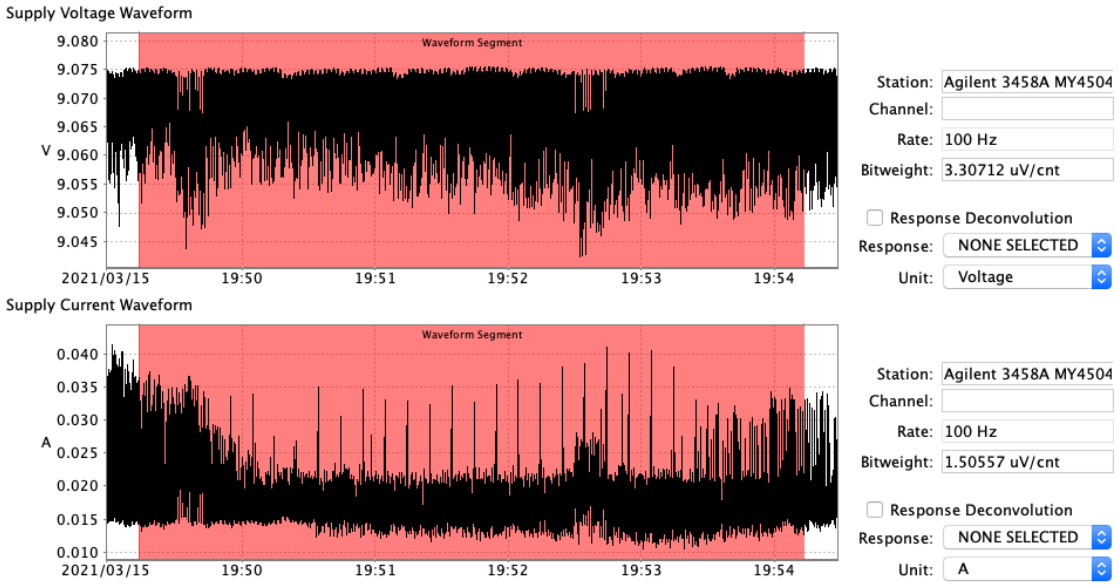

Figure 15 Power Consumption Voltage and Current Time Series: Gem Package

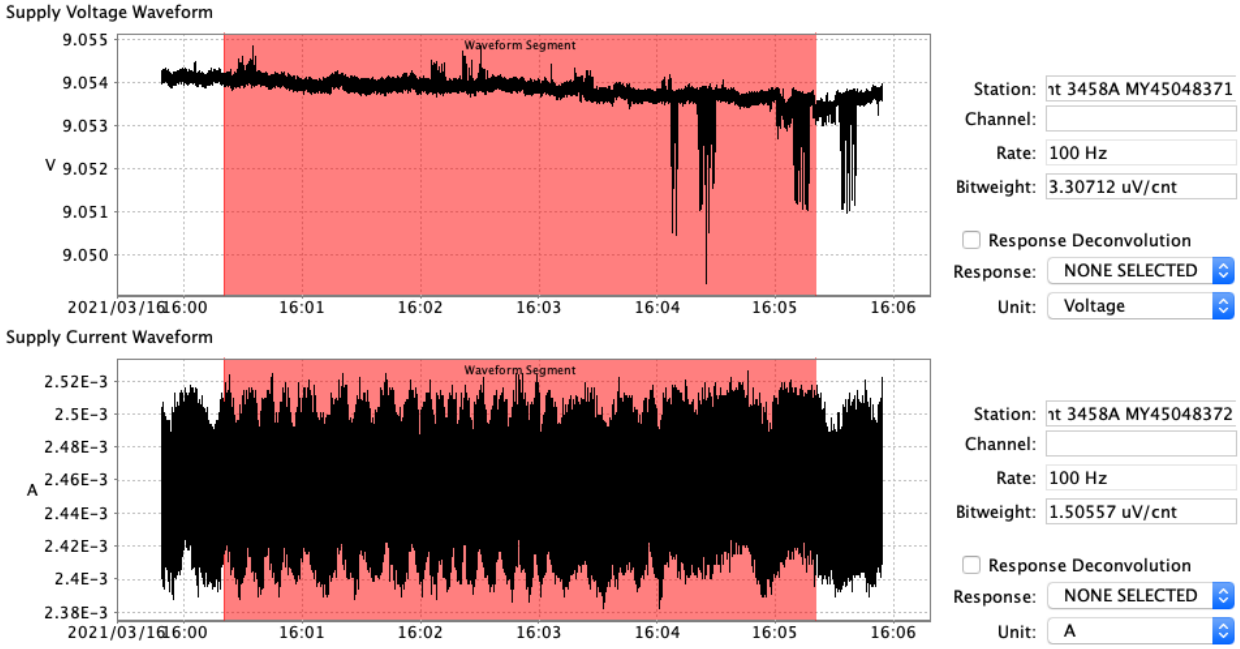

Figure 16 Power Consumption Voltage and Current Time Series: InfraBSU Sensor

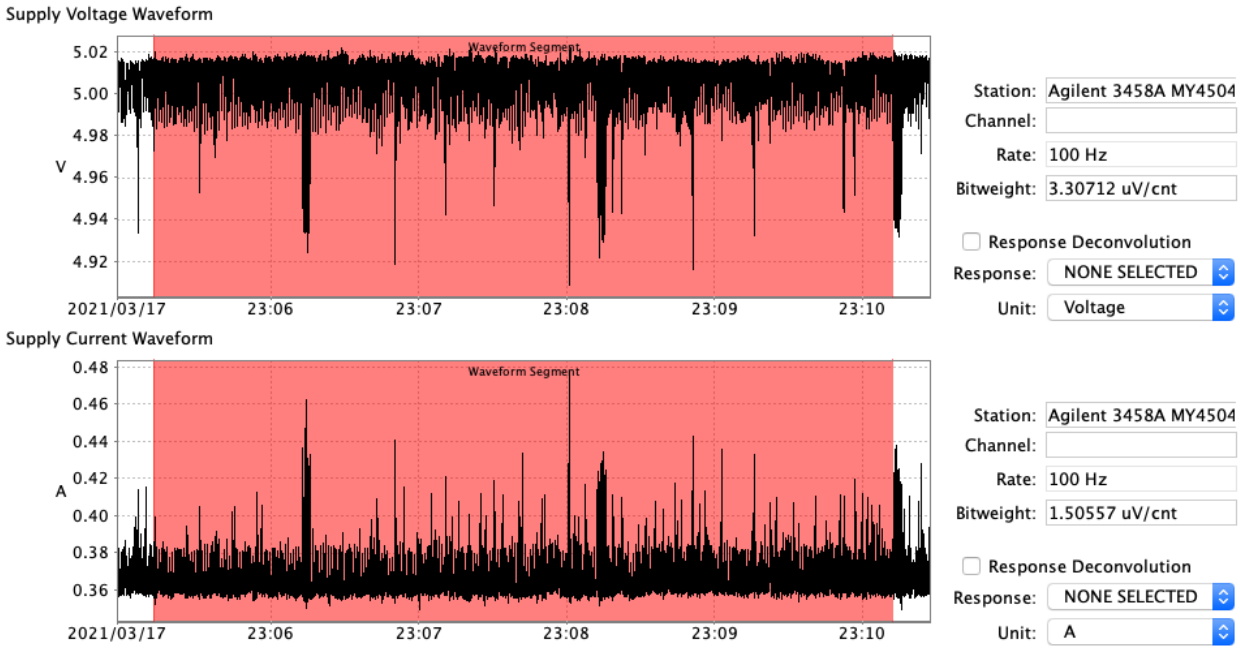

Figure 17 Power Consumption Voltage and Current Time Series: Raspberry Boom Package

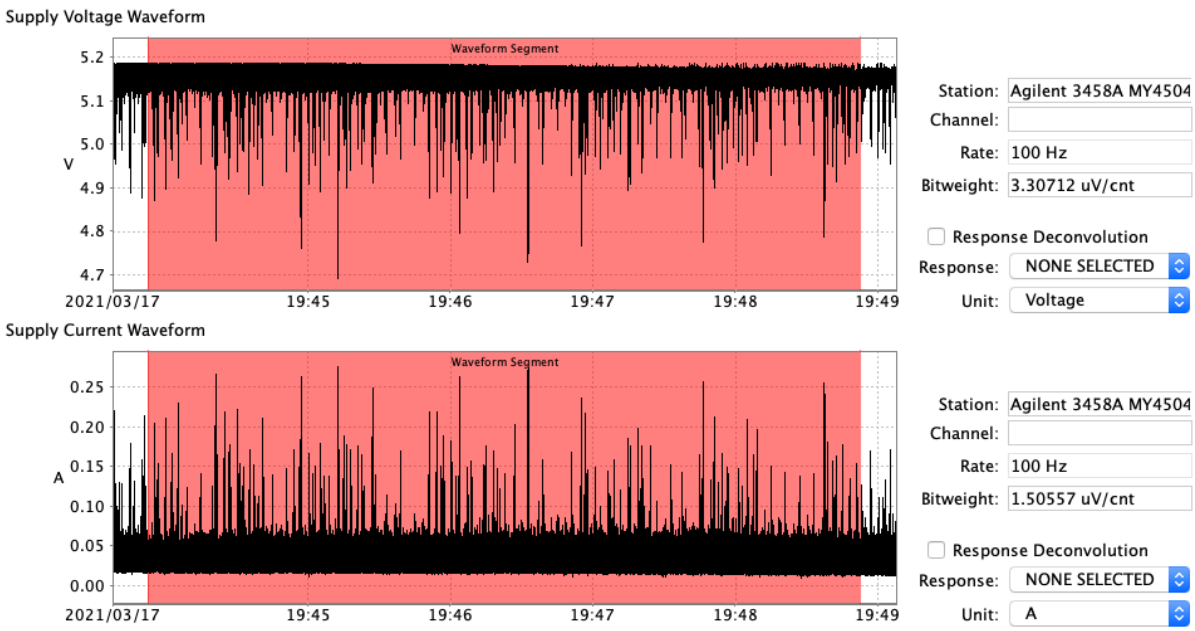

Figure 18 Power Consumption Voltage and Current Time Series: Samsung S10 Package

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

Table 9 Power Consumption Results

Sensor Package	Supply Voltage	Supply Current	Power	Power Standard Deviation
Camas Microphone #1	3.04 V	1.00 mA	0.0030 W	0.103 mW
Camas Microphone #2	3.04 V	0.92 mA	0.0028 W	0.093 mW
Camas Microphone #3	3.04 V	1.01 mA	0.0031 W	0.103 mW
Gem 063	9.07 V	16.04 mA	0.1455 W	18.555 mW
Gem 069	9.07 V	15.64 mA	0.1418 W	13.416 mW
Gem 070	9.07 V	14.82 mA	0.1344 W	17.457 mW
InfraBSU 400	9.05 V	2.45 mA	0.0222 W	0.255 mW
InfraBSU 422	9.05 V	2.37 mA	0.0214 W	0.253 mW
InfraBSU 424	9.05 V	2.35 mA	0.0213 W	0.253 mW
Raspberry Boom R1C9F	5.05 V	364.47 mA	1.8402 W	63.109 mW
Raspberry Boom R2A6D	5.01 V	363.91 mA	1.8230 W	32.605 mW
Raspberry Boom RF958	4.88 V	368.53 mA	1.8002 W	41.542 mW
Samsung S10 E	5.15 V	39.22 mA	0.2020 W	105.586 mW
Samsung S10 P	5.16 V	33.63 mA	0.1735 W	107.341 mW
Samsung S10 W	5.15 V	42.27 mA	0.2177 W	95.737 mW

The sensor-only units, the Camas microphones and InfraBSU sensors, consumed the least power, ranging from as low as 2.8 mW for Camas #1 to as much as 22.2 mW for InfraBSU #400, lower than the specifications suggest for the InfraBSU. The integrated packages drew significantly more power, as expected, where the Gem #069 drew as little as 141.8 mW, more than the specifications suggest for power consumption while the GPS is on, though within approximately one standard deviation of the measurement. The Raspberry Boom R1C9F consumed as much as 1.84 W with a higher variability in its power consumption, at slightly less than the quoted 1.9 W. The Samsung S10 phones consumed between 0.17 W and 0.21 W, with the largest standard deviation in measured power of approximately 100 mW.

3.2 Sensitivity

The sensitivity of a sensor is defined to be the ratio between the change in the output voltage and the corresponding change in the quantity being measured. For an infrasound sensor, the sensitivity value is expressed at a given frequency in units of V/Pa.

3.2.1 Measurand

The quantity being measured is the sensor's sensitivity in V/Pa and degrees at a reference frequency.

3.2.2 Configuration

The infrasound sensor under test and a reference sensor with known response characteristics are placed inside of a pressure isolation chamber. The isolation chamber serves to attenuate any external ambient variations in temperature or pressure and provide air coupling between the sensor inlets.

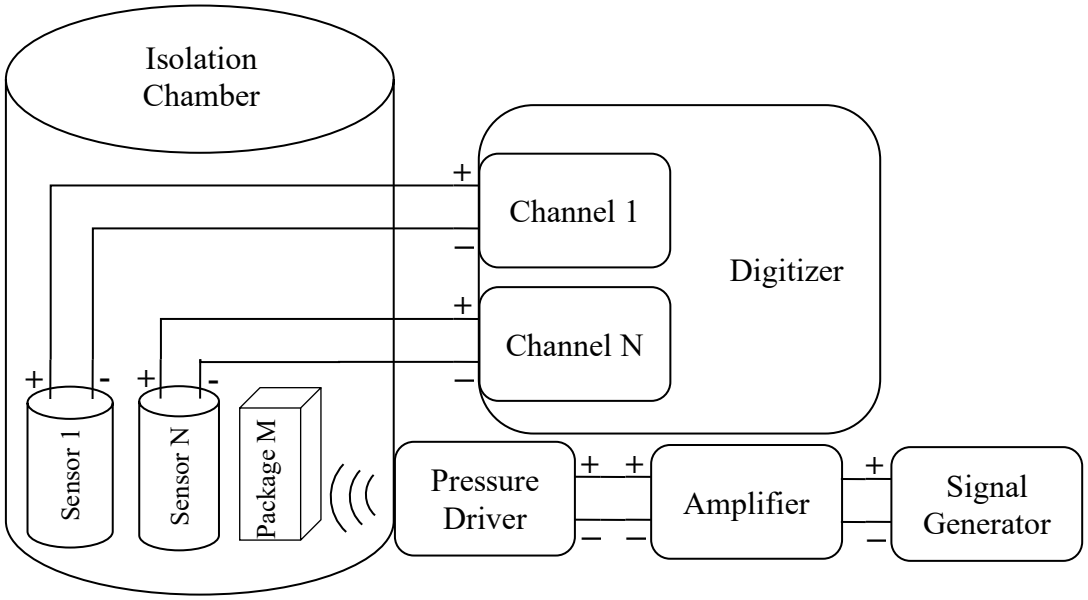

Figure 19 Sensitivity Configuration Diagram

A pressure driver is attached to the isolation chamber. The pressure driver is driven with a sinusoid from a signal generator and amplifier. The pressure driver serves to generate a pressure wave with characteristics defined by the signal generator. The pressure inlets of reference sensors and the sensors and packages under test are exposed to this pressure wave.

The digitizer records the output of the reference sensor and the sensors under test simultaneously, while the sensor packages record independently on their internal digitizers. The recorded output from the reference sensor and the sensor/package-under-test are then compared.

The following table documents the testbed equipment utilized and the environmental conditions at the time of the test.

Table 10 Sensitivity Testbed Equipment

	Manufacturer / Model	Serial Number	Configuration
Reference Sensor, >= 1 Hz	B&K 4193	2812287	2.15 mV/Pa at 1 Hz, 1000 hPa, 23 C
Reference Sensor, < 1 Hz	Setra 278	6837528	0.0833997 mV/Pa
Infrasound Chamber	SNL	1400 L Chamber	1002 hPa, +/- 5 hPa 21.8 C, +/- 1 C 15 % Rh, +/- 1 % Rh
Digitizer	Guralp Affinity	405A5B	200 Hz, 1x gain 40 Vpp
Voltage Signal Source	Stanford Research Systems DS360	N/A	0.25 Hz and 1 Hz, 0.4 Vp sinusoid
Voltage Amplifier	AE Techron 7224p	N/A	20x gain DC Coupled Amplifier
Pressure Driver	JL Audio 10w7ae	N/A	N/A

3.2.3 Analysis

A minimum of 10 cycles, or 10 seconds at 1 Hz, 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 sensor in Pascals and the sensor under test in Volts in order to determine the sinusoid's amplitude, frequency, phase, and DC offset:

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

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

The sensor amplitude sensitivity in Volts / Pascal is computed:

$$Sensitivity = \frac{V_{test}}{P_{ref}}$$

The sensor phase sensitivity in degrees is computed:

$$Phase = \theta_{test} - \theta_{ref}$$

Measurements are repeated 10 times and the resulting averages are reported.

3.2.4 Results

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

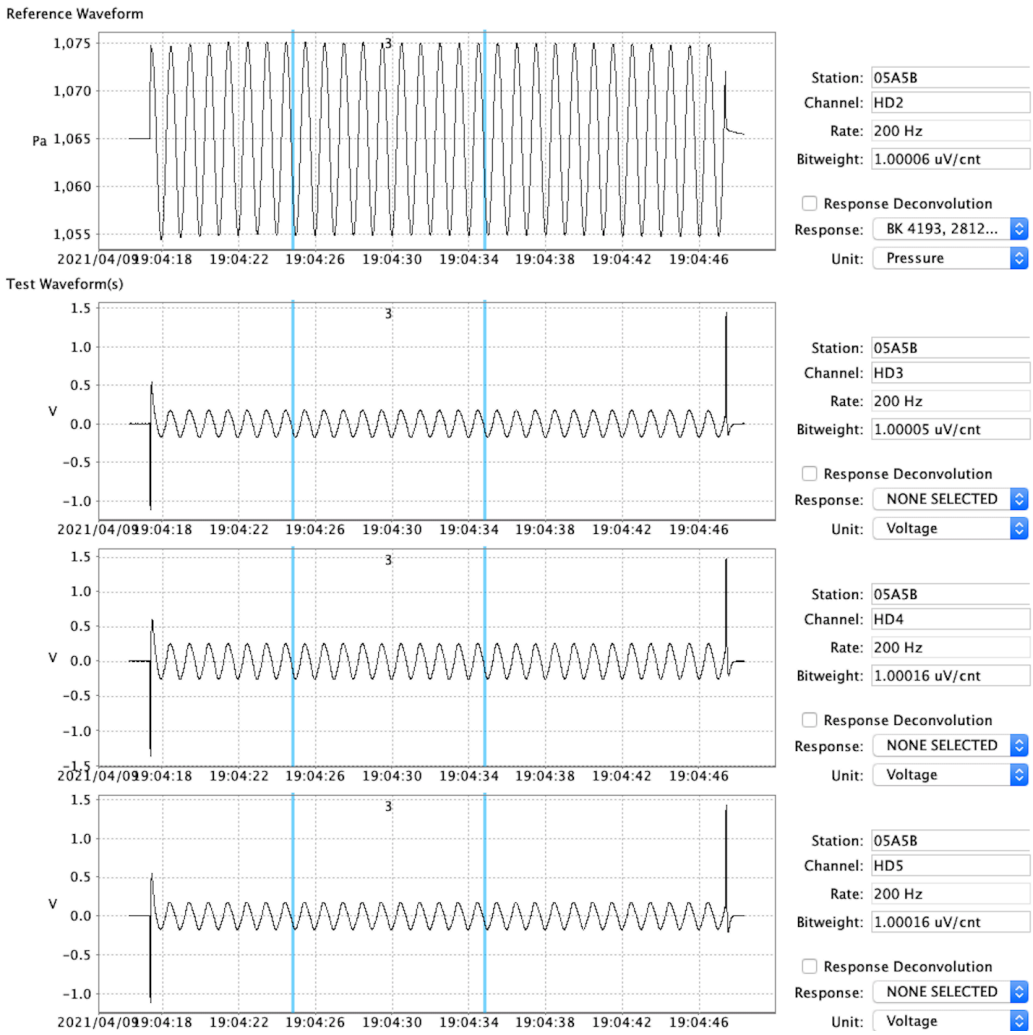

Figure 20 Sensitivity Test, Representative Time Series

The measurement of sensitivity was computed as the average of 10 iterations of a sinusoidal tone. The total combined uncertainty in the measurement system are reported as well. The assumptions for combined uncertainty include the reference sensors, testing environment, and a presumed sensor under test that is relatively stable. Sufficient testing on these sensor models has not been performed to be able to include their repeatability.

Table 11 Camas Microphone Sensitivity at 0.25 Hz

	Camas #1	Camas #2	Camas #3	Combined Uncertainty (k=2)
Amplitude	0.3485 mV/Pa	0.4956 mV/Pa	0.3171 mV/Pa	1.0 %
Phase	-111.10 deg	-111.80 deg	-110.00 deg	1.0 deg

Table 12 Camas Microphone Sensitivity at 1 Hz

	Camas #1	Camas #2	Camas #3	Combined Uncertainty (k=2)
Amplitude	16.32 mV/Pa	23.45 mV/Pa	15.53 mV/Pa	0.92 %
Phase	-164.70 deg	-167.20 deg	-161.60 deg	0.32 deg

Neither 0.25 Hz nor the 1.0 Hz reference frequencies lie within the passband of the Camas sensor's amplitude response, which is why there is a significant difference between 0.25 Hz and 1 Hz. The Frequency Response Section, 3.7, of this report will illustrate this point. Notice the 0.25 Hz sensitivity is more than 2 orders of magnitude lower than that of the observed 1.0 Hz sensitivity.

Table 13 InfraBSU Sensor Sensitivity at 0.25 Hz

	InfraBSU #400	InfraBSU #422	InfraBSU #424	Combined Uncertainty (k=2)
Amplitude	44.55 uV/Pa	44.58 uV/Pa	44.60 uV/Pa	1.0 %
Phase	4.98 deg	5.19 deg	5.16 deg	1.0 deg

Table 14 InfraBSU Sensor Sensitivity at 1 Hz

	InfraBSU Sensor #400	InfraBSU Sensor #422	InfraBSU Sensor #424	Combined Uncertainty (k=2)
Amplitude	44.98 uV/Pa	45.08 uV/Pa	45.02 uV/Pa	0.92 %
Phase	0.20 deg	0.30 deg	0.23 deg	0.32 deg

The InfraBSU sensors exhibit relatively consistent amplitude and phase sensitivity, well within the expected combined uncertainties.

Table 15 Gem Package Sensitivity at 0.25 Hz

	Gem #073	Gem #070	Gem #073	Combined Uncertainty (k=2)
Amplitude	272 counts/Pa	272 counts/Pa	272 counts/Pa	1.0 %
Phase	8.53 deg	8.29 deg	8.45 deg	1.0 deg

Table 16 Gem Package Sensitivity at 1 Hz

	Gem #073	Gem #070	Gem #073	Combined Uncertainty (k=2)
Amplitude	276 counts/Pa	275 counts/Pa	276 counts/Pa	0.92 %
Phase	4.27 deg	4.24 deg	4.30 deg	0.32 deg

Being an integrated package, the Gem Infrasound Logger records data as digital counts and the sensitivities provided are in terms of cts/Pa. Across the three packages, amplitude sensitivities are within a single count/Pa at both 0.25 Hz and 1 Hz. A comparison to specifications is not

relevant as the specifications explain that the sensitivity is adjustable within the package. Phase sensitivities are well within the estimated phase uncertainties for both the 0.25 Hz and 1.0 Hz phase sensitivity values.

Table 17 Raspberry Boom Package Sensitivity at 0.25 Hz

	Boom R1C9F	Boom R2A6D	Boom RF958	Combined Uncertainty (k=2)
Amplitude	53430 counts/Pa	44240 counts/Pa	5822 counts/Pa	1.0 %
Phase	26.17 deg	43.84 deg	94.51 deg	1.0 deg

Table 18 Raspberry Boom Package Sensitivity at 1 Hz

	Boom R1C9F	Boom R2A6D	Boom RF958	Combined Uncertainty (k=2)
Amplitude	56910 counts/Pa	53680 counts/Pa	21540 counts/Pa	0.92 %
Phase	9.61 deg	15.80 deg	69.32 deg	0.32 deg

Similar to the Gem infrasound packages, the Boom packages record data as digital counts and the sensitivities provided are in terms of cts/Pa. The amplitude and phase sensitivities vary significantly from sensor to sensor, even if the amplitude sensitivity of Boom RF958 is discounted. Amplitude sensitivity of R2A6D is 21% lower than the sensitivity listed in the specifications. Considering the Boom is an integrated datalogger and sensor, the variation of phase may be due to a number of reasons, including, but not limited to: variations in the pressure transducer, timing algorithms of the digitizer, whether or not the GPS receiver was on and locked, and the time since the last GPS lock and subsequent timing slew.

Table 19 S10 Package Sensitivity at 0.25 Hz

	S10 E	S10 P	S10 W	Combined Uncertainty (k=2)
Amplitude	47 cts/Pa	49 cts/Pa	53 cts/Pa	1.0 %

Table 20 S10 Package Sensitivity at 1 Hz

	S10 E	S10 P	S10 W	Combined Uncertainty (k=2)
Amplitude	949 cts/Pa	886 cts/Pa	962 cts/Pa	0.92 %

Similar to the Camas Microphone evaluated, the S10 package has a relatively high low-frequency corner as neither the 0.25 Hz nor the 1.0 Hz reference frequencies lie within the passband of the sensor's amplitude response. The Frequency Response Section, 3.7, will illustrate this point. Notice the 0.25 Hz sensitivity is more than an order of magnitude lower than that of the observed 1.0 Hz sensitivity. Phase is not evaluated for the Samsung S10 and Redvox package as the package utilizes network time, rather the GPS, and phase was observed to vary widely throughout the evaluations undertaken.

3.3 Sensitivity vs Input Amplitude in Isolation Chamber

The sensitivity vs input amplitude is measured as an indicator of linearity with respect to amplitude. The pressure sensitivity values are measured at a calibration frequency across several increments of dynamic input pressure amplitude.

3.3.1 Measurand

The quantity being measured is the change in sensitivity as a function of the dynamic input pressure, expressed as a relative percentage in amplitude and degrees difference in phase.

3.3.2 Configuration

The infrasound sensor under test and a reference sensor with known response characteristics are placed inside of a pressure isolation chamber. The isolation chamber serves to attenuate any external ambient variations in temperature or pressure and provide air coupling between the sensor inlets.

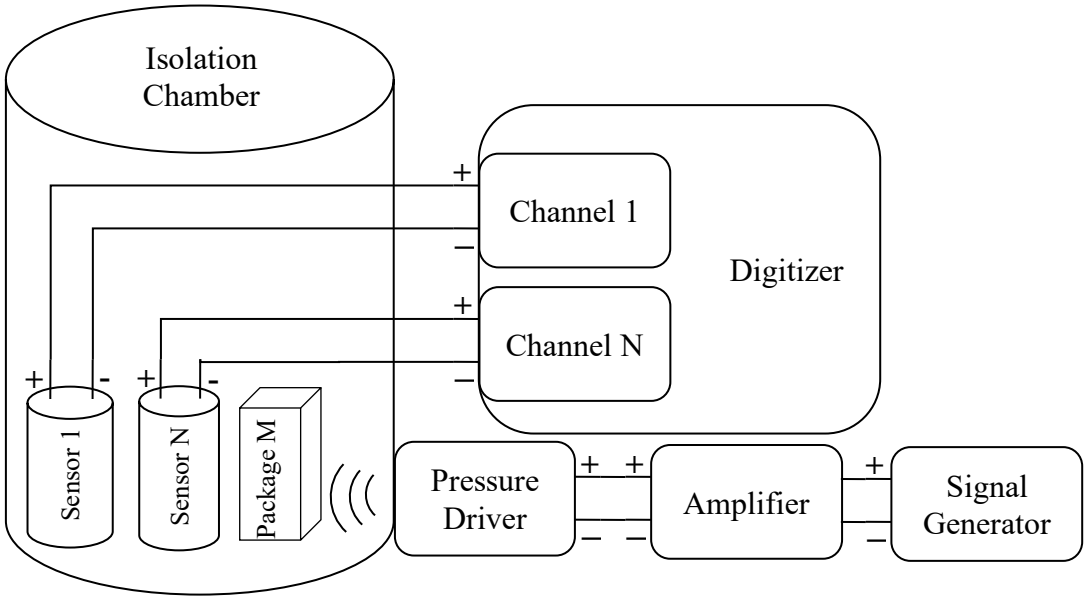

Figure 21 Sensitivity vs Input Amplitude Configuration Diagram

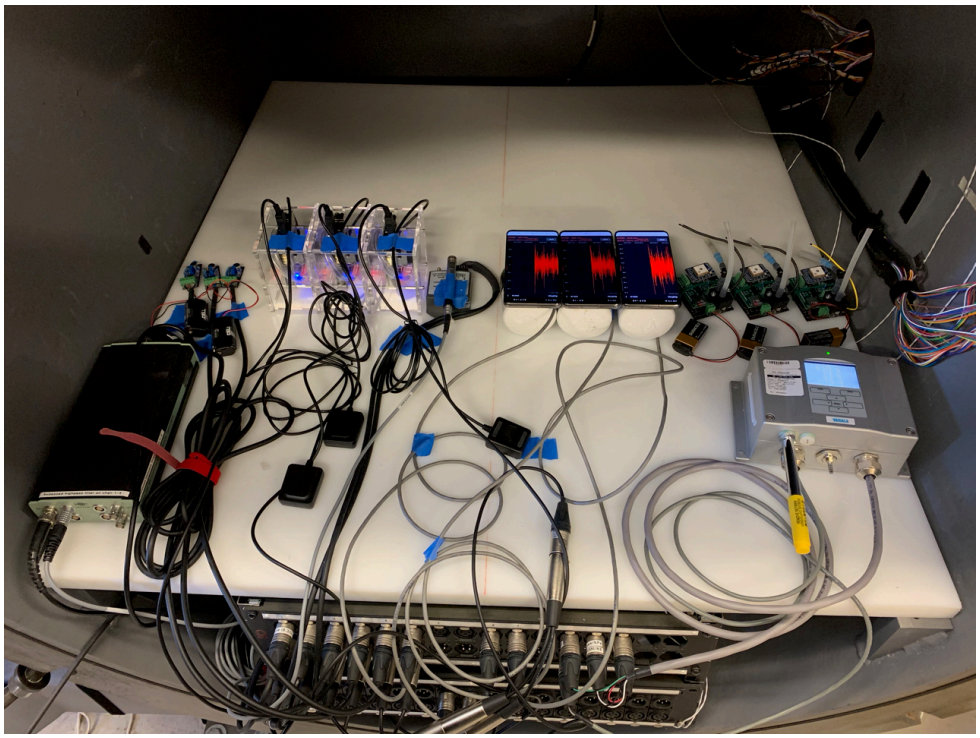

Figure 22 Sensitivity Test Configuration

A pressure driver is attached to the isolation chamber. The pressure driver is driven with a sinusoid from a signal generator and amplifier. The pressure driver serves to generate a pressure wave with characteristics defined by the signal generator. The pressure inlets of reference sensors and sensors/packages under test are exposed to this pressure wave.

The digitizer records the output of the reference sensor and the sensors under test simultaneously, while the packages record independently on their internal digitizers. The recorded output from the reference sensor and the sensor/package-under-test are then compared.

The following table documents the testbed equipment utilized and the environmental conditions at the time of the test.

Table 21 Sensitivity vs Input Amplitude Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
Reference Sensor	B&K 4193	2812287	2.174 mV/Pa at 1 Hz, 810 hPa, 23 C
Infrasound Chamber	SNL	1400 L Chamber	809 hPa, +/- 5 hPa 22.8 C, +/- 0.5 C 15 % Rh, +/- 1 % Rh
Digitizer	Guralp Affinity	405A5B	200 Hz, 1x gain 40 Vpp
Voltage Signal Source	Stanford Research Systems DS360	N/A	1 Hz, 50 mV to 1 V sinusoid
Voltage Amplifier	AE Techron 7224p	N/A	20x gain DC Coupled Amplifier
Pressure Driver	JL Audio 10w7ae	N/A	N/A

3.3.3 Analysis

A minimum of 10 cycles, or 10 seconds at 1 Hz, 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 sensor in Pascals and the sensor under test in Volts in order to determine the sinusoid's amplitude, frequency, phase, and DC offset:

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

$$V_{test} \sin(2\ pi\ f_{test}\ t +\ \theta_{test}\ ) + V_{dc\ test}$$

The sensor amplitude sensitivity in Volts / Pascal is computed:

$$S_{amp} = \frac{V_{test}}{P_{ref}}$$

The sensor phase sensitivity in degrees is computed:

$$S_{phase} =\ \theta_{test} -\ \theta_{ref}$$

The change in sensitivity, expressed as a percentage in amplitude and degrees in phase, at each amplitude level are computed relative to a reference amplitude level:

$$Change\ S_{amp}(Ampl\ ) = 100 * \frac{(S_{amp}(Ampl) - S_{amp}(Ref\ Ampl))}{S_{amp}(Ref\ Ampl)}$$

$$Change\ S_{phase}(Ampl\ ) = S_{phase}(Ampl) - S_{phase}(Ref\ Ampl)$$

3.3.4 Results

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

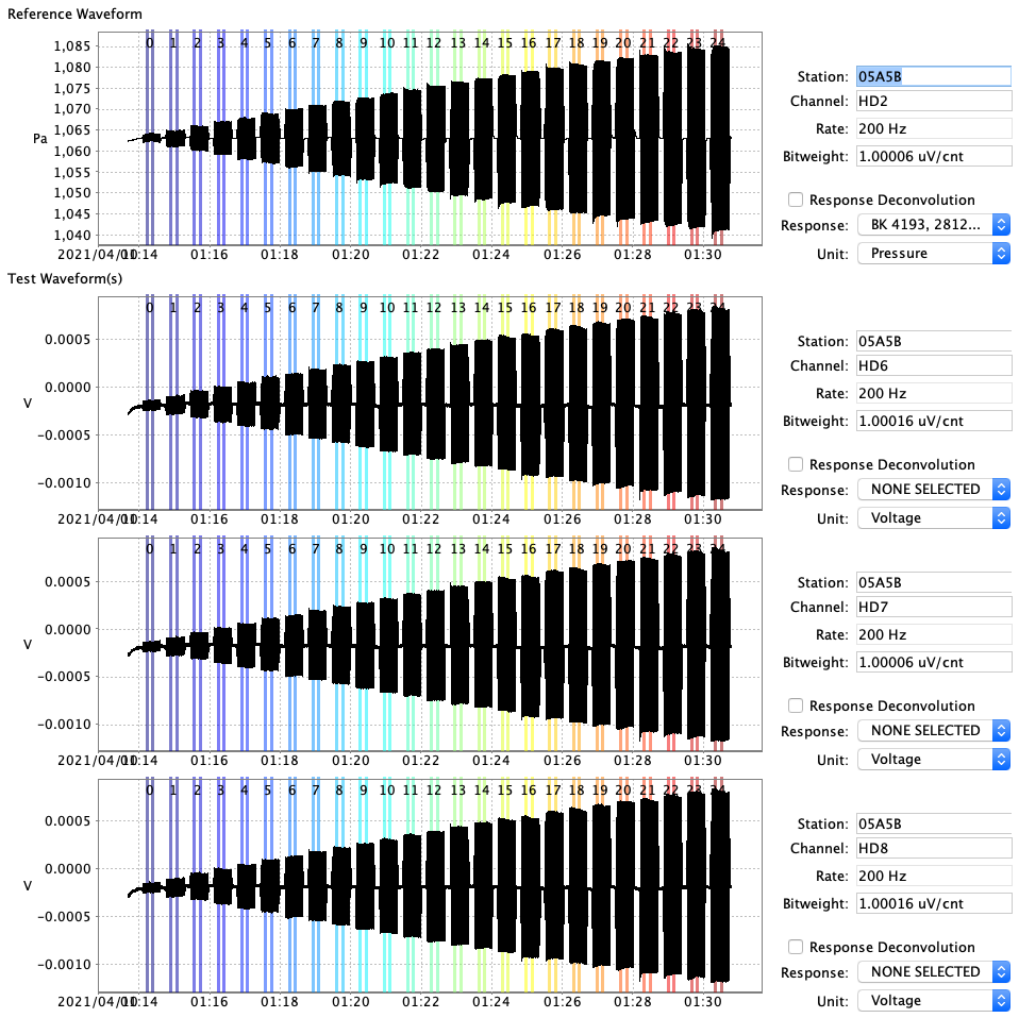

Figure 23 Sensitivity vs Input Amplitude, Representative Time Series

The following plots represent the changes in amplitude and phase sensitivity, relative to the measurement at 9.8 Pa, that were observed across the input amplitude range for the sensors and packages under test.

The estimated absolute uncertainty (k=2) at 1 Hz is 0.92% in amplitude and 0.32 deg in phase, the estimated relative uncertainty is 0.3% in amplitude and 0.09 deg in phase for a stable sensor tested multiple times under unchanging conditions.

The following two plots illustrate the changes in amplitude and phase for the Camas microphones.

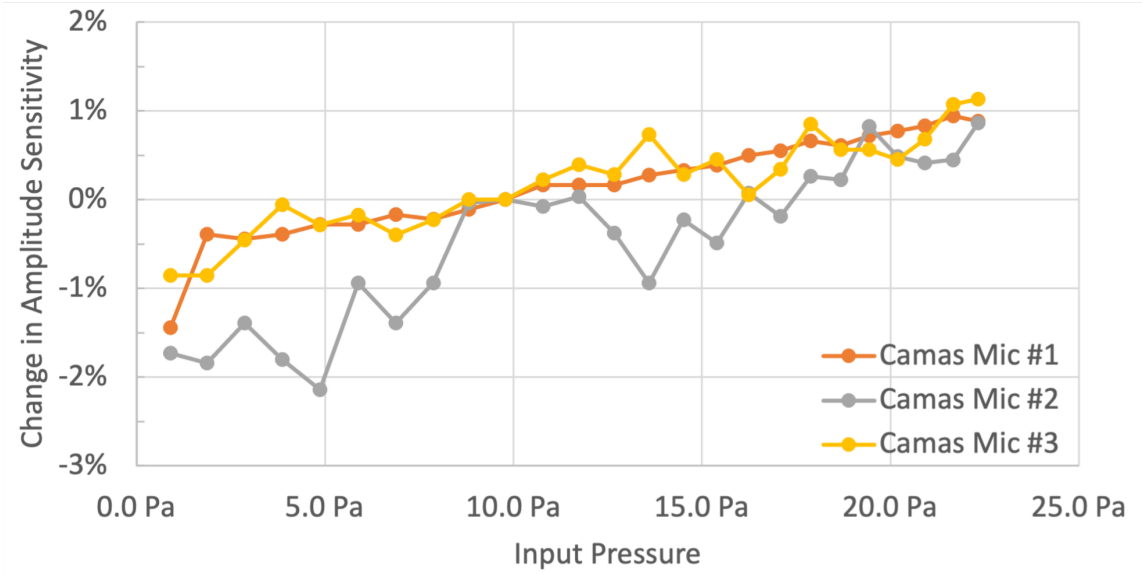

Figure 24 Amplitude Sensitivity Change vs Input Amplitude: Camas Microphones

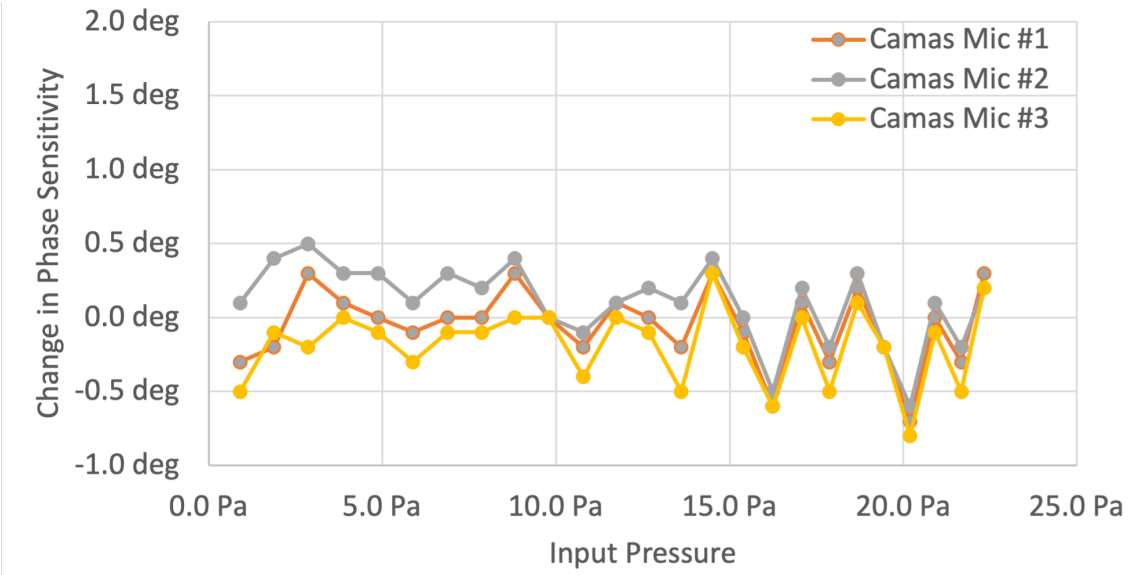

Figure 25 Phase Change vs Input Amplitude: Camas Microphones

Figure 24 illustrates that Camas microphones have an increasing sensitivity with pressure, varying from 1.73% to 0.85% below, and between 0.89% to 1.13% above, that of the 9.8 Pa amplitude sensitivity, which is greater than the 0.3% relative uncertainty and has a noticeable increasing trend. Figure 25 shows the phase observed of the microphones. The Camas microphones exhibit phase which varies, yet remains roughly equivalent to the phase at 9.8 Pa, when considering the uncertainty in phase (0.32 degrees).

The following two tables contain the data plotted in the above figures.

Table 22 Amplitude Sensitivity Change vs Input Amplitude: Camas Microphones

	Camas #1		Camas #2		Camas #3	
Pressure	Absolute Amplitude	Relative Amplitude	Absolute Amplitude	Relative Amplitude	Absolute Amplitude	Relative Amplitude
0.9 Pa	17.79 mV/Pa	-1.440%	26.17 mV/Pa	-1.727%	17.49 mV/Pa	-0.850%
1.9 Pa	17.98 mV/Pa	-0.388%	26.14 mV/Pa	-1.840%	17.49 mV/Pa	-0.850%
2.9 Pa	17.97 mV/Pa	-0.443%	26.26 mV/Pa	-1.389%	17.56 mV/Pa	-0.454%
3.9 Pa	17.98 mV/Pa	-0.388%	26.15 mV/Pa	-1.802%	17.63 mV/Pa	-0.057%
4.9 Pa	18.00 mV/Pa	-0.277%	26.06 mV/Pa	-2.140%	17.59 mV/Pa	-0.283%
5.9 Pa	18.00 mV/Pa	-0.277%	26.38 mV/Pa	-0.939%	17.61 mV/Pa	-0.170%
6.9 Pa	18.02 mV/Pa	-0.166%	26.26 mV/Pa	-1.389%	17.57 mV/Pa	-0.397%
7.9 Pa	18.01 mV/Pa	-0.222%	26.38 mV/Pa	-0.939%	17.60 mV/Pa	-0.227%
8.8 Pa	18.03 mV/Pa	-0.111%	26.62 mV/Pa	-0.038%	17.64 mV/Pa	0.000%
9.8 Pa	18.05 mV/Pa	0.000%	26.63 mV/Pa	0.000%	17.64 mV/Pa	0.000%
10.8 Pa	18.08 mV/Pa	0.166%	26.61 mV/Pa	-0.075%	17.68 mV/Pa	0.227%
11.7 Pa	18.08 mV/Pa	0.166%	26.64 mV/Pa	0.038%	17.71 mV/Pa	0.397%
12.7 Pa	18.08 mV/Pa	0.166%	26.53 mV/Pa	-0.376%	17.69 mV/Pa	0.283%
13.6 Pa	18.10 mV/Pa	0.277%	26.38 mV/Pa	-0.939%	17.77 mV/Pa	0.737%
14.5 Pa	18.11 mV/Pa	0.332%	26.57 mV/Pa	-0.225%	17.69 mV/Pa	0.283%
15.4 Pa	18.12 mV/Pa	0.388%	26.50 mV/Pa	-0.488%	17.72 mV/Pa	0.454%
16.2 Pa	18.14 mV/Pa	0.499%	26.65 mV/Pa	0.075%	17.65 mV/Pa	0.057%
17.1 Pa	18.15 mV/Pa	0.554%	26.58 mV/Pa	-0.188%	17.70 mV/Pa	0.340%
17.9 Pa	18.17 mV/Pa	0.665%	26.70 mV/Pa	0.263%	17.79 mV/Pa	0.850%
18.7 Pa	18.16 mV/Pa	0.609%	26.69 mV/Pa	0.225%	17.74 mV/Pa	0.567%
19.4 Pa	18.18 mV/Pa	0.720%	26.85 mV/Pa	0.826%	17.74 mV/Pa	0.567%
20.2 Pa	18.19 mV/Pa	0.776%	26.76 mV/Pa	0.488%	17.72 mV/Pa	0.454%
20.9 Pa	18.20 mV/Pa	0.831%	26.74 mV/Pa	0.413%	17.76 mV/Pa	0.680%
21.7 Pa	18.22 mV/Pa	0.942%	26.75 mV/Pa	0.451%	17.83 mV/Pa	1.077%
22.3 Pa	18.21 mV/Pa	0.886%	26.86 mV/Pa	0.864%	17.84 mV/Pa	1.134%

Table 23 Phase Change vs Input Amplitude: Camas Microphones

	Camas #1		Camas #2		Camas #3	
Pressure	Absolute Phase	Relative Phase	Absolute Phase	Relative Phase	Absolute Phase	Relative Phase
0.9 Pa	-168.20 deg	-0.30 deg	-169.70 deg	0.10 deg	-162.80 deg	-0.50 deg
1.9 Pa	-168.10 deg	-0.20 deg	-169.40 deg	0.40 deg	-162.40 deg	-0.10 deg
2.9 Pa	-167.60 deg	0.30 deg	-169.30 deg	0.50 deg	-162.50 deg	-0.20 deg
3.9 Pa	-167.80 deg	0.10 deg	-169.50 deg	0.30 deg	-162.30 deg	0.00 deg
4.9 Pa	-167.90 deg	0.00 deg	-169.50 deg	0.30 deg	-162.40 deg	-0.10 deg
5.9 Pa	-168.00 deg	-0.10 deg	-169.70 deg	0.10 deg	-162.60 deg	-0.30 deg
6.9 Pa	-167.90 deg	0.00 deg	-169.50 deg	0.30 deg	-162.40 deg	-0.10 deg
7.9 Pa	-167.90 deg	0.00 deg	-169.60 deg	0.20 deg	-162.40 deg	-0.10 deg
8.8 Pa	-167.60 deg	0.30 deg	-169.40 deg	0.40 deg	-162.30 deg	0.00 deg
9.8 Pa	-167.90 deg	0.00 deg	-169.80 deg	0.00 deg	-162.30 deg	0.00 deg
10.8 Pa	-168.10 deg	-0.20 deg	-169.90 deg	-0.10 deg	-162.70 deg	-0.40 deg
11.7 Pa	-167.80 deg	0.10 deg	-169.70 deg	0.10 deg	-162.30 deg	0.00 deg
12.7 Pa	-167.90 deg	0.00 deg	-169.60 deg	0.20 deg	-162.40 deg	-0.10 deg
13.6 Pa	-168.10 deg	-0.20 deg	-169.70 deg	0.10 deg	-162.80 deg	-0.50 deg
14.5 Pa	-167.60 deg	0.30 deg	-169.40 deg	0.40 deg	-162.00 deg	0.30 deg
15.4 Pa	-168.00 deg	-0.10 deg	-169.80 deg	0.00 deg	-162.50 deg	-0.20 deg
16.2 Pa	-168.50 deg	-0.60 deg	-170.30 deg	-0.50 deg	-162.90 deg	-0.60 deg
17.1 Pa	-167.80 deg	0.10 deg	-169.60 deg	0.20 deg	-162.30 deg	0.00 deg
17.9 Pa	-168.20 deg	-0.30 deg	-170.00 deg	-0.20 deg	-162.80 deg	-0.50 deg
18.7 Pa	-167.70 deg	0.20 deg	-169.50 deg	0.30 deg	-162.20 deg	0.10 deg
19.4 Pa	-168.10 deg	-0.20 deg	-170.00 deg	-0.20 deg	-162.50 deg	-0.20 deg
20.2 Pa	-168.60 deg	-0.70 deg	-170.40 deg	-0.60 deg	-163.10 deg	-0.80 deg
20.9 Pa	-167.90 deg	0.00 deg	-169.70 deg	0.10 deg	-162.40 deg	-0.10 deg
21.7 Pa	-168.20 deg	-0.30 deg	-170.00 deg	-0.20 deg	-162.80 deg	-0.50 deg
22.3 Pa	-167.60 deg	0.30 deg	-169.60 deg	0.20 deg	-162.10 deg	0.20 deg

The following two plots illustrate the changes in amplitude and phase for the InfraBSU sensors.

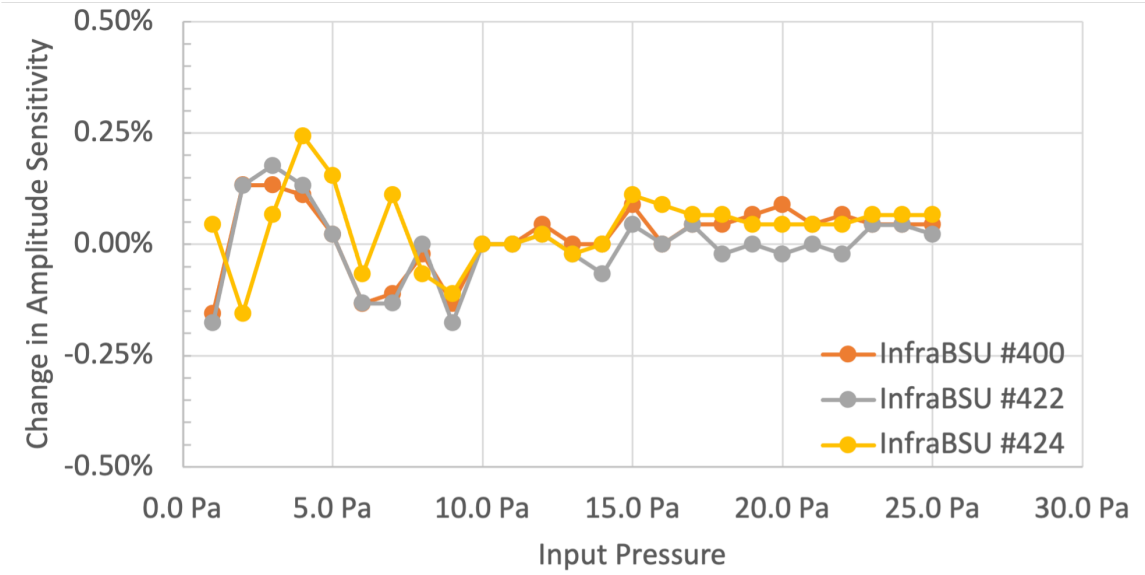

Figure 26 Amplitude Sensitivity Change vs Input Amplitude: InfraBSU Sensors

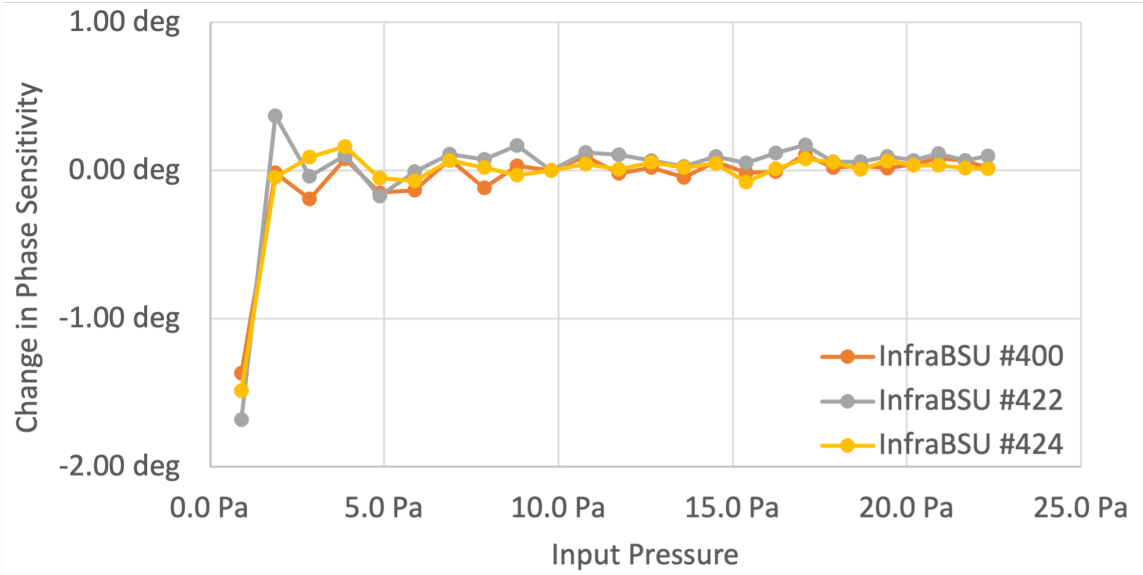

Figure 27 Phase Change vs Input Amplitude: InfraBSU Sensors

Amplitude sensitivity of the InfraBSU sensor has proven to be very stable over the pressure range tested, as illustrated in Figure 26. Changes in sensitivities were no more than 0.25% while being observed at the lowest amplitudes with relatively low SNR. Similarly, the InfraBSU sensor phase sensitivity, discounting the variation observed at low amplitudes with low SNR, remains relatively constant across the pressure range evaluated, as shown in Figure 27. In either case, the InfraBSU changes in amplitude and phase remain well within the uncertainties at all but the lowest amplitudes, which were adversely affected by low SNR.

The following two tables contain the data plotted in the above figures.

Table 24 Amplitude Sensitivity Change vs Input Amplitude: InfraBSU Sensors

	InfraBSU #400		InfraBSU #422		InfraBSU #424	
Pressure	Absolute Amplitude	Relative Amplitude	Absolute Amplitude	Relative Amplitude	Absolute Amplitude	Relative Amplitude
0.9 Pa	45.07 uV/Pa	-0.155%	45.18 uV/Pa	-0.177%	45.21 uV/Pa	0.044%
1.9 Pa	45.20 uV/Pa	0.133%	45.32 uV/Pa	0.133%	45.12 uV/Pa	-0.155%
2.9 Pa	45.20 uV/Pa	0.133%	45.34 uV/Pa	0.177%	45.22 uV/Pa	0.066%
3.9 Pa	45.19 uV/Pa	0.111%	45.32 uV/Pa	0.133%	45.30 uV/Pa	0.243%
4.9 Pa	45.15 uV/Pa	0.022%	45.27 uV/Pa	0.022%	45.26 uV/Pa	0.155%
5.9 Pa	45.08 uV/Pa	-0.133%	45.20 uV/Pa	-0.133%	45.16 uV/Pa	-0.066%
6.9 Pa	45.09 uV/Pa	-0.111%	45.20 uV/Pa	-0.133%	45.24 uV/Pa	0.111%
7.9 Pa	45.13 uV/Pa	-0.022%	45.26 uV/Pa	0.000%	45.16 uV/Pa	-0.066%
8.8 Pa	45.08 uV/Pa	-0.133%	45.18 uV/Pa	-0.177%	45.14 uV/Pa	-0.111%
9.8 Pa	45.14 uV/Pa	0.000%	45.26 uV/Pa	0.000%	45.19 uV/Pa	0.000%
10.8 Pa	45.14 uV/Pa	0.000%	45.26 uV/Pa	0.000%	45.19 uV/Pa	0.000%
11.7 Pa	45.16 uV/Pa	0.044%	45.27 uV/Pa	0.022%	45.20 uV/Pa	0.022%
12.7 Pa	45.14 uV/Pa	0.000%	45.25 uV/Pa	-0.022%	45.18 uV/Pa	-0.022%
13.6 Pa	45.14 uV/Pa	0.000%	45.23 uV/Pa	-0.066%	45.19 uV/Pa	0.000%
14.5 Pa	45.18 uV/Pa	0.089%	45.28 uV/Pa	0.044%	45.24 uV/Pa	0.111%
15.4 Pa	45.14 uV/Pa	0.000%	45.26 uV/Pa	0.000%	45.23 uV/Pa	0.089%
16.2 Pa	45.16 uV/Pa	0.044%	45.28 uV/Pa	0.044%	45.22 uV/Pa	0.066%
17.1 Pa	45.16 uV/Pa	0.044%	45.25 uV/Pa	-0.022%	45.22 uV/Pa	0.066%
17.9 Pa	45.17 uV/Pa	0.066%	45.26 uV/Pa	0.000%	45.21 uV/Pa	0.044%
18.7 Pa	45.18 uV/Pa	0.089%	45.25 uV/Pa	-0.022%	45.21 uV/Pa	0.044%
19.4 Pa	45.16 uV/Pa	0.044%	45.26 uV/Pa	0.000%	45.21 uV/Pa	0.044%
20.2 Pa	45.17 uV/Pa	0.066%	45.25 uV/Pa	-0.022%	45.21 uV/Pa	0.044%
20.9 Pa	45.16 uV/Pa	0.044%	45.28 uV/Pa	0.044%	45.22 uV/Pa	0.066%
21.7 Pa	45.16 uV/Pa	0.044%	45.28 uV/Pa	0.044%	45.22 uV/Pa	0.066%
22.3 Pa	45.16 uV/Pa	0.044%	45.27 uV/Pa	0.022%	45.22 uV/Pa	0.066%

Table 25 Phase Sensitivity vs Input Amplitude: InfraBSU Sensors

	InfraBSU #400		InfraBSU #422		InfraBSU #424	
Pressure	Absolute Phase	Relative Phase	Absolute Phase	Relative Phase	Absolute Phase	Relative Phase
0.9 Pa	-1.13 deg	-1.37 deg	-1.39 deg	-1.68 deg	-1.21 deg	-1.49 deg
1.9 Pa	0.23 deg	-0.01 deg	0.67 deg	0.37 deg	0.23 deg	-0.05 deg
2.9 Pa	0.05 deg	-0.19 deg	0.26 deg	-0.04 deg	0.37 deg	0.09 deg
3.9 Pa	0.32 deg	0.08 deg	0.40 deg	0.10 deg	0.44 deg	0.16 deg
4.9 Pa	0.09 deg	-0.15 deg	0.13 deg	-0.17 deg	0.23 deg	-0.05 deg
5.9 Pa	0.11 deg	-0.13 deg	0.29 deg	-0.01 deg	0.21 deg	-0.07 deg
6.9 Pa	0.32 deg	0.08 deg	0.41 deg	0.11 deg	0.35 deg	0.07 deg
7.9 Pa	0.13 deg	-0.12 deg	0.37 deg	0.08 deg	0.30 deg	0.02 deg
8.8 Pa	0.27 deg	0.03 deg	0.47 deg	0.17 deg	0.25 deg	-0.03 deg
9.8 Pa	0.24 deg	0.00 deg	0.30 deg	0.00 deg	0.28 deg	0.00 deg
10.8 Pa	0.34 deg	0.10 deg	0.42 deg	0.12 deg	0.33 deg	0.05 deg
11.7 Pa	0.22 deg	-0.02 deg	0.40 deg	0.11 deg	0.29 deg	0.01 deg
12.7 Pa	0.26 deg	0.02 deg	0.36 deg	0.07 deg	0.33 deg	0.06 deg
13.6 Pa	0.20 deg	-0.04 deg	0.32 deg	0.03 deg	0.30 deg	0.02 deg
14.5 Pa	0.30 deg	0.06 deg	0.39 deg	0.09 deg	0.33 deg	0.05 deg
15.4 Pa	0.23 deg	-0.01 deg	0.35 deg	0.05 deg	0.20 deg	-0.08 deg
16.2 Pa	0.24 deg	0.00 deg	0.42 deg	0.12 deg	0.29 deg	0.01 deg
17.1 Pa	0.35 deg	0.11 deg	0.47 deg	0.17 deg	0.36 deg	0.08 deg
17.9 Pa	0.26 deg	0.02 deg	0.36 deg	0.06 deg	0.33 deg	0.06 deg
18.7 Pa	0.28 deg	0.03 deg	0.36 deg	0.06 deg	0.29 deg	0.01 deg
19.4 Pa	0.26 deg	0.02 deg	0.39 deg	0.10 deg	0.35 deg	0.07 deg
20.2 Pa	0.28 deg	0.04 deg	0.37 deg	0.07 deg	0.32 deg	0.04 deg
20.9 Pa	0.33 deg	0.08 deg	0.41 deg	0.12 deg	0.32 deg	0.04 deg
21.7 Pa	0.31 deg	0.07 deg	0.36 deg	0.07 deg	0.29 deg	0.02 deg
22.3 Pa	0.26 deg	0.02 deg	0.39 deg	0.10 deg	0.29 deg	0.01 deg

The following two plots illustrate the changes in amplitude and phase for the Gem packages.

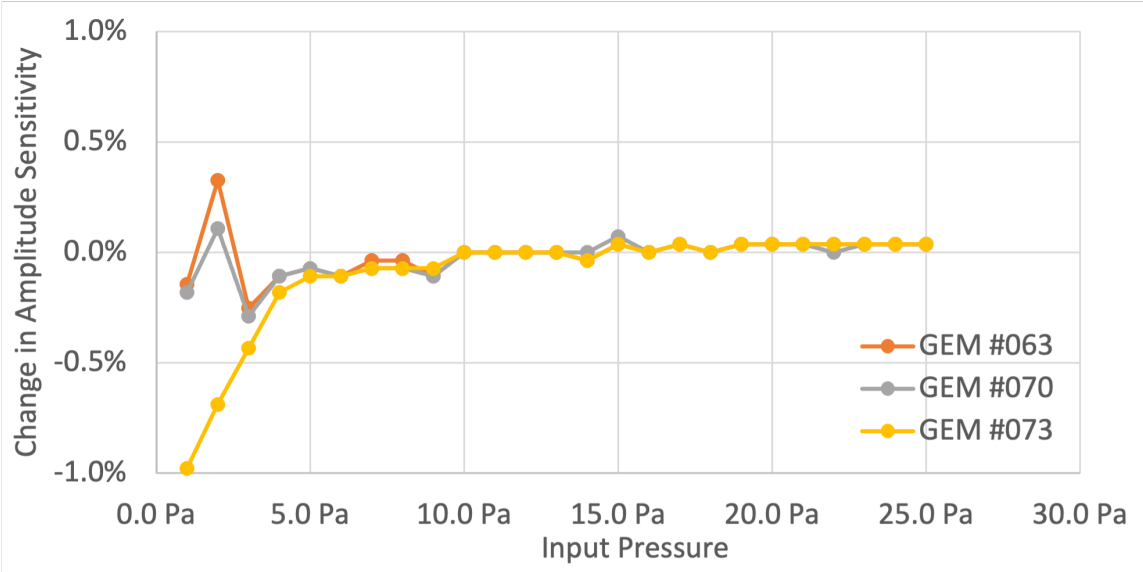

Figure 28 Amplitude Sensitivity Change vs Input Amplitude: Gem Packages

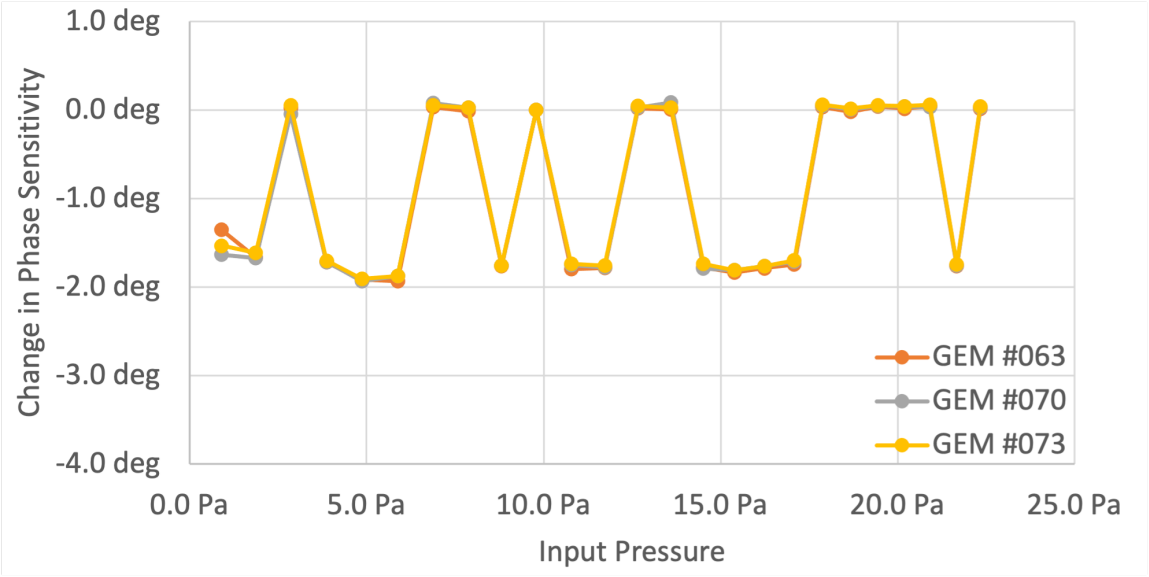

Figure 29 Phase Change vs Input Amplitude: Gem Packages

Similar to the InfraBSU sensors, the Gem packages exhibit little change in sensitivity over the evaluated range of amplitudes, if those amplitudes with low SNR are discounted (Figure 28). The difference in phase sensitivity illustrated in Figure 29 shows a bi-modal distribution in phase, with values observed near zero degrees or approaching as much as -1.94 degrees (equivalent to 5.39 ms at 1 Hz). Considering the Gem package utilizes its own digitizer and GPS receiver, the grouping of phase values may be a manifestation of the timing algorithm of the digitizer and/or GPS receiver locking.

The following two tables contain the data plotted in the above figures.

Table 26 Amplitude Sensitivity Change vs Input Amplitude: Gem Packages

	Gem #063		Gem #070		Gem #073	
Pressure	Absolute Amplitude	Relative Amplitude	Absolute Amplitude	Relative Amplitude	Absolute Amplitude	Relative Amplitude
0.9 Pa	276.1 cts/Pa	-0.145%	275.6 cts/Pa	-0.181%	273.6 cts/Pa	-0.977%
1.9 Pa	277.4 cts/Pa	0.325%	276.4 cts/Pa	0.109%	274.4 cts/Pa	-0.688%
2.9 Pa	275.8 cts/Pa	-0.253%	275.3 cts/Pa	-0.290%	275.1 cts/Pa	-0.434%
3.9 Pa	276.2 cts/Pa	-0.108%	275.8 cts/Pa	-0.109%	275.8 cts/Pa	-0.181%
4.9 Pa	276.3 cts/Pa	-0.072%	275.9 cts/Pa	-0.072%	276.0 cts/Pa	-0.109%
5.9 Pa	276.2 cts/Pa	-0.108%	275.8 cts/Pa	-0.109%	276.0 cts/Pa	-0.109%
6.9 Pa	276.4 cts/Pa	-0.036%	275.9 cts/Pa	-0.072%	276.1 cts/Pa	-0.072%
7.9 Pa	276.4 cts/Pa	-0.036%	275.9 cts/Pa	-0.072%	276.1 cts/Pa	-0.072%
8.8 Pa	276.2 cts/Pa	-0.108%	275.8 cts/Pa	-0.109%	276.1 cts/Pa	-0.072%
9.8 Pa	276.5 cts/Pa	0.000%	276.1 cts/Pa	0.000%	276.3 cts/Pa	0.000%
10.8 Pa	276.5 cts/Pa	0.000%	276.1 cts/Pa	0.000%	276.3 cts/Pa	0.000%
11.7 Pa	276.5 cts/Pa	0.000%	276.1 cts/Pa	0.000%	276.3 cts/Pa	0.000%
12.7 Pa	276.5 cts/Pa	0.000%	276.1 cts/Pa	0.000%	276.3 cts/Pa	0.000%
13.6 Pa	276.4 cts/Pa	-0.036%	276.1 cts/Pa	0.000%	276.2 cts/Pa	-0.036%
14.5 Pa	276.6 cts/Pa	0.036%	276.3 cts/Pa	0.072%	276.4 cts/Pa	0.036%
15.4 Pa	276.5 cts/Pa	0.000%	276.1 cts/Pa	0.000%	276.3 cts/Pa	0.000%
16.2 Pa	276.6 cts/Pa	0.036%	276.2 cts/Pa	0.036%	276.4 cts/Pa	0.036%
17.1 Pa	276.5 cts/Pa	0.000%	276.1 cts/Pa	0.000%	276.3 cts/Pa	0.000%
17.9 Pa	276.6 cts/Pa	0.036%	276.2 cts/Pa	0.036%	276.4 cts/Pa	0.036%
18.7 Pa	276.6 cts/Pa	0.036%	276.2 cts/Pa	0.036%	276.4 cts/Pa	0.036%
19.4 Pa	276.6 cts/Pa	0.036%	276.2 cts/Pa	0.036%	276.4 cts/Pa	0.036%
20.2 Pa	276.6 cts/Pa	0.036%	276.1 cts/Pa	0.000%	276.4 cts/Pa	0.036%
20.9 Pa	276.6 cts/Pa	0.036%	276.2 cts/Pa	0.036%	276.4 cts/Pa	0.036%
21.7 Pa	276.6 cts/Pa	0.036%	276.2 cts/Pa	0.036%	276.4 cts/Pa	0.036%
22.3 Pa	276.6 cts/Pa	0.036%	276.2 cts/Pa	0.036%	276.4 cts/Pa	0.036%

Table 27 Phase Sensitivity vs Input Amplitude: Gem Packages

	Gem #063		Gem #070		Gem #073	
Pressure	Absolute Phase	Relative Phase	Absolute Phase	Relative Phase	Absolute Phase	Relative Phase
0.9 Pa	3.43 deg	-1.35 deg	3.09 deg	-1.64 deg	3.21 deg	-1.53 deg
1.9 Pa	3.12 deg	-1.67 deg	3.05 deg	-1.67 deg	3.13 deg	-1.62 deg
2.9 Pa	4.80 deg	0.02 deg	4.68 deg	-0.05 deg	4.80 deg	0.06 deg
3.9 Pa	3.06 deg	-1.72 deg	3.01 deg	-1.72 deg	3.04 deg	-1.70 deg
4.9 Pa	2.87 deg	-1.92 deg	2.79 deg	-1.94 deg	2.84 deg	-1.91 deg
5.9 Pa	2.85 deg	-1.93 deg	2.85 deg	-1.88 deg	2.87 deg	-1.88 deg
6.9 Pa	4.81 deg	0.03 deg	4.80 deg	0.08 deg	4.80 deg	0.05 deg
7.9 Pa	4.77 deg	-0.01 deg	4.75 deg	0.02 deg	4.77 deg	0.03 deg
8.8 Pa	3.02 deg	-1.77 deg	2.96 deg	-1.76 deg	2.99 deg	-1.76 deg
9.8 Pa	4.78 deg	0.00 deg	4.72 deg	0.00 deg	4.74 deg	0.00 deg
10.8 Pa	2.99 deg	-1.80 deg	2.97 deg	-1.75 deg	3.00 deg	-1.74 deg
11.7 Pa	3.00 deg	-1.78 deg	2.94 deg	-1.78 deg	2.99 deg	-1.76 deg
12.7 Pa	4.80 deg	0.02 deg	4.75 deg	0.02 deg	4.79 deg	0.04 deg
13.6 Pa	4.79 deg	0.00 deg	4.81 deg	0.09 deg	4.77 deg	0.02 deg
14.5 Pa	3.01 deg	-1.78 deg	2.93 deg	-1.79 deg	3.01 deg	-1.74 deg
15.4 Pa	2.95 deg	-1.84 deg	2.91 deg	-1.81 deg	2.93 deg	-1.81 deg
16.2 Pa	3.00 deg	-1.79 deg	2.96 deg	-1.77 deg	2.98 deg	-1.77 deg
17.1 Pa	3.04 deg	-1.75 deg	3.01 deg	-1.71 deg	3.04 deg	-1.70 deg
17.9 Pa	4.82 deg	0.03 deg	4.77 deg	0.05 deg	4.81 deg	0.06 deg
18.7 Pa	4.76 deg	-0.02 deg	4.73 deg	0.00 deg	4.76 deg	0.02 deg
19.4 Pa	4.82 deg	0.04 deg	4.77 deg	0.04 deg	4.80 deg	0.05 deg
20.2 Pa	4.80 deg	0.02 deg	4.76 deg	0.04 deg	4.79 deg	0.04 deg
20.9 Pa	4.82 deg	0.04 deg	4.76 deg	0.03 deg	4.80 deg	0.06 deg
21.7 Pa	3.02 deg	-1.76 deg	2.97 deg	-1.76 deg	3.00 deg	-1.75 deg
22.3 Pa	4.80 deg	0.01 deg	4.75 deg	0.03 deg	4.78 deg	0.04 deg

The following two plots illustrate the changes in amplitude and phase for the Raspberry Boom packages.

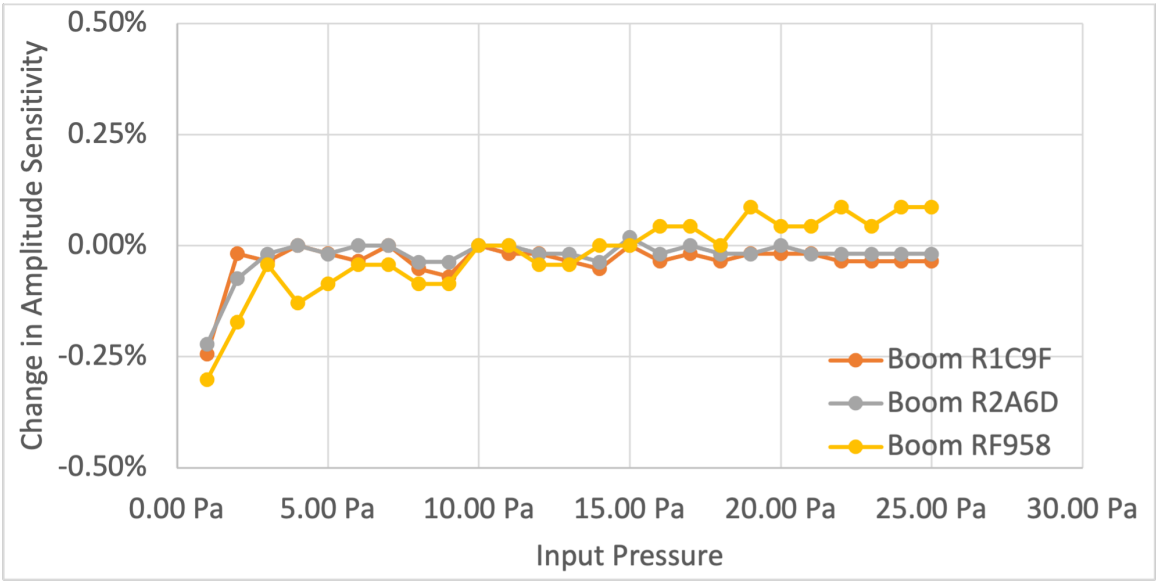

Figure 30 Amplitude Sensitivity Change vs Input Amplitude: Raspberry Boom Packages

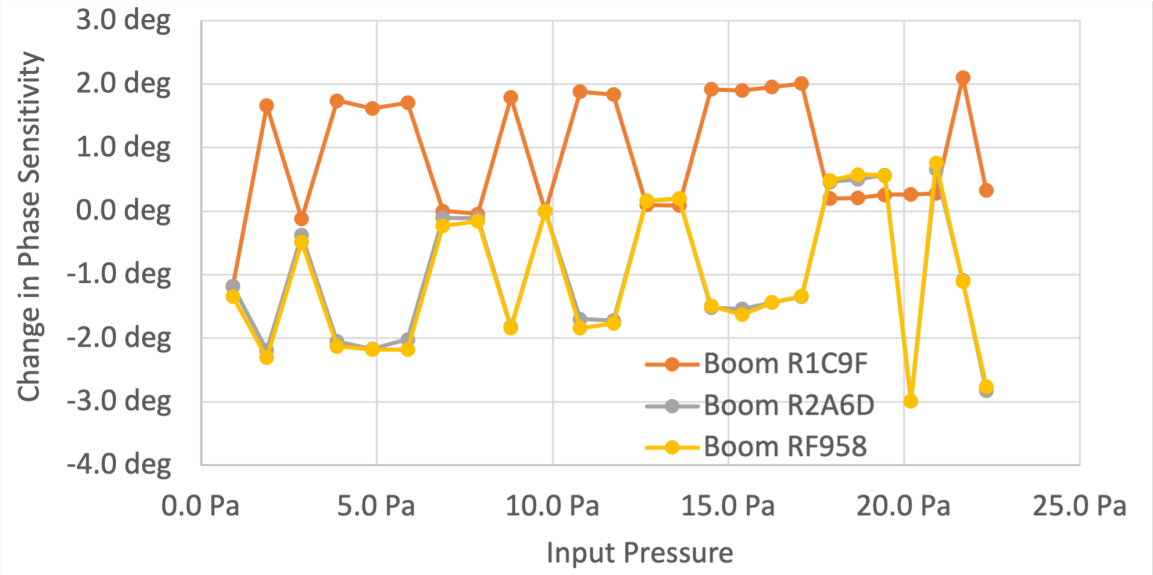

Figure 31 Phase Change vs Input Amplitude: Raspberry Boom Packages

As noted with the Gem packages, the Raspberry Boom packages exhibit little change in sensitivity over the evaluated range of amplitudes. Boom RF958 shows a slight increase in sensitivity with input amplitude in Figure 30, though the magnitude is less than the estimated uncertainty in relative amplitude of 0.3%. The change in phase sensitivity illustrated in Figure 31 shows the variation in phase for each package, where values were observed to fall near 2 degrees, 0 degrees, -1 degrees, -2 degrees or near -3 degrees. The Boom packages also utilize their own digitizer and GPS receiver; the grouping of phase values may be a manifestation of the timing algorithm of the digitizer and/or GPS receiver locking.

