ASTP Board Calibration Certificate

2022-01-26
VMP500RT SN230
P049R02 ASTP-LP SN153
National Taiwan Univ.

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1 Document Summary

This document contains the calibration parameters for the electronics on the P049R02 board, which controls the conditioning and sampling of the accelerometer, shear, thermistor and pressure (i.e. ASTP) signals. The ASTP board is present in your instrument (SN 230) and is common to many instruments built by Rockland Scientific. The ASTP board is designed specifically to have low electronic noise to enable the precise measurement of oceanic microstructure turbulence signals.

The calibration parameters that are summarized in this document need to be included in the `setup.cfg` file so that the data can be converted from raw counts to physical units. **A summary of the necessary coefficients is provided in Section 2.** These values are specific to instrument SN 230 and were entered into the `setup.cfg` file before it was shipped from Rockland Scientific's production facility, but it is important to verify that the values are correct prior to any deployment. Note: The calibration parameters for the sensors (e.g. shear probes, thermistors, CT sensor, etc.) are either provided in separate documents, or to be determined post-deployment via an *in situ* calibration[1].

The procedures and data used to generate the calibration parameters are outlined in the subsequent sections of the document. In particular:

- Section 3 gives the estimated power draw of the ASTP board.
- Section 4 outlines the calibration of the pressure transducer and the computed regression equation.
- Section 5 outlines the response of the thermistor channels to changes in input resistance.
- Section 6 outlines the frequency response of all the ASTP channels. The transfer functions are presented and the differentiator gains are summarized.
- Section 7 shows the electronic noise spectra from all the ASTP channels. **Figure 12 should be used as a baseline to compare bench test data to.**

If you have any questions regarding the ASTP calibration report, or your instrument in general, please contact support@rocklandscientific.com.

[1]Note: The FP07 thermistor(s) are typically uncalibrated. We recommend performing a post-deployment *in situ* calibration, which is outlined in Technical Note 039.

2 Parameters for `setup.cfg` file

The following parameters should be included as the "instrument dependent" parameters in your `setup.cfg` file. For "sensor dependent" parameters (e.g. shear probe sensitivities), please refer to the appropriate calibration report, or determine them using an *in situ* calibration.

Thermistors:

	T1	T2
adc_fs	4.096	4.096
adc_Bits	16	16
a	-10.6	-11.8
b	0.99855	0.99885
G	6.0	6.0
E_B	0.68194	0.68210

Thermistors (with pre-emphasis):

	T1_dT1	T2_dT2
diff_gain	0.915	0.918

Shear Probes:

	sh1	sh2
adc_fs	4.096	4.096
adc_Bits	16	16
diff_gain	0.955	0.951

Pressure Sensor:

	P
coef0[2]	-3.63
coef1	0.102153
coef2	-2.0092e-08

Pressure Sensor (with pre-emphasis):

	P_dP
diff_gain	20.05

[2]Note: The value of coef0 in the `setup.cfg` file on your instrument was adjusted to obtain a zero pressure reading at Rockland Scientific. Therefore, it will be slightly different than that determined from the regression (Section 4). The value of coef0 may need to be further adjusted for your deployment site. See the blog post on Rockland Scientific's website for details.

3 Power Draw

The measured voltage and current draw of the ASTP board is given in the following table:

Voltage [V]	Current [mA]	Limit [mA]
5.05	85	90

The corresponding power consumption is therefore: P = IV = 0.429 W

Note: This is only the analog power consumption of the ASTP board and *the instrument itself will draw significantly more power*. Consult your instrument manual.

4 Pressure Transducer Calibration

The pressure transducer was calibrated at Rockland Scientific using a dead weight tester. The details of the sensor and its calibration are as follows:

Date:	2022-01-27
Model:	PA11/200BAR/80059
SN:	1014214
Circuit Board:	P049R02 ASTP-LP SN153
Operator:	Dave Cronkrite

Data were collected on both the pre-emphasized[3] pressure channel (ch11) and the pressure channel (ch10) for applied pressures increasing from 200 psi to 1400 psi and then decreasing back to 200 psi, in 200 psi increments. The data are supplied in Table 1. A second order regression was used to determine the coefficients (Figure 1) that convert the measured counts into physical units. The equation is provided below. The Keller Calibration sheet is also provided for your reference (Figure 2).

