Evaluation of Lower Cost Infrasound Sensors and Sensor Packages

George Slad, John Merchant and Danny Bowman, Sandia National Laboratories

Jeremy Webster, Los Alamos National Laboratory

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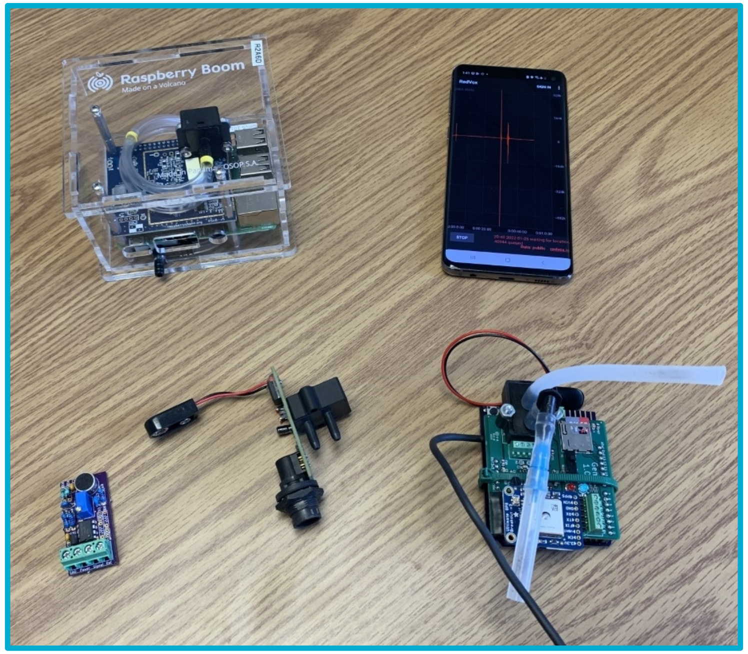
What we evaluated: a diverse group of low-cost sensors/packages

Why? *Researchers in the monitoring community are utilizing these sensors to conduct scientific research.*

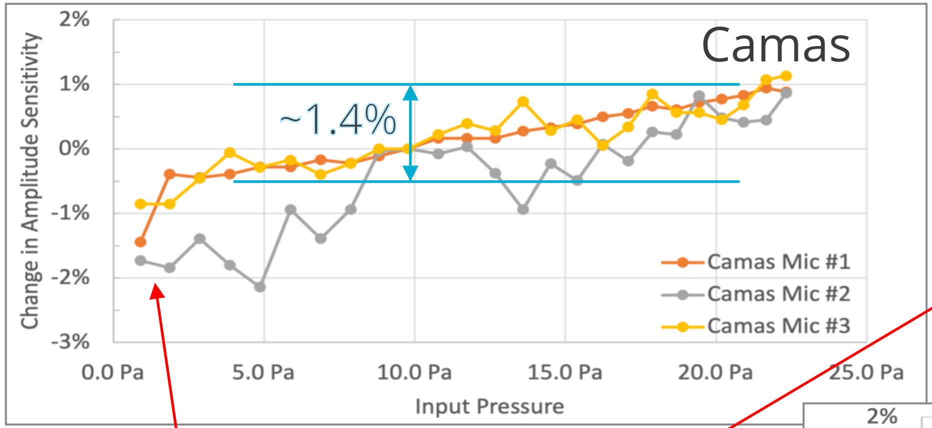
- Samsung S10 running Redvox
- Raspberry Boom Package
- Camas Microphone
- InfraBSU Sensor
- Gem Infrasound Logger

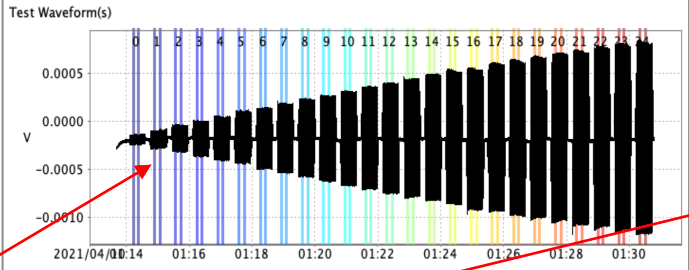


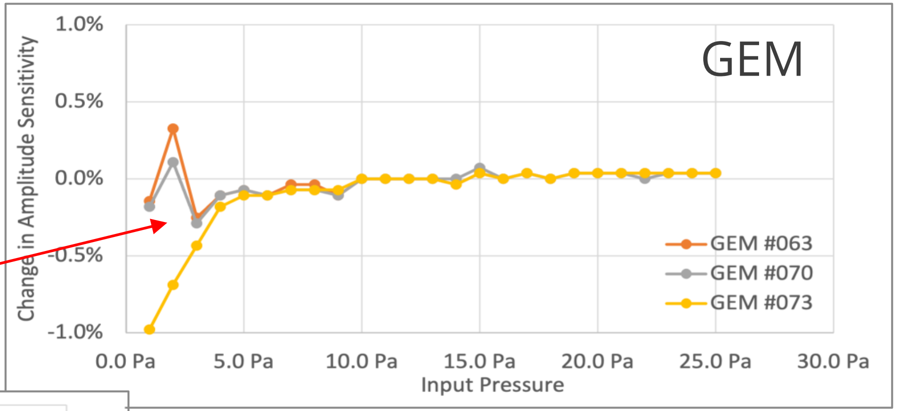
Evaluated:

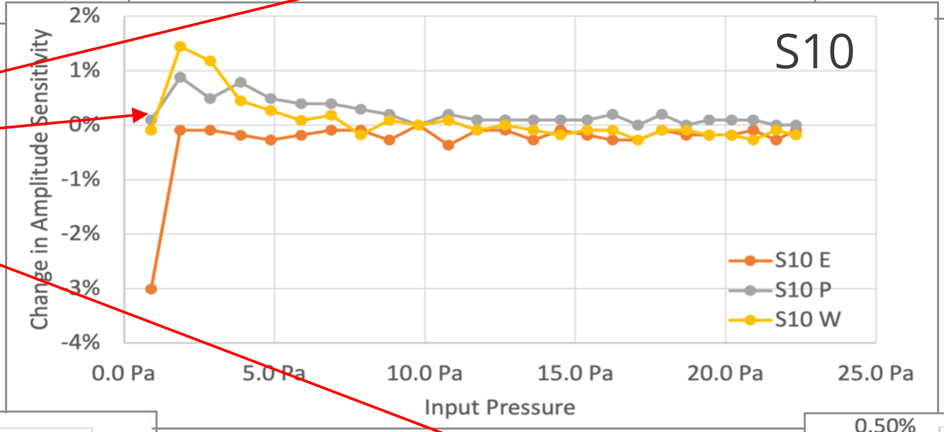
- Sensitivity, 1 Hz and 0.25 Hz
- Sensitivity vs input amplitude
- Self noise
- Dynamic range
- Frequency Response
- Pass-band
- Static Pressure Response Variation
- Static Temperature Response Variation
- Response to Vertical Acceleration

Change in Amplitude Sensitivity vs Input Amplitude (1 Hz)