The following two tables contain the data plotted in the above figures.

Table 28 Amplitude Sensitivity Change vs Input Amplitude: Raspberry Boom Packages

	Boom R1C9F		Boom R2A6D		Boom RF958	
Pressure	Absolute Amplitude	Relative Amplitude	Absolute Amplitude	Relative Amplitude	Absolute Amplitude	Relative Amplitude
0.9 Pa	57350 cts/Pa	-0.244%	54110 cts/Pa	-0.221%	23140 cts/Pa	-0.302%
1.9 Pa	57480 cts/Pa	-0.017%	54190 cts/Pa	-0.074%	23170 cts/Pa	-0.172%
2.9 Pa	57470 cts/Pa	-0.035%	54220 cts/Pa	-0.018%	23200 cts/Pa	-0.043%
3.9 Pa	57490 cts/Pa	0.000%	54230 cts/Pa	0.000%	23180 cts/Pa	-0.129%
4.9 Pa	57480 cts/Pa	-0.017%	54220 cts/Pa	-0.018%	23190 cts/Pa	-0.086%
5.9 Pa	57470 cts/Pa	-0.035%	54230 cts/Pa	0.000%	23200 cts/Pa	-0.043%
6.9 Pa	57490 cts/Pa	0.000%	54230 cts/Pa	0.000%	23200 cts/Pa	-0.043%
7.9 Pa	57460 cts/Pa	-0.052%	54210 cts/Pa	-0.037%	23190 cts/Pa	-0.086%
8.8 Pa	57450 cts/Pa	-0.070%	54210 cts/Pa	-0.037%	23190 cts/Pa	-0.086%
9.8 Pa	57490 cts/Pa	0.000%	54230 cts/Pa	0.000%	23210 cts/Pa	0.000%
10.8 Pa	57480 cts/Pa	-0.017%	54230 cts/Pa	0.000%	23210 cts/Pa	0.000%
11.7 Pa	57480 cts/Pa	-0.017%	54220 cts/Pa	-0.018%	23200 cts/Pa	-0.043%
12.7 Pa	57470 cts/Pa	-0.035%	54220 cts/Pa	-0.018%	23200 cts/Pa	-0.043%
13.6 Pa	57460 cts/Pa	-0.052%	54210 cts/Pa	-0.037%	23210 cts/Pa	0.000%
14.5 Pa	57490 cts/Pa	0.000%	54240 cts/Pa	0.018%	23210 cts/Pa	0.000%
15.4 Pa	57470 cts/Pa	-0.035%	54220 cts/Pa	-0.018%	23220 cts/Pa	0.043%
16.2 Pa	57480 cts/Pa	-0.017%	54230 cts/Pa	0.000%	23220 cts/Pa	0.043%
17.1 Pa	57470 cts/Pa	-0.035%	54220 cts/Pa	-0.018%	23210 cts/Pa	0.000%
17.9 Pa	57480 cts/Pa	-0.017%	54220 cts/Pa	-0.018%	23230 cts/Pa	0.086%
18.7 Pa	57480 cts/Pa	-0.017%	54230 cts/Pa	0.000%	23220 cts/Pa	0.043%
19.4 Pa	57480 cts/Pa	-0.017%	54220 cts/Pa	-0.018%	23220 cts/Pa	0.043%
20.2 Pa	57470 cts/Pa	-0.035%	54220 cts/Pa	-0.018%	23230 cts/Pa	0.086%
20.9 Pa	57470 cts/Pa	-0.035%	54220 cts/Pa	-0.018%	23220 cts/Pa	0.043%
21.7 Pa	57470 cts/Pa	-0.035%	54220 cts/Pa	-0.018%	23230 cts/Pa	0.086%
22.3 Pa	57470 cts/Pa	-0.035%	54220 cts/Pa	-0.018%	23230 cts/Pa	0.086%

Table 29 Phase Sensitivity vs Input Amplitude: Raspberry Boom Packages

	Boom R1C9F		Boom R2A6D		Boom RF958	
Pressure	Absolute Phase	Relative Phase	Absolute Phase	Relative Phase	Absolute Phase	Relative Phase
0.9 Pa	6.74 deg	-1.18 deg	12.04 deg	-1.18 deg	67.53 deg	-1.35 deg
1.9 Pa	9.59 deg	1.67 deg	11.03 deg	-2.19 deg	66.57 deg	-2.31 deg
2.9 Pa	7.80 deg	-0.12 deg	12.84 deg	-0.38 deg	68.39 deg	-0.49 deg
3.9 Pa	9.67 deg	1.74 deg	11.17 deg	-2.05 deg	66.75 deg	-2.13 deg
4.9 Pa	9.54 deg	1.62 deg	11.05 deg	-2.17 deg	66.70 deg	-2.18 deg
5.9 Pa	9.63 deg	1.71 deg	11.20 deg	-2.02 deg	66.70 deg	-2.18 deg
6.9 Pa	7.93 deg	0.00 deg	13.12 deg	-0.10 deg	68.65 deg	-0.23 deg
7.9 Pa	7.88 deg	-0.04 deg	13.11 deg	-0.11 deg	68.72 deg	-0.16 deg
8.8 Pa	9.72 deg	1.80 deg	11.40 deg	-1.82 deg	67.04 deg	-1.84 deg
9.8 Pa	7.92 deg	0.00 deg	13.22 deg	0.00 deg	68.88 deg	0.00 deg
10.8 Pa	9.80 deg	1.88 deg	11.52 deg	-1.70 deg	67.04 deg	-1.84 deg
11.7 Pa	9.76 deg	1.84 deg	11.50 deg	-1.72 deg	67.11 deg	-1.77 deg
12.7 Pa	8.02 deg	0.10 deg	13.38 deg	0.16 deg	69.04 deg	0.16 deg
13.6 Pa	8.01 deg	0.09 deg	13.42 deg	0.20 deg	69.08 deg	0.20 deg
14.5 Pa	9.84 deg	1.92 deg	11.70 deg	-1.52 deg	67.39 deg	-1.49 deg
15.4 Pa	9.83 deg	1.90 deg	11.68 deg	-1.54 deg	67.25 deg	-1.63 deg
16.2 Pa	9.88 deg	1.95 deg	11.78 deg	-1.44 deg	67.44 deg	-1.44 deg
17.1 Pa	9.94 deg	2.01 deg	11.87 deg	-1.35 deg	67.54 deg	-1.34 deg
17.9 Pa	8.12 deg	0.20 deg	13.68 deg	0.46 deg	69.36 deg	0.48 deg
18.7 Pa	8.13 deg	0.21 deg	13.72 deg	0.50 deg	69.46 deg	0.58 deg
19.4 Pa	8.18 deg	0.26 deg	13.79 deg	0.57 deg	69.44 deg	0.56 deg
20.2 Pa	8.19 deg	0.26 deg	10.23 deg	-2.99 deg	65.89 deg	-2.99 deg
20.9 Pa	8.20 deg	0.28 deg	13.88 deg	0.66 deg	69.64 deg	0.76 deg
21.7 Pa	10.03 deg	2.11 deg	12.13 deg	-1.09 deg	67.77 deg	-1.11 deg
22.3 Pa	8.25 deg	0.33 deg	10.39 deg	-2.83 deg	66.12 deg	-2.76 deg

The following plot illustrates the changes in amplitude sensitivity of the Samsung S10 smartphones.

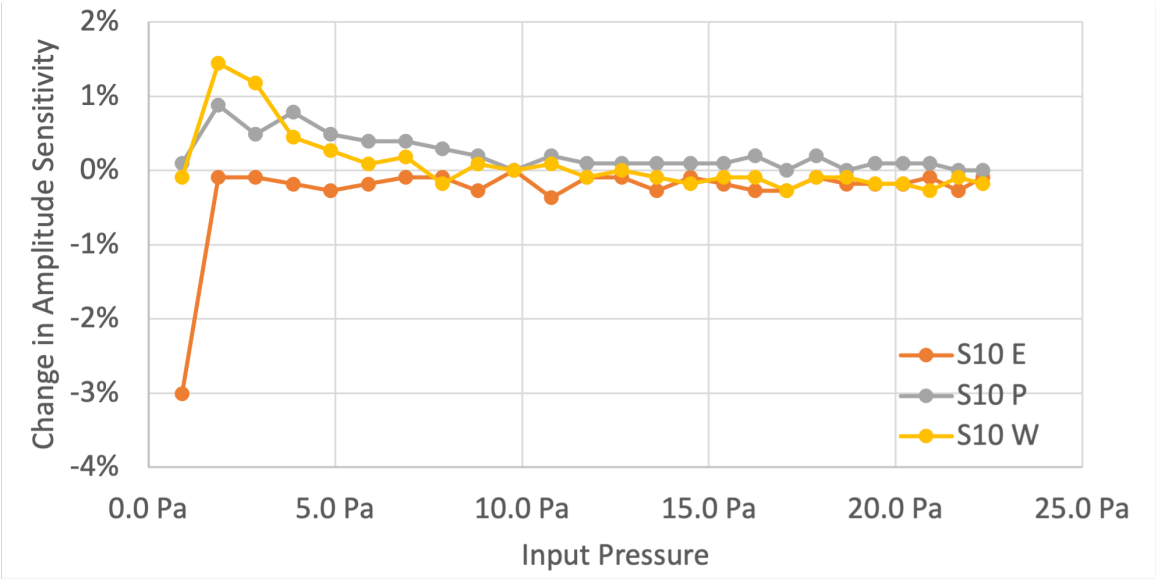

Figure 32 Relative Amplitude Sensitivity Change vs Input Amplitude: Samsung Packages

The S10 smartphones were also observed to have relatively consistent amplitude sensitivities across the input pressure range evaluated with no increasing or decreasing trend apparent, if one considers the estimated relative uncertainty of 0.3% and discounts the lowest pressures, which had low SNR. Phase results are not reported as the Samsung S10 utilizes network timing, rather than GPS timing, and observed phase varied widely throughout the evaluations.

The following table provides the data plotted in Figure 32.

Table 30 Amplitude Sensitivity Change vs Input Amplitude: S10 Packages

	Boom R1C9F		Boom R2A6D		Boom RF958	
Pressure	Absolute Amplitude	Relative Amplitude	Absolute Amplitude	Relative Amplitude	Absolute Amplitude	Relative Amplitude
0.9 Pa	1065 cts/Pa	-3.005%	1019 cts/Pa	0.098%	1104 cts/Pa	-0.090%
1.9 Pa	1097 cts/Pa	-0.091%	1027 cts/Pa	0.884%	1121 cts/Pa	1.448%
2.9 Pa	1097 cts/Pa	-0.091%	1023 cts/Pa	0.491%	1118 cts/Pa	1.176%
3.9 Pa	1096 cts/Pa	-0.182%	1026 cts/Pa	0.786%	1110 cts/Pa	0.452%
4.9 Pa	1095 cts/Pa	-0.273%	1023 cts/Pa	0.491%	1108 cts/Pa	0.271%
5.9 Pa	1096 cts/Pa	-0.182%	1022 cts/Pa	0.393%	1106 cts/Pa	0.090%
6.9 Pa	1097 cts/Pa	-0.091%	1022 cts/Pa	0.393%	1107 cts/Pa	0.181%
7.9 Pa	1097 cts/Pa	-0.091%	1021 cts/Pa	0.295%	1103 cts/Pa	-0.181%
8.8 Pa	1095 cts/Pa	-0.273%	1020 cts/Pa	0.196%	1106 cts/Pa	0.090%
9.8 Pa	1098 cts/Pa	0.000%	1018 cts/Pa	0.000%	1105 cts/Pa	0.000%
10.8 Pa	1094 cts/Pa	-0.364%	1020 cts/Pa	0.196%	1106 cts/Pa	0.090%
11.7 Pa	1097 cts/Pa	-0.091%	1019 cts/Pa	0.098%	1104 cts/Pa	-0.090%
12.7 Pa	1097 cts/Pa	-0.091%	1019 cts/Pa	0.098%	1105 cts/Pa	0.000%
13.6 Pa	1095 cts/Pa	-0.273%	1019 cts/Pa	0.098%	1104 cts/Pa	-0.090%
14.5 Pa	1097 cts/Pa	-0.091%	1019 cts/Pa	0.098%	1103 cts/Pa	-0.181%
15.4 Pa	1096 cts/Pa	-0.182%	1019 cts/Pa	0.098%	1104 cts/Pa	-0.090%
16.2 Pa	1095 cts/Pa	-0.273%	1020 cts/Pa	0.196%	1104 cts/Pa	-0.090%
17.1 Pa	1095 cts/Pa	-0.273%	1018 cts/Pa	0.000%	1102 cts/Pa	-0.271%
17.9 Pa	1097 cts/Pa	-0.091%	1020 cts/Pa	0.196%	1104 cts/Pa	-0.090%
18.7 Pa	1096 cts/Pa	-0.182%	1018 cts/Pa	0.000%	1104 cts/Pa	-0.090%
19.4 Pa	1096 cts/Pa	-0.182%	1019 cts/Pa	0.098%	1103 cts/Pa	-0.181%
20.2 Pa	1096 cts/Pa	-0.182%	1019 cts/Pa	0.098%	1103 cts/Pa	-0.181%
20.9 Pa	1097 cts/Pa	-0.091%	1019 cts/Pa	0.098%	1102 cts/Pa	-0.271%
21.7 Pa	1095 cts/Pa	-0.273%	1018 cts/Pa	0.000%	1104 cts/Pa	-0.090%
22.3 Pa	1097 cts/Pa	-0.091%	1018 cts/Pa	0.000%	1103 cts/Pa	-0.181%

The Camas microphones exhibited variations in amplitude greater than the relative uncertainty with a noticeable trend and less than the estimated relative uncertainty in phase. The InfraBSU, Gem, Boom, and S10 all exhibited amplitude responses well within the estimated relative uncertainty in amplitude, notwithstanding the measurements with low SNR. Observed phase sensitivities for the InfraBSU were similarly consistent across the amplitude range evaluated as well. The Gem and Boom infrasound packages, each of which utilize an internal digitizer to record signals, showed variations in phase sensitivities, which may be an artifact of their particular mechanisms for digitizer timing.

3.4 Sensitivity vs input Amplitude in External Calibrator

The sensitivity vs input amplitude is measured as an indicator of linearity with respect to amplitude. The pressure sensitivity values are measured at a calibration frequency across several increments of dynamic input pressure amplitude.

3.4.1 Measurand

The quantity being measured is the change in sensitivity versus input pressure, expressed as a percent in amplitude and degrees difference in phase.

3.4.2 Configuration

The infrasound sensors and packages under test, and a reference sensor with known response characteristics, are attached to the PSU linearity calibrator. The calibrator generates a sinusoidal pressure wave with a motor driven piston. The output of the sensor/package is compared against a reference sensor attached to one of the sensor inlets. Due to the limited volume of the manifold, this calibrator is capable of reaching higher pressure levels than the calibrator in the isolation chamber.

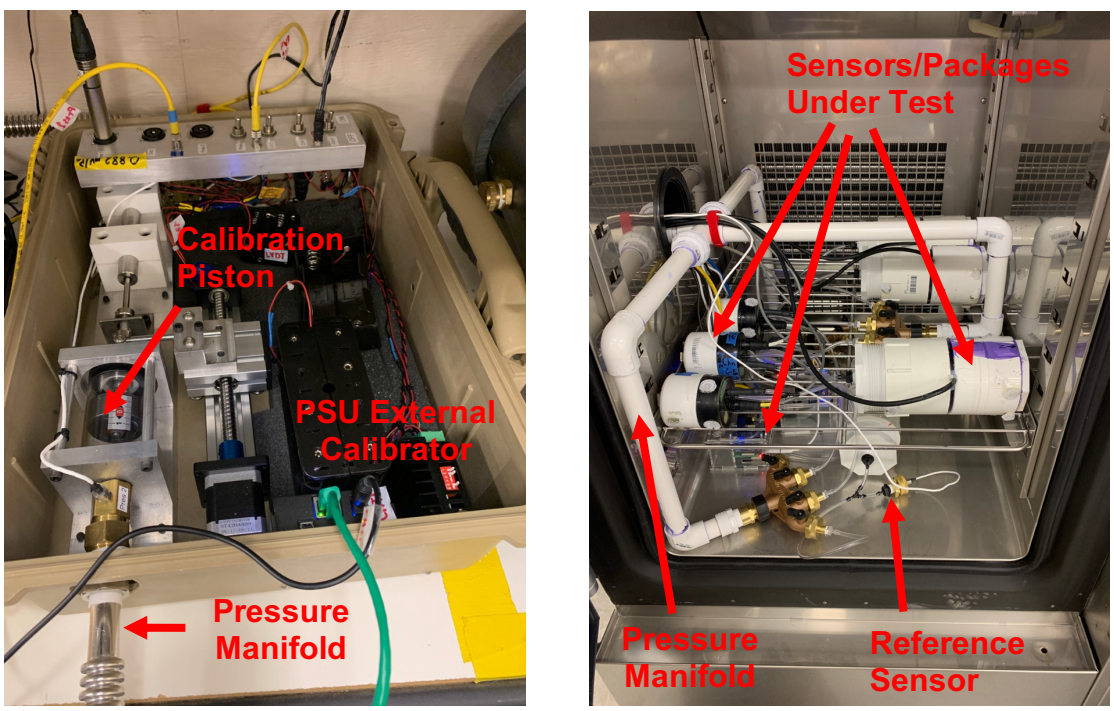

Figure 33 Relative Sensitivity vs Input Amplitude Configuration Diagram

The digitizer records the output of the reference sensor and the sensors under test simultaneously, while the packages record independently on their internal digitizers. The recorded output from the reference sensor and the sensor/package-under-test are then compared. The following table documents the testbed equipment utilized and the environmental conditions at the time of the test.

Table 31 PSU Sensitivity vs Input Amplitude Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
Reference Sensor	Kulite XCS-190S-5D	N/A	0.856900 mV/Pa
Infrasound Chamber	N/A	N/A	821 hPa, +/- 5 hPa 22 C, +/- 3 C 17% Rh, +/- 3% Rh
Digitizer	Guralp Affinity	405A5B	200 Hz, 1x gain 40 Vpp
Voltage Signal Source	PSU Linearity Calibrator	N/A	1 Hz, 0.05 to 2 mm piston displacement
Voltage Amplifier	N/A	N/A	20x gain DC Coupled Amplifier
Pressure Driver	PSU Linearity Calibrator	N/A	N/A

3.4.3 Analysis

A minimum of 10 cycles, or 10 seconds at 1 Hz, 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 sensor in Pascals and the sensor under test in Volts in order to determine the sinusoid's amplitude, frequency, phase, and DC offset:

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

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

The sensor amplitude sensitivity in Volts / Pascal is computed:

$$S_{amp} = \frac{V_{test}}{P_{ref}}$$

The sensor phase sensitivity in degrees is computed:

$$S_{phase} = \theta_{test} - \theta_{ref}$$

The change in sensitivity, expressed as a percentage in amplitude and degrees in phase, at each amplitude level are computed relative to a reference amplitude level:

$$Change\ S_{amp}(Ampl) = 100 * \frac{(S_{amp}(Ampl) - S_{amp}(Ref\ Ampl))}{S_{amp}(Ref\ Ampl)}$$

$$Change\ S_{phase}(Ampl) = S_{phase}(Ampl) - S_{phase}(Ref\ Ampl)$$

3.4.4 Result

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

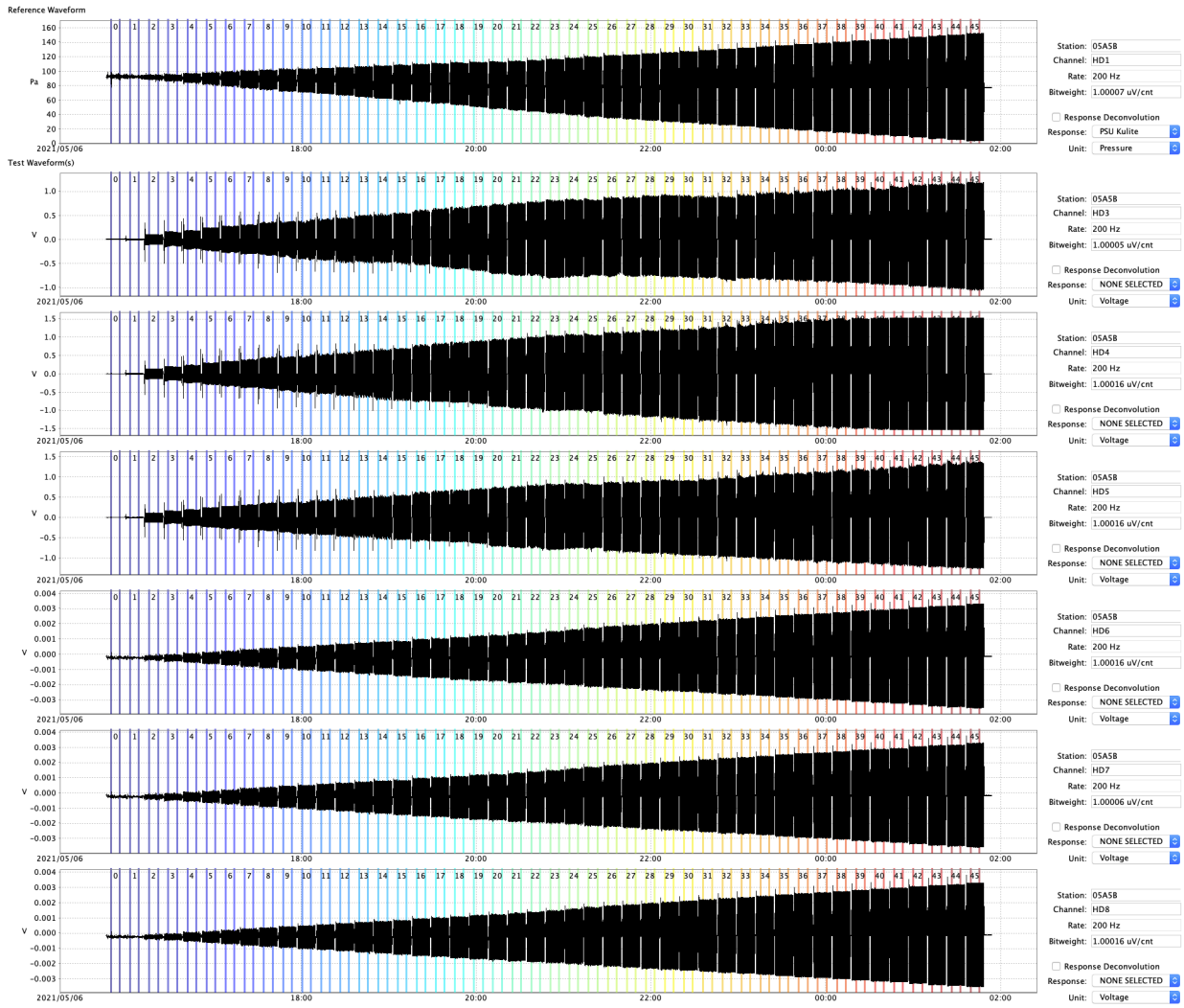

Figure 34 PSU Sensitivity vs Input Amplitude, Representative Time Series

The following plots and tables represent the changes in amplitude and phase sensitivity, relative to the measurement at approximately 20 Pa, that were observed across the input amplitude range of the sensors and packages under test. Note that since the reference sensor used in the external calibrator does not have a traceable calibration, absolute measurements of the amplitude and phase sensitivity are not reported, but rather changes in amplitude sensitivity relative to a baseline are provided.

The following two plots illustrate the observations of relative changes in amplitude and phase for the Camas microphones.

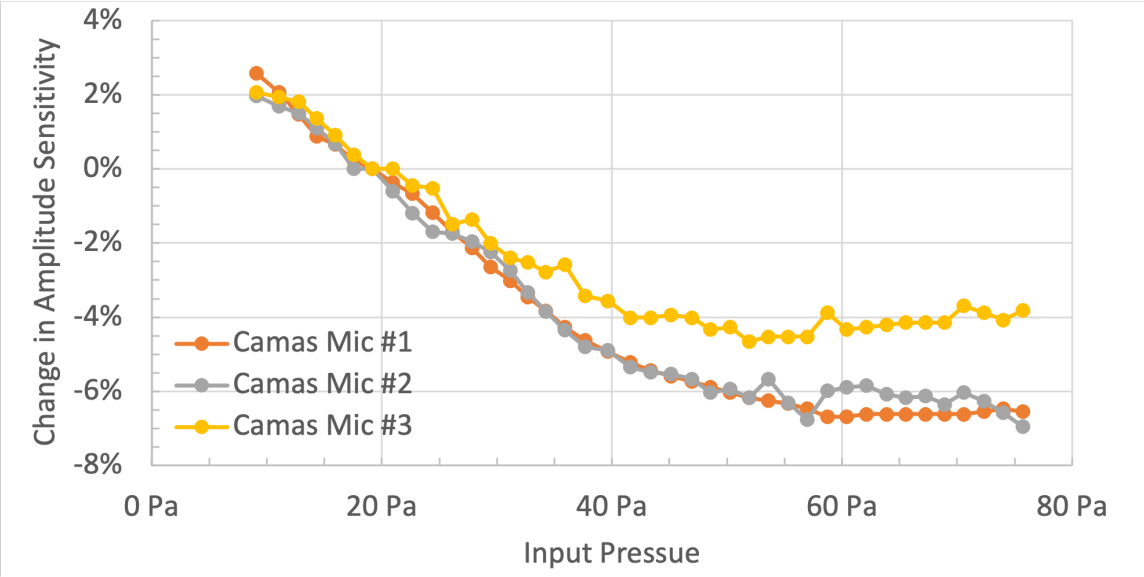

Figure 35 PSU Relative Change in Amplitude Sensitivity vs Input Pressure: Camas Microphones

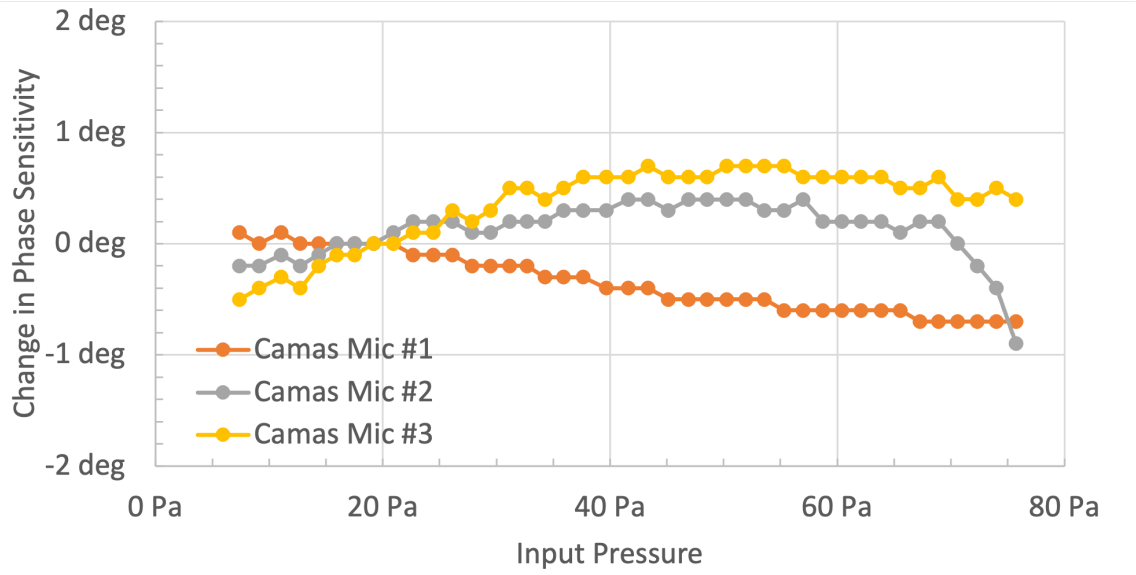

Figure 36 PSU Relative Change in Phase vs Input Pressure: Camas Microphones

Figure 35 illustrates the Camas microphones were observed to have a relative change in amplitude sensitivity that varied from the baseline level between 4% and 6%, for microphone #2 and microphones #1 and #3, respectively. Changes in phase compared to that observed at 20 Pa are within 1 degree for all microphones. The phase changes of microphone #2 and #3 though, trend opposite in direction to that of microphone #1 below approximately 50 Pa (Figure 36).

The following table contains the data for the above plots.

Table 32 Relative Changes in Amplitude Sensitivity and in Phase vs Input Amplitude: Camas Microphones

	Camas #1		Camas #2		Camas #3	
Pressure	Relative Amplitude	Relative Phase	Relative Amplitude	Relative Phase	Relative Amplitude	Relative Phase
7.38 Pa	3.60%	0.10 deg	2.24%	-0.20 deg	2.59%	-0.50 deg
9.12 Pa	2.57%	0.00 deg	1.97%	-0.20 deg	2.07%	-0.40 deg
11.07 Pa	2.06%	0.10 deg	1.69%	-0.10 deg	1.94%	-0.30 deg
12.76 Pa	1.47%	0.00 deg	1.51%	-0.20 deg	1.81%	-0.40 deg
14.35 Pa	0.88%	0.00 deg	1.10%	-0.10 deg	1.36%	-0.20 deg
15.95 Pa	0.66%	0.00 deg	0.69%	0.00 deg	0.91%	-0.10 deg
17.54 Pa	0.22%	0.00 deg	0.00%	0.00 deg	0.39%	-0.10 deg
19.18 Pa	0.00%	0.00 deg	0.00%	0.00 deg	0.00%	0.00 deg
20.93 Pa	-0.37%	0.00 deg	-0.59%	0.10 deg	0.00%	0.00 deg
22.65 Pa	-0.66%	-0.10 deg	-1.19%	0.20 deg	-0.45%	0.10 deg
24.43 Pa	-1.18%	-0.10 deg	-1.69%	0.20 deg	-0.52%	0.10 deg
26.11 Pa	-1.69%	-0.10 deg	-1.74%	0.20 deg	-1.49%	0.30 deg
27.86 Pa	-2.13%	-0.20 deg	-1.97%	0.10 deg	-1.36%	0.20 deg
29.48 Pa	-2.65%	-0.20 deg	-2.24%	0.10 deg	-2.01%	0.30 deg
31.18 Pa	-3.01%	-0.20 deg	-2.74%	0.20 deg	-2.39%	0.50 deg
32.69 Pa	-3.46%	-0.20 deg	-3.34%	0.20 deg	-2.52%	0.50 deg
34.26 Pa	-3.82%	-0.30 deg	-3.84%	0.20 deg	-2.78%	0.40 deg
35.93 Pa	-4.26%	-0.30 deg	-4.34%	0.30 deg	-2.59%	0.50 deg
37.65 Pa	-4.63%	-0.30 deg	-4.80%	0.30 deg	-3.43%	0.60 deg
39.66 Pa	-4.93%	-0.40 deg	-4.89%	0.30 deg	-3.56%	0.60 deg
41.61 Pa	-5.22%	-0.40 deg	-5.35%	0.40 deg	-4.01%	0.60 deg
43.36 Pa	-5.44%	-0.40 deg	-5.48%	0.40 deg	-4.01%	0.70 deg
45.14 Pa	-5.59%	-0.50 deg	-5.53%	0.30 deg	-3.95%	0.60 deg
46.92 Pa	-5.74%	-0.50 deg	-5.67%	0.40 deg	-4.01%	0.60 deg
48.56 Pa	-5.88%	-0.50 deg	-6.03%	0.40 deg	-4.33%	0.60 deg
50.27 Pa	-6.03%	-0.50 deg	-5.94%	0.40 deg	-4.27%	0.70 deg
51.94 Pa	-6.18%	-0.50 deg	-6.17%	0.40 deg	-4.66%	0.70 deg
53.60 Pa	-6.25%	-0.50 deg	-5.67%	0.30 deg	-4.53%	0.70 deg
55.29 Pa	-6.32%	-0.60 deg	-6.31%	0.30 deg	-4.53%	0.70 deg
56.99 Pa	-6.47%	-0.60 deg	-6.76%	0.40 deg	-4.53%	0.60 deg
58.73 Pa	-6.69%	-0.60 deg	-5.99%	0.20 deg	-3.88%	0.60 deg
60.42 Pa	-6.69%	-0.60 deg	-5.90%	0.20 deg	-4.33%	0.60 deg
62.10 Pa	-6.62%	-0.60 deg	-5.85%	0.20 deg	-4.27%	0.60 deg
63.86 Pa	-6.62%	-0.60 deg	-6.08%	0.20 deg	-4.20%	0.60 deg
65.55 Pa	-6.62%	-0.60 deg	-6.17%	0.10 deg	-4.14%	0.50 deg
67.25 Pa	-6.62%	-0.70 deg	-6.12%	0.20 deg	-4.14%	0.50 deg
68.91 Pa	-6.62%	-0.70 deg	-6.35%	0.20 deg	-4.14%	0.60 deg
70.60 Pa	-6.62%	-0.70 deg	-6.03%	0.00 deg	-3.69%	0.40 deg
72.34 Pa	-6.54%	-0.70 deg	-6.26%	-0.20 deg	-3.88%	0.40 deg
74.00 Pa	-6.47%	-0.70 deg	-6.58%	-0.40 deg	-4.08%	0.50 deg
75.71 Pa	-6.54%	-0.70 deg	-6.95%	-0.90 deg	-3.82%	0.40 deg

The following two plots illustrate the measurements of relative changes in amplitude and phase for the InfraBSU sensors.

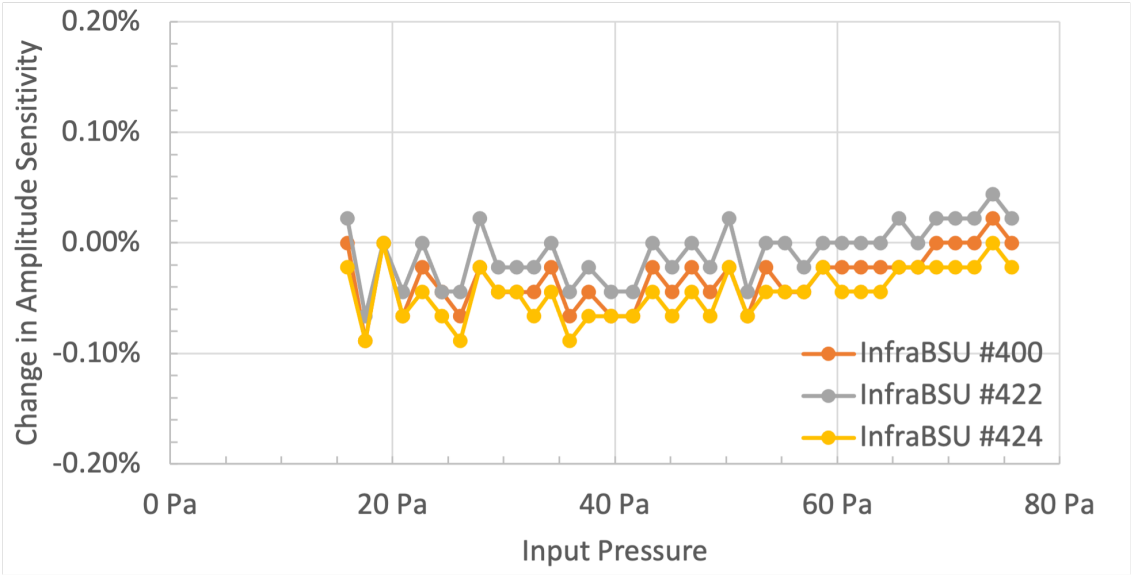

Figure 37 PSU Relative Change in Amplitude Sensitivity vs Input Pressure: InfraBSU Sensors

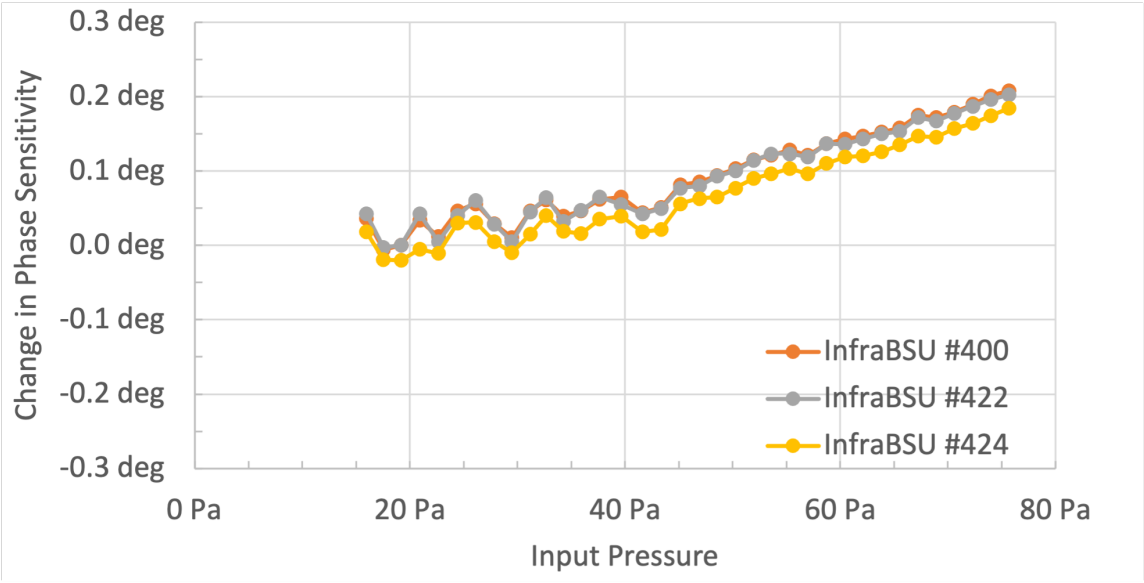

Figure 38 PSU Relative Change in Phase vs Input Pressure: InfraBSU Sensors

The InfraBSU sensors exhibited low SNR in observations below 15 Pa, and therefore, are omitted from the evaluation. Figure 37 illustrates the InfraBSU sensors were observed to have little change in amplitude sensitivity, 0.1% across all sensors. There is a small, but noticeable, trend in the change in the phase, greater than the 0.09 degrees of relative uncertainty.

The following table contains the data for the above plots.

Table 33 Relative Changes in Amplitude Sensitivity and Phase vs Input Amplitude: InfraBSU Sensors

	InfraBSU #400		InfraBSU #422		InfraBSU #424	
Pressure	Relative Amplitude	Relative Phase	Relative Amplitude	Relative Phase	Relative Amplitude	Relative Phase
15.95 Pa	0.00%	0.04 deg	2.21%	0.04 deg	-2.21%	0.02 deg
17.54 Pa	-8.86%	-0.01 deg	-6.63%	0.00 deg	-8.84%	-0.02 deg
19.18 Pa	0.00%	0.00 deg	0.00%	0.00 deg	0.00%	-0.02 deg
20.93 Pa	-6.65%	0.03 deg	-4.42%	0.04 deg	-6.63%	-0.01 deg
22.65 Pa	-2.22%	0.01 deg	0.00%	0.00 deg	-4.42%	-0.01 deg
24.43 Pa	-4.43%	0.05 deg	-4.42%	0.04 deg	-6.63%	0.03 deg
26.11 Pa	-6.65%	0.06 deg	-4.42%	0.06 deg	-8.84%	0.03 deg
27.86 Pa	-2.22%	0.03 deg	2.21%	0.03 deg	-2.21%	0.00 deg
29.48 Pa	-4.43%	0.01 deg	-2.21%	0.00 deg	-4.42%	-0.01 deg
31.18 Pa	-4.43%	0.05 deg	-2.21%	0.04 deg	-4.42%	0.01 deg
32.69 Pa	-4.43%	0.06 deg	-2.21%	0.06 deg	-6.63%	0.04 deg
34.26 Pa	-2.22%	0.04 deg	0.00%	0.03 deg	-4.42%	0.02 deg
35.93 Pa	-6.65%	0.05 deg	-4.42%	0.05 deg	-8.84%	0.02 deg
37.65 Pa	-4.43%	0.06 deg	-2.21%	0.06 deg	-6.63%	0.03 deg
39.66 Pa	-6.65%	0.07 deg	-4.42%	0.05 deg	-6.63%	0.04 deg
41.61 Pa	-6.65%	0.04 deg	-4.42%	0.04 deg	-6.63%	0.02 deg
43.36 Pa	-2.22%	0.05 deg	0.00%	0.05 deg	-4.42%	0.02 deg
45.14 Pa	-4.43%	0.08 deg	-2.21%	0.08 deg	-6.63%	0.06 deg
46.92 Pa	-2.22%	0.09 deg	0.00%	0.08 deg	-4.42%	0.06 deg
48.56 Pa	-4.43%	0.09 deg	-2.21%	0.09 deg	-6.63%	0.06 deg
50.27 Pa	-2.22%	0.10 deg	2.21%	0.10 deg	-2.21%	0.08 deg
51.94 Pa	-6.65%	0.12 deg	-4.42%	0.11 deg	-6.63%	0.09 deg
53.60 Pa	-2.22%	0.12 deg	0.00%	0.12 deg	-4.42%	0.10 deg
55.29 Pa	-4.43%	0.13 deg	0.00%	0.12 deg	-4.42%	0.10 deg
56.99 Pa	-4.43%	0.12 deg	-2.21%	0.12 deg	-4.42%	0.10 deg
58.73 Pa	-2.22%	0.14 deg	0.00%	0.14 deg	-2.21%	0.11 deg
60.42 Pa	-2.22%	0.14 deg	0.00%	0.14 deg	-4.42%	0.12 deg
62.10 Pa	-2.22%	0.15 deg	0.00%	0.14 deg	-4.42%	0.12 deg
63.86 Pa	-2.22%	0.15 deg	0.00%	0.15 deg	-4.42%	0.13 deg
65.55 Pa	-2.22%	0.16 deg	2.21%	0.15 deg	-2.21%	0.14 deg
67.25 Pa	-2.22%	0.18 deg	0.00%	0.17 deg	-2.21%	0.15 deg
68.91 Pa	0.00%	0.17 deg	2.21%	0.17 deg	-2.21%	0.15 deg
70.60 Pa	0.00%	0.18 deg	2.21%	0.18 deg	-2.21%	0.16 deg
72.34 Pa	0.00%	0.19 deg	2.21%	0.19 deg	-2.21%	0.16 deg
74.00 Pa	2.22%	0.20 deg	4.42%	0.20 deg	0.00%	0.17 deg
75.71 Pa	0.00%	0.21 deg	2.21%	0.20 deg	-2.21%	0.18 deg

The following two plots illustrate the measurements of relative changes in amplitude and phase for Gem package #070.

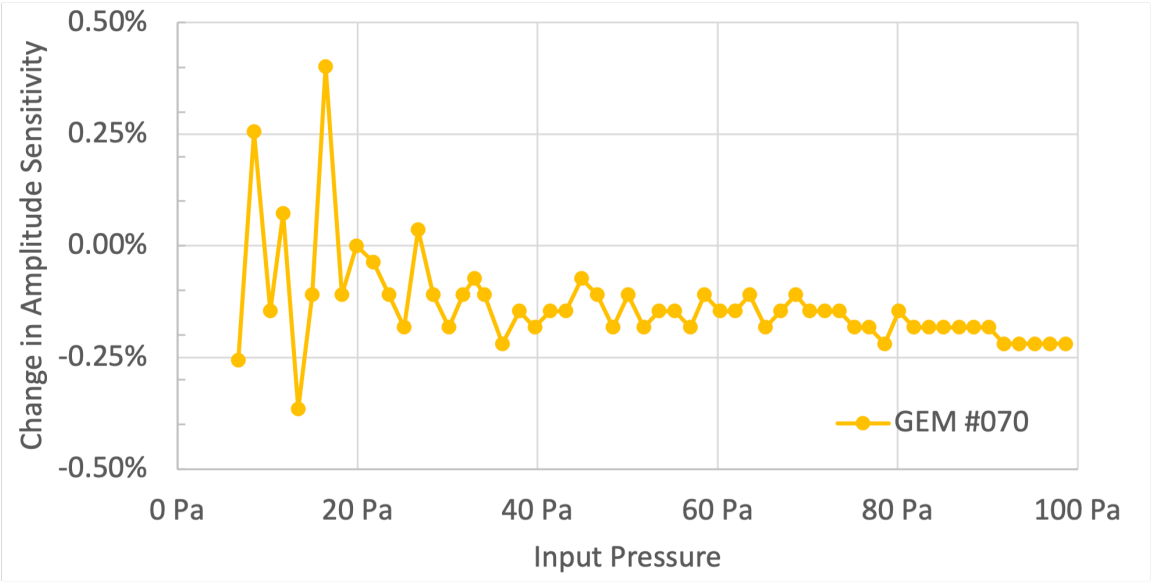

Figure 39 PSU Relative Change in Amplitude Sensitivity vs Input Pressure: Gem package

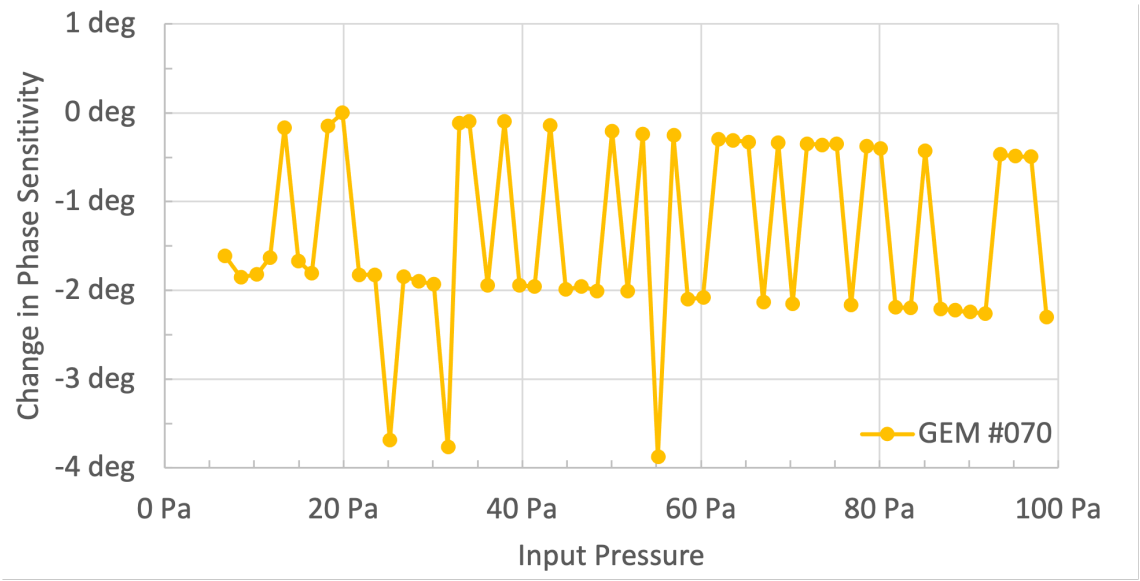

Figure 40 PSU Relative Phase Change vs Input Pressure: Gem Package

The above figures illustrate Gem package #070 has relatively small changes in amplitude sensitivity, less than +/- 0.25%, even with the higher SNR of lower amplitude observations, and differences in phase were within 4 degrees. As noted in the amplitude tests conducted in the isolation chamber, Section 3.3, grouping of phase changes may be an artifact of the timing algorithms of the digitizer utilized within the Gem package or GPS receiver locking. Note malfunctions of Gems #063 and #070 during the testing period prevented evaluation of these sensors.

The following table contains the data for the above plots.

Table 34 Relative Changes in Amplitude Sensitivity and Phase vs Input Amplitude: Gem #070

Pressure	Relative Amplitude	Relative Phase
8.51 Pa	0.26%	-1.85 deg
10.31 Pa	-0.15%	-1.82 deg
11.76 Pa	0.07%	-1.63 deg
13.39 Pa	-0.37%	-0.16 deg
14.96 Pa	-0.11%	-1.67 deg
16.42 Pa	0.40%	-1.81 deg
18.28 Pa	-0.11%	-0.15 deg
19.86 Pa	0.00%	0.00 deg
21.74 Pa	-0.04%	-1.82 deg
23.49 Pa	-0.11%	-1.82 deg
25.16 Pa	-0.18%	-3.68 deg
26.73 Pa	0.04%	-1.84 deg
28.40 Pa	-0.11%	-1.90 deg
30.13 Pa	-0.18%	-1.93 deg
31.69 Pa	-0.11%	-3.77 deg
32.96 Pa	-0.07%	-0.11 deg
34.07 Pa	-0.11%	-0.10 deg
36.10 Pa	-0.22%	-1.94 deg
37.98 Pa	-0.15%	-0.10 deg
39.68 Pa	-0.18%	-1.94 deg
41.39 Pa	-0.15%	-1.96 deg
43.12 Pa	-0.15%	-0.14 deg
44.87 Pa	-0.07%	-1.99 deg
46.61 Pa	-0.11%	-1.96 deg
48.38 Pa	-0.18%	-2.01 deg
50.03 Pa	-0.11%	-0.21 deg
51.80 Pa	-0.18%	-2.01 deg
53.49 Pa	-0.15%	-0.24 deg

Pressure	Relative Amplitude	Relative Phase
53.49 Pa	-0.15%	-0.24 deg
55.20 Pa	-0.15%	-3.87 deg
56.95 Pa	-0.18%	-0.25 deg
58.54 Pa	-0.11%	-2.10 deg
60.25 Pa	-0.15%	-2.08 deg
61.93 Pa	-0.15%	-0.30 deg
63.58 Pa	-0.11%	-0.31 deg
65.30 Pa	-0.18%	-0.33 deg
66.98 Pa	-0.15%	-2.13 deg
68.64 Pa	-0.11%	-0.34 deg
70.24 Pa	-0.15%	-2.15 deg
71.89 Pa	-0.15%	-0.35 deg
73.54 Pa	-0.15%	-0.36 deg
75.20 Pa	-0.18%	-0.35 deg
76.80 Pa	-0.18%	-2.17 deg
78.53 Pa	-0.22%	-0.38 deg
80.10 Pa	-0.15%	-0.40 deg
81.77 Pa	-0.18%	-2.19 deg
83.45 Pa	-0.18%	-2.20 deg
85.07 Pa	-0.18%	-0.43 deg
86.83 Pa	-0.18%	-2.21 deg
88.46 Pa	-0.18%	-2.23 deg
90.12 Pa	-0.18%	-2.24 deg
91.80 Pa	-0.22%	-2.26 deg
93.50 Pa	-0.22%	-0.47 deg
95.21 Pa	-0.22%	-0.49 deg
96.91 Pa	-0.22%	-0.49 deg
98.65 Pa	-0.22%	-2.30 deg

The two plots below illustrate the observations of relative changes in amplitude and phase for the Raspberry Boom packages.

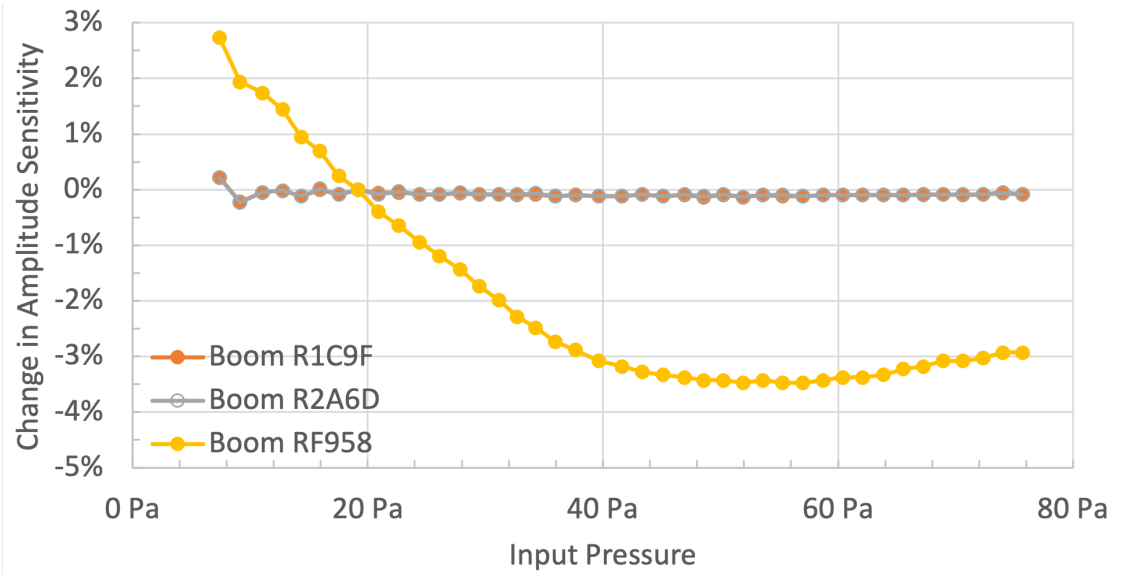

Figure 41 PSU Relative Change in Amplitude Sensitivity vs Input Pressure: Raspberry Boom Packages

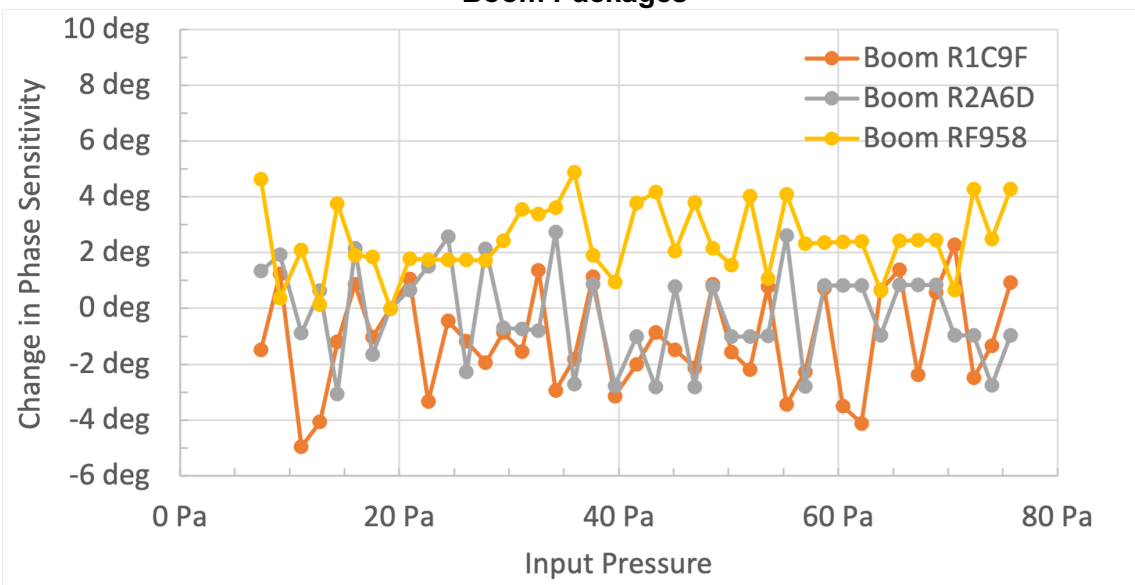

Figure 42 PSU Relative Phase Change vs Input Pressure: Raspberry Boom Packages

The Boom packages show a very stable amplitude sensitivity over the input pressure range evaluated, if omitting the performance of RF958, remaining withing 0.5% percent of the baseline amplitude sensitivity (Figure 41). Changes in phase compared to the baseline value remain within 6 degrees of the phase (Figure 42). As noted in the amplitude tests conducted in the isolation chamber, Section 0, grouping of phase errors may be an artifact of the timing algorithms of the digitizer and GPS receiver utilized within the Gem package.

The following table contains the data for the above plots.

Table 35 Relative Changes in Amplitude Sensitivity and Phase: Raspberry Boom Packages

	Boom R1C9F		Boom R2A6D		Boom RF958	
Pressure	Relative Amplitude	Relative Phase	Relative Amplitude	Relative Phase	Relative Amplitude	Relative Phase
7.38 Pa	0.21%	-1.48 deg	0.21%	1.35 deg	2.73%	4.63 deg
9.12 Pa	-0.21%	1.24 deg	-0.23%	1.92 deg	1.94%	0.36 deg
11.07 Pa	-0.05%	-4.96 deg	-0.05%	-0.88 deg	1.74%	2.10 deg
12.76 Pa	-0.02%	-4.06 deg	-0.02%	0.64 deg	1.44%	0.13 deg
14.35 Pa	-0.12%	-1.19 deg	-0.12%	-3.07 deg	0.94%	3.75 deg
15.95 Pa	0.00%	0.87 deg	0.02%	2.16 deg	0.70%	1.91 deg
17.54 Pa	-0.08%	-1.02 deg	-0.08%	-1.65 deg	0.25%	1.84 deg
19.18 Pa	0.00%	0.00 deg	0.00%	0.00 deg	0.00%	0.00 deg
20.93 Pa	-0.07%	1.05 deg	-0.08%	0.65 deg	-0.40%	1.79 deg
22.65 Pa	-0.05%	-3.34 deg	-0.03%	1.52 deg	-0.65%	1.74 deg
24.43 Pa	-0.08%	-0.45 deg	-0.08%	2.57 deg	-0.94%	1.75 deg
26.11 Pa	-0.08%	-1.18 deg	-0.08%	-2.27 deg	-1.19%	1.74 deg
27.86 Pa	-0.07%	-1.94 deg	-0.05%	2.14 deg	-1.44%	1.72 deg
29.48 Pa	-0.08%	-0.87 deg	-0.08%	-0.70 deg	-1.74%	2.43 deg
31.18 Pa	-0.08%	-1.55 deg	-0.08%	-0.74 deg	-1.99%	3.56 deg
32.69 Pa	-0.10%	1.37 deg	-0.08%	-0.79 deg	-2.29%	3.38 deg
34.26 Pa	-0.08%	-2.94 deg	-0.07%	2.73 deg	-2.48%	3.62 deg
35.93 Pa	-0.12%	-1.81 deg	-0.12%	-2.71 deg	-2.73%	4.88 deg
37.65 Pa	-0.10%	1.13 deg	-0.10%	0.87 deg	-2.88%	1.91 deg
39.66 Pa	-0.12%	-3.14 deg	-0.12%	-2.77 deg	-3.08%	0.96 deg
41.61 Pa	-0.12%	-2.01 deg	-0.12%	-1.00 deg	-3.18%	3.77 deg
43.36 Pa	-0.08%	-0.86 deg	-0.08%	-2.82 deg	-3.28%	4.18 deg
45.14 Pa	-0.12%	-1.48 deg	-0.12%	0.79 deg	-3.33%	2.06 deg
46.92 Pa	-0.10%	-2.12 deg	-0.08%	-2.81 deg	-3.38%	3.79 deg
48.56 Pa	-0.13%	0.86 deg	-0.12%	0.79 deg	-3.43%	2.15 deg
50.27 Pa	-0.10%	-1.57 deg	-0.08%	-1.01 deg	-3.43%	1.55 deg
51.94 Pa	-0.13%	-2.19 deg	-0.13%	-1.00 deg	-3.48%	4.02 deg
53.60 Pa	-0.10%	0.79 deg	-0.10%	-0.99 deg	-3.43%	1.08 deg
55.29 Pa	-0.12%	-3.44 deg	-0.10%	2.61 deg	-3.48%	4.10 deg
56.99 Pa	-0.12%	-2.27 deg	-0.12%	-2.80 deg	-3.48%	2.32 deg
58.73 Pa	-0.10%	0.72 deg	-0.10%	0.82 deg	-3.43%	2.36 deg
60.42 Pa	-0.10%	-3.50 deg	-0.10%	0.82 deg	-3.38%	2.38 deg
62.10 Pa	-0.10%	-4.12 deg	-0.10%	0.83 deg	-3.38%	2.40 deg
63.86 Pa	-0.10%	0.66 deg	-0.10%	-0.96 deg	-3.33%	0.63 deg
65.55 Pa	-0.10%	1.38 deg	-0.10%	0.84 deg	-3.23%	2.43 deg
67.25 Pa	-0.08%	-2.38 deg	-0.10%	0.85 deg	-3.18%	2.45 deg
68.91 Pa	-0.08%	0.57 deg	-0.08%	0.84 deg	-3.08%	2.45 deg
70.60 Pa	-0.10%	2.28 deg	-0.08%	-0.96 deg	-3.08%	0.66 deg
72.34 Pa	-0.08%	-2.49 deg	-0.08%	-0.96 deg	-3.03%	4.27 deg
74.00 Pa	-0.05%	-1.33 deg	-0.07%	-2.76 deg	-2.93%	2.48 deg
75.71 Pa	-0.08%	0.92 deg	-0.08%	-0.96 deg	-2.93%	4.28 deg

The following plot provides the relative change in amplitude sensitivity with input pressure for the Samsung S10 packages.

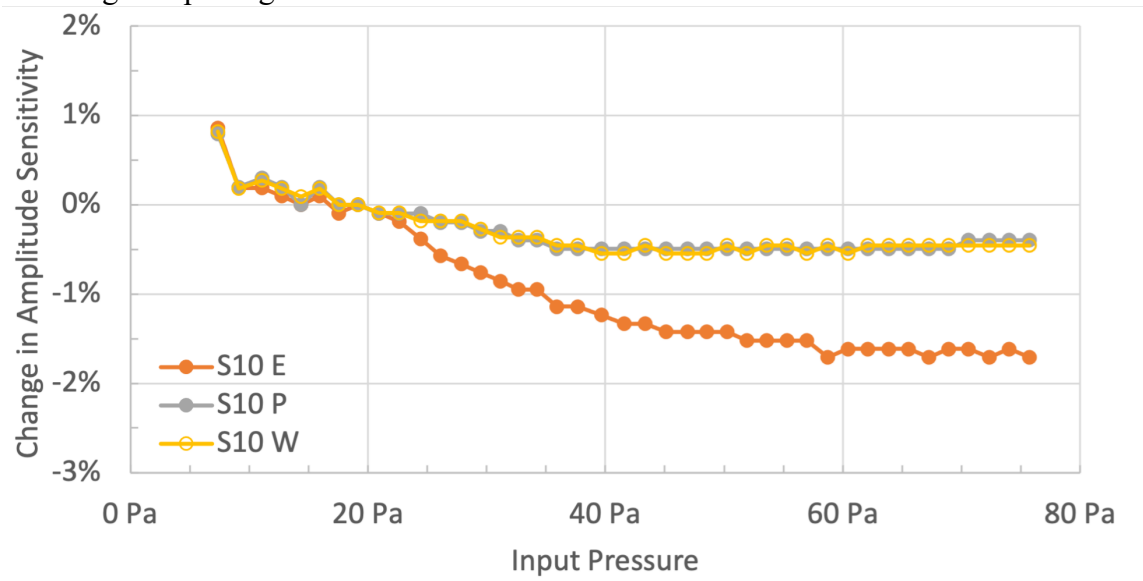

Figure 43 PSU Relative Change in Amplitude Sensitivity vs Input Pressure: S10 Packages

The Samsung S10 packages are observed to have very similar relative changes in amplitude sensitivity below 22 Pa input pressure. Above 22 Pa, package S10E shows over a 1.5% decrease in amplitude sensitivity compared to the baseline value. Packages S10 P and S10 W remain well within 1% of the baseline amplitude sensitivity. Phase results are not report as the Samsung S10 utilizes network timing, rather than GPS timing, and observed phase varied widely throughout the evaluations.

The following table contains the data for the above plots.

Table 36 Relative Changes in Amplitude Sensitivity vs Input Amplitude, S10 Packages

	Boom R1C9F	Boom R2A6D	Boom RF958
Pressure	Relative Amplitude	Relative Amplitude	Relative Amplitude
7.38 Pa	0.86%	0.79%	0.82%
9.12 Pa	0.19%	0.20%	0.18%
11.07 Pa	0.19%	0.30%	0.27%
12.76 Pa	0.10%	0.20%	0.18%
14.35 Pa	0.00%	0.00%	0.09%
15.95 Pa	0.10%	0.20%	0.18%
17.54 Pa	-0.10%	0.00%	0.00%
19.18 Pa	0.00%	0.00%	0.00%
20.93 Pa	-0.10%	-0.10%	-0.09%
22.65 Pa	-0.19%	-0.10%	-0.09%
24.43 Pa	-0.38%	-0.10%	-0.18%
26.11 Pa	-0.57%	-0.20%	-0.18%
27.86 Pa	-0.67%	-0.20%	-0.18%
29.48 Pa	-0.76%	-0.30%	-0.27%
31.18 Pa	-0.86%	-0.30%	-0.36%
32.69 Pa	-0.95%	-0.40%	-0.36%
34.26 Pa	-0.95%	-0.40%	-0.36%
35.93 Pa	-1.14%	-0.49%	-0.46%
37.65 Pa	-1.14%	-0.49%	-0.46%
39.66 Pa	-1.24%	-0.49%	-0.55%
41.61 Pa	-1.33%	-0.49%	-0.55%
43.36 Pa	-1.33%	-0.49%	-0.46%
45.14 Pa	-1.43%	-0.49%	-0.55%
46.92 Pa	-1.43%	-0.49%	-0.55%
48.56 Pa	-1.43%	-0.49%	-0.55%
50.27 Pa	-1.43%	-0.49%	-0.46%
51.94 Pa	-1.52%	-0.49%	-0.55%
53.60 Pa	-1.52%	-0.49%	-0.46%
55.29 Pa	-1.52%	-0.49%	-0.46%
56.99 Pa	-1.52%	-0.49%	-0.55%
58.73 Pa	-1.71%	-0.49%	-0.46%
60.42 Pa	-1.62%	-0.49%	-0.55%
62.10 Pa	-1.62%	-0.49%	-0.46%
63.86 Pa	-1.62%	-0.49%	-0.46%
65.55 Pa	-1.62%	-0.49%	-0.46%
67.25 Pa	-1.71%	-0.49%	-0.46%
68.91 Pa	-1.62%	-0.49%	-0.46%
70.60 Pa	-1.62%	-0.40%	-0.46%
72.34 Pa	-1.71%	-0.40%	-0.46%
74.00 Pa	-1.62%	-0.40%	-0.46%
75.71 Pa	-1.71%	-0.40%	-0.46%

The Camas microphones were observed to exhibit up to 6% relative change in amplitude sensitivity and less than 1 degree of change in phase. The InfraBSU sensors change in amplitude sensitivity varied little, less than 0.1%, while the change in phase of these sensors remained within 0.25 degrees of the baseline measurement. Gem package #070 was observed to have less

than 0.5% change in amplitude sensitivity up to the 98 Pa input pressure evaluated, while its change in phase did not exceed 4 degrees. The Raspberry Boom packages, discounting the performance of one outlier sensor, exhibited change in amplitude sensitivity and phase of no more than 0.5% and 6 degrees, respectively. Finally, the Samsung S10 packages provided a relative change in amplitude sensitivity that did not exceed 0.5% for two of the units and 2% for the remaining unit.

3.5 Self-Noise

Sensor self-noise is defined to be any deviation between the sensor output signal and the input signal that is unrelated to the linear time invariant (LTI) amplitude and phase response, DC offset, and harmonic distortion of the sensor. This definition of self-noise is consistent with established definitions of total noise used for digitizers (IEEE Std 1241-2010 section 9.1). The measurement unit is the decibel (dB) relative to 1 Pa^2/Hz.

3.5.1 Measurand

Static self-noise expressed in power spectral density in units of dB relative to 1 Pa^2/Hz over the defined frequencies.

3.5.2 Configuration

The infrasound sensors under test are placed inside of a pressure isolation chamber. The isolation chamber serves to attenuate any external ambient variations in temperature or pressure. In addition, the sensors were capped to further attenuate any input signal and to eliminate any noise from convective air currents within the chamber.

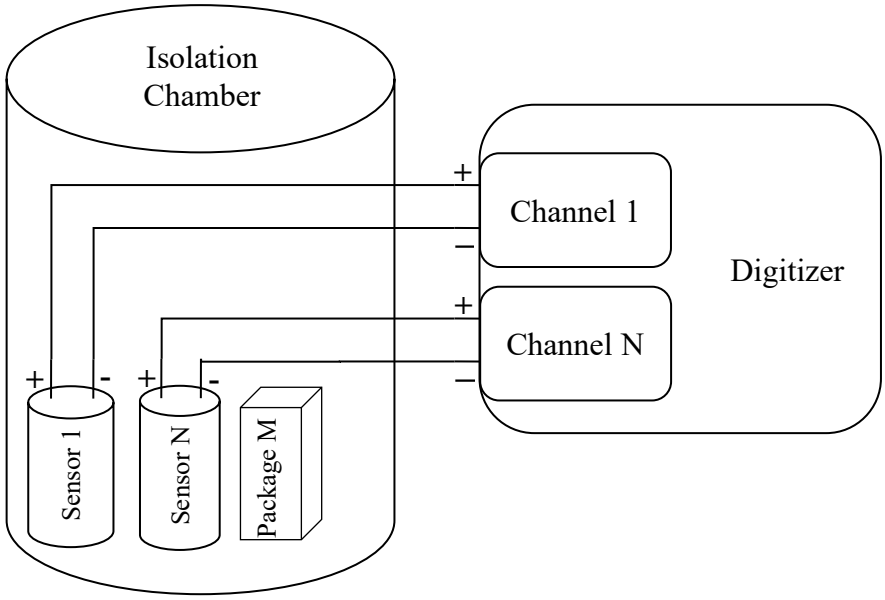

Figure 44 Self-Noise Configuration Diagram

The following table documents the testbed equipment during the test.

Table 37 Self-Noise Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
Digitizer	Guralp Affinity	405A5B	40 Hz, 1x gain, 40 Vpp
Infrasound Chamber	SNL	1400 L Chamber	21.4 C +/- 0.3 C, 817 hPa +/- 1 hPa, and 45% Rh +/- 0.3%

The digitizer records the output of the reference sensor and the sensors under test simultaneously, while the packages record independently on their internal digitizers.

The segment of data is selected to be used once the temperature and pressure conditions within the isolation chamber have stabilized.

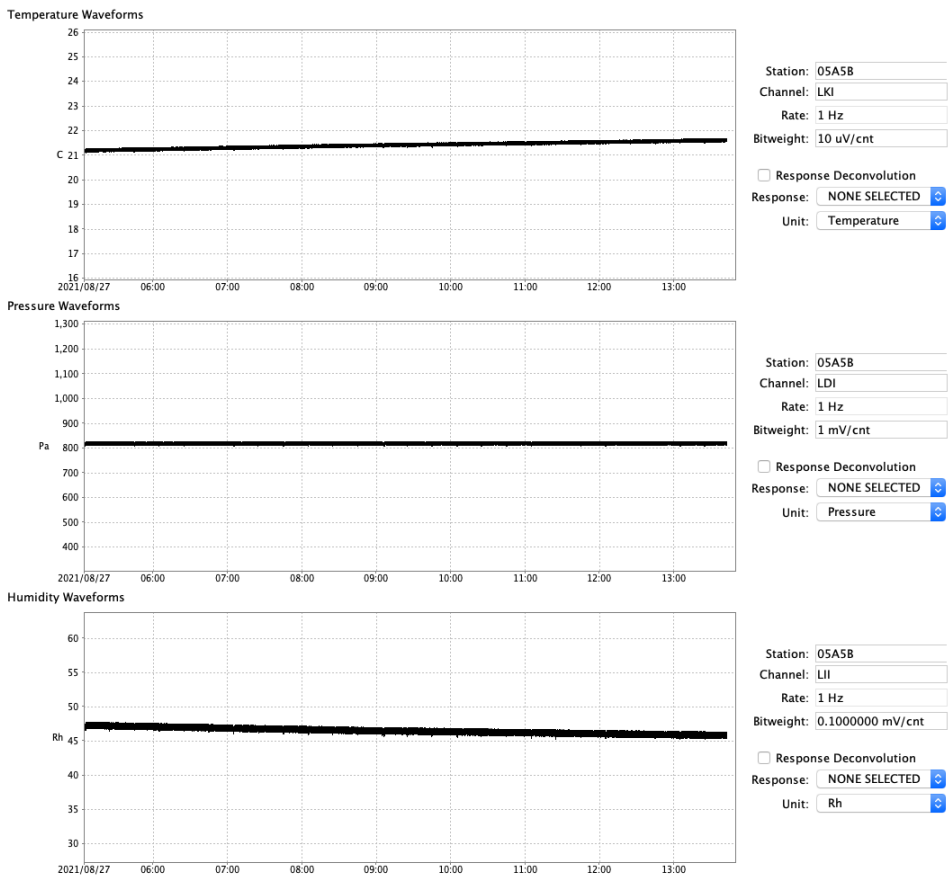

Figure 45 Self-Noise Environmental Conditions

Environmental conditions over the period of self-noise from 2021/08/27 05:00 to 13:00, as shown in the above plot of the recorded temperature, pressure, and relative humidity were 21.4 C +/- 0.3 C, 817 hPa +/- 1 hPa, and 45% Rh +/- 0.3%.

3.5.3 Analysis

The measured sensitivities and frequency response shape are applied to the collected data:

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

The PSD is computed from the time series (Merchant, 2011) from the time series using a 32k-sample Hann window. The window length and data duration were chosen such that there were several points below the lower limit of the evaluation passband of 0.01 Hz and the 95% confidence interval or approximately 0.5 dB. The resulting 95% confidence interval was determined to be 0.589 dB.

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

Over frequencies (in Hertz):

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

If necessary, a multi-channel coherence technique (Sleeman, 2006; Merchant, 2011) is applied to further remove any coherent portion of the PSD.

In addition, the total rms noise over the application passband is computed:

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

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

3.5.4 Results

The following figures show representative waveform time series for recordings made of sensors under test. The window regions in red indicate the segment of data used for analysis.

The self-noise data was collected overnight while conditions were quiet. The sensor inputs were capped, or the sensors were placed in sealed PVC containers, then placed within the 1400L Infrasound Chamber. An 8-hour window of time was selected when environmental conditions were stable in order to obtain the best measurement of the sensor self-noise.

Note, self-noise data for the Camas microphones are not available due to an issue with data collection.

3.5.4.1 InfraBSU Sensors

The following figure contains plots of the time series used to measure the self-noise of the InfraBSU sensors.

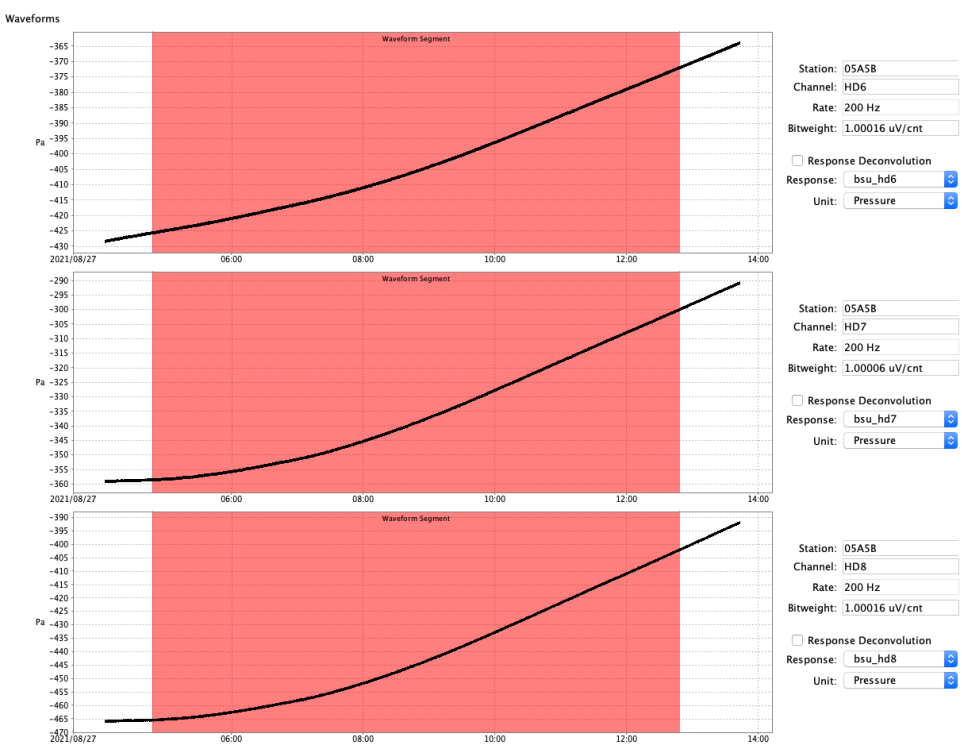

Figure 46 Self-Noise Time Series, InfraBSU Sensors

The InfraBSU sensors were placed in a PVC sealed container. The InfraBSU sensor passband, evaluated in section 3.8, clearly shows the sensors have a low frequency corner of approximately 100 seconds. The observed rise in pressure over approximately 10 hours of data in the above figure may be an artifact of powering the sensors with 9 volt alkaline batteries, as opposed to a lab power supply providing a stable 9 VDC. The effects of varying input voltage of the power source on sensor performance was not within the scope of this evaluation.

The power spectra plot below shows the self-noise spectra corresponding to the time series shown earlier. The respective self-noise spectra are plotted alongside the Bowman Low Noise Model (LNM) in green.