Regression equation: $P = \text{-3.6255} + 0.10215 \cdot N_{10} + \text{-2.0092e-08} \cdot N_{10}^2$ [dBar]

Note: To zero your pressure sensor, the first coefficient can be adjusted. This was done in the `setup.cfg` file to account for the height difference of the pressure source and the pressure transducer. It may need to be adjusted specifically for your deployment site.

[3] For information on the pre-emphasis technique see Technical Note 003 available from the downloads section of Rockland Scientific's website

Table 1: Pressure Calibration Data

P_dP [ch 11]	P [ch 10]	Pressure [PSI]
1388	1388	200
2738	2737	400
4088	4088	600
5440	5440	800
6792	6793	1000
8145	8149	1200
9501	9503	1400
10853	10858	1600
12213	12214	1800
13571	13570	2000
14929	14929	2200
16283	16287	2400
17646	17646	2600
19007	19005	2800
20368	20364	3000
20369	20364	3000
19008	19005	2800
17648	17646	2600
16286	16287	2400
14927	14929	2200
13571	13572	2000
12216	12213	1800
10856	10858	1600
9501	9502	1400
8148	8148	1200
6793	6793	1000
5440	5440	800
4088	4088	600
2738	2736	400
1386	1387	200

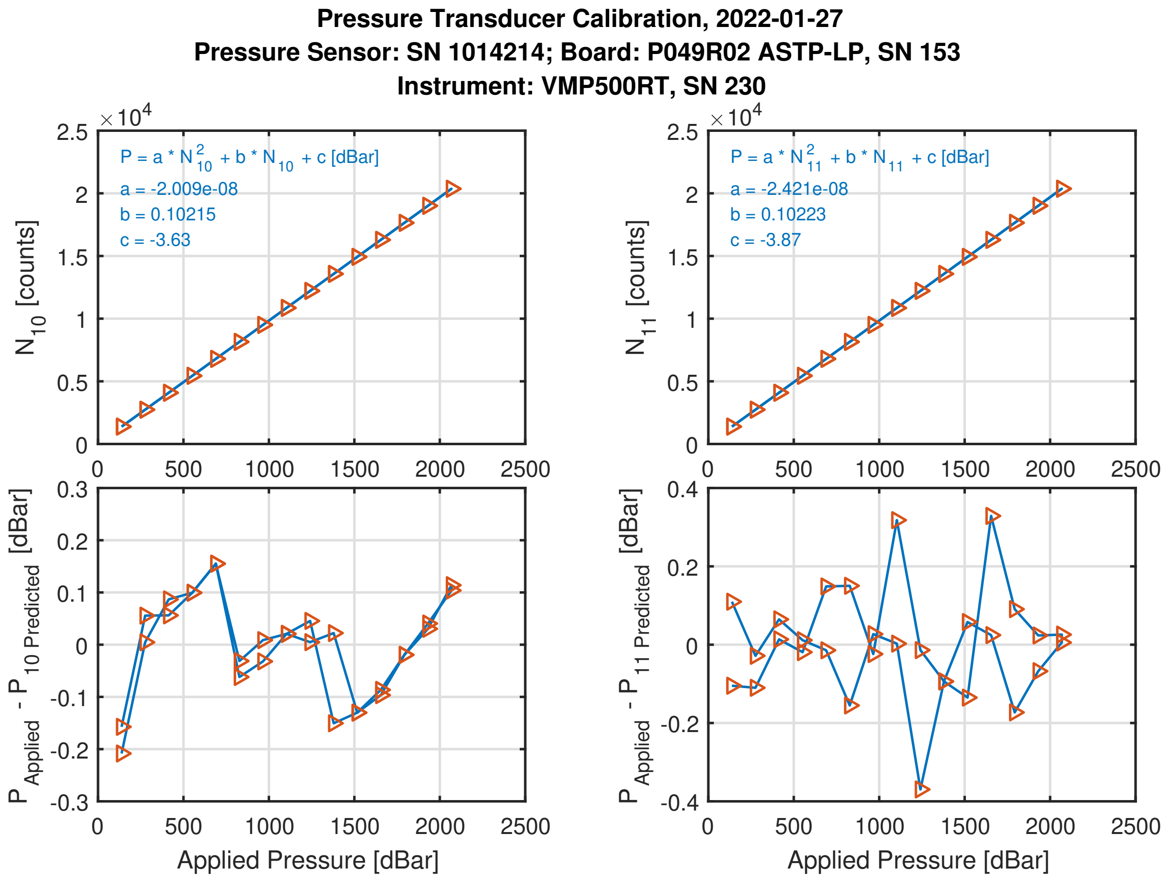
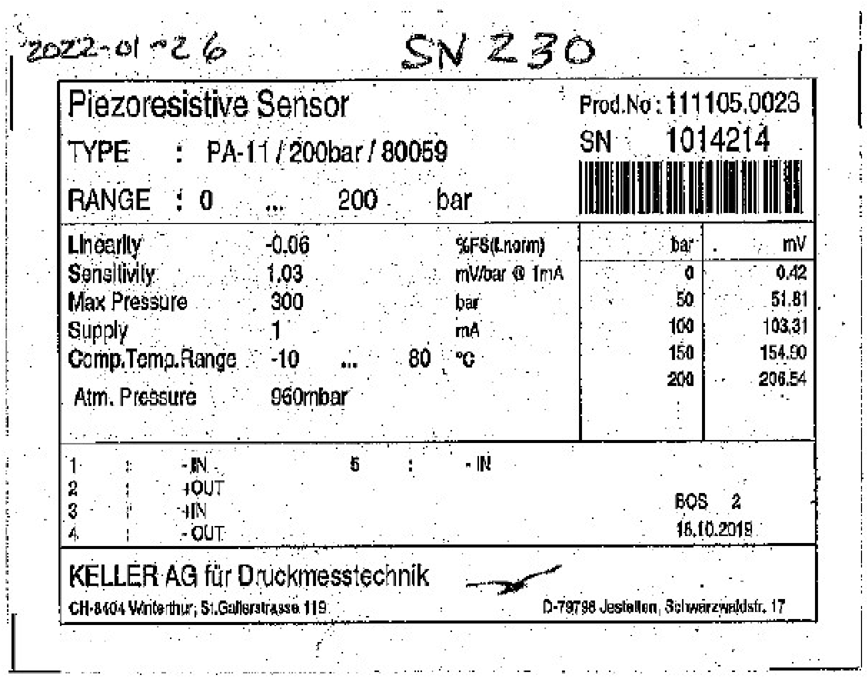