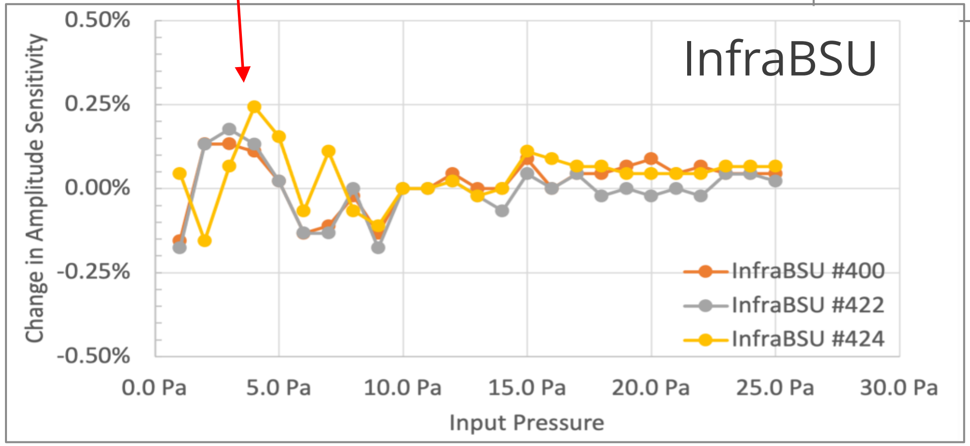






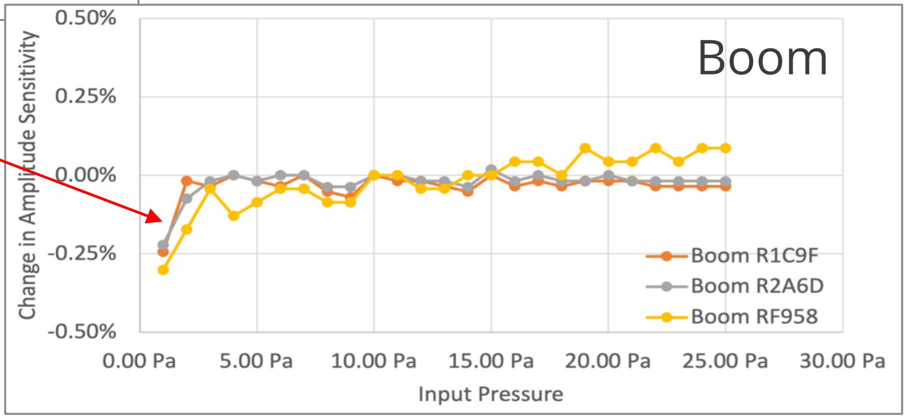


Variability due to Low SNR

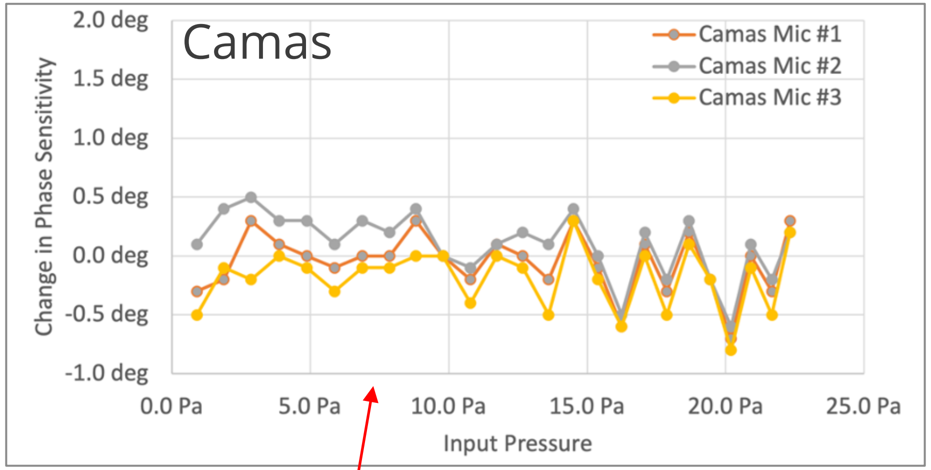


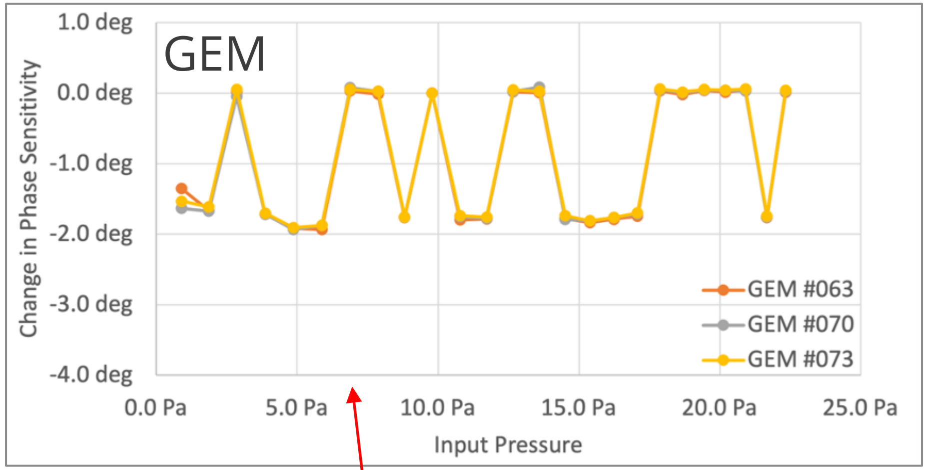
% change relative to sensitivity at ~10 Pa

Estimated relative uncertainty 0.3%



Change in Phase Sensitivity vs Input Amplitude (1 Hz)

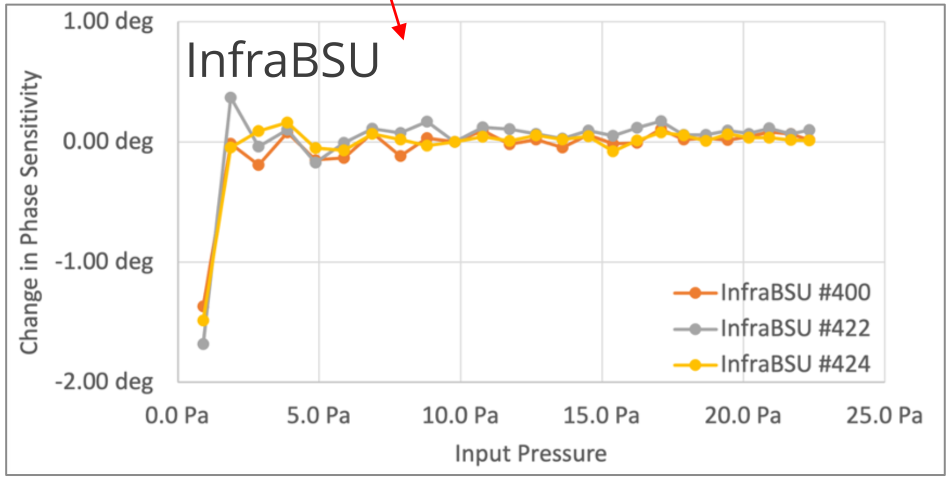


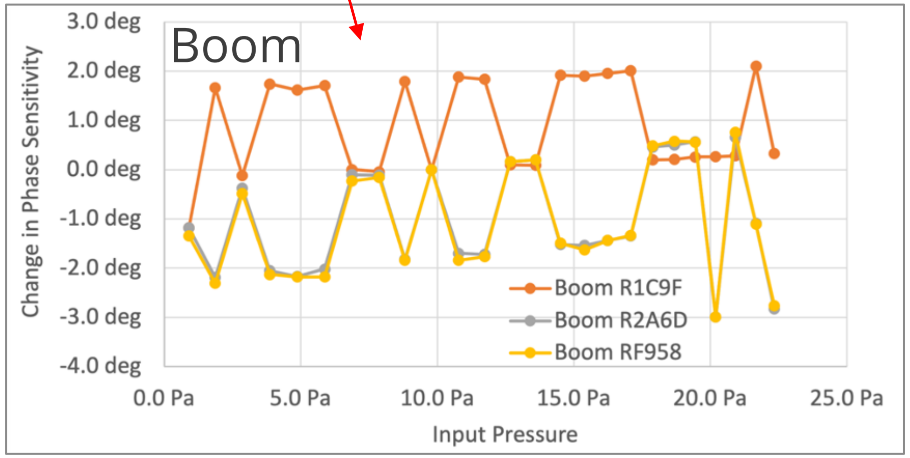


Utilizing chamber testbed reference digitizer

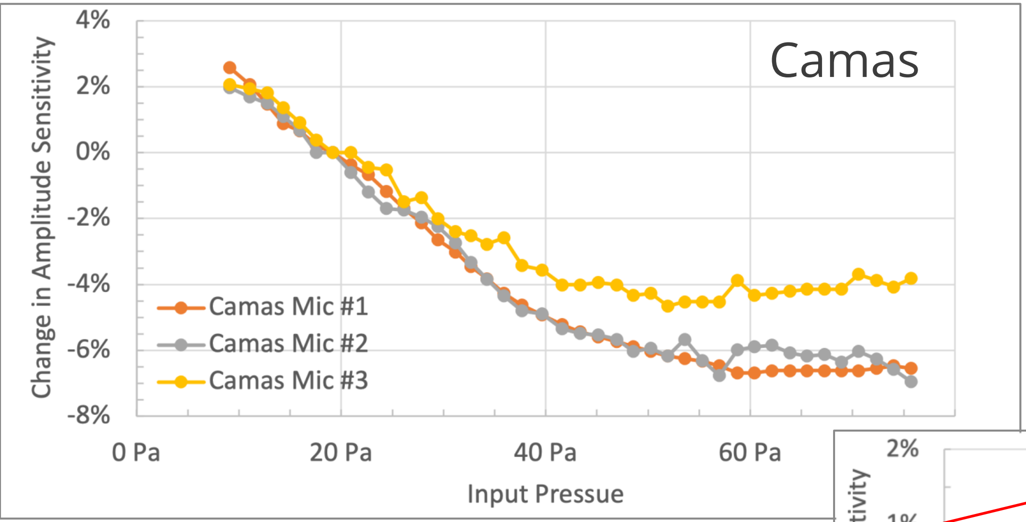
Estimated uncertainty 0.32 degrees

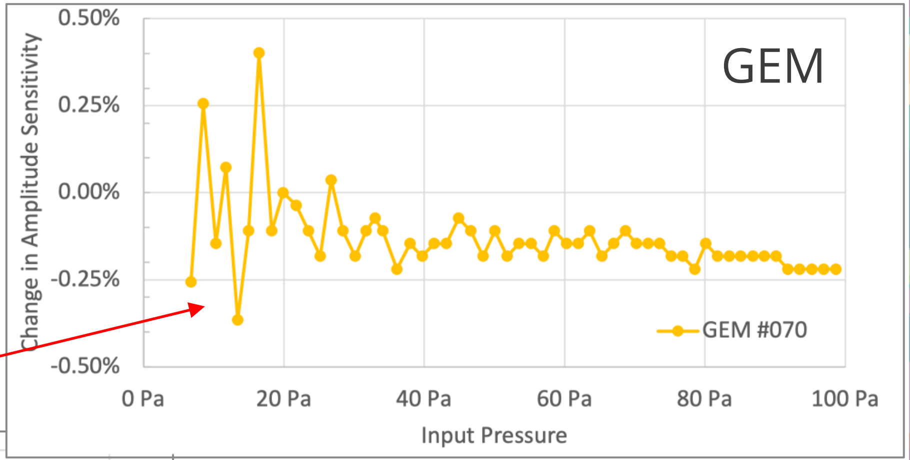
Variability possibly due to digitizer timing of sensor/digitizer package