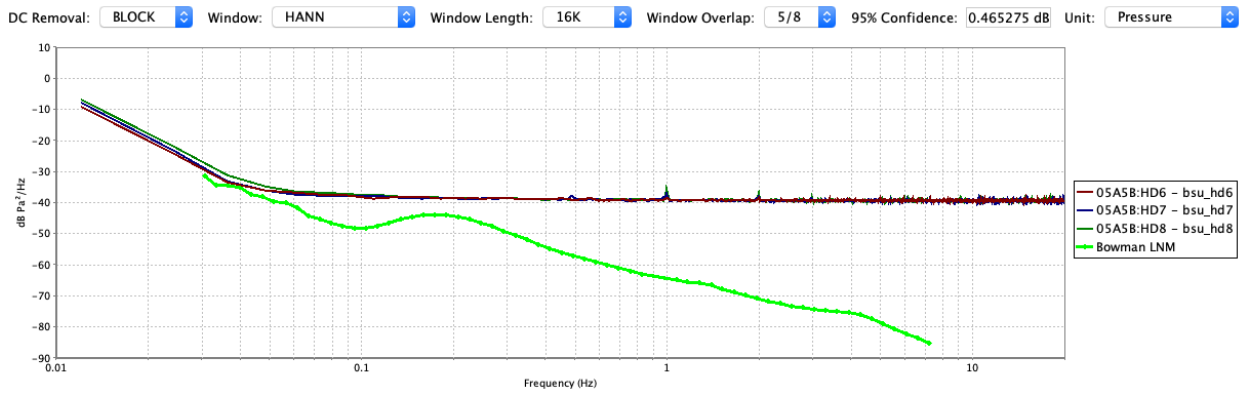

Figure 47 Self-Noise Power Spectra: InfraBSU sensors

Table 38 contains self-noise levels in dB relative to 1 Pa^2/Hz as well as the total combined uncertainty.

Table 38 Static Self-Noise Power Spectra: InfraBSU Sensors

Frequency	InfraBSU #400	InfraBSU #422	InfraBSU #424	Total Combined Uncertainty (k=2)
0.010 Hz	-9.39 dB	-8.12 dB	-7.27 dB	12.92 dB
0.013 Hz	-9.39 dB	-8.12 dB	-7.27 dB	11.63 dB
0.016 Hz	-9.39 dB	-8.12 dB	-7.27 dB	10.34 dB
0.020 Hz	-24.61 dB	-23.50 dB	-22.21 dB	9.05 dB
0.025 Hz	-24.61 dB	-23.50 dB	-22.21 dB	7.76 dB
0.032 Hz	-33.68 dB	-33.34 dB	-31.53 dB	6.47 dB
0.040 Hz	-33.68 dB	-33.34 dB	-31.53 dB	5.19 dB
0.050 Hz	-36.30 dB	-36.23 dB	-35.13 dB	4.29 dB
0.063 Hz	-36.30 dB	-36.23 dB	-35.13 dB	3.65 dB
0.080 Hz	-37.73 dB	-38.05 dB	-37.40 dB	3.14 dB
0.100 Hz	-38.22 dB	-38.05 dB	-37.64 dB	2.88 dB
0.125 Hz	-38.68 dB	-38.14 dB	-37.98 dB	2.63 dB
0.160 Hz	-38.44 dB	-38.59 dB	-38.34 dB	2.38 dB
0.200 Hz	-38.78 dB	-38.65 dB	-38.54 dB	2.13 dB
0.250 Hz	-38.81 dB	-38.83 dB	-38.75 dB	1.88 dB
0.315 Hz	-38.89 dB	-38.89 dB	-38.80 dB	1.63 dB
0.400 Hz	-39.05 dB	-39.08 dB	-39.02 dB	1.39 dB
0.500 Hz	-39.04 dB	-39.13 dB	-39.03 dB	1.15 dB
0.630 Hz	-39.33 dB	-39.26 dB	-39.08 dB	0.93 dB
0.800 Hz	-39.30 dB	-39.35 dB	-39.14 dB	0.73 dB
1.000 Hz	-39.26 dB	-39.24 dB	-39.20 dB	0.57 dB
1.250 Hz	-39.32 dB	-39.33 dB	-39.31 dB	0.57 dB
1.600 Hz	-39.34 dB	-39.42 dB	-39.26 dB	0.57 dB
2.000 Hz	-39.30 dB	-39.45 dB	-39.30 dB	0.57 dB
2.500 Hz	-39.38 dB	-39.44 dB	-39.31 dB	0.57 dB
3.150 Hz	-39.34 dB	-39.41 dB	-39.38 dB	0.57 dB
4.000 Hz	-39.35 dB	-39.52 dB	-39.32 dB	0.57 dB
5.000 Hz	-39.41 dB	-39.53 dB	-39.38 dB	0.57 dB
6.300 Hz	-39.39 dB	-39.48 dB	-39.38 dB	0.57 dB
8.000 Hz	-39.39 dB	-39.53 dB	-39.41 dB	0.57 dB
10.000 Hz	-39.45 dB	-39.53 dB	-39.39 dB	1.29 dB
12.500 Hz	-39.42 dB	-39.51 dB	-39.41 dB	5.80 dB
16.000 Hz	-39.40 dB	-39.50 dB	-39.39 dB	17.33 dB
20.000 Hz	-39.36 dB	-39.55 dB	-39.41 dB	23.24 dB

The following table contains the integrated RMS self-noise levels over the 0.02 – 4 Hz application passband.

Table 39 Self Noise RMS: InfraBSU Sensors

Sensor	20 mHz - 4 Hz
InfraBSU #400	0.023 Pa rms
InfraBSU #422	0.023 Pa rms
InfraBSU #424	0.024 Pa rms

The InfraBSU sensors provided a consistent 0.023 Pa rms to 0.024 Pa rms over 0.02 Hz to 4 Hz across the three sensors evaluated. While the range of frequencies is different than that provided in the specifications, the self noise is significantly higher than the 0.00562 Pa rms over 0.05 Hz to 20 Hz listed in the specifications.

3.5.4.2 Gem Infrasound Logger Package

The following figure contains plots of the time series used to measure the self-noise of the Gem packages.

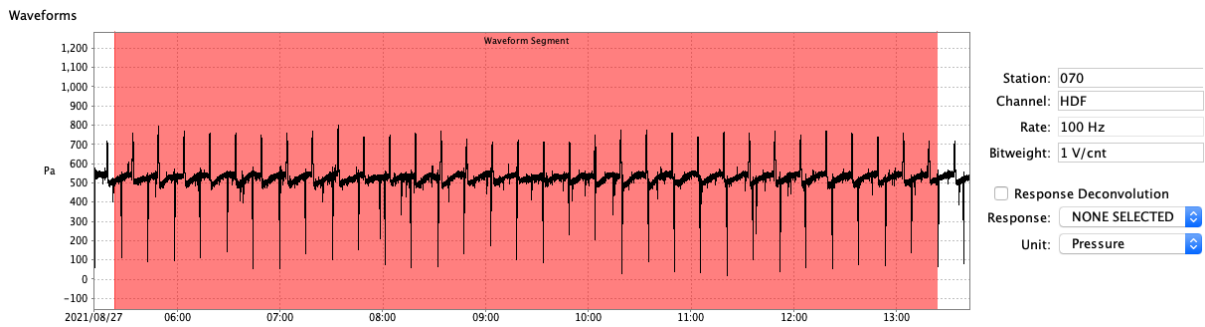

Figure 48 Self-Noise Time Series: Gem Package #070

The power spectra plot below shows the self-noise spectra corresponding to the time series shown earlier. The respective self-noise spectra are plotted alongside the Bowman LNM in green.

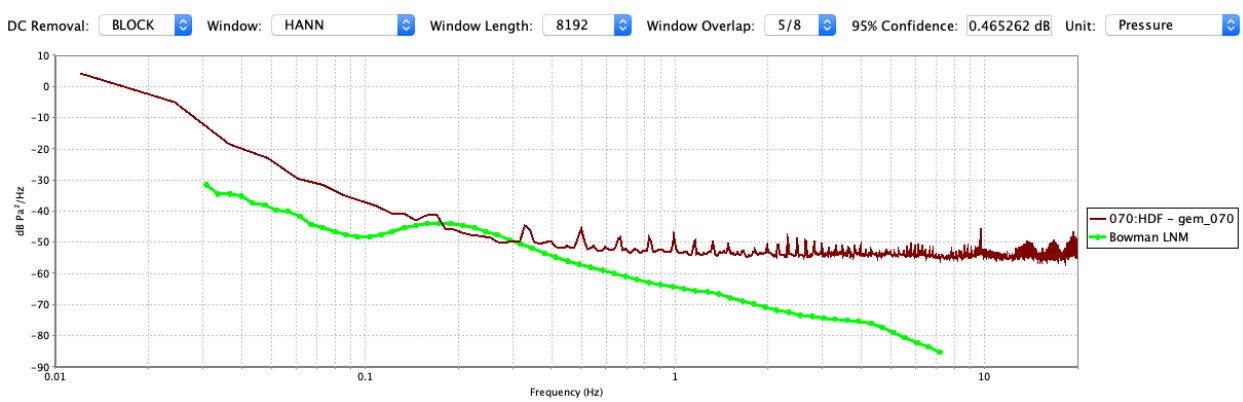

Figure 49 Self-Noise Power Spectra, Gem Package #070

Notice the transients in the time-series occur with regularity, four times an hour. The GPS receiver comes out of standby mode, every 15 minutes to slew timing as necessary. It is feasible we are observing power-related transients, rather than actual pressure transients. Recall the Gem sensor is powered by a 9 volt battery, rather than a laboratory power supply.

Table 40 contains self-noise levels in dB relative to 1 Pa^2/Hz as well as the total combined uncertainty.

Table 40 Static Self-Noise Power Spectra: Gem Package #070

Frequency	Self-Noise	Total Combined Uncertainty (k=2)	Frequency	Self-Noise	Total Combined Uncertainty (k=2)
0.010 Hz	3.94 dB	12.92 dB	0.500 Hz	-51.46 dB	1.20 dB
0.013 Hz	3.94 dB	11.63 dB	0.630 Hz	-52.52 dB	0.99 dB
0.016 Hz	3.94 dB	10.35 dB	0.800 Hz	-53.03 dB	0.80 dB
0.020 Hz	-5.37 dB	9.06 dB	1.000 Hz	-53.23 dB	0.66 dB
0.025 Hz	-5.37 dB	7.77 dB	1.250 Hz	-53.77 dB	0.66 dB
0.032 Hz	-18.71 dB	6.48 dB	1.600 Hz	-53.85 dB	0.66 dB
0.040 Hz	-18.71 dB	5.20 dB	2.000 Hz	-53.79 dB	0.66 dB
0.050 Hz	-23.32 dB	4.30 dB	2.500 Hz	-54.37 dB	0.66 dB
0.063 Hz	-23.32 dB	3.66 dB	3.150 Hz	-54.04 dB	0.66 dB
0.080 Hz	-35.11 dB	3.16 dB	4.000 Hz	-54.10 dB	0.66 dB
0.100 Hz	-37.14 dB	2.90 dB	5.000 Hz	-54.20 dB	0.67 dB
0.125 Hz	-40.79 dB	2.65 dB	6.300 Hz	-54.45 dB	0.68 dB
0.160 Hz	-41.47 dB	2.40 dB	8.000 Hz	-55.00 dB	0.70 dB
0.200 Hz	-46.16 dB	2.15 dB	10.000 Hz	-54.57 dB	0.71 dB
0.250 Hz	-48.28 dB	1.91 dB	12.500 Hz	-55.17 dB	0.73 dB
0.315 Hz	-49.93 dB	1.66 dB	16.000 Hz	-55.27 dB	0.73 dB
0.400 Hz	-50.67 dB	1.43 dB	20.000 Hz	-55.32 dB	0.76 dB

The following table contains the integrated rms self-noise levels over the 0.02 – 4 Hz application passband.

Table 41 Self Noise RMS: Gem Package #070

20 mHz - 4 Hz
0.062 Pa rms

3.5.4.3 Raspberry Boom Package

The following figure contains plots of the time series used to measure the self-noise of the Raspberry Boom packages.

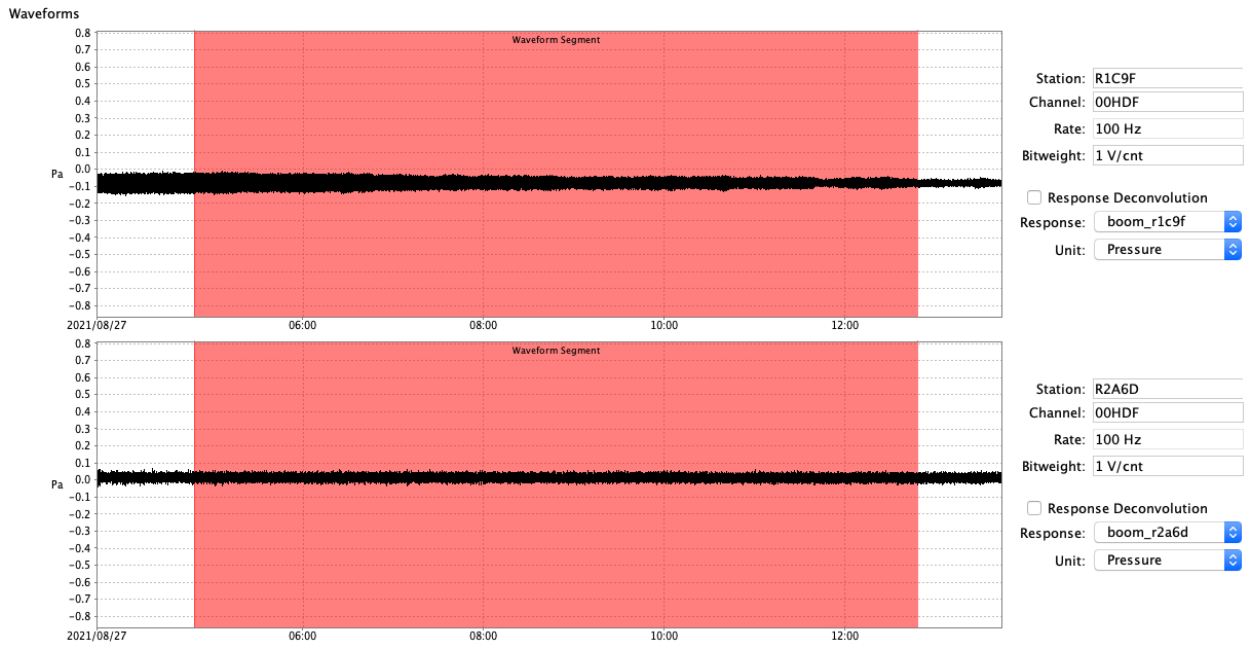

Figure 50 Self-Noise Time Series: Raspberry Boom Packages

The power spectra plot below shows the self-noise spectra corresponding to the time series shown earlier. The respective self-noise spectra are plotted alongside the Bowman LNM in green.

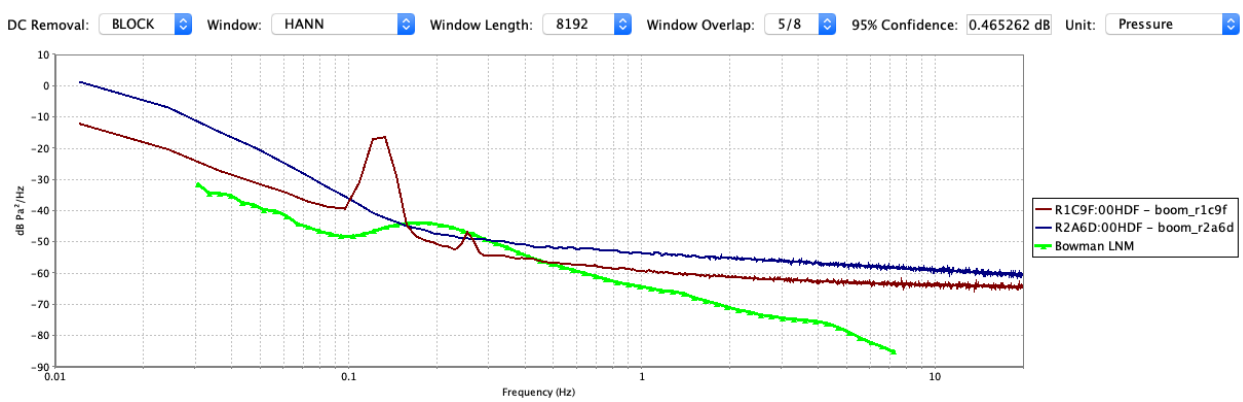

Figure 51 Self-Noise Power Spectra, Raspberry Boom Packages

The time-series and power spectra plotted in the above figures illustrate the variations in self-noise of packages R1C9F and R2A6D. Difficulties with power supplied to package RF958 did not allow for continuous recording during this time period, therefore not results are not available.

Table 42 contains self-noise levels in dB relative to 1 Pa^2/Hz as well as the total combined uncertainty.

Table 42 Static Self-Noise Power Spectra, Raspberry Boom Packages

Frequency	Boom R1C9F	Boom R2A6D	Total Combined Uncertainty (k=2)
0.010 Hz	-12.29 dB	1.15 dB	12.92 dB
0.013 Hz	-12.29 dB	1.15 dB	11.63 dB
0.016 Hz	-12.29 dB	1.15 dB	10.35 dB
0.020 Hz	-20.51 dB	-7.10 dB	9.06 dB
0.025 Hz	-20.51 dB	-7.10 dB	7.77 dB
0.032 Hz	-27.39 dB	-15.16 dB	6.48 dB
0.040 Hz	-27.39 dB	-15.16 dB	5.20 dB
0.050 Hz	-31.47 dB	-20.26 dB	4.30 dB
0.063 Hz	-31.47 dB	-20.26 dB	3.66 dB
0.080 Hz	-39.09 dB	-32.72 dB	3.16 dB
0.100 Hz	-39.09 dB	-35.72 dB	2.90 dB
0.125 Hz	-17.27 dB	-40.78 dB	2.65 dB
0.160 Hz	-44.97 dB	-45.19 dB	2.40 dB
0.200 Hz	-50.50 dB	-47.32 dB	2.15 dB
0.250 Hz	-51.21 dB	-49.05 dB	1.91 dB
0.315 Hz	-54.59 dB	-49.93 dB	1.66 dB
0.400 Hz	-55.52 dB	-51.22 dB	1.43 dB
0.500 Hz	-56.85 dB	-52.11 dB	1.20 dB
0.630 Hz	-57.62 dB	-52.38 dB	0.99 dB
0.800 Hz	-58.62 dB	-53.13 dB	0.80 dB
1.000 Hz	-59.50 dB	-53.85 dB	0.66 dB
1.250 Hz	-60.15 dB	-54.39 dB	0.66 dB
1.600 Hz	-60.81 dB	-55.02 dB	0.66 dB
2.000 Hz	-61.39 dB	-55.43 dB	0.66 dB
2.500 Hz	-61.98 dB	-55.99 dB	0.66 dB
3.150 Hz	-62.31 dB	-56.51 dB	0.66 dB
4.000 Hz	-62.79 dB	-57.12 dB	0.66 dB
5.000 Hz	-63.17 dB	-57.66 dB	0.67 dB
6.300 Hz	-63.47 dB	-58.19 dB	0.68 dB
8.000 Hz	-63.76 dB	-58.72 dB	0.70 dB
10.000 Hz	-63.99 dB	-59.22 dB	0.71 dB
12.500 Hz	-64.18 dB	-59.70 dB	0.73 dB
16.000 Hz	-64.41 dB	-60.28 dB	0.73 dB
20.000 Hz	-64.67 dB	-60.83 dB	0.76 dB

The following table contains the integrated rms self-noise levels over the 0.02 – 4 Hz application passband.

Table 43 Self Noise RMS: Raspberry Boom Packages

Package	20 mHz - 4 Hz
R1C9F	0.026 Pa rms
R2A6D	0.054 Pa rms

3.5.4.4 Samsung S10 Package

The following figure contains plots of the time series used to measure the self-noise of the Samsung S10 smartphones.

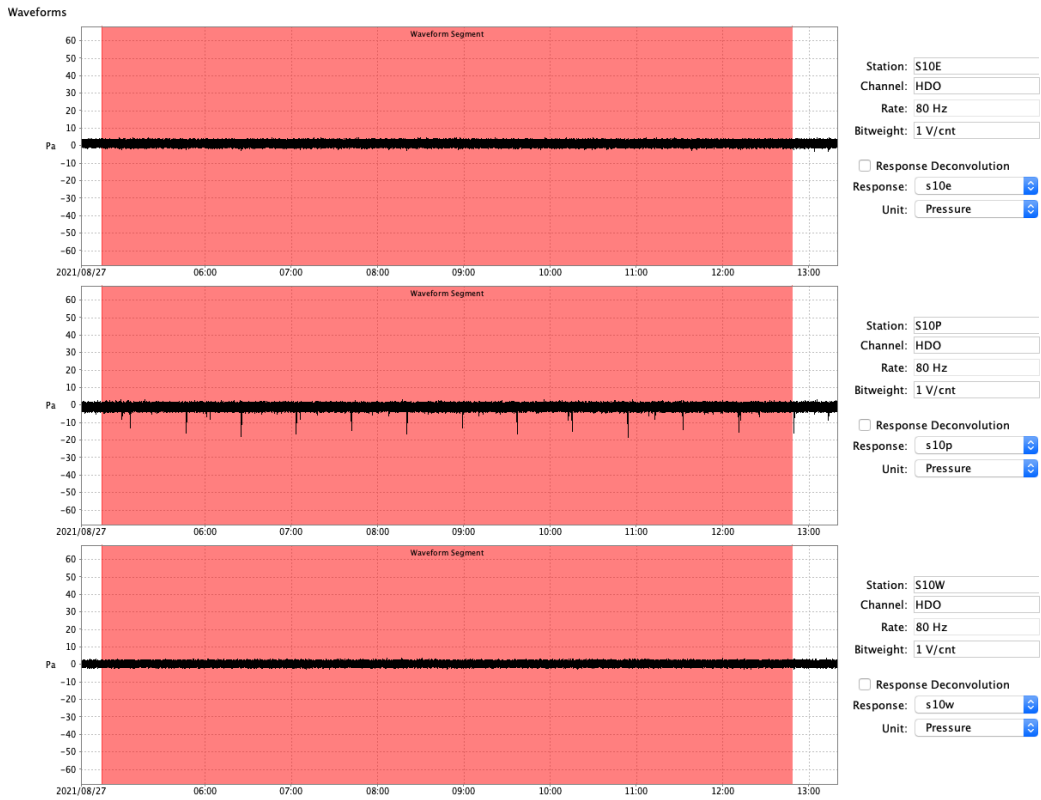

Figure 52 Self-Noise Time Series, Samsung S10

The power spectra plot below shows the self-noise spectra corresponding to the time series shown above. The respective self-noise spectra are plotted alongside the Bowman LNM in green. Given the narrow range of frequencies the Samsung S10 has exhibited response, as measured in section 3.7, self-noise is provided over the 0.158 Hz to 15.8 Hz frequency range.

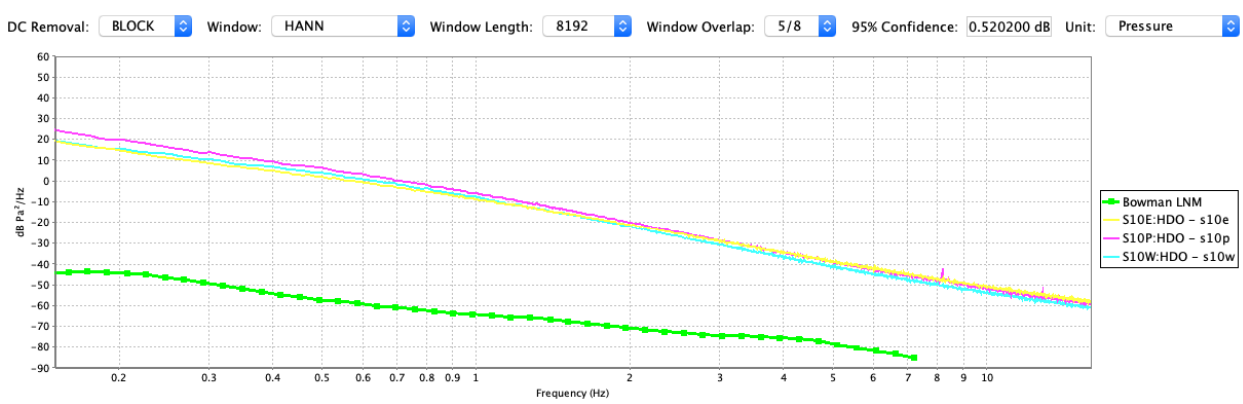

Figure 53 Self-Noise Power Spectra, Samsung S10 Packages

Table 44 contains self-noise levels in dB relative to 1 Pa^2/Hz as well as the total combined uncertainty.

Table 44 Static Self-Noise Power Spectra: Samsung S10 Packages

Frequency	S10 E	S10 P	S10 W	Total Combined Uncertainty (k=2)
0.160 Hz	17.88 dB	23.46 dB	18.45 dB	12.92 dB
0.200 Hz	14.98 dB	19.46 dB	15.05 dB	11.63 dB
0.250 Hz	10.60 dB	15.67 dB	12.38 dB	10.35 dB
0.315 Hz	7.73 dB	12.85 dB	9.56 dB	9.06 dB
0.400 Hz	4.78 dB	9.05 dB	6.52 dB	7.77 dB
0.500 Hz	1.71 dB	6.07 dB	3.73 dB	6.48 dB
0.630 Hz	-1.85 dB	2.01 dB	-0.12 dB	5.20 dB
0.800 Hz	-5.53 dB	-2.08 dB	-4.04 dB	4.30 dB
1.000 Hz	-8.75 dB	-6.04 dB	-7.84 dB	3.66 dB
1.250 Hz	-12.55 dB	-10.59 dB	-12.39 dB	3.16 dB
1.600 Hz	-17.00 dB	-15.38 dB	-17.06 dB	2.90 dB
2.000 Hz	-21.26 dB	-20.14 dB	-21.98 dB	2.65 dB
2.500 Hz	-25.52 dB	-24.93 dB	-27.04 dB	2.40 dB
3.150 Hz	-30.20 dB	-30.03 dB	-31.93 dB	2.15 dB
4.000 Hz	-34.80 dB	-34.92 dB	-37.10 dB	1.91 dB
5.000 Hz	-39.24 dB	-39.48 dB	-41.58 dB	1.66 dB
6.300 Hz	-43.38 dB	-43.86 dB	-45.87 dB	1.43 dB
8.000 Hz	-47.47 dB	-47.85 dB	-50.20 dB	1.20 dB
10.000 Hz	-51.22 dB	-51.85 dB	-54.06 dB	0.99 dB
12.500 Hz	-54.64 dB	-55.61 dB	-57.51 dB	0.80 dB
16.000 Hz	-58.22 dB	-59.41 dB	-61.14 dB	0.66 dB

The following table contains the integrated rms self-noise levels over the 0.158 Hz – 15.8 Hz, the frequencies over which the sensor had a measurable response within the limitations of the frequency response evaluation, 3.7, as the sensor has little to no overlap of its passband with the application passband.

Table 45 Self Noise RMS: Samsung S10 Packages

Smartphone	0.158 Hz - 15.8 Hz
S10 E	1.95018 Pa rms
S10 P	3.43991 Pa rms
S10 W	2.20960 Pa rms

The InfraBSU sensors provided a consistent 0.023 Pa rms to 0.024 Pa rms self-noise over 0.02 Hz to 4 Hz across the three sensors evaluated. The Gem #070, over the same frequencies, exhibited a self-noise of 0.062 Pa rms. The two Raspberry Booms evaluated have self-noise values ranging from as low as 0.026 Pa rms to as high as 0.054 Pa rms over the same frequency band. The Samsung S10 smartphones were observed to have self-noise ranging from 1.95 Pa rms to 3.44 Pa rms. Given the narrow range of frequencies the Samsung S10 has exhibited response in this evaluation self-noise is provided over the 0.158 Hz to 15.8 Hz frequency range.

3.6 Dynamic Range

Dynamic Range is defined to be the ratio between the power of the largest and smallest signals that may be output from the sensor.

3.6.1 Measurand

The Dynamic Range is measured in dB as 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 output of the sensor. The smallest signal is defined to have power equal to the self-noise of the sensor. 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).

3.6.2 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 of a maximum of 0.575 V output for the InfraBSU sensors, scaled by each sensor's sensitivity determine in section 3.2 Sensitivity. The value for the smallest signal comes from the evaluated sensor self-noise determined in section 3.5.
.

3.6.3 Analysis

The dynamic range over a given passband 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 frequency passband over which the noise is integrated should be selected to be consistent with the application passband.

3.6.4 Results

The following table contains the dynamic range levels over the 0.02 – 4 Hz application passband using the measured amplitude levels that the sensitivity stayed linear to within 5% of nominal, and self-noise over 0.02 Hz – 4 Hz.

Dynamic range is not provided for the Camas microphone, as there were no self-noise data, specifications or measurements for the maximum output voltage of the sensor available.

The Gem packages utilized in this evaluation have sensitivities that differ from specifications. During this evaluation we were not able to determine the packages' full scale output, therefore no dynamic range is provided for the Gem sensors.

Dynamic range is not provided for the Samsung S10 smartphones as no technical specifications are available, nor were we able to determine the sensors full scale output.

Table 46 Dynamic Range, InfraBSU Sensors

	Linear full scale	Measured self-noise over 20 mHz – 4 Hz	Dynamic range over 20 mHz - 4 Hz
InfraBSU #400	124.5 Pa	0.022 Pa rms	71.91 dB
InfraBSU #422	124.5 Pa	0.022 Pa rms	71.84 dB
InfraBSU #424	124.5 Pa	0.022 Pa rms	71.55 dB

The InfraBSU sensors have between 71.55 dB and 71.91 dB of dynamic range over 0.02 Hz to 4 Hz.

Table 47 Dynamic Range, Raspberry Boom Packages

	Linear full scale*	Measured self-noise over 20 mHz – 4 Hz	Dynamic range over 20 mHz - 4 Hz
IR1C9F	125 Pa	0.026 Pa rms	70.53 dB
R2A6D	125 Pa	0.054 Pa rms	64.57 dB

*Linear full scale calculated from the manufacturer specifications: transducer full scale of 125 Pa x sensitivity of 56000 counts/Pa, or 700000 counts.

The Raspberry Boom packages have between 64.57 dB and 70.53 dB of dynamic range over 0.02 Hz to 4 Hz.

3.7 Frequency Response

The sensor frequency response is defined as being the linear time-invariant (LTI) change in the sensor output signal amplitude and phase relative to an input pressure signal.

3.7.1 Measurand

Response including the amplitude expressed in V/Pa and the phase expressed in degrees over the defined frequencies.

3.7.2 Configuration

The infrasound sensor under test and a reference sensor with known response characteristics are placed inside of a pressure isolation chamber. The isolation chamber serves to attenuate any external ambient variations in temperature or pressure and provide air coupling between the sensor inlets.

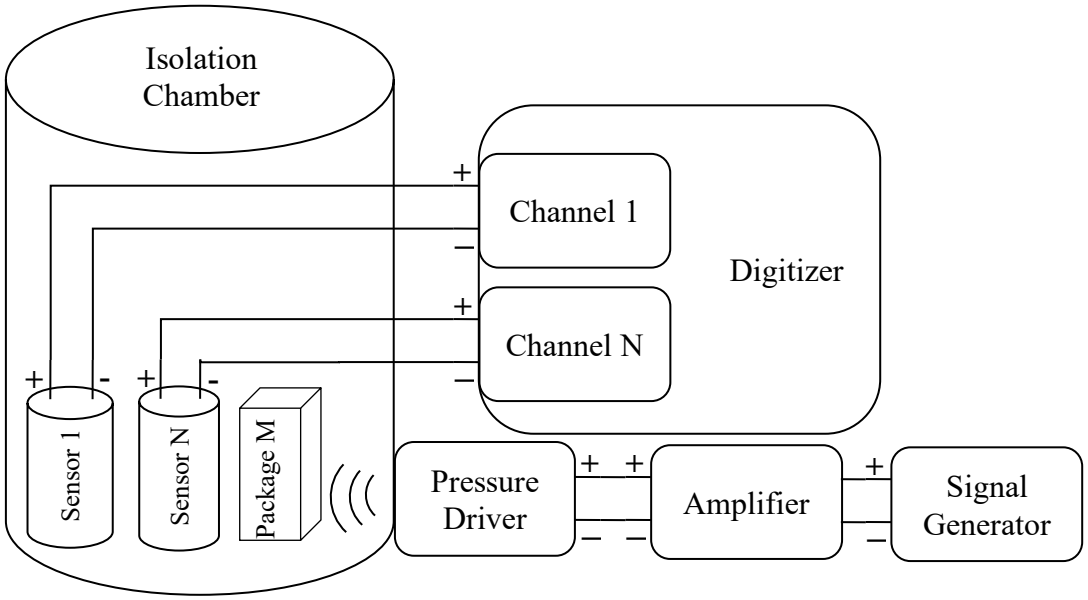

Figure 54 Frequency Response Configuration Diagram

A pressure driver is attached to the isolation chamber. The pressure driver is driven with a sinusoid from a signal generator and amplifier. The pressure driver serves to generate a pressure wave with characteristics defined by the signal generator. The pressure inlets of reference sensors and sensors and packages under test are exposed to this pressure wave.

The digitizer records the output of the reference sensor and the sensors under test simultaneously, while the packages record independently on their internal digitizers. The recorded output from the reference sensor and the sensor/package-under-test are then compared. The Setra 278 microbarometer was used as a reference for frequencies below 1 Hz and the B&K

4193 microphone was used as a reference for frequencies at 1 Hz and above. Combined, the two references span the 0.01 to 20 Hz evaluation passband.

This test was performed with a set of tones that span the evaluation frequencies in a randomized order.

The following table documents the testbed equipment utilized and the environmental conditions at the time of the test.

Table 48 Frequency Response Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
Reference Sensor, < 1 Hz	Setra 278	6837528	0.0833997 mV/Pa
Reference Sensor, >= 1 Hz	B&K 4193	2812287	2.15 mV/Pa at 1 Hz, 1000 hPa, 23 C
Infrasound Chamber	SNL	1400 L Chamber	1002 hPa, +/- 5 hPa 21.8 C, +/- 1 C 15 % Rh, +/- 1 % Rh
Digitizer	Guralp Affinity	405A5B	200 Hz, 1x gain 40 Vpp
Voltage Signal Source	Stanford Research Systems DS360	N/A	0.01 – 20 Hz, 0.4 Vp sinusoid
Voltage Amplifier	AE Techron 7224p	N/A	20x gain DC Coupled Amplifier
Pressure Driver	JL Audio 10w7ae	N/A	N/A

3.7.3 Analysis

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

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

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

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

The sensor amplitude sensitivity in Volts / Pascal is computed:

$$Sensitivity = \frac{V_{test}}{P_{ref}}$$

The sensor phase sensitivity in degrees is computed:

$$Phase = \theta_{test} - \theta_{ref}$$

3.7.4 Results

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

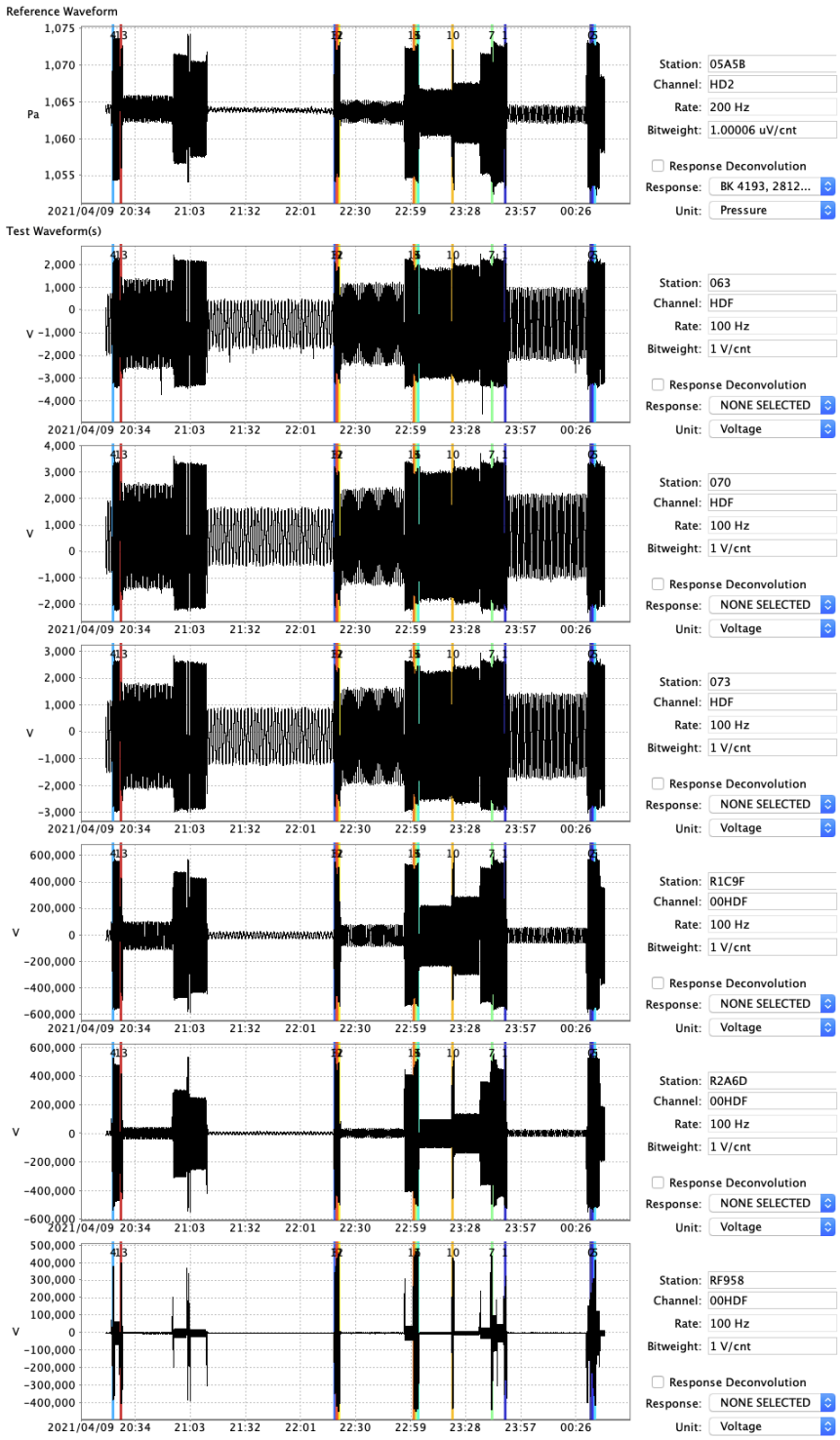

Figure 55 Frequency Response, Representative Time Series

The following plots show the amplitude and phase responses that were measured for the Camas microphones.

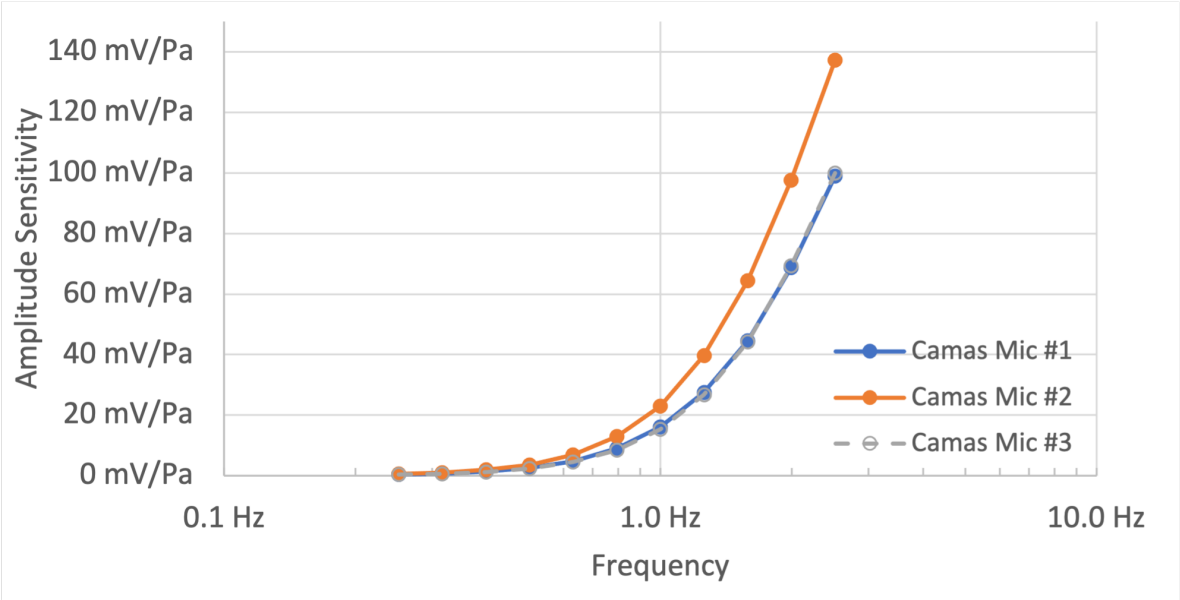

Figure 56 Amplitude Response: Camas Microphones

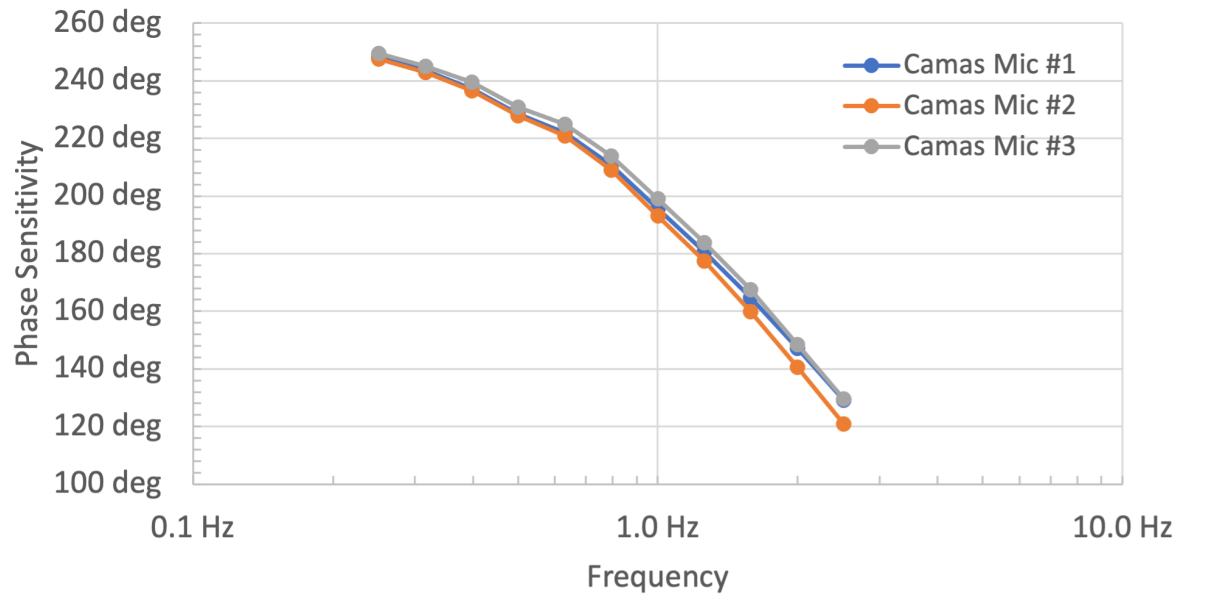

Figure 57 Phase Response: Camas Microphones

The response test illustrates that the Camas microphones passband spans frequencies higher than those evaluated, with a low frequency corner well above 1 Hz. As with most other tests described in this report, the frequency response test for all sensors was conducted simultaneously as tailoring each test to specific sensors was beyond the scope of the project. The response plots shown in Figure 58 and Figure 59 are limited on the high frequency end by the sensor clipping due to the approximate 10 Pa signal and on the low end of the spectrum by low SNR at reduced amplitude sensitivity. At the highest frequency evaluated, 2.5 Hz, amplitude sensitivity between

Camas microphones varies as much as 38% between the Camas #1 and #2 – a difference well above the estimated uncertainty. Phase response varied well beyond the estimated uncertainty, for Camas #1 and #2, as much as 8.4 degrees at 2.5 Hz.

The following tables contains the values used to generate Figure 56 and Figure 57.

Table 49 Amplitude Response: Camas Microphones

Frequency	Camas #1	Camas #2	Camas #3	Combined Uncertainty (k=2)
0.251 Hz	0.35 mV/Pa	0.50 mV/Pa	0.32 mV/Pa	0.78%
0.316 Hz	0.67 mV/Pa	0.95 mV/Pa	0.61 mV/Pa	0.78%
0.398 Hz	1.36 mV/Pa	1.93 mV/Pa	1.23 mV/Pa	0.78%
0.501 Hz	2.51 mV/Pa	3.55 mV/Pa	2.30 mV/Pa	0.78%
0.631 Hz	4.81 mV/Pa	6.80 mV/Pa	4.48 mV/Pa	0.78%
0.794 Hz	9.02 mV/Pa	12.95 mV/Pa	8.41 mV/Pa	0.78%
1.000 Hz	16.02 mV/Pa	23.01 mV/Pa	15.30 mV/Pa	0.78%
1.259 Hz	27.57 mV/Pa	39.59 mV/Pa	26.75 mV/Pa	0.78%
1.585 Hz	44.51 mV/Pa	64.43 mV/Pa	44.17 mV/Pa	0.78%
1.995 Hz	68.72 mV/Pa	97.67 mV/Pa	69.27 mV/Pa	0.81%
2.512 Hz	98.96 mV/Pa	137.30 mV/Pa	100.00 mV/Pa	0.83%

Table 50 Phase Response: Camas Microphones

Frequency	Camas #1	Camas #2	Camas #3	Combined Uncertainty (k=2)
0.251 Hz	248.50 deg	247.50 deg	249.40 deg	6.71 deg
0.316 Hz	243.60 deg	243.00 deg	245.00 deg	5.26 deg
0.398 Hz	237.20 deg	236.50 deg	239.60 deg	4.32 deg
0.501 Hz	228.60 deg	227.80 deg	230.80 deg	3.63 deg
0.631 Hz	221.90 deg	220.80 deg	224.80 deg	3.29 deg
0.794 Hz	210.80 deg	209.00 deg	213.90 deg	2.68 deg
1.000 Hz	195.60 deg	193.20 deg	199.00 deg	2.22 deg
1.259 Hz	180.70 deg	177.40 deg	183.90 deg	1.95 deg
1.585 Hz	164.70 deg	159.90 deg	167.50 deg	1.52 deg
1.995 Hz	147.10 deg	140.50 deg	148.50 deg	1.48 deg
2.512 Hz	129.20 deg	120.80 deg	129.50 deg	1.37 deg

The following plots show the amplitude and phase responses that were measured for the InfraBSU sensors.

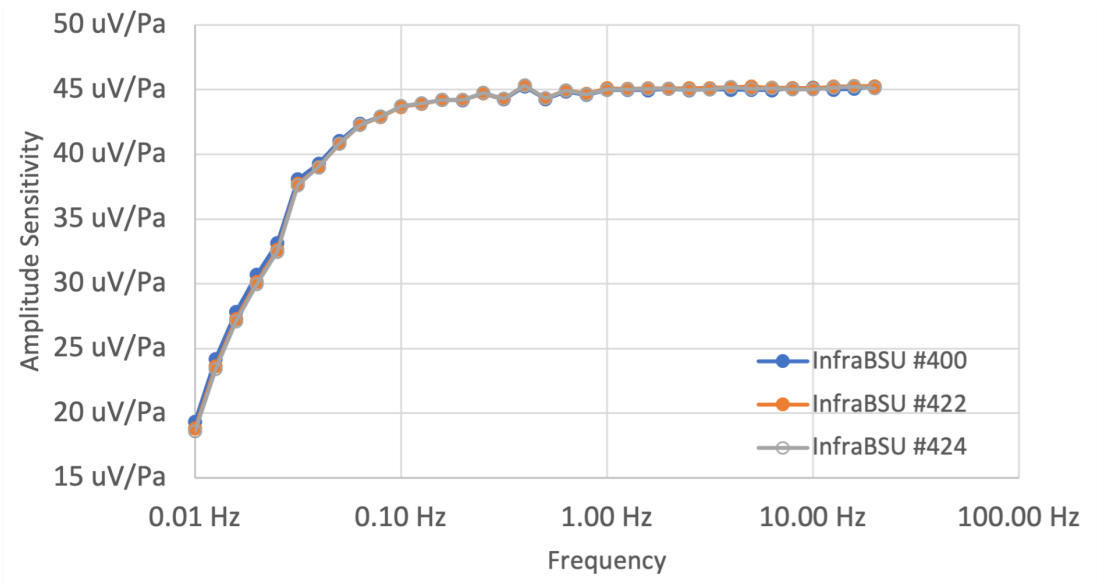

Figure 58 Amplitude Response: InfraBSU Sensors

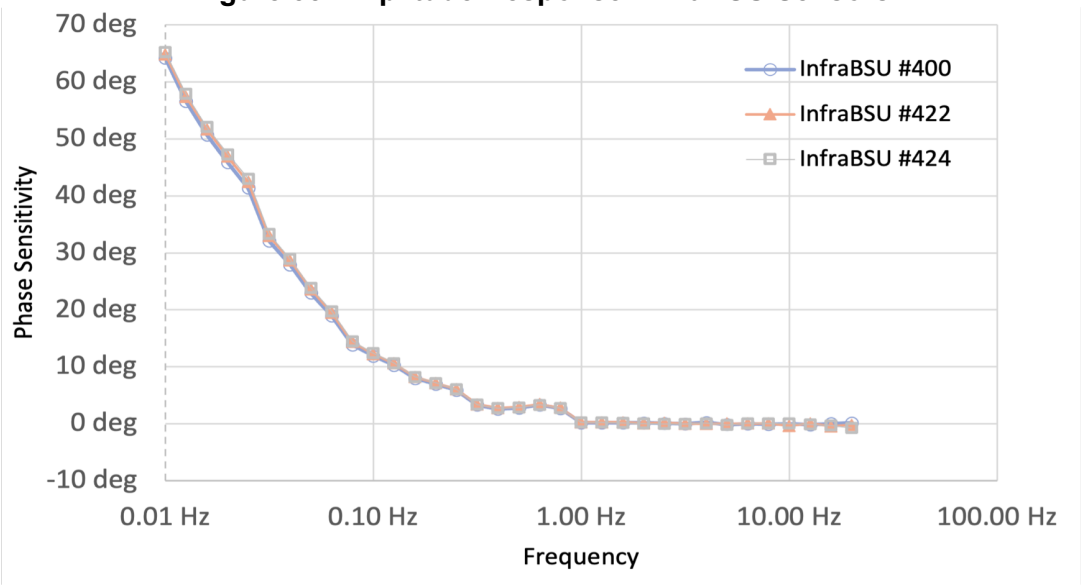

Figure 59 Phase Response: InfraBSU Sensors

InfraBSU sensors exhibited very consistent responses across the frequencies evaluated; just above the estimated uncertainty in amplitude and within the estimated uncertainty in phase, as shown in the above plots.

The amplitude and phase sensitivities illustrated in Figure 58 and Figure 59 are provided in the following tables.

Table 51 Amplitude Response: InfraBSU Sensors

Frequency	InfraBSU #400	InfraBSU #422	InfraBSU #424	Combined Uncertainty (k=2)
0.010 Hz	19.33 uV/Pa	18.82 uV/Pa	18.61 uV/Pa	0.78%
0.013 Hz	24.20 uV/Pa	23.63 uV/Pa	23.42 uV/Pa	0.78%
0.016 Hz	27.85 uV/Pa	27.29 uV/Pa	27.12 uV/Pa	0.78%
0.020 Hz	30.70 uV/Pa	30.15 uV/Pa	29.98 uV/Pa	0.78%
0.025 Hz	33.14 uV/Pa	32.64 uV/Pa	32.48 uV/Pa	0.78%
0.032 Hz	38.06 uV/Pa	37.72 uV/Pa	37.63 uV/Pa	0.78%
0.040 Hz	39.29 uV/Pa	39.02 uV/Pa	39.00 uV/Pa	0.78%
0.050 Hz	41.03 uV/Pa	40.83 uV/Pa	40.84 uV/Pa	0.78%
0.063 Hz	42.38 uV/Pa	42.27 uV/Pa	42.28 uV/Pa	0.78%
0.079 Hz	42.94 uV/Pa	42.87 uV/Pa	42.91 uV/Pa	0.81%
0.100 Hz	43.70 uV/Pa	43.67 uV/Pa	43.73 uV/Pa	0.83%
0.126 Hz	43.93 uV/Pa	43.91 uV/Pa	43.96 uV/Pa	0.83%
0.158 Hz	44.21 uV/Pa	44.20 uV/Pa	44.22 uV/Pa	0.90%
0.200 Hz	44.19 uV/Pa	44.20 uV/Pa	44.22 uV/Pa	0.97%
0.251 Hz	44.73 uV/Pa	44.73 uV/Pa	44.77 uV/Pa	1.04%
0.316 Hz	44.25 uV/Pa	44.30 uV/Pa	44.28 uV/Pa	1.12%
0.398 Hz	45.23 uV/Pa	45.32 uV/Pa	45.32 uV/Pa	1.17%
0.501 Hz	44.27 uV/Pa	44.33 uV/Pa	44.33 uV/Pa	1.21%
0.631 Hz	44.87 uV/Pa	44.96 uV/Pa	44.93 uV/Pa	1.29%
0.794 Hz	44.60 uV/Pa	44.69 uV/Pa	44.63 uV/Pa	1.38%
1.000 Hz	44.98 uV/Pa	45.12 uV/Pa	45.00 uV/Pa	0.92%
1.259 Hz	44.99 uV/Pa	45.07 uV/Pa	45.03 uV/Pa	0.92%
1.585 Hz	44.96 uV/Pa	45.11 uV/Pa	45.05 uV/Pa	0.92%
1.995 Hz	45.05 uV/Pa	45.09 uV/Pa	45.09 uV/Pa	0.92%
2.512 Hz	44.96 uV/Pa	45.10 uV/Pa	44.98 uV/Pa	0.92%
3.162 Hz	45.01 uV/Pa	45.13 uV/Pa	45.03 uV/Pa	0.92%
3.981 Hz	45.00 uV/Pa	45.18 uV/Pa	45.19 uV/Pa	0.92%
5.012 Hz	44.99 uV/Pa	45.25 uV/Pa	45.05 uV/Pa	0.92%
6.310 Hz	44.96 uV/Pa	45.16 uV/Pa	45.11 uV/Pa	0.92%
7.943 Hz	45.12 uV/Pa	45.13 uV/Pa	45.03 uV/Pa	0.92%
10.000 Hz	45.14 uV/Pa	45.11 uV/Pa	45.04 uV/Pa	0.92%
12.589 Hz	45.00 uV/Pa	45.24 uV/Pa	45.17 uV/Pa	0.92%
15.849 Hz	45.08 uV/Pa	45.29 uV/Pa	45.23 uV/Pa	0.92%
19.953 Hz	45.25 uV/Pa	45.26 uV/Pa	45.11 uV/Pa	0.92%

Table 52 Phase Response: InfraBSU Sensors

Frequency	InfraBSU #400	InfraBSU #422	InfraBSU #424	Combined Uncertainty (k=2)
0.010 Hz	64.13 deg	64.81 deg	65.25 deg	6.71 deg
0.013 Hz	56.53 deg	57.42 deg	57.88 deg	5.26 deg
0.016 Hz	50.66 deg	51.66 deg	52.12 deg	4.32 deg
0.020 Hz	45.88 deg	46.88 deg	47.30 deg	3.63 deg
0.025 Hz	41.34 deg	42.41 deg	42.97 deg	3.29 deg
0.032 Hz	32.07 deg	32.96 deg	33.33 deg	2.68 deg
0.040 Hz	27.87 deg	28.70 deg	28.97 deg	2.22 deg
0.050 Hz	22.94 deg	23.64 deg	23.91 deg	1.95 deg
0.063 Hz	18.94 deg	19.53 deg	19.75 deg	1.52 deg
0.079 Hz	13.85 deg	14.35 deg	14.49 deg	1.48 deg
0.100 Hz	11.91 deg	12.28 deg	12.40 deg	1.37 deg
0.126 Hz	10.26 deg	10.60 deg	10.66 deg	1.32 deg
0.158 Hz	7.95 deg	8.26 deg	8.27 deg	1.14 deg
0.200 Hz	6.95 deg	7.17 deg	7.20 deg	0.94 deg
0.251 Hz	5.88 deg	6.12 deg	6.10 deg	1.04 deg
0.316 Hz	3.27 deg	3.42 deg	3.41 deg	0.94 deg
0.398 Hz	2.60 deg	2.80 deg	2.76 deg	1.06 deg
0.501 Hz	2.75 deg	2.97 deg	2.84 deg	1.04 deg
0.631 Hz	3.34 deg	3.46 deg	3.33 deg	1.36 deg
0.794 Hz	2.67 deg	2.84 deg	2.78 deg	1.64 deg
1.000 Hz	0.18 deg	0.29 deg	0.24 deg	0.31 deg
1.259 Hz	0.16 deg	0.26 deg	0.27 deg	0.31 deg
1.585 Hz	0.19 deg	0.27 deg	0.18 deg	0.31 deg
1.995 Hz	0.19 deg	0.12 deg	0.10 deg	0.32 deg
2.512 Hz	0.11 deg	0.21 deg	-0.01 deg	0.33 deg
3.162 Hz	0.04 deg	0.03 deg	-0.01 deg	0.34 deg
3.981 Hz	0.32 deg	0.01 deg	0.14 deg	0.36 deg
5.012 Hz	-0.13 deg	0.05 deg	-0.19 deg	0.39 deg
6.310 Hz	0.02 deg	0.06 deg	0.12 deg	0.43 deg
7.943 Hz	-0.08 deg	0.10 deg	0.10 deg	0.49 deg
10.000 Hz	0.04 deg	-0.36 deg	0.09 deg	0.57 deg
12.589 Hz	-0.14 deg	0.13 deg	-0.10 deg	0.68 deg
15.849 Hz	0.07 deg	-0.40 deg	-0.27 deg	0.83 deg
19.953 Hz	0.18 deg	-0.18 deg	-0.67 deg	1.02 deg

The following plots show the amplitude and phase responses that were measured for the Gem packages.

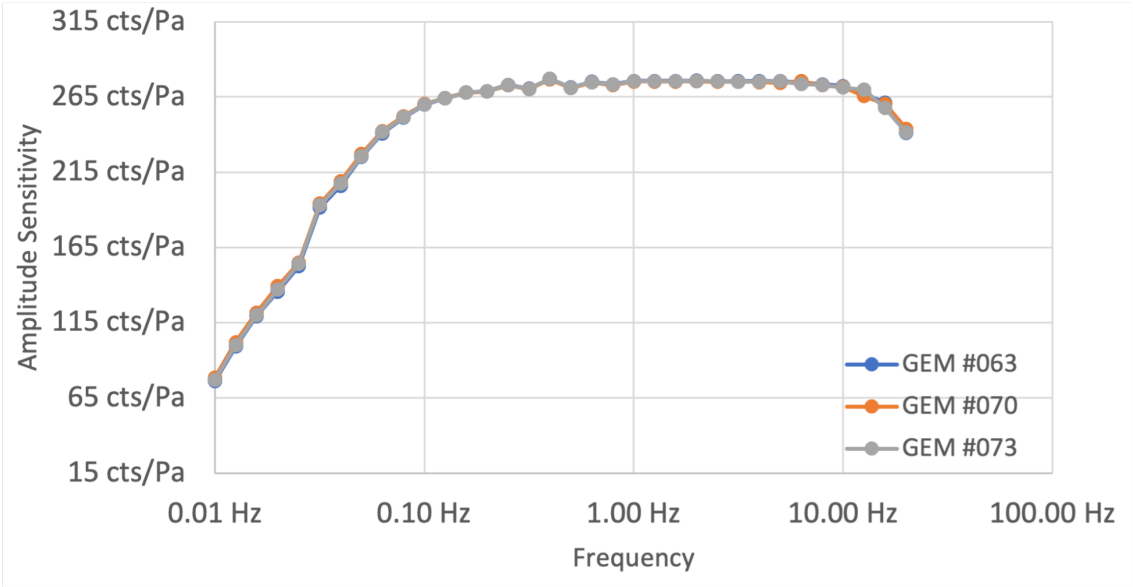

Figure 60 Amplitude Response: Gem Packages

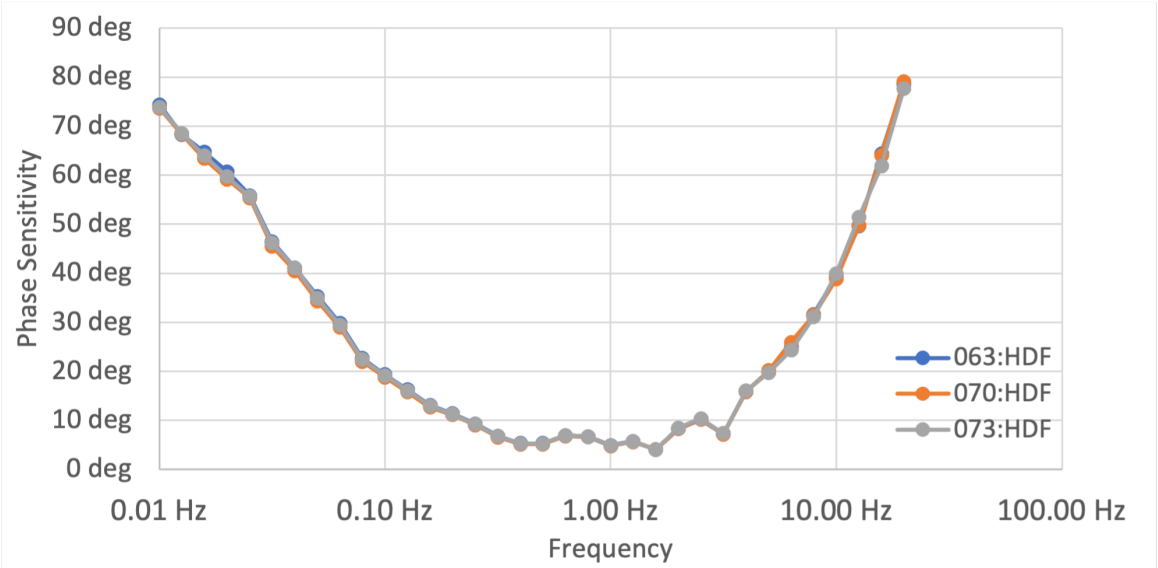

Figure 61 Phase Response: Gem Packages

Figure 60 and Figure 61 illustrate that the Gem packages also exhibited very consistent responses over the frequencies evaluated; just above the estimated uncertainty in both amplitude and phase. The increase in phase response at frequencies above 4 Hz is likely due to a constant timing offset between the digitizer recording the reference sensor and the Gem package timing system.

The amplitude and phase sensitivities illustrated in the previous plots are provided in the following tables.

Table 53 Amplitude Response: Gem Packages

Frequency	Gem #063	Gem #070	Gem #073	Combined Uncertainty (k=2)
0.010 Hz	76 cts/Pa	78 cts/Pa	77 cts/Pa	0.78%
0.013 Hz	99 cts/Pa	102 cts/Pa	100 cts/Pa	0.78%
0.016 Hz	119 cts/Pa	122 cts/Pa	120 cts/Pa	0.78%
0.020 Hz	136 cts/Pa	139 cts/Pa	137 cts/Pa	0.78%
0.025 Hz	153 cts/Pa	155 cts/Pa	154 cts/Pa	0.78%
0.032 Hz	192 cts/Pa	194 cts/Pa	193 cts/Pa	0.78%
0.040 Hz	206 cts/Pa	209 cts/Pa	207 cts/Pa	0.78%
0.050 Hz	225 cts/Pa	227 cts/Pa	226 cts/Pa	0.78%
0.063 Hz	241 cts/Pa	242 cts/Pa	242 cts/Pa	0.78%
0.079 Hz	251 cts/Pa	252 cts/Pa	252 cts/Pa	0.81%
0.100 Hz	260 cts/Pa	260 cts/Pa	260 cts/Pa	0.83%
0.126 Hz	264 cts/Pa	264 cts/Pa	264 cts/Pa	0.83%
0.158 Hz	268 cts/Pa	268 cts/Pa	268 cts/Pa	0.90%
0.200 Hz	269 cts/Pa	269 cts/Pa	269 cts/Pa	0.97%
0.251 Hz	273 cts/Pa	273 cts/Pa	273 cts/Pa	1.04%
0.316 Hz	271 cts/Pa	270 cts/Pa	270 cts/Pa	1.12%
0.398 Hz	277 cts/Pa	277 cts/Pa	277 cts/Pa	1.17%
0.501 Hz	271 cts/Pa	271 cts/Pa	271 cts/Pa	1.21%
0.631 Hz	275 cts/Pa	275 cts/Pa	275 cts/Pa	1.29%
0.794 Hz	273 cts/Pa	273 cts/Pa	273 cts/Pa	1.38%
1.000 Hz	276 cts/Pa	275 cts/Pa	276 cts/Pa	0.92%
1.259 Hz	276 cts/Pa	275 cts/Pa	275 cts/Pa	0.92%
1.585 Hz	276 cts/Pa	275 cts/Pa	276 cts/Pa	0.92%
1.995 Hz	276 cts/Pa	275 cts/Pa	276 cts/Pa	0.92%
2.512 Hz	276 cts/Pa	275 cts/Pa	275 cts/Pa	0.92%
3.162 Hz	276 cts/Pa	275 cts/Pa	275 cts/Pa	0.92%
3.981 Hz	276 cts/Pa	275 cts/Pa	275 cts/Pa	0.92%
5.012 Hz	276 cts/Pa	274 cts/Pa	275 cts/Pa	0.92%
6.310 Hz	275 cts/Pa	276 cts/Pa	274 cts/Pa	0.92%
7.943 Hz	273 cts/Pa	273 cts/Pa	273 cts/Pa	0.92%
10.000 Hz	272 cts/Pa	272 cts/Pa	271 cts/Pa	0.92%
12.589 Hz	267 cts/Pa	266 cts/Pa	270 cts/Pa	0.92%
15.849 Hz	261 cts/Pa	260 cts/Pa	258 cts/Pa	0.92%
19.953 Hz	241 cts/Pa	244 cts/Pa	241 cts/Pa	0.92%

Table 54 Phase Response: Gem Packages

Frequency	Gem #063	Gem #070	Gem #073	Combined Uncertainty (k=2)
0.010 Hz	74.36 deg	73.63 deg	73.89 deg	6.71 deg
0.013 Hz	68.32 deg	68.36 deg	68.54 deg	5.26 deg
0.016 Hz	64.69 deg	63.36 deg	63.95 deg	4.32 deg
0.020 Hz	60.74 deg	59.19 deg	59.71 deg	3.63 deg
0.025 Hz	55.83 deg	55.34 deg	55.69 deg	3.29 deg
0.032 Hz	46.47 deg	45.50 deg	46.19 deg	2.68 deg
0.040 Hz	41.11 deg	40.51 deg	41.13 deg	2.22 deg
0.050 Hz	35.27 deg	34.34 deg	34.92 deg	1.95 deg
0.063 Hz	29.78 deg	28.95 deg	29.44 deg	1.52 deg
0.079 Hz	22.64 deg	21.98 deg	22.39 deg	1.48 deg
0.100 Hz	19.35 deg	18.78 deg	19.12 deg	1.37 deg
0.126 Hz	16.24 deg	15.78 deg	16.04 deg	1.32 deg
0.158 Hz	13.08 deg	12.70 deg	12.95 deg	1.14 deg
0.200 Hz	11.36 deg	11.11 deg	11.26 deg	0.94 deg
0.251 Hz	9.33 deg	9.09 deg	9.22 deg	1.04 deg
0.316 Hz	6.80 deg	6.59 deg	6.72 deg	0.94 deg
0.398 Hz	5.30 deg	5.17 deg	5.27 deg	1.06 deg
0.501 Hz	5.32 deg	5.15 deg	5.26 deg	1.04 deg
0.631 Hz	6.92 deg	6.83 deg	6.90 deg	1.36 deg
0.794 Hz	6.71 deg	6.65 deg	6.71 deg	1.64 deg
1.000 Hz	4.90 deg	4.80 deg	4.86 deg	0.31 deg
1.259 Hz	5.70 deg	5.62 deg	5.70 deg	0.31 deg
1.585 Hz	4.08 deg	3.99 deg	4.08 deg	0.31 deg
1.995 Hz	8.31 deg	8.29 deg	8.43 deg	0.32 deg
2.512 Hz	10.21 deg	10.27 deg	10.35 deg	0.33 deg
3.162 Hz	7.21 deg	7.15 deg	7.31 deg	0.34 deg
3.981 Hz	15.96 deg	15.82 deg	16.02 deg	0.36 deg
5.012 Hz	19.89 deg	20.14 deg	19.75 deg	0.39 deg
6.310 Hz	24.99 deg	25.92 deg	24.31 deg	0.43 deg
7.943 Hz	31.63 deg	31.46 deg	31.08 deg	0.49 deg
10.000 Hz	39.36 deg	38.83 deg	39.91 deg	0.57 deg
12.589 Hz	49.65 deg	49.81 deg	51.42 deg	0.68 deg
15.849 Hz	64.38 deg	63.97 deg	61.83 deg	0.83 deg
19.953 Hz	78.59 deg	79.04 deg	77.66 deg	1.02 deg

The following plots show the amplitude and phase responses that were measured for the Raspberry Boom packages.

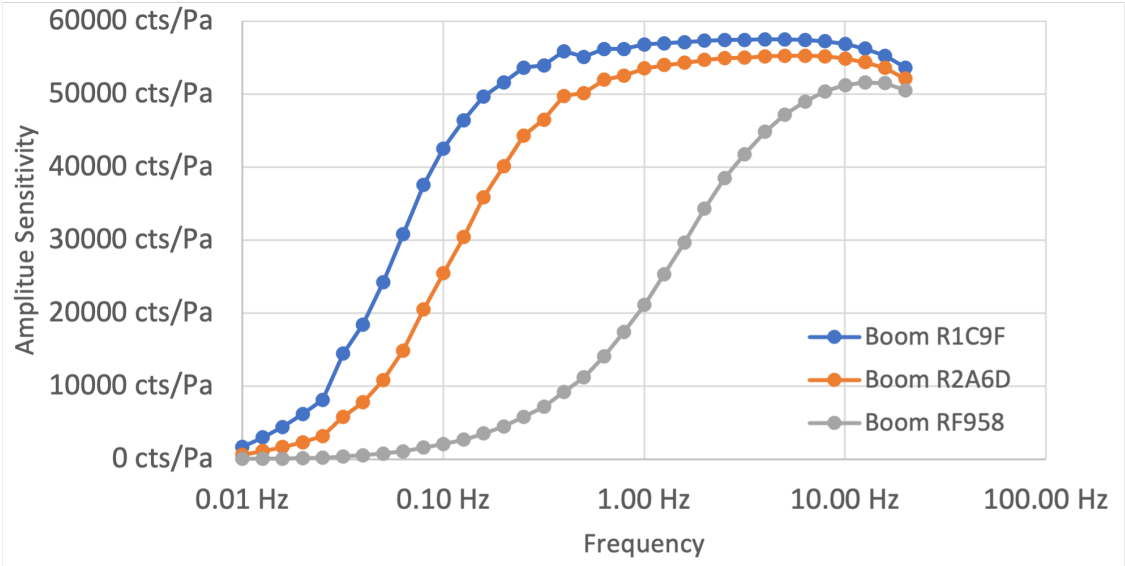

Figure 62 Amplitude Response: Boom Packages

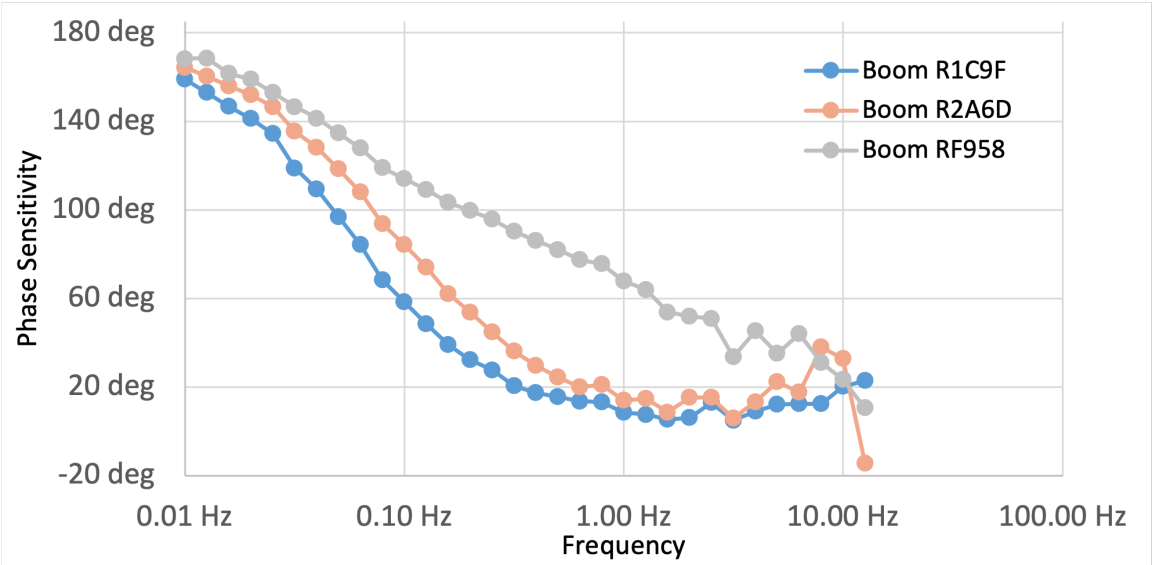

Figure 63 Phase Response: Boom Packages

Unlike the InfraBSU sensor and Gem packages, the Raspberry Boom packages show significant variation in amplitude and phase responses across all units. In addition, Boom RF958 differs remarkably from the other two units, both in amplitude and phase response.

The following two tables contain the values of amplitude and phase illustrated in Figure 62 and Figure 63.

Table 55 Amplitude Response: Raspberry Boom Packages

Frequency	Boom R1C9F	Boom R2A6D	Boom RF958	Combined Uncertainty (k=2)
0.010 Hz	1714 cts/Pa	635 cts/Pa	45 cts/Pa	0.78%
0.013 Hz	2996 cts/Pa	1126 cts/Pa	76 cts/Pa	0.78%
0.016 Hz	4456 cts/Pa	1670 cts/Pa	112 cts/Pa	0.78%
0.020 Hz	6188 cts/Pa	2363 cts/Pa	163 cts/Pa	0.78%
0.025 Hz	8131 cts/Pa	3179 cts/Pa	215 cts/Pa	0.78%
0.032 Hz	14470 cts/Pa	5838 cts/Pa	412 cts/Pa	0.78%
0.040 Hz	18450 cts/Pa	7800 cts/Pa	551 cts/Pa	0.78%
0.050 Hz	24240 cts/Pa	10870 cts/Pa	776 cts/Pa	0.78%
0.063 Hz	30800 cts/Pa	14890 cts/Pa	1097 cts/Pa	0.78%
0.079 Hz	37550 cts/Pa	20510 cts/Pa	1590 cts/Pa	0.81%
0.100 Hz	42530 cts/Pa	25470 cts/Pa	2090 cts/Pa	0.83%
0.126 Hz	46410 cts/Pa	30430 cts/Pa	2693 cts/Pa	0.83%
0.158 Hz	49680 cts/Pa	35890 cts/Pa	3550 cts/Pa	0.90%
0.200 Hz	51610 cts/Pa	40130 cts/Pa	4509 cts/Pa	0.97%
0.251 Hz	53620 cts/Pa	44350 cts/Pa	5815 cts/Pa	1.04%
0.316 Hz	53940 cts/Pa	46480 cts/Pa	7172 cts/Pa	1.12%
0.398 Hz	55880 cts/Pa	49760 cts/Pa	9247 cts/Pa	1.17%
0.501 Hz	55100 cts/Pa	50150 cts/Pa	11200 cts/Pa	1.21%
0.631 Hz	56190 cts/Pa	51960 cts/Pa	14090 cts/Pa	1.29%
0.794 Hz	56170 cts/Pa	52560 cts/Pa	17450 cts/Pa	1.38%
1.000 Hz	56810 cts/Pa	53510 cts/Pa	21130 cts/Pa	0.92%
1.259 Hz	56980 cts/Pa	53970 cts/Pa	25370 cts/Pa	0.92%
1.585 Hz	57130 cts/Pa	54290 cts/Pa	29690 cts/Pa	0.92%
1.995 Hz	57320 cts/Pa	54680 cts/Pa	34300 cts/Pa	0.92%
2.512 Hz	57430 cts/Pa	54930 cts/Pa	38510 cts/Pa	0.92%
3.162 Hz	57430 cts/Pa	54990 cts/Pa	41750 cts/Pa	0.92%
3.981 Hz	57500 cts/Pa	55170 cts/Pa	44840 cts/Pa	0.92%
5.012 Hz	57510 cts/Pa	55260 cts/Pa	47180 cts/Pa	0.92%
6.310 Hz	57400 cts/Pa	55240 cts/Pa	49000 cts/Pa	0.92%
7.943 Hz	57240 cts/Pa	55170 cts/Pa	50380 cts/Pa	0.92%
10.000 Hz	56870 cts/Pa	54880 cts/Pa	51240 cts/Pa	0.92%
12.589 Hz	56230 cts/Pa	54360 cts/Pa	51590 cts/Pa	0.92%
15.849 Hz	55270 cts/Pa	53590 cts/Pa	51510 cts/Pa	0.92%
19.953 Hz	53630 cts/Pa	52130 cts/Pa	50530 cts/Pa	0.92%

Table 56 Phase Response: Raspberry Boom Packages

Frequency	Boom R1C9F	Boom R2A6D	Boom RF958	Combined Uncertainty (k=2)
0.010 Hz	159.00 deg	164.30 deg	168.30 deg	6.71 deg
0.013 Hz	153.00 deg	160.30 deg	168.50 deg	5.26 deg
0.016 Hz	146.70 deg	156.00 deg	161.60 deg	4.32 deg
0.020 Hz	141.20 deg	152.00 deg	159.10 deg	3.63 deg
0.025 Hz	134.40 deg	146.60 deg	153.10 deg	3.29 deg
0.032 Hz	118.90 deg	135.60 deg	146.60 deg	2.68 deg
0.040 Hz	109.40 deg	128.10 deg	141.40 deg	2.22 deg
0.050 Hz	96.95 deg	118.50 deg	134.70 deg	1.95 deg
0.063 Hz	84.29 deg	108.10 deg	127.90 deg	1.52 deg
0.079 Hz	68.36 deg	93.62 deg	119.00 deg	1.48 deg
0.100 Hz	58.38 deg	84.24 deg	114.10 deg	1.37 deg
0.126 Hz	48.48 deg	74.13 deg	109.10 deg	1.32 deg
0.158 Hz	39.04 deg	62.03 deg	103.40 deg	1.14 deg
0.200 Hz	32.37 deg	53.85 deg	99.62 deg	0.94 deg
0.251 Hz	27.74 deg	44.92 deg	95.83 deg	1.04 deg
0.316 Hz	20.45 deg	36.19 deg	90.38 deg	0.94 deg
0.398 Hz	17.45 deg	29.77 deg	86.13 deg	1.06 deg
0.501 Hz	15.65 deg	24.53 deg	82.08 deg	1.04 deg
0.631 Hz	13.61 deg	19.94 deg	77.54 deg	1.36 deg
0.794 Hz	13.26 deg	21.12 deg	75.67 deg	1.64 deg
1.000 Hz	8.53 deg	14.03 deg	67.75 deg	0.31 deg
1.259 Hz	7.63 deg	14.88 deg	64.03 deg	0.31 deg
1.585 Hz	5.34 deg	8.67 deg	53.86 deg	0.31 deg
1.995 Hz	6.12 deg	15.36 deg	51.92 deg	0.32 deg
2.512 Hz	13.05 deg	15.26 deg	50.99 deg	0.33 deg
3.162 Hz	4.90 deg	5.98 deg	33.68 deg	0.34 deg
3.981 Hz	8.96 deg	13.37 deg	45.29 deg	0.36 deg
5.012 Hz	12.13 deg	22.36 deg	35.22 deg	0.39 deg
6.310 Hz	12.43 deg	17.59 deg	44.02 deg	0.43 deg
7.943 Hz	12.37 deg	38.01 deg	31.08 deg	0.49 deg
10.000 Hz	20.24 deg	32.77 deg	23.46 deg	0.57 deg
12.589 Hz	22.82 deg	-14.44 deg	10.54 deg	0.68 deg
15.849 Hz	22.96 deg	72.11 deg	34.79 deg	0.83 deg
19.953 Hz	82.85 deg	83.09 deg	79.80 deg	1.02 deg

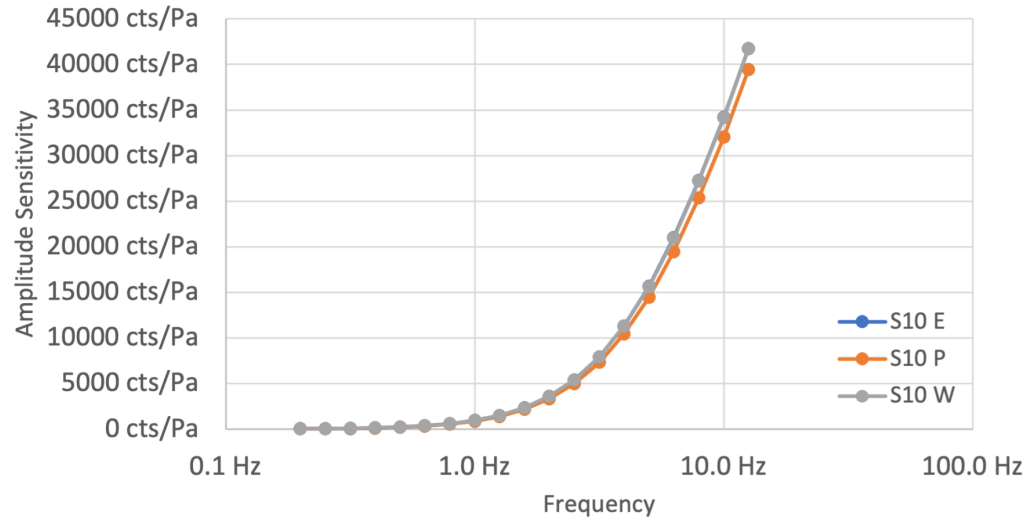

Figure 64 Amplitude Response: S10 Packages

The Samsung S10 packages, similar to the Camas microphones, have minimal overlap between their passband and the infrasound passband being evaluated. Considering the sensor within the smartphone is intended to effectively respond to the human voice, this higher frequency passband should be of no surprise. The lower bound of frequency evaluated was limited by the low SNR available. The high frequency of the evaluation was limited by the lower sampling rate of the S10 packages, 80 sps, the lowest sampling rate of the sensors and packages under test.