Figure 1: Pressure calibration data and second order regressions (top row) and the regression errors (bottom row).



2022-01-26 SN 230

Piezoresistive Sensor

Prod.No : 111105.0023

SN 1014214

TYPE : PA-11 / 200bar / 80059

RANGE : 0 ... 200 bar

Linearity	-0.06		%FS(Lnorm)	bar	mV
Sensitivity	1.03		mV/bar @ 1mA	0	0.42
Max Pressure	300		bar	50	51.81
Supply	1		mA	100	103.31
Comp.Temp.Range	-10 ...	80	°C	150	154.90
Atm. Pressure	960mbar			200	206.54

1 : -IN 5 : -IN
2 : +OUT
3 : +IN
4 : -OUT

BOS 2
16.10.2019

KELLER AG für Druckmesstechnik

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Figure 2: Keller Calibration Sheet

5 Thermistor Resistance Response

The purpose of this section is to test the accuracy, linearity and precision of the thermistor circuit. It also provides the relationship between thermistor resistance and the output of the thermistor circuit. This relationship, and the calibration of the thermistor itself[4], are used to convert the data into physical units. The details of the thermistor circuit are as follows:

Date:	2022-01-26
Circuit Board:	P049R02 ASTP-LP SN153
Operator:	Dave Cronkrite

Reference Voltage	V_{ref} [V]	2.0468
T1 excitation voltage	E_{B1} [V]	0.68194
T2 excitation voltage	E_{B2} [V]	0.6821
Designed excitation voltage	E_B [V]	0.68227
Circuit front end gain	G	6

The table below shows the measured response of the thermistor output channels, in units of counts, to a change in resistance of a probe. The thermistor probe was simulated with a Vishay decade resistance box of 0.01% accuracy. Low resistance represents high temperature, while high resistance corresponds to low temperatures of an actual thermistor. The nominal resistance of FP07 thermistors should be 3000Ω at 17°C, which is the balance point of the thermistor circuit on the ASTP board. Resistances of 5000Ω and 2000Ω correspond approximately to 2 and 25°C, respectively.