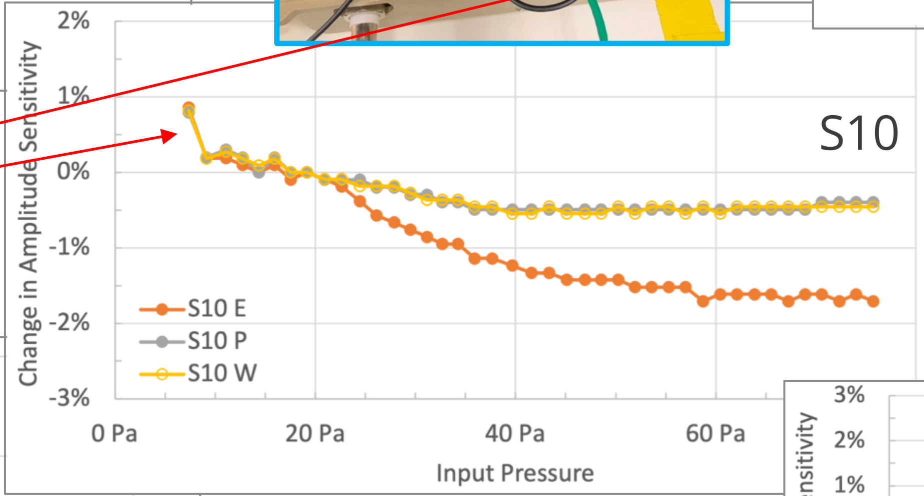
Relative Change in Amplitude Sensitivity vs Input Amplitude (1 Hz)