Table 57 contains the S10 amplitude sensitivities over the frequencies evaluated.

Table 57 Amplitude Response, Samsung S10 Packages

Frequency	S10 E	S10 P	S10 W	Combined Uncertainty (k=2)
0.200 Hz	27 cts/Pa	29 cts/Pa	32 cts/Pa	0.97%
0.251 Hz	47 cts/Pa	49 cts/Pa	53 cts/Pa	1.04%
0.316 Hz	81 cts/Pa	80 cts/Pa	88 cts/Pa	1.12%
0.398 Hz	139 cts/Pa	136 cts/Pa	148 cts/Pa	1.17%
0.501 Hz	223 cts/Pa	213 cts/Pa	231 cts/Pa	1.21%
0.631 Hz	367 cts/Pa	348 cts/Pa	378 cts/Pa	1.29%
0.794 Hz	589 cts/Pa	554 cts/Pa	602 cts/Pa	1.38%
1.000 Hz	945 cts/Pa	883 cts/Pa	960 cts/Pa	0.92%
1.259 Hz	1491 cts/Pa	1386 cts/Pa	1509 cts/Pa	0.92%
1.585 Hz	2329 cts/Pa	2160 cts/Pa	2345 cts/Pa	0.92%
1.995 Hz	3579 cts/Pa	3310 cts/Pa	3594 cts/Pa	0.92%
2.512 Hz	5399 cts/Pa	4985 cts/Pa	5407 cts/Pa	0.92%
3.162 Hz	7926 cts/Pa	7319 cts/Pa	7926 cts/Pa	0.92%
3.981 Hz	11330 cts/Pa	10450 cts/Pa	11300 cts/Pa	0.92%
5.012 Hz	15670 cts/Pa	14490 cts/Pa	15630 cts/Pa	0.92%
6.310 Hz	21000 cts/Pa	19450 cts/Pa	20930 cts/Pa	0.92%
7.943 Hz	27280 cts/Pa	25370 cts/Pa	27200 cts/Pa	0.92%
10.000 Hz	34240 cts/Pa	32060 cts/Pa	34160 cts/Pa	0.92%
12.589 Hz	41760 cts/Pa	39460 cts/Pa	41760 cts/Pa	0.92%

The Camas microphone clearly has a passband above 2.5 Hz. Amplitude response varied significantly across all three units, as much as 38%. The InfraBSU sensor and Gem package, were observed to have much more consistent responses across units, with differences between like units just exceeding the estimated uncertainties. The Raspberry Boom packages varied significantly in amplitude and phase responses across all units, further, Boom RF958 differs remarkably from the other two units and should be considered an outlier. Finally, the response observed of the Samsung S10 packages clearly illustrates much of their passband is above the frequencies evaluated in this report.

3.8 Passband

The passband of a sensor is defined to be the frequency range over which the sensor is able to measure with a nominally constant sensitivity. The upper and lower frequency bounds of the passband are defined as the points at which the sensors amplitude response is 3 dB below, or 0.707x of, the measured sensitivity at a given frequency. This definition of passband is consistent with the definition of bandwidth for digitizers (IEEE Std 1241-2000 section 4.7.1).

3.8.1 Measurand

The upper and lower frequency bounds of the passband are defined as the points at which the sensors amplitude response is 3 dB below, or 0.707x, the measured sensitivity at the calibration frequency.

3.8.2 Configuration

There is no test configuration for the passband test. The amplitude response used in computing the passband is determined in section 3.7 Frequency Response.

3.8.3 Analysis

The passband limits are determined by interpolating between frequency points at which the amplitude response was measured to determine the frequencies at which the amplitude response is 3 dB below, or 0.707x of, the sensitivity at the 1 Hz calibration frequency.

3.8.4 Results

The following table contains the passband limits observed for the InfraBSU sensors and Gem and Raspberry Boom packages. Note the response test did not illustrate any flat portion of the respective response curves for either the Camas microphone or Samsung S10 package, therefore we do not comment on their passband.

Table 58 Passband: InfraBSU Sensors

	Lower Limit	Upper Limit
InfraBSU #400	0.019 Hz	> 20 Hz
InfraBSU #422	0.020 Hz	> 20 Hz
InfraBSU #424	0.020 Hz	> 20 Hz

Table 59 Passband: Gem Packages

	Lower Limit	Upper Limit
Gem #063	0.033 Hz	> 20 Hz
Gem #070	0.032 Hz	> 20 Hz
Gem #073	0.032 Hz	> 20 Hz

Table 60 Passband: Raspberry Boom Packages

	Lower Limit	Upper Limit
Boom R1C9F	0.091 Hz	> 20 Hz
Boom R2A6D	0.19 Hz	> 20 Hz
Boom RF958	2.26 Hz	> 20 Hz

The passband calculated for InfraBSU sensor spans from 0.02 Hz to greater than the evaluation limit of 20 Hz. The Gem packages' passband extends to a slightly higher lower frequency limit of 0.032 Hz to 0.033 Hz, below what is listed in the specifications. The Raspberry Boom packages, excluding the outlier unit, have low frequency corners varying from 0.091 Hz to 0.19 Hz, the lowest observed being slightly higher than the 0.08 Hz suggested in the specification. The Camas sensor and Samsung smartphone passbands were not resolvable in this evaluation.

3.9 Static Temperature Response Variation

The response variation with static temperature is defined as being the observable change in sensor response as the ambient static temperature is varied. The purpose of this test is to confirm that the sensor response will be sufficiently stable when the sensor is deployed in an environment where the temperature will vary over time from when the sensor was first installed.

3.9.1 Measurand

The measured quantity is the percent change in amplitude and the degrees change in phase of the response as a function of temperature.

3.9.2 Configuration

The sensors under test are placed inside of a thermal chamber that is used to control the temperature of the sensors. A reference sensor with known performance characteristics is outside of the thermal chamber where it is maintained at ambient lab conditions, near 23 C, and not impacted by the temperature inside of the thermal chamber. A signal generator, amplifier, and pressure driver external to the thermal chamber generates a pressure signal inside of an equalization volume that is also connected to both the reference sensor and the sensors and packages under test via a manifold. The diagram below represents this configuration.

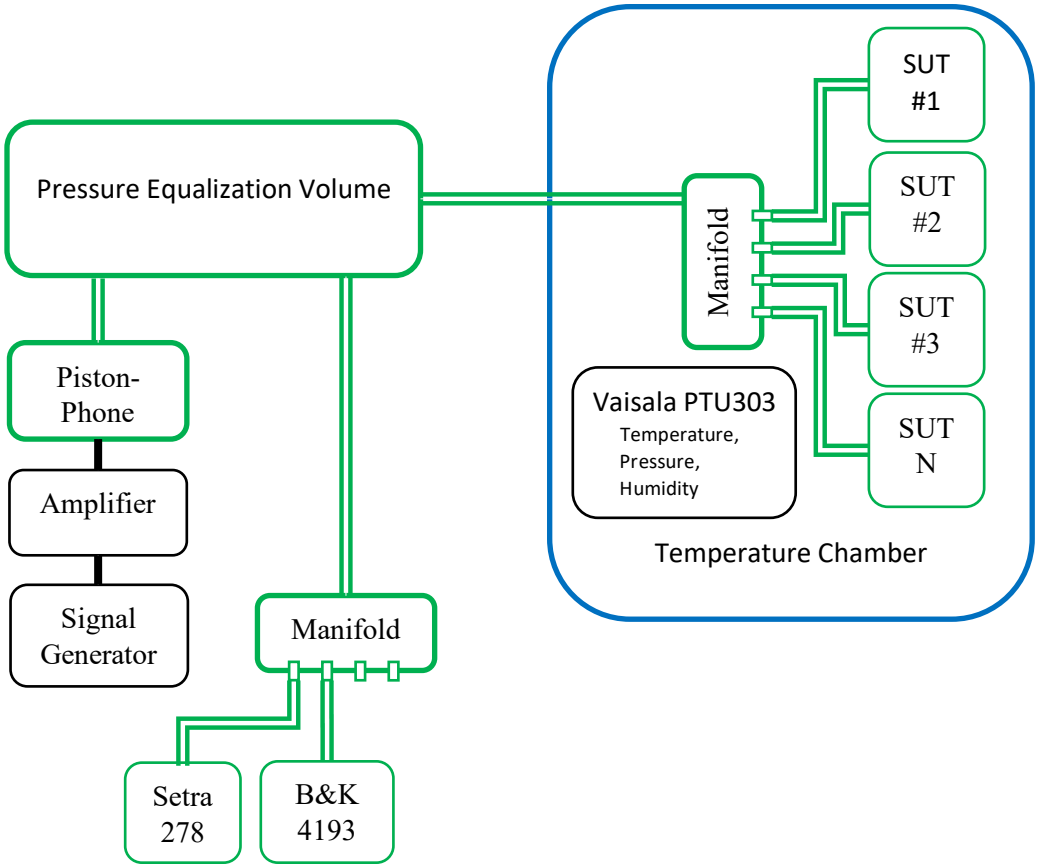

Figure 65 Sensitivity Variation with Static Temperature Configuration Diagram

In the configuration diagram above, the blue line representing the perimeter of the temperature chamber indicates that all the instruments within the chamber are maintained at the controlled temperature levels. The green lines represent the pressure lines and distribution manifold providing an airtight connection between the piston-phone, equalization volume, and sensors and the PVC containers containing the sensors/packages, allowing the pressure signal from the piston phone to propagate to the sensor inlets.

Note that this configuration is not suitable for absolute measurements of response as variations in the pipe diameter and length are expected to result in attenuation and harmonics, depending on the frequency, that will prevent the sensor under test and reference sensor from observing a common signal amplitude and phase. Placing a reference sensor on the same manifold as the sensors under test within the temperature chamber would also be problematic as the reference sensor would be subjected to changing temperature conditions.

However, we do expect that the test system is highly repeatable, such that in repeated measurements we can expect to get the same relative pressure amplitude levels at each of the sensors, regardless of the temperature within the chamber. Therefore, with this system it is possible to make measurements of how much the sensitivity changes from a baseline configuration as the temperature of the sensor under test is changed.

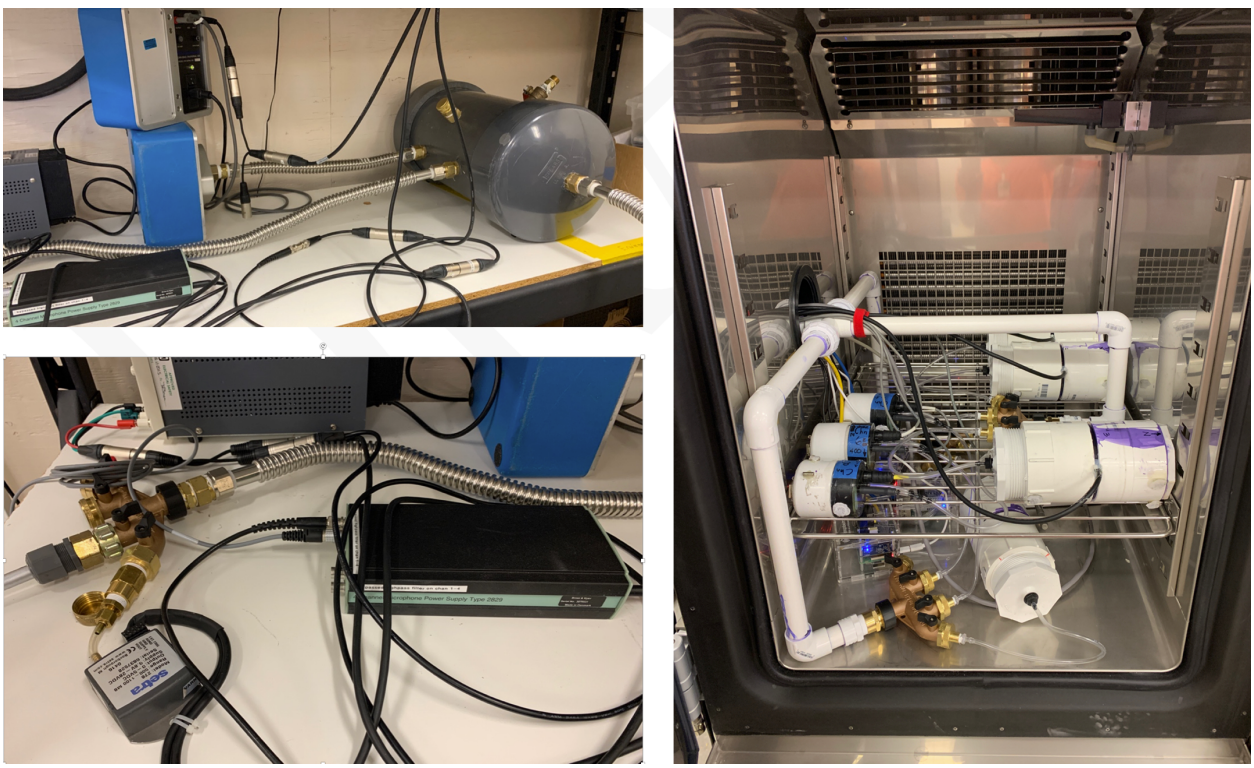

Figure 66 Sensitivity Variation with Static Temperature Configuration

At each temperature step, the thermal chamber maintains the programmed temperature for a minimum of 3 hours in order for the sensors for fully equilibrate. At the end of each temperature step, a series of pressure tones from 0.1 Hz to 20 Hz are generated to measure the response of the sensor under test relative to the reference sensor.

The thermal chamber is programmed to iterate through temperature cycles from 0 C up to 50 C. Upon the completion of the 50 C tests, the chamber was returned to ambient lab temperature so the applicable sensors/packages could have their batteries replaced and data downloaded. Next the thermal chamber was programmed to iterate through temperature cycles from -5 C down to -35 C. After periodic data reviews, any temperature levels that required a re-test were performed separately.

The digitizer records the output of the reference sensors and the sensors under test. Recall the packages under test utilize their own digitizer, recording data simultaneously. The recorded output from the reference sensor and the sensor/package-under-test are then compared.
The following table documents the testbed equipment utilized and the environmental conditions at the time of the test.

Table 61 Sensitivity Variation with Static Temperature Testbed Equipment

	Manufacturer / Model	Serial Number	Nominal Configuration
Reference Sensor, >= 1 Hz (outside chamber)	B&K 4193	2812287	2.1724 mV/Pa at 1 Hz, 820 hPa, 23 C
Reference Sensor, < 1 Hz (outside chamber)	Setra 278	7632595	0.0833245 mV/Pa
Thermal Chamber	ESPEC		-35 C to 50 C
Digitizer	Guralp Affinity	405A5B	200 Hz, 1x gain 40 Vpp
Voltage Signal Source	Stanford Research Systems DS360	N/A	1 Hz, 0.25 Vp sinusoid, generating 35 Pa
Voltage Amplifier	AE Techron 7224p	N/A	20x gain DC Coupled Amplifier
Pressure Driver	JL Audio 10w7ae	N/A	N/A
Environmental Monitor (inside chamber)	Vaisala PTU300	J3040003	Ambient Temperature, Pressure, and Humidity
Environmental Monitor (outside chamber)	Vaisala PTU300	D1050016	Ambient Temperature, Pressure, and Humidity

3.9.3 Analysis

A minimum of 10 cycles, or 10 seconds at 1 Hz, 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 sensor in Pascals and the sensor under test in Volts in order to determine the sinusoid's amplitude, frequency, phase, and DC offset:

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

$$V_{test} \sin(2\ pi\ f_{test}\ t +\ \theta_{test}\ ) + V_{dc\ test}$$

The sensor amplitude sensitivity in Volts / Pascal is computed:

$$S_{amp} = \frac{V_{test}}{P_{ref}}$$

The sensor phase sensitivity in degrees is computed:

$$S_{phase} =\ \theta_{test} -\ \theta_{ref}$$

The change in sensitivity, expressed as a percentage in amplitude and degrees in phase, are computed as relative to a baseline measurement:

$$Change\ S_{amp} = 100 * \frac{(S_{amp1} - S_{amp0})}{S_{amp0}}$$

$$Change\ S_{phase} = S_{phase1} - S_{phase0}$$

3.9.4 Results

3.9.4.1 Camas Microphones

Figure 67, Figure 68 and Figure 69 illustrate the relative change in the amplitude response at 1 Hz over -35 C to +50 C for the Camas microphones relative to the amplitude sensitivity observed at 23 C.

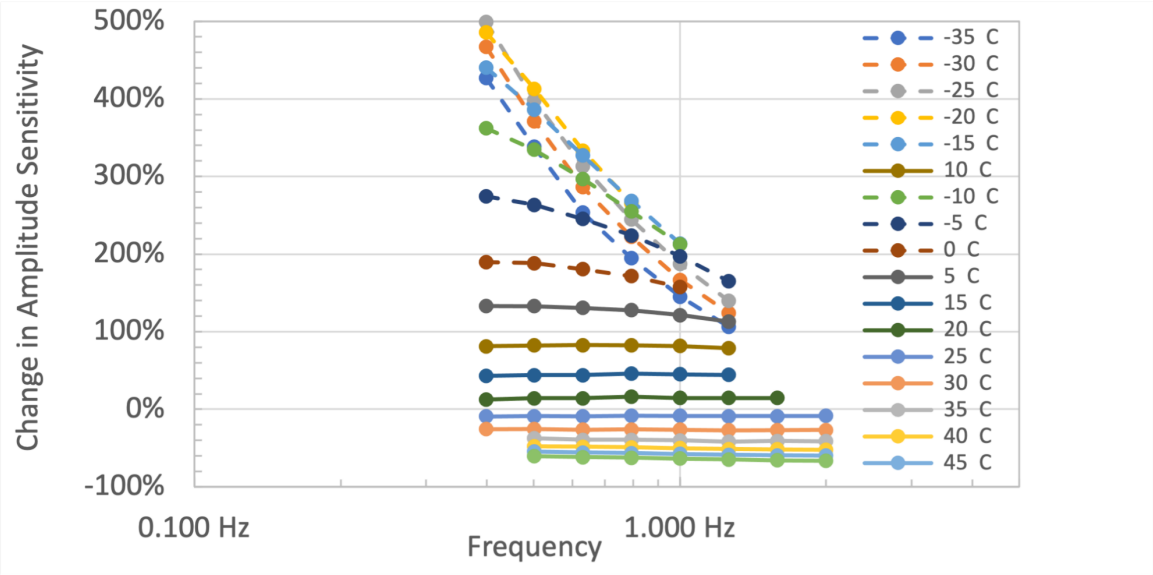

Figure 67 Relative Change in Amplitude Response with Temperature: Camas #1

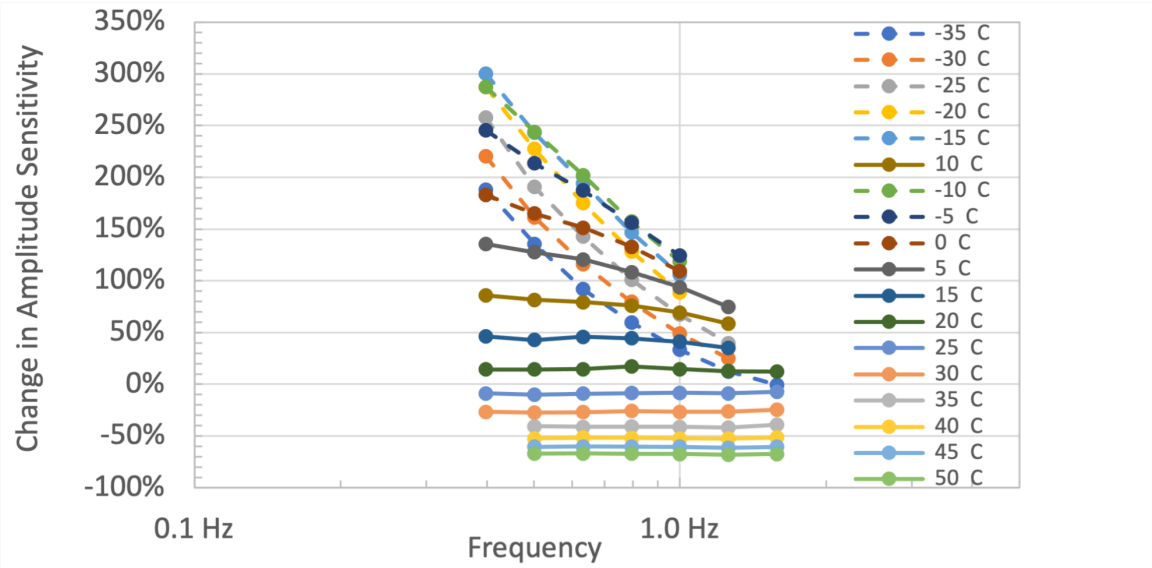

Figure 68 Relative Change in Amplitude Response with Temperature: Camas #2

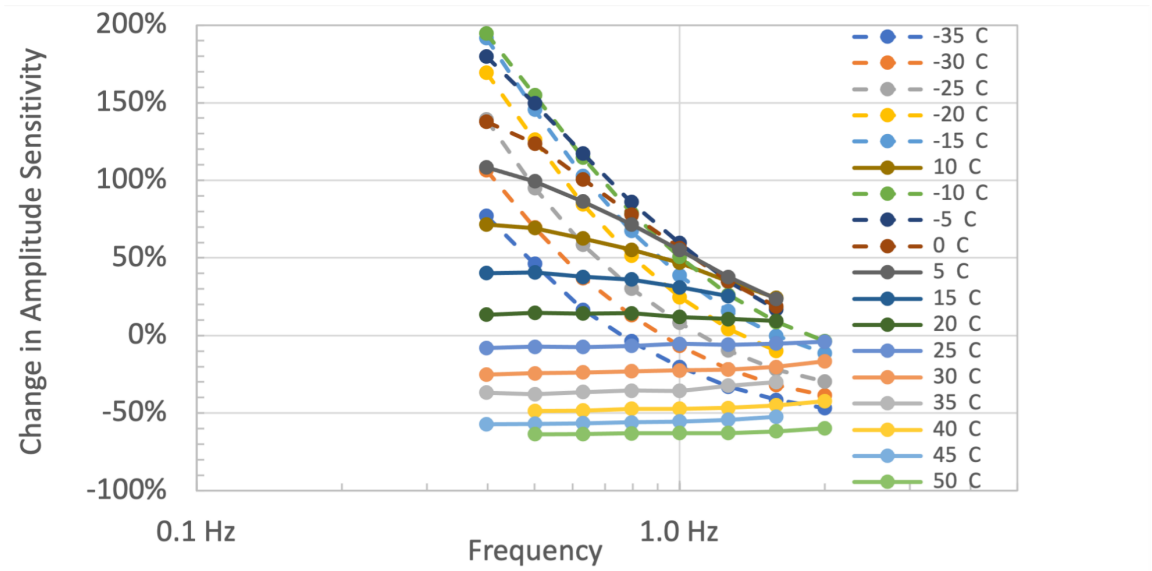

Figure 69 Relative Change in Amplitude Response with Temperature: Camas #3

Two distinct trends are visible in the plots illustrating relative change in amplitude response with temperature of the Camas microphones. First, the largest changes in sensitivity do not occur at the largest temperature extremes, rather at temperatures between -10 C and -25 C. Second, these changes are largest at the lowest frequencies evaluated. Relative amplitude sensitivity of Camas microphone #1 changed as much as 498%, at 0.4 Hz during the -25 C test. As noted in the Frequency Response section, 3.7, sensor clipping and low SNR limited the frequencies over which the evaluation could take place; these limitations varied over the temperatures at which tests occurred. As the trend at the higher frequencies is for less relative change to occur, it is to be expected that this represents a shift in the corner frequency of the sensor passband. However, since we were unable to determine a flat portion of this sensor's passband, the amount of change in the low frequency corner was not determined.

The following tables contain the data utilized in the above figures.

Table 62 Relative Change in Amplitude Response with Temperature: Camas #1

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.398 Hz	426.74%	467.19%	498.84%	485.68%	439.90%	362.41%	274.76%	189.29%	133.29%
0.501 Hz	338.09%	371.40%	398.19%	413.03%	386.24%	334.47%	263.50%	188.27%	132.77%
0.631 Hz	253.37%	286.19%	313.28%	333.51%	327.02%	296.87%	245.35%	180.67%	130.68%
0.794 Hz	194.47%	222.24%	244.53%	265.46%	268.57%	255.00%	224.00%	171.66%	127.51%
1.000 Hz	145.18%	166.84%	187.35%	-	213.58%	212.82%	197.11%	157.54%	121.32%
1.259 Hz	106.62%	123.85%	139.90%	-	-	-	165.17%	-	112.80%
1.585 Hz	-	-	-	-	-	-	-	-	-
1.995 Hz	-	-	-	-	-	-	-	-	-
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.398 Hz	81.31%	42.84%	12.82%	-9.21%	-25.72%	-	-	-	-
0.501 Hz	82.40%	44.06%	14.34%	-8.62%	-25.45%	-37.62%	-47.76%	-54.60%	-60.57%
0.631 Hz	82.73%	44.08%	14.35%	-9.27%	-26.08%	-39.21%	-48.29%	-55.56%	-61.55%
0.794 Hz	82.84%	46.25%	16.19%	-8.18%	-25.79%	-39.27%	-48.88%	-56.25%	-62.35%
1.000 Hz	81.46%	45.06%	14.67%	-8.61%	-26.40%	-39.86%	-50.24%	-57.63%	-63.55%
1.259 Hz	78.45%	44.39%	14.70%	-8.78%	-26.79%	-41.35%	-51.18%	-58.58%	-64.66%
1.585 Hz	-	-	14.47%	-8.85%	-26.92%	-40.62%	-51.47%	-59.38%	-65.54%
1.995 Hz	-	-	-	-8.58%	-26.65%	-41.02%	-51.82%	-59.68%	-65.94%

Table 63 Relative Change in Amplitude Response with Temperature: Camas #2

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.398 Hz	187.79%	220.29%	257.93%	287.34%	299.85%	287.39%	245.31%	182.75%	135.39%
0.501 Hz	135.76%	161.38%	190.77%	227.44%	243.04%	243.82%	213.65%	165.02%	127.59%
0.631 Hz	91.98%	116.10%	142.56%	174.94%	194.24%	201.96%	187.21%	151.38%	120.51%
0.794 Hz	59.73%	79.72%	101.04%	128.50%	146.78%	157.14%	156.18%	132.94%	108.22%
1.000 Hz	33.18%	49.02%	67.43%	88.64%	105.82%	119.01%	124.47%	109.08%	93.85%
1.259 Hz	12.33%	25.13%	39.84%	-	-	-	-	-	74.87%
1.585 Hz	-0.39%	-	-	-	-	-	-	-	-
1.995 Hz	-	-	-	-	-	-	-	-	-
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.398 Hz	85.99%	46.31%	14.31%	-8.77%	-26.72%	-	-	-	-
0.501 Hz	81.56%	42.76%	14.28%	-9.96%	-27.52%	-40.55%	-52.41%	-60.42%	-66.81%
0.631 Hz	79.30%	45.81%	14.59%	-9.03%	-26.87%	-41.15%	-51.54%	-60.17%	-66.92%
0.794 Hz	75.87%	44.56%	17.02%	-8.66%	-25.83%	-40.96%	-51.67%	-60.17%	-67.02%
1.000 Hz	69.22%	41.00%	14.50%	-8.22%	-26.63%	-41.08%	-52.24%	-60.57%	-67.53%
1.259 Hz	58.43%	35.08%	12.80%	-8.92%	-26.53%	-41.76%	-52.55%	-61.30%	-67.84%
1.585 Hz	-	-	12.27%	-7.47%	-24.39%	-39.34%	-51.21%	-60.31%	-67.35%
1.995 Hz	-	-	-	-	-	-	-	-	-

Table 64 Relative Change in Amplitude Response with Temperature: Camas #3

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.398 Hz	77.15%	106.41%	139.29%	169.23%	191.63%	194.65%	179.71%	137.56%	108.22%
0.501 Hz	46.25%	69.49%	95.03%	126.14%	145.37%	154.95%	149.50%	123.68%	99.36%
0.631 Hz	16.57%	37.05%	58.48%	84.38%	102.76%	114.51%	117.19%	100.66%	86.40%
0.794 Hz	-3.73%	13.13%	30.29%	51.38%	67.34%	79.04%	86.03%	77.94%	71.60%
1.000 Hz	-20.26%	-6.64%	8.12%	24.82%	38.63%	50.53%	59.54%	56.34%	55.15%
1.259 Hz	-32.97%	-21.78%	-9.66%	4.26%	15.85%	26.31%	34.97%	35.06%	37.76%
1.585 Hz	-41.43%	-31.98%	-21.82%	-10.04%	-0.18%	8.77%	16.89%	18.59%	23.45%
1.995 Hz	-46.78%	-38.57%	-29.82%	-	-11.26%	-3.56%	-	-	-
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.398 Hz	71.42%	40.27%	13.50%	-8.22%	-25.08%	-	-	-	-
0.501 Hz	69.17%	40.56%	14.50%	-7.27%	-24.27%	-36.71%	-48.67%	-57.05%	-63.56%
0.631 Hz	62.58%	37.77%	14.24%	-7.34%	-23.72%	-37.77%	-48.34%	-56.83%	-63.65%
0.794 Hz	55.21%	36.08%	14.33%	-6.58%	-23.11%	-36.42%	-47.12%	-56.42%	-63.10%
1.000 Hz	46.98%	31.10%	11.91%	-5.39%	-22.39%	-35.49%	-47.23%	-55.95%	-62.92%
1.259 Hz	34.80%	25.37%	10.62%	-5.99%	-21.94%	-35.73%	-46.59%	-55.41%	-62.77%
1.585 Hz	24.40%	-	9.25%	-5.19%	-20.30%	-32.44%	-44.95%	-54.22%	-61.68%
1.995 Hz	-	-	-	-3.99%	-16.75%	-30.14%	-42.23%	-52.25%	-59.91%

The next three figures illustrate the relative difference in the phase response at 1 Hz over -35 C to +50 C for the Camas microphones when compared to the phase observed at 23 C.

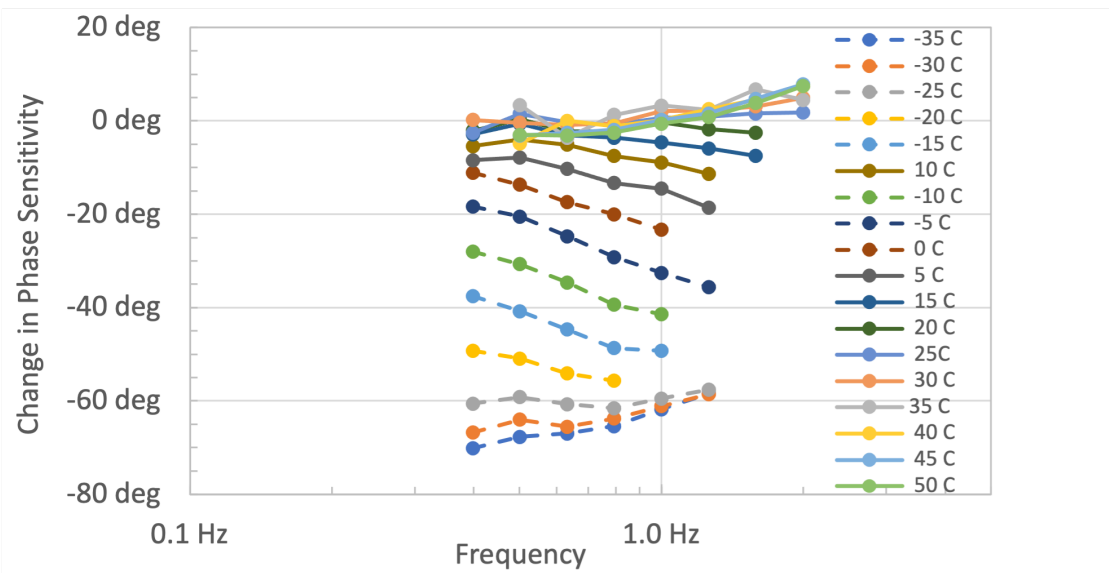

Figure 70 Relative Change in Phase Response with Temperature: Camas #1

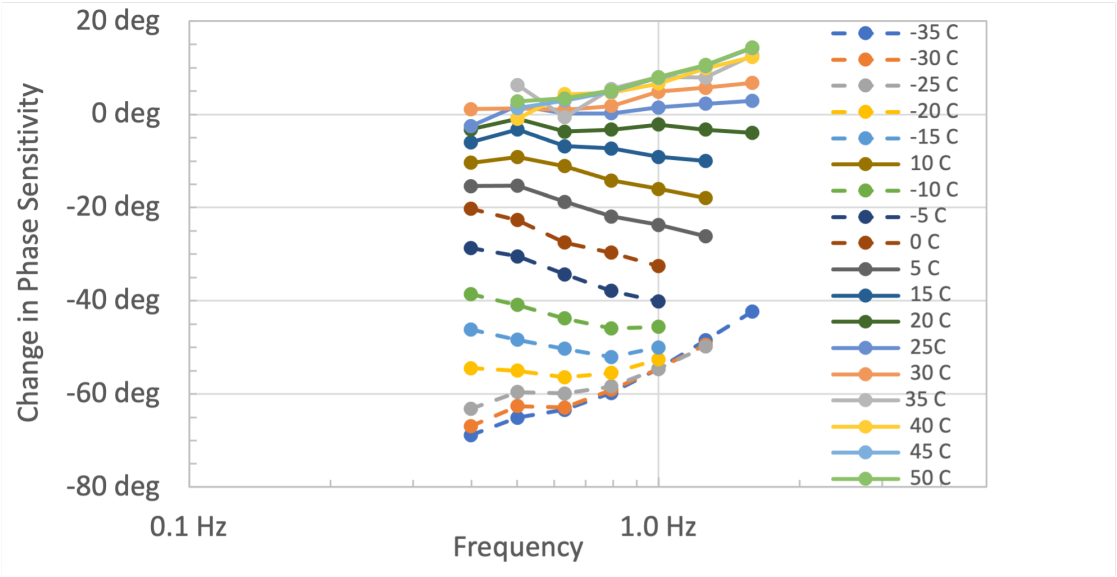

Figure 71 Relative Change in Phase Response with Temperature: Camas #2

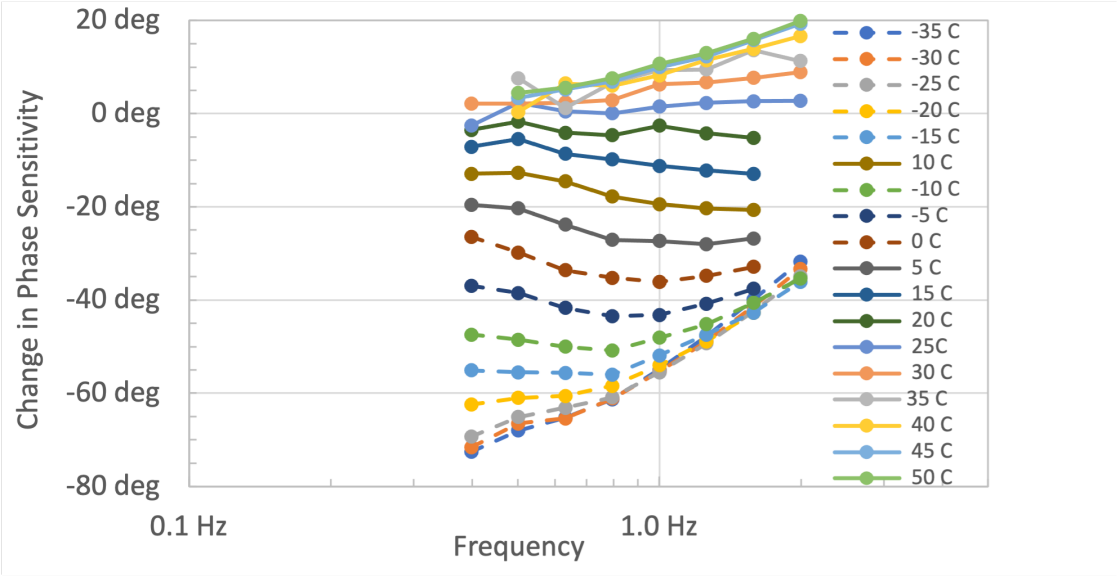

Figure 72 Relative Change in Phase Response with Temperature: Camas #3

Figure 70, Figure 71 and Figure 72 illustrate trends common to all Camas microphones evaluated that were observed in the phase change plots. These include: a) the most significant differences in phase occur at the lowest frequencies and the lowest temperatures, and b) differences in phase generally are negative for those temperatures below 23 C (the sole exception being, Camas #1 0.5 Hz at 20 C). As mentioned in the discussion regarding relative changing in amplitude sensitivity, measurements of phase change were limited by low SNR and sensor clipping, and these limitations varied some with temperature. These changes in phase response with temperature are consistent with a shift in the low frequency corner of the passband.

The following tables contain the data shown in the above plots.

Table 65 Relative Change in Phase Response with Temperature: Camas #1

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.398 Hz	-70.20 deg	-66.80 deg	-60.60 deg	-49.20 deg	-37.50 deg	-28.00 deg	-18.40 deg	-11.10 deg	-8.40 deg
0.501 Hz	-67.70 deg	-64.00 deg	-59.20 deg	-50.90 deg	-40.80 deg	-30.70 deg	-20.50 deg	-13.70 deg	-7.90 deg
0.631 Hz	-67.00 deg	-65.50 deg	-60.70 deg	-54.10 deg	-44.70 deg	-34.60 deg	-24.70 deg	-17.40 deg	-10.30 deg
0.794 Hz	-65.40 deg	-63.80 deg	-61.60 deg	-55.60 deg	-48.70 deg	-39.40 deg	-29.20 deg	-20.00 deg	-13.30 deg
1.000 Hz	-61.80 deg	-61.10 deg	-59.50 deg	-	-49.20 deg	-41.40 deg	-32.60 deg	-23.30 deg	-14.50 deg
1.259 Hz	-58.40 deg	-58.60 deg	-57.60 deg	-	-	-	-35.60 deg	-	-18.60 deg
1.585 Hz	-	-	-	-	-	-	-	-	-
1.995 Hz	-	-	-	-	-	-	-	-	-
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.398 Hz	-5.40 deg	-2.90 deg	-2.10 deg	-2.60 deg	0.20 deg	-	-	-	-
0.501 Hz	-4.00 deg	-0.60 deg	0.30 deg	1.50 deg	-0.40 deg	3.40 deg	-4.80 deg	-3.10 deg	-3.00 deg
0.631 Hz	-5.10 deg	-3.10 deg	-2.30 deg	-0.30 deg	-0.80 deg	-3.60 deg	0.00 deg	-2.60 deg	-3.10 deg
0.794 Hz	-7.50 deg	-3.60 deg	-2.20 deg	-0.80 deg	-0.60 deg	1.30 deg	-1.10 deg	-1.90 deg	-2.50 deg
1.000 Hz	-8.90 deg	-4.60 deg	-0.30 deg	0.60 deg	2.10 deg	3.30 deg	0.20 deg	0.20 deg	-0.60 deg
1.259 Hz	-11.40 deg	-5.90 deg	-1.80 deg	0.90 deg	2.20 deg	2.30 deg	2.50 deg	1.60 deg	0.80 deg
1.585 Hz	-	-	-	1.60 deg	3.10 deg	6.70 deg	4.50 deg	4.70 deg	3.80 deg
1.995 Hz	-	-	-	1.80 deg	4.90 deg	4.50 deg	7.50 deg	7.80 deg	7.50 deg

Table 66 Relative Change in Phase Response with Temperature: Camas #2

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.398 Hz	-68.80 deg	-66.90 deg	-63.20 deg	-54.50 deg	-46.20 deg	-38.60 deg	-28.70 deg	-20.20 deg	-15.40 deg
0.501 Hz	-65.10 deg	-62.60 deg	-59.60 deg	-55.00 deg	-48.40 deg	-40.90 deg	-30.50 deg	-22.70 deg	-15.30 deg
0.631 Hz	-63.40 deg	-62.90 deg	-59.90 deg	-56.40 deg	-50.30 deg	-43.80 deg	-34.30 deg	-27.50 deg	-18.80 deg
0.794 Hz	-59.80 deg	-59.10 deg	-58.40 deg	-55.50 deg	-52.10 deg	-45.90 deg	-37.90 deg	-29.70 deg	-21.90 deg
1.000 Hz	-54.60 deg	-54.60 deg	-54.60 deg	-52.60 deg	-50.00 deg	-45.60 deg	-40.10 deg	-32.50 deg	-23.70 deg
1.259 Hz	-48.50 deg	-49.40 deg	-49.80 deg	-	-	-	-	-	-26.10 deg
1.585 Hz	-42.30 deg	-	-	-	-	-	-	-	-
1.995 Hz	-	-	-	-	-	-	-	-	-
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.398 Hz	-10.40 deg	-6.00 deg	-3.20 deg	-2.50 deg	1.10 deg	-	-	-	-
0.501 Hz	-9.20 deg	-3.20 deg	-1.00 deg	1.90 deg	1.30 deg	6.30 deg	-1.00 deg	1.40 deg	2.80 deg
0.631 Hz	-11.10 deg	-6.80 deg	-3.70 deg	0.20 deg	1.00 deg	-0.60 deg	4.30 deg	3.00 deg	3.40 deg
0.794 Hz	-14.20 deg	-7.30 deg	-3.30 deg	0.20 deg	1.80 deg	5.50 deg	4.60 deg	4.90 deg	5.10 deg
1.000 Hz	-16.00 deg	-9.10 deg	-2.20 deg	1.50 deg	4.90 deg	8.00 deg	6.60 deg	7.90 deg	8.00 deg
1.259 Hz	-18.00 deg	-10.00 deg	-3.30 deg	2.30 deg	5.70 deg	7.90 deg	9.90 deg	10.40 deg	10.60 deg
1.585 Hz	-	-	-4.00 deg	2.90 deg	6.80 deg	12.70 deg	12.30 deg	14.30 deg	14.40 deg
1.995 Hz	-	-	-	-	-	-	-	-	-

Table 67 Relative Change in Phase Response with Temperature: Camas #3

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.398 Hz	-72.50 deg	-71.60 deg	-69.30 deg	-62.40 deg	-55.10 deg	-47.40 deg	-37.00 deg	-26.40 deg	-19.60 deg
0.501 Hz	-68.00 deg	-66.50 deg	-65.10 deg	-61.00 deg	-55.50 deg	-48.50 deg	-38.50 deg	-29.80 deg	-20.30 deg
0.631 Hz	-65.20 deg	-65.40 deg	-63.10 deg	-60.60 deg	-55.60 deg	-50.00 deg	-41.70 deg	-33.60 deg	-23.80 deg
0.794 Hz	-61.30 deg	-61.10 deg	-60.90 deg	-58.40 deg	-56.00 deg	-50.80 deg	-43.50 deg	-35.20 deg	-27.10 deg
1.000 Hz	-54.90 deg	-55.30 deg	-55.50 deg	-54.00 deg	-51.90 deg	-48.10 deg	-43.20 deg	-36.10 deg	-27.30 deg
1.259 Hz	-47.70 deg	-48.90 deg	-49.30 deg	-48.90 deg	-47.40 deg	-45.20 deg	-40.80 deg	-34.80 deg	-28.00 deg
1.585 Hz	-39.90 deg	-41.40 deg	-42.50 deg	-42.80 deg	-42.70 deg	-40.60 deg	-37.60 deg	-32.90 deg	-26.80 deg
1.995 Hz	-31.80 deg	-33.30 deg	-34.90 deg	-	-36.10 deg	-35.40 deg	-	-	-
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.398 Hz	-12.90 deg	-7.10 deg	-3.50 deg	-2.60 deg	2.20 deg	-	-	-	-
0.501 Hz	-12.70 deg	-5.40 deg	-1.70 deg	2.40 deg	2.20 deg	7.60 deg	0.40 deg	3.40 deg	4.40 deg
0.631 Hz	-14.50 deg	-8.60 deg	-4.10 deg	0.50 deg	2.40 deg	1.20 deg	6.50 deg	5.20 deg	5.60 deg
0.794 Hz	-17.80 deg	-9.80 deg	-4.60 deg	0.10 deg	2.90 deg	6.70 deg	6.00 deg	6.90 deg	7.60 deg
1.000 Hz	-19.40 deg	-11.20 deg	-2.60 deg	1.50 deg	6.30 deg	9.30 deg	8.20 deg	10.00 deg	10.70 deg
1.259 Hz	-20.30 deg	-12.20 deg	-4.20 deg	2.30 deg	6.70 deg	9.50 deg	11.50 deg	12.30 deg	13.00 deg
1.585 Hz	-20.60 deg	-	-5.20 deg	2.70 deg	7.70 deg	13.60 deg	13.90 deg	15.80 deg	16.10 deg
1.995 Hz	-	-	-	2.80 deg	8.90 deg	11.30 deg	16.70 deg	19.30 deg	19.90 deg

3.9.4.2 InfraBSU Sensor

Figure 73, Figure 74 and Figure 75 illustrate the relative change in the amplitude response over -35 C to +50 C relative to the amplitude sensitivity observed at 23 C for the InfraBSU sensors.

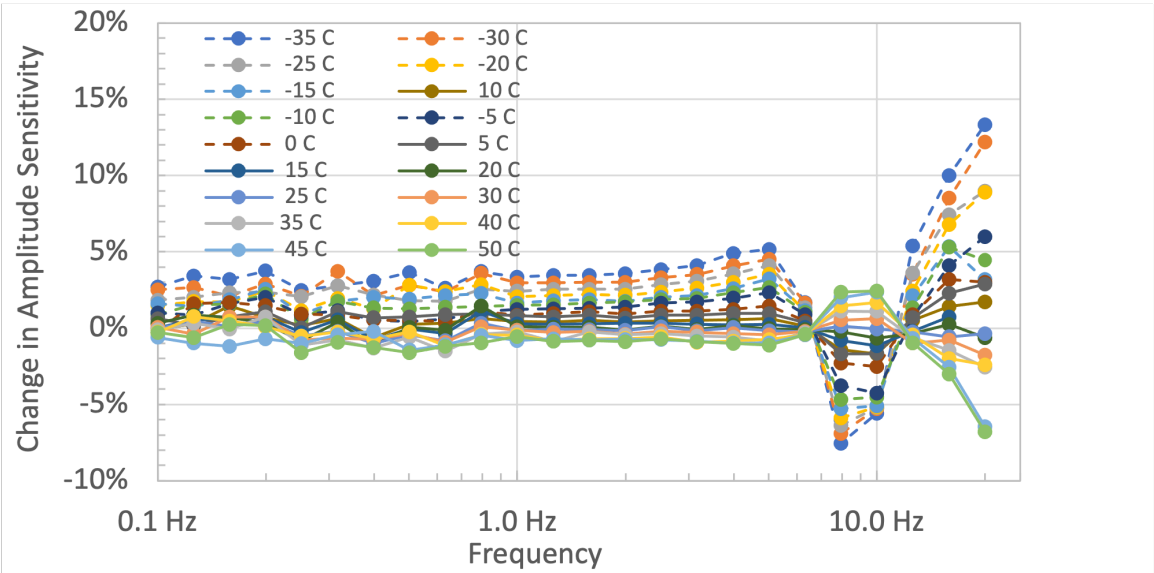

Figure 73 Relative Change in Amplitude Response with Temperature: InfraBSU #400

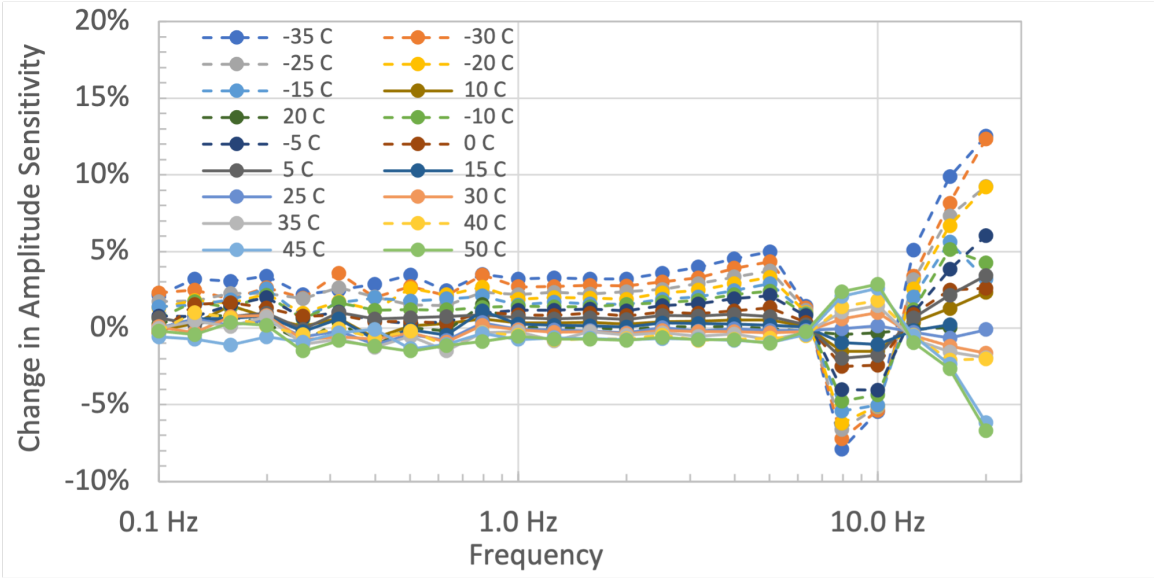

Figure 74 Relative Change in Amplitude Response with Temperature: InfraBSU #422

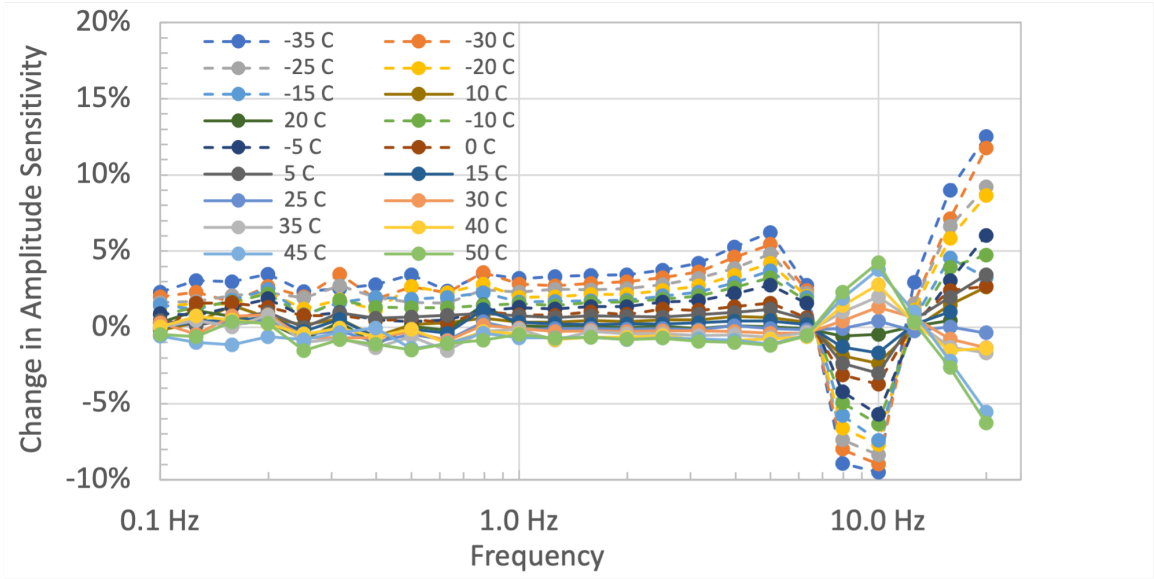

Figure 75 Relative Change in Amplitude Response with Temperature: InfraBSU #424

All InfraBSU sensors evaluated exhibit similar trends: below 8 Hz and above 12 Hz relative changes in amplitude sensitivity increase as temperature decreases, though between 8 Hz and 12 Hz, the relative change in sensitivity increases as temperature increases. The relative changes in amplitude sensitivities reach 6.23% (sensor #424) between 0.1 Hz and 5 Hz. Above 5 Hz, largest relative changes in amplitude sensitivity observed were -9.5% at 10 Hz and 13.32%, at 19.53 Hz during the -35 C test for InfraBSU #424.

These changes in amplitude response indicate that there are minimal changes in the frequency passband with temperature and the changes are more a shift in overall sensitivity.
Table 68, Table 69 and Table 70 contain the data shown in the above figures.

Table 68 Relative Change in Amplitude Response with Temperature: InfraBSU #400

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	2.71%	2.51%	1.84%	1.48%	1.59%	0.90%	1.01%	-0.25%	0.63%
0.126 Hz	3.43%	2.65%	2.03%	1.74%	1.43%	1.52%	0.87%	1.61%	0.18%
0.158 Hz	3.19%	2.12%	2.32%	1.74%	1.85%	1.58%	1.63%	1.67%	0.74%
0.200 Hz	3.75%	2.90%	2.36%	2.43%	2.54%	2.23%	2.03%	1.47%	1.07%
0.251 Hz	2.49%	2.09%	2.05%	1.15%	0.90%	0.57%	0.84%	0.93%	0.02%
0.316 Hz	2.77%	3.72%	2.79%	1.95%	1.75%	1.77%	1.15%	0.86%	1.06%
0.398 Hz	3.08%	2.16%	2.18%	1.25%	2.02%	1.32%	0.53%	0.53%	0.68%
0.501 Hz	3.67%	2.83%	1.79%	2.80%	1.92%	1.26%	0.44%	0.53%	0.73%
0.631 Hz	2.61%	2.37%	1.78%	2.39%	2.13%	1.36%	0.57%	0.44%	0.90%
0.794 Hz	3.71%	3.60%	2.56%	2.87%	2.27%	1.43%	1.08%	1.08%	0.93%
1.000 Hz	3.36%	2.96%	2.42%	2.05%	1.66%	1.50%	1.24%	0.85%	0.81%
1.259 Hz	3.48%	2.98%	2.56%	2.15%	1.78%	1.52%	1.26%	0.96%	0.74%
1.585 Hz	3.45%	3.00%	2.57%	2.20%	1.88%	1.64%	1.29%	1.08%	0.84%
1.995 Hz	3.58%	3.01%	2.56%	2.15%	1.77%	1.71%	1.36%	0.92%	0.66%
2.512 Hz	3.85%	3.30%	2.86%	2.35%	2.04%	1.87%	1.66%	1.11%	0.86%
3.162 Hz	4.09%	3.52%	3.07%	2.64%	2.15%	1.94%	1.72%	1.12%	0.84%
3.981 Hz	4.89%	4.08%	3.55%	3.00%	2.59%	2.32%	1.96%	1.24%	0.96%
5.012 Hz	5.18%	4.51%	4.10%	3.52%	3.25%	2.65%	2.34%	1.45%	0.96%
6.310 Hz	1.67%	1.64%	1.33%	1.10%	1.15%	1.04%	0.90%	0.47%	0.36%
7.943 Hz	-7.57%	-6.89%	-6.36%	-5.89%	-5.30%	-4.68%	-3.76%	-2.29%	-1.68%
10.000 Hz	-5.58%	-5.27%	-5.19%	-5.16%	-5.08%	-4.51%	-4.25%	-2.50%	-1.67%
12.589 Hz	5.39%	3.53%	3.61%	2.43%	2.12%	1.33%	0.71%	0.87%	0.68%
15.849 Hz	10.01%	8.51%	7.43%	6.78%	5.36%	5.33%	4.11%	3.18%	2.30%
19.953 Hz	13.32%	12.21%	8.97%	8.89%	3.18%	4.43%	5.99%	3.00%	2.89%
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	-0.09%	0.02%	0.31%	0.00%	0.04%	-0.11%	-0.27%	-0.61%	-0.29%
0.126 Hz	0.27%	0.54%	0.85%	0.47%	-0.38%	0.33%	0.76%	-0.98%	-0.62%
0.158 Hz	1.45%	0.58%	0.71%	0.11%	0.74%	-0.07%	0.47%	-1.18%	0.25%
0.200 Hz	0.71%	0.74%	0.33%	0.45%	0.74%	0.74%	0.09%	-0.71%	0.18%
0.251 Hz	0.18%	-0.29%	-0.86%	-0.51%	-0.77%	-1.12%	-0.53%	-0.99%	-1.61%
0.316 Hz	0.64%	0.55%	0.40%	-0.20%	-0.66%	-0.78%	-0.24%	-0.42%	-0.93%
0.398 Hz	-0.62%	-0.77%	-1.12%	-1.01%	-0.75%	-1.32%	-0.68%	-0.22%	-1.28%
0.501 Hz	0.24%	-0.07%	0.04%	-0.44%	-0.35%	-0.60%	-0.24%	-1.44%	-1.61%
0.631 Hz	0.33%	-0.35%	-0.13%	-0.83%	-0.92%	-1.51%	-1.14%	-1.10%	-1.19%
0.794 Hz	0.64%	1.10%	1.46%	0.31%	0.09%	-0.40%	-0.42%	-0.46%	-0.97%
1.000 Hz	0.44%	0.28%	0.09%	-0.15%	-0.13%	-0.26%	-0.46%	-0.81%	-0.55%
1.259 Hz	0.41%	0.24%	0.04%	-0.07%	-0.28%	-0.87%	-0.83%	-0.70%	-0.87%
1.585 Hz	0.50%	0.28%	0.06%	-0.09%	-0.22%	-0.26%	-0.69%	-0.78%	-0.80%
1.995 Hz	0.38%	0.32%	-0.13%	-0.15%	-0.38%	-0.45%	-0.68%	-0.75%	-0.90%
2.512 Hz	0.48%	0.32%	0.13%	0.08%	-0.19%	-0.36%	-0.57%	-0.76%	-0.71%
3.162 Hz	0.53%	0.27%	-0.08%	-0.16%	-0.27%	-0.51%	-0.94%	-0.84%	-0.90%
3.981 Hz	0.57%	0.22%	0.18%	0.04%	-0.37%	-0.59%	-0.84%	-0.98%	-1.00%
5.012 Hz	0.61%	0.24%	-0.04%	-0.17%	-0.45%	-0.83%	-0.72%	-0.96%	-1.13%
6.310 Hz	0.14%	0.04%	-0.09%	-0.23%	-0.22%	-0.31%	-0.45%	-0.45%	-0.41%
7.943 Hz	-1.41%	-0.80%	-0.22%	0.12%	0.53%	1.12%	1.45%	2.00%	2.35%
10.000 Hz	-1.69%	-1.17%	-0.68%	-0.05%	0.63%	1.10%	1.67%	2.37%	2.43%
12.589 Hz	0.51%	-0.20%	-0.34%	-0.25%	-0.99%	-0.62%	-0.45%	-0.68%	-0.96%
15.849 Hz	1.42%	0.72%	0.26%	-0.57%	-0.78%	-1.45%	-1.99%	-2.56%	-3.00%
19.953 Hz	1.70%	-	-0.63%	-0.36%	-1.78%	-2.57%	-2.39%	-6.44%	-6.78%

Table 69 Relative Change in Amplitude Response with Temperature: InfraBSU #422

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	2.15%	2.31%	1.72%	1.32%	1.39%	0.63%	0.78%	-0.31%	0.45%
0.126 Hz	3.21%	2.47%	1.76%	1.80%	1.49%	1.74%	0.76%	1.56%	0.11%
0.158 Hz	3.05%	1.87%	2.27%	1.60%	1.85%	1.34%	1.49%	1.65%	0.60%
0.200 Hz	3.40%	2.63%	2.27%	2.23%	2.56%	2.14%	2.00%	1.31%	0.98%
0.251 Hz	2.18%	1.96%	1.93%	0.97%	0.77%	0.59%	0.66%	0.77%	-0.02%
0.316 Hz	2.48%	3.58%	2.63%	1.75%	1.66%	1.66%	1.04%	0.88%	0.95%
0.398 Hz	2.87%	2.00%	2.04%	1.16%	1.97%	1.16%	0.48%	0.42%	0.59%
0.501 Hz	3.48%	2.71%	1.50%	2.60%	1.78%	1.19%	0.31%	0.44%	0.68%
0.631 Hz	2.43%	2.12%	1.49%	2.17%	1.90%	1.18%	0.42%	0.31%	0.79%
0.794 Hz	3.52%	3.48%	2.36%	2.66%	2.09%	1.36%	0.99%	1.06%	0.93%
1.000 Hz	3.20%	2.70%	2.20%	1.87%	1.50%	1.44%	1.15%	0.85%	0.74%
1.259 Hz	3.29%	2.73%	2.34%	1.99%	1.69%	1.41%	1.17%	0.82%	0.65%
1.585 Hz	3.21%	2.80%	2.22%	1.96%	1.59%	1.40%	1.23%	0.97%	0.75%
1.995 Hz	3.21%	2.76%	2.36%	1.87%	1.53%	1.53%	1.13%	0.81%	0.70%
2.512 Hz	3.58%	3.02%	2.54%	2.29%	1.89%	1.68%	1.47%	1.07%	0.67%
3.162 Hz	3.98%	3.29%	2.90%	2.47%	2.04%	1.80%	1.57%	0.96%	0.85%
3.981 Hz	4.53%	3.90%	3.33%	2.90%	2.45%	2.18%	1.92%	1.14%	0.98%
5.012 Hz	4.96%	4.35%	3.72%	3.32%	2.91%	2.43%	2.13%	1.33%	1.19%
6.310 Hz	1.44%	1.33%	1.15%	1.02%	0.93%	0.88%	0.81%	0.36%	0.52%
7.943 Hz	-7.89%	-7.20%	-6.61%	-6.20%	-5.41%	-4.77%	-4.02%	-2.49%	-2.37%
10.000 Hz	-5.44%	-5.37%	-5.13%	-5.05%	-5.03%	-4.35%	-4.04%	-2.42%	-3.00%
12.589 Hz	5.09%	3.40%	3.15%	2.56%	2.02%	1.21%	1.01%	0.90%	0.50%
15.849 Hz	9.87%	8.14%	7.32%	6.68%	5.60%	5.11%	3.83%	2.49%	1.97%
19.953 Hz	12.51%	12.33%	9.25%	9.19%	3.18%	4.27%	6.02%	2.60%	3.46%
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	-0.16%	0.00%	0.25%	0.00%	0.09%	0.00%	-0.18%	-0.58%	-0.20%
0.126 Hz	0.31%	0.60%	0.94%	0.58%	-0.29%	0.47%	1.02%	-0.73%	-0.42%
0.158 Hz	1.47%	0.65%	0.76%	0.18%	0.73%	0.11%	0.67%	-1.09%	0.36%
0.200 Hz	0.71%	0.80%	0.31%	0.53%	0.82%	0.76%	0.16%	-0.58%	0.20%
0.251 Hz	0.11%	-0.24%	-0.86%	-0.55%	-0.77%	-1.06%	-0.44%	-0.90%	-1.50%
0.316 Hz	0.64%	0.60%	0.40%	-0.18%	-0.57%	-0.71%	-0.04%	-0.31%	-0.82%
0.398 Hz	-0.66%	-0.75%	-1.14%	-1.05%	-0.72%	-1.25%	-0.64%	-0.09%	-1.16%
0.501 Hz	0.15%	-0.13%	0.02%	-0.42%	-0.29%	-0.53%	-0.20%	-1.34%	-1.50%
0.631 Hz	0.28%	-0.46%	-0.20%	-0.79%	-0.90%	-1.47%	-1.12%	-1.05%	-1.14%
0.794 Hz	0.59%	1.12%	1.54%	0.35%	0.18%	-0.29%	-0.31%	-0.33%	-0.86%
1.000 Hz	0.33%	0.26%	0.07%	-0.09%	-0.11%	-0.22%	-0.46%	-0.74%	-0.54%
1.259 Hz	0.35%	0.19%	0.00%	-0.13%	-0.28%	-0.82%	-0.78%	-0.63%	-0.74%
1.585 Hz	0.37%	0.15%	0.02%	-0.17%	-0.22%	-0.24%	-0.69%	-0.67%	-0.73%
1.995 Hz	0.28%	0.09%	-0.11%	-0.30%	-0.36%	-0.45%	-0.70%	-0.74%	-0.81%
2.512 Hz	0.40%	0.34%	0.10%	0.04%	-0.15%	-0.31%	-0.46%	-0.67%	-0.61%
3.162 Hz	0.47%	0.29%	0.08%	-0.20%	-0.24%	-0.53%	-0.80%	-0.71%	-0.76%
3.981 Hz	0.51%	0.27%	0.10%	-0.04%	-0.24%	-0.39%	-0.71%	-0.80%	-0.76%
5.012 Hz	0.54%	0.19%	-0.04%	-0.17%	-0.30%	-0.74%	-0.67%	-0.94%	-1.00%
6.310 Hz	0.11%	0.07%	-0.20%	-0.14%	-0.23%	-0.29%	-0.50%	-0.43%	-0.23%
7.943 Hz	-1.51%	-0.94%	-0.41%	-0.04%	0.61%	1.06%	1.39%	2.06%	2.37%
10.000 Hz	-1.51%	-1.07%	-0.31%	0.16%	1.02%	1.46%	1.80%	2.60%	2.87%
12.589 Hz	0.37%	-0.14%	-0.08%	-0.25%	-0.48%	-0.73%	-0.45%	-0.51%	-0.96%
15.849 Hz	1.28%	0.23%	0.03%	-0.64%	-1.18%	-1.54%	-2.08%	-2.36%	-2.65%
19.953 Hz	2.34%	-	-	-0.10%	-1.63%	-1.93%	-1.99%	-6.16%	-6.69%

Table 70 Relative Change in Amplitude Response with Temperature: InfraBSU #424

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	2.31%	2.00%	1.64%	1.37%	1.46%	0.81%	0.92%	-0.49%	0.45%
0.126 Hz	3.05%	2.32%	1.72%	1.54%	1.16%	1.34%	0.80%	1.58%	0.11%
0.158 Hz	2.99%	1.65%	2.10%	1.52%	1.78%	1.67%	1.34%	1.61%	0.60%
0.200 Hz	3.48%	2.70%	2.28%	2.30%	2.50%	2.19%	1.87%	1.34%	0.98%
0.251 Hz	2.34%	2.01%	1.94%	1.21%	0.82%	0.71%	0.73%	0.77%	-0.02%
0.316 Hz	2.53%	3.50%	2.72%	1.82%	1.62%	1.77%	1.00%	0.80%	0.95%
0.398 Hz	2.82%	1.87%	1.96%	1.12%	1.96%	1.32%	0.51%	0.46%	0.59%
0.501 Hz	3.44%	2.65%	1.63%	2.69%	1.85%	1.28%	0.38%	0.53%	0.68%
0.631 Hz	2.39%	2.26%	1.60%	2.28%	1.95%	1.29%	0.48%	0.31%	0.79%
0.794 Hz	3.53%	3.59%	2.47%	2.84%	2.27%	1.43%	1.08%	1.01%	0.93%
1.000 Hz	3.20%	2.83%	2.31%	1.98%	1.65%	1.55%	1.31%	0.83%	0.74%
1.259 Hz	3.34%	2.73%	2.49%	2.01%	1.69%	1.45%	1.21%	0.78%	0.65%
1.585 Hz	3.40%	2.88%	2.45%	2.15%	1.74%	1.61%	1.35%	1.01%	0.75%
1.995 Hz	3.44%	2.99%	2.52%	2.14%	1.78%	1.68%	1.36%	0.85%	0.70%
2.512 Hz	3.75%	3.27%	2.81%	2.42%	2.06%	1.85%	1.67%	1.21%	0.67%
3.162 Hz	4.22%	3.64%	3.21%	2.71%	2.32%	2.06%	1.74%	1.11%	0.85%
3.981 Hz	5.28%	4.61%	3.87%	3.41%	2.93%	2.62%	2.22%	1.37%	0.98%
5.012 Hz	6.23%	5.44%	4.81%	4.22%	3.71%	3.26%	2.77%	1.59%	1.19%
6.310 Hz	2.75%	2.43%	2.23%	2.04%	1.96%	1.73%	1.58%	0.64%	0.52%
7.943 Hz	-8.94%	-8.00%	-7.38%	-6.62%	-5.77%	-4.93%	-4.21%	-3.13%	-2.37%
10.000 Hz	-9.50%	-8.95%	-8.35%	-7.67%	-7.43%	-6.33%	-5.71%	-3.71%	-3.00%
12.589 Hz	2.95%	1.54%	1.51%	1.13%	0.53%	0.16%	-0.09%	0.31%	0.50%
15.849 Hz	9.00%	7.11%	6.62%	5.84%	4.56%	3.95%	3.05%	2.44%	1.97%
19.953 Hz	12.53%	11.75%	9.21%	8.66%	3.27%	4.74%	6.05%	2.70%	3.46%
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	-0.20%	-0.09%	0.29%	0.04%	0.29%	-0.02%	0.04%	-0.58%	-0.45%
0.126 Hz	0.29%	0.40%	1.09%	0.45%	-0.47%	0.45%	0.74%	-0.98%	-0.62%
0.158 Hz	1.45%	0.40%	0.71%	0.16%	0.74%	0.04%	0.49%	-1.14%	0.38%
0.200 Hz	0.62%	0.69%	0.33%	0.47%	0.83%	0.80%	0.22%	-0.62%	0.25%
0.251 Hz	0.13%	-0.26%	-0.79%	-0.44%	-0.68%	-0.99%	-0.44%	-0.82%	-1.52%
0.316 Hz	0.55%	0.53%	0.33%	-0.22%	-0.69%	-0.71%	-0.04%	-0.33%	-0.80%
0.398 Hz	-0.62%	-0.66%	-1.14%	-0.95%	-0.70%	-1.32%	-0.62%	-0.04%	-1.10%
0.501 Hz	0.18%	-0.13%	0.07%	-0.44%	-0.29%	-0.60%	-0.11%	-1.39%	-1.50%
0.631 Hz	0.31%	-0.39%	-0.18%	-0.83%	-0.88%	-1.51%	-1.05%	-1.05%	-1.07%
0.794 Hz	0.62%	1.17%	1.48%	0.35%	0.13%	-0.29%	-0.26%	-0.37%	-0.84%
1.000 Hz	0.35%	0.33%	0.11%	-0.17%	-0.07%	-0.11%	-0.41%	-0.70%	-0.46%
1.259 Hz	0.35%	0.24%	0.04%	-0.09%	-0.26%	-0.84%	-0.80%	-0.69%	-0.74%
1.585 Hz	0.45%	0.17%	0.06%	-0.09%	-0.22%	-0.26%	-0.67%	-0.67%	-0.67%
1.995 Hz	0.36%	0.23%	0.00%	-0.13%	-0.28%	-0.42%	-0.66%	-0.81%	-0.79%
2.512 Hz	0.50%	0.23%	0.06%	-0.08%	-0.23%	-0.42%	-0.54%	-0.69%	-0.71%
3.162 Hz	0.48%	0.28%	-0.06%	-0.16%	-0.24%	-0.55%	-0.85%	-0.77%	-0.93%
3.981 Hz	0.73%	0.42%	0.10%	0.10%	-0.27%	-0.48%	-0.85%	-0.85%	-1.00%
5.012 Hz	0.65%	0.43%	0.02%	-0.09%	-0.38%	-0.65%	-0.76%	-1.12%	-1.19%
6.310 Hz	0.35%	0.17%	-0.07%	-0.17%	-0.40%	-0.33%	-0.62%	-0.54%	-0.55%
7.943 Hz	-1.88%	-1.28%	-0.58%	-0.08%	0.42%	1.00%	1.42%	1.90%	2.31%
10.000 Hz	-2.35%	-1.69%	-0.46%	0.41%	1.34%	1.99%	2.81%	3.79%	4.26%
12.589 Hz	-0.09%	0.19%	0.06%	-0.22%	0.66%	0.47%	0.28%	1.00%	0.35%
15.849 Hz	1.48%	1.02%	0.46%	0.03%	-0.75%	-1.31%	-1.54%	-2.21%	-2.64%
19.953 Hz	2.66%	-	-	-0.37%	-1.35%	-1.67%	-1.37%	-5.54%	-6.27%

The next three figures show the relative difference in the phase response over -35 C to +50 C when compared to the phase observed at 23 C for the InfraBSU sensors.