T1 [ch4]	T1_dT1[ch5]	T2[ch6]	T2_dT2[ch7]	RT[Ω]
10884.9	10901.6	10889.7	10909.2	1500.0
6526.6	6540.5	6528.8	6545.1	2000.0
2960.7	2972.9	2961.1	2974.4	2500.0
-10.6	-0.9	-12.0	-0.6	3000.0
-2524.9	-2516.5	-2527.6	-2518.0	3500.0
-4680.2	-4673.7	-4684.0	-4675.9	4000.0
-6547.8	-6541.4	-6552.6	-6545.8	4500.0
-8182.0	-8177.0	-8187.4	-8181.6	5000.0
-10905.4	-10902.0	-10912.3	-10909.1	6000.0

[4]The resistance-temperature relationship of a thermistor can be established by calibration in a laboratory bath, but it can also be established *in situ* from a simultaneous measure of the environmental temperature by an independent thermometer attached to the instrument. Refer to Technical Note 039 for information on performing this *in situ* calibration

The expected output, in counts, from the thermistor circuit (x) is:

$$x = \frac{2^B}{V_{FS}} \frac{G E_B}{2} \frac{R_0 - R_T}{R_0 + R_T} \tag{1}$$

where R_T is the applied resistance and $R_0 = 3000\,\Omega$ is the nominal resistance of an FP07 thermistor. The other parameters are functions of the circuit where G is the gain, E_B is the bridge excitation voltage (one-third of $V_{ref} = 2.048\,\text{V}$), and $B = 16$ and $V_{FS} = 4.096\,\text{V}$ are the number of bits and full-scale range of the AD-Converter, respectively[5].

The measured outputs (N_4 and N_6) from the thermistor channels are compared against the expected outputs (x) in the top panels of Figure 3 for thermistor 1 (ch4), and in Figure 4 for thermistor 2 (ch6). The measured outputs are regressed against the expected outputs using

$$N = a + bx \tag{2}$$

where N is the output in counts and a and b are the regression coefficients. Since N is expected to be close to x, the offset, a, should be small and the slope, b, should be close to unity.

The errors in the regression fit as a function of thermistor resistance ratio, R_T/R_0, are shown in the middle and lower subpanels of Figure 3 and Figure 4. The middle panel shows the difference, in counts, between the measured output and the output predicted by the linear regression, i.e. eq. (2). The bottom panel shows the error in R_T/R_0 itself. By combining eqs. (1) and (2), it can be shown that

$$\frac{R_T}{R_0} = \frac{1 - Z}{1 + Z}, \tag{3}$$

where

$$Z = \left(\frac{N - a}{b}\right) \frac{V_{FS}}{2^B} \frac{2}{G E_B}. \tag{4}$$

[5]See Technical Note 005 available from the downloads section of Rockland Scientific's website.