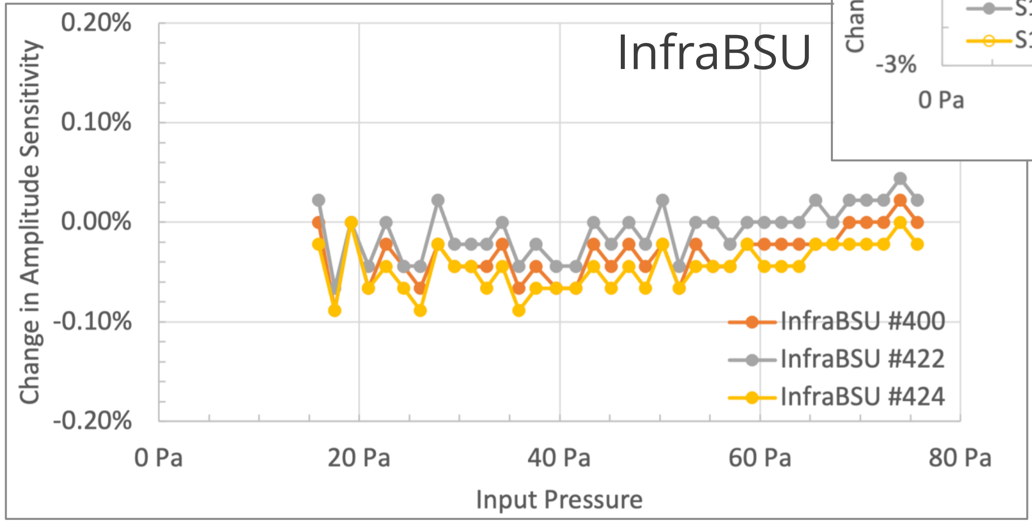


GEM 063 and 073 failed

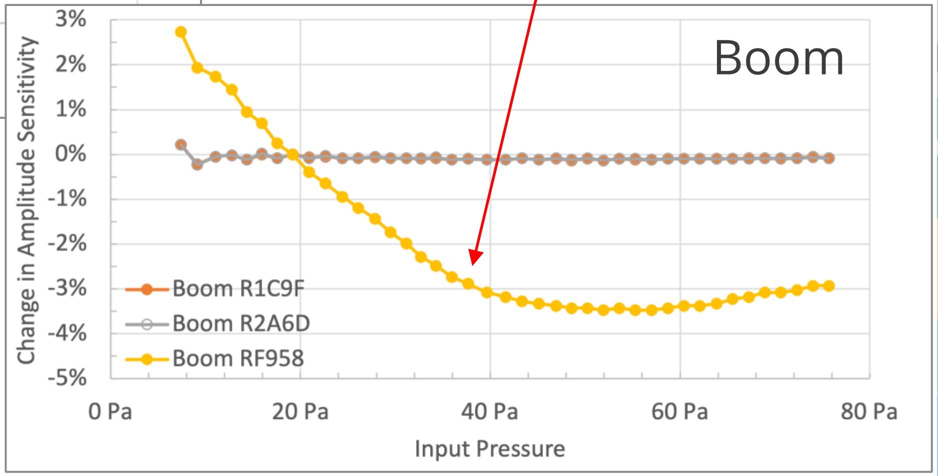
Variability due to low SNR



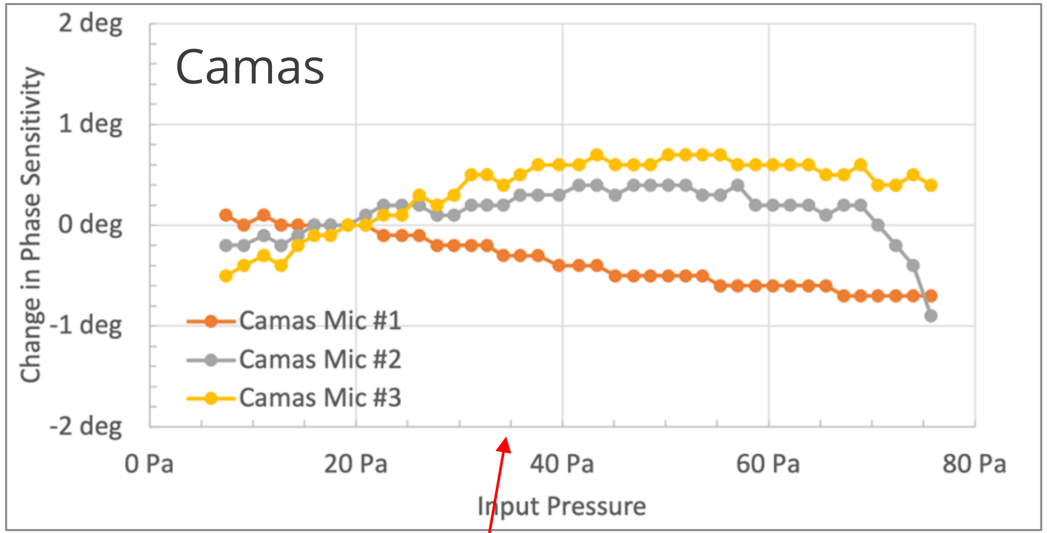
RF958 anomalous behavior

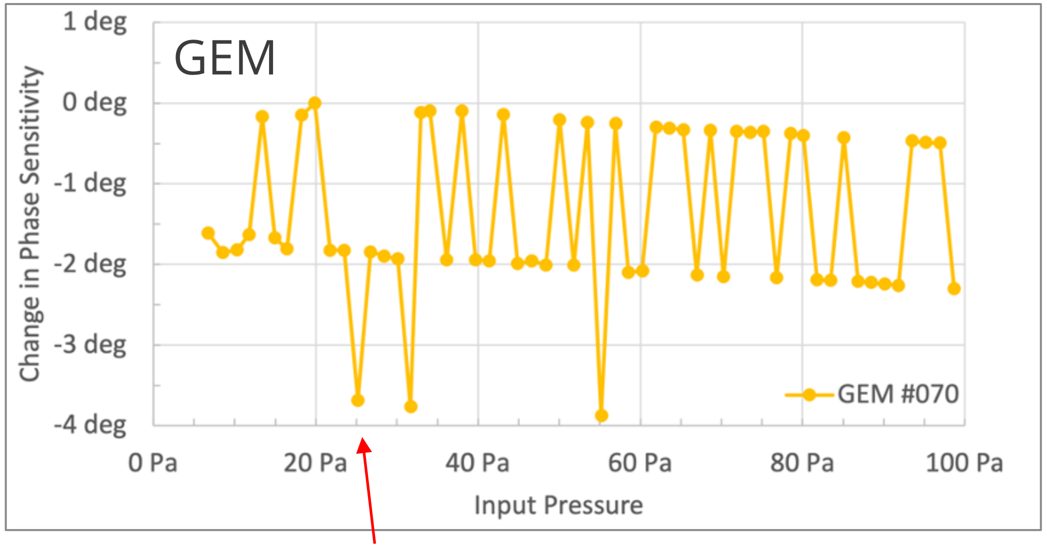


% change relative to sensitivity at ~20 Pa



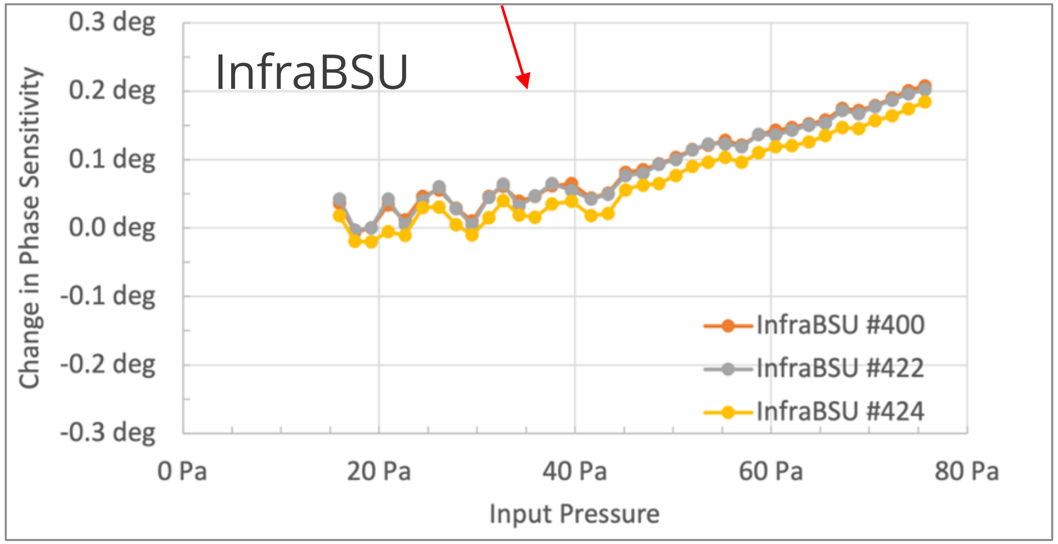
Relative Change in Phase Sensitivity vs Input Amplitude (1Hz)

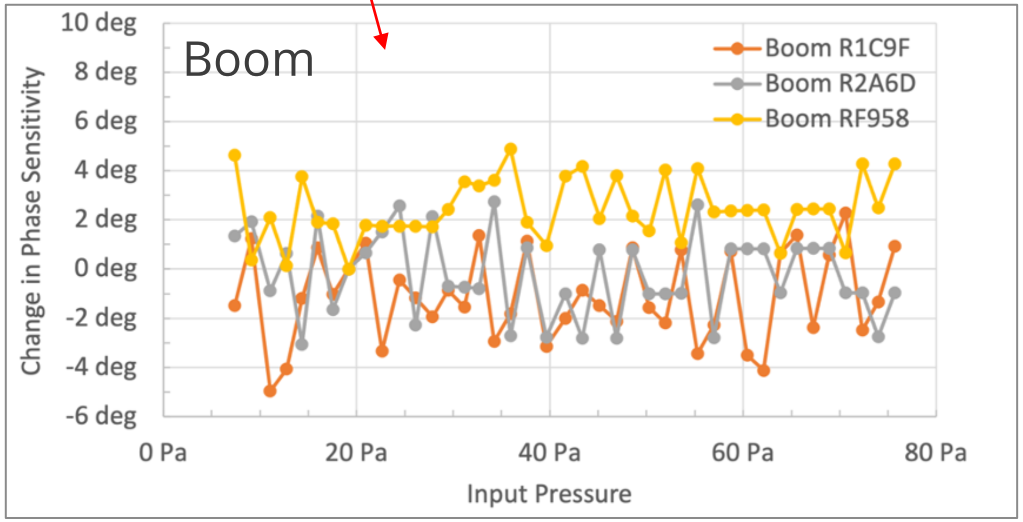




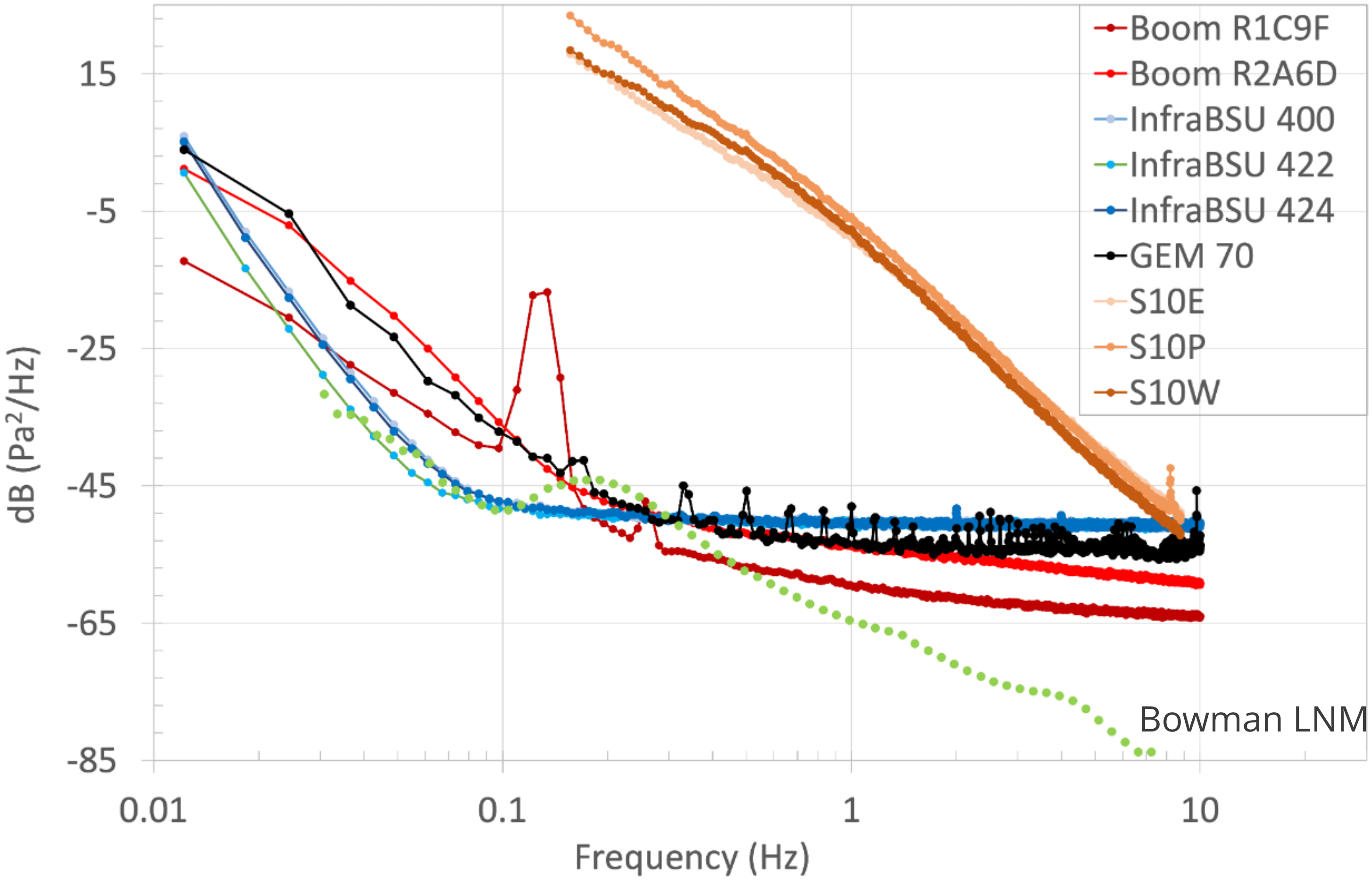
Utilizing chamber testbed reference digitizer