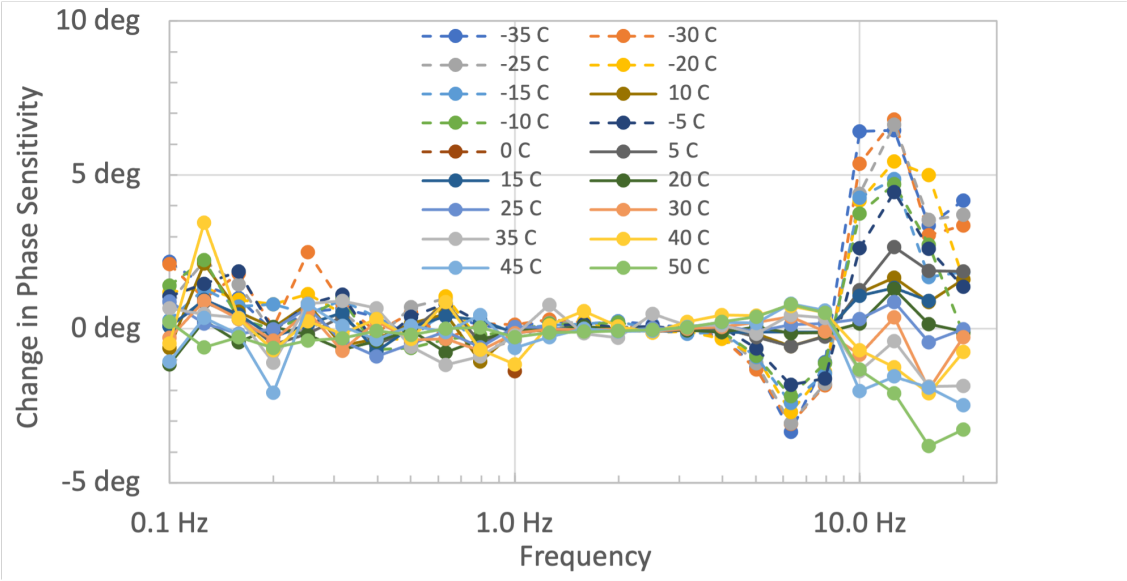

Figure 76 Relative Change in Phase Response with Temperature: InfraBSU #400

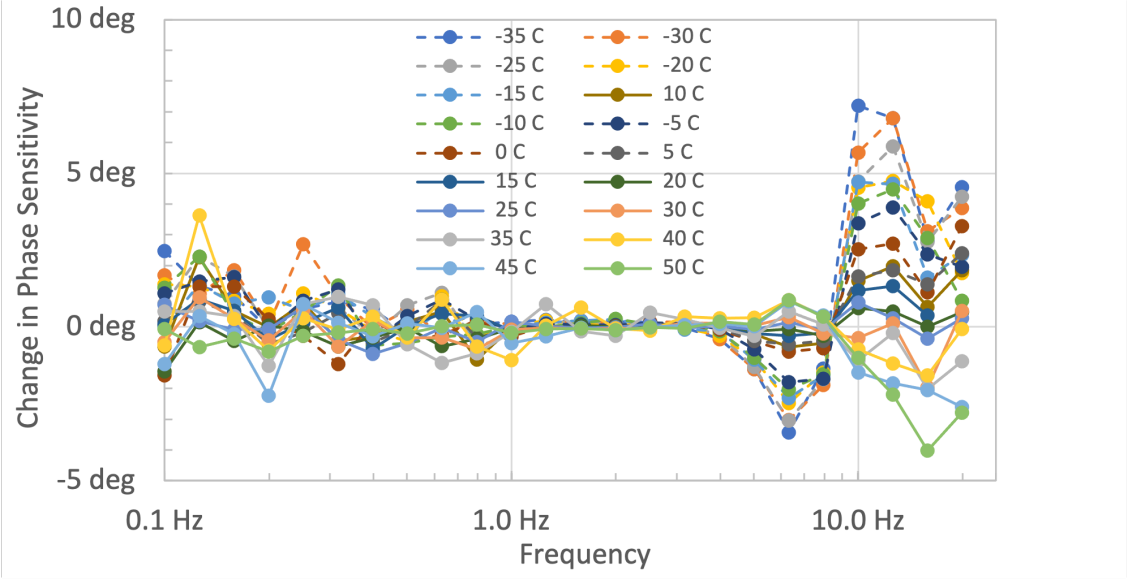

Figure 77 Relative Change in Phase Response with Temperature: InfraBSU #422

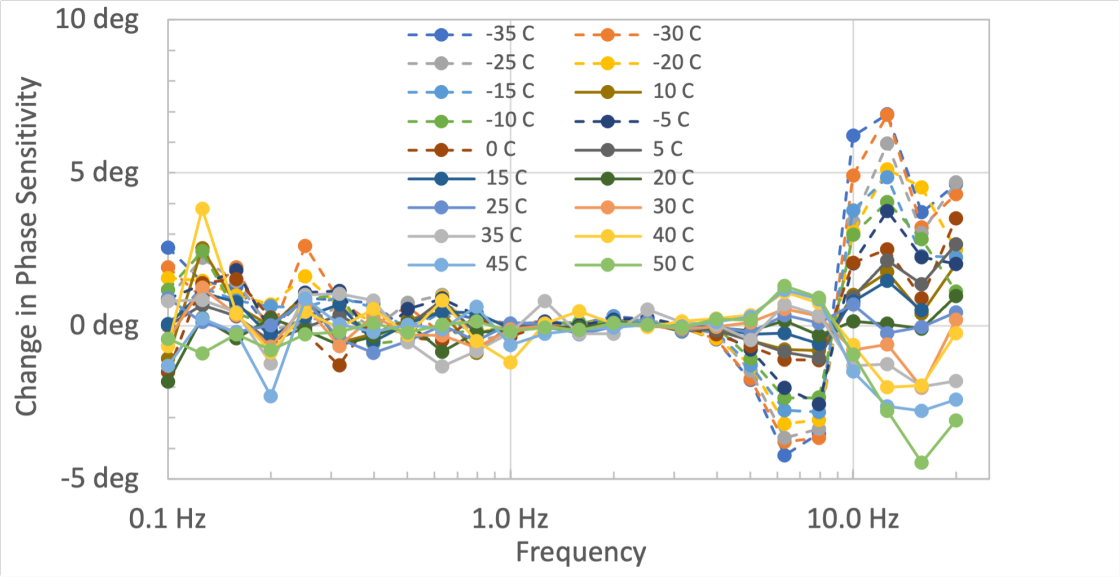

Figure 78 Relative Change in Phase Response with Temperature: InfraBSU #424

As observed with changes in amplitude sensitivity of the InfraBSU sensors, differences in phase of the are similar in character across sensors. Phase differences are largest in magnitude at frequencies above 10 Hz, where at the lowest temperatures evaluated phase changes exceed 7 degrees (sensor #422), and at the highest temperatures, phase changes approach 5 degrees (sensor #424). Phase differences at lower frequencies evaluated (below 1 Hz) show significant scatter in phase magnitude and polarity. Trends between 5 Hz and 8 Hz are for phase changes to become negative and increase in magnitude as temperature decreases; at and above 10 Hz phase changes shift, becoming increasingly positive with decreasing temperature.

The following tables contain the data shown in the above figures.

Table 71 Relative Change in Phase Response with Temperature: InfraBSU #400

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	2.18 deg	2.10 deg	0.85 deg	1.18 deg	0.29 deg	1.40 deg	1.05 deg	-1.38 deg	0.10 deg
0.126 Hz	1.40 deg	0.99 deg	2.20 deg	1.33 deg	1.30 deg	2.24 deg	1.46 deg	1.23 deg	0.87 deg
0.158 Hz	0.99 deg	1.80 deg	1.45 deg	0.94 deg	0.73 deg	0.32 deg	1.87 deg	1.45 deg	0.39 deg
0.200 Hz	-0.10 deg	0.05 deg	-0.15 deg	0.79 deg	0.80 deg	-0.02 deg	-0.07 deg	0.34 deg	-0.50 deg
0.251 Hz	0.55 deg	2.50 deg	-0.03 deg	1.14 deg	0.49 deg	0.42 deg	0.80 deg	-0.29 deg	-0.16 deg
0.316 Hz	0.65 deg	0.83 deg	0.56 deg	0.51 deg	0.94 deg	0.98 deg	1.12 deg	-1.33 deg	0.40 deg
0.398 Hz	0.39 deg	-0.10 deg	-0.34 deg	-0.26 deg	0.37 deg	-0.68 deg	-0.54 deg	0.19 deg	-0.49 deg
0.501 Hz	-0.25 deg	0.52 deg	0.70 deg	-0.40 deg	-0.17 deg	-0.62 deg	0.40 deg	-0.39 deg	-0.06 deg
0.631 Hz	0.51 deg	-0.34 deg	0.98 deg	1.05 deg	0.50 deg	-0.34 deg	0.81 deg	-0.42 deg	0.84 deg
0.794 Hz	0.10 deg	0.17 deg	-0.73 deg	-0.42 deg	-0.54 deg	-0.21 deg	0.22 deg	0.24 deg	-0.43 deg
1.000 Hz	0.02 deg	0.13 deg	-0.36 deg	0.03 deg	-0.01 deg	-0.04 deg	-0.10 deg	-0.40 deg	-0.02 deg
1.259 Hz	0.29 deg	0.30 deg	0.19 deg	0.06 deg	0.11 deg	0.17 deg	0.10 deg	0.05 deg	0.02 deg
1.585 Hz	0.11 deg	0.22 deg	0.20 deg	0.24 deg	0.15 deg	0.14 deg	0.15 deg	0.00 deg	-0.12 deg
1.995 Hz	0.24 deg	0.14 deg	0.04 deg	-0.01 deg	0.25 deg	0.20 deg	0.05 deg	0.00 deg	0.02 deg
2.512 Hz	0.14 deg	-0.02 deg	0.03 deg	-0.13 deg	-0.03 deg	-0.02 deg	0.07 deg	0.00 deg	-0.09 deg
3.162 Hz	0.05 deg	0.02 deg	-0.03 deg	-0.09 deg	-0.16 deg	0.08 deg	-0.02 deg	-0.09 deg	-0.05 deg
3.981 Hz	-0.28 deg	-0.29 deg	-0.13 deg	-0.32 deg	-0.10 deg	-0.08 deg	0.06 deg	-0.04 deg	0.03 deg
5.012 Hz	-1.25 deg	-1.32 deg	-1.12 deg	-0.89 deg	-0.91 deg	-0.88 deg	-0.64 deg	-0.35 deg	-0.28 deg
6.310 Hz	-3.35 deg	-3.09 deg	-3.07 deg	-2.71 deg	-2.41 deg	-2.18 deg	-1.81 deg	-0.81 deg	-0.57 deg
7.943 Hz	-1.08 deg	-1.83 deg	-1.78 deg	-1.40 deg	-1.45 deg	-1.11 deg	-1.61 deg	-0.33 deg	-0.25 deg
10.000 Hz	6.42 deg	5.36 deg	4.39 deg	4.16 deg	4.26 deg	3.75 deg	2.63 deg	2.23 deg	1.25 deg
12.589 Hz	6.45 deg	6.80 deg	6.63 deg	5.44 deg	4.86 deg	4.71 deg	4.44 deg	2.79 deg	2.66 deg
15.849 Hz	3.36 deg	3.05 deg	3.55 deg	5.00 deg	1.68 deg	2.74 deg	2.60 deg	1.51 deg	1.89 deg
19.953 Hz	4.17 deg	3.36 deg	3.70 deg	1.61 deg	1.85 deg	-0.16 deg	1.36 deg	2.58 deg	1.87 deg
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	-0.62 deg	0.07 deg	-1.16 deg	0.88 deg	-0.30 deg	0.66 deg	-0.47 deg	-1.06 deg	0.23 deg
0.126 Hz	2.12 deg	0.94 deg	0.26 deg	0.17 deg	0.92 deg	0.48 deg	3.45 deg	0.36 deg	-0.60 deg
0.158 Hz	0.55 deg	0.47 deg	-0.44 deg	-0.16 deg	0.32 deg	0.36 deg	0.34 deg	-0.18 deg	-0.27 deg
0.200 Hz	0.04 deg	-0.27 deg	0.07 deg	-0.01 deg	-0.38 deg	-1.11 deg	-0.70 deg	-2.08 deg	-0.61 deg
0.251 Hz	0.82 deg	0.15 deg	-0.20 deg	0.69 deg	0.56 deg	0.81 deg	0.24 deg	0.80 deg	-0.38 deg
0.316 Hz	-0.54 deg	0.52 deg	-0.68 deg	-0.40 deg	-0.71 deg	0.91 deg	-0.16 deg	0.09 deg	-0.31 deg
0.398 Hz	-0.32 deg	-0.72 deg	-0.41 deg	-0.90 deg	0.24 deg	0.67 deg	0.31 deg	-0.34 deg	-0.06 deg
0.501 Hz	0.18 deg	0.05 deg	-0.05 deg	-0.49 deg	-0.36 deg	-0.58 deg	-0.32 deg	0.09 deg	-0.19 deg
0.631 Hz	0.48 deg	0.42 deg	-0.76 deg	-0.08 deg	-0.33 deg	-1.17 deg	0.87 deg	-0.11 deg	0.01 deg
0.794 Hz	-1.06 deg	0.28 deg	-0.35 deg	-0.60 deg	-0.71 deg	-0.89 deg	-0.67 deg	0.45 deg	0.05 deg
1.000 Hz	-0.08 deg	-0.15 deg	-0.07 deg	0.05 deg	-0.14 deg	-0.22 deg	-1.15 deg	-0.62 deg	-0.27 deg
1.259 Hz	-0.04 deg	0.00 deg	-0.01 deg	0.05 deg	-0.01 deg	0.77 deg	0.12 deg	-0.28 deg	-0.13 deg
1.585 Hz	0.04 deg	-0.02 deg	0.08 deg	-0.06 deg	-0.03 deg	-0.15 deg	0.58 deg	0.00 deg	-0.09 deg
1.995 Hz	-0.01 deg	0.01 deg	-0.01 deg	-0.07 deg	-0.01 deg	-0.29 deg	0.08 deg	-0.09 deg	-0.06 deg
2.512 Hz	-0.05 deg	-0.02 deg	0.01 deg	0.02 deg	-0.09 deg	0.49 deg	-0.13 deg	-0.08 deg	-0.03 deg
3.162 Hz	0.01 deg	0.00 deg	-0.06 deg	0.01 deg	0.01 deg	0.09 deg	0.23 deg	0.06 deg	0.04 deg
3.981 Hz	0.05 deg	-0.11 deg	-0.10 deg	0.10 deg	0.06 deg	0.11 deg	0.45 deg	0.21 deg	0.23 deg
5.012 Hz	-0.16 deg	-0.11 deg	0.06 deg	-0.08 deg	0.20 deg	-0.16 deg	0.43 deg	0.20 deg	0.39 deg
6.310 Hz	-0.56 deg	-0.11 deg	-0.14 deg	0.14 deg	0.40 deg	0.44 deg	0.75 deg	0.81 deg	0.80 deg
7.943 Hz	-0.24 deg	-0.10 deg	-0.13 deg	0.18 deg	-0.09 deg	0.35 deg	0.53 deg	0.60 deg	0.52 deg
10.000 Hz	1.17 deg	1.07 deg	0.18 deg	0.32 deg	-0.84 deg	-1.38 deg	-0.69 deg	-2.02 deg	-1.33 deg
12.589 Hz	1.67 deg	1.34 deg	1.30 deg	0.88 deg	0.38 deg	-0.40 deg	-1.25 deg	-1.55 deg	-2.09 deg
15.849 Hz	0.88 deg	0.91 deg	0.16 deg	-0.43 deg	-1.97 deg	-1.87 deg	-2.10 deg	-1.91 deg	-3.80 deg
19.953 Hz	1.61 deg	-	-0.08 deg	-0.02 deg	-0.27 deg	-1.85 deg	-0.75 deg	-2.48 deg	-3.27 deg

Table 72 Relative Change in Phase Response with Temperature: InfraBSU #422

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	2.48 deg	1.69 deg	0.77 deg	1.39 deg	0.01 deg	1.28 deg	1.09 deg	-1.57 deg	0.19 deg
0.126 Hz	1.34 deg	1.08 deg	2.29 deg	1.32 deg	1.40 deg	2.29 deg	1.48 deg	1.31 deg	0.84 deg
0.158 Hz	1.01 deg	1.85 deg	1.65 deg	0.85 deg	0.75 deg	0.37 deg	1.63 deg	1.31 deg	0.42 deg
0.200 Hz	-0.06 deg	0.08 deg	-0.05 deg	0.43 deg	0.96 deg	-0.17 deg	-0.10 deg	0.25 deg	-0.55 deg
0.251 Hz	0.59 deg	2.69 deg	0.12 deg	1.09 deg	0.53 deg	0.50 deg	0.85 deg	-0.29 deg	-0.17 deg
0.316 Hz	0.82 deg	0.98 deg	0.64 deg	0.60 deg	1.08 deg	1.36 deg	1.23 deg	-1.21 deg	0.45 deg
0.398 Hz	0.59 deg	-0.04 deg	-0.29 deg	-0.12 deg	0.32 deg	-0.60 deg	-0.47 deg	0.19 deg	-0.50 deg
0.501 Hz	-0.21 deg	0.56 deg	0.71 deg	-0.47 deg	-0.26 deg	-0.53 deg	0.36 deg	-0.38 deg	0.00 deg
0.631 Hz	0.58 deg	-0.25 deg	1.10 deg	1.01 deg	0.56 deg	-0.32 deg	0.88 deg	-0.29 deg	0.86 deg
0.794 Hz	0.08 deg	0.22 deg	-0.60 deg	-0.31 deg	-0.42 deg	-0.23 deg	0.23 deg	0.22 deg	-0.36 deg
1.000 Hz	0.17 deg	0.08 deg	-0.32 deg	0.05 deg	0.02 deg	0.03 deg	-0.06 deg	-0.31 deg	-0.05 deg
1.259 Hz	0.23 deg	0.12 deg	0.17 deg	0.21 deg	0.13 deg	0.01 deg	0.09 deg	0.04 deg	-0.02 deg
1.585 Hz	0.14 deg	0.21 deg	0.16 deg	0.08 deg	0.22 deg	0.13 deg	0.09 deg	-0.04 deg	-0.05 deg
1.995 Hz	0.17 deg	0.08 deg	0.06 deg	0.07 deg	0.25 deg	0.26 deg	0.06 deg	0.03 deg	0.00 deg
2.512 Hz	0.15 deg	0.17 deg	0.08 deg	0.11 deg	0.04 deg	0.09 deg	0.13 deg	0.02 deg	0.11 deg
3.162 Hz	-0.03 deg	0.16 deg	0.05 deg	-0.03 deg	-0.08 deg	0.10 deg	0.12 deg	0.07 deg	0.06 deg
3.981 Hz	-0.38 deg	-0.40 deg	-0.25 deg	-0.29 deg	-0.13 deg	-0.15 deg	-0.07 deg	-0.08 deg	-0.03 deg
5.012 Hz	-1.36 deg	-1.37 deg	-1.31 deg	-1.05 deg	-1.07 deg	-1.01 deg	-0.73 deg	-0.46 deg	-0.44 deg
6.310 Hz	-3.43 deg	-3.02 deg	-3.05 deg	-2.48 deg	-2.31 deg	-2.04 deg	-1.79 deg	-0.80 deg	-0.57 deg
7.943 Hz	-1.36 deg	-1.88 deg	-1.71 deg	-1.49 deg	-1.58 deg	-1.54 deg	-1.68 deg	-0.69 deg	-0.46 deg
10.000 Hz	7.20 deg	5.67 deg	4.73 deg	4.53 deg	4.72 deg	4.02 deg	3.37 deg	2.52 deg	1.65 deg
12.589 Hz	6.80 deg	6.79 deg	5.88 deg	4.76 deg	4.65 deg	4.47 deg	3.89 deg	2.71 deg	1.84 deg
15.849 Hz	2.81 deg	3.11 deg	2.76 deg	4.09 deg	1.60 deg	2.90 deg	2.37 deg	1.12 deg	1.39 deg
19.953 Hz	4.54 deg	3.87 deg	4.24 deg	1.75 deg	2.35 deg	0.86 deg	1.96 deg	3.28 deg	2.40 deg
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	-0.63 deg	0.09 deg	-1.44 deg	0.72 deg	-0.49 deg	0.51 deg	-0.60 deg	-1.21 deg	-0.07 deg
0.126 Hz	2.26 deg	0.91 deg	0.16 deg	0.19 deg	0.97 deg	0.51 deg	3.62 deg	0.35 deg	-0.66 deg
0.158 Hz	0.52 deg	0.52 deg	-0.45 deg	-0.09 deg	0.27 deg	0.35 deg	0.27 deg	-0.23 deg	-0.39 deg
0.200 Hz	-0.01 deg	-0.41 deg	0.05 deg	-0.06 deg	-0.43 deg	-1.27 deg	-0.77 deg	-2.23 deg	-0.80 deg
0.251 Hz	0.77 deg	0.13 deg	-0.14 deg	0.65 deg	0.55 deg	0.74 deg	0.28 deg	0.75 deg	-0.29 deg
0.316 Hz	-0.46 deg	0.64 deg	-0.64 deg	-0.42 deg	-0.64 deg	0.99 deg	-0.08 deg	0.13 deg	-0.19 deg
0.398 Hz	-0.30 deg	-0.72 deg	-0.34 deg	-0.88 deg	0.22 deg	0.70 deg	0.33 deg	-0.30 deg	-0.07 deg
0.501 Hz	0.17 deg	0.02 deg	-0.03 deg	-0.52 deg	-0.35 deg	-0.56 deg	-0.34 deg	0.12 deg	-0.21 deg
0.631 Hz	0.51 deg	0.43 deg	-0.63 deg	-0.03 deg	-0.35 deg	-1.18 deg	0.90 deg	-0.03 deg	0.03 deg
0.794 Hz	-1.05 deg	0.35 deg	-0.38 deg	-0.50 deg	-0.72 deg	-0.86 deg	-0.63 deg	0.49 deg	0.08 deg
1.000 Hz	-0.01 deg	-0.13 deg	-0.05 deg	0.17 deg	-0.09 deg	-0.16 deg	-1.08 deg	-0.52 deg	-0.19 deg
1.259 Hz	0.03 deg	-0.05 deg	-0.09 deg	0.02 deg	-0.03 deg	0.75 deg	0.04 deg	-0.30 deg	-0.07 deg
1.585 Hz	0.06 deg	0.02 deg	0.04 deg	-0.03 deg	-0.07 deg	-0.14 deg	0.63 deg	-0.03 deg	-0.06 deg
1.995 Hz	-0.01 deg	-0.02 deg	0.01 deg	-0.01 deg	-0.05 deg	-0.28 deg	-0.04 deg	-0.11 deg	-0.09 deg
2.512 Hz	0.10 deg	-0.02 deg	-0.01 deg	0.09 deg	-0.04 deg	0.46 deg	-0.12 deg	-0.02 deg	0.00 deg
3.162 Hz	0.08 deg	0.06 deg	0.02 deg	-0.03 deg	0.13 deg	0.25 deg	0.34 deg	0.06 deg	-0.05 deg
3.981 Hz	0.00 deg	-0.01 deg	0.06 deg	0.02 deg	0.12 deg	-0.02 deg	0.28 deg	0.10 deg	0.18 deg
5.012 Hz	-0.22 deg	-0.21 deg	-0.15 deg	-0.08 deg	0.04 deg	-0.30 deg	0.30 deg	0.02 deg	0.09 deg
6.310 Hz	-0.66 deg	-0.28 deg	-0.06 deg	0.16 deg	0.32 deg	0.51 deg	0.87 deg	0.84 deg	0.88 deg
7.943 Hz	-0.53 deg	-0.20 deg	-0.28 deg	-0.10 deg	-0.21 deg	0.09 deg	0.35 deg	0.38 deg	0.33 deg
10.000 Hz	1.50 deg	1.18 deg	0.61 deg	0.79 deg	-0.36 deg	-1.09 deg	-0.72 deg	-1.48 deg	-1.00 deg
12.589 Hz	1.98 deg	1.33 deg	0.51 deg	0.28 deg	0.12 deg	-0.20 deg	-1.18 deg	-1.83 deg	-2.20 deg
15.849 Hz	0.66 deg	0.38 deg	0.00 deg	-0.38 deg	-1.96 deg	-2.02 deg	-1.58 deg	-2.06 deg	-4.01 deg
19.953 Hz	1.85 deg	-	-	0.29 deg	0.52 deg	-1.11 deg	-0.07 deg	-2.60 deg	-2.78 deg

Table 73 Relative Change in Phase Response with Temperature: InfraBSU #424

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	2.56 deg	1.92 deg	0.88 deg	1.57 deg	0.06 deg	1.18 deg	0.89 deg	-1.50 deg	0.00 deg
0.126 Hz	1.45 deg	0.93 deg	2.22 deg	1.48 deg	1.25 deg	2.44 deg	1.35 deg	1.41 deg	0.69 deg
0.158 Hz	1.29 deg	1.91 deg	1.46 deg	0.99 deg	0.83 deg	0.43 deg	1.82 deg	1.52 deg	0.32 deg
0.200 Hz	-0.16 deg	-0.27 deg	-0.11 deg	0.71 deg	0.64 deg	-0.03 deg	-0.16 deg	0.27 deg	-0.51 deg
0.251 Hz	0.90 deg	2.61 deg	0.06 deg	1.62 deg	0.61 deg	0.85 deg	1.08 deg	-0.23 deg	-0.06 deg
0.316 Hz	0.85 deg	0.83 deg	0.65 deg	0.63 deg	0.94 deg	1.04 deg	1.14 deg	-1.29 deg	0.36 deg
0.398 Hz	0.74 deg	0.06 deg	-0.09 deg	0.13 deg	0.60 deg	-0.58 deg	-0.47 deg	0.32 deg	-0.28 deg
0.501 Hz	-0.20 deg	0.63 deg	0.76 deg	-0.34 deg	-0.09 deg	-0.46 deg	0.56 deg	-0.37 deg	0.00 deg
0.631 Hz	0.49 deg	-0.27 deg	1.01 deg	0.95 deg	0.48 deg	-0.28 deg	0.90 deg	-0.47 deg	0.85 deg
0.794 Hz	0.23 deg	0.25 deg	-0.47 deg	-0.24 deg	-0.36 deg	-0.12 deg	0.36 deg	0.32 deg	-0.23 deg
1.000 Hz	0.08 deg	0.05 deg	-0.27 deg	0.04 deg	0.06 deg	-0.10 deg	-0.04 deg	-0.34 deg	-0.07 deg
1.259 Hz	0.15 deg	0.14 deg	0.11 deg	0.03 deg	0.13 deg	0.10 deg	0.14 deg	0.04 deg	0.07 deg
1.585 Hz	0.06 deg	0.01 deg	0.10 deg	0.10 deg	0.05 deg	0.12 deg	0.02 deg	-0.18 deg	-0.17 deg
1.995 Hz	0.31 deg	0.20 deg	0.19 deg	0.19 deg	0.30 deg	0.16 deg	0.21 deg	0.08 deg	0.06 deg
2.512 Hz	0.20 deg	0.10 deg	0.20 deg	0.17 deg	0.11 deg	0.09 deg	0.26 deg	0.03 deg	0.00 deg
3.162 Hz	-0.04 deg	-0.06 deg	-0.07 deg	-0.09 deg	-0.08 deg	0.02 deg	0.02 deg	-0.04 deg	-0.08 deg
3.981 Hz	-0.45 deg	-0.43 deg	-0.23 deg	-0.40 deg	-0.20 deg	-0.02 deg	-0.17 deg	-0.28 deg	-0.14 deg
5.012 Hz	-1.77 deg	-1.72 deg	-1.46 deg	-1.25 deg	-1.29 deg	-1.06 deg	-0.77 deg	-0.66 deg	-0.48 deg
6.310 Hz	-4.22 deg	-3.78 deg	-3.66 deg	-3.19 deg	-2.76 deg	-2.35 deg	-2.02 deg	-1.10 deg	-0.85 deg
7.943 Hz	-3.51 deg	-3.65 deg	-3.36 deg	-3.06 deg	-2.81 deg	-2.34 deg	-2.55 deg	-1.11 deg	-1.05 deg
10.000 Hz	6.21 deg	4.91 deg	3.40 deg	3.08 deg	3.77 deg	2.99 deg	2.05 deg	2.06 deg	0.94 deg
12.589 Hz	6.91 deg	6.90 deg	5.96 deg	5.12 deg	4.85 deg	4.05 deg	3.76 deg	2.50 deg	2.13 deg
15.849 Hz	3.71 deg	3.22 deg	3.04 deg	4.53 deg	2.28 deg	2.83 deg	2.25 deg	0.90 deg	1.37 deg
19.953 Hz	4.64 deg	4.31 deg	4.69 deg	2.48 deg	2.25 deg	1.12 deg	2.03 deg	3.51 deg	2.67 deg
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	-1.07 deg	0.05 deg	-1.82 deg	0.91 deg	-0.43 deg	0.81 deg	-0.66 deg	-1.30 deg	-0.42 deg
0.126 Hz	2.54 deg	1.09 deg	0.26 deg	0.12 deg	1.25 deg	0.85 deg	3.83 deg	0.25 deg	-0.90 deg
0.158 Hz	0.67 deg	0.78 deg	-0.40 deg	-0.19 deg	0.36 deg	0.45 deg	0.41 deg	-0.21 deg	-0.27 deg
0.200 Hz	0.00 deg	-0.37 deg	0.25 deg	0.02 deg	-0.67 deg	-1.23 deg	-0.85 deg	-2.30 deg	-0.79 deg
0.251 Hz	1.04 deg	0.31 deg	-0.15 deg	0.85 deg	0.68 deg	1.02 deg	0.47 deg	0.89 deg	-0.26 deg
0.316 Hz	-0.54 deg	0.70 deg	-0.62 deg	-0.41 deg	-0.65 deg	1.05 deg	-0.07 deg	0.06 deg	-0.20 deg
0.398 Hz	-0.25 deg	-0.52 deg	-0.35 deg	-0.88 deg	0.34 deg	0.83 deg	0.56 deg	-0.20 deg	0.10 deg
0.501 Hz	0.21 deg	0.07 deg	0.10 deg	-0.49 deg	-0.29 deg	-0.53 deg	-0.29 deg	0.04 deg	-0.22 deg
0.631 Hz	0.46 deg	0.46 deg	-0.84 deg	0.02 deg	-0.30 deg	-1.31 deg	0.84 deg	-0.10 deg	0.05 deg
0.794 Hz	-0.88 deg	0.43 deg	-0.22 deg	-0.49 deg	-0.72 deg	-0.83 deg	-0.49 deg	0.64 deg	0.15 deg
1.000 Hz	0.04 deg	-0.08 deg	-0.12 deg	0.07 deg	-0.10 deg	-0.21 deg	-1.19 deg	-0.62 deg	-0.17 deg
1.259 Hz	-0.04 deg	-0.04 deg	-0.03 deg	0.07 deg	0.01 deg	0.82 deg	0.08 deg	-0.24 deg	-0.05 deg
1.585 Hz	-0.10 deg	-0.18 deg	-0.04 deg	-0.27 deg	-0.16 deg	-0.26 deg	0.48 deg	-0.13 deg	-0.13 deg
1.995 Hz	0.18 deg	0.15 deg	0.04 deg	-0.03 deg	0.10 deg	-0.25 deg	0.08 deg	-0.05 deg	0.09 deg
2.512 Hz	0.04 deg	-0.02 deg	0.08 deg	0.15 deg	0.00 deg	0.54 deg	-0.03 deg	0.05 deg	0.04 deg
3.162 Hz	0.07 deg	-0.03 deg	-0.19 deg	-0.16 deg	-0.09 deg	0.11 deg	0.15 deg	-0.02 deg	-0.05 deg
3.981 Hz	-0.01 deg	-0.05 deg	-0.05 deg	-0.01 deg	-0.04 deg	0.04 deg	0.25 deg	0.13 deg	0.23 deg
5.012 Hz	-0.48 deg	-0.26 deg	-0.16 deg	-0.21 deg	0.11 deg	-0.46 deg	0.35 deg	0.30 deg	0.19 deg
6.310 Hz	-0.76 deg	-0.24 deg	0.17 deg	0.35 deg	0.56 deg	0.70 deg	1.11 deg	1.18 deg	1.31 deg
7.943 Hz	-0.80 deg	-0.58 deg	-0.31 deg	0.09 deg	0.31 deg	0.35 deg	0.75 deg	0.87 deg	0.92 deg
10.000 Hz	1.01 deg	0.79 deg	0.15 deg	0.71 deg	-0.78 deg	-1.30 deg	-0.62 deg	-1.49 deg	-0.94 deg
12.589 Hz	1.76 deg	1.47 deg	0.07 deg	-0.23 deg	-0.60 deg	-1.25 deg	-2.00 deg	-2.63 deg	-2.77 deg
15.849 Hz	0.41 deg	0.51 deg	-0.09 deg	-0.03 deg	-2.02 deg	-1.98 deg	-1.94 deg	-2.77 deg	-4.47 deg
19.953 Hz	2.03 deg	-	-	0.45 deg	0.20 deg	-1.79 deg	-0.24 deg	-2.41 deg	-3.08 deg

3.9.4.3 Gem Infrasound Logger

The figure below illustrates the relative change in the amplitude response over -35 C to +50 C relative to the amplitude sensitivity observed at 23 C for Gem package #070.

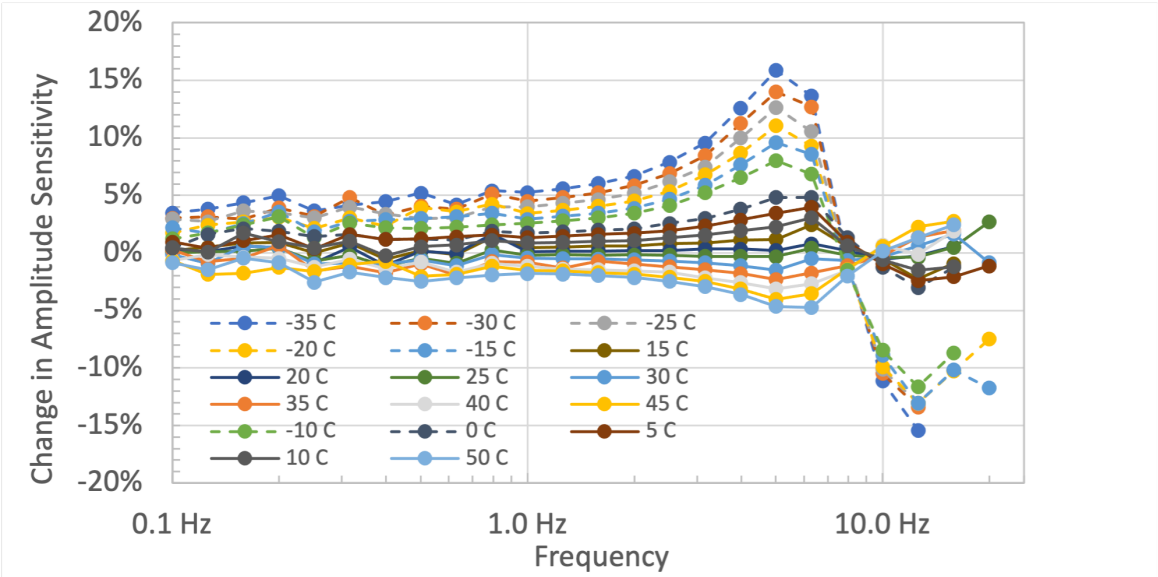

Figure 79 Relative Change in Amplitude Response with Temperature: Gem #070

Below approximately 8 Hz, relative changes in amplitude sensitivity increase for temperatures above 23 C and decrease for those below 23 C. Above 8 Hz, the trend in relative change in amplitude sensitivity is opposite of that below 8 Hz. The largest changes are associated with the highest and lowest temperatures. Gem #070 exceeds +/-15% relative change in sensitivity at 5 Hz and 12.5 Hz during the -35 C evaluation. Note, due to the lower sample rate of the Gem package, robust sine fits for the analysis at higher frequencies were not always possible, hence varying high frequency limits of the evaluation.

The following three table contain the data shown in the above figure.

Table 74 Relative Change in Amplitude Response with Temperature: Gem #070

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	3.47%	3.02%	2.94%	1.74%	2.19%	1.21%	-	0.42%	0.94%
0.126 Hz	3.79%	3.16%	2.71%	2.42%	1.75%	1.75%	-	1.60%	0.41%
0.158 Hz	4.38%	2.93%	3.67%	2.71%	2.56%	2.45%	-	2.11%	1.08%
0.200 Hz	4.99%	3.92%	3.47%	3.10%	3.55%	3.14%	-	1.88%	1.55%
0.251 Hz	3.64%	3.17%	3.06%	2.15%	1.82%	1.31%	-	1.42%	0.36%
0.316 Hz	4.14%	4.83%	3.99%	3.04%	2.75%	2.60%	-	1.61%	1.61%
0.398 Hz	4.46%	3.30%	3.38%	2.32%	2.90%	2.18%	-	1.16%	1.16%
0.501 Hz	5.21%	4.08%	2.99%	3.93%	2.99%	2.15%	-	1.20%	1.24%
0.631 Hz	4.19%	3.79%	3.04%	3.58%	3.14%	2.24%	-	1.12%	1.41%
0.794 Hz	5.40%	5.11%	3.99%	4.24%	3.44%	2.43%	-	1.89%	1.56%
1.000 Hz	5.25%	4.50%	4.00%	3.43%	2.93%	2.57%	-	1.71%	1.32%
1.259 Hz	5.59%	4.81%	4.32%	3.72%	3.19%	2.80%	-	1.84%	1.45%
1.585 Hz	6.03%	5.23%	4.64%	4.05%	3.45%	3.03%	-	1.99%	1.60%
1.995 Hz	6.67%	5.86%	5.18%	4.53%	3.88%	3.44%	-	2.08%	1.70%
2.512 Hz	7.88%	6.90%	6.17%	5.35%	4.66%	4.11%	-	2.56%	1.94%
3.162 Hz	9.55%	8.47%	7.47%	6.79%	5.89%	5.24%	-	3.01%	2.33%
3.981 Hz	12.59%	11.26%	9.98%	8.67%	7.65%	6.54%	-	3.81%	2.87%
5.012 Hz	15.86%	14.02%	12.65%	11.04%	9.60%	8.02%	-	4.81%	3.45%
6.310 Hz	13.63%	12.71%	10.53%	9.28%	8.56%	6.85%	-	4.84%	3.98%
7.943 Hz	-0.39%	-0.50%	-0.60%	-1.07%	-1.28%	-1.49%	-	1.36%	0.94%
10.000 Hz	-11.13%	-10.48%	-10.13%	-9.90%	-8.90%	-8.44%	-	-1.23%	-0.96%
12.589 Hz	-15.43%	-13.41%	-13.10%	-13.04%	-13.04%	-11.65%	-	-3.02%	-2.39%
15.849 Hz	-	-	-	-10.25%	-10.18%	-8.70%	-	-1.27%	-2.07%
19.953 Hz	-	-	-	-7.48%	-11.74%	-	-	-	-1.14%

Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	0.45%	0.19%	0.34%	0.00%	-0.15%	0.26%	-0.64%	-0.68%	-0.87%
0.126 Hz	0.07%	0.48%	0.11%	0.11%	-0.93%	-0.74%	-0.15%	-1.86%	-1.45%
0.158 Hz	1.74%	0.85%	0.59%	0.15%	0.59%	-0.44%	-0.37%	-1.78%	-0.44%
0.200 Hz	0.96%	0.92%	0.48%	0.41%	0.48%	0.67%	-0.48%	-1.26%	-0.85%
0.251 Hz	0.44%	0.00%	-0.84%	-0.69%	-0.95%	-1.57%	-1.24%	-1.60%	-2.55%
0.316 Hz	1.03%	0.84%	0.51%	-0.22%	-0.84%	-1.17%	-0.55%	-1.03%	-1.65%
0.398 Hz	-0.25%	-0.54%	-1.09%	-1.13%	-0.94%	-1.74%	-1.38%	-0.73%	-2.14%
0.501 Hz	0.55%	0.18%	0.15%	-0.47%	-0.58%	-0.95%	-0.80%	-2.04%	-2.48%
0.631 Hz	0.69%	-0.14%	-0.04%	-0.90%	-1.12%	-1.92%	-1.66%	-1.88%	-2.17%
0.794 Hz	1.09%	1.38%	1.63%	0.25%	-0.15%	-0.76%	-0.91%	-1.16%	-1.92%
1.000 Hz	0.86%	0.46%	0.11%	-0.18%	-0.46%	-0.79%	-1.14%	-1.50%	-1.79%
1.259 Hz	0.92%	0.53%	0.14%	-0.14%	-0.50%	-1.31%	-1.42%	-1.56%	-1.84%
1.585 Hz	1.01%	0.59%	0.17%	-0.21%	-0.52%	-0.73%	-1.46%	-1.71%	-1.95%
1.995 Hz	1.06%	0.61%	0.20%	-0.17%	-0.61%	-0.95%	-1.57%	-1.84%	-2.15%
2.512 Hz	1.31%	0.79%	0.20%	-0.20%	-0.69%	-1.22%	-1.67%	-2.13%	-2.46%
3.162 Hz	1.55%	0.84%	0.34%	-0.31%	-0.87%	-1.46%	-2.17%	-2.48%	-2.95%
3.981 Hz	1.93%	1.14%	0.34%	-0.31%	-1.11%	-1.79%	-2.56%	-3.13%	-3.61%
5.012 Hz	2.27%	1.16%	0.23%	-0.33%	-1.51%	-2.32%	-3.13%	-4.03%	-4.66%
6.310 Hz	3.08%	2.43%	0.79%	0.42%	-0.51%	-1.74%	-2.68%	-3.54%	-4.74%
7.943 Hz	0.63%	0.55%	0.18%	-0.18%	-0.65%	-1.12%	-1.54%	-1.44%	-2.01%
10.000 Hz	-0.61%	-0.50%	-0.54%	-0.42%	-0.35%	-0.23%	0.65%	0.58%	0.15%
12.589 Hz	-1.51%	-2.27%	-0.25%	-0.38%	0.63%	1.39%	-0.13%	2.27%	1.32%
15.849 Hz	-1.19%	-0.93%	0.55%	0.48%	1.64%	1.94%	1.89%	2.73%	2.45%
19.953 Hz	-	-	-	2.72%	-0.86%	-	-	-	-

The figure below illustrates the difference in the phase response over -35 C to +50 C relative to the amplitude sensitivity observed at 23 C for Gem package #070.

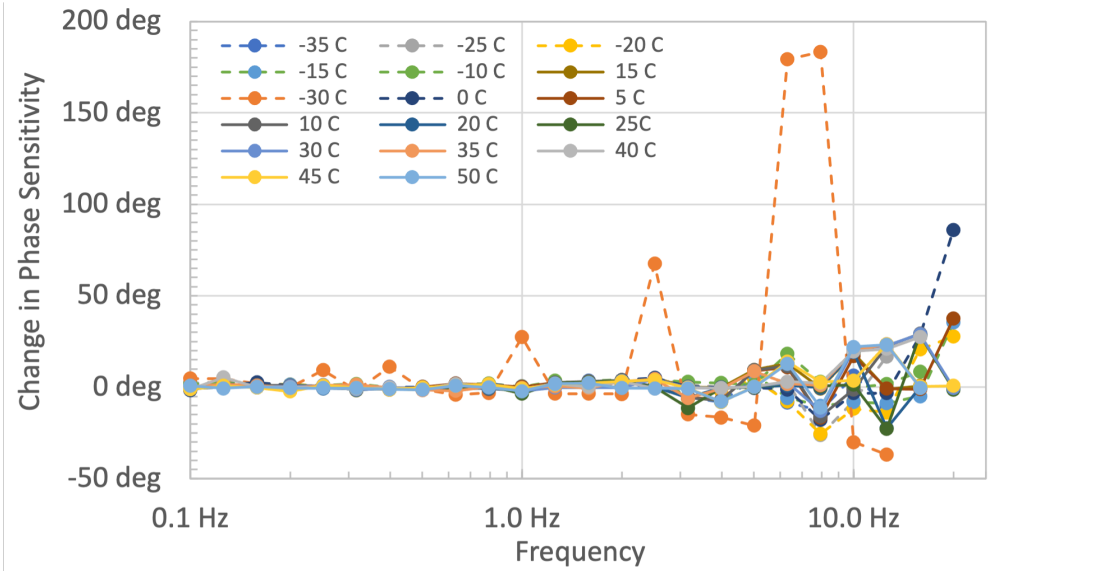

Figure 80 Relative Change in Phase Response with Temperature: Gem #070

Discounting the anomalous phase change observed at -30 C, relative phase changes at frequencies below 2.5 Hz remain less than +/- 5 degrees. The magnitude of relative phases differences above 2.5 Hz gradually increases with frequency to values as has as -37.73 degrees, discounting the outlier of -86 observed at 0 C. These large relative phase changes at higher frequencies. observed in the Gem data, may be an artifact of the timing algorithm of its internal digitizer and GPS receiver.

Table 75 contains the data shown in the above figure.

Table 75 Relative Change in Phase Response with Temperature: Gem #070

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	2.38 deg	4.86 deg	2.34 deg	1.12 deg	0.67 deg	1.74 deg	-	-1.47 deg	-0.24 deg
0.126 Hz	1.74 deg	4.71 deg	2.77 deg	2.18 deg	2.02 deg	2.70 deg	-	1.25 deg	1.17 deg
0.158 Hz	2.10 deg	1.84 deg	2.30 deg	1.37 deg	0.89 deg	1.39 deg	-	2.61 deg	0.66 deg
0.200 Hz	1.04 deg	-0.15 deg	1.43 deg	1.57 deg	1.55 deg	0.93 deg	-	0.93 deg	-0.03 deg
0.251 Hz	1.12 deg	9.37 deg	-0.08 deg	0.82 deg	0.36 deg	0.95 deg	-	0.29 deg	-0.39 deg
0.316 Hz	1.34 deg	-1.58 deg	1.15 deg	1.06 deg	0.70 deg	1.86 deg	-	-0.92 deg	0.11 deg
0.398 Hz	0.15 deg	11.23 deg	-0.86 deg	-0.63 deg	-0.08 deg	-0.23 deg	-	-0.21 deg	-1.28 deg
0.501 Hz	0.29 deg	-1.04 deg	0.07 deg	-1.25 deg	-0.82 deg	-0.91 deg	-	-0.23 deg	0.14 deg
0.631 Hz	0.93 deg	-4.04 deg	1.59 deg	1.07 deg	2.06 deg	1.63 deg	-	0.86 deg	2.03 deg
0.794 Hz	0.55 deg	-2.96 deg	1.50 deg	1.21 deg	-0.09 deg	2.10 deg	-	1.85 deg	1.22 deg
1.000 Hz	-0.95 deg	27.49 deg	-1.35 deg	0.49 deg	0.46 deg	0.23 deg	-	-0.06 deg	0.18 deg
1.259 Hz	0.69 deg	-3.50 deg	3.33 deg	2.48 deg	0.62 deg	3.66 deg	-	0.35 deg	2.58 deg
1.585 Hz	3.68 deg	-3.39 deg	1.10 deg	2.98 deg	3.49 deg	1.71 deg	-	0.35 deg	0.36 deg
1.995 Hz	0.88 deg	-3.68 deg	0.61 deg	-0.32 deg	4.05 deg	1.70 deg	-	4.11 deg	3.96 deg
2.512 Hz	1.09 deg	67.50 deg	5.19 deg	4.97 deg	4.84 deg	4.22 deg	-	5.04 deg	0.54 deg
3.162 Hz	-5.25 deg	-14.72 deg	1.45 deg	-6.09 deg	-5.17 deg	2.91 deg	-	0.42 deg	-5.29 deg
3.981 Hz	-8.03 deg	-16.43 deg	0.03 deg	-2.06 deg	-7.64 deg	2.38 deg	-	-0.14 deg	-6.99 deg
5.012 Hz	5.40 deg	-20.91 deg	7.08 deg	4.43 deg	6.91 deg	1.65 deg	-	-0.28 deg	9.07 deg
6.310 Hz	-8.22 deg	179.29 deg	2.54 deg	-7.71 deg	-5.79 deg	18.26 deg	-	-1.16 deg	10.95 deg
7.943 Hz	-12.79 deg	183.33 deg	-26.01 deg	-25.40 deg	-9.99 deg	2.92 deg	-	-17.74 deg	-16.58 deg
10.000 Hz	6.42 deg	-29.90 deg	-7.40 deg	-11.70 deg	-8.10 deg	-0.30 deg	-	-3.20 deg	16.98 deg
12.589 Hz	-10.10 deg	-36.80 deg	16.80 deg	-13.70 deg	-8.60 deg	1.70 deg	-	-3.20 deg	-0.70 deg
15.849 Hz	-	-	-	20.70 deg	-4.80 deg	8.60 deg	-	28.10 deg	-1.00 deg
19.953 Hz	-	-	-	27.79 deg	35.41 deg	-	-	86.09 deg	37.73 deg
Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	0.05 deg	-0.15 deg	-0.76 deg	-0.48 deg	-0.52 deg	0.38 deg	-0.94 deg	-1.00 deg	0.76 deg
0.126 Hz	1.52 deg	1.08 deg	0.19 deg	0.47 deg	0.21 deg	1.72 deg	5.48 deg	0.83 deg	-0.49 deg
0.158 Hz	1.15 deg	0.55 deg	0.06 deg	0.20 deg	0.48 deg	1.00 deg	0.02 deg	-0.07 deg	0.33 deg
0.200 Hz	0.97 deg	0.56 deg	-0.37 deg	0.25 deg	0.57 deg	-0.59 deg	0.03 deg	-2.21 deg	-0.32 deg
0.251 Hz	0.76 deg	0.29 deg	-0.50 deg	0.74 deg	0.76 deg	1.01 deg	-0.08 deg	0.91 deg	-0.48 deg
0.316 Hz	-0.92 deg	0.35 deg	-0.68 deg	-1.51 deg	-1.24 deg	1.46 deg	-0.70 deg	-0.27 deg	-0.38 deg
0.398 Hz	-0.15 deg	-0.75 deg	-0.49 deg	-0.52 deg	-0.41 deg	-0.29 deg	-0.14 deg	-1.14 deg	-1.02 deg
0.501 Hz	-0.57 deg	-0.69 deg	-0.87 deg	-1.22 deg	-1.32 deg	-1.52 deg	-0.65 deg	-0.11 deg	-1.31 deg
0.631 Hz	0.46 deg	0.51 deg	-0.67 deg	-1.12 deg	0.71 deg	-1.95 deg	1.95 deg	0.95 deg	1.00 deg
0.794 Hz	-0.87 deg	1.90 deg	-0.33 deg	0.75 deg	0.54 deg	0.31 deg	0.73 deg	1.74 deg	-0.10 deg
1.000 Hz	-1.61 deg	-1.73 deg	-1.83 deg	-3.53 deg	-1.94 deg	-0.39 deg	-0.96 deg	-0.63 deg	-2.14 deg
1.259 Hz	2.52 deg	2.45 deg	2.32 deg	2.25 deg	-0.08 deg	0.65 deg	2.08 deg	1.65 deg	1.88 deg
1.585 Hz	3.28 deg	0.35 deg	0.08 deg	2.89 deg	-0.12 deg	-0.45 deg	0.22 deg	2.43 deg	2.42 deg
1.995 Hz	3.86 deg	0.27 deg	3.67 deg	3.49 deg	-0.05 deg	3.07 deg	3.24 deg	3.12 deg	-0.46 deg
2.512 Hz	0.40 deg	4.92 deg	0.18 deg	-0.01 deg	4.35 deg	4.48 deg	-0.57 deg	4.10 deg	-0.57 deg
3.162 Hz	-5.59 deg	0.04 deg	-5.70 deg	-11.28 deg	-0.25 deg	-5.95 deg	-0.13 deg	-0.35 deg	-0.64 deg
3.981 Hz	-7.15 deg	-0.18 deg	-0.29 deg	-0.36 deg	-0.38 deg	-0.68 deg	-0.41 deg	-7.92 deg	-7.78 deg
5.012 Hz	9.38 deg	9.57 deg	0.28 deg	0.03 deg	0.30 deg	8.74 deg	0.33 deg	0.39 deg	0.24 deg
6.310 Hz	11.75 deg	13.08 deg	1.04 deg	2.15 deg	2.45 deg	1.95 deg	3.13 deg	14.04 deg	12.85 deg
7.943 Hz	-15.94 deg	-0.53 deg	-0.23 deg	0.61 deg	-12.76 deg	1.18 deg	2.37 deg	2.89 deg	-10.97 deg
10.000 Hz	-1.20 deg	18.76 deg	19.29 deg	1.40 deg	20.78 deg	19.94 deg	19.64 deg	3.70 deg	22.07 deg
12.589 Hz	22.34 deg	-1.20 deg	-22.30 deg	-22.60 deg	22.65 deg	23.60 deg	20.96 deg	23.70 deg	23.20 deg
15.849 Hz	29.37 deg	0.90 deg	0.00 deg	28.71 deg	28.97 deg	-0.30 deg	27.57 deg	0.50 deg	-0.20 deg
19.953 Hz	-	-	-	-1.10 deg	-0.20 deg	-	-	0.90 deg	-

3.9.4.4 Raspberry Boom

Figure 81, Figure 82 and Figure 83 illustrate the relative change in the amplitude over -35 C to +50 C relative to the amplitude sensitivity observed at 23 C for the Raspberry Boom packages.

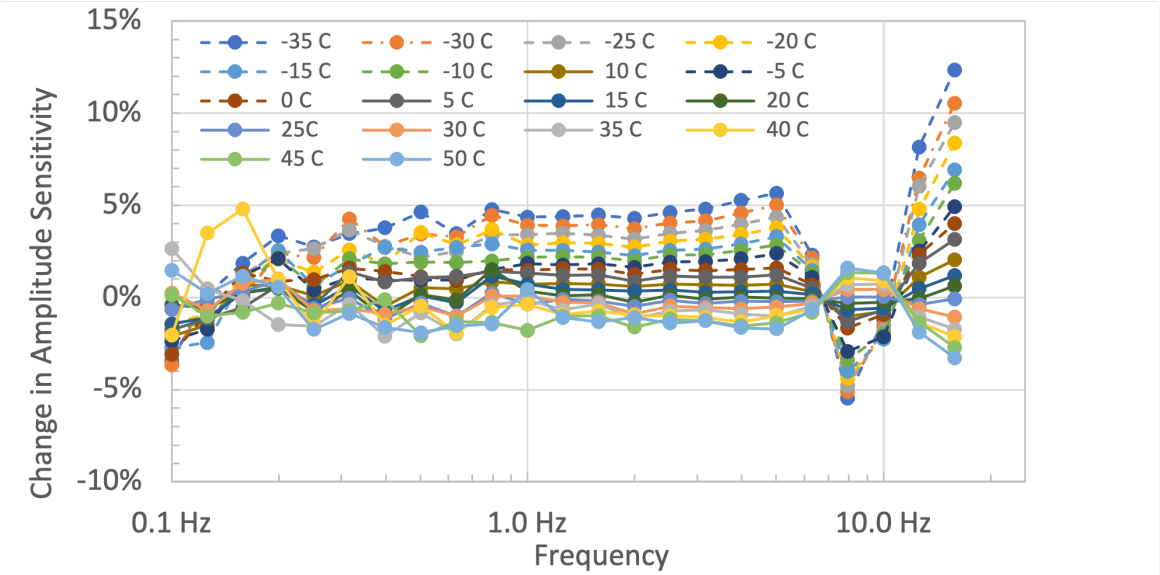

Figure 81 Relative Change in Amplitude Response with Temperature: Boom R1C9F

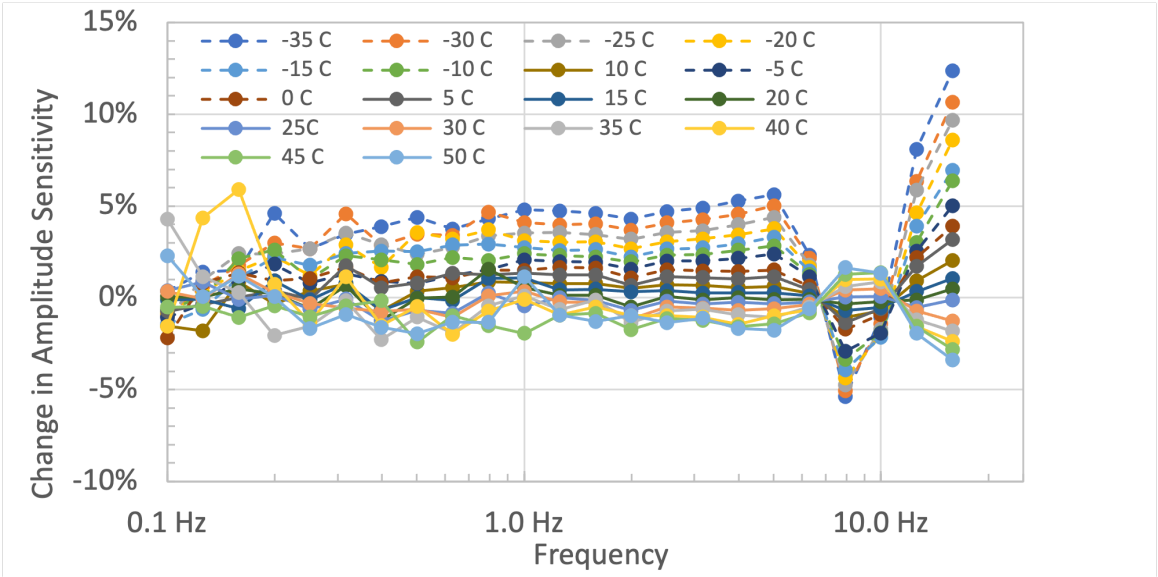

Figure 82 C Relative hange in Amplitude Response with Temperature: Boom R2A6D

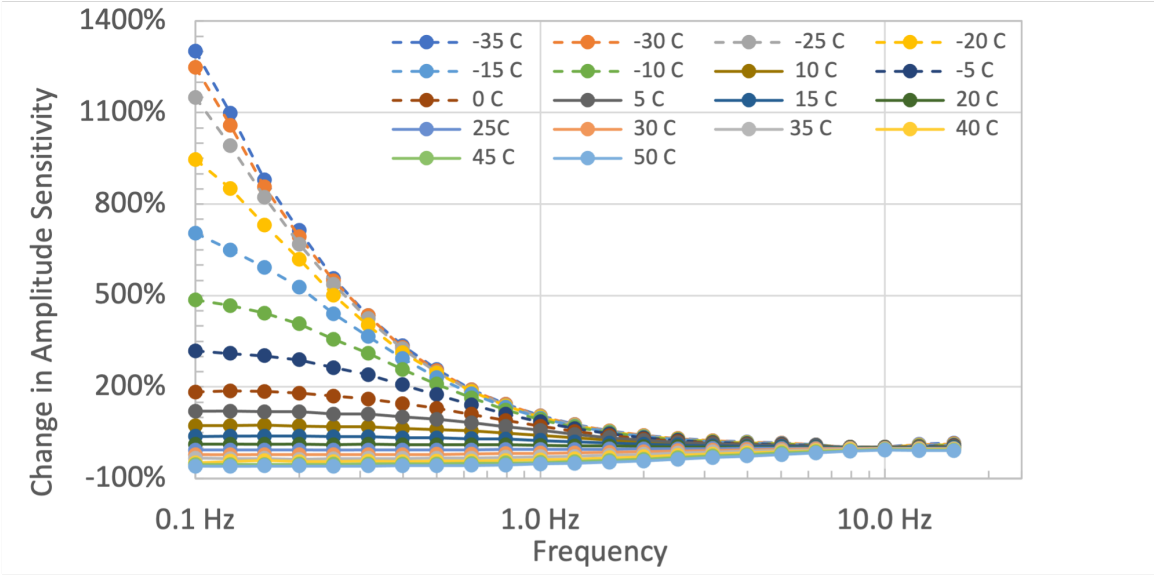

Figure 83 Relative Change in Amplitude Response with Temperature: Boom RF958

The relative change in amplitude response of the Raspberry Boom packages, excluding unit RF958, shares some similarities to that of the InfraBSU and Gem packages. Below 8 Hz and above 10 Hz, as temperature decreases from 23 C, our baseline for comparison, the packages become more sensitive, with relative changes in amplitude sensitivity at -35 C reaching a maximum of 12% at 15.8 Hz (R2A6D). Both units show a similar reversal of this trend between 0.1 Hz and 0.2 Hz in the 40 C data set. At 5 Hz, both units exceed a 5% relative change in amplitude sensitivity. Between 8 Hz and 10 Hz, the trend reverses; as temperature drops in this frequency band, changes in sensitivity decreases. Comments regarding package RF958 are withheld, due to its an anomalous response, as noted earlier in section 3.7. Its relative change in response with temperature is similarly anomalous when compared to that of the other Raspberry Booms, indicating a change in its frequency passband.

The following three tables contain the data show in the above figures.

Table 76 Relative Change in Amplitude Response with Temperature: Boom R1C9F

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	-3.43%	-3.65%	-2.96%	-1.44%	-2.74%	-1.95%	-2.35%	-3.08%	-1.76%
0.126 Hz	0.19%	0.47%	-1.01%	-0.90%	-2.46%	-1.18%	-1.73%	-0.84%	-1.14%
0.158 Hz	1.86%	0.04%	1.22%	1.11%	1.04%	0.68%	1.18%	1.33%	-0.56%
0.200 Hz	3.35%	2.39%	2.40%	2.07%	2.54%	2.16%	2.09%	0.89%	0.66%
0.251 Hz	2.73%	2.16%	2.65%	1.37%	0.62%	0.62%	0.41%	0.96%	-0.42%
0.316 Hz	3.45%	4.26%	3.65%	2.58%	1.76%	2.09%	1.07%	1.59%	1.37%
0.398 Hz	3.77%	2.78%	2.78%	1.83%	2.70%	1.83%	0.96%	1.42%	0.84%
0.501 Hz	4.63%	3.44%	2.19%	3.54%	2.45%	1.93%	0.94%	1.14%	1.07%
0.631 Hz	3.46%	3.28%	2.49%	2.85%	2.71%	1.89%	0.93%	0.98%	1.14%
0.794 Hz	4.77%	4.45%	3.38%	3.68%	2.89%	1.98%	1.50%	1.52%	1.42%
1.000 Hz	4.36%	3.93%	3.41%	2.84%	2.57%	2.18%	1.84%	1.49%	1.31%
1.259 Hz	4.39%	3.89%	3.49%	2.98%	2.56%	2.22%	1.77%	1.56%	1.21%
1.585 Hz	4.47%	3.95%	3.39%	2.92%	2.46%	2.19%	1.82%	1.55%	1.21%
1.995 Hz	4.29%	3.72%	3.17%	2.73%	2.27%	1.99%	1.63%	1.26%	0.88%
2.512 Hz	4.61%	4.04%	3.49%	3.06%	2.56%	2.31%	1.92%	1.53%	1.15%
3.162 Hz	4.80%	4.16%	3.62%	3.17%	2.62%	2.31%	1.95%	1.46%	1.11%
3.981 Hz	5.26%	4.58%	3.98%	3.42%	2.91%	2.56%	2.10%	1.51%	1.10%
5.012 Hz	5.65%	5.00%	4.36%	3.77%	3.30%	2.84%	2.38%	1.59%	1.22%
6.310 Hz	2.31%	2.13%	1.78%	1.65%	1.49%	1.31%	1.09%	0.70%	0.51%
7.943 Hz	-5.45%	-5.11%	-4.79%	-4.39%	-4.00%	-3.37%	-2.93%	-1.65%	-1.30%
10.000 Hz	-1.20%	-1.52%	-1.75%	-2.06%	-2.27%	-1.98%	-2.13%	-0.93%	-0.69%
12.589 Hz	8.17%	6.49%	6.03%	4.78%	3.94%	3.08%	2.50%	2.32%	1.86%
15.849 Hz	12.33%	10.53%	9.49%	8.39%	6.92%	6.20%	4.92%	4.00%	3.14%
19.953 Hz	-	-	-	-	-	-	-	-	-

Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	-2.11%	-1.44%	-0.41%	-0.65%	0.24%	2.63%	-2.05%	0.14%	1.48%
0.126 Hz	-1.50%	-1.09%	-0.54%	-0.11%	-0.71%	0.43%	3.49%	-1.03%	0.21%
0.158 Hz	0.66%	0.23%	0.23%	0.32%	0.77%	-0.18%	4.79%	-0.81%	1.17%
0.200 Hz	0.64%	0.58%	0.51%	0.94%	1.01%	-1.46%	0.96%	-0.31%	0.54%
0.251 Hz	0.08%	-0.44%	-0.76%	-0.59%	-0.73%	-1.57%	-1.52%	-0.84%	-1.74%
0.316 Hz	0.92%	0.64%	0.37%	-0.03%	-0.60%	-0.35%	1.14%	-0.72%	-0.87%
0.398 Hz	-0.49%	-0.74%	-1.14%	-1.17%	-0.91%	-2.09%	-1.50%	-0.12%	-1.61%
0.501 Hz	0.53%	0.10%	0.15%	-0.31%	-0.48%	-0.84%	-0.46%	-2.07%	-1.91%
0.631 Hz	0.47%	-0.28%	-0.15%	-1.01%	-1.03%	-1.97%	-1.92%	-1.30%	-1.55%
0.794 Hz	0.83%	1.16%	1.52%	0.25%	0.07%	-0.42%	-0.56%	-1.36%	-1.44%
1.000 Hz	0.73%	0.71%	0.34%	-0.37%	0.10%	-0.15%	-0.37%	-1.79%	0.44%
1.259 Hz	0.76%	0.43%	0.10%	-0.10%	-0.27%	-0.68%	-0.93%	-1.03%	-1.09%
1.585 Hz	0.73%	0.42%	0.14%	-0.21%	-0.30%	-0.35%	-0.73%	-0.99%	-1.33%
1.995 Hz	0.58%	0.33%	-0.27%	-0.49%	-0.90%	-1.14%	-0.98%	-1.61%	-1.09%
2.512 Hz	0.72%	0.41%	0.11%	-0.16%	-0.47%	-0.75%	-0.98%	-1.17%	-1.39%
3.162 Hz	0.69%	0.27%	-0.09%	-0.32%	-0.55%	-0.69%	-1.10%	-1.26%	-1.26%
3.981 Hz	0.65%	0.31%	0.03%	-0.21%	-0.60%	-0.90%	-1.32%	-1.54%	-1.64%
5.012 Hz	0.71%	0.34%	-0.03%	-0.22%	-0.52%	-1.02%	-0.98%	-1.37%	-1.71%
6.310 Hz	0.30%	0.16%	-0.05%	-0.20%	-0.31%	-0.48%	-0.64%	-0.79%	-0.66%
7.943 Hz	-1.02%	-0.66%	-0.31%	0.03%	0.43%	0.68%	1.07%	1.34%	1.61%
10.000 Hz	-0.76%	-0.57%	-0.25%	0.04%	0.44%	0.72%	0.91%	1.33%	1.32%
12.589 Hz	1.10%	0.48%	-0.06%	-0.40%	-0.60%	-1.06%	-1.34%	-1.34%	-1.88%
15.849 Hz	2.06%	1.19%	0.62%	-0.07%	-1.06%	-1.72%	-2.15%	-2.70%	-3.27%
19.953 Hz	-	-	-	-	-	-	-	-	-

Table 77 Relative Change in Amplitude Response with Temperature: Boom R2A6D

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	0.36%	-0.96%	-1.00%	-0.84%	-1.43%	-0.64%	-1.08%	-2.17%	-0.74%
0.126 Hz	1.41%	0.63%	0.97%	0.26%	-0.63%	0.06%	-0.33%	0.80%	-0.35%
0.158 Hz	1.51%	1.76%	2.40%	1.48%	1.10%	2.13%	1.03%	1.35%	0.02%
0.200 Hz	4.60%	2.99%	2.41%	2.27%	2.21%	2.61%	1.83%	0.92%	0.40%
0.251 Hz	2.66%	2.68%	2.68%	1.21%	1.77%	1.03%	0.79%	1.06%	-0.07%
0.316 Hz	3.45%	4.58%	3.54%	2.90%	2.41%	2.28%	1.32%	1.66%	1.74%
0.398 Hz	3.87%	2.87%	2.90%	1.65%	2.54%	2.08%	0.89%	0.81%	0.54%
0.501 Hz	4.38%	3.47%	2.37%	3.56%	2.50%	1.81%	0.77%	1.15%	0.81%
0.631 Hz	3.74%	3.40%	2.75%	3.20%	2.88%	2.19%	1.23%	1.08%	1.34%
0.794 Hz	4.31%	4.67%	3.37%	3.70%	2.93%	2.05%	1.52%	1.49%	1.26%
1.000 Hz	4.80%	4.10%	3.53%	3.11%	2.74%	2.40%	2.06%	1.51%	1.35%
1.259 Hz	4.73%	3.97%	3.55%	3.02%	2.58%	2.31%	1.97%	1.66%	1.24%
1.585 Hz	4.61%	4.04%	3.44%	3.04%	2.63%	2.23%	1.94%	1.62%	1.25%
1.995 Hz	4.28%	3.68%	3.19%	2.67%	2.23%	1.96%	1.56%	1.09%	0.66%
2.512 Hz	4.69%	4.08%	3.55%	3.05%	2.66%	2.33%	2.02%	1.53%	1.16%
3.162 Hz	4.88%	4.26%	3.66%	3.22%	2.72%	2.35%	2.01%	1.46%	1.10%
3.981 Hz	5.27%	4.56%	3.99%	3.44%	2.94%	2.59%	2.15%	1.44%	1.03%
5.012 Hz	5.63%	5.01%	4.38%	3.77%	3.30%	2.83%	2.38%	1.51%	1.15%
6.310 Hz	2.33%	2.16%	1.78%	1.66%	1.48%	1.29%	1.15%	0.63%	0.44%
7.943 Hz	-5.40%	-5.06%	-4.75%	-4.36%	-3.93%	-3.34%	-2.92%	-1.72%	-1.35%
10.000 Hz	-1.07%	-1.43%	-1.72%	-2.01%	-2.14%	-1.89%	-1.93%	-0.92%	-0.59%
12.589 Hz	8.09%	6.35%	5.87%	4.62%	3.90%	3.02%	2.54%	2.20%	1.72%
15.849 Hz	12.37%	10.64%	9.67%	8.61%	6.94%	6.39%	5.01%	3.89%	3.17%
19.953 Hz	-	-	-	-	-	-	-	-	-

Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	-1.53%	-0.12%	0.06%	0.38%	0.34%	4.28%	-1.55%	-0.52%	2.27%
0.126 Hz	-1.80%	-0.09%	0.06%	0.85%	-0.06%	1.15%	4.35%	-0.46%	0.06%
0.158 Hz	0.87%	-0.60%	0.50%	-0.09%	1.30%	0.28%	5.90%	-1.07%	1.17%
0.200 Hz	-0.33%	0.92%	0.21%	0.14%	0.29%	-2.04%	0.74%	-0.43%	0.05%
0.251 Hz	0.37%	-0.12%	-0.59%	-0.61%	-0.30%	-1.55%	-1.37%	-1.03%	-1.67%
0.316 Hz	0.75%	0.79%	0.65%	-0.07%	-0.57%	-0.17%	1.16%	-0.44%	-0.92%
0.398 Hz	-0.72%	-0.68%	-1.22%	-1.25%	-0.76%	-2.29%	-1.52%	-0.16%	-1.61%
0.501 Hz	0.36%	0.00%	-0.02%	-0.68%	-0.61%	-1.05%	-0.48%	-2.42%	-1.96%
0.631 Hz	0.56%	-0.15%	0.03%	-0.85%	-1.06%	-1.91%	-1.98%	-0.98%	-1.32%
0.794 Hz	0.87%	1.06%	1.56%	0.26%	0.11%	-0.44%	-0.72%	-1.51%	-1.34%
1.000 Hz	0.83%	1.07%	0.55%	-0.45%	0.36%	0.11%	-0.08%	-1.94%	1.15%
1.259 Hz	0.77%	0.44%	0.13%	0.02%	-0.23%	-0.65%	-0.95%	-0.94%	-0.95%
1.585 Hz	0.79%	0.46%	0.13%	-0.16%	-0.24%	-0.13%	-0.50%	-0.85%	-1.28%
1.995 Hz	0.51%	0.32%	-0.49%	-0.68%	-1.15%	-1.34%	-0.98%	-1.74%	-0.96%
2.512 Hz	0.70%	0.39%	0.08%	-0.17%	-0.50%	-0.72%	-0.97%	-1.14%	-1.36%
3.162 Hz	0.67%	0.26%	-0.12%	-0.34%	-0.56%	-0.61%	-1.05%	-1.22%	-1.11%
3.981 Hz	0.56%	0.28%	0.00%	-0.25%	-0.69%	-0.93%	-1.44%	-1.57%	-1.66%
5.012 Hz	0.63%	0.28%	-0.10%	-0.32%	-0.59%	-1.08%	-0.98%	-1.43%	-1.76%
6.310 Hz	0.25%	0.11%	-0.08%	-0.23%	-0.36%	-0.51%	-0.64%	-0.82%	-0.59%
7.943 Hz	-1.07%	-0.68%	-0.32%	0.05%	0.42%	0.62%	0.99%	1.28%	1.64%
10.000 Hz	-0.71%	-0.53%	-0.21%	0.08%	0.50%	0.86%	1.01%	1.36%	1.34%
12.589 Hz	0.92%	0.34%	-0.12%	-0.54%	-0.72%	-1.20%	-1.56%	-1.56%	-1.94%
15.849 Hz	2.02%	1.05%	0.48%	-0.11%	-1.27%	-1.82%	-2.37%	-2.83%	-3.40%
19.953 Hz	-	-	-	-	-	-	-	-	-

Table 78 Relative Change in Amplitude Response with Temperature: Boom RF958

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	1301.59%	1247.75%	1148.90%	947.07%	704.06%	484.88%	318.06%	182.99%	120.83%
0.126 Hz	1098.37%	1059.19%	991.49%	851.54%	650.00%	466.58%	310.33%	186.23%	120.45%
0.158 Hz	879.48%	855.83%	822.97%	731.68%	592.05%	441.99%	302.71%	185.34%	118.74%
0.200 Hz	713.19%	693.86%	668.64%	619.57%	527.47%	407.13%	289.25%	179.19%	118.20%
0.251 Hz	555.87%	548.21%	537.31%	501.36%	440.26%	356.39%	263.88%	170.08%	111.90%
0.316 Hz	434.95%	434.43%	424.05%	403.20%	366.61%	311.59%	240.14%	160.64%	110.99%
0.398 Hz	335.61%	329.34%	325.21%	312.40%	294.42%	258.33%	207.44%	145.80%	102.27%
0.501 Hz	258.03%	253.65%	248.26%	245.96%	231.52%	209.27%	174.94%	130.28%	93.88%
0.631 Hz	191.68%	190.13%	186.88%	185.33%	177.88%	164.58%	142.00%	110.33%	82.82%
0.794 Hz	144.02%	143.19%	139.77%	138.67%	133.43%	124.55%	111.57%	90.78%	70.59%
1.000 Hz	105.90%	104.50%	102.95%	101.01%	98.03%	93.47%	85.71%	71.51%	57.65%
1.259 Hz	77.46%	76.26%	75.07%	73.68%	71.56%	68.62%	63.73%	54.68%	44.97%
1.585 Hz	56.65%	55.55%	54.60%	53.41%	51.88%	49.88%	46.73%	40.78%	34.32%
1.995 Hz	41.26%	40.36%	39.49%	38.55%	37.28%	35.94%	33.66%	29.57%	25.15%
2.512 Hz	31.21%	30.37%	29.51%	28.70%	27.65%	26.52%	24.94%	21.93%	18.83%
3.162 Hz	24.09%	23.25%	22.46%	21.70%	20.74%	19.77%	18.49%	16.20%	13.92%
3.981 Hz	19.64%	18.76%	17.96%	17.17%	16.30%	15.44%	14.31%	12.29%	10.51%
5.012 Hz	16.55%	15.71%	14.94%	14.11%	13.34%	12.48%	11.50%	9.60%	8.21%
6.310 Hz	10.33%	10.02%	9.55%	9.29%	8.92%	8.44%	7.86%	6.61%	5.67%
7.943 Hz	0.18%	0.47%	0.83%	1.09%	1.37%	1.81%	1.90%	2.64%	2.44%
10.000 Hz	3.41%	3.07%	2.68%	2.24%	1.96%	2.04%	1.74%	2.42%	2.32%
12.589 Hz	12.00%	10.07%	9.57%	8.21%	7.25%	6.26%	5.48%	4.96%	4.06%
15.849 Hz	15.49%	13.47%	12.57%	11.32%	9.54%	8.91%	7.43%	5.86%	4.88%
19.953 Hz	-	-	-	-	-	-	-	-	-

Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	73.11%	38.04%	11.94%	-7.06%	-22.27%	-33.89%	-48.31%	-53.99%	-59.69%
0.126 Hz	72.71%	38.77%	11.68%	-6.27%	-22.69%	-34.58%	-43.55%	-53.65%	-59.76%
0.158 Hz	74.75%	38.53%	12.47%	-6.35%	-21.34%	-34.03%	-41.54%	-53.71%	-59.10%
0.200 Hz	72.42%	38.43%	12.18%	-6.18%	-21.57%	-36.81%	-44.02%	-53.08%	-58.96%
0.251 Hz	70.12%	36.55%	10.64%	-7.34%	-22.43%	-35.65%	-44.43%	-53.07%	-59.59%
0.316 Hz	69.20%	37.28%	11.94%	-6.49%	-21.90%	-34.12%	-43.27%	-52.60%	-59.02%
0.398 Hz	63.77%	33.88%	9.99%	-7.30%	-21.63%	-34.41%	-44.15%	-52.03%	-58.48%
0.501 Hz	60.90%	33.20%	10.79%	-6.52%	-20.90%	-33.76%	-43.43%	-51.84%	-58.18%
0.631 Hz	55.58%	30.35%	10.05%	-6.86%	-20.57%	-33.27%	-42.92%	-50.50%	-56.98%
0.794 Hz	48.77%	28.92%	10.82%	-5.24%	-18.67%	-30.47%	-40.61%	-49.30%	-55.52%
1.000 Hz	41.24%	24.91%	8.65%	-5.39%	-17.15%	-28.65%	-38.64%	-47.51%	-52.46%
1.259 Hz	33.31%	20.42%	7.15%	-4.38%	-15.69%	-26.94%	-36.32%	-43.99%	-50.65%
1.585 Hz	25.98%	16.35%	5.98%	-3.77%	-13.58%	-23.14%	-32.27%	-40.44%	-47.16%
1.995 Hz	19.45%	12.51%	4.23%	-3.51%	-11.91%	-20.70%	-28.60%	-36.53%	-42.45%
2.512 Hz	14.69%	9.61%	3.62%	-2.51%	-9.26%	-16.65%	-24.05%	-31.07%	-37.41%
3.162 Hz	10.80%	7.01%	2.53%	-2.08%	-7.39%	-13.17%	-19.59%	-25.92%	-31.64%
3.981 Hz	8.12%	5.33%	2.04%	-1.49%	-5.78%	-10.56%	-15.71%	-21.25%	-26.40%
5.012 Hz	6.27%	4.13%	1.52%	-1.13%	-4.34%	-8.33%	-12.21%	-16.81%	-21.21%
6.310 Hz	4.45%	2.93%	1.05%	-0.97%	-3.28%	-6.12%	-9.31%	-12.74%	-16.20%
7.943 Hz	1.99%	1.35%	0.49%	-0.50%	-1.84%	-3.69%	-5.65%	-8.04%	-10.51%
10.000 Hz	1.57%	1.03%	0.50%	-0.36%	-1.25%	-2.56%	-4.07%	-5.65%	-7.75%
12.589 Hz	2.82%	1.65%	0.39%	-0.84%	-1.94%	-3.46%	-5.00%	-6.53%	-8.63%
15.849 Hz	3.41%	2.02%	0.80%	-0.41%	-2.11%	-3.63%	-5.05%	-6.64%	-8.25%
19.953 Hz	-	-	-	-	-	-	-	-	-

The next three figures illustrate the relative difference in the phase response over -35 C to +50 C when compared to the phase observed at 23 C for the Raspberry Boom packages.