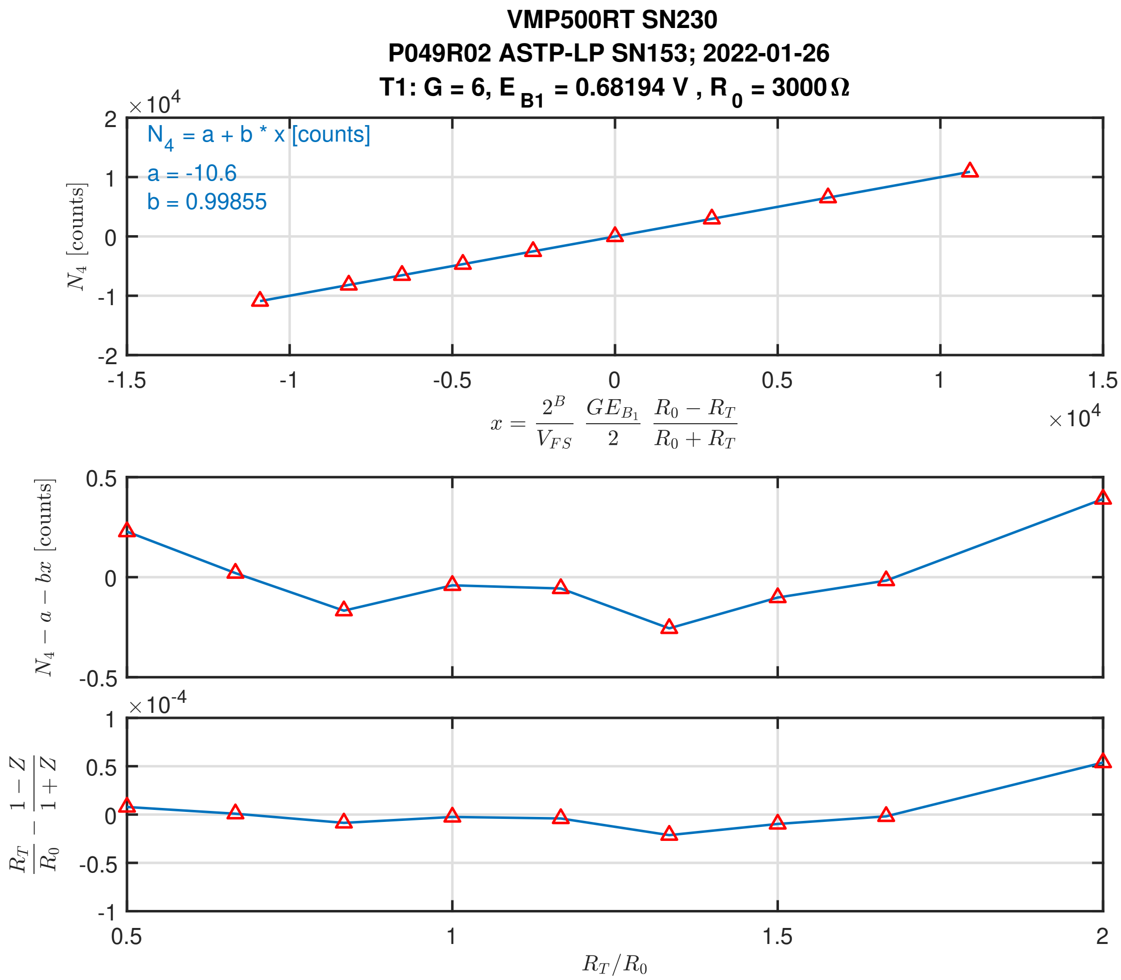

Figure 3: (Top panel) Linear regression of the actual output from ch4 (N_4) against the expected output, x, described by (1). The linear least-squares fit gives the offset, a, and the slope, b. (Middle panel) The difference, in counts, between the measured output and the output estimated from the linear regression as a function of the thermistor resistance ratio, R_T/R_0. (Bottom panel) The difference between the measured thermistor resistance ratio, R_T/R_0 and that predicted by the inverse linear regression, i.e. eq. 3, where Z is defined in eq. 4.