Variability possibly due to digitizer timing of sensor/digitizer package





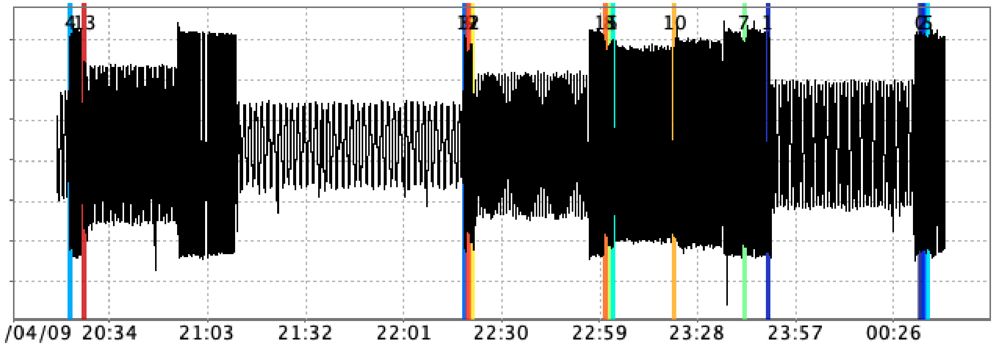
Self Noise and Dynamic Range

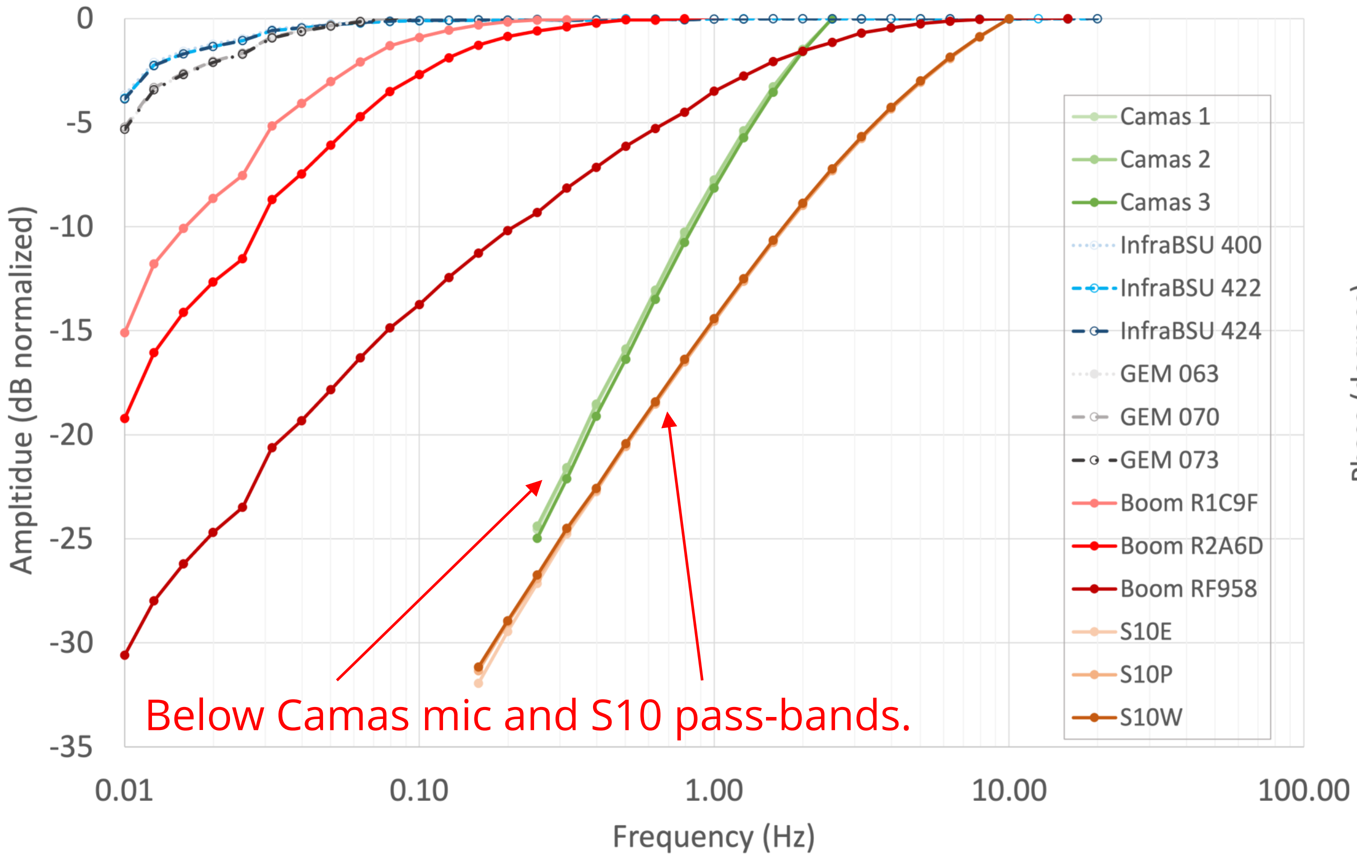


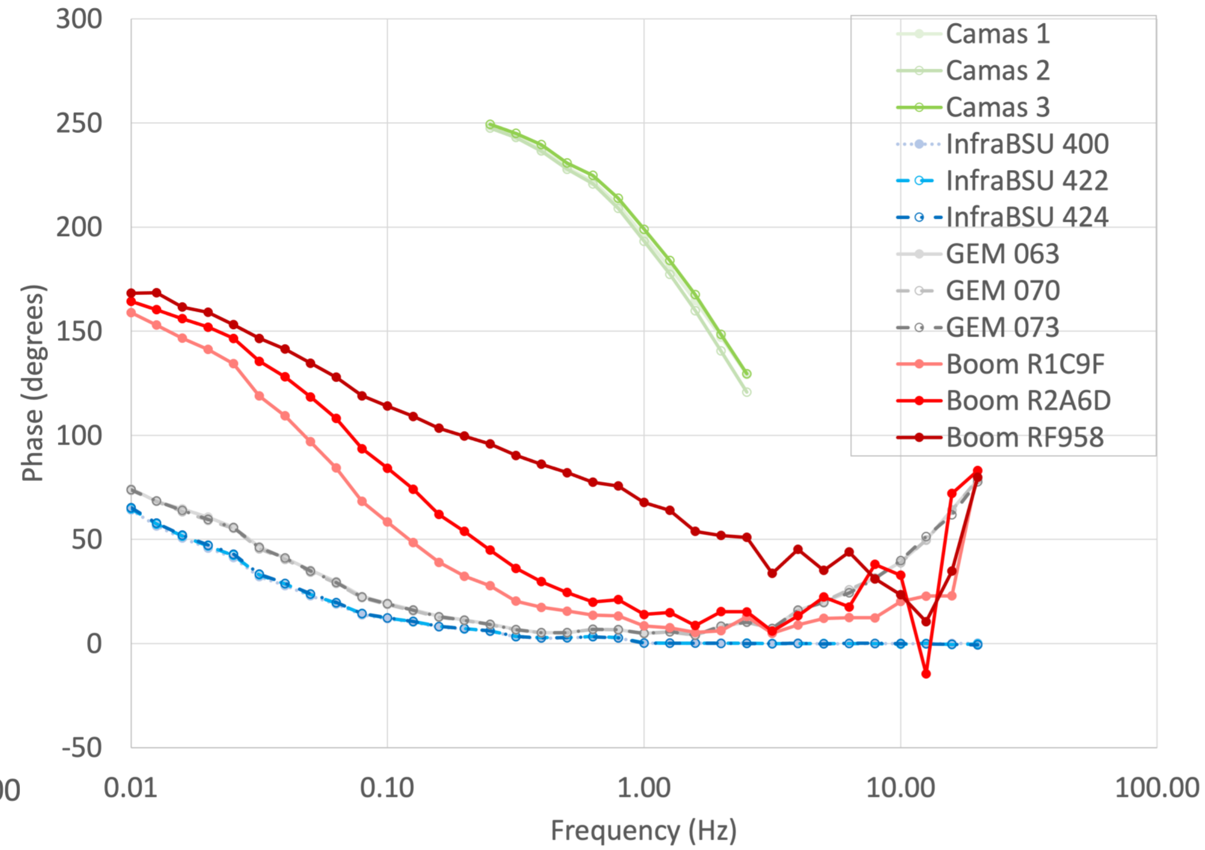
Sensor	Linear full scale	Self Noise 20 mHz – 4 Hz	Dynamic Range 20 mHz - 4 Hz
InfraBSU #400	124.5 Pa	0.014 Pa rms	75.72 dB
InfraBSU #422	124.5 Pa	0.009 Pa rms	79.54 dB
InfraBSU #424	124.5 Pa	0.013 Pa rms	76.41 dB
GEM #70	N/A	0.062 Pa rms	N/A
Boom R1C9F	125 Pa	0.026 Pa rms	70.53 dB
Boom R2A6D	125 Pa	0.054 Pa rms	64.57 dB

- S10 is well outside of its pass-band
- Troubles with Camas limited ability to collect self-noise data

Amplitude and Phase Response (1000 hPa)