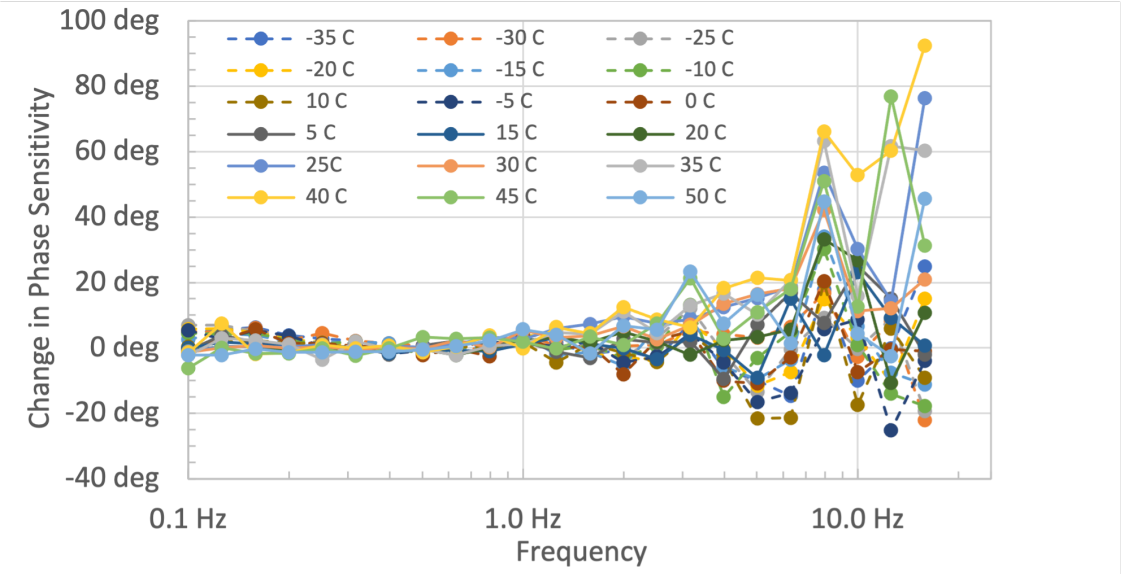

Figure 84 Relative Change in Phase Response with Temperature: Boom R1C9F

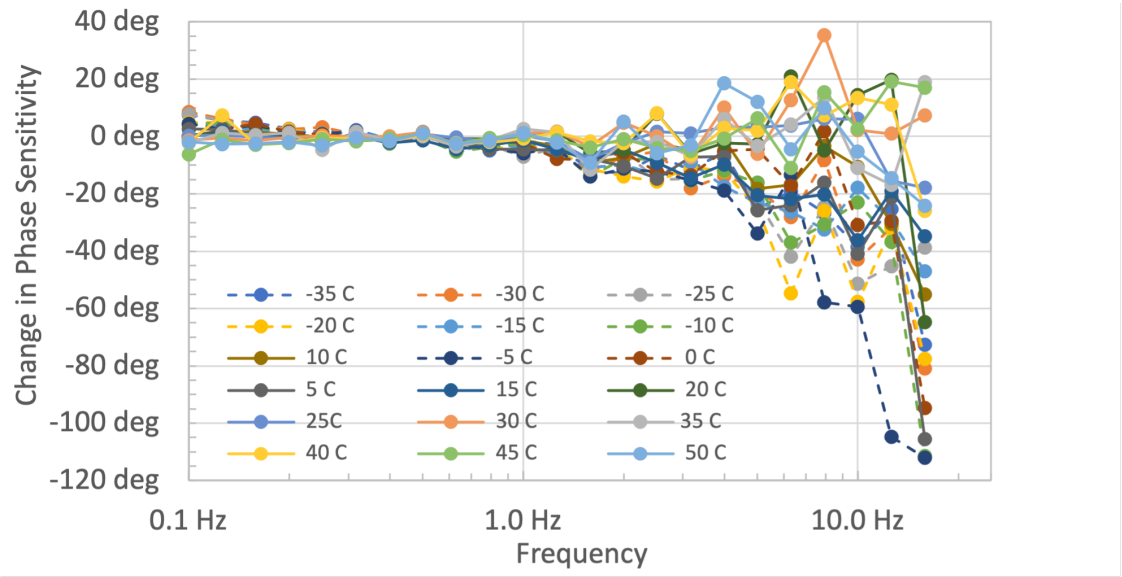

Figure 85 Relative Change in Phase Response with Temperature: Boom R2A6D

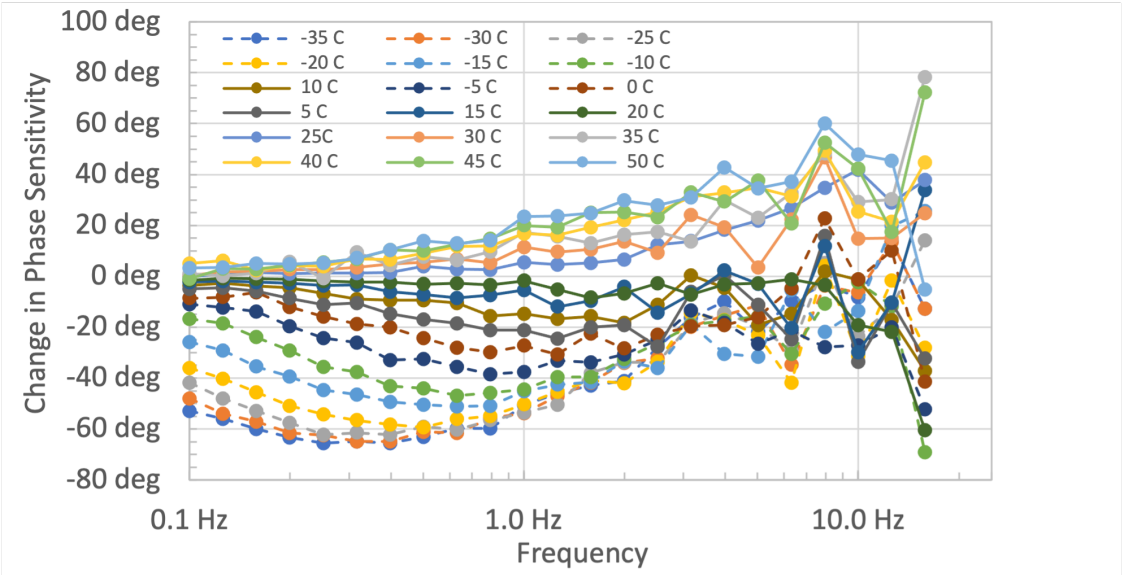

Figure 86 Relative Change in Phase Response with Temperature: Boom RF958

Phase differences of R1C9F and R2A6D share similarities at lower frequencies, indicating the sensors have minimal change due to temperature. Above 1 Hz there is considerable scatter in phase changes at higher frequencies. Phase differences generally become increasingly negative as temperature drops. As noted with the Gem package, larger phase changes at higher frequencies may be a result of the timing algorithm and GPS clock used by the Raspberry Boom. As noted in previous sections we limit comment on RF958 due to its anomalous response.

Table 79, Table 80 and Table 81 contain the data shown in the above plots.

Table 79 Relative Change in Phase Response with Temperature: Boom R1C9F

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	4.59 deg	5.11 deg	6.97 deg	5.69 deg	2.60 deg	4.53 deg	5.36 deg	-0.16 deg	-0.73 deg
0.126 Hz	5.65 deg	4.67 deg	6.95 deg	5.96 deg	4.54 deg	4.14 deg	2.60 deg	2.50 deg	3.86 deg
0.158 Hz	6.23 deg	6.11 deg	5.06 deg	4.74 deg	3.81 deg	4.52 deg	5.41 deg	5.80 deg	1.79 deg
0.200 Hz	3.83 deg	2.24 deg	3.42 deg	2.75 deg	1.90 deg	2.23 deg	3.68 deg	1.48 deg	0.24 deg
0.251 Hz	2.79 deg	4.47 deg	0.03 deg	1.66 deg	1.65 deg	1.19 deg	0.64 deg	1.45 deg	0.04 deg
0.316 Hz	2.05 deg	2.17 deg	1.71 deg	0.62 deg	1.92 deg	1.96 deg	0.82 deg	0.64 deg	0.58 deg
0.398 Hz	0.97 deg	1.48 deg	-0.06 deg	-0.10 deg	1.36 deg	-0.34 deg	-1.77 deg	0.28 deg	-1.96 deg
0.501 Hz	-0.75 deg	0.66 deg	-0.59 deg	-1.08 deg	-1.31 deg	-1.57 deg	-0.87 deg	-2.21 deg	0.67 deg
0.631 Hz	0.23 deg	0.38 deg	1.18 deg	0.62 deg	-0.63 deg	0.54 deg	0.51 deg	-0.34 deg	2.06 deg
0.794 Hz	0.97 deg	-0.83 deg	1.47 deg	-0.84 deg	0.63 deg	-1.07 deg	1.62 deg	-2.61 deg	0.96 deg
1.000 Hz	0.64 deg	4.43 deg	1.29 deg	3.70 deg	4.20 deg	1.81 deg	2.14 deg	3.40 deg	2.19 deg
1.259 Hz	1.58 deg	0.56 deg	3.31 deg	4.06 deg	-2.21 deg	-0.65 deg	0.17 deg	-0.42 deg	-1.12 deg
1.585 Hz	-1.86 deg	-0.20 deg	0.35 deg	-1.87 deg	-1.31 deg	0.81 deg	1.98 deg	0.97 deg	-3.13 deg
1.995 Hz	-0.62 deg	0.51 deg	-2.85 deg	-2.51 deg	-5.40 deg	-2.81 deg	-4.47 deg	-8.05 deg	2.71 deg
2.512 Hz	-3.22 deg	0.95 deg	2.94 deg	-4.32 deg	6.31 deg	0.61 deg	-2.62 deg	2.53 deg	1.60 deg
3.162 Hz	7.60 deg	5.16 deg	12.09 deg	7.78 deg	8.98 deg	13.22 deg	4.37 deg	5.02 deg	1.99 deg
3.981 Hz	-6.53 deg	4.14 deg	-1.64 deg	-0.26 deg	-5.80 deg	-14.99 deg	-4.40 deg	-10.06 deg	-9.55 deg
5.012 Hz	-9.91 deg	3.12 deg	-13.48 deg	-11.50 deg	-9.69 deg	-3.05 deg	-16.53 deg	-10.77 deg	7.16 deg
6.310 Hz	-14.59 deg	6.47 deg	-0.45 deg	-7.41 deg	-3.62 deg	4.92 deg	-13.83 deg	-2.87 deg	16.88 deg
7.943 Hz	17.82 deg	16.72 deg	9.20 deg	14.90 deg	34.12 deg	30.24 deg	5.73 deg	20.49 deg	7.65 deg
10.000 Hz	-9.90 deg	-2.76 deg	-0.34 deg	3.12 deg	6.64 deg	0.92 deg	8.67 deg	-7.31 deg	25.06 deg
12.589 Hz	-0.08 deg	8.12 deg	8.96 deg	-10.73 deg	-7.55 deg	-14.02 deg	-25.11 deg	-0.46 deg	15.06 deg
15.849 Hz	24.82 deg	-22.03 deg	-19.30 deg	15.08 deg	-11.23 deg	-17.82 deg	-3.87 deg	-1.02 deg	-2.05 deg
19.953 Hz	-	-	-	-	-	-	-	-	-

Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	0.31 deg	-0.03 deg	-0.81 deg	-0.99 deg	-1.40 deg	-2.29 deg	-1.41 deg	-6.15 deg	-2.21 deg
0.126 Hz	1.71 deg	1.81 deg	0.38 deg	0.48 deg	0.08 deg	2.94 deg	7.53 deg	0.10 deg	-2.19 deg
0.158 Hz	2.26 deg	1.28 deg	0.48 deg	0.43 deg	0.76 deg	2.24 deg	-1.85 deg	-1.71 deg	-0.25 deg
0.200 Hz	1.50 deg	0.48 deg	-0.61 deg	0.18 deg	-0.11 deg	1.07 deg	-1.57 deg	-1.70 deg	-1.35 deg
0.251 Hz	1.51 deg	0.73 deg	-0.08 deg	1.15 deg	0.32 deg	-3.62 deg	0.94 deg	-0.09 deg	-1.32 deg
0.316 Hz	-0.26 deg	0.12 deg	-0.54 deg	-0.82 deg	-0.71 deg	1.88 deg	-0.18 deg	-2.31 deg	-1.16 deg
0.398 Hz	-0.36 deg	-1.70 deg	-0.09 deg	0.65 deg	0.28 deg	-0.31 deg	0.76 deg	-0.18 deg	-1.15 deg
0.501 Hz	-1.21 deg	-0.38 deg	-0.52 deg	0.18 deg	-0.26 deg	-0.47 deg	-1.37 deg	3.37 deg	-0.56 deg
0.631 Hz	0.54 deg	-0.75 deg	-2.24 deg	1.09 deg	2.29 deg	-2.23 deg	0.33 deg	2.77 deg	0.60 deg
0.794 Hz	-0.17 deg	-0.96 deg	0.07 deg	3.33 deg	0.13 deg	0.61 deg	3.88 deg	3.12 deg	2.21 deg
1.000 Hz	1.76 deg	1.04 deg	2.10 deg	2.69 deg	5.38 deg	1.31 deg	-0.12 deg	1.84 deg	5.65 deg
1.259 Hz	-4.43 deg	3.15 deg	3.38 deg	5.89 deg	3.12 deg	4.70 deg	6.35 deg	-0.22 deg	3.98 deg
1.585 Hz	1.22 deg	1.33 deg	1.68 deg	7.25 deg	3.77 deg	4.23 deg	4.44 deg	3.42 deg	-1.69 deg
1.995 Hz	-1.53 deg	-0.19 deg	4.95 deg	9.63 deg	6.58 deg	11.12 deg	12.45 deg	0.93 deg	6.78 deg
2.512 Hz	-4.32 deg	-3.44 deg	1.99 deg	7.56 deg	2.58 deg	4.50 deg	8.71 deg	7.49 deg	5.53 deg
3.162 Hz	4.42 deg	4.02 deg	-2.11 deg	8.67 deg	7.03 deg	13.04 deg	6.20 deg	21.33 deg	23.27 deg
3.981 Hz	-3.52 deg	-0.69 deg	2.38 deg	12.46 deg	13.56 deg	16.64 deg	18.28 deg	2.88 deg	7.44 deg
5.012 Hz	-21.60 deg	-9.18 deg	3.29 deg	15.19 deg	16.47 deg	10.25 deg	21.39 deg	10.98 deg	16.29 deg
6.310 Hz	-21.34 deg	14.99 deg	5.62 deg	18.69 deg	18.11 deg	20.81 deg	20.69 deg	17.98 deg	1.45 deg
7.943 Hz	19.98 deg	-2.17 deg	33.15 deg	53.55 deg	42.16 deg	63.21 deg	66.20 deg	50.99 deg	44.79 deg
10.000 Hz	-17.38 deg	23.25 deg	26.84 deg	30.27 deg	11.33 deg	15.91 deg	52.79 deg	12.66 deg	4.31 deg
12.589 Hz	5.86 deg	9.26 deg	-10.70 deg	14.32 deg	12.11 deg	61.68 deg	60.26 deg	76.95 deg	-2.50 deg
15.849 Hz	-9.18 deg	0.73 deg	10.82 deg	76.28 deg	20.98 deg	60.28 deg	92.47 deg	31.25 deg	45.65 deg
19.953 Hz	-	-	-	-	-	-	-	-	-

Table 80 Relative Change in Phase Response with Temperature: Boom R2A6D

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	-7.60 deg	-8.47 deg	-7.68 deg	-4.73 deg	-4.23 deg	-4.14 deg	-4.45 deg	0.97 deg	-2.58 deg
0.126 Hz	-5.66 deg	-6.16 deg	-5.62 deg	-5.03 deg	-4.01 deg	-4.78 deg	-2.66 deg	-2.45 deg	-2.42 deg
0.158 Hz	-4.85 deg	-3.97 deg	-3.01 deg	-2.58 deg	-1.97 deg	-3.44 deg	-3.80 deg	-4.36 deg	-0.86 deg
0.200 Hz	-2.70 deg	-2.53 deg	-2.45 deg	-2.40 deg	-1.85 deg	-1.35 deg	-1.47 deg	-1.73 deg	-0.46 deg
0.251 Hz	-1.53 deg	-3.18 deg	0.86 deg	-0.96 deg	-1.03 deg	0.65 deg	-0.82 deg	-0.68 deg	1.81 deg
0.316 Hz	-2.19 deg	-0.72 deg	-0.39 deg	-0.29 deg	-1.19 deg	-0.50 deg	-1.78 deg	0.06 deg	-1.13 deg
0.398 Hz	0.94 deg	0.56 deg	1.45 deg	1.09 deg	0.36 deg	2.55 deg	1.81 deg	0.72 deg	1.33 deg
0.501 Hz	-0.23 deg	-1.14 deg	-1.65 deg	-0.21 deg	-0.85 deg	0.70 deg	-1.47 deg	1.28 deg	-0.05 deg
0.631 Hz	2.22 deg	2.77 deg	5.02 deg	3.22 deg	4.36 deg	5.34 deg	3.13 deg	3.93 deg	2.12 deg
0.794 Hz	4.86 deg	1.96 deg	3.04 deg	3.48 deg	1.85 deg	3.58 deg	4.30 deg	1.41 deg	4.43 deg
1.000 Hz	1.43 deg	3.14 deg	7.03 deg	5.04 deg	4.28 deg	2.36 deg	5.88 deg	2.32 deg	4.39 deg
1.259 Hz	2.86 deg	5.19 deg	3.83 deg	4.57 deg	6.04 deg	4.13 deg	4.01 deg	7.85 deg	4.83 deg
1.585 Hz	11.73 deg	12.20 deg	7.61 deg	11.41 deg	10.77 deg	14.00 deg	13.98 deg	8.21 deg	7.78 deg
1.995 Hz	13.01 deg	6.94 deg	5.37 deg	13.96 deg	9.93 deg	7.57 deg	11.24 deg	5.69 deg	10.42 deg
2.512 Hz	6.64 deg	5.31 deg	15.11 deg	15.68 deg	13.28 deg	8.11 deg	12.30 deg	12.34 deg	14.76 deg
3.162 Hz	11.82 deg	17.97 deg	14.64 deg	10.49 deg	8.96 deg	15.43 deg	15.18 deg	13.57 deg	7.10 deg
3.981 Hz	5.42 deg	13.68 deg	9.70 deg	12.12 deg	17.45 deg	11.89 deg	18.76 deg	5.10 deg	7.02 deg
5.012 Hz	25.28 deg	18.05 deg	22.13 deg	25.07 deg	23.16 deg	16.17 deg	33.76 deg	4.36 deg	25.76 deg
6.310 Hz	19.03 deg	28.06 deg	41.87 deg	54.65 deg	26.28 deg	37.06 deg	13.41 deg	17.30 deg	24.01 deg
7.943 Hz	26.69 deg	8.24 deg	24.52 deg	26.03 deg	32.36 deg	30.66 deg	57.84 deg	-1.82 deg	16.06 deg
10.000 Hz	38.56 deg	42.93 deg	51.31 deg	57.73 deg	17.96 deg	22.91 deg	59.41 deg	30.89 deg	40.88 deg
12.589 Hz	25.38 deg	31.88 deg	45.23 deg	32.03 deg	29.27 deg	36.83 deg	104.78 deg	29.45 deg	21.29 deg
15.849 Hz	72.56 deg	80.99 deg	38.81 deg	77.60 deg	46.99 deg	111.36 deg	112.11 deg	94.78 deg	105.61 deg
19.953 Hz	-	-	-	-	-	-	-	-	-

Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	-0.32 deg	0.02 deg	-0.24 deg	-0.33 deg	1.37 deg	2.29 deg	1.98 deg	6.19 deg	1.93 deg
0.126 Hz	-2.03 deg	-1.79 deg	-1.06 deg	-0.47 deg	0.48 deg	-1.26 deg	-7.36 deg	1.12 deg	2.73 deg
0.158 Hz	-1.49 deg	0.45 deg	0.32 deg	0.25 deg	1.56 deg	-0.48 deg	2.75 deg	2.80 deg	2.44 deg
0.200 Hz	-0.97 deg	-0.36 deg	0.62 deg	0.56 deg	0.32 deg	-1.32 deg	1.92 deg	2.29 deg	1.88 deg
0.251 Hz	0.33 deg	0.83 deg	0.33 deg	0.00 deg	-0.22 deg	4.59 deg	0.49 deg	0.98 deg	3.18 deg
0.316 Hz	1.58 deg	-0.01 deg	0.54 deg	0.73 deg	0.08 deg	-1.62 deg	0.70 deg	1.68 deg	0.55 deg
0.398 Hz	1.15 deg	2.19 deg	0.44 deg	1.66 deg	-0.07 deg	1.56 deg	1.21 deg	0.80 deg	1.51 deg
0.501 Hz	-1.06 deg	1.38 deg	-0.55 deg	-0.93 deg	-1.45 deg	-0.04 deg	-0.56 deg	-1.07 deg	-0.99 deg
0.631 Hz	1.09 deg	4.41 deg	0.65 deg	0.42 deg	2.67 deg	3.45 deg	2.37 deg	2.43 deg	2.52 deg
0.794 Hz	2.46 deg	3.04 deg	0.85 deg	1.66 deg	0.65 deg	1.30 deg	2.00 deg	0.57 deg	1.47 deg
1.000 Hz	1.21 deg	1.34 deg	-0.95 deg	-0.31 deg	-0.98 deg	-2.67 deg	0.81 deg	-0.46 deg	-1.24 deg
1.259 Hz	3.51 deg	4.36 deg	-1.64 deg	1.70 deg	-1.65 deg	-1.42 deg	-1.42 deg	1.27 deg	2.04 deg
1.585 Hz	9.17 deg	8.19 deg	5.76 deg	7.93 deg	3.50 deg	11.66 deg	1.72 deg	3.94 deg	9.24 deg
1.995 Hz	7.34 deg	4.72 deg	4.65 deg	2.33 deg	-4.75 deg	1.77 deg	2.22 deg	0.91 deg	-5.19 deg
2.512 Hz	2.48 deg	9.17 deg	-7.94 deg	-1.67 deg	-0.14 deg	1.90 deg	-8.04 deg	4.10 deg	5.79 deg
3.162 Hz	4.70 deg	14.58 deg	5.96 deg	-1.09 deg	7.31 deg	6.79 deg	6.52 deg	5.02 deg	3.04 deg
3.981 Hz	0.87 deg	9.79 deg	2.30 deg	-3.16 deg	-10.05 deg	-6.20 deg	-2.92 deg	0.78 deg	-18.63 deg
5.012 Hz	18.29 deg	20.50 deg	2.73 deg	-3.33 deg	5.97 deg	3.22 deg	-2.10 deg	-6.28 deg	-12.12 deg
6.310 Hz	16.78 deg	21.79 deg	-20.96 deg	-3.84 deg	-12.61 deg	-4.13 deg	-18.89 deg	10.92 deg	4.49 deg
7.943 Hz	3.36 deg	20.21 deg	4.87 deg	-6.24 deg	-35.29 deg	-13.69 deg	-7.27 deg	-15.36 deg	-9.85 deg
10.000 Hz	10.60 deg	36.11 deg	-14.52 deg	-6.09 deg	-2.21 deg	11.05 deg	-13.42 deg	-2.71 deg	5.35 deg
12.589 Hz	30.43 deg	19.05 deg	-19.72 deg	15.55 deg	-0.95 deg	16.94 deg	-11.08 deg	-19.18 deg	14.53 deg
15.849 Hz	55.10 deg	34.71 deg	64.68 deg	17.83 deg	-7.32 deg	-19.05 deg	25.97 deg	-17.00 deg	24.24 deg
19.953 Hz	-	-	-	-	-	-	-	-	-

Table 81 Relative Change in Phase Response with Temperature: Boom RF958

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.100 Hz	-52.81 deg	-48.01 deg	-41.74 deg	-36.02 deg	-25.78 deg	-16.75 deg	-10.90 deg	-8.60 deg	-4.90 deg
0.126 Hz	-55.92 deg	-53.99 deg	-48.01 deg	-40.30 deg	-29.11 deg	-18.57 deg	-12.35 deg	-8.18 deg	-4.60 deg
0.158 Hz	-60.09 deg	-57.13 deg	-52.85 deg	-45.49 deg	-35.47 deg	-23.92 deg	-13.92 deg	-6.22 deg	-5.91 deg
0.200 Hz	-63.36 deg	-61.60 deg	-57.54 deg	-50.90 deg	-39.32 deg	-29.08 deg	-19.55 deg	-12.09 deg	-8.63 deg
0.251 Hz	-65.66 deg	-62.51 deg	-62.33 deg	-54.23 deg	-44.76 deg	-35.54 deg	-24.18 deg	-15.79 deg	-11.10 deg
0.316 Hz	-64.97 deg	-64.94 deg	-61.43 deg	-56.57 deg	-46.40 deg	-37.57 deg	-25.98 deg	-18.76 deg	-10.51 deg
0.398 Hz	-65.57 deg	-64.96 deg	-62.21 deg	-58.24 deg	-49.29 deg	-43.17 deg	-32.97 deg	-20.06 deg	-14.65 deg
0.501 Hz	-63.08 deg	-61.08 deg	-59.20 deg	-59.40 deg	-50.37 deg	-44.00 deg	-32.44 deg	-24.20 deg	-16.97 deg
0.631 Hz	-59.78 deg	-61.48 deg	-60.31 deg	-56.12 deg	-51.15 deg	-46.81 deg	-35.49 deg	-28.03 deg	-18.40 deg
0.794 Hz	-59.84 deg	-55.75 deg	-56.57 deg	-54.82 deg	-50.83 deg	-45.72 deg	-38.51 deg	-29.85 deg	-21.21 deg
1.000 Hz	-50.59 deg	-53.86 deg	-53.60 deg	-50.34 deg	-45.07 deg	-44.48 deg	-37.50 deg	-27.26 deg	-21.07 deg
1.259 Hz	-46.07 deg	-47.04 deg	-50.49 deg	-45.27 deg	-42.56 deg	-39.67 deg	-33.22 deg	-30.67 deg	-24.41 deg
1.585 Hz	-42.91 deg	-41.85 deg	-38.01 deg	-40.83 deg	-41.60 deg	-39.62 deg	-33.78 deg	-22.44 deg	-19.96 deg
1.995 Hz	-41.22 deg	-33.95 deg	-33.82 deg	-42.04 deg	-33.34 deg	-32.47 deg	-30.63 deg	-28.38 deg	-19.09 deg
2.512 Hz	-27.79 deg	-32.33 deg	-33.81 deg	-33.56 deg	-36.02 deg	-26.26 deg	-24.90 deg	-22.99 deg	-27.72 deg
3.162 Hz	-16.28 deg	-19.85 deg	-18.56 deg	-14.41 deg	-18.90 deg	-19.19 deg	-13.37 deg	-19.58 deg	-5.97 deg
3.981 Hz	-9.91 deg	-15.38 deg	-14.46 deg	-17.10 deg	-30.48 deg	-17.42 deg	-18.30 deg	-19.21 deg	0.44 deg
5.012 Hz	-21.92 deg	-11.37 deg	-19.69 deg	-23.21 deg	-31.66 deg	-15.79 deg	-26.53 deg	-16.05 deg	-11.21 deg
6.310 Hz	-9.69 deg	-34.64 deg	-29.07 deg	-41.76 deg	-5.52 deg	-30.51 deg	-21.25 deg	-4.66 deg	-24.63 deg
7.943 Hz	-3.16 deg	-3.57 deg	5.25 deg	4.22 deg	-21.80 deg	-10.68 deg	-27.81 deg	22.85 deg	15.96 deg
10.000 Hz	-8.35 deg	-6.39 deg	-23.56 deg	-31.38 deg	-13.62 deg	-2.23 deg	-27.15 deg	-1.13 deg	-33.58 deg
12.589 Hz	13.64 deg	13.54 deg	-11.96 deg	-1.65 deg	19.81 deg	-11.55 deg	-20.03 deg	10.13 deg	-10.49 deg
15.849 Hz	-12.79 deg	-12.77 deg	14.03 deg	-28.13 deg	25.71 deg	-69.17 deg	-52.27 deg	-41.47 deg	-32.38 deg
19.953 Hz	-	-	-	-	-	-	-	-	-

Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.100 Hz	-3.60 deg	-2.20 deg	-1.50 deg	-0.20 deg	0.40 deg	1.10 deg	5.10 deg	-1.00 deg	3.20 deg
0.126 Hz	-2.70 deg	-1.90 deg	-0.80 deg	1.00 deg	1.70 deg	0.10 deg	6.10 deg	3.10 deg	3.40 deg
0.158 Hz	-3.74 deg	-2.23 deg	-0.98 deg	1.59 deg	1.89 deg	1.29 deg	2.29 deg	2.79 deg	4.99 deg
0.200 Hz	-4.58 deg	-2.68 deg	-1.20 deg	1.05 deg	2.71 deg	5.64 deg	4.13 deg	4.37 deg	4.79 deg
0.251 Hz	-6.76 deg	-3.61 deg	-1.83 deg	1.36 deg	2.57 deg	-0.74 deg	3.92 deg	5.46 deg	5.30 deg
0.316 Hz	-8.93 deg	-3.45 deg	-2.19 deg	1.31 deg	3.43 deg	9.40 deg	6.81 deg	6.85 deg	7.16 deg
0.398 Hz	-9.32 deg	-6.12 deg	-2.34 deg	1.46 deg	4.88 deg	4.32 deg	6.62 deg	10.35 deg	10.44 deg
0.501 Hz	-9.47 deg	-7.14 deg	-3.05 deg	3.93 deg	5.55 deg	7.61 deg	8.95 deg	10.02 deg	13.98 deg
0.631 Hz	-10.53 deg	-8.43 deg	-2.70 deg	2.89 deg	6.80 deg	6.46 deg	11.82 deg	12.64 deg	12.92 deg
0.794 Hz	-15.54 deg	-7.34 deg	-3.35 deg	2.65 deg	5.27 deg	9.79 deg	11.89 deg	14.87 deg	14.11 deg
1.000 Hz	-14.77 deg	-5.44 deg	-1.72 deg	5.40 deg	11.49 deg	17.16 deg	16.88 deg	20.01 deg	23.47 deg
1.259 Hz	-16.66 deg	-11.94 deg	-5.21 deg	4.67 deg	9.59 deg	15.63 deg	16.20 deg	19.23 deg	23.71 deg
1.585 Hz	-15.73 deg	-9.56 deg	-8.40 deg	5.24 deg	10.54 deg	13.11 deg	19.27 deg	25.06 deg	24.72 deg
1.995 Hz	-18.30 deg	-4.18 deg	-6.77 deg	6.60 deg	13.62 deg	16.39 deg	22.16 deg	25.20 deg	29.78 deg
2.512 Hz	-11.19 deg	-14.26 deg	-2.64 deg	12.31 deg	9.29 deg	17.45 deg	25.25 deg	23.19 deg	27.97 deg
3.162 Hz	0.45 deg	-6.85 deg	-7.11 deg	13.79 deg	24.16 deg	13.65 deg	31.28 deg	32.93 deg	31.08 deg
3.981 Hz	-4.58 deg	2.27 deg	-3.18 deg	18.25 deg	19.29 deg	29.82 deg	32.90 deg	29.33 deg	42.78 deg
5.012 Hz	-19.07 deg	-2.98 deg	-2.74 deg	21.95 deg	3.51 deg	22.93 deg	34.79 deg	37.74 deg	34.65 deg
6.310 Hz	-14.74 deg	-20.39 deg	-1.15 deg	26.78 deg	22.31 deg	32.70 deg	31.47 deg	20.75 deg	37.23 deg
7.943 Hz	2.00 deg	11.83 deg	-3.50 deg	34.74 deg	46.64 deg	48.21 deg	49.46 deg	52.48 deg	60.14 deg
10.000 Hz	-1.28 deg	-29.83 deg	-19.07 deg	41.92 deg	14.75 deg	29.21 deg	25.37 deg	42.26 deg	47.94 deg
12.589 Hz	-17.20 deg	-10.25 deg	-21.91 deg	29.00 deg	14.99 deg	30.25 deg	21.46 deg	17.38 deg	45.38 deg
15.849 Hz	-37.10 deg	33.97 deg	-60.48 deg	37.76 deg	24.86 deg	78.33 deg	44.80 deg	72.27 deg	-5.15 deg
19.953 Hz	-	-	-	-	-	-	-	-	-

3.9.4.5 Samsung S10

The next three figures illustrate the relative change in the amplitude response over -20 C to +50 C when compared to the phase observed at 23 C for the Samsung S10 packages. Note the lithium-ion batteries powering the Samsung S10 packages lost their ability to provide power below -20 C.

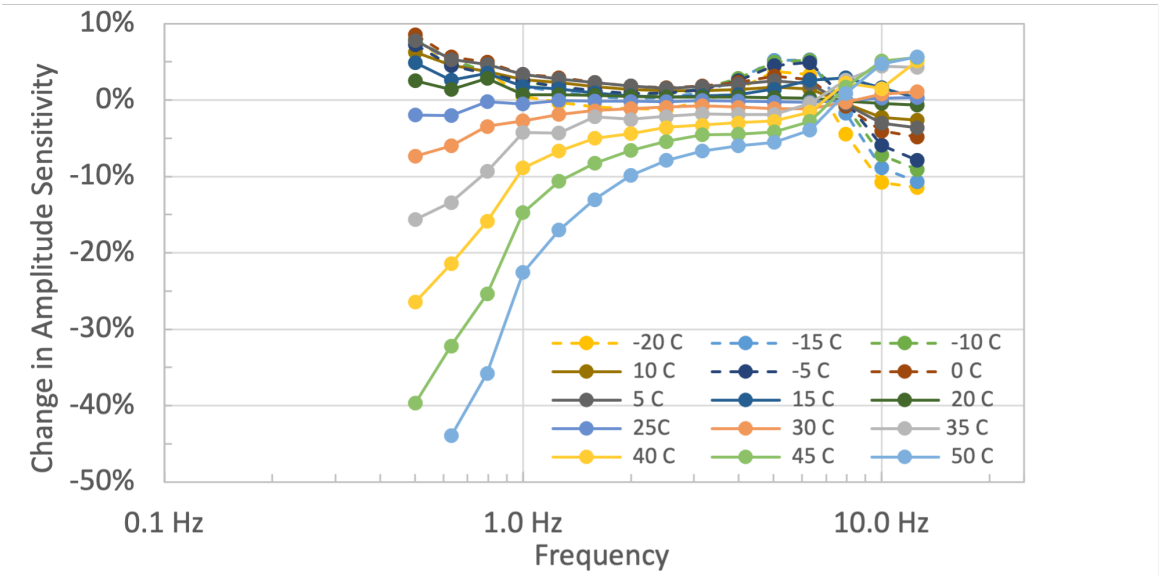

Figure 87 Relative Change in Amplitude Response with Temperature: S10 E

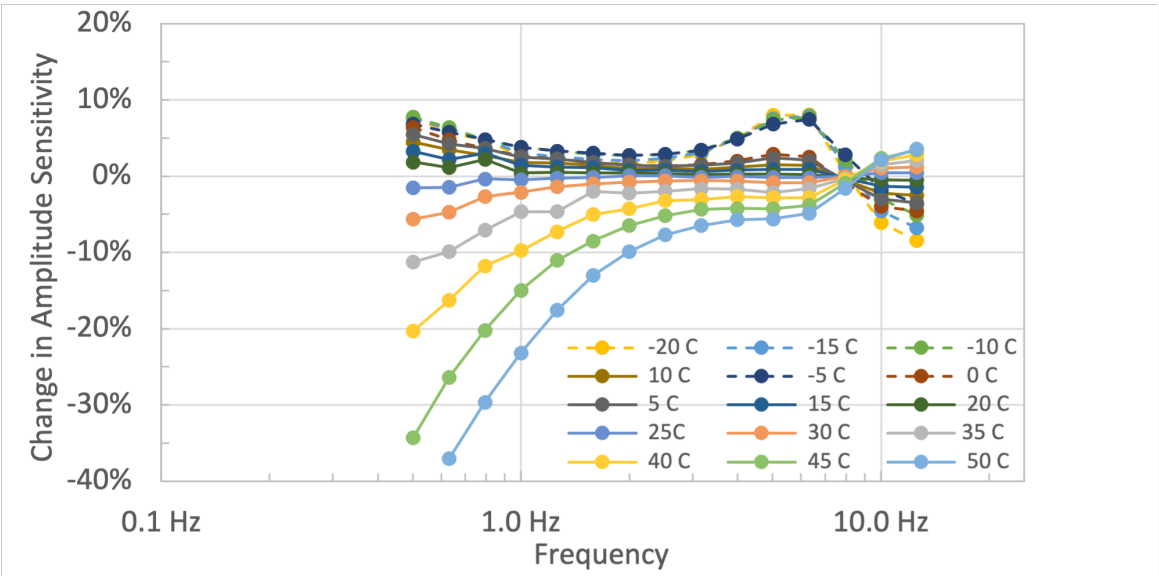

Figure 88 Relative Change in Amplitude Response with Temperature: S10 P

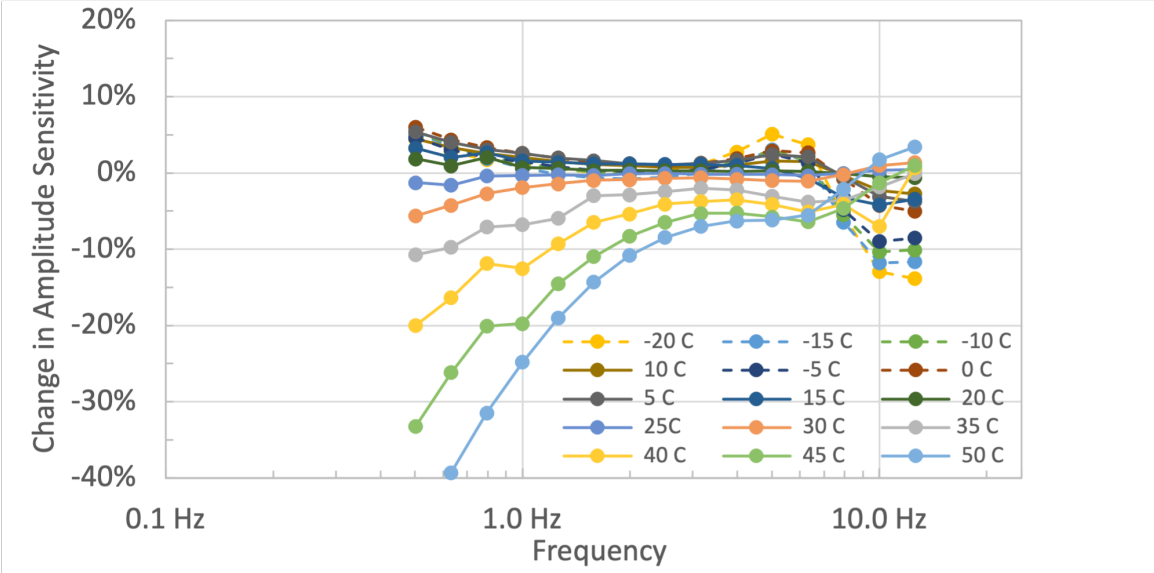

Figure 89 Relative Change in Amplitude Response with Temperature: S10 W

The Samsung S10 packages all exhibit similar relative amplitude sensitivity changes across the temperatures evaluated. The amplitude response is more significantly impacted at lower frequencies and hotter temperatures, indicating that there is a change in the corner frequency of the passband at these higher temperatures.

The following three tables contain the data shown in the above figures.

Table 82 Relative Change in Amplitude Response with Temperature: S10 E

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.501 Hz	-	-	-	8.00%	7.93%	7.85%	7.25%	8.56%	7.74%
0.631 Hz	-	-	-	4.70%	5.04%	5.34%	4.49%	5.61%	5.29%
0.794 Hz	-	-	-	3.70%	3.67%	3.66%	3.39%	4.93%	4.66%
1.000 Hz	-	-	-	0.44%	1.76%	2.38%	2.47%	3.35%	3.35%
1.259 Hz	-	-	-	-0.33%	1.05%	1.72%	1.78%	2.94%	2.78%
1.585 Hz	-	-	-	-0.95%	0.49%	1.05%	1.23%	2.32%	2.32%
1.995 Hz	-	-	-	-1.14%	0.16%	0.71%	0.85%	1.85%	1.85%
2.512 Hz	-	-	-	-1.18%	0.27%	0.78%	0.90%	1.63%	1.54%
3.162 Hz	-	-	-	-0.18%	1.01%	1.47%	1.37%	1.83%	1.74%
3.981 Hz	-	-	-	1.35%	2.64%	2.81%	2.52%	2.28%	2.05%
5.012 Hz	-	-	-	3.74%	5.16%	4.93%	4.49%	3.10%	2.54%
6.310 Hz	-	-	-	3.31%	5.25%	5.22%	4.92%	2.67%	2.11%
7.943 Hz	-	-	-	-4.44%	-1.70%	-0.79%	-0.05%	-0.84%	-0.54%
10.000 Hz	-	-	-	-10.78%	-8.87%	-7.24%	-5.94%	-4.06%	-3.04%
12.589 Hz	-	-	-	-11.48%	-10.68%	-9.14%	-7.91%	-4.88%	-3.65%

Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.501 Hz	6.24%	4.86%	2.50%	-1.94%	-7.36%	-15.66%	-26.43%	-39.70%	-
0.631 Hz	4.56%	2.60%	1.39%	-2.03%	-6.00%	-13.42%	-21.42%	-32.19%	-43.97%
0.794 Hz	3.76%	3.52%	2.81%	-0.21%	-3.45%	-9.34%	-15.90%	-25.37%	-35.76%
1.000 Hz	2.65%	1.76%	0.71%	-0.53%	-2.73%	-4.23%	-8.91%	-14.74%	-22.55%
1.259 Hz	2.28%	1.44%	0.67%	-0.06%	-1.89%	-4.33%	-6.66%	-10.66%	-17.05%
1.585 Hz	1.72%	0.95%	0.60%	-0.14%	-1.40%	-2.18%	-5.02%	-8.25%	-13.03%
1.995 Hz	1.38%	0.54%	0.45%	-0.18%	-1.14%	-2.54%	-4.38%	-6.61%	-9.87%
2.512 Hz	1.21%	0.41%	0.38%	-0.20%	-0.94%	-2.15%	-3.61%	-5.43%	-7.91%
3.162 Hz	1.19%	0.55%	0.37%	-0.09%	-0.73%	-1.83%	-3.30%	-4.58%	-6.68%
3.981 Hz	1.41%	0.70%	0.41%	-0.12%	-0.94%	-1.87%	-2.99%	-4.45%	-5.98%
5.012 Hz	1.68%	1.42%	0.30%	-0.26%	-1.16%	-1.91%	-2.77%	-4.15%	-5.53%
6.310 Hz	1.45%	2.60%	0.25%	-0.31%	-1.17%	-0.46%	-1.60%	-2.78%	-3.95%
7.943 Hz	-0.43%	2.92%	-0.11%	-0.07%	-0.27%	2.58%	2.22%	1.67%	0.84%
10.000 Hz	-2.27%	1.63%	-0.47%	0.25%	0.77%	4.45%	1.49%	5.08%	4.75%
12.589 Hz	-2.65%	0.27%	-0.65%	0.31%	1.08%	4.26%	5.11%	5.57%	5.65%

Table 83 Relative Change in Amplitude Response with Temperature: S10 P

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.501 Hz	-	-	-	7.66%	7.58%	7.74%	6.81%	6.37%	5.49%
0.631 Hz	-	-	-	5.78%	6.23%	6.37%	5.78%	4.74%	4.24%
0.794 Hz	-	-	-	4.69%	4.77%	4.72%	4.80%	3.61%	3.62%
1.000 Hz	-	-	-	2.60%	2.98%	3.75%	3.75%	2.60%	2.50%
1.259 Hz	-	-	-	2.18%	2.55%	3.28%	3.28%	2.25%	2.25%
1.585 Hz	-	-	-	1.81%	2.16%	2.89%	3.00%	1.69%	1.77%
1.995 Hz	-	-	-	1.64%	2.06%	2.69%	2.69%	1.49%	1.44%
2.512 Hz	-	-	-	2.04%	2.29%	2.82%	2.85%	1.30%	1.30%
3.162 Hz	-	-	-	2.88%	3.08%	3.39%	3.39%	1.48%	1.38%
3.981 Hz	-	-	-	4.95%	4.89%	5.02%	4.82%	1.99%	1.74%
5.012 Hz	-	-	-	7.94%	7.53%	7.37%	6.84%	2.87%	2.37%
6.310 Hz	-	-	-	8.04%	7.88%	7.76%	7.43%	2.51%	2.07%
7.943 Hz	-	-	-	0.46%	1.30%	2.15%	2.77%	-0.87%	-0.60%
10.000 Hz	-	-	-	-6.10%	-4.62%	-3.02%	-1.74%	-4.01%	-3.02%
12.589 Hz	-	-	-	-8.49%	-6.77%	-5.10%	-3.71%	-4.58%	-3.51%

Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.501 Hz	4.49%	3.29%	1.84%	-1.56%	-5.61%	-11.30%	-20.32%	-34.31%	-
0.631 Hz	3.50%	2.16%	1.09%	-1.46%	-4.71%	-9.90%	-16.27%	-26.39%	-37.03%
0.794 Hz	2.74%	2.97%	2.15%	-0.37%	-2.66%	-7.11%	-11.77%	-20.21%	-29.64%
1.000 Hz	1.83%	1.44%	0.38%	-0.48%	-2.12%	-4.64%	-9.74%	-14.97%	-23.18%
1.259 Hz	1.70%	1.21%	0.49%	-0.24%	-1.40%	-4.67%	-7.28%	-11.04%	-17.60%
1.585 Hz	1.39%	1.12%	0.42%	-0.19%	-1.00%	-2.00%	-5.04%	-8.51%	-13.01%
1.995 Hz	0.98%	0.76%	0.44%	0.05%	-0.81%	-2.23%	-4.29%	-6.46%	-9.92%
2.512 Hz	1.02%	0.77%	0.34%	0.03%	-0.61%	-1.97%	-3.21%	-5.20%	-7.72%
3.162 Hz	0.87%	0.57%	0.18%	-0.18%	-0.60%	-1.66%	-3.09%	-4.38%	-6.46%
3.981 Hz	1.16%	0.77%	0.26%	-0.06%	-0.64%	-1.67%	-2.70%	-4.24%	-5.72%
5.012 Hz	1.51%	0.86%	0.29%	-0.20%	-0.86%	-2.13%	-2.87%	-4.26%	-5.61%
6.310 Hz	1.38%	0.88%	0.19%	-0.22%	-0.86%	-1.60%	-2.85%	-3.84%	-4.92%
7.943 Hz	-0.51%	-0.27%	-0.19%	0.00%	-0.05%	-0.34%	-0.46%	-0.92%	-1.62%
10.000 Hz	-2.26%	-1.34%	-0.49%	0.44%	1.04%	1.48%	1.97%	2.32%	2.09%
12.589 Hz	-2.51%	-1.47%	-0.52%	0.44%	1.24%	2.03%	2.79%	3.39%	3.59%

Table 84 Relative Change in Amplitude Response with Temperature: S10 W

Frequency	-35° C	-30° C	-25° C	-20° C	-15° C	-10° C	-5° C	0° C	5° C
0.501 Hz	-	-	-	5.06%	5.24%	5.42%	4.58%	5.97%	5.39%
0.631 Hz	-	-	-	2.80%	3.48%	3.62%	3.01%	4.34%	3.98%
0.794 Hz	-	-	-	1.75%	1.88%	2.02%	2.05%	3.35%	3.05%
1.000 Hz	-	-	-	1.14%	0.62%	1.32%	1.50%	2.55%	2.55%
1.259 Hz	-	-	-	0.55%	-0.17%	0.55%	0.83%	1.94%	1.94%
1.585 Hz	-	-	-	0.07%	-0.67%	0.14%	0.32%	1.40%	1.61%
1.995 Hz	-	-	-	0.07%	-0.83%	-0.11%	0.18%	1.16%	1.21%
2.512 Hz	-	-	-	0.31%	-0.56%	-0.01%	0.13%	0.97%	1.06%
3.162 Hz	-	-	-	1.10%	0.00%	0.46%	0.46%	1.28%	1.28%
3.981 Hz	-	-	-	2.75%	1.29%	1.52%	1.29%	1.87%	1.64%
5.012 Hz	-	-	-	5.06%	3.01%	2.90%	2.46%	2.90%	2.38%
6.310 Hz	-	-	-	3.71%	1.50%	1.55%	1.33%	2.63%	2.10%
7.943 Hz	-	-	-	-5.51%	-6.45%	-5.49%	-4.81%	-0.75%	-0.48%
10.000 Hz	-	-	-	-12.93%	-11.81%	-10.38%	-8.96%	-4.24%	-3.11%
12.589 Hz	-	-	-	-13.86%	-11.68%	-10.09%	-8.51%	-5.05%	-3.73%

Frequency	10° C	15° C	20° C	25° C	30° C	35° C	40° C	45° C	50° C
0.501 Hz	4.43%	3.26%	1.83%	-1.28%	-5.68%	-10.74%	-19.97%	-33.20%	-
0.631 Hz	3.28%	2.04%	0.93%	-1.65%	-4.25%	-9.75%	-16.38%	-26.15%	-36.85%
0.794 Hz	2.53%	2.61%	2.03%	-0.42%	-2.72%	-7.07%	-11.89%	-20.10%	-28.98%
1.000 Hz	2.02%	1.58%	0.70%	-0.35%	-1.93%	-6.77%	-12.53%	-19.74%	-28.74%
1.259 Hz	1.50%	1.39%	0.61%	-0.28%	-1.44%	-5.98%	-9.31%	-14.57%	-22.38%
1.585 Hz	1.09%	1.19%	0.32%	-0.35%	-0.98%	-2.98%	-6.49%	-10.95%	-16.88%
1.995 Hz	0.92%	1.16%	0.36%	-0.11%	-0.89%	-2.88%	-5.39%	-8.29%	-12.74%
2.512 Hz	0.73%	1.10%	0.27%	-0.07%	-0.73%	-2.43%	-4.09%	-6.49%	-9.83%
3.162 Hz	0.73%	1.10%	0.27%	-0.18%	-0.64%	-2.02%	-3.76%	-5.32%	-7.97%
3.981 Hz	1.05%	0.94%	0.18%	-0.18%	-0.82%	-2.23%	-3.51%	-5.27%	-7.21%
5.012 Hz	1.56%	0.60%	0.26%	-0.22%	-1.00%	-3.09%	-4.13%	-5.77%	-7.37%
6.310 Hz	1.48%	-0.70%	0.23%	-0.38%	-1.10%	-3.83%	-5.14%	-6.41%	-7.74%
7.943 Hz	-0.33%	-3.23%	-0.11%	-0.07%	-0.22%	-3.64%	-4.10%	-4.68%	-5.60%
10.000 Hz	-2.33%	-4.19%	-0.46%	0.32%	0.94%	-1.85%	-7.00%	-1.34%	-1.72%
12.589 Hz	-2.75%	-3.43%	-0.60%	0.41%	1.36%	-0.11%	0.68%	0.94%	1.05%

3.10 Static Pressure Response Variation

The response variation with static pressure is defined as the observable change in sensor response as the ambient static pressure is varied. The purpose of this test is to confirm that the sensor's response will be sufficiently stable when they are deployed in an environment where the barometric pressure will vary over time from when the sensor was first installed.

3.10.1 Measurand

The measured quantity is the percent change in amplitude and the degrees change in phase of the sensitivity as a function of barometric pressure.

3.10.2 Configuration

The infrasound sensor under test and a reference sensor with known response characteristics are placed inside of a pressure isolation chamber. The isolation chamber serves to attenuate any external ambient variations in pressure.

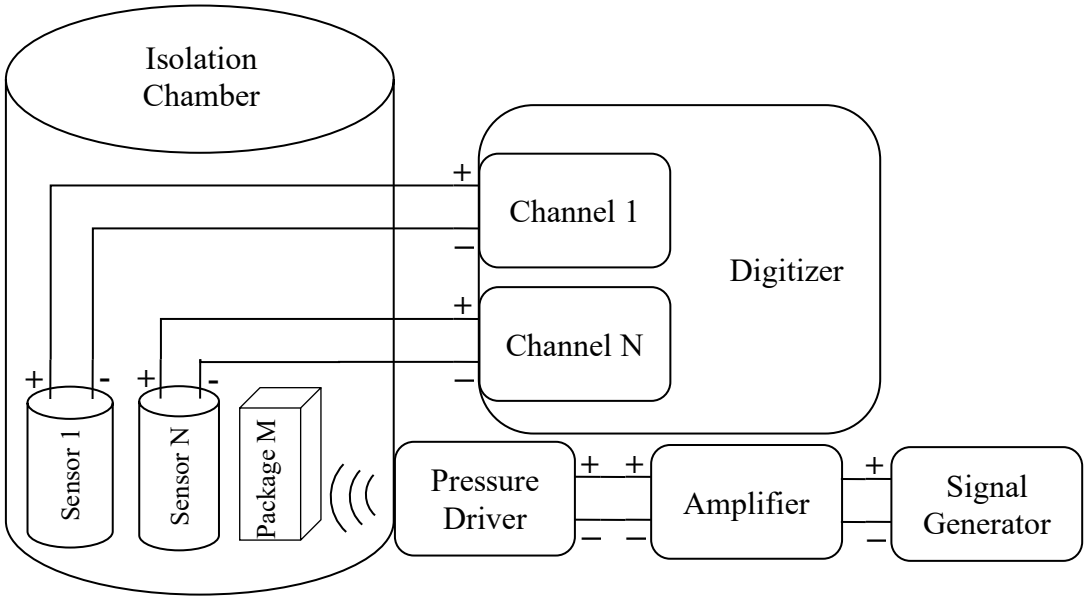

Figure 90 Sensitivity Variation with Static Pressure Configuration Diagram

A pressure driver is attached to the isolation chamber. The pressure driver is driven with a sinusoid from a signal generator and amplifier. The pressure driver serves to generate a pressure wave with characteristics defined by the signal generator. The pressure inlets of the reference sensors, the sensors and packages under test are exposed to this pressure wave.

The digitizer records the output of the reference sensor and the sensors under test simultaneously, while the internal dataloggers of the sensor packages record independently. The recorded output from the reference sensor and the sensor/package-under-test are then compared.

In addition, a compressor and a vacuum pump are attached to the isolation chamber and are used to vary the static pressure within the isolation chamber during the evaluation, above and below, respectively, the local ambient pressure at the FACT site.

The isolation chamber is pressurized or evacuated to a known static pressure at which the sensors are equalized.

The static pressure was initially set to 1000 hPa for a baseline calibration. The static pressure level was then decreased to each of 1000 hPa, 900 hPa, 800 hPa, 700 hPa, and 600 hPa. At each pressure step, the sensors were allowed to re-equilibrate for a minimum of 1 hour before the sensitivity of each sensor under test was evaluated against the reference sensors across 0.01 to 20 Hz.

The following table documents the testbed equipment and environmental conditions during the test.

Table 85 Static Pressure Sensitivity Testbed Equipment

	Manufacturer / Model	Serial Number	Configuration
Reference Sensor, >= 1 Hz	B&K 4193	2812287	2.15 mV/Pa at 1 Hz, 1000 hPa, 23 C, with corrections suitable for barometric pressure.
Reference Sensor, < 1 Hz	Setra 278	6837528	0.0833997 mV/Pa
Infrasound Chamber	SNL	1400 L Chamber	500 – 1013 hPa 22.75 C, +/- 0.75 C 17 %, +/- 3% RH
Digitizer	Guralp Affinity	405A5B	200 Hz, 1x gain 40 Vpp
Voltage Signal Source	Stanford Research Systems DS360	N/A	0.01 – 20 Hz, 0.4 Vp sinusoid
Voltage Amplifier	AE Techron 7224p	N/A	20x gain DC Coupled Amplifier
Pressure Driver	JL Audio 10w7ae	N/A	N/A

3.10.3 Analysis

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

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

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

$$V_{test} \sin(2\ pi\ f_{test}\ t +\ \theta_{test}\ ) + V_{dc\ test}$$

The sensor amplitude sensitivity in Volts / Pascal is computed:

$$S_{amp} = \frac{V_{test}}{P_{ref}}$$

The sensor phase sensitivity in degrees is computed:

$$S_{phase} =\ \theta_{test} -\ \theta_{ref}$$

The change in sensitivity, expressed as a percentage in amplitude and degrees in phase, are computed as relative to a baseline measurement:

$$Change\ S_{amp} = 100 * \frac{(S_{amp1} - S_{amp0})}{S_{amp0}}$$

$$Change\ S_{phase} = S_{phase1} - S_{phase0}$$

3.10.4 Results

The results presented utilize the traceable reference sensors and are from tests conducted within the same, large, temperature-stable volume as the sensors under test, therefore measurement uncertainties are provided in Table 86.

The total combined uncertainty estimates for the calibrations performed in the isolation chamber using the specified references sensors are frequency dependent and shown in Table 86.

Table 86 Absolute Combined Uncertainties

Frequency	Amplitude	Phase
0.010 Hz	0.57%	0.59 deg
0.013 Hz	0.57%	0.76 deg
0.016 Hz	0.57%	0.76 deg
0.020 Hz	0.57%	0.76 deg
0.025 Hz	0.57%	0.82 deg
0.032 Hz	0.57%	0.82 deg
0.040 Hz	0.57%	0.79 deg
0.050 Hz	0.57%	0.71 deg
0.063 Hz	0.57%	0.71 deg
0.079 Hz	0.65%	0.71 deg
0.100 Hz	0.71%	0.71 deg
0.126 Hz	0.71%	0.71 deg
0.158 Hz	0.85%	0.71 deg
0.200 Hz	0.99%	0.85 deg
0.251 Hz	1.14%	0.99 deg
0.316 Hz	1.28%	1.02 deg
0.398 Hz	1.36%	1.27 deg
0.501 Hz	1.42%	1.41 deg
0.631 Hz	1.56%	1.84 deg
0.794 Hz	1.71%	1.98 deg
1.000 Hz	0.30%	0.09 deg
1.259 Hz	0.30%	0.09 deg
1.585 Hz	0.30%	0.09 deg
1.995 Hz	0.30%	0.09 deg
2.512 Hz	0.30%	0.09 deg
3.162 Hz	0.30%	0.09 deg
3.981 Hz	0.30%	0.09 deg
5.012 Hz	0.30%	0.09 deg
6.310 Hz	0.30%	0.09 deg
7.943 Hz	0.30%	0.09 deg
10.000 Hz	0.30%	0.09 deg
12.589 Hz	0.30%	0.09 deg
15.849 Hz	0.30%	0.09 deg
19.953 Hz	0.30%	0.09 deg

3.10.4.1 Camas Microphones

The following six figures show the amplitude and phase responses of the Camas microphones at 600 hPa, 700 hPa, 800 hPa, 900 hPa and 1000 hPa.

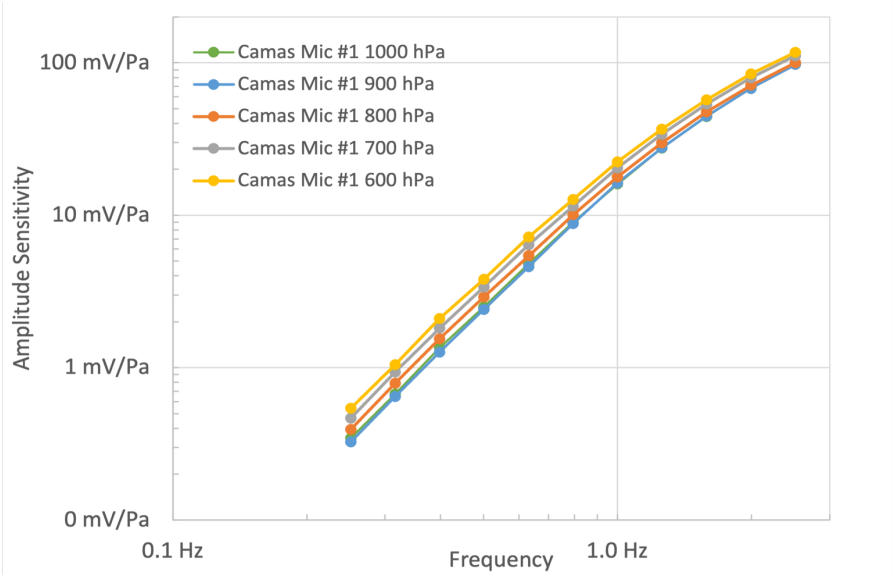

Figure 91 Amplitude Response at Evaluated Static Pressures: Camas #1

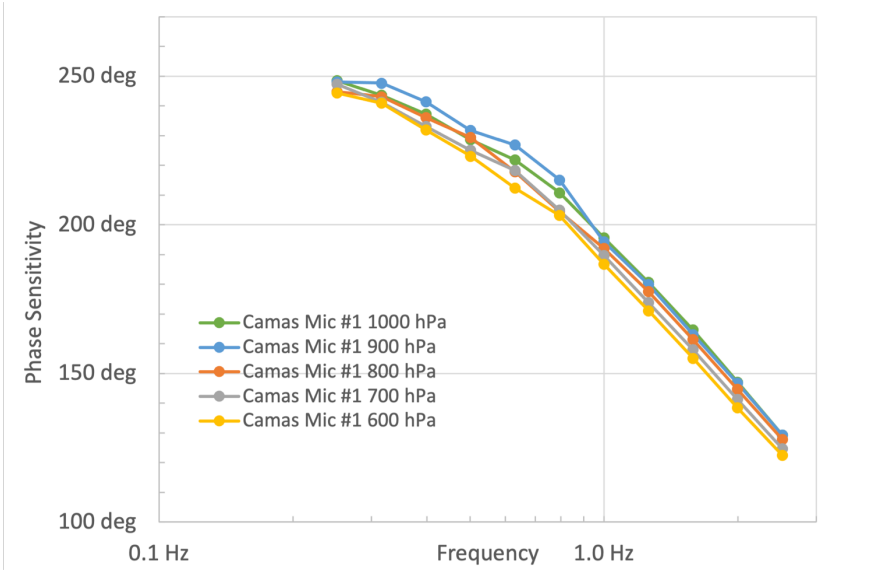

Figure 92 Phase Response at Evaluated Static Pressures: Camas #1

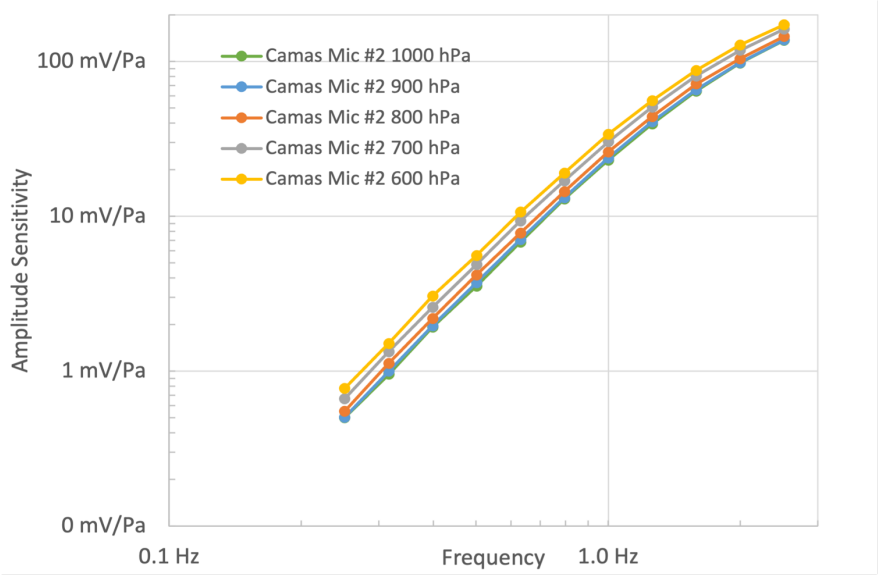

Figure 93 Amplitude Response at Evaluated Static Pressures: Camas #2

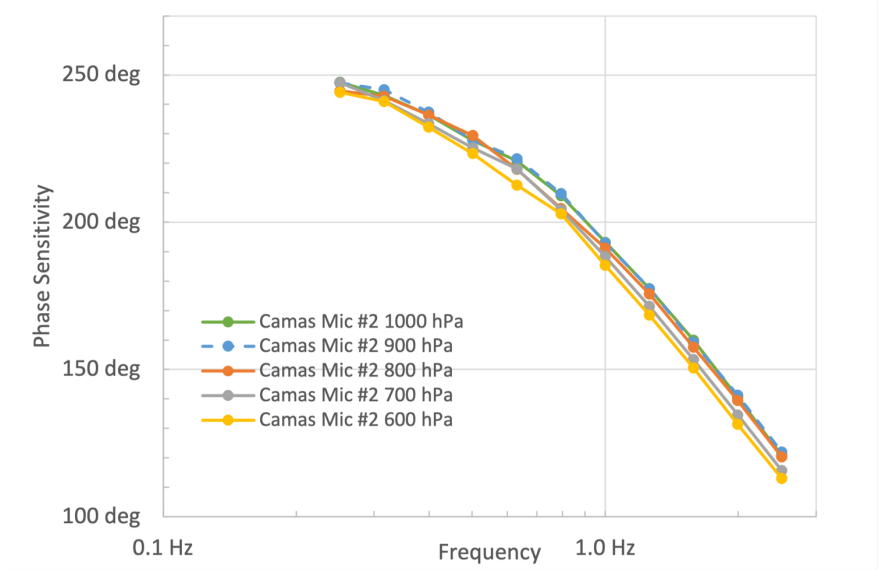

Figure 94 Phase Response at Evaluated Static Pressures: Camas #2

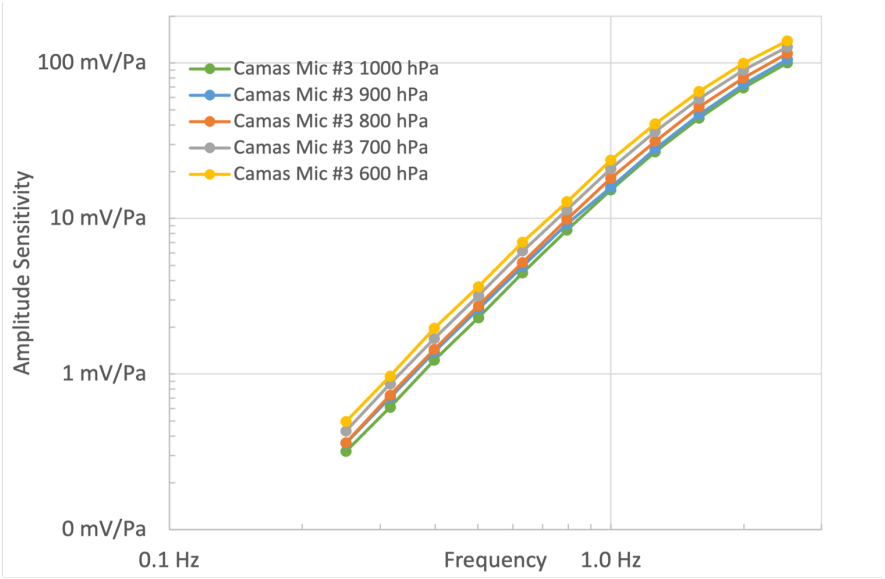

Figure 95 Amplitude Response at Evaluated Static Pressures: Camas #3

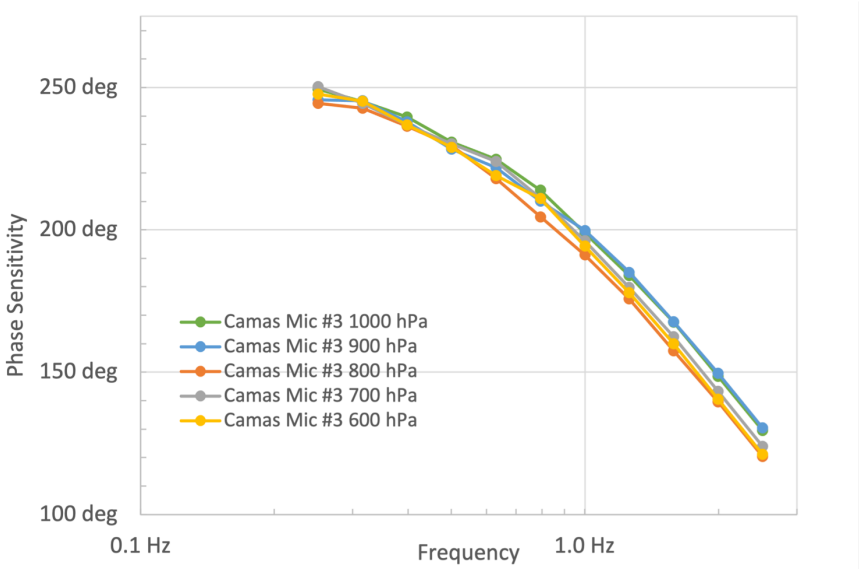

Figure 96 Phase Response at Evaluated Static Pressures: Camas #3

While there is some variability across microphones, especially at 800 hPa and lower, and at frequencies above approximately 1 Hz, the amplitude response generally increases as pressure drops. Differences due to barometric pressure are not as clear in phase, though above 1.6 Hz the effect of pressure on the phase becomes more evident.

The following tables show the values presented in the above figures.

Table 87 Amplitude Response over Evaluated Pressures: Camas #1

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.251 Hz	0.54 mV/Pa	0.47 mV/Pa	0.39 mV/Pa	0.33 mV/Pa	0.35 mV/Pa
0.316 Hz	1.05 mV/Pa	0.94 mV/Pa	0.79 mV/Pa	0.64 mV/Pa	0.67 mV/Pa
0.398 Hz	2.11 mV/Pa	1.82 mV/Pa	1.55 mV/Pa	1.27 mV/Pa	1.36 mV/Pa
0.501 Hz	3.80 mV/Pa	3.39 mV/Pa	2.91 mV/Pa	2.42 mV/Pa	2.51 mV/Pa
0.631 Hz	7.20 mV/Pa	6.41 mV/Pa	5.43 mV/Pa	4.59 mV/Pa	4.81 mV/Pa
0.794 Hz	12.69 mV/Pa	11.49 mV/Pa	10.08 mV/Pa	8.81 mV/Pa	9.02 mV/Pa
1.000 Hz	22.35 mV/Pa	20.42 mV/Pa	17.80 mV/Pa	16.31 mV/Pa	16.02 mV/Pa
1.259 Hz	36.82 mV/Pa	34.03 mV/Pa	29.84 mV/Pa	27.73 mV/Pa	27.57 mV/Pa
1.585 Hz	57.27 mV/Pa	53.64 mV/Pa	47.63 mV/Pa	44.57 mV/Pa	44.51 mV/Pa
1.995 Hz	84.45 mV/Pa	79.64 mV/Pa	71.19 mV/Pa	67.97 mV/Pa	68.72 mV/Pa
2.512 Hz	117.50 mV/Pa	111.40 mV/Pa	100.50 mV/Pa	97.31 mV/Pa	98.96 mV/Pa

Table 88 Phase Response over Evaluated Pressures: Camas #1

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.251 Hz	244.40 deg	247.30 deg	244.80 deg	248.10 deg	248.50 deg
0.316 Hz	241.00 deg	241.30 deg	243.10 deg	247.70 deg	243.60 deg
0.398 Hz	231.90 deg	233.10 deg	236.10 deg	241.40 deg	237.20 deg
0.501 Hz	223.10 deg	225.10 deg	229.40 deg	231.80 deg	228.60 deg
0.631 Hz	212.30 deg	218.30 deg	217.90 deg	226.90 deg	221.90 deg
0.794 Hz	203.20 deg	204.90 deg	204.50 deg	215.10 deg	210.80 deg
1.000 Hz	186.70 deg	189.70 deg	192.10 deg	194.30 deg	195.60 deg
1.259 Hz	171.10 deg	173.90 deg	177.50 deg	179.90 deg	180.70 deg
1.585 Hz	155.10 deg	158.00 deg	161.40 deg	163.10 deg	164.70 deg
1.995 Hz	138.40 deg	141.20 deg	144.70 deg	146.70 deg	147.10 deg
2.512 Hz	122.40 deg	124.60 deg	127.80 deg	129.30 deg	129.20 deg

Table 89 Amplitude Response over Evaluated Pressures: Camas #2

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.251 Hz	0.78 mV/Pa	0.66 mV/Pa	0.55 mV/Pa	0.50 mV/Pa	0.50 mV/Pa
0.316 Hz	1.51 mV/Pa	1.33 mV/Pa	1.13 mV/Pa	1.00 mV/Pa	0.95 mV/Pa
0.398 Hz	3.06 mV/Pa	2.58 mV/Pa	2.19 mV/Pa	1.96 mV/Pa	1.93 mV/Pa
0.501 Hz	5.58 mV/Pa	4.88 mV/Pa	4.19 mV/Pa	3.73 mV/Pa	3.55 mV/Pa
0.631 Hz	10.64 mV/Pa	9.32 mV/Pa	7.80 mV/Pa	7.07 mV/Pa	6.80 mV/Pa
0.794 Hz	19.04 mV/Pa	16.93 mV/Pa	14.44 mV/Pa	13.21 mV/Pa	12.95 mV/Pa
1.000 Hz	33.93 mV/Pa	30.27 mV/Pa	26.10 mV/Pa	23.78 mV/Pa	23.01 mV/Pa
1.259 Hz	56.02 mV/Pa	50.80 mV/Pa	44.01 mV/Pa	40.73 mV/Pa	39.59 mV/Pa
1.585 Hz	87.37 mV/Pa	80.66 mV/Pa	71.56 mV/Pa	65.51 mV/Pa	64.43 mV/Pa
1.995 Hz	127.80 mV/Pa	118.00 mV/Pa	104.30 mV/Pa	98.37 mV/Pa	97.67 mV/Pa
2.512 Hz	172.40 mV/Pa	161.60 mV/Pa	145.50 mV/Pa	138.30 mV/Pa	137.30 mV/Pa

Table 90 Phase Response over Evaluated Pressures: Camas #2

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.251 Hz	244.10 deg	247.40 deg	244.50 deg	247.20 deg	247.50 deg
0.316 Hz	240.90 deg	241.20 deg	242.70 deg	245.00 deg	243.00 deg
0.398 Hz	232.30 deg	233.50 deg	236.40 deg	237.40 deg	236.50 deg
0.501 Hz	223.30 deg	225.30 deg	229.50 deg	227.90 deg	227.80 deg
0.631 Hz	212.60 deg	218.10 deg	218.00 deg	221.60 deg	220.80 deg
0.794 Hz	202.80 deg	204.20 deg	204.60 deg	209.70 deg	209.00 deg
1.000 Hz	185.40 deg	188.30 deg	191.20 deg	193.00 deg	193.20 deg
1.259 Hz	168.40 deg	171.40 deg	175.70 deg	177.50 deg	177.40 deg
1.585 Hz	150.50 deg	153.40 deg	157.50 deg	159.20 deg	159.90 deg
1.995 Hz	131.40 deg	134.60 deg	139.50 deg	141.20 deg	140.50 deg
2.512 Hz	113.00 deg	115.70 deg	120.40 deg	121.90 deg	120.80 deg

Table 91 Amplitude Response over Evaluated Pressures: Camas #3

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.251 Hz	0.50 mV/Pa	0.66 mV/Pa	0.36 mV/Pa	0.36 mV/Pa	0.32 mV/Pa
0.316 Hz	0.97 mV/Pa	1.33 mV/Pa	0.73 mV/Pa	0.71 mV/Pa	0.61 mV/Pa
0.398 Hz	1.97 mV/Pa	2.58 mV/Pa	1.44 mV/Pa	1.39 mV/Pa	1.23 mV/Pa
0.501 Hz	3.65 mV/Pa	4.88 mV/Pa	2.75 mV/Pa	2.62 mV/Pa	2.30 mV/Pa
0.631 Hz	7.06 mV/Pa	9.32 mV/Pa	5.22 mV/Pa	4.93 mV/Pa	4.48 mV/Pa
0.794 Hz	12.81 mV/Pa	16.93 mV/Pa	9.88 mV/Pa	9.22 mV/Pa	8.41 mV/Pa
1.000 Hz	23.73 mV/Pa	30.27 mV/Pa	18.13 mV/Pa	15.91 mV/Pa	15.30 mV/Pa
1.259 Hz	40.57 mV/Pa	50.80 mV/Pa	31.38 mV/Pa	28.08 mV/Pa	26.75 mV/Pa
1.585 Hz	65.73 mV/Pa	80.66 mV/Pa	52.04 mV/Pa	46.55 mV/Pa	44.17 mV/Pa
1.995 Hz	99.47 mV/Pa	118.00 mV/Pa	80.13 mV/Pa	72.97 mV/Pa	69.27 mV/Pa
2.512 Hz	139.00 mV/Pa	161.60 mV/Pa	115.30 mV/Pa	105.50 mV/Pa	100.00 mV/Pa

Table 92 Phase Response over Evaluated Pressures: Camas #3

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.251 Hz	247.70 deg	250.30 deg	247.50 deg	245.70 deg	249.40 deg
0.316 Hz	245.20 deg	244.50 deg	245.80 deg	245.30 deg	245.00 deg
0.398 Hz	236.80 deg	236.80 deg	240.30 deg	237.90 deg	239.60 deg
0.501 Hz	228.90 deg	230.20 deg	233.80 deg	228.40 deg	230.80 deg
0.631 Hz	219.10 deg	224.00 deg	223.60 deg	221.90 deg	224.80 deg
0.794 Hz	211.00 deg	211.10 deg	210.60 deg	210.10 deg	213.90 deg
1.000 Hz	194.30 deg	196.10 deg	198.30 deg	199.80 deg	199.00 deg
1.259 Hz	177.90 deg	179.80 deg	183.60 deg	185.10 deg	183.90 deg
1.585 Hz	160.00 deg	162.40 deg	166.20 deg	167.70 deg	167.50 deg
1.995 Hz	138.40 deg	143.30 deg	147.80 deg	149.60 deg	148.50 deg
2.512 Hz	122.40 deg	124.00 deg	128.30 deg	130.40 deg	129.50 deg

3.10.4.2 InfraBSU Sensor

The following six figures show the amplitude and phase responses of the InfraBSU sensors at 600 hPa, 700 hPa, 800 hPa, 900 hPa and 1000 hPa.