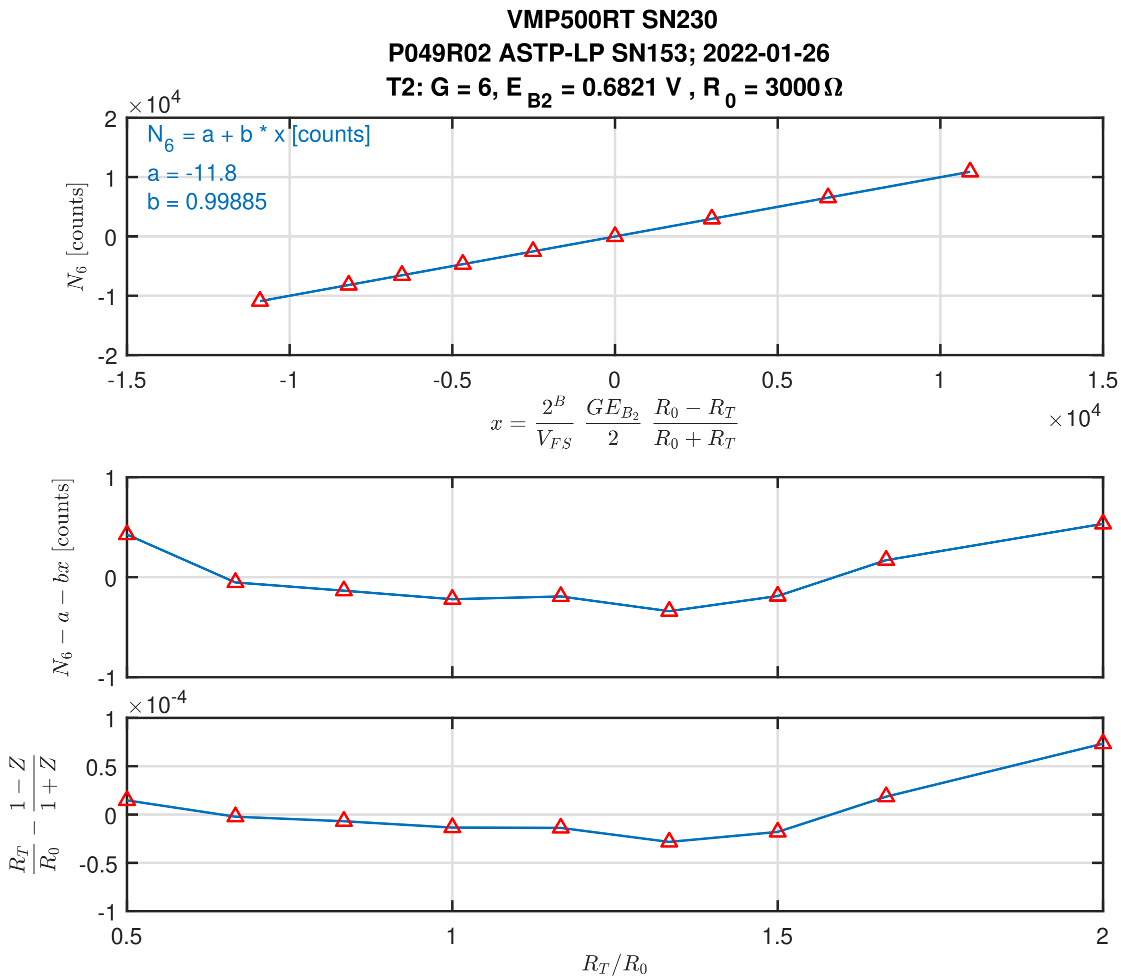

Figure 4: (Top panel) Linear regression of the actual output from ch6 (N_6) against the expected output, x, described by (1). The linear least-squares fit gives the offset, a, and the slope, b. (Middle panel) The difference, in counts, between the measured output and the output estimated from the linear regression as a function of the thermistor resistance ratio, R_T/R_0. (Bottom panel) The difference between the measured thermistor resistance ratio, R_T/R_0 and that predicted by the inverse linear regression, i.e. eq. 3, where Z is defined in eq. 4.

6 Frequency Response of ASTP Board

The frequency response of the the thermistor, shear probe, pressure and piezo-accelerometer circuits was calibrated by applying known input signals and recording the sampled output from these channels (see Figure 5).

To generate the input signal, we use a custom built signal generator that produces synthetic pink noise which has a spectrum that decreases inversely with frequency. Precision attenuators in the ODAS Calibrator (P034R03) reduce the signal amplitudes and band limit the signals to make them suitable for direct input in to the ASTP signal conditioning board. The band limited signal without attenuation is used as reference and sent to channel 15.