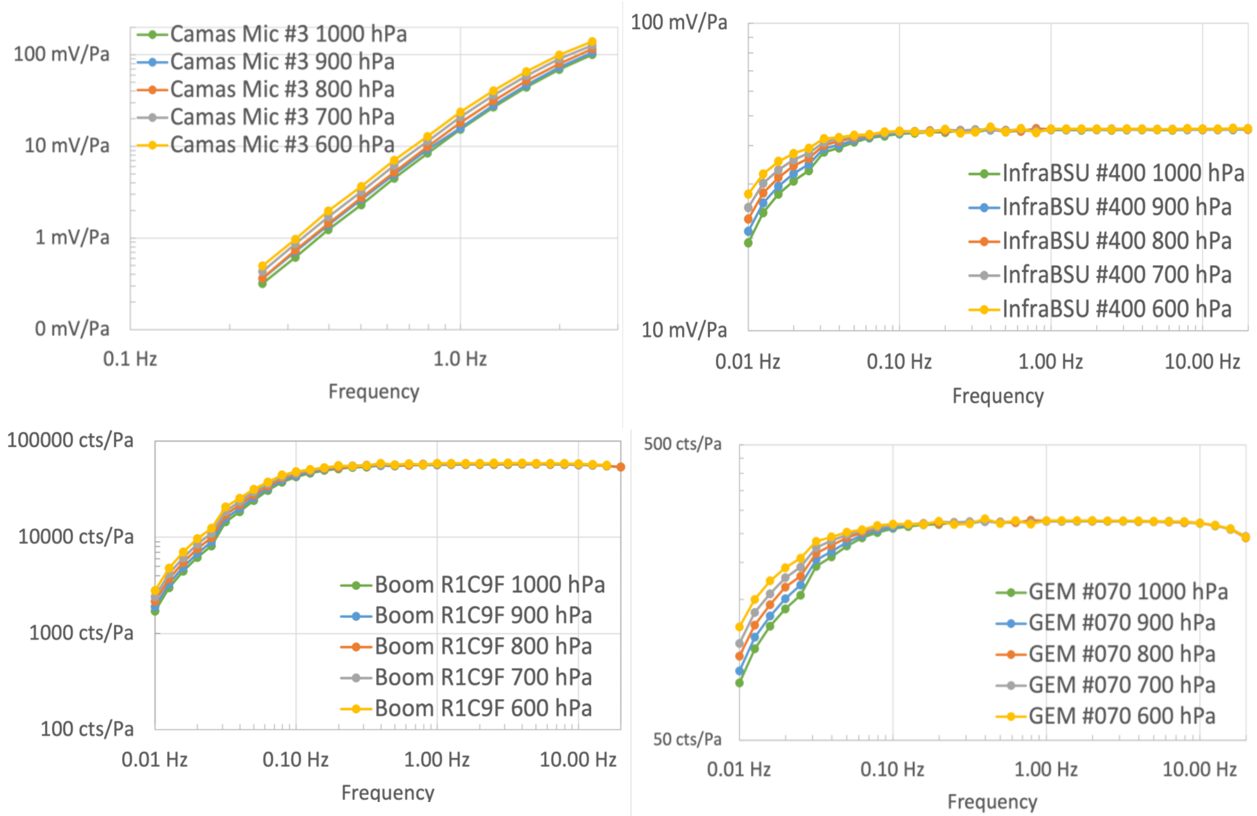


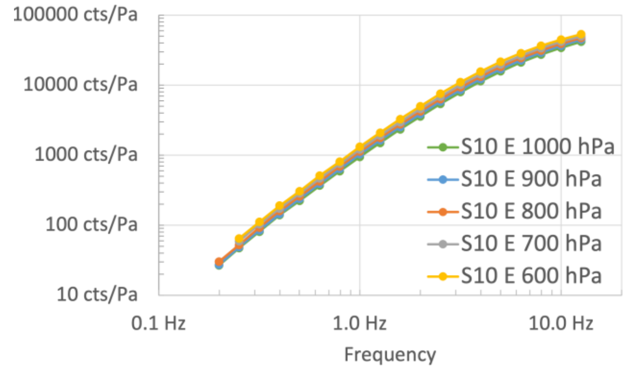




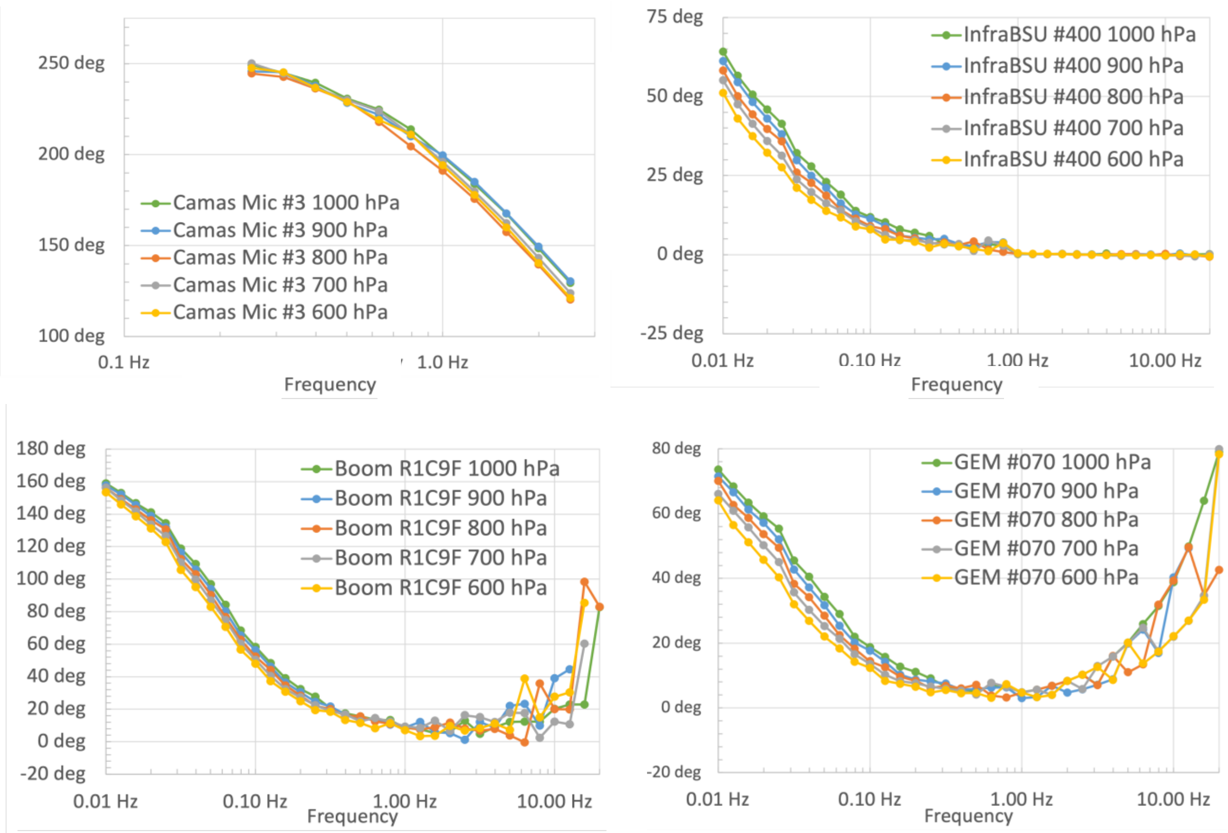
Response over Select Ambient Pressures

Amplitude Sensitivity





Phase Sensitivity

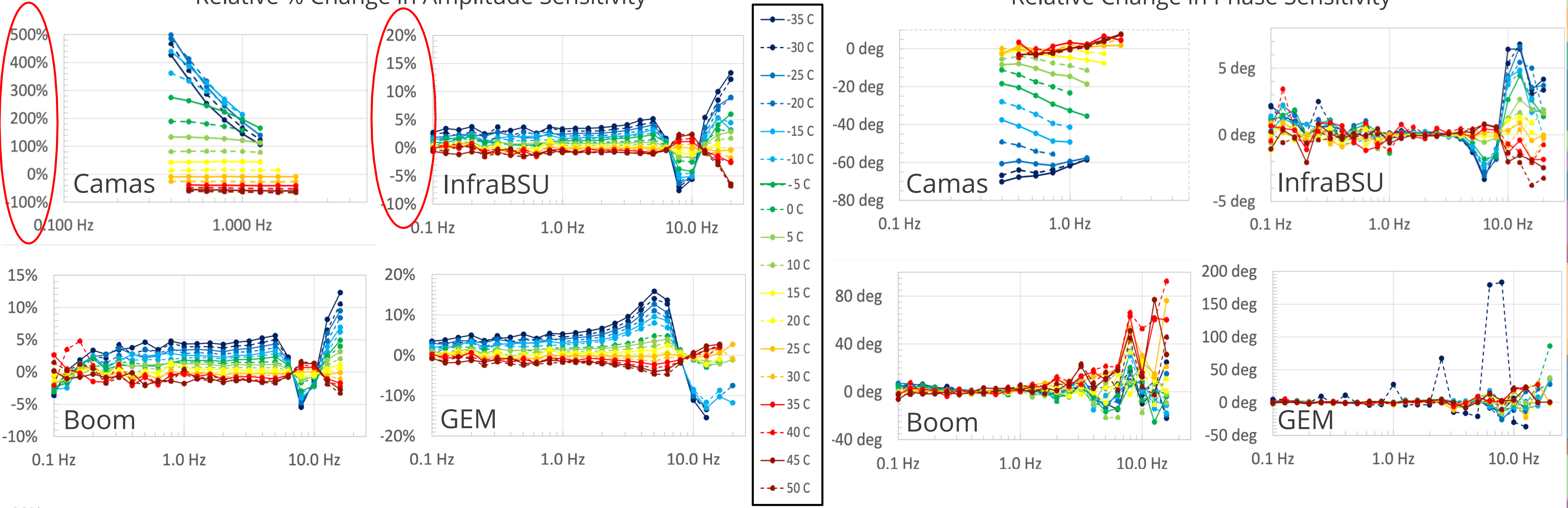


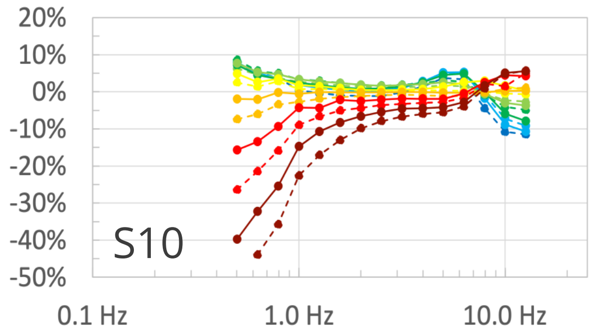
- Low corner frequency shifts as pressure drops
- Amplitude in passband relatively stable
- Phase shift at lower frequencies

Relative Response Change at Select Ambient Temperatures