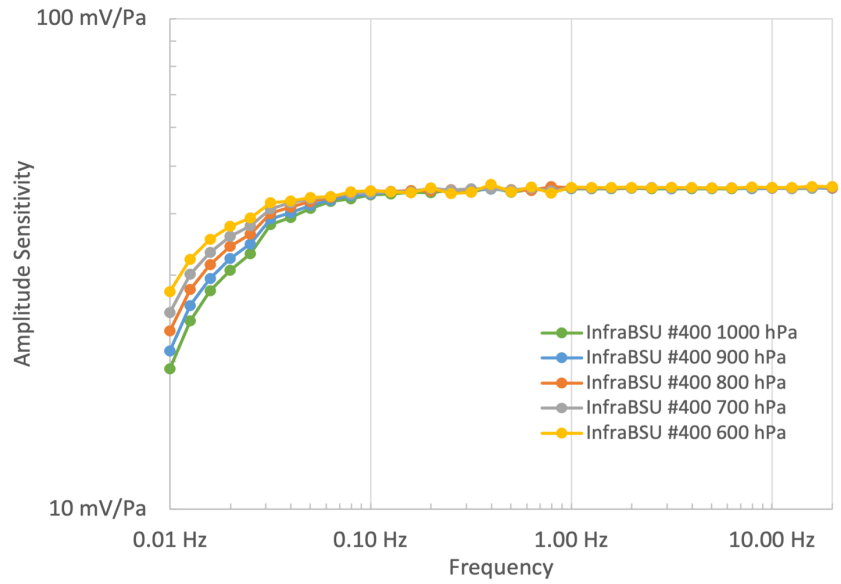

Figure 97 Amplitude Response at Evaluated Static Pressures: InfraBSU #400

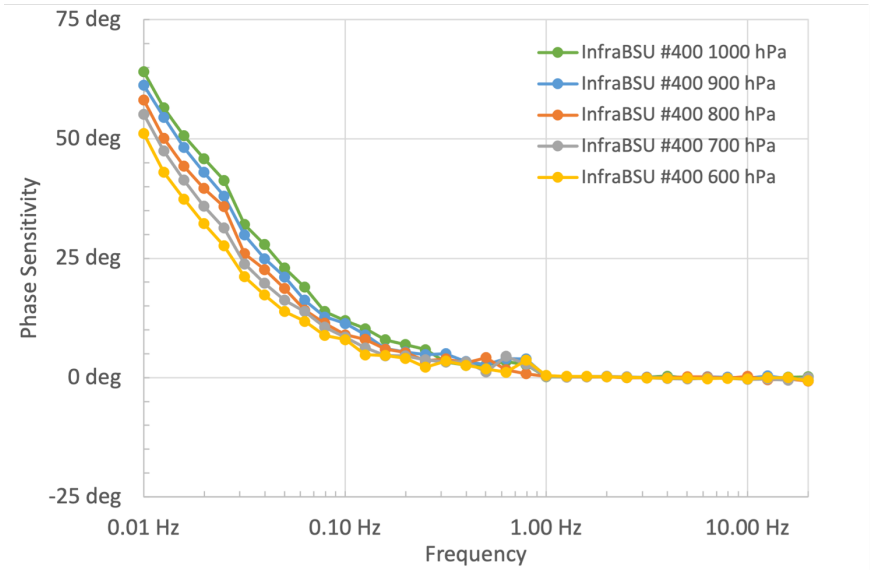

Figure 98 Phase Response at Evaluated Static Pressures: InfraBSU #400

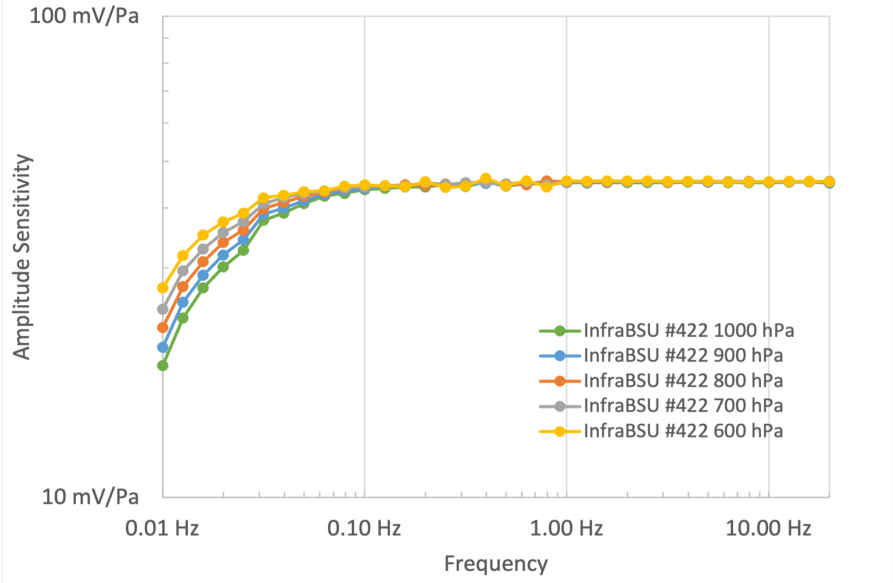

Figure 99 Amplitude Response at Evaluated Static Pressures: InfraBSU #422

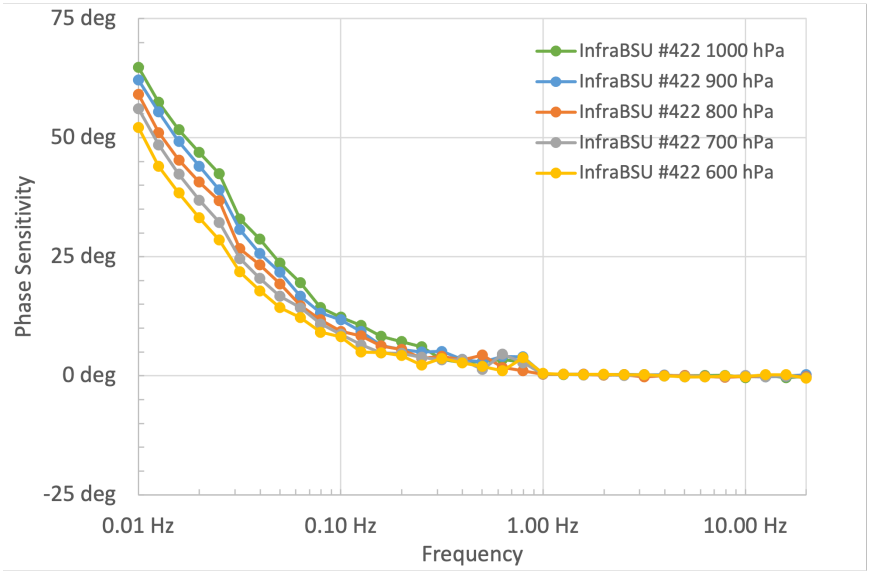

Figure 100 Phase Response at Evaluated Static Pressures: InfraBSU #422

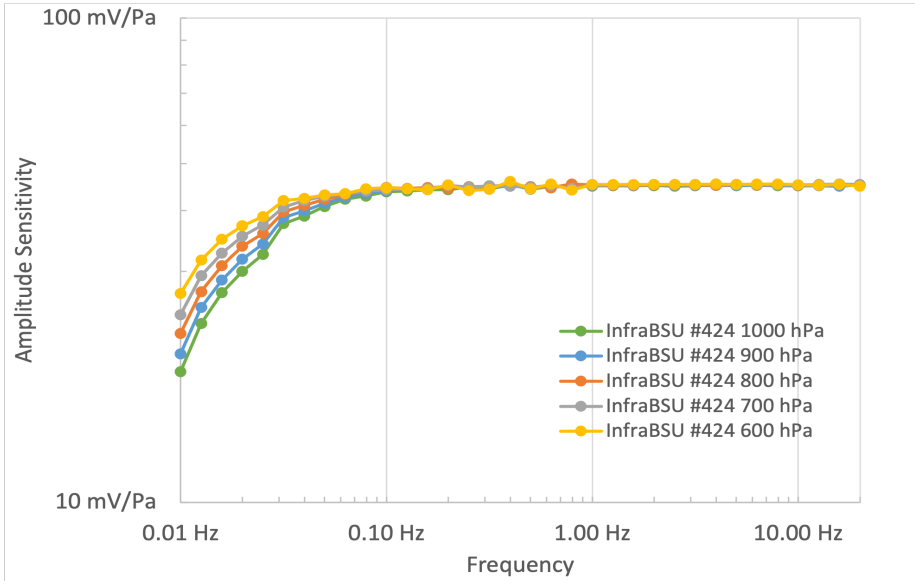

Figure 101 Amplitude Response at Evaluated Static Pressures: InfraBSU #424

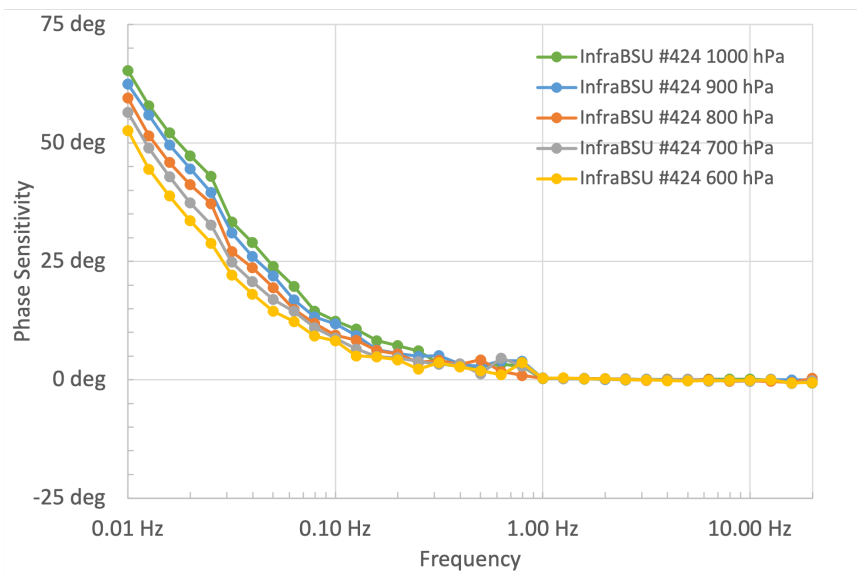

Figure 102 Phase Response at Evaluated Static Pressures: InfraBSU #424

Figure 97, Figure 99 and Figure 101 clearly show static pressure changes on the InfrBSU sensors are very uniform from one sensor to the other. Changes in response due to static pressure are minimal at higher frequencies, above 0.1 Hz in amplitude and 0.5 Hz in phase. The low frequency corner of the InfraBSU amplitude response migrates to lower frequencies as pressure drops. Note that variability is higher at frequencies below 1 Hz due to the increased relative uncertainty of the reference sensor in use.

The following tables contains the values used to generate the above figures.

Table 93 Amplitude Response over Evaluated Pressures: InfraBSU #400

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	27.79 uV/Pa	25.19 uV/Pa	23.08 uV/Pa	21.04 uV/Pa	19.33 uV/Pa
0.013 Hz	32.33 uV/Pa	30.15 uV/Pa	28.03 uV/Pa	26.03 uV/Pa	24.20 uV/Pa
0.016 Hz	35.50 uV/Pa	33.35 uV/Pa	31.49 uV/Pa	29.50 uV/Pa	27.85 uV/Pa
0.020 Hz	37.72 uV/Pa	35.98 uV/Pa	34.35 uV/Pa	32.43 uV/Pa	30.70 uV/Pa
0.025 Hz	39.22 uV/Pa	37.78 uV/Pa	36.37 uV/Pa	34.73 uV/Pa	33.14 uV/Pa
0.032 Hz	42.11 uV/Pa	40.94 uV/Pa	40.08 uV/Pa	39.09 uV/Pa	38.06 uV/Pa
0.040 Hz	42.51 uV/Pa	42.14 uV/Pa	41.28 uV/Pa	40.20 uV/Pa	39.29 uV/Pa
0.050 Hz	43.19 uV/Pa	42.89 uV/Pa	42.35 uV/Pa	41.60 uV/Pa	41.03 uV/Pa
0.063 Hz	43.40 uV/Pa	43.38 uV/Pa	43.15 uV/Pa	42.70 uV/Pa	42.38 uV/Pa
0.079 Hz	44.33 uV/Pa	43.95 uV/Pa	43.96 uV/Pa	43.52 uV/Pa	42.94 uV/Pa
0.100 Hz	44.58 uV/Pa	44.17 uV/Pa	44.58 uV/Pa	43.93 uV/Pa	43.70 uV/Pa
0.126 Hz	44.35 uV/Pa	44.39 uV/Pa	44.45 uV/Pa	44.37 uV/Pa	43.93 uV/Pa
0.158 Hz	44.17 uV/Pa	44.40 uV/Pa	44.62 uV/Pa	44.52 uV/Pa	44.21 uV/Pa
0.200 Hz	45.20 uV/Pa	45.04 uV/Pa	44.50 uV/Pa	44.94 uV/Pa	44.19 uV/Pa
0.251 Hz	43.97 uV/Pa	44.71 uV/Pa	44.79 uV/Pa	44.55 uV/Pa	44.73 uV/Pa
0.316 Hz	44.24 uV/Pa	45.02 uV/Pa	44.79 uV/Pa	44.75 uV/Pa	44.25 uV/Pa
0.398 Hz	45.97 uV/Pa	45.01 uV/Pa	45.28 uV/Pa	44.89 uV/Pa	45.23 uV/Pa
0.501 Hz	44.35 uV/Pa	44.68 uV/Pa	44.77 uV/Pa	44.73 uV/Pa	44.27 uV/Pa
0.631 Hz	45.40 uV/Pa	45.13 uV/Pa	44.59 uV/Pa	44.72 uV/Pa	44.87 uV/Pa
0.794 Hz	44.10 uV/Pa	44.51 uV/Pa	45.42 uV/Pa	45.00 uV/Pa	44.60 uV/Pa
1.000 Hz	45.31 uV/Pa	45.22 uV/Pa	45.18 uV/Pa	45.11 uV/Pa	44.98 uV/Pa
1.259 Hz	45.28 uV/Pa	45.19 uV/Pa	45.16 uV/Pa	45.08 uV/Pa	44.99 uV/Pa
1.585 Hz	45.25 uV/Pa	45.22 uV/Pa	45.14 uV/Pa	45.06 uV/Pa	44.96 uV/Pa
1.995 Hz	45.31 uV/Pa	45.21 uV/Pa	45.19 uV/Pa	45.18 uV/Pa	45.05 uV/Pa
2.512 Hz	45.22 uV/Pa	45.25 uV/Pa	45.19 uV/Pa	45.14 uV/Pa	44.96 uV/Pa
3.162 Hz	45.30 uV/Pa	45.22 uV/Pa	45.24 uV/Pa	45.04 uV/Pa	45.01 uV/Pa
3.981 Hz	45.29 uV/Pa	45.21 uV/Pa	45.17 uV/Pa	45.16 uV/Pa	45.00 uV/Pa
5.012 Hz	45.21 uV/Pa	45.21 uV/Pa	45.14 uV/Pa	45.11 uV/Pa	44.99 uV/Pa
6.310 Hz	45.19 uV/Pa	45.18 uV/Pa	45.16 uV/Pa	45.18 uV/Pa	44.96 uV/Pa
7.943 Hz	45.36 uV/Pa	45.17 uV/Pa	45.27 uV/Pa	45.02 uV/Pa	45.12 uV/Pa
10.000 Hz	45.29 uV/Pa	45.26 uV/Pa	45.19 uV/Pa	45.08 uV/Pa	45.14 uV/Pa
12.589 Hz	45.26 uV/Pa	44.98 uV/Pa	45.20 uV/Pa	45.12 uV/Pa	45.00 uV/Pa
15.849 Hz	45.50 uV/Pa	45.18 uV/Pa	45.31 uV/Pa	45.15 uV/Pa	45.08 uV/Pa
19.953 Hz	45.43 uV/Pa	45.37 uV/Pa	45.15 uV/Pa	45.11 uV/Pa	45.25 uV/Pa

Table 94 Phase Response over Evaluated Pressures: InfraBSU #400

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	51.14 deg	55.14 deg	58.18 deg	61.24 deg	64.13 deg
0.013 Hz	43.00 deg	47.51 deg	50.11 deg	54.55 deg	56.53 deg
0.016 Hz	37.42 deg	41.35 deg	44.32 deg	48.24 deg	50.66 deg
0.020 Hz	32.26 deg	35.90 deg	39.67 deg	43.00 deg	45.88 deg
0.025 Hz	27.61 deg	31.32 deg	35.82 deg	38.04 deg	41.34 deg
0.032 Hz	21.17 deg	23.84 deg	25.95 deg	29.89 deg	32.07 deg
0.040 Hz	17.29 deg	19.76 deg	22.65 deg	24.93 deg	27.87 deg
0.050 Hz	13.84 deg	16.21 deg	18.66 deg	21.09 deg	22.94 deg
0.063 Hz	11.81 deg	13.88 deg	14.18 deg	16.21 deg	18.94 deg
0.079 Hz	8.85 deg	10.54 deg	11.38 deg	12.70 deg	13.85 deg
0.100 Hz	7.98 deg	8.45 deg	8.97 deg	11.35 deg	11.91 deg
0.126 Hz	4.78 deg	6.24 deg	8.02 deg	8.96 deg	10.26 deg
0.158 Hz	4.64 deg	4.59 deg	5.97 deg	6.07 deg	7.95 deg
0.200 Hz	4.06 deg	4.54 deg	5.23 deg	5.37 deg	6.95 deg
0.251 Hz	2.19 deg	3.73 deg	3.50 deg	4.81 deg	5.88 deg
0.316 Hz	3.46 deg	3.26 deg	3.89 deg	5.00 deg	3.27 deg
0.398 Hz	2.59 deg	3.32 deg	3.10 deg	3.34 deg	2.60 deg
0.501 Hz	1.79 deg	1.15 deg	4.19 deg	2.68 deg	2.75 deg
0.631 Hz	1.13 deg	4.48 deg	1.63 deg	3.96 deg	3.34 deg
0.794 Hz	3.67 deg	2.80 deg	0.83 deg	3.90 deg	2.67 deg
1.000 Hz	0.43 deg	0.29 deg	0.29 deg	0.28 deg	0.18 deg
1.259 Hz	0.29 deg	0.13 deg	0.19 deg	0.21 deg	0.16 deg
1.585 Hz	0.28 deg	0.21 deg	0.15 deg	0.18 deg	0.19 deg
1.995 Hz	0.18 deg	0.24 deg	0.17 deg	0.27 deg	0.19 deg
2.512 Hz	0.03 deg	0.19 deg	-0.01 deg	-0.02 deg	0.11 deg
3.162 Hz	-0.06 deg	-0.05 deg	-0.01 deg	0.08 deg	0.04 deg
3.981 Hz	-0.13 deg	-0.20 deg	-0.04 deg	-0.02 deg	0.32 deg
5.012 Hz	-0.07 deg	-0.31 deg	0.19 deg	-0.05 deg	-0.13 deg
6.310 Hz	-0.23 deg	-0.07 deg	0.13 deg	0.14 deg	0.02 deg
7.943 Hz	-0.15 deg	-0.07 deg	-0.10 deg	0.06 deg	-0.08 deg
10.000 Hz	-0.30 deg	-0.39 deg	0.30 deg	-0.10 deg	0.04 deg
12.589 Hz	0.01 deg	-0.28 deg	-0.45 deg	0.34 deg	-0.14 deg
15.849 Hz	0.01 deg	-0.57 deg	-0.25 deg	-0.20 deg	0.07 deg
19.953 Hz	-0.59 deg	0.02 deg	-0.68 deg	-0.51 deg	0.18 deg

Table 95 Amplitude Response over Evaluated Pressures: InfraBSU #422

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	27.26 uV/Pa	24.63 uV/Pa	22.54 uV/Pa	20.51 uV/Pa	18.82 uV/Pa
0.013 Hz	31.85 uV/Pa	29.61 uV/Pa	27.46 uV/Pa	25.46 uV/Pa	23.63 uV/Pa
0.016 Hz	35.10 uV/Pa	32.87 uV/Pa	30.91 uV/Pa	28.95 uV/Pa	27.29 uV/Pa
0.020 Hz	37.39 uV/Pa	35.58 uV/Pa	33.90 uV/Pa	31.93 uV/Pa	30.15 uV/Pa
0.025 Hz	38.97 uV/Pa	37.44 uV/Pa	35.97 uV/Pa	34.30 uV/Pa	32.64 uV/Pa
0.032 Hz	41.98 uV/Pa	40.78 uV/Pa	39.84 uV/Pa	38.80 uV/Pa	37.72 uV/Pa
0.040 Hz	42.45 uV/Pa	42.01 uV/Pa	41.05 uV/Pa	40.00 uV/Pa	39.02 uV/Pa
0.050 Hz	43.15 uV/Pa	42.83 uV/Pa	42.25 uV/Pa	41.44 uV/Pa	40.83 uV/Pa
0.063 Hz	43.40 uV/Pa	43.36 uV/Pa	43.11 uV/Pa	42.62 uV/Pa	42.27 uV/Pa
0.079 Hz	44.36 uV/Pa	43.97 uV/Pa	43.94 uV/Pa	43.48 uV/Pa	42.87 uV/Pa
0.100 Hz	44.63 uV/Pa	44.18 uV/Pa	44.58 uV/Pa	43.92 uV/Pa	43.67 uV/Pa
0.126 Hz	44.43 uV/Pa	44.42 uV/Pa	44.48 uV/Pa	44.37 uV/Pa	43.91 uV/Pa
0.158 Hz	44.24 uV/Pa	44.41 uV/Pa	44.64 uV/Pa	44.53 uV/Pa	44.20 uV/Pa
0.200 Hz	45.29 uV/Pa	45.14 uV/Pa	44.53 uV/Pa	44.96 uV/Pa	44.20 uV/Pa
0.251 Hz	44.06 uV/Pa	44.75 uV/Pa	44.83 uV/Pa	44.60 uV/Pa	44.73 uV/Pa
0.316 Hz	44.37 uV/Pa	45.11 uV/Pa	44.83 uV/Pa	44.80 uV/Pa	44.30 uV/Pa
0.398 Hz	46.09 uV/Pa	45.10 uV/Pa	45.33 uV/Pa	44.98 uV/Pa	45.32 uV/Pa
0.501 Hz	44.49 uV/Pa	44.79 uV/Pa	44.87 uV/Pa	44.82 uV/Pa	44.33 uV/Pa
0.631 Hz	45.54 uV/Pa	45.26 uV/Pa	44.69 uV/Pa	44.80 uV/Pa	44.96 uV/Pa
0.794 Hz	44.23 uV/Pa	44.65 uV/Pa	45.51 uV/Pa	45.08 uV/Pa	44.69 uV/Pa
1.000 Hz	45.46 uV/Pa	45.37 uV/Pa	45.29 uV/Pa	45.20 uV/Pa	45.12 uV/Pa
1.259 Hz	45.44 uV/Pa	45.39 uV/Pa	45.32 uV/Pa	45.16 uV/Pa	45.07 uV/Pa
1.585 Hz	45.52 uV/Pa	45.39 uV/Pa	45.31 uV/Pa	45.25 uV/Pa	45.11 uV/Pa
1.995 Hz	45.46 uV/Pa	45.40 uV/Pa	45.36 uV/Pa	45.27 uV/Pa	45.09 uV/Pa
2.512 Hz	45.51 uV/Pa	45.38 uV/Pa	45.37 uV/Pa	45.26 uV/Pa	45.10 uV/Pa
3.162 Hz	45.42 uV/Pa	45.29 uV/Pa	45.22 uV/Pa	45.29 uV/Pa	45.13 uV/Pa
3.981 Hz	45.42 uV/Pa	45.41 uV/Pa	45.36 uV/Pa	45.35 uV/Pa	45.18 uV/Pa
5.012 Hz	45.52 uV/Pa	45.39 uV/Pa	45.40 uV/Pa	45.19 uV/Pa	45.25 uV/Pa
6.310 Hz	45.33 uV/Pa	45.45 uV/Pa	45.35 uV/Pa	45.28 uV/Pa	45.16 uV/Pa
7.943 Hz	45.31 uV/Pa	45.45 uV/Pa	45.40 uV/Pa	45.28 uV/Pa	45.13 uV/Pa
10.000 Hz	45.35 uV/Pa	45.22 uV/Pa	45.28 uV/Pa	45.27 uV/Pa	45.11 uV/Pa
12.589 Hz	45.41 uV/Pa	45.32 uV/Pa	45.37 uV/Pa	45.31 uV/Pa	45.24 uV/Pa
15.849 Hz	45.43 uV/Pa	45.42 uV/Pa	45.30 uV/Pa	45.32 uV/Pa	45.29 uV/Pa
19.953 Hz	45.28 uV/Pa	45.42 uV/Pa	45.38 uV/Pa	45.01 uV/Pa	45.26 uV/Pa

Table 96 Phase Response over Evaluated Pressures: InfraBSU #422

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	52.14 deg	56.05 deg	59.08 deg	62.10 deg	64.81 deg
0.013 Hz	43.98 deg	48.52 deg	51.08 deg	55.43 deg	57.42 deg
0.016 Hz	38.41 deg	42.35 deg	45.31 deg	49.21 deg	51.66 deg
0.020 Hz	33.18 deg	36.89 deg	40.71 deg	44.03 deg	46.88 deg
0.025 Hz	28.51 deg	32.23 deg	36.76 deg	39.06 deg	42.41 deg
0.032 Hz	21.84 deg	24.61 deg	26.70 deg	30.74 deg	32.96 deg
0.040 Hz	17.86 deg	20.47 deg	23.32 deg	25.69 deg	28.70 deg
0.050 Hz	14.35 deg	16.71 deg	19.32 deg	21.76 deg	23.64 deg
0.063 Hz	12.19 deg	14.29 deg	14.74 deg	16.73 deg	19.53 deg
0.079 Hz	9.14 deg	10.89 deg	11.79 deg	13.18 deg	14.35 deg
0.100 Hz	8.20 deg	8.72 deg	9.35 deg	11.75 deg	12.28 deg
0.126 Hz	5.01 deg	6.51 deg	8.36 deg	9.26 deg	10.60 deg
0.158 Hz	4.84 deg	4.80 deg	6.27 deg	6.32 deg	8.26 deg
0.200 Hz	4.24 deg	4.73 deg	5.52 deg	5.54 deg	7.17 deg
0.251 Hz	2.26 deg	3.91 deg	3.69 deg	5.02 deg	6.12 deg
0.316 Hz	3.66 deg	3.35 deg	4.04 deg	5.12 deg	3.42 deg
0.398 Hz	2.67 deg	3.34 deg	3.32 deg	3.46 deg	2.80 deg
0.501 Hz	1.95 deg	1.31 deg	4.32 deg	2.87 deg	2.97 deg
0.631 Hz	1.06 deg	4.55 deg	1.73 deg	4.06 deg	3.46 deg
0.794 Hz	3.79 deg	2.75 deg	1.02 deg	4.01 deg	2.84 deg
1.000 Hz	0.50 deg	0.42 deg	0.33 deg	0.38 deg	0.29 deg
1.259 Hz	0.34 deg	0.34 deg	0.33 deg	0.32 deg	0.26 deg
1.585 Hz	0.27 deg	0.18 deg	0.31 deg	0.32 deg	0.27 deg
1.995 Hz	0.34 deg	0.28 deg	0.12 deg	0.26 deg	0.12 deg
2.512 Hz	0.25 deg	0.05 deg	0.20 deg	0.29 deg	0.21 deg
3.162 Hz	0.25 deg	0.20 deg	-0.21 deg	0.21 deg	0.03 deg
3.981 Hz	-0.01 deg	-0.03 deg	0.05 deg	0.19 deg	0.01 deg
5.012 Hz	-0.21 deg	-0.10 deg	0.08 deg	-0.22 deg	0.05 deg
6.310 Hz	-0.20 deg	-0.19 deg	-0.13 deg	-0.14 deg	0.06 deg
7.943 Hz	-0.07 deg	-0.13 deg	-0.27 deg	-0.26 deg	0.10 deg
10.000 Hz	-0.18 deg	0.04 deg	-0.12 deg	-0.14 deg	-0.36 deg
12.589 Hz	0.26 deg	-0.18 deg	-0.15 deg	-0.20 deg	0.13 deg
15.849 Hz	0.22 deg	-0.03 deg	-0.01 deg	-0.10 deg	-0.40 deg
19.953 Hz	-0.51 deg	-0.38 deg	-0.24 deg	0.20 deg	-0.18 deg

Table 97 Amplitude Response over Evaluated Pressures: InfraBSU #424

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	24.37 uV/Pa	22.32 uV/Pa	20.27 uV/Pa	18.61 uV/Pa	18.61 uV/Pa
0.013 Hz	29.39 uV/Pa	27.24 uV/Pa	25.27 uV/Pa	23.42 uV/Pa	23.42 uV/Pa
0.016 Hz	32.68 uV/Pa	30.79 uV/Pa	28.75 uV/Pa	27.12 uV/Pa	27.12 uV/Pa
0.020 Hz	35.43 uV/Pa	33.79 uV/Pa	31.77 uV/Pa	29.98 uV/Pa	29.98 uV/Pa
0.025 Hz	37.36 uV/Pa	35.86 uV/Pa	34.16 uV/Pa	32.48 uV/Pa	32.48 uV/Pa
0.032 Hz	40.74 uV/Pa	39.78 uV/Pa	38.75 uV/Pa	37.63 uV/Pa	37.63 uV/Pa
0.040 Hz	42.01 uV/Pa	41.08 uV/Pa	39.99 uV/Pa	39.00 uV/Pa	39.00 uV/Pa
0.050 Hz	42.83 uV/Pa	42.27 uV/Pa	41.44 uV/Pa	40.84 uV/Pa	40.84 uV/Pa
0.063 Hz	43.36 uV/Pa	43.14 uV/Pa	42.65 uV/Pa	42.28 uV/Pa	42.28 uV/Pa
0.079 Hz	43.98 uV/Pa	43.99 uV/Pa	43.51 uV/Pa	42.91 uV/Pa	42.91 uV/Pa
0.100 Hz	44.20 uV/Pa	44.64 uV/Pa	43.97 uV/Pa	43.73 uV/Pa	43.73 uV/Pa
0.126 Hz	44.43 uV/Pa	44.52 uV/Pa	44.40 uV/Pa	43.96 uV/Pa	43.96 uV/Pa
0.158 Hz	44.42 uV/Pa	44.64 uV/Pa	44.58 uV/Pa	44.22 uV/Pa	44.22 uV/Pa
0.200 Hz	45.12 uV/Pa	44.54 uV/Pa	44.98 uV/Pa	44.22 uV/Pa	44.22 uV/Pa
0.251 Hz	44.73 uV/Pa	44.83 uV/Pa	44.62 uV/Pa	44.77 uV/Pa	44.77 uV/Pa
0.316 Hz	45.02 uV/Pa	44.84 uV/Pa	44.79 uV/Pa	44.28 uV/Pa	44.28 uV/Pa
0.398 Hz	45.06 uV/Pa	45.31 uV/Pa	44.93 uV/Pa	45.32 uV/Pa	45.32 uV/Pa
0.501 Hz	44.72 uV/Pa	44.83 uV/Pa	44.80 uV/Pa	44.33 uV/Pa	44.33 uV/Pa
0.631 Hz	45.17 uV/Pa	44.63 uV/Pa	44.74 uV/Pa	44.93 uV/Pa	44.93 uV/Pa
0.794 Hz	44.53 uV/Pa	45.45 uV/Pa	45.00 uV/Pa	44.63 uV/Pa	44.63 uV/Pa
1.000 Hz	45.27 uV/Pa	45.20 uV/Pa	45.12 uV/Pa	45.00 uV/Pa	45.00 uV/Pa
1.259 Hz	45.22 uV/Pa	45.17 uV/Pa	45.10 uV/Pa	45.03 uV/Pa	45.03 uV/Pa
1.585 Hz	45.26 uV/Pa	45.17 uV/Pa	45.06 uV/Pa	45.05 uV/Pa	45.05 uV/Pa
1.995 Hz	45.29 uV/Pa	45.27 uV/Pa	45.20 uV/Pa	45.09 uV/Pa	45.09 uV/Pa
2.512 Hz	45.32 uV/Pa	45.24 uV/Pa	45.13 uV/Pa	44.98 uV/Pa	44.98 uV/Pa
3.162 Hz	45.33 uV/Pa	45.23 uV/Pa	45.17 uV/Pa	45.03 uV/Pa	45.03 uV/Pa
3.981 Hz	45.39 uV/Pa	45.13 uV/Pa	45.16 uV/Pa	45.19 uV/Pa	45.19 uV/Pa
5.012 Hz	45.30 uV/Pa	45.29 uV/Pa	45.17 uV/Pa	45.05 uV/Pa	45.05 uV/Pa
6.310 Hz	45.25 uV/Pa	45.18 uV/Pa	45.15 uV/Pa	45.11 uV/Pa	45.11 uV/Pa
7.943 Hz	45.22 uV/Pa	45.32 uV/Pa	45.21 uV/Pa	45.03 uV/Pa	45.03 uV/Pa
10.000 Hz	45.24 uV/Pa	45.18 uV/Pa	45.07 uV/Pa	45.04 uV/Pa	45.04 uV/Pa
12.589 Hz	45.30 uV/Pa	45.22 uV/Pa	45.06 uV/Pa	45.17 uV/Pa	45.17 uV/Pa
15.849 Hz	45.45 uV/Pa	45.29 uV/Pa	44.95 uV/Pa	45.23 uV/Pa	45.23 uV/Pa
19.953 Hz	45.29 uV/Pa	45.22 uV/Pa	45.28 uV/Pa	45.11 uV/Pa	18.61 uV/Pa

Table 98 Phase Response over Evaluated Pressures: InfraBSU #424

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	52.56 deg	56.48 deg	59.46 deg	62.44 deg	65.25 deg
0.013 Hz	44.46 deg	48.94 deg	51.54 deg	55.89 deg	57.88 deg
0.016 Hz	38.82 deg	42.89 deg	45.87 deg	49.59 deg	52.12 deg
0.020 Hz	33.54 deg	37.36 deg	41.22 deg	44.55 deg	47.30 deg
0.025 Hz	28.85 deg	32.69 deg	37.20 deg	39.51 deg	42.97 deg
0.032 Hz	22.13 deg	24.83 deg	27.10 deg	31.05 deg	33.33 deg
0.040 Hz	18.10 deg	20.71 deg	23.63 deg	26.04 deg	28.97 deg
0.050 Hz	14.44 deg	16.92 deg	19.47 deg	21.94 deg	23.91 deg
0.063 Hz	12.29 deg	14.45 deg	14.86 deg	16.88 deg	19.75 deg
0.079 Hz	9.21 deg	11.00 deg	11.88 deg	13.26 deg	14.49 deg
0.100 Hz	8.23 deg	8.74 deg	9.43 deg	11.79 deg	12.40 deg
0.126 Hz	5.05 deg	6.51 deg	8.34 deg	9.35 deg	10.66 deg
0.158 Hz	4.84 deg	4.87 deg	6.20 deg	6.31 deg	8.27 deg
0.200 Hz	4.20 deg	4.65 deg	5.46 deg	5.53 deg	7.20 deg
0.251 Hz	2.23 deg	3.85 deg	3.66 deg	4.93 deg	6.10 deg
0.316 Hz	3.62 deg	3.24 deg	4.07 deg	5.09 deg	3.41 deg
0.398 Hz	2.67 deg	3.32 deg	3.26 deg	3.35 deg	2.76 deg
0.501 Hz	1.90 deg	1.26 deg	4.20 deg	2.78 deg	2.84 deg
0.631 Hz	1.05 deg	4.57 deg	1.74 deg	4.02 deg	3.33 deg
0.794 Hz	3.63 deg	2.85 deg	0.90 deg	3.94 deg	2.78 deg
1.000 Hz	0.32 deg	0.42 deg	0.31 deg	0.32 deg	0.24 deg
1.259 Hz	0.38 deg	0.20 deg	0.32 deg	0.18 deg	0.27 deg
1.585 Hz	0.19 deg	0.32 deg	0.26 deg	0.19 deg	0.18 deg
1.995 Hz	0.20 deg	0.20 deg	0.23 deg	0.09 deg	0.10 deg
2.512 Hz	0.00 deg	0.19 deg	0.04 deg	-0.03 deg	-0.01 deg
3.162 Hz	-0.01 deg	0.05 deg	-0.11 deg	0.10 deg	-0.01 deg
3.981 Hz	-0.21 deg	-0.03 deg	0.03 deg	-0.01 deg	0.14 deg
5.012 Hz	-0.22 deg	0.10 deg	0.05 deg	0.02 deg	-0.19 deg
6.310 Hz	-0.17 deg	-0.28 deg	0.02 deg	0.04 deg	0.12 deg
7.943 Hz	-0.12 deg	-0.13 deg	-0.35 deg	-0.15 deg	0.10 deg
10.000 Hz	-0.18 deg	-0.33 deg	-0.25 deg	-0.33 deg	0.09 deg
12.589 Hz	-0.04 deg	0.12 deg	-0.34 deg	0.00 deg	-0.10 deg
15.849 Hz	-0.67 deg	-0.79 deg	-0.63 deg	0.00 deg	-0.27 deg
19.953 Hz	-0.55 deg	-0.27 deg	0.32 deg	-0.07 deg	-0.67 deg

3.10.4.3 Gem Infrasound Logger

The following six figures show the amplitude and phase responses of the Gem packages at 600 hPa, 700 hPa, 800 hPa, 900 hPa and 1000 hPa.

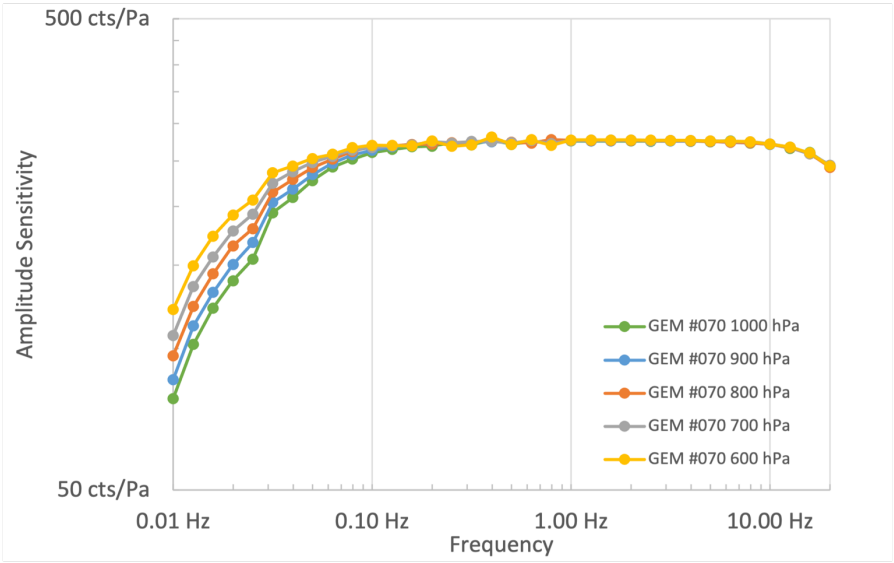

Figure 103 Amplitude Response at Evaluated Static Pressures: Gem #070

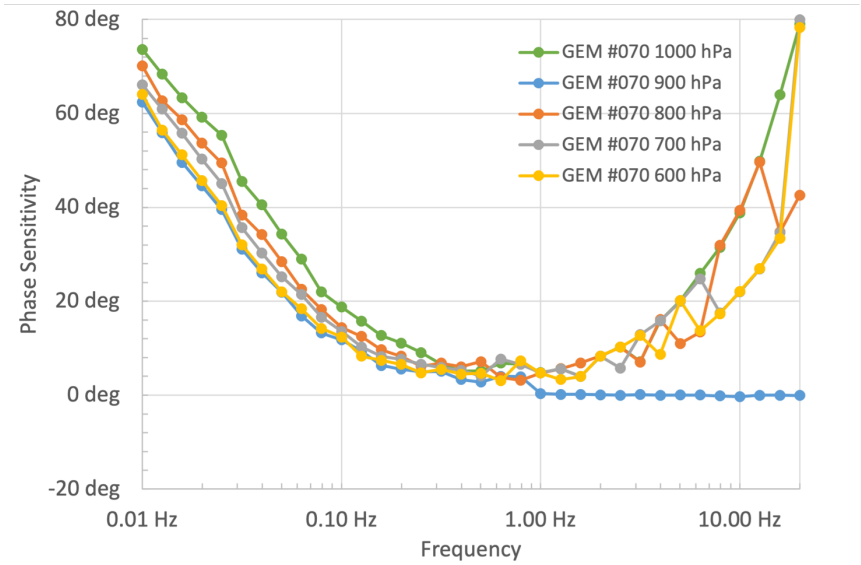

Figure 104 Phase Response at Evaluated Static Pressures: Gem #070

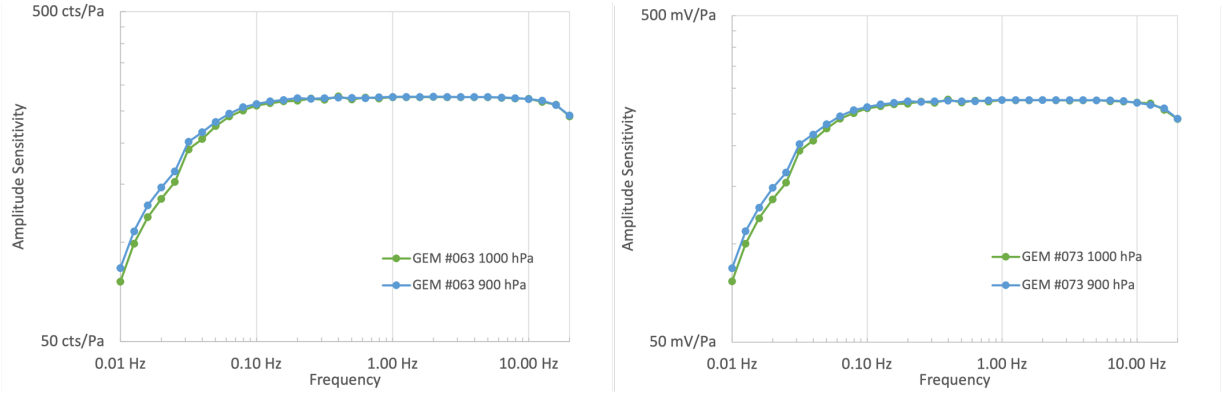

Figure 105 Amplitude Response at Evaluated Static Pressures: Gem #063 and #073

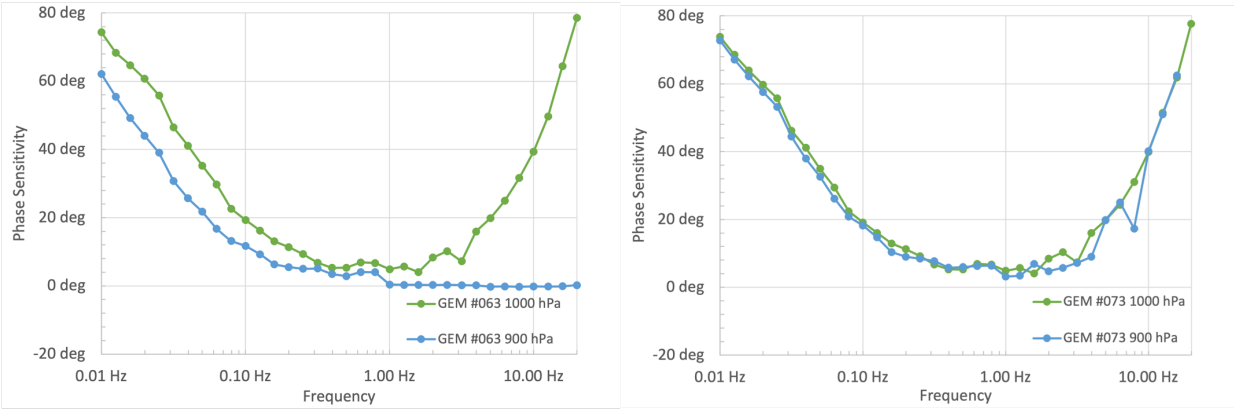

Figure 106 Phase Response at Evaluated Static Pressures: Gem #063 and #073

Generally, the amplitude response of the Gem sensors was unchanged due to static pressure at frequencies above 0.1 Hz. Below 0.1 Hz, there were more significant changes as the low frequency corner clearly drops in frequency due to a reduction static pressure.

The phase response has similar shifts at low frequencies, becoming evident at 0.316 Hz and lower. Higher frequency variations, above 1 Hz, are likely due to timing changes within the Gem digitizer package, relative to the reference sensor recording.

Note that Gem #063 and #073 encountered issues that prevented acquiring data during most of the static pressure evaluation. Only results from 1000 hPa and 900 hPa were available.

The following tables contain the values used to generate the above figures.

Table 99 Amplitude Response over Evaluated Pressures: Gem #070

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	121 cts/Pa	106 cts/Pa	96 cts/Pa	86 cts/Pa	78 cts/Pa
0.013 Hz	150 cts/Pa	135 cts/Pa	123 cts/Pa	112 cts/Pa	102 cts/Pa
0.016 Hz	173 cts/Pa	156 cts/Pa	144 cts/Pa	132 cts/Pa	122 cts/Pa
0.020 Hz	192 cts/Pa	177 cts/Pa	165 cts/Pa	151 cts/Pa	139 cts/Pa
0.025 Hz	206 cts/Pa	193 cts/Pa	180 cts/Pa	168 cts/Pa	155 cts/Pa
0.032 Hz	236 cts/Pa	224 cts/Pa	215 cts/Pa	204 cts/Pa	194 cts/Pa
0.040 Hz	244 cts/Pa	237 cts/Pa	228 cts/Pa	218 cts/Pa	209 cts/Pa
0.050 Hz	253 cts/Pa	248 cts/Pa	242 cts/Pa	234 cts/Pa	227 cts/Pa
0.063 Hz	258 cts/Pa	256 cts/Pa	252 cts/Pa	247 cts/Pa	242 cts/Pa
0.079 Hz	267 cts/Pa	263 cts/Pa	262 cts/Pa	257 cts/Pa	252 cts/Pa
0.100 Hz	270 cts/Pa	267 cts/Pa	268 cts/Pa	263 cts/Pa	260 cts/Pa
0.126 Hz	269 cts/Pa	269 cts/Pa	269 cts/Pa	268 cts/Pa	264 cts/Pa
0.158 Hz	269 cts/Pa	270 cts/Pa	271 cts/Pa	270 cts/Pa	268 cts/Pa
0.200 Hz	276 cts/Pa	275 cts/Pa	271 cts/Pa	274 cts/Pa	269 cts/Pa
0.251 Hz	268 cts/Pa	273 cts/Pa	273 cts/Pa	272 cts/Pa	273 cts/Pa
0.316 Hz	270 cts/Pa	275 cts/Pa	274 cts/Pa	273 cts/Pa	270 cts/Pa
0.398 Hz	281 cts/Pa	275 cts/Pa	277 cts/Pa	274 cts/Pa	277 cts/Pa
0.501 Hz	271 cts/Pa	273 cts/Pa	274 cts/Pa	274 cts/Pa	271 cts/Pa
0.631 Hz	277 cts/Pa	276 cts/Pa	273 cts/Pa	273 cts/Pa	275 cts/Pa
0.794 Hz	269 cts/Pa	272 cts/Pa	278 cts/Pa	275 cts/Pa	273 cts/Pa
1.000 Hz	277 cts/Pa	276 cts/Pa	276 cts/Pa	276 cts/Pa	275 cts/Pa
1.259 Hz	277 cts/Pa	276 cts/Pa	276 cts/Pa	276 cts/Pa	275 cts/Pa
1.585 Hz	277 cts/Pa	276 cts/Pa	276 cts/Pa	276 cts/Pa	275 cts/Pa
1.995 Hz	277 cts/Pa	277 cts/Pa	276 cts/Pa	276 cts/Pa	275 cts/Pa
2.512 Hz	277 cts/Pa	276 cts/Pa	276 cts/Pa	276 cts/Pa	275 cts/Pa
3.162 Hz	276 cts/Pa	276 cts/Pa	276 cts/Pa	275 cts/Pa	275 cts/Pa
3.981 Hz	276 cts/Pa	276 cts/Pa	276 cts/Pa	275 cts/Pa	275 cts/Pa
5.012 Hz	275 cts/Pa	276 cts/Pa	275 cts/Pa	275 cts/Pa	274 cts/Pa
6.310 Hz	275 cts/Pa	275 cts/Pa	274 cts/Pa	274 cts/Pa	276 cts/Pa
7.943 Hz	275 cts/Pa	274 cts/Pa	273 cts/Pa	273 cts/Pa	273 cts/Pa
10.000 Hz	271 cts/Pa	272 cts/Pa	271 cts/Pa	271 cts/Pa	272 cts/Pa
12.589 Hz	267 cts/Pa	267 cts/Pa	267 cts/Pa	267 cts/Pa	266 cts/Pa
15.849 Hz	260 cts/Pa	259 cts/Pa	259 cts/Pa	259 cts/Pa	260 cts/Pa
19.953 Hz	243 cts/Pa	245 cts/Pa	242 cts/Pa	243 cts/Pa	244 cts/Pa

Table 100 Phase Response over Evaluated Pressures: Gem #070

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	64.05 deg	66.13 deg	70.08 deg	62.44 deg	73.63 deg
0.013 Hz	56.45 deg	60.93 deg	62.72 deg	55.89 deg	68.36 deg
0.016 Hz	51.17 deg	55.76 deg	58.65 deg	49.59 deg	63.36 deg
0.020 Hz	45.74 deg	50.25 deg	53.64 deg	44.55 deg	59.19 deg
0.025 Hz	40.37 deg	45.06 deg	49.45 deg	39.51 deg	55.34 deg
0.032 Hz	31.98 deg	35.67 deg	38.36 deg	31.05 deg	45.50 deg
0.040 Hz	26.87 deg	30.31 deg	34.21 deg	26.04 deg	40.51 deg
0.050 Hz	22.03 deg	25.25 deg	28.44 deg	21.94 deg	34.34 deg
0.063 Hz	18.39 deg	21.41 deg	22.52 deg	16.88 deg	28.95 deg
0.079 Hz	14.22 deg	16.59 deg	18.25 deg	13.26 deg	21.98 deg
0.100 Hz	12.38 deg	13.57 deg	14.40 deg	11.79 deg	18.78 deg
0.126 Hz	8.30 deg	10.27 deg	12.52 deg	9.35 deg	15.78 deg
0.158 Hz	7.44 deg	8.25 deg	9.65 deg	6.31 deg	12.70 deg
0.200 Hz	6.55 deg	7.65 deg	8.30 deg	5.53 deg	11.11 deg
0.251 Hz	4.77 deg	6.58 deg	6.16 deg	4.93 deg	9.09 deg
0.316 Hz	5.50 deg	5.92 deg	6.84 deg	5.09 deg	6.59 deg
0.398 Hz	4.48 deg	5.29 deg	6.06 deg	3.35 deg	5.17 deg
0.501 Hz	4.66 deg	4.09 deg	7.15 deg	2.78 deg	5.15 deg
0.631 Hz	3.07 deg	7.70 deg	3.79 deg	4.02 deg	6.83 deg
0.794 Hz	7.34 deg	6.54 deg	3.21 deg	3.94 deg	6.65 deg
1.000 Hz	4.73 deg	4.78 deg	4.72 deg	0.32 deg	4.80 deg
1.259 Hz	3.34 deg	5.60 deg	5.62 deg	0.18 deg	5.62 deg
1.585 Hz	3.98 deg	3.99 deg	6.86 deg	0.19 deg	3.99 deg
1.995 Hz	8.32 deg	8.31 deg	8.35 deg	0.09 deg	8.29 deg
2.512 Hz	10.20 deg	5.79 deg	10.20 deg	-0.03 deg	10.27 deg
3.162 Hz	12.68 deg	12.90 deg	7.07 deg	0.10 deg	7.15 deg
3.981 Hz	8.66 deg	15.82 deg	16.09 deg	-0.01 deg	15.82 deg
5.012 Hz	20.15 deg	19.94 deg	10.99 deg	0.02 deg	20.14 deg
6.310 Hz	13.70 deg	24.79 deg	13.43 deg	0.04 deg	25.92 deg
7.943 Hz	17.32 deg	17.52 deg	31.90 deg	-0.15 deg	31.46 deg
10.000 Hz	22.13 deg	21.96 deg	39.35 deg	-0.33 deg	38.83 deg
12.589 Hz	26.94 deg	26.85 deg	49.63 deg	0.00 deg	49.81 deg
15.849 Hz	33.36 deg	34.59 deg	34.75 deg	0.00 deg	63.97 deg
19.953 Hz	78.34 deg	79.99 deg	42.60 deg	-0.07 deg	79.04 deg

Table 101 Amplitude Response at Evaluated Static Pressures: Gem #063 and #073

	Gem #063		Gem #073	
Frequency	1000 hPa	900 hPa	1000 hPa	900 hPa
0.010 Hz	76 cts/Pa	84 cts/Pa	77 cts/Pa	84 cts/Pa
0.013 Hz	99 cts/Pa	108 cts/Pa	100 cts/Pa	109 cts/Pa
0.016 Hz	119 cts/Pa	130 cts/Pa	120 cts/Pa	129 cts/Pa
0.020 Hz	136 cts/Pa	147 cts/Pa	137 cts/Pa	149 cts/Pa
0.025 Hz	153 cts/Pa	164 cts/Pa	154 cts/Pa	166 cts/Pa
0.032 Hz	192 cts/Pa	202 cts/Pa	193 cts/Pa	202 cts/Pa
0.040 Hz	206 cts/Pa	216 cts/Pa	207 cts/Pa	216 cts/Pa
0.050 Hz	225 cts/Pa	232 cts/Pa	226 cts/Pa	233 cts/Pa
0.063 Hz	241 cts/Pa	246 cts/Pa	242 cts/Pa	246 cts/Pa
0.079 Hz	251 cts/Pa	257 cts/Pa	252 cts/Pa	257 cts/Pa
0.100 Hz	260 cts/Pa	263 cts/Pa	260 cts/Pa	263 cts/Pa
0.126 Hz	264 cts/Pa	268 cts/Pa	264 cts/Pa	268 cts/Pa
0.158 Hz	268 cts/Pa	270 cts/Pa	268 cts/Pa	270 cts/Pa
0.200 Hz	269 cts/Pa	274 cts/Pa	269 cts/Pa	274 cts/Pa
0.251 Hz	273 cts/Pa	272 cts/Pa	273 cts/Pa	272 cts/Pa
0.316 Hz	271 cts/Pa	274 cts/Pa	270 cts/Pa	274 cts/Pa
0.398 Hz	277 cts/Pa	275 cts/Pa	277 cts/Pa	275 cts/Pa
0.501 Hz	271 cts/Pa	274 cts/Pa	271 cts/Pa	274 cts/Pa
0.631 Hz	275 cts/Pa	274 cts/Pa	275 cts/Pa	274 cts/Pa
0.794 Hz	273 cts/Pa	275 cts/Pa	273 cts/Pa	275 cts/Pa
1.000 Hz	276 cts/Pa	276 cts/Pa	276 cts/Pa	276 cts/Pa
1.259 Hz	276 cts/Pa	276 cts/Pa	275 cts/Pa	276 cts/Pa
1.585 Hz	276 cts/Pa	276 cts/Pa	276 cts/Pa	276 cts/Pa
1.995 Hz	276 cts/Pa	276 cts/Pa	276 cts/Pa	276 cts/Pa
2.512 Hz	276 cts/Pa	276 cts/Pa	275 cts/Pa	276 cts/Pa
3.162 Hz	276 cts/Pa	276 cts/Pa	275 cts/Pa	276 cts/Pa
3.981 Hz	276 cts/Pa	276 cts/Pa	275 cts/Pa	276 cts/Pa
5.012 Hz	276 cts/Pa	276 cts/Pa	275 cts/Pa	275 cts/Pa
6.310 Hz	275 cts/Pa	275 cts/Pa	274 cts/Pa	275 cts/Pa
7.943 Hz	273 cts/Pa	274 cts/Pa	273 cts/Pa	274 cts/Pa
10.000 Hz	272 cts/Pa	272 cts/Pa	271 cts/Pa	271 cts/Pa
12.589 Hz	267 cts/Pa	269 cts/Pa	270 cts/Pa	267 cts/Pa
15.849 Hz	261 cts/Pa	261 cts/Pa	258 cts/Pa	260 cts/Pa
19.953 Hz	241 cts/Pa	242 cts/Pa	241 cts/Pa	242 cts/Pa

Table 102 Phase Response at Evaluated Static Pressures: Gem #063 and #073

	Gem #063		Gem #073	
Frequency	1000 hPa	900 hPa	1000 hPa	900 hPa
0.010 Hz	74.36 deg	73.89 deg	62.10 deg	72.76 deg
0.013 Hz	68.32 deg	68.54 deg	55.43 deg	67.12 deg
0.016 Hz	64.69 deg	63.95 deg	49.21 deg	62.23 deg
0.020 Hz	60.74 deg	59.71 deg	44.03 deg	57.55 deg
0.025 Hz	55.83 deg	55.69 deg	39.06 deg	53.18 deg
0.032 Hz	46.47 deg	46.19 deg	30.74 deg	44.42 deg
0.040 Hz	41.11 deg	41.13 deg	25.69 deg	37.94 deg
0.050 Hz	35.27 deg	34.92 deg	21.76 deg	32.61 deg
0.063 Hz	29.78 deg	29.44 deg	16.73 deg	26.15 deg
0.079 Hz	22.64 deg	22.39 deg	13.18 deg	20.83 deg
0.100 Hz	19.35 deg	19.12 deg	11.75 deg	18.21 deg
0.126 Hz	16.24 deg	16.04 deg	9.26 deg	14.69 deg
0.158 Hz	13.08 deg	12.95 deg	6.32 deg	10.38 deg
0.200 Hz	11.36 deg	11.26 deg	5.54 deg	9.04 deg
0.251 Hz	9.33 deg	9.22 deg	5.02 deg	8.43 deg
0.316 Hz	6.80 deg	6.72 deg	5.12 deg	7.72 deg
0.398 Hz	5.30 deg	5.27 deg	3.46 deg	5.80 deg
0.501 Hz	5.32 deg	5.26 deg	2.87 deg	5.95 deg
0.631 Hz	6.92 deg	6.90 deg	4.06 deg	6.30 deg
0.794 Hz	6.71 deg	6.71 deg	4.01 deg	6.40 deg
1.000 Hz	4.90 deg	4.86 deg	0.38 deg	3.12 deg
1.259 Hz	5.70 deg	5.70 deg	0.32 deg	3.41 deg
1.585 Hz	4.08 deg	4.08 deg	0.32 deg	6.88 deg
1.995 Hz	8.31 deg	8.43 deg	0.26 deg	4.75 deg
2.512 Hz	10.21 deg	10.35 deg	0.29 deg	5.73 deg
3.162 Hz	7.21 deg	7.31 deg	0.21 deg	7.19 deg
3.981 Hz	15.96 deg	16.02 deg	0.19 deg	8.96 deg
5.012 Hz	19.89 deg	19.75 deg	-0.22 deg	19.87 deg
6.310 Hz	24.99 deg	24.31 deg	-0.14 deg	25.06 deg
7.943 Hz	31.63 deg	31.08 deg	-0.26 deg	17.29 deg
10.000 Hz	39.36 deg	39.91 deg	-0.14 deg	40.18 deg
12.589 Hz	49.65 deg	51.42 deg	-0.20 deg	51.02 deg
15.849 Hz	64.38 deg	61.83 deg	-0.10 deg	62.47 deg
19.953 Hz	78.59 deg	77.66 deg	0.20 deg	72.76 deg

3.10.4.4 Raspberry Boom

The following six figures show the amplitude and phase responses of the Raspberry Boom packages at 600 hPa, 700 hPa, 800 hPa, 900 hPa and 1000 hPa.

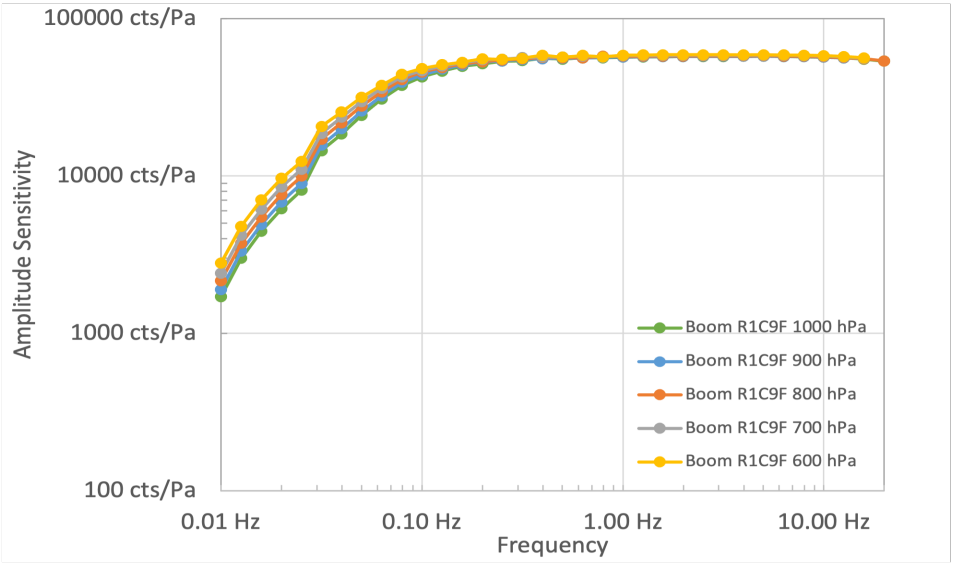

Figure 107 Amplitude Response at Evaluated Static Pressures: Boom R1C9F

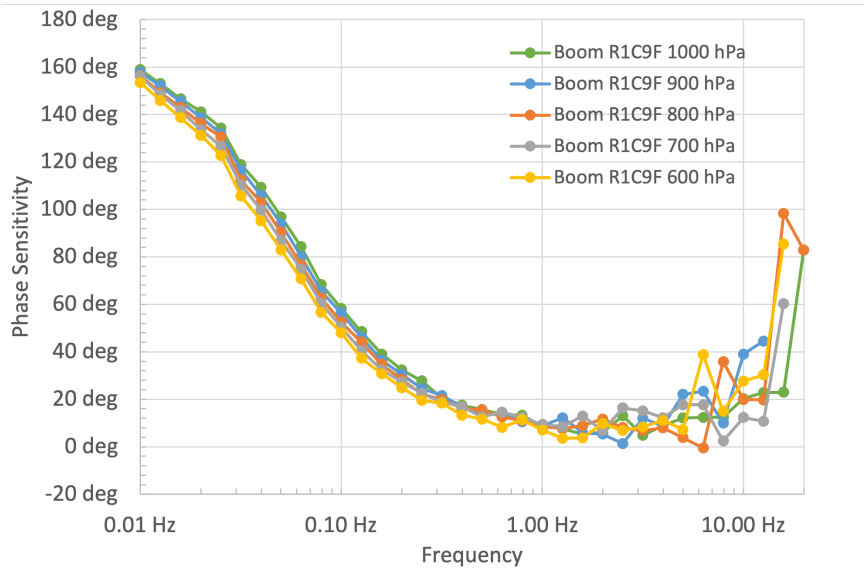

Figure 108 Phase Response at Evaluated Static Pressures: Boom R1C9F

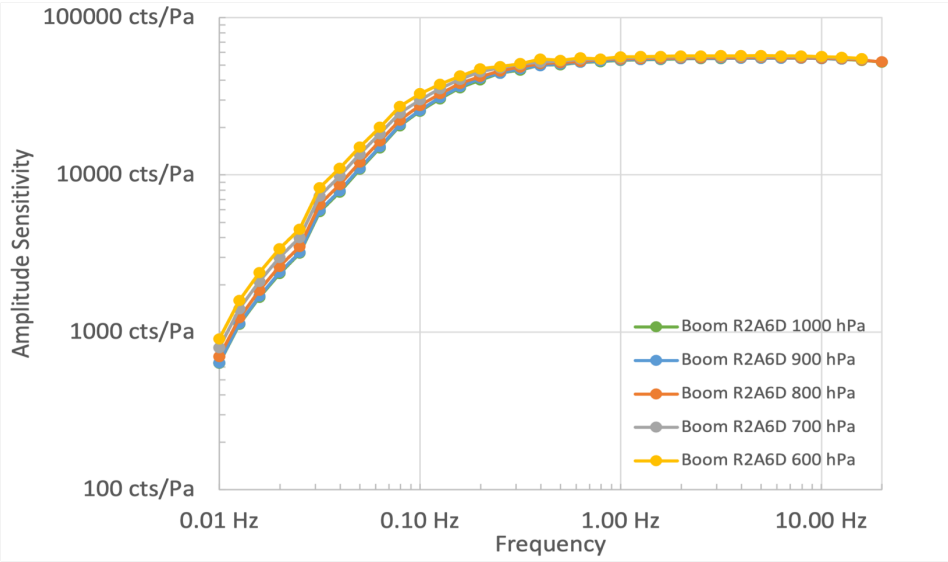

Figure 109 Amplitude Response at Evaluated Static Pressures: Boom R2A6D

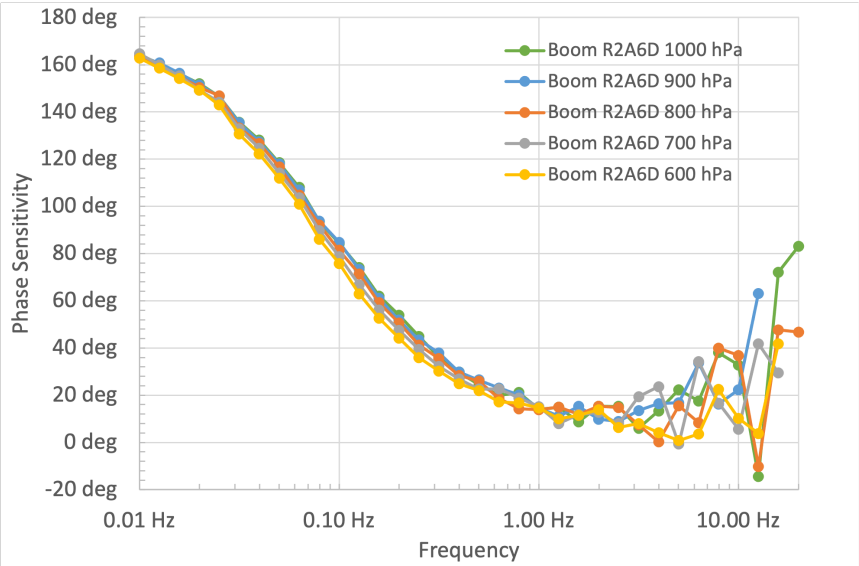

Figure 110 Phase Response at Evaluated Static Pressures: Boom R2A6D

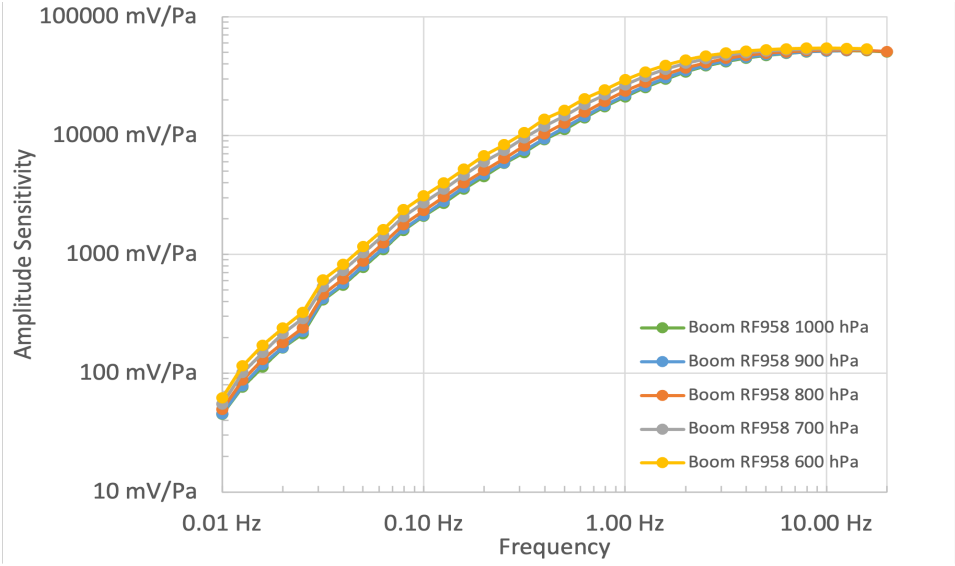

Figure 111 Amplitude Response at Evaluated Static Pressures: Boom RF958

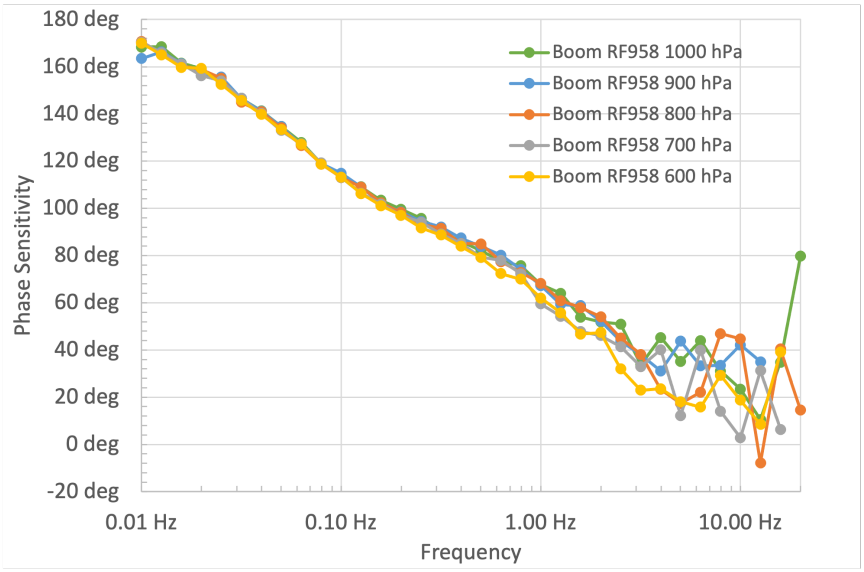

Figure 112 Phase Response at Evaluated Static Pressures: Boom RF958

Unlike the previous sensors and packages evaluated, even discounting RF958, there is significant variability in phase across the sensors observed at lower frequencies and at the lower pressures evaluated. At frequencies below 0.125 Hz Boom #R1C9F is clearly more sensitive to static pressures changes than R2A6D. At 800 hPa and 900 hPa, observed changes in amplitude response generally above 0.63 Hz are less than 5%. Below this frequency, observed changes in amplitude response grow with increasingly lower pressures, indicating a shift in the low frequency corner of the passband. Variations in phase response above 1 Hz are likely due to changes in the Raspberry Room digitizer timing, relative to the reference sensor recording.

The following tables contains the values used to generate the above figures.