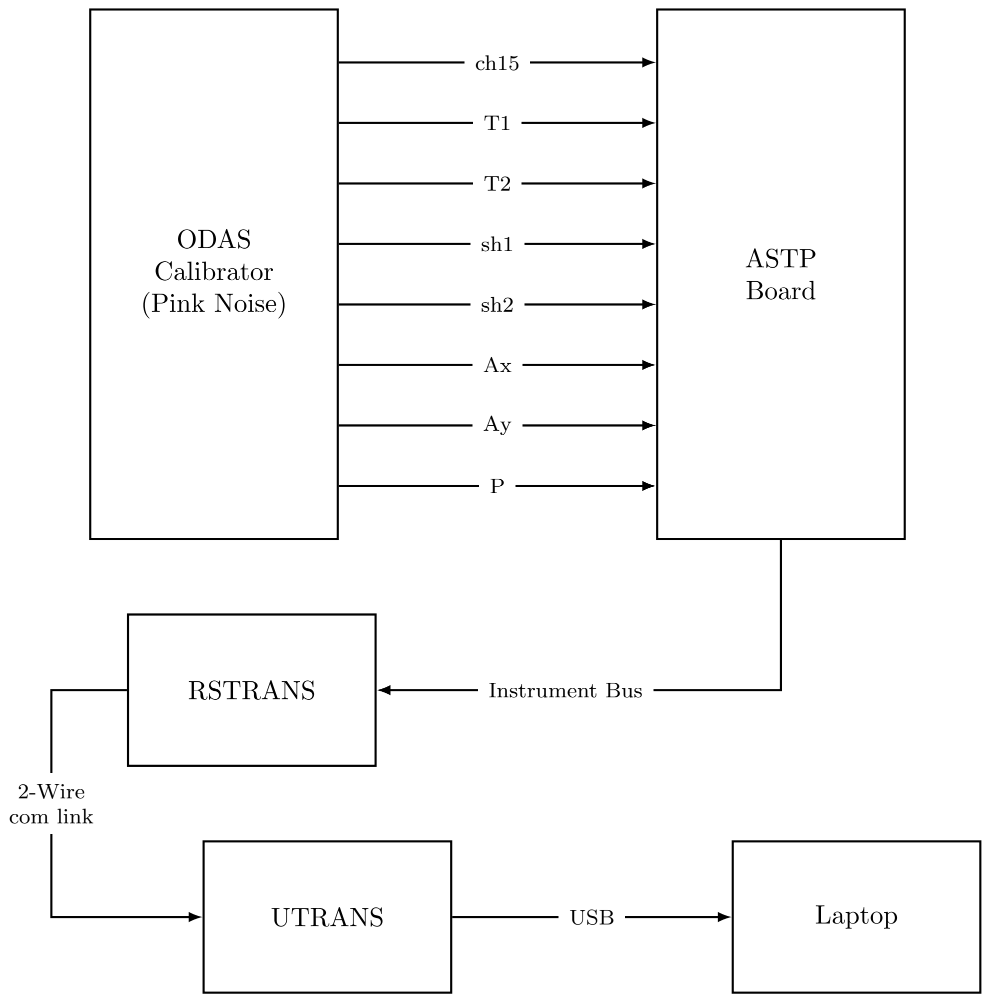

Figure 5: Schematic illustration of setup for frequency response testing of the thermistor, shear probe, accelerometer and pressure channels of a ASTP board.

For each channel, spectra are plotted of the input and output signals used for the frequency response calibration (Figure 6 for pressure, Figure 7 for thermistor, shear and piezo-accelerometer). The frequency response relative to that of an ideal differentiator are shown separately in Figures 8 – 11.

The differentiator gains of the microstructure signals are derived from these calibrations and are required to deconvolve these signals and to convert them into physical units.

Channel	Calibrated gain relative to an ideal differentiator
P_dP	20.05
sh1	0.955
sh2	0.951
T1_dT1	0.915
T2_dT2	0.918
Ax	0.957
Ay	0.962

Table 2: Differentiator gain calibration results.