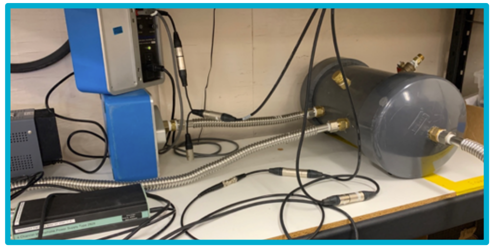
Relative % Change in Amplitude Sensitivity

Relative Change in Phase Sensitivity

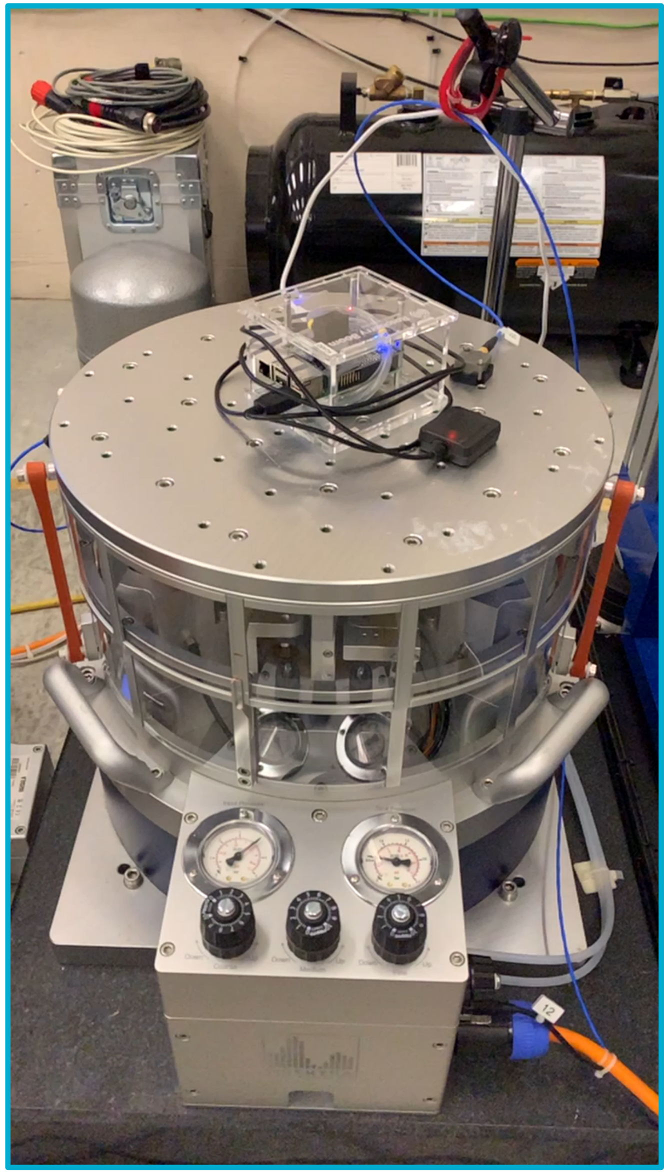


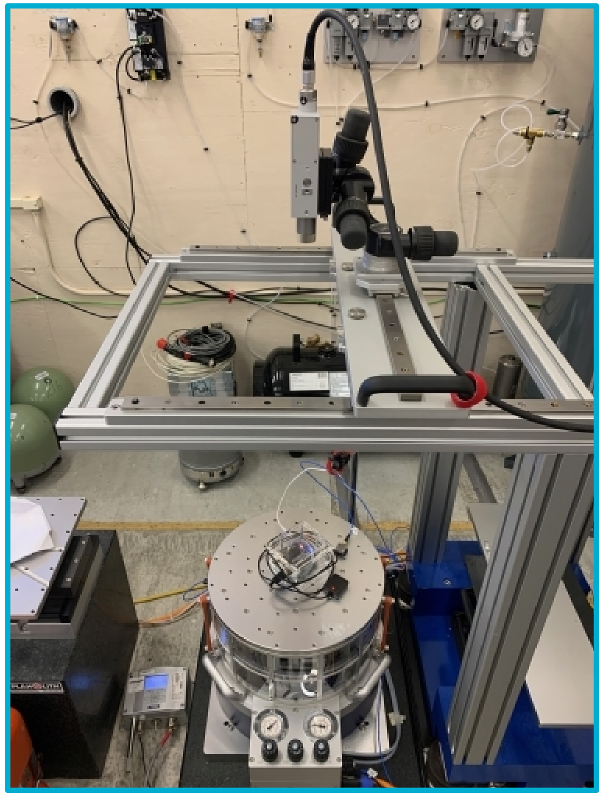


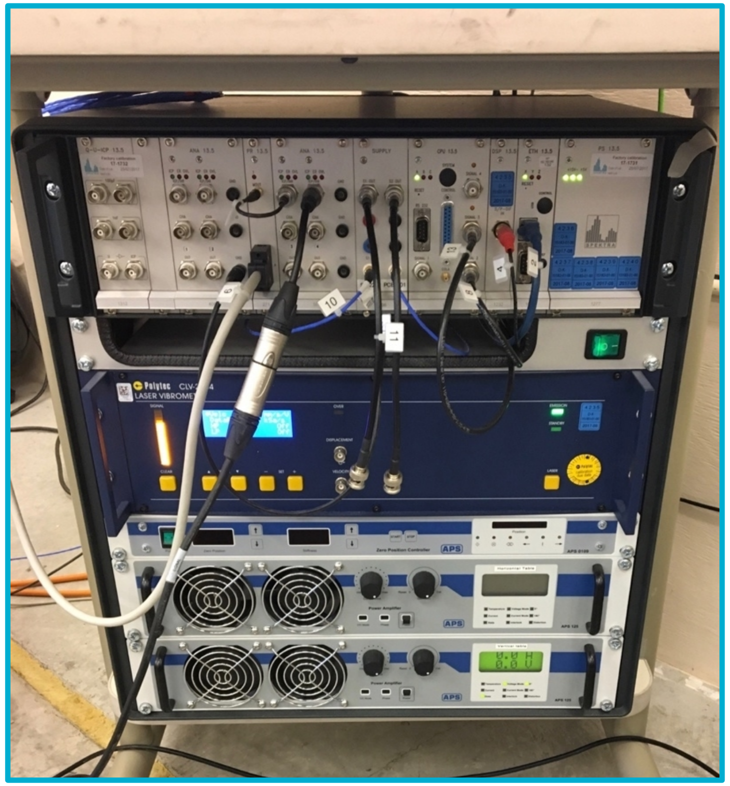
- Y axes are NOT set to a uniform scale!
- < 8 Hz trend is for increasing amplitude response
- > 8 Hz trends diverge, as temperature increases InfraBSU and Boom lose amplitude response, GEM gains