Table 103 Amplitude Response over Evaluated Pressures: Boom R1C9F

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	2787 cts/Pa	2415 cts/Pa	2152 cts/Pa	1891 cts/Pa	1714 cts/Pa
0.013 Hz	4779 cts/Pa	4190 cts/Pa	3732 cts/Pa	3325 cts/Pa	2996 cts/Pa
0.016 Hz	7045 cts/Pa	6142 cts/Pa	5487 cts/Pa	4905 cts/Pa	4456 cts/Pa
0.020 Hz	9661 cts/Pa	8509 cts/Pa	7641 cts/Pa	6837 cts/Pa	6188 cts/Pa
0.025 Hz	12390 cts/Pa	11030 cts/Pa	9972 cts/Pa	8966 cts/Pa	8131 cts/Pa
0.032 Hz	20650 cts/Pa	18650 cts/Pa	17150 cts/Pa	15690 cts/Pa	14470 cts/Pa
0.040 Hz	25480 cts/Pa	23580 cts/Pa	21730 cts/Pa	19940 cts/Pa	18450 cts/Pa
0.050 Hz	31610 cts/Pa	29690 cts/Pa	27820 cts/Pa	25830 cts/Pa	24240 cts/Pa
0.063 Hz	37620 cts/Pa	35950 cts/Pa	34230 cts/Pa	32320 cts/Pa	30800 cts/Pa
0.079 Hz	44380 cts/Pa	42610 cts/Pa	41050 cts/Pa	39300 cts/Pa	37550 cts/Pa
0.100 Hz	48270 cts/Pa	46620 cts/Pa	45760 cts/Pa	43850 cts/Pa	42530 cts/Pa
0.126 Hz	50900 cts/Pa	49930 cts/Pa	48900 cts/Pa	47750 cts/Pa	46410 cts/Pa
0.158 Hz	52830 cts/Pa	52310 cts/Pa	51610 cts/Pa	50660 cts/Pa	49680 cts/Pa
0.200 Hz	55600 cts/Pa	54680 cts/Pa	53140 cts/Pa	52950 cts/Pa	51610 cts/Pa
0.251 Hz	55020 cts/Pa	55280 cts/Pa	54580 cts/Pa	53780 cts/Pa	53620 cts/Pa
0.316 Hz	55980 cts/Pa	56390 cts/Pa	55430 cts/Pa	54840 cts/Pa	53940 cts/Pa
0.398 Hz	58580 cts/Pa	56920 cts/Pa	56550 cts/Pa	55610 cts/Pa	55880 cts/Pa
0.501 Hz	56850 cts/Pa	56830 cts/Pa	56340 cts/Pa	55830 cts/Pa	55100 cts/Pa
0.631 Hz	58370 cts/Pa	57660 cts/Pa	56380 cts/Pa	56120 cts/Pa	56190 cts/Pa
0.794 Hz	56910 cts/Pa	57060 cts/Pa	57570 cts/Pa	56670 cts/Pa	56170 cts/Pa
1.000 Hz	58590 cts/Pa	58120 cts/Pa	57490 cts/Pa	57010 cts/Pa	56810 cts/Pa
1.259 Hz	58690 cts/Pa	58240 cts/Pa	57610 cts/Pa	57140 cts/Pa	56980 cts/Pa
1.585 Hz	58810 cts/Pa	58380 cts/Pa	57750 cts/Pa	57290 cts/Pa	57130 cts/Pa
1.995 Hz	58910 cts/Pa	58500 cts/Pa	57850 cts/Pa	57470 cts/Pa	57320 cts/Pa
2.512 Hz	58960 cts/Pa	58530 cts/Pa	57880 cts/Pa	57540 cts/Pa	57430 cts/Pa
3.162 Hz	58960 cts/Pa	58590 cts/Pa	57980 cts/Pa	57560 cts/Pa	57430 cts/Pa
3.981 Hz	58980 cts/Pa	58600 cts/Pa	57970 cts/Pa	57600 cts/Pa	57500 cts/Pa
5.012 Hz	58950 cts/Pa	58570 cts/Pa	57990 cts/Pa	57610 cts/Pa	57510 cts/Pa
6.310 Hz	58760 cts/Pa	58390 cts/Pa	57800 cts/Pa	57480 cts/Pa	57400 cts/Pa
7.943 Hz	58480 cts/Pa	58160 cts/Pa	57600 cts/Pa	57270 cts/Pa	57240 cts/Pa
10.000 Hz	58060 cts/Pa	57730 cts/Pa	57190 cts/Pa	56880 cts/Pa	56870 cts/Pa
12.589 Hz	57310 cts/Pa	57020 cts/Pa	56500 cts/Pa	56230 cts/Pa	56230 cts/Pa
15.849 Hz	56250 cts/Pa	55960 cts/Pa	55480 cts/Pa	-	55270 cts/Pa
19.953 Hz	-	-	53770 cts/Pa	-	53630 cts/Pa

Table 104 Phase Response over Evaluated Pressures: Boom R1C9F

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	153.40 deg	156.20 deg	156.30 deg	157.80 deg	159.00 deg
0.013 Hz	146.00 deg	148.40 deg	149.30 deg	152.10 deg	153.00 deg
0.016 Hz	138.70 deg	141.70 deg	143.00 deg	145.50 deg	146.70 deg
0.020 Hz	131.20 deg	133.60 deg	136.30 deg	138.80 deg	141.20 deg
0.025 Hz	122.80 deg	126.60 deg	130.60 deg	132.00 deg	134.40 deg
0.032 Hz	105.70 deg	110.30 deg	112.40 deg	116.50 deg	118.90 deg
0.040 Hz	95.25 deg	99.86 deg	103.00 deg	105.90 deg	109.40 deg
0.050 Hz	82.98 deg	86.89 deg	90.38 deg	94.00 deg	96.95 deg
0.063 Hz	70.71 deg	74.82 deg	76.64 deg	80.12 deg	84.29 deg
0.079 Hz	56.61 deg	60.43 deg	62.78 deg	65.44 deg	68.36 deg
0.100 Hz	47.98 deg	50.42 deg	52.53 deg	56.37 deg	58.38 deg
0.126 Hz	37.26 deg	40.47 deg	44.08 deg	46.20 deg	48.48 deg
0.158 Hz	30.78 deg	32.39 deg	34.70 deg	36.41 deg	39.04 deg
0.200 Hz	24.83 deg	27.24 deg	28.35 deg	30.47 deg	32.37 deg
0.251 Hz	19.49 deg	22.46 deg	22.09 deg	24.53 deg	27.74 deg
0.316 Hz	18.38 deg	18.79 deg	19.97 deg	21.59 deg	20.45 deg
0.398 Hz	13.33 deg	16.79 deg	16.01 deg	16.83 deg	17.45 deg
0.501 Hz	11.62 deg	12.57 deg	15.53 deg	13.51 deg	15.65 deg
0.631 Hz	8.22 deg	14.57 deg	12.52 deg	14.10 deg	13.61 deg
0.794 Hz	11.36 deg	12.36 deg	11.01 deg	10.59 deg	13.26 deg
1.000 Hz	7.06 deg	9.37 deg	8.68 deg	8.79 deg	8.53 deg
1.259 Hz	3.47 deg	8.55 deg	7.60 deg	12.22 deg	7.63 deg
1.585 Hz	3.74 deg	12.96 deg	8.89 deg	5.94 deg	5.34 deg
1.995 Hz	9.81 deg	6.77 deg	11.67 deg	5.32 deg	6.12 deg
2.512 Hz	6.81 deg	16.32 deg	8.08 deg	1.26 deg	13.05 deg
3.162 Hz	8.35 deg	15.10 deg	6.79 deg	12.06 deg	4.90 deg
3.981 Hz	11.11 deg	12.19 deg	7.98 deg	8.69 deg	8.96 deg
5.012 Hz	7.30 deg	17.75 deg	3.87 deg	22.02 deg	12.13 deg
6.310 Hz	38.84 deg	17.69 deg	-0.41 deg	23.36 deg	12.43 deg
7.943 Hz	15.00 deg	2.44 deg	35.86 deg	9.97 deg	12.37 deg
10.000 Hz	27.64 deg	12.29 deg	19.97 deg	38.99 deg	20.24 deg
12.589 Hz	30.32 deg	10.79 deg	19.77 deg	44.54 deg	22.82 deg
15.849 Hz	85.50 deg	60.31 deg	98.42 deg	-	22.96 deg
19.953 Hz	-	-	82.97 deg	-	82.85 deg

Table 105 Amplitude Response over Evaluated Pressures: Boom R2A6D

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	908 cts/Pa	797 cts/Pa	701 cts/Pa	642 cts/Pa	635 cts/Pa
0.013 Hz	1598 cts/Pa	1414 cts/Pa	1236 cts/Pa	1140 cts/Pa	1126 cts/Pa
0.016 Hz	2401 cts/Pa	2108 cts/Pa	1856 cts/Pa	1696 cts/Pa	1670 cts/Pa
0.020 Hz	3397 cts/Pa	2991 cts/Pa	2622 cts/Pa	2407 cts/Pa	2363 cts/Pa
0.025 Hz	4528 cts/Pa	3994 cts/Pa	3500 cts/Pa	3222 cts/Pa	3179 cts/Pa
0.032 Hz	8294 cts/Pa	7336 cts/Pa	6504 cts/Pa	5956 cts/Pa	5838 cts/Pa
0.040 Hz	11020 cts/Pa	9866 cts/Pa	8681 cts/Pa	7945 cts/Pa	7800 cts/Pa
0.050 Hz	15070 cts/Pa	13560 cts/Pa	12050 cts/Pa	11040 cts/Pa	10870 cts/Pa
0.063 Hz	20100 cts/Pa	18290 cts/Pa	16430 cts/Pa	15110 cts/Pa	14890 cts/Pa
0.079 Hz	27300 cts/Pa	24760 cts/Pa	22380 cts/Pa	20890 cts/Pa	20510 cts/Pa
0.100 Hz	32800 cts/Pa	30000 cts/Pa	27680 cts/Pa	25780 cts/Pa	25470 cts/Pa
0.126 Hz	37770 cts/Pa	35390 cts/Pa	32860 cts/Pa	31040 cts/Pa	30430 cts/Pa
0.158 Hz	42490 cts/Pa	40500 cts/Pa	38190 cts/Pa	36440 cts/Pa	35890 cts/Pa
0.200 Hz	47270 cts/Pa	45140 cts/Pa	42300 cts/Pa	41130 cts/Pa	40130 cts/Pa
0.251 Hz	48780 cts/Pa	47850 cts/Pa	45870 cts/Pa	44430 cts/Pa	44350 cts/Pa
0.316 Hz	51020 cts/Pa	50510 cts/Pa	48630 cts/Pa	47330 cts/Pa	46480 cts/Pa
0.398 Hz	54460 cts/Pa	52230 cts/Pa	51030 cts/Pa	49590 cts/Pa	49760 cts/Pa
0.501 Hz	53550 cts/Pa	53000 cts/Pa	51870 cts/Pa	50900 cts/Pa	50150 cts/Pa
0.631 Hz	55490 cts/Pa	54380 cts/Pa	52610 cts/Pa	51960 cts/Pa	51960 cts/Pa
0.794 Hz	54470 cts/Pa	54230 cts/Pa	54210 cts/Pa	53080 cts/Pa	52560 cts/Pa
1.000 Hz	56300 cts/Pa	55530 cts/Pa	54500 cts/Pa	53760 cts/Pa	53510 cts/Pa
1.259 Hz	56570 cts/Pa	55860 cts/Pa	54860 cts/Pa	54170 cts/Pa	53970 cts/Pa
1.585 Hz	56790 cts/Pa	56130 cts/Pa	55190 cts/Pa	54520 cts/Pa	54290 cts/Pa
1.995 Hz	57010 cts/Pa	56360 cts/Pa	55410 cts/Pa	54850 cts/Pa	54680 cts/Pa
2.512 Hz	57150 cts/Pa	56510 cts/Pa	55530 cts/Pa	55060 cts/Pa	54930 cts/Pa
3.162 Hz	57210 cts/Pa	56630 cts/Pa	55740 cts/Pa	55140 cts/Pa	54990 cts/Pa
3.981 Hz	57300 cts/Pa	56690 cts/Pa	55800 cts/Pa	55290 cts/Pa	55170 cts/Pa
5.012 Hz	57310 cts/Pa	56750 cts/Pa	55890 cts/Pa	55350 cts/Pa	55260 cts/Pa
6.310 Hz	57190 cts/Pa	56630 cts/Pa	55790 cts/Pa	55300 cts/Pa	55240 cts/Pa
7.943 Hz	56990 cts/Pa	56470 cts/Pa	55620 cts/Pa	55180 cts/Pa	55170 cts/Pa
10.000 Hz	56600 cts/Pa	56110 cts/Pa	55330 cts/Pa	54880 cts/Pa	54880 cts/Pa
12.589 Hz	55960 cts/Pa	55500 cts/Pa	54740 cts/Pa	54330 cts/Pa	54360 cts/Pa
15.849 Hz	54990 cts/Pa	54600 cts/Pa	53850 cts/Pa	-	53590 cts/Pa
19.953 Hz	-	-	52300 cts/Pa	-	52130 cts/Pa

Table 106 Phase Response over Evaluated Pressures: Boom R2A6D

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	162.80 deg	164.70 deg	164.00 deg	163.80 deg	164.30 deg
0.013 Hz	158.50 deg	159.90 deg	158.90 deg	160.70 deg	160.30 deg
0.016 Hz	154.10 deg	155.20 deg	155.00 deg	156.40 deg	156.00 deg
0.020 Hz	149.30 deg	149.30 deg	150.30 deg	151.40 deg	152.00 deg
0.025 Hz	142.90 deg	144.10 deg	146.80 deg	146.60 deg	146.60 deg
0.032 Hz	130.60 deg	132.90 deg	133.20 deg	135.40 deg	135.60 deg
0.040 Hz	122.30 deg	124.60 deg	126.60 deg	127.40 deg	128.10 deg
0.050 Hz	111.90 deg	114.20 deg	116.70 deg	118.00 deg	118.50 deg
0.063 Hz	100.90 deg	103.70 deg	104.80 deg	107.00 deg	108.10 deg
0.079 Hz	86.08 deg	89.67 deg	92.11 deg	93.78 deg	93.62 deg
0.100 Hz	75.79 deg	78.69 deg	81.38 deg	84.78 deg	84.24 deg
0.126 Hz	62.97 deg	66.70 deg	71.35 deg	73.26 deg	74.13 deg
0.158 Hz	52.59 deg	56.15 deg	59.12 deg	61.05 deg	62.03 deg
0.200 Hz	44.17 deg	47.42 deg	50.54 deg	51.80 deg	53.85 deg
0.251 Hz	35.89 deg	39.43 deg	41.29 deg	43.37 deg	44.92 deg
0.316 Hz	30.21 deg	32.24 deg	35.55 deg	37.96 deg	36.19 deg
0.398 Hz	24.90 deg	26.93 deg	28.34 deg	29.86 deg	29.77 deg
0.501 Hz	21.90 deg	22.60 deg	25.93 deg	26.46 deg	24.53 deg
0.631 Hz	17.13 deg	22.71 deg	18.60 deg	23.08 deg	19.94 deg
0.794 Hz	16.73 deg	18.76 deg	14.27 deg	20.13 deg	21.12 deg
1.000 Hz	14.57 deg	15.14 deg	13.85 deg	14.57 deg	14.03 deg
1.259 Hz	9.97 deg	7.95 deg	15.01 deg	11.15 deg	14.88 deg
1.585 Hz	11.43 deg	11.80 deg	11.89 deg	15.22 deg	8.67 deg
1.995 Hz	13.84 deg	12.67 deg	15.37 deg	9.76 deg	15.36 deg
2.512 Hz	6.37 deg	7.87 deg	14.74 deg	8.82 deg	15.26 deg
3.162 Hz	7.96 deg	19.37 deg	7.42 deg	13.52 deg	5.98 deg
3.981 Hz	4.13 deg	23.65 deg	0.32 deg	16.40 deg	13.37 deg
5.012 Hz	0.88 deg	-0.66 deg	15.46 deg	16.84 deg	22.36 deg
6.310 Hz	3.54 deg	34.27 deg	8.37 deg	33.76 deg	17.59 deg
7.943 Hz	22.41 deg	16.57 deg	39.93 deg	16.21 deg	38.01 deg
10.000 Hz	10.15 deg	5.59 deg	36.88 deg	22.29 deg	32.77 deg
12.589 Hz	3.71 deg	41.84 deg	-10.18 deg	63.14 deg	-14.44 deg
15.849 Hz	41.74 deg	29.52 deg	47.68 deg	-	72.11 deg
19.953 Hz	-	-	46.69 deg	-	83.09 deg

Table 107 Amplitude Response over Evaluated Pressures: Boom RF958

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	62 cts/Pa	55 cts/Pa	50 cts/Pa	45 cts/Pa	45 cts/Pa
0.013 Hz	115 cts/Pa	101 cts/Pa	87 cts/Pa	78 cts/Pa	76 cts/Pa
0.016 Hz	171 cts/Pa	149 cts/Pa	130 cts/Pa	119 cts/Pa	112 cts/Pa
0.020 Hz	240 cts/Pa	215 cts/Pa	180 cts/Pa	165 cts/Pa	163 cts/Pa
0.025 Hz	325 cts/Pa	288 cts/Pa	241 cts/Pa	224 cts/Pa	215 cts/Pa
0.032 Hz	610 cts/Pa	533 cts/Pa	461 cts/Pa	423 cts/Pa	412 cts/Pa
0.040 Hz	821 cts/Pa	730 cts/Pa	620 cts/Pa	566 cts/Pa	551 cts/Pa
0.050 Hz	1159 cts/Pa	1029 cts/Pa	878 cts/Pa	804 cts/Pa	776 cts/Pa
0.063 Hz	1615 cts/Pa	1443 cts/Pa	1241 cts/Pa	1130 cts/Pa	1097 cts/Pa
0.079 Hz	2373 cts/Pa	2080 cts/Pa	1775 cts/Pa	1636 cts/Pa	1590 cts/Pa
0.100 Hz	3103 cts/Pa	2712 cts/Pa	2334 cts/Pa	2135 cts/Pa	2090 cts/Pa
0.126 Hz	3978 cts/Pa	3534 cts/Pa	3043 cts/Pa	2784 cts/Pa	2693 cts/Pa
0.158 Hz	5197 cts/Pa	4622 cts/Pa	3983 cts/Pa	3664 cts/Pa	3550 cts/Pa
0.200 Hz	6778 cts/Pa	5984 cts/Pa	5074 cts/Pa	4698 cts/Pa	4509 cts/Pa
0.251 Hz	8362 cts/Pa	7484 cts/Pa	6391 cts/Pa	5908 cts/Pa	5815 cts/Pa
0.316 Hz	10540 cts/Pa	9529 cts/Pa	8176 cts/Pa	7464 cts/Pa	7172 cts/Pa
0.398 Hz	13690 cts/Pa	11930 cts/Pa	10320 cts/Pa	9413 cts/Pa	9247 cts/Pa
0.501 Hz	16290 cts/Pa	14650 cts/Pa	12720 cts/Pa	11640 cts/Pa	11200 cts/Pa
0.631 Hz	20450 cts/Pa	18240 cts/Pa	15680 cts/Pa	14430 cts/Pa	14090 cts/Pa
0.794 Hz	24210 cts/Pa	21930 cts/Pa	19420 cts/Pa	17940 cts/Pa	17450 cts/Pa
1.000 Hz	29420 cts/Pa	26720 cts/Pa	23570 cts/Pa	21750 cts/Pa	21130 cts/Pa
1.259 Hz	34290 cts/Pa	31430 cts/Pa	27960 cts/Pa	26030 cts/Pa	25370 cts/Pa
1.585 Hz	38920 cts/Pa	36120 cts/Pa	32620 cts/Pa	30480 cts/Pa	29690 cts/Pa
1.995 Hz	43180 cts/Pa	40460 cts/Pa	36950 cts/Pa	35010 cts/Pa	34300 cts/Pa
2.512 Hz	46730 cts/Pa	44210 cts/Pa	40870 cts/Pa	39140 cts/Pa	38510 cts/Pa
3.162 Hz	49310 cts/Pa	47250 cts/Pa	44470 cts/Pa	42550 cts/Pa	41750 cts/Pa
3.981 Hz	51370 cts/Pa	49560 cts/Pa	47060 cts/Pa	45480 cts/Pa	44840 cts/Pa
5.012 Hz	52780 cts/Pa	51260 cts/Pa	49160 cts/Pa	47750 cts/Pa	47180 cts/Pa
6.310 Hz	53680 cts/Pa	52390 cts/Pa	50580 cts/Pa	49420 cts/Pa	49000 cts/Pa
7.943 Hz	54220 cts/Pa	53150 cts/Pa	51590 cts/Pa	50660 cts/Pa	50380 cts/Pa
10.000 Hz	54390 cts/Pa	53520 cts/Pa	52200 cts/Pa	51430 cts/Pa	51240 cts/Pa
12.589 Hz	54170 cts/Pa	53450 cts/Pa	52320 cts/Pa	51710 cts/Pa	51590 cts/Pa
15.849 Hz	53580 cts/Pa	52950 cts/Pa	51960 cts/Pa	-	51510 cts/Pa
19.953 Hz	-	-	50840 cts/Pa	-	50530 cts/Pa

Table 108 Phase Response over Evaluated Pressures: Boom RF958

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.010 Hz	169.90 deg	170.40 deg	170.70 deg	163.50 deg	168.30 deg
0.013 Hz	165.10 deg	166.00 deg	165.40 deg	166.30 deg	168.50 deg
0.016 Hz	159.70 deg	161.20 deg	160.50 deg	161.40 deg	161.60 deg
0.020 Hz	159.30 deg	156.20 deg	158.80 deg	156.40 deg	159.10 deg
0.025 Hz	152.50 deg	154.00 deg	155.10 deg	155.70 deg	153.10 deg
0.032 Hz	145.70 deg	146.60 deg	144.90 deg	146.60 deg	146.60 deg
0.040 Hz	139.90 deg	140.30 deg	141.00 deg	141.10 deg	141.40 deg
0.050 Hz	133.40 deg	133.00 deg	134.10 deg	134.70 deg	134.70 deg
0.063 Hz	127.10 deg	127.30 deg	126.70 deg	126.90 deg	127.90 deg
0.079 Hz	118.80 deg	119.20 deg	118.80 deg	118.90 deg	119.00 deg
0.100 Hz	113.30 deg	113.10 deg	113.10 deg	114.90 deg	114.10 deg
0.126 Hz	106.20 deg	106.50 deg	109.00 deg	109.00 deg	109.10 deg
0.158 Hz	101.10 deg	101.80 deg	102.40 deg	102.00 deg	103.40 deg
0.200 Hz	97.02 deg	97.03 deg	98.29 deg	98.53 deg	99.62 deg
0.251 Hz	91.75 deg	94.16 deg	93.19 deg	94.55 deg	95.83 deg
0.316 Hz	88.73 deg	89.18 deg	91.62 deg	92.11 deg	90.38 deg
0.398 Hz	83.96 deg	85.11 deg	85.09 deg	87.45 deg	86.13 deg
0.501 Hz	79.17 deg	79.26 deg	85.01 deg	83.85 deg	82.08 deg
0.631 Hz	72.38 deg	77.91 deg	77.36 deg	80.22 deg	77.54 deg
0.794 Hz	70.00 deg	72.26 deg	72.89 deg	74.15 deg	75.67 deg
1.000 Hz	61.97 deg	59.52 deg	68.30 deg	67.31 deg	67.75 deg
1.259 Hz	55.75 deg	54.26 deg	60.84 deg	59.32 deg	64.03 deg
1.585 Hz	46.80 deg	47.84 deg	57.98 deg	58.75 deg	53.86 deg
1.995 Hz	47.41 deg	46.11 deg	54.06 deg	52.24 deg	51.92 deg
2.512 Hz	31.99 deg	41.37 deg	45.04 deg	43.77 deg	50.99 deg
3.162 Hz	22.94 deg	33.01 deg	38.10 deg	37.96 deg	33.68 deg
3.981 Hz	23.57 deg	40.08 deg	23.31 deg	31.12 deg	45.29 deg
5.012 Hz	18.06 deg	12.21 deg	17.33 deg	43.70 deg	35.22 deg
6.310 Hz	15.80 deg	39.99 deg	22.08 deg	33.22 deg	44.02 deg
7.943 Hz	29.35 deg	14.09 deg	46.93 deg	33.47 deg	31.08 deg
10.000 Hz	18.75 deg	2.80 deg	44.77 deg	42.20 deg	23.46 deg
12.589 Hz	8.43 deg	31.23 deg	-7.90 deg	34.96 deg	10.54 deg
15.849 Hz	39.15 deg	6.37 deg	40.46 deg	-	34.79 deg
19.953 Hz	-	-	14.48 deg	-	79.80 deg

3.10.4.5 Samsung S10

The following six figures show the amplitude and phase responses of the Samsung S10 smartphones at 600 hPa, 700 hPa, 800 hPa, 900 hPa and 1000 hPa.

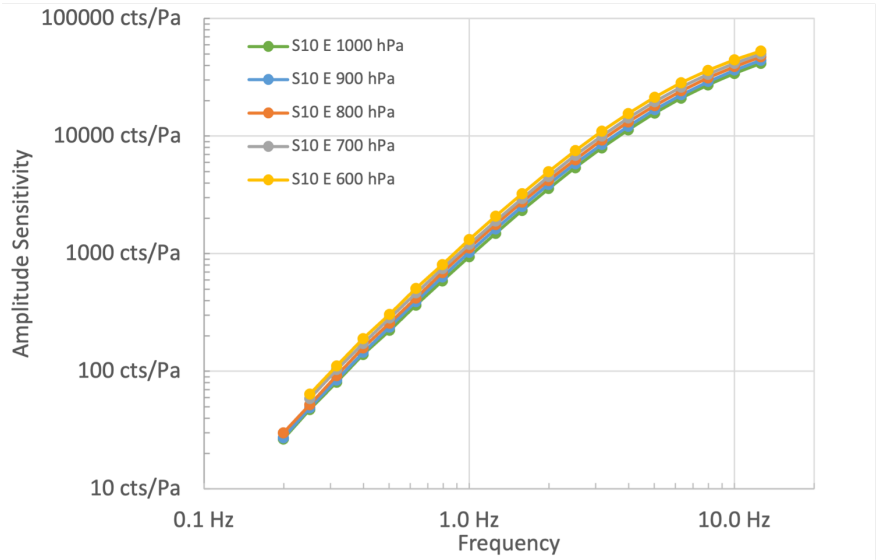

Figure 113 Amplitude Response at Evaluated Static Pressures: S10 E

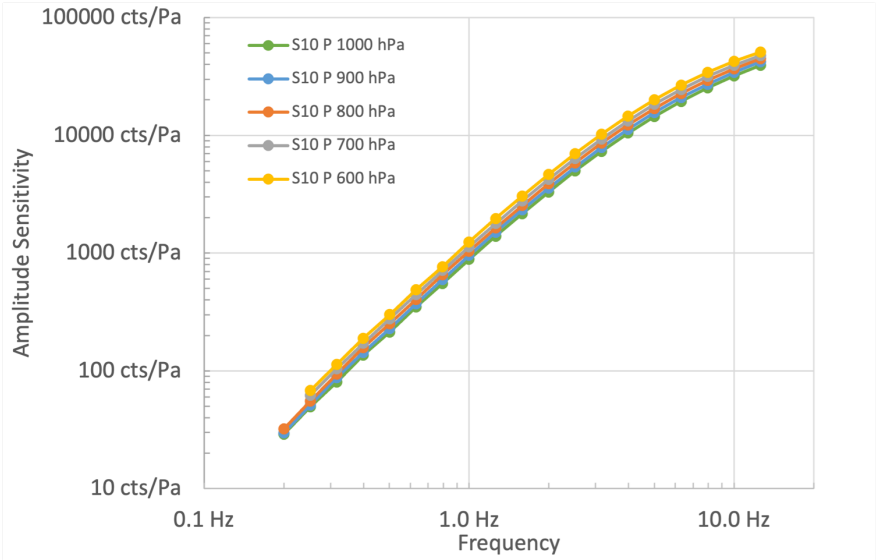

Figure 114 Amplitude Response at Evaluated Static Pressures: S10 P

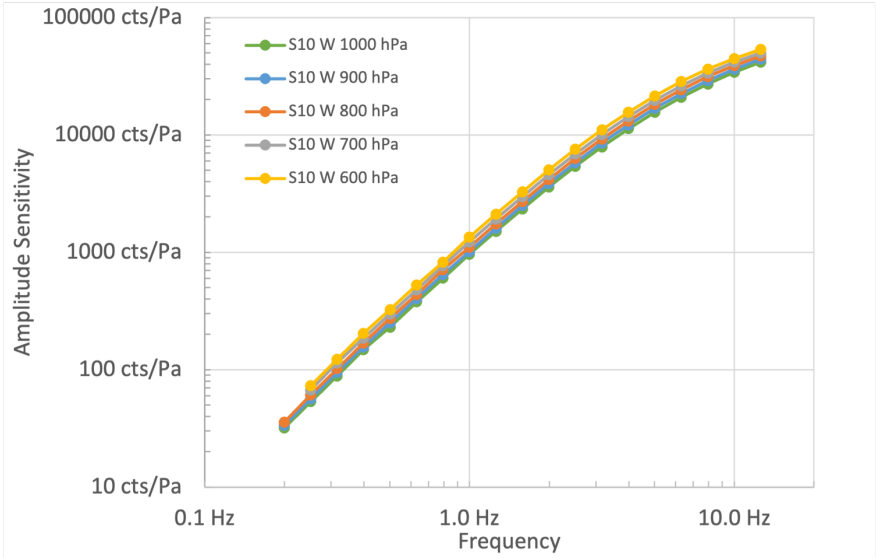

Figure 115 Amplitude Response at Evaluated Static Pressures: S10 W

The Samsung S10 smartphones exhibit consistency across sensors as each package's amplitude response reacts similarly to static pressure changes. Within the frequencies at which the response could be evaluated, the amplitude response increased as pressure dropped, as much as 40% at 600 hPa relative to the response at 1000 hPa.

The following tables contain the values used to generate the above figures.

Table 109 Amplitude Response at Evaluated Static Pressures: S10 E

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.200 Hz	-	-	30 cts/Pa	27 cts/Pa	27 cts/Pa
0.251 Hz	64 cts/Pa	59 cts/Pa	52 cts/Pa	49 cts/Pa	47 cts/Pa
0.316 Hz	111 cts/Pa	103 cts/Pa	92 cts/Pa	84 cts/Pa	81 cts/Pa
0.398 Hz	190 cts/Pa	172 cts/Pa	159 cts/Pa	145 cts/Pa	139 cts/Pa
0.501 Hz	306 cts/Pa	284 cts/Pa	257 cts/Pa	238 cts/Pa	223 cts/Pa
0.631 Hz	509 cts/Pa	464 cts/Pa	420 cts/Pa	391 cts/Pa	367 cts/Pa
0.794 Hz	807 cts/Pa	750 cts/Pa	691 cts/Pa	634 cts/Pa	589 cts/Pa
1.000 Hz	1320 cts/Pa	1204 cts/Pa	1122 cts/Pa	1030 cts/Pa	945 cts/Pa
1.259 Hz	2086 cts/Pa	1900 cts/Pa	1767 cts/Pa	1624 cts/Pa	1491 cts/Pa
1.585 Hz	3249 cts/Pa	2958 cts/Pa	2745 cts/Pa	2527 cts/Pa	2329 cts/Pa
1.995 Hz	4994 cts/Pa	4549 cts/Pa	4207 cts/Pa	3873 cts/Pa	3579 cts/Pa
2.512 Hz	7517 cts/Pa	6842 cts/Pa	6318 cts/Pa	5825 cts/Pa	5399 cts/Pa
3.162 Hz	11010 cts/Pa	10040 cts/Pa	9266 cts/Pa	8535 cts/Pa	7926 cts/Pa
3.981 Hz	15630 cts/Pa	14300 cts/Pa	13200 cts/Pa	12170 cts/Pa	11330 cts/Pa
5.012 Hz	21500 cts/Pa	19690 cts/Pa	18200 cts/Pa	16810 cts/Pa	15670 cts/Pa
6.310 Hz	28450 cts/Pa	26170 cts/Pa	24280 cts/Pa	22480 cts/Pa	21000 cts/Pa
7.943 Hz	36330 cts/Pa	33610 cts/Pa	31300 cts/Pa	29100 cts/Pa	27280 cts/Pa
10.000 Hz	44640 cts/Pa	41580 cts/Pa	39040 cts/Pa	36420 cts/Pa	34240 cts/Pa
12.589 Hz	53030 cts/Pa	49810 cts/Pa	47160 cts/Pa	44300 cts/Pa	41760 cts/Pa

Table 110 Amplitude Response at Evaluated Static Pressures: S10 P Package

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.200 Hz	-	-	32 cts/Pa	30 cts/Pa	29 cts/Pa
0.251 Hz	68 cts/Pa	62 cts/Pa	56 cts/Pa	51 cts/Pa	49 cts/Pa
0.316 Hz	114 cts/Pa	104 cts/Pa	94 cts/Pa	88 cts/Pa	80 cts/Pa
0.398 Hz	189 cts/Pa	171 cts/Pa	157 cts/Pa	143 cts/Pa	136 cts/Pa
0.501 Hz	300 cts/Pa	276 cts/Pa	251 cts/Pa	229 cts/Pa	213 cts/Pa
0.631 Hz	489 cts/Pa	445 cts/Pa	403 cts/Pa	370 cts/Pa	348 cts/Pa
0.794 Hz	768 cts/Pa	712 cts/Pa	656 cts/Pa	598 cts/Pa	554 cts/Pa
1.000 Hz	1247 cts/Pa	1132 cts/Pa	1036 cts/Pa	955 cts/Pa	883 cts/Pa
1.259 Hz	1961 cts/Pa	1779 cts/Pa	1631 cts/Pa	1499 cts/Pa	1386 cts/Pa
1.585 Hz	3045 cts/Pa	2767 cts/Pa	2535 cts/Pa	2327 cts/Pa	2160 cts/Pa
1.995 Hz	4670 cts/Pa	4240 cts/Pa	3891 cts/Pa	3575 cts/Pa	3310 cts/Pa
2.512 Hz	7019 cts/Pa	6370 cts/Pa	5846 cts/Pa	5378 cts/Pa	4985 cts/Pa
3.162 Hz	10270 cts/Pa	9339 cts/Pa	8588 cts/Pa	7893 cts/Pa	7319 cts/Pa
3.981 Hz	14600 cts/Pa	13300 cts/Pa	12240 cts/Pa	11270 cts/Pa	10450 cts/Pa
5.012 Hz	20120 cts/Pa	18350 cts/Pa	16930 cts/Pa	15600 cts/Pa	14490 cts/Pa
6.310 Hz	26750 cts/Pa	24490 cts/Pa	22660 cts/Pa	20940 cts/Pa	19450 cts/Pa
7.943 Hz	34360 cts/Pa	31630 cts/Pa	29360 cts/Pa	27200 cts/Pa	25370 cts/Pa
10.000 Hz	42630 cts/Pa	39450 cts/Pa	36830 cts/Pa	34280 cts/Pa	32060 cts/Pa
12.589 Hz	51200 cts/Pa	47770 cts/Pa	44860 cts/Pa	42000 cts/Pa	39460 cts/Pa

Table 111 Amplitude Response at Evaluated Static Pressures: S10 W

Frequency	600 hPa	700 hPa	800 hPa	900 hPa	1000 hPa
0.200 Hz	-	-	36 cts/Pa	34 cts/Pa	32 cts/Pa
0.251 Hz	73 cts/Pa	67 cts/Pa	61 cts/Pa	56 cts/Pa	53 cts/Pa
0.316 Hz	123 cts/Pa	114 cts/Pa	102 cts/Pa	94 cts/Pa	88 cts/Pa
0.398 Hz	204 cts/Pa	186 cts/Pa	169 cts/Pa	156 cts/Pa	148 cts/Pa
0.501 Hz	324 cts/Pa	299 cts/Pa	273 cts/Pa	250 cts/Pa	231 cts/Pa
0.631 Hz	528 cts/Pa	481 cts/Pa	436 cts/Pa	402 cts/Pa	378 cts/Pa
0.794 Hz	828 cts/Pa	768 cts/Pa	711 cts/Pa	649 cts/Pa	602 cts/Pa
1.000 Hz	1345 cts/Pa	1222 cts/Pa	1103 cts/Pa	1012 cts/Pa	960 cts/Pa
1.259 Hz	2114 cts/Pa	1924 cts/Pa	1742 cts/Pa	1603 cts/Pa	1509 cts/Pa
1.585 Hz	3287 cts/Pa	2986 cts/Pa	2720 cts/Pa	2504 cts/Pa	2345 cts/Pa
1.995 Hz	5029 cts/Pa	4575 cts/Pa	4182 cts/Pa	3856 cts/Pa	3594 cts/Pa
2.512 Hz	7548 cts/Pa	6867 cts/Pa	6293 cts/Pa	5807 cts/Pa	5407 cts/Pa
3.162 Hz	11030 cts/Pa	10060 cts/Pa	9249 cts/Pa	8522 cts/Pa	7926 cts/Pa
3.981 Hz	15660 cts/Pa	14300 cts/Pa	13180 cts/Pa	12170 cts/Pa	11300 cts/Pa
5.012 Hz	21510 cts/Pa	19690 cts/Pa	18210 cts/Pa	16830 cts/Pa	15630 cts/Pa
6.310 Hz	28480 cts/Pa	26160 cts/Pa	24290 cts/Pa	22530 cts/Pa	20930 cts/Pa
7.943 Hz	36400 cts/Pa	33630 cts/Pa	31320 cts/Pa	29150 cts/Pa	27200 cts/Pa
10.000 Hz	44810 cts/Pa	41660 cts/Pa	38990 cts/Pa	36470 cts/Pa	34160 cts/Pa
12.589 Hz	53340 cts/Pa	50000 cts/Pa	46990 cts/Pa	44250 cts/Pa	41760 cts/Pa

3.11 Response to Vertical Acceleration

The response to vertical acceleration is defined as being the linear time-invariant (LTI) change in the sensor output signal amplitude and phase relative to an input acceleration.

3.11.1 Measurand

The quantity being measured is the sensor's response to acceleration in V/(m/s^2) as a function of frequency.

3.11.2 Configuration

The sensor is placed on a seismic calibration table to measure its sensitivity to vertical acceleration.

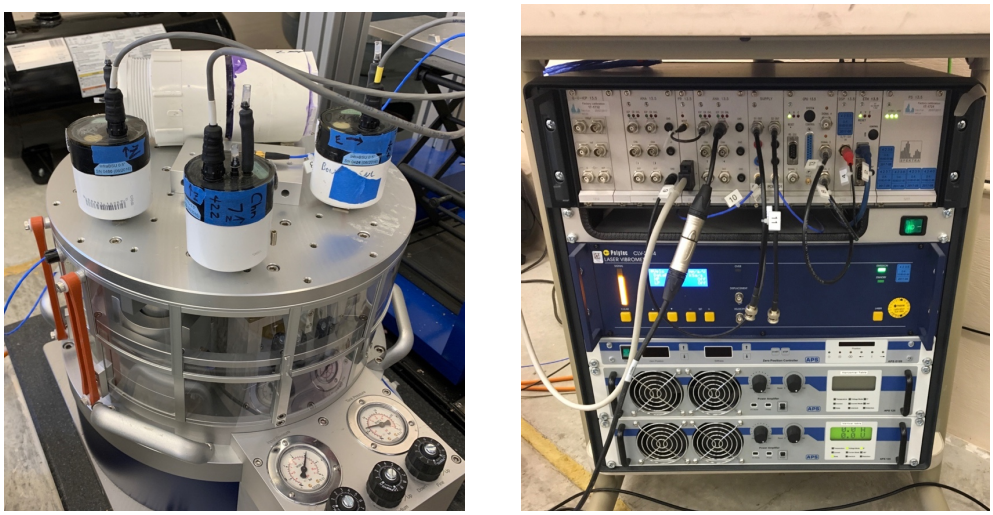

Figure 116 Response to Vertical Acceleration Testbed Equipment

Table 112 Response to Vertical Acceleration Testbed Equipment

	Manufacturer / Model	Serial #	Environmental Conditions
Calibration System	Spektra SE-13	#6	814 hPa, +/- 4 hPa 22.5 C, +/- 2.5 C 13 % Rh, +/- 1 % Rh

The Spektra CS-18P Seismic Calibration system, using the SE-13 vertical shaker, provides integrated control, data acquisition, and analysis systems to provide a primary calibration of a sensor's amplitude and phase sensitivity utilizing sinusoidal driving signals of varying amplitude and frequency.

The sensor's pressure inlets are capped or the sensor/package is placed in sealed PVC container during this test to reduce the measurement of ambient pressure variation and improve the signal to noise ratio of the sensor output. Specifically, the Camas microphones, InfraBSU sensors and Samsung S10 smartphones had pressure inlets which were not easily capped, therefore these units were sealed into PVC containers, to ensure accelerations induced by the calibration system

were transmitted to these units under test. The Gem sensor and Raspberry Boom packages allowed for their pressure inlets to be conveniently capped to reduce the effects of ambient pressure variations.

Sensors/packages were exposed to accelerations between 0.196 m/s^2 and 0.198 m/s^2.

Measurements were made on each of the sensors and packages under test three times, once in each orientation: vertical, side, and back, oriented as shown in the following figures.

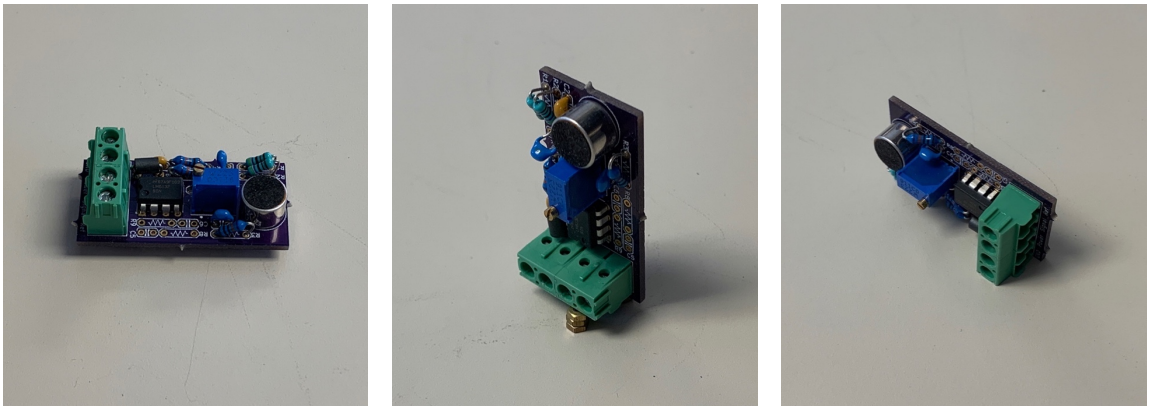

Figure 117 Camas Acceleration Orientations: A, B and C

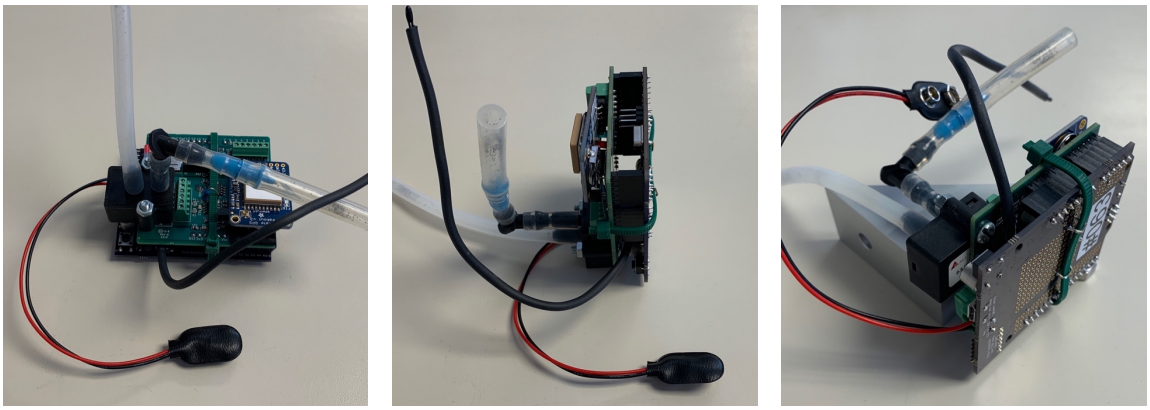

Figure 118 Acceleration Orientations: A, B and C

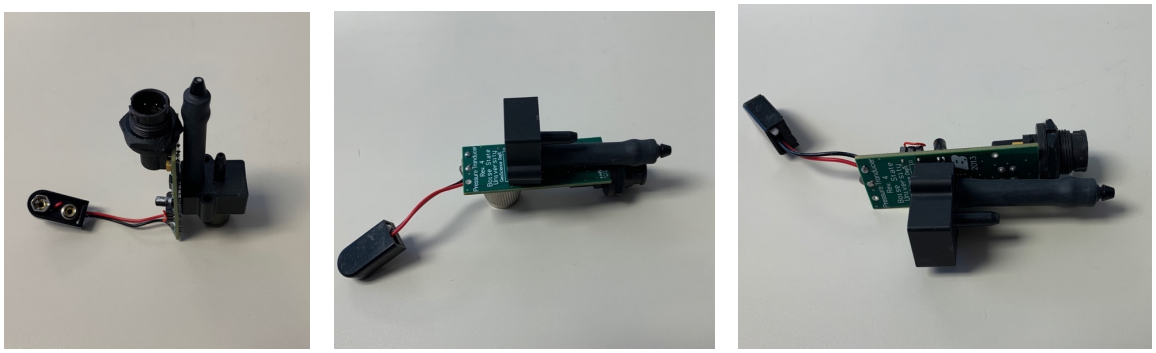

Figure 119 InfraBSU Acceleration Orientations: A, B and C

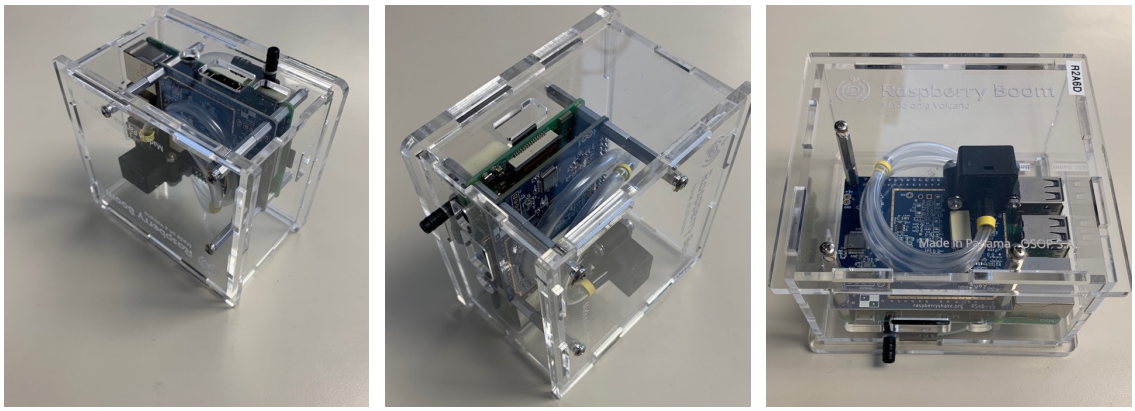

Figure 120 Raspbeerry Boom Acceleration Orientations: A, B and C

Figure 121 S10 Acceleration Orientations: A, B and C

3.11.3 Analysis

The Spektra seismic calibration system performs the analysis of data internally by fitting a sine function to a primary measurement of the shake table displacement, which is converted to acceleration. Measurements are made using sinusoidal tones at each of the specified frequencies, averaged over multiple readings.

A four-parameter sine fit (Merchant, 2011; IEEE-STD1281) is applied to the time segment of data, comprised of at least 5 cycles at the specified frequencies, from the sensor under test in volts in order to determine the sinusoid's amplitude, frequency, phase, and DC offset:

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

The Voltage computed from the four-parameter sine fit is divided by the measured acceleration measured by the Spektra Calibration System to provide a sensor or package sensitivity to acceleration in V/(m/s^2)

$$Sensitivity = \frac{V_{SUT}}{Acceleration}$$

3.11.4 Results

The figure below plots the calculated sensitivity to acceleration for the Camas microphone.

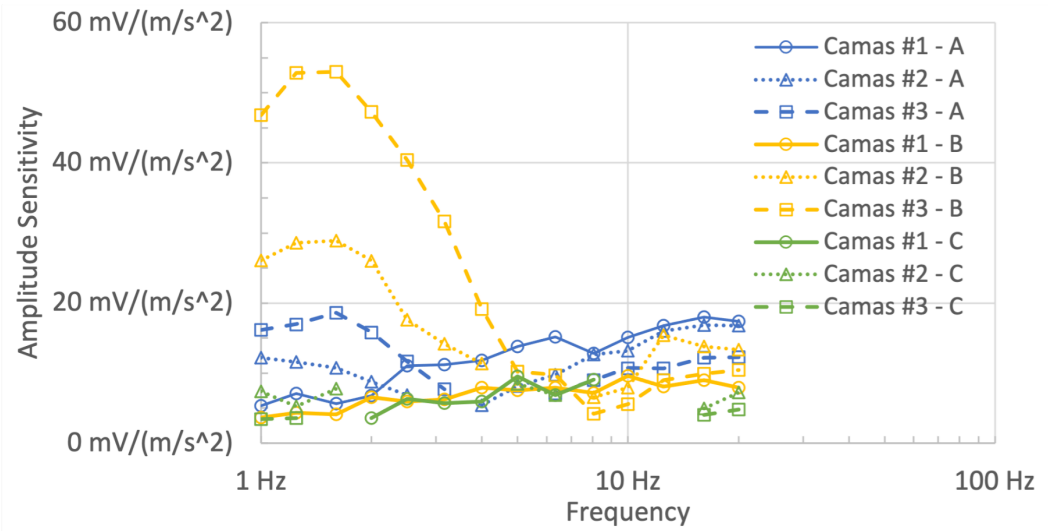

Figure 122 Amplitude Response to Acceleration: Camas Microphone

The Camas microphones had amplitudes with sufficient SNR for measurement ranging from 3.41 mV/(m/s^2) to as high as 53.04 mV/(m/s^2) for Camas #3 orientation C and B respectively. The bulk of the calculated accelerations remain below 20 mV/(m/s^2).. While there is measurable acceleration on all axes for each microphone, there is a lack of a dominant orientation in which acceleration is highest across all microphones.

The following tables contains the values used to generate the above figure.

Table 113 Amplitude Response to Acceleration: Camas Microphones, Orientation A

Frequency	Camas #1	Camas #2	Camas #3
1.000 Hz	5.33 mV/(m/s^2)	12.20 mV/(m/s^2)	16.20 mV/(m/s^2)
1.250 Hz	7.12 mV/(m/s^2)	11.62 mV/(m/s^2)	16.97 mV/(m/s^2)
1.603 Hz	5.65 mV/(m/s^2)	10.74 mV/(m/s^2)	18.65 mV/(m/s^2)
2.000 Hz	6.77 mV/(m/s^2)	8.74 mV/(m/s^2)	15.83 mV/(m/s^2)
2.500 Hz	11.03 mV/(m/s^2)	6.89 mV/(m/s^2)	11.66 mV/(m/s^2)
3.165 Hz	11.23 mV/(m/s^2)	-	7.72 mV/(m/s^2)
4.000 Hz	11.83 mV/(m/s^2)	5.45 mV/(m/s^2)	-
5.000 Hz	13.84 mV/(m/s^2)	8.19 mV/(m/s^2)	-
6.329 Hz	15.19 mV/(m/s^2)	9.75 mV/(m/s^2)	7.13 mV/(m/s^2)
8.065 Hz	12.79 mV/(m/s^2)	12.63 mV/(m/s^2)	9.01 mV/(m/s^2)
10.000 Hz	15.13 mV/(m/s^2)	13.20 mV/(m/s^2)	10.72 mV/(m/s^2)
12.500 Hz	16.81 mV/(m/s^2)	16.05 mV/(m/s^2)	10.71 mV/(m/s^2)
16.129 Hz	18.01 mV/(m/s^2)	16.89 mV/(m/s^2)	12.24 mV/(m/s^2)
20.000 Hz	17.41 mV/(m/s^2)	16.80 mV/(m/s^2)	12.25 mV/(m/s^2)

Table 114 Amplitude Response to Acceleration: Camas Microphones, Orientation B

Frequency	Camas #1	Camas #2	Camas #3
1.000 Hz	3.65 mV/(m/s^2)	26.11 mV/(m/s^2)	46.79 mV/(m/s^2)
1.250 Hz	4.37 mV/(m/s^2)	28.59 mV/(m/s^2)	52.85 mV/(m/s^2)
1.603 Hz	4.10 mV/(m/s^2)	28.94 mV/(m/s^2)	53.04 mV/(m/s^2)
2.000 Hz	6.54 mV/(m/s^2)	26.04 mV/(m/s^2)	47.25 mV/(m/s^2)
2.500 Hz	5.95 mV/(m/s^2)	17.64 mV/(m/s^2)	40.40 mV/(m/s^2)
3.165 Hz	6.27 mV/(m/s^2)	14.16 mV/(m/s^2)	31.66 mV/(m/s^2)
4.000 Hz	7.95 mV/(m/s^2)	11.37 mV/(m/s^2)	19.18 mV/(m/s^2)
5.000 Hz	7.55 mV/(m/s^2)	-	10.22 mV/(m/s^2)
6.329 Hz	7.94 mV/(m/s^2)	-	9.73 mV/(m/s^2)
8.065 Hz	7.15 mV/(m/s^2)	6.57 mV/(m/s^2)	4.20 mV/(m/s^2)
10.000 Hz	9.64 mV/(m/s^2)	7.90 mV/(m/s^2)	5.55 mV/(m/s^2)
12.500 Hz	8.08 mV/(m/s^2)	15.43 mV/(m/s^2)	9.02 mV/(m/s^2)
16.129 Hz	9.00 mV/(m/s^2)	13.83 mV/(m/s^2)	9.93 mV/(m/s^2)
20.000 Hz	7.93 mV/(m/s^2)	13.35 mV/(m/s^2)	10.43 mV/(m/s^2)

Table 115 Amplitude Response to Acceleration: Camas Microphones, Orientation C

Frequency	Camas #1	Camas #2	Camas #3
1.000 Hz	-	7.38 mV/(m/s^2)	3.41 mV/(m/s^2)
1.250 Hz	-	5.25 mV/(m/s^2)	3.61 mV/(m/s^2)
1.603 Hz	-	7.75 mV/(m/s^2)	-
2.000 Hz	3.62 mV/(m/s^2)	-	-
2.500 Hz	6.32 mV/(m/s^2)	-	-
3.165 Hz	5.75 mV/(m/s^2)	-	-
4.000 Hz	5.95 mV/(m/s^2)	-	-
5.000 Hz	9.51 mV/(m/s^2)	8.44 mV/(m/s^2)	-
6.329 Hz	6.90 mV/(m/s^2)	6.84 mV/(m/s^2)	-
8.065 Hz	9.08 mV/(m/s^2)	-	-
10.000 Hz	-	-	-
12.500 Hz	-	-	-
16.129 Hz	-	4.95 mV/(m/s^2)	4.07 mV/(m/s^2)
20.000 Hz	-	7.23 mV/(m/s^2)	4.81 mV/(m/s^2)

The following figure plots the calculated sensitivity to acceleration for the Gem package #070.

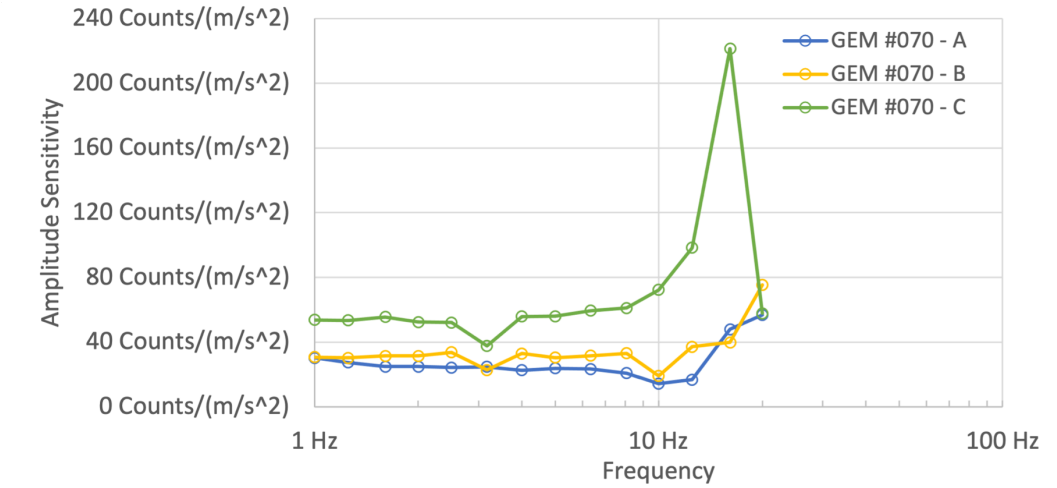

Figure 123 Amplitude Response to Acceleration: Gem Package #070

The Gem package #070 responds with some consistency to acceleration across the frequencies evaluated. The package had its highest acceleration while placed in orientation C on the vertical shake table, where below 10 Hz accelerations were nearly 1.65 times higher in sensitivity to acceleration than orientations A and B, respectively. Between 10 Hz and 12.5 Hz the C orientation sensitivity to acceleration greatly increased, with unknown cause.

The following tables contains the values used to generate the above figure.

Table 116 Amplitude Response to Acceleration: Gem Package #070

Frequency	Orientation A	Orientation B	Orientation C
1.000 Hz	30 cts/(m/s^2)	31 cts/(m/s^2)	54 cts/(m/s^2)
1.250 Hz	27 cts/(m/s^2)	30 cts/(m/s^2)	53 cts/(m/s^2)
1.603 Hz	25 cts/(m/s^2)	31 cts/(m/s^2)	56 cts/(m/s^2)
2.000 Hz	25 cts/(m/s^2)	31 cts/(m/s^2)	52 cts/(m/s^2)
2.500 Hz	24 cts/(m/s^2)	34 cts/(m/s^2)	52 cts/(m/s^2)
3.165 Hz	25 cts/(m/s^2)	23 cts/(m/s^2)	38 cts/(m/s^2)
4.000 Hz	23 cts/(m/s^2)	33 cts/(m/s^2)	56 cts/(m/s^2)
5.000 Hz	24 cts/(m/s^2)	30 cts/(m/s^2)	56 cts/(m/s^2)
6.329 Hz	23 cts/(m/s^2)	32 cts/(m/s^2)	59 cts/(m/s^2)
8.065 Hz	21 cts/(m/s^2)	33 cts/(m/s^2)	61 cts/(m/s^2)
10.000 Hz	14 cts/(m/s^2)	19 cts/(m/s^2)	72 cts/(m/s^2)
12.500 Hz	17 cts/(m/s^2)	37 cts/(m/s^2)	98 cts/(m/s^2)
16.129 Hz	48 cts/(m/s^2)	40 cts/(m/s^2)	221 cts/(m/s^2)
20.000 Hz	57 cts/(m/s^2)	75 cts/(m/s^2)	58 cts/(m/s^2)

The plots of acceleration observed for the InfraBSU sensors are omitted, as these sensors did not produce any signal with sufficiently high SNR to allow for measurement, except in the case of sensor #424, at 1.0 Hz and 1.25 Hz, as shown below. The measurements that were made indicate a very low level of response to acceleration for the InfraBSU sensor.

Table 117 Amplitude Response to Acceleration: InfraBSU Sensors, Orientation B

Frequency	InfraBSU #424
1.000 Hz	17.05 uV/(m/s^2)
1.250 Hz	10.97 uV/(m/s^2)

Figure 124 plots the calculated sensitivity to acceleration for the Raspberry Boom packages.

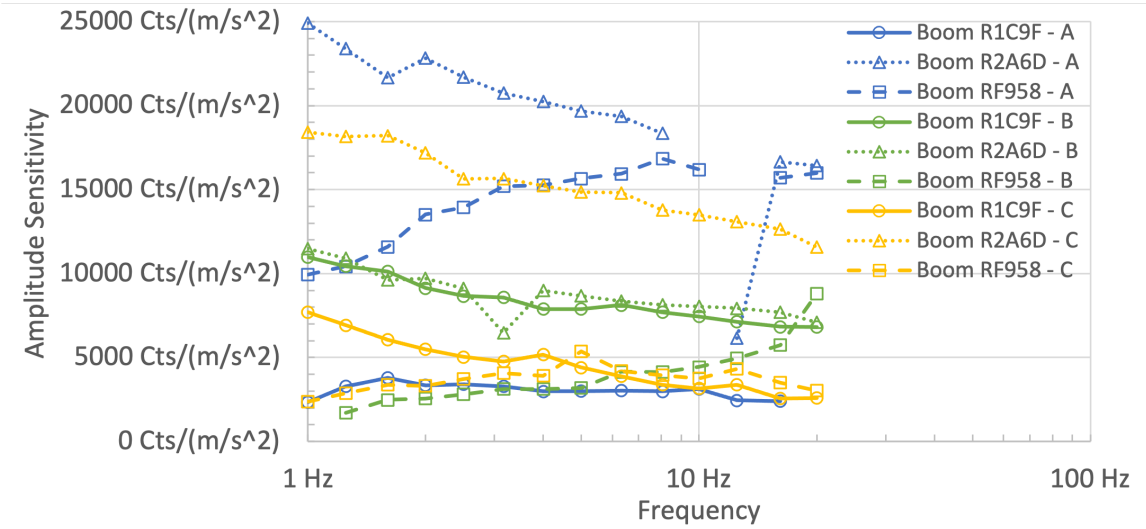

Figure 124 Amplitude Response to Acceleration: Raspberry Boom Packages

The Raspberry Boom packages show amplitude sensitivity to acceleration, though in each orientation at least one sensor shows significantly less sensitivity than the remaining two.

The following tables contains the values used to generate the above figure.

Table 118 Amplitude Response to Acceleration: Raspberry Booms, Orientation A

Frequency	R1C9F	R2A6D	RF958
1.000 Hz	2327 cts/(m/s^2)	24914 cts/(m/s^2)	9946 cts/(m/s^2)
1.250 Hz	3296 cts/(m/s^2)	23393 cts/(m/s^2)	10424 cts/(m/s^2)
1.603 Hz	3802 cts/(m/s^2)	21648 cts/(m/s^2)	11588 cts/(m/s^2)
2.000 Hz	3351 cts/(m/s^2)	22826 cts/(m/s^2)	13511 cts/(m/s^2)
2.500 Hz	3415 cts/(m/s^2)	21703 cts/(m/s^2)	13949 cts/(m/s^2)
3.165 Hz	3281 cts/(m/s^2)	20757 cts/(m/s^2)	15191 cts/(m/s^2)
4.000 Hz	2986 cts/(m/s^2)	20233 cts/(m/s^2)	15262 cts/(m/s^2)
5.000 Hz	2995 cts/(m/s^2)	19670 cts/(m/s^2)	15655 cts/(m/s^2)
6.329 Hz	3040 cts/(m/s^2)	19350 cts/(m/s^2)	15940 cts/(m/s^2)
8.065 Hz	2987 cts/(m/s^2)	18348 cts/(m/s^2)	16840 cts/(m/s^2)
10.000 Hz	3132 cts/(m/s^2)	-	16193 cts/(m/s^2)
12.500 Hz	2447 cts/(m/s^2)	6159 cts/(m/s^2)	-
16.129 Hz	2413 cts/(m/s^2)	16638 cts/(m/s^2)	15697 cts/(m/s^2)
20.000 Hz	-	16432 cts/(m/s^2)	15993 cts/(m/s^2)

Table 119 Amplitude Response to Acceleration: Raspberry Booms, Orientation B

Frequency	R1C9F	R2A6D	RF958
1.000 Hz	10978 cts/(m/s^2)	11479 cts/(m/s^2)	-
1.250 Hz	10441 cts/(m/s^2)	10911 cts/(m/s^2)	1713 cts/(m/s^2)
1.603 Hz	10132 cts/(m/s^2)	9617 cts/(m/s^2)	2482 cts/(m/s^2)
2.000 Hz	9132 cts/(m/s^2)	9703 cts/(m/s^2)	2555 cts/(m/s^2)
2.500 Hz	8656 cts/(m/s^2)	9108 cts/(m/s^2)	2806 cts/(m/s^2)
3.165 Hz	8575 cts/(m/s^2)	6477 cts/(m/s^2)	3126 cts/(m/s^2)
4.000 Hz	7891 cts/(m/s^2)	8984 cts/(m/s^2)	3130 cts/(m/s^2)
5.000 Hz	7877 cts/(m/s^2)	8675 cts/(m/s^2)	3187 cts/(m/s^2)
6.329 Hz	8123 cts/(m/s^2)	8355 cts/(m/s^2)	4150 cts/(m/s^2)
8.065 Hz	7690 cts/(m/s^2)	8128 cts/(m/s^2)	4125 cts/(m/s^2)
10.000 Hz	7455 cts/(m/s^2)	8052 cts/(m/s^2)	4436 cts/(m/s^2)
12.500 Hz	7129 cts/(m/s^2)	7934 cts/(m/s^2)	4965 cts/(m/s^2)
16.129 Hz	6831 cts/(m/s^2)	7703 cts/(m/s^2)	5748 cts/(m/s^2)
20.000 Hz	6830 cts/(m/s^2)	7088 cts/(m/s^2)	8809 cts/(m/s^2)

Table 120 Amplitude Response to Acceleration: Raspberry Booms, Orientation C

Frequency	R1C9F	R2A6D	RF958
1.000 Hz	7687 cts/(m/s^2)	18408 cts/(m/s^2)	2360 cts/(m/s^2)
1.250 Hz	6926 cts/(m/s^2)	18150 cts/(m/s^2)	2865 cts/(m/s^2)
1.603 Hz	6050 cts/(m/s^2)	18210 cts/(m/s^2)	3379 cts/(m/s^2)
2.000 Hz	5492 cts/(m/s^2)	17187 cts/(m/s^2)	3317 cts/(m/s^2)
2.500 Hz	5031 cts/(m/s^2)	15634 cts/(m/s^2)	3734 cts/(m/s^2)
3.165 Hz	4766 cts/(m/s^2)	15656 cts/(m/s^2)	4081 cts/(m/s^2)
4.000 Hz	5181 cts/(m/s^2)	15222 cts/(m/s^2)	3920 cts/(m/s^2)
5.000 Hz	4404 cts/(m/s^2)	14852 cts/(m/s^2)	5371 cts/(m/s^2)
6.329 Hz	3878 cts/(m/s^2)	14806 cts/(m/s^2)	4201 cts/(m/s^2)
8.065 Hz	3391 cts/(m/s^2)	13768 cts/(m/s^2)	3937 cts/(m/s^2)
10.000 Hz	3152 cts/(m/s^2)	13491 cts/(m/s^2)	3748 cts/(m/s^2)
12.500 Hz	3378 cts/(m/s^2)	13086 cts/(m/s^2)	4327 cts/(m/s^2)
16.129 Hz	2574 cts/(m/s^2)	12655 cts/(m/s^2)	3513 cts/(m/s^2)
20.000 Hz	2602 cts/(m/s^2)	11566 cts/(m/s^2)	3029 cts/(m/s^2)

The plot below plots sensitivity to acceleration of the Samsung S10 smartphones.

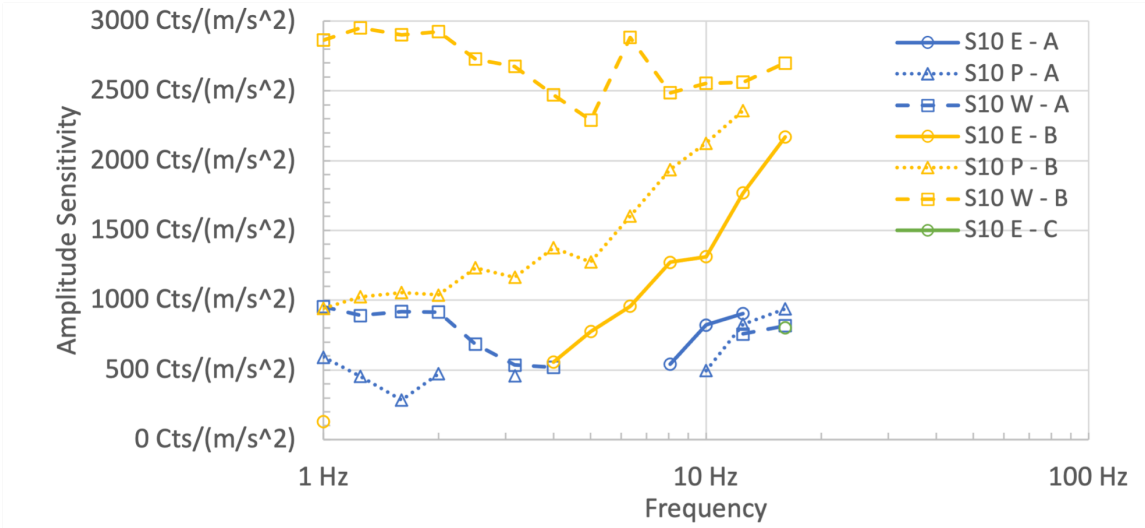

Figure 125 Amplitude Response to Acceleration: S10 Packages

The Samsung S10 smartphone shows varying levels of sensitivity to acceleration. The B orientation shows a clear trend of having the highest sensitivity for each sensor, relative to measurements made in orientation A. It was not possible to measure a response to acceleration in orientation C.

The following tables contains the values used to generate the above figure.

Samsung S10 E is the only unit to show any sensitivity to acceleration while in orientation C of 801 counts/(m/s^2) at 16.129 Hz. No table is provided for the C orientation sensitivity.

Table 121 Amplitude Response to Vertical Acceleration: S10 Package, Orientation A

Frequency	S10 E	S10 P	S10 W
1.000 Hz	-	591 cts/(m/s^2)	955 cts/(m/s^2)
1.250 Hz	-	454 cts/(m/s^2)	890 cts/(m/s^2)
1.603 Hz	-	283 cts/(m/s^2)	919 cts/(m/s^2)
2.000 Hz	-	473 cts/(m/s^2)	914 cts/(m/s^2)
2.500 Hz	-	-	685 cts/(m/s^2)
3.165 Hz	-	457 cts/(m/s^2)	535 cts/(m/s^2)
4.000 Hz	-	-	518 cts/(m/s^2)
5.000 Hz	-	-	-
6.329 Hz	-	-	-
8.065 Hz	541 cts/(m/s^2)	-	-
10.000 Hz	822 cts/(m/s^2)	495 cts/(m/s^2)	-
12.500 Hz	905 cts/(m/s^2)	829 cts/(m/s^2)	758 cts/(m/s^2)
16.129 Hz	-	938 cts/(m/s^2)	815 cts/(m/s^2)
20.000 Hz	-	-	-

Table 122 Amplitude Response to Side Acceleration: S10 Packages, Orientation B

Frequency	S10 E	S10 P	S10 W
1.000 Hz	129 cts/(m/s^2)	943 cts/(m/s^2)	2865 cts/(m/s^2)
1.250 Hz	-	1024 cts/(m/s^2)	2952 cts/(m/s^2)
1.603 Hz	-	1055 cts/(m/s^2)	2902 cts/(m/s^2)
2.000 Hz	-	1037 cts/(m/s^2)	2925 cts/(m/s^2)
2.500 Hz	-	1232 cts/(m/s^2)	2727 cts/(m/s^2)
3.165 Hz	-	1165 cts/(m/s^2)	2674 cts/(m/s^2)
4.000 Hz	556 cts/(m/s^2)	1376 cts/(m/s^2)	2470 cts/(m/s^2)
5.000 Hz	774 cts/(m/s^2)	1273 cts/(m/s^2)	2292 cts/(m/s^2)
6.329 Hz	955 cts/(m/s^2)	1602 cts/(m/s^2)	2882 cts/(m/s^2)
8.065 Hz	1271 cts/(m/s^2)	1937 cts/(m/s^2)	2485 cts/(m/s^2)
10.000 Hz	1312 cts/(m/s^2)	2125 cts/(m/s^2)	2554 cts/(m/s^2)
12.500 Hz	1768 cts/(m/s^2)	2357 cts/(m/s^2)	2562 cts/(m/s^2)
16.129 Hz	2170 cts/(m/s^2)	-	2700 cts/(m/s^2)
20.000 Hz	-	-	-

With the exception of the InfraBSU sensors, each sensor type was observed to have a level of sensitivity to acceleration along multiple axes. Gem #070 was observed to have a consistently higher sensitivity to acceleration in orientation B. The InfraBSU sensor was observed to be the least affected by acceleration. In general, response to acceleration in infrasound sensors is typically a function of the mass and orientation of the transducer used to measure pressure.

4 SUMMARY

Power Consumption
The sensor only units, the Camas microphones and InfraBSU sensors, consumed the least power, ranging as low as 2.8 mW for camas #1 to as much as 22.2 mW for InfraBSU #400. The integrated packages drew significantly more power, as expected, where the Gem #069 drew as little as 141.8 mW. The Raspberry Boom R1C9F consumed as much as 1.84 W, slightly less than the quoted 1.9 W.

Sensitivity
The Camas microphone amplitude and phase sensitivities were observed to have widely varying amplitude sensitivities, at both 0.25 Hz and 1 Hz, indicating that these measurements were not within the flat portion of their passband. The InfraBSU sensors and Gem packages, on the other hand, were observed to have very consistent amplitude and phase sensitivities at both 0.25 Hz and 1 Hz. The Raspberry Boom packages exhibited a large variation in sensitivities, even if discounting the observations of unit RF958. The Samsung S10 units also appear have much of their passbands above 1 Hz given the more than order of magnitude difference between the observed 0.25 Hz and 1 Hz amplitude sensitivities.

Sensitivity vs Input Amplitude in Isolation Chamber
The Camas microphones exhibited variations in amplitude sensitivity due to the input amplitude of approximately 2% and minimal changes in phase. The InfraBSU, Gem, Raspberry Boom, and S10 sensors all exhibited minimal change in amplitude sensitivity. Observed phase sensitivities for the InfraBSU were similarly consistent across the amplitude range evaluated as well. The Gem and Raspberry Boom infrasound packages, each of which utilize an internal digitizer to record signals, showed variations in phase sensitivities, which may be due to their relative digitizer timing.

Sensitivity vs input Amplitude in External Calibrator
The Camas microphones were observed to exhibit up to a 6% change in amplitude sensitivity and less than 1 degree of relative difference in phase at dynamic pressures of up to 75 Pa. The InfraBSU sensors relative change in amplitude sensitivity varied little, less than 0.1%, while the relative difference in phase of these sensors remained within 0.25 degrees of the baseline measurement. Gem package #070 was observed to have less than 0.5% relative change in amplitude sensitivity up to the 98 Pa input pressure evaluated, while its relative difference in phase did not exceed 4 degrees. The Raspberry Boom packages, discounting the performance of one outlier sensor, exhibited relative change in amplitude sensitivity and relative difference in phase of no more than 0.5% and 6 degrees, respectively. Finally, the Samsung S10 packages provided a relative change in amplitude sensitivity that did not exceed 2%.

Self-Noise and Dynamic Range
The InfraBSU sensors provided a consistent 0.023 Pa rms to 0.024 Pa rms self-noise over 0.02 Hz to 4 Hz across the three sensors evaluated. The Gem #070, over the same frequencies, exhibited a self-noise of 0.062 Pa rms. The two Raspberry Booms evaluated have self-noise values ranging from as low as 0.026 Pa rms to as high as 0.054 Pa rms over the same frequency band. The Samsung S10 smartphones were observed to have self-noise ranging from 1.95 Pa

rms to 2.21 Pa rms. Given the narrow range of frequencies the Samsung S10 has exhibited response in this evaluation self-noise is provided over the 0.158 Hz to 15.8 Hz frequency range. The InfraBSU sensors and Raspberry Boom packages have between 71.55 dB and 71.91 dB, and 64.57 dB and 70.53 dB, respectively, of dynamic range over 0.02 Hz to 4 Hz band.

Frequency Response and Passband

The Camas microphone clearly has a frequency passband with minimal overlap with the evaluated range of 0.01 Hz to 20 Hz. Amplitude response varied significantly between all three units by as much as 38%. The InfraBSU sensor and Gem package were observed to have much more consistent responses with minimal differences between units. The InfraBSU sensors have a frequency passband ranging from 0.02 Hz to beyond 20 Hz. The Gem sensors have a frequency passband ranging from 0.033 Hz to beyond 20 Hz. The Raspberry Boom packages varied significantly in amplitude and phase responses across all units. The two Raspberry Boom sensors that were most similar have a low frequency corner of between 0.09 Hz and 0.19 Hz and all three sensors' passbands extended beyond 20 Hz. Finally, the response observed of the Samsung S10 packages clearly illustrates much of their passband is above the evaluated range of 0.01 Hz to 20 Hz

Static Temperature Response Variation

The Camas microphones demonstrated a significant shift in their low frequency corner at colder temperatures below -5 C and less variation at hotter temperatures. Similarly, changes in phase generally only occurred at colder temperatures below 23 C. The InfraBSU sensors exhibited reasonably minimal relative changes in amplitude and phase response as a function of temperature, with only changes in overall sensitivity of a few percent across -35 C to 50 C. The Gem and Raspberry Boom sensors showed similar level of minimal change in amplitude response with temperature. However, variability in the phase response at high frequency in the Gem and Raspberry Boom was observed that was likely due to each platform having an independent recording system with variable timing accuracy. Finally, the Samsung S10 smartphone exhibited a significant shift in its low frequency corner at higher temperatures, above 23 C, that would make it less able to measure low frequency signals at those higher temperatures.

Static Pressure Sensitivity Variation

The Camas microphones demonstrated an overall increase in amplitude response at lower static pressure levels, over the range of 600 to 1000 hPa evaluated. Changes in its phase response were more mixed with a slight decrease in phase response at lower static pressure levels. The InfraBSU sensor had minimal changes in its response, above 0.1 Hz in amplitude and 0.5 Hz in phase. However, below these frequencies there was evidence of a shift in the low frequency corner of its passband due to static pressure. The Gem and Raspberry Boom both exhibited similar changes in the low frequency corner of their amplitude response. Changes in phase response above 1 Hz in the Gem and Raspberry Boom were difficult to determine due to variability likely due to their integrated recording system. Finally, the Samsung S10 appeared to have an overall shift it is amplitude response, by as much as 40% at 600 hPa compared that of the response at 1000 hPa.

Response to Vertical Acceleration

The InfraBSU sensors had a very low level of response to acceleration that, for the most part, could not be measured. The Camas, Gem, and S10 sensors had minimal response to acceleration and the Raspberry Boom had the most response to acceleration. In general, response to acceleration in infrasound sensors is typically a function of the mass and orientation of the transducer used to measure pressure.

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APPENDEX A: TESTBED CALIBRATIONS

Guralp Affinity #405A5B Bit weights

The Guralp Affinity #405A5B used for data collected was calibrated against a reference meter Agilent 3458A serial number MY45048371 just prior to use in the data collection for this test. The digitizer bit weights were calculated use a stable positive and negative DC Source, simultaneously recorded on both the digitizer and Agilent meter. The bit weights used in this test were determined to be as listed below.

Table 123 Guralp Affinity #405A5B Channel bit weights

Digitizer Channel	Bitweights
Channel 1	1.00007 uV/cnt
Channel 2	1.00006 uV/cnt
Channel 3	1.00005 uV/cnt
Channel 4	1.00016 uV/cnt
Channel 5	1.00016 uV/cnt
Channel 6	1.00016 uV/cnt
Channel 7	1.00006 uV/cnt
Channel 8	1.00016 uV/cnt

B&K 4193 #2812287 Response

The response model for the reference B&K 4193, #2812287 was determined from a calibration by LNE on February 28, 2020 over the 0.01 to 20 Hz passband.

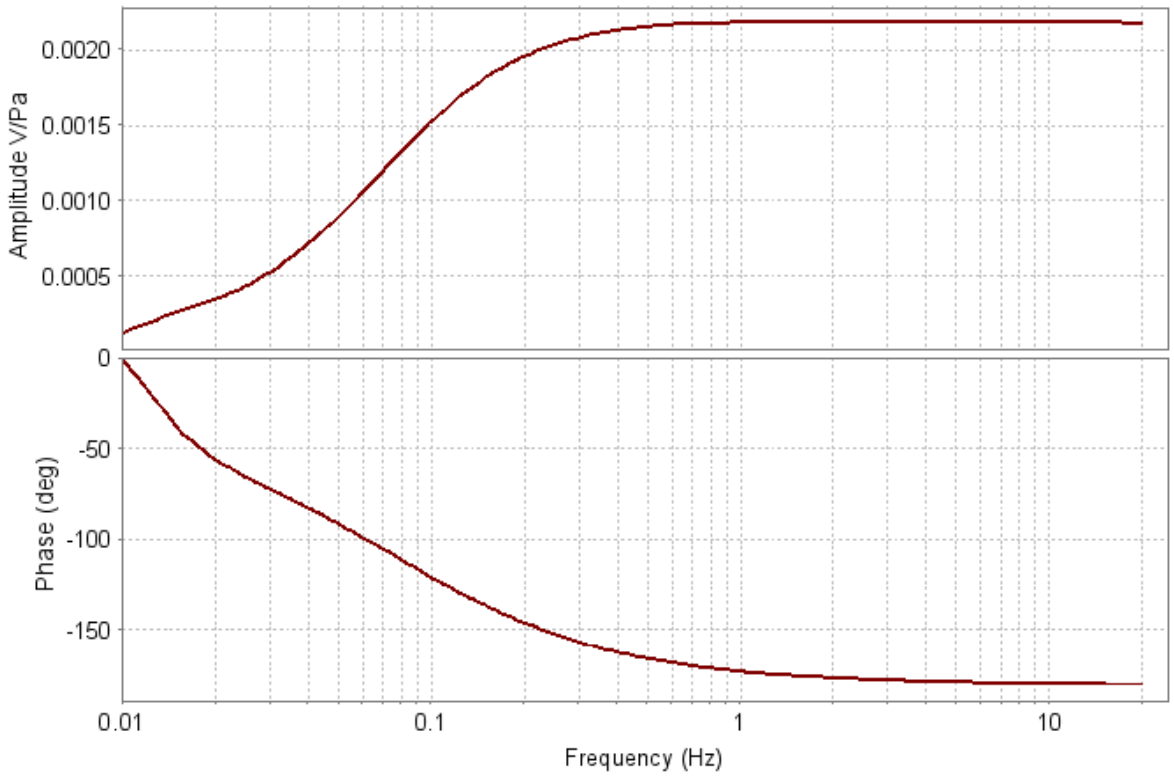

Figure 126 B&K 4193 #2812287 Response

The sensitivity of the B&K 4193 was calibrated and determined to be 2.153 mV/Pa at 1 Hz under conditions of 23 C and 977.6 hPa.

Setra 278 #6937528 Calibration

The Setra 278 #6937528 pressure sensor was calibrated by SNL's PSL at DC over 500 to 1000 hPa on August 11, 2020 and found to have a sensitivity of 0.0833997 mV/Pa and offset of 499.712 hPa with an uncertainty of 0.6%.

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