Sensitivity to Acceleration

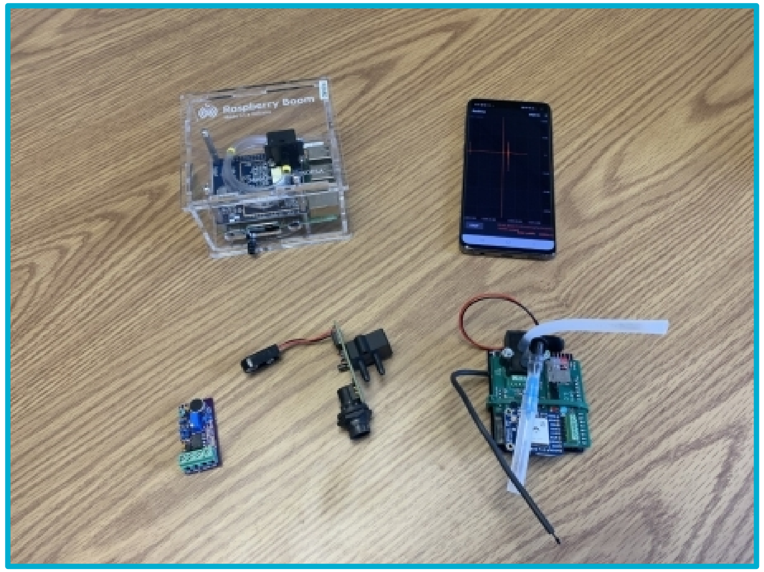






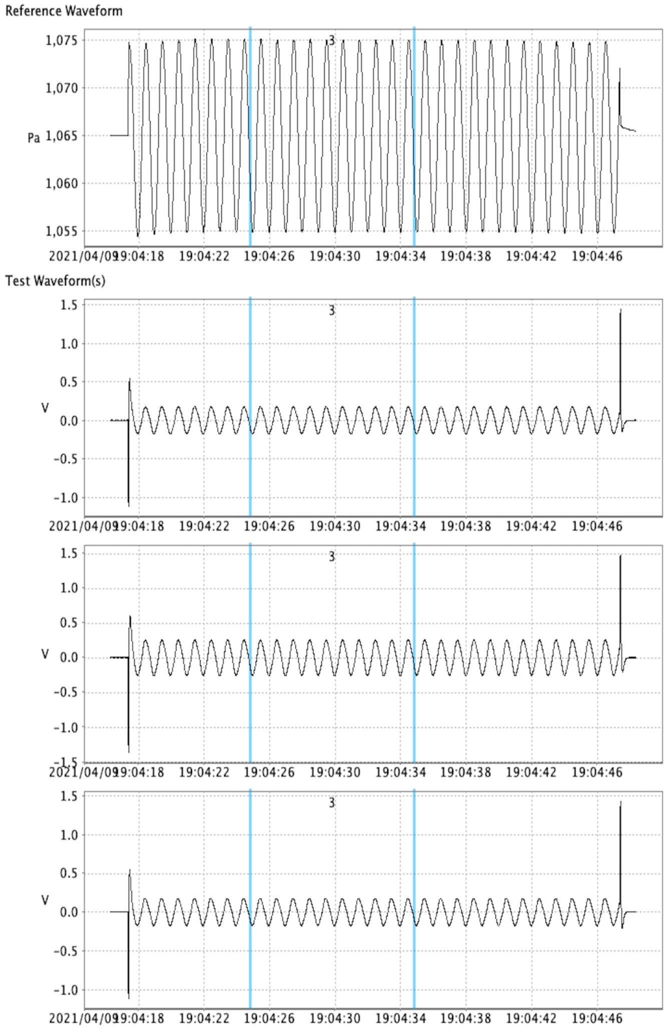
- Units accelerated along each of their three axes.
- No significant sensitivity to acceleration observed.
- Consistent with a transducer/membrane with low mass.

Conclusions



- Between 0 Pa and 20 Pa, most units exhibit stable sensitivities.
- The responses of the GEMs, InfraBSU and Raspberry Boom units remain stable with ambient pressure changes; only small changes observed in the units' response roll-off.
- Changes in temperature induce minimal changes to amplitude sensitivity (< 5% to 13%) and phase (< 4 deg to ~23 deg) within the IMS infrasound band for the Boom, GEM and InfraBSU units.
- GEM infrasound logger, InfraBSU and Raspberry Boom exhibit comparable self-noise levels.
- Camas microphone shows significant response change with variations in temperature in the IMS infrasound band.
- Passbands of Camas microphone and Samsung S10/Redvox are above the IMS infrasound band.
- Samsung S10 have high self noise in the IMS infrasound band.
- Sensor response to acceleration for the units evaluated was not significant.

Sensitivity at 1 Hz



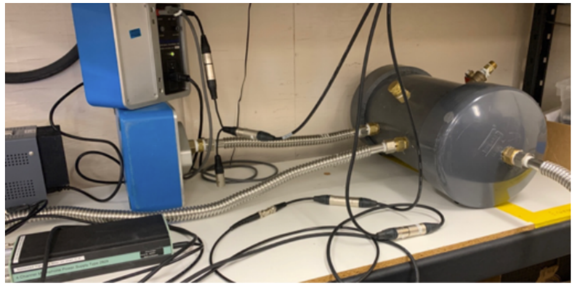
	Sensor 1	Sensor 2	Sensor 3	Max. Deviation from Average	Combined Uncertainty
Camas microphones	16.32 mV/Pa	23.45 mV/Pa	15.53 mV/Pa	27.23%	0.92 %
	-164.70 deg	-167.20 deg	-161.60 deg		0.32 deg
INfraBSU sensor	44.98 uV/Pa	45.08 uV/Pa	45.02 uV/Pa	0.13%	0.92 %
	0.20 deg	0.30 deg	0.23 deg		0.32 deg
GEM package	276 cts/Pa	275 cts/Pa	276 cts/Pa	-0.09%	0.92 %
	4.27 deg	4.24 deg	4.30 deg		0.32 deg
Boom package	56910 cts/Pa	53680 cts/Pa	21540 cts/Pa*	2.92%*	0.92 %
	9.61 deg	15.80 deg	69.32 deg		0.32 deg
S10/Redvox package	949 cts/Pa	886 cts/Pa	962 cts/Pa	-4.96%	0.92 %
	-	-	-		-

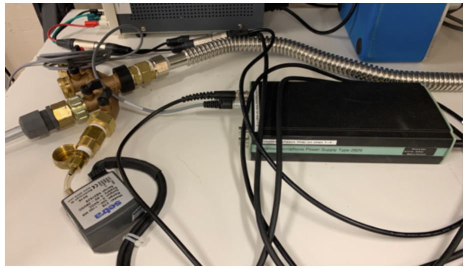
*3rd Raspberry Boom excluded from average

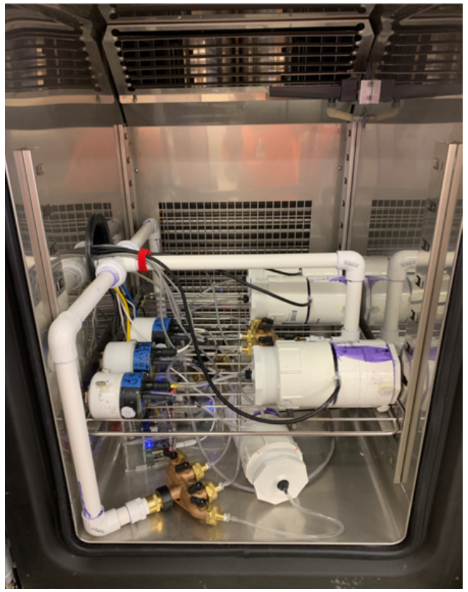
Testbeds Utilized for these Evaluations

Acoustic Isolation Chamber

Environmental Chamber

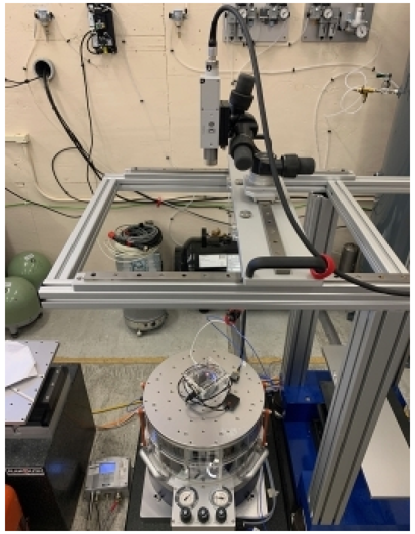






Linearity Testbed

Spektra Seismic Calibration System



Measurements made: absolute versus relative

Absolute measurements made in infrasound chamber

- Large volume (1400 liters) and large mass (~1800 kg)
- Resonance not an issue below 20 Hz
- Well-characterized, traceable reference sensors
- Interior volume isolated from the external pressure and temperature changes and infrasound in the environment, improves SNR

Relative measurements made with environmental chamber and linearity testbed

- Exposed to environment (wind-induced infrasound signals, other infrasound signals), reduces SNR
- Hose and pipes may introduce resonances – limits evaluation, at any given frequency, to comparison of response changes induced by exposure to different temperatures or input pressures.