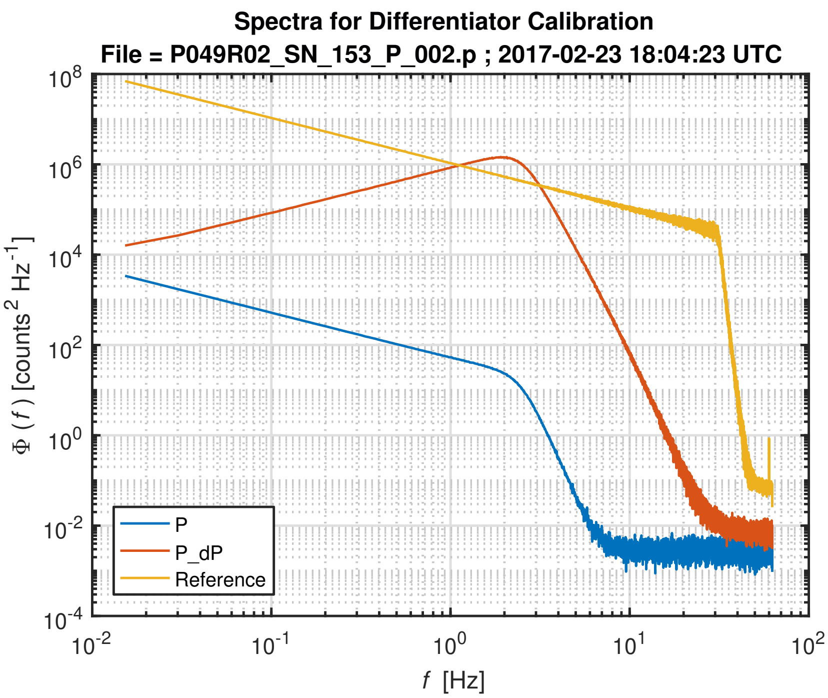

Figure 6: Spectra of signals used for the frequency response calibration of the pressure channels. The raw pressure output (ch10) is blue while the pre-emphasized output (ch11) is red. The effectiveness of the 2.5 Hz 8^{th} order Butterworth low-pass filters on the pressure signals is evident by the spectral roll-off at 2.5 Hz.

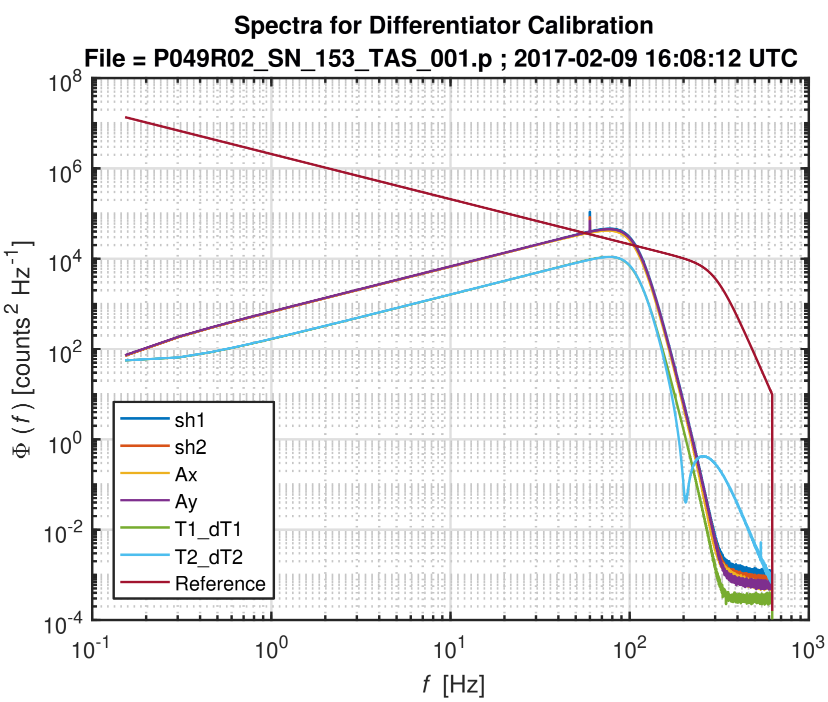

Figure 7: Spectra of signals used for the frequency response calibration of the shear probe, accelerometer and thermistor channels. Note: the shear and accelerometer channels should be overlapping because the circuitry is the same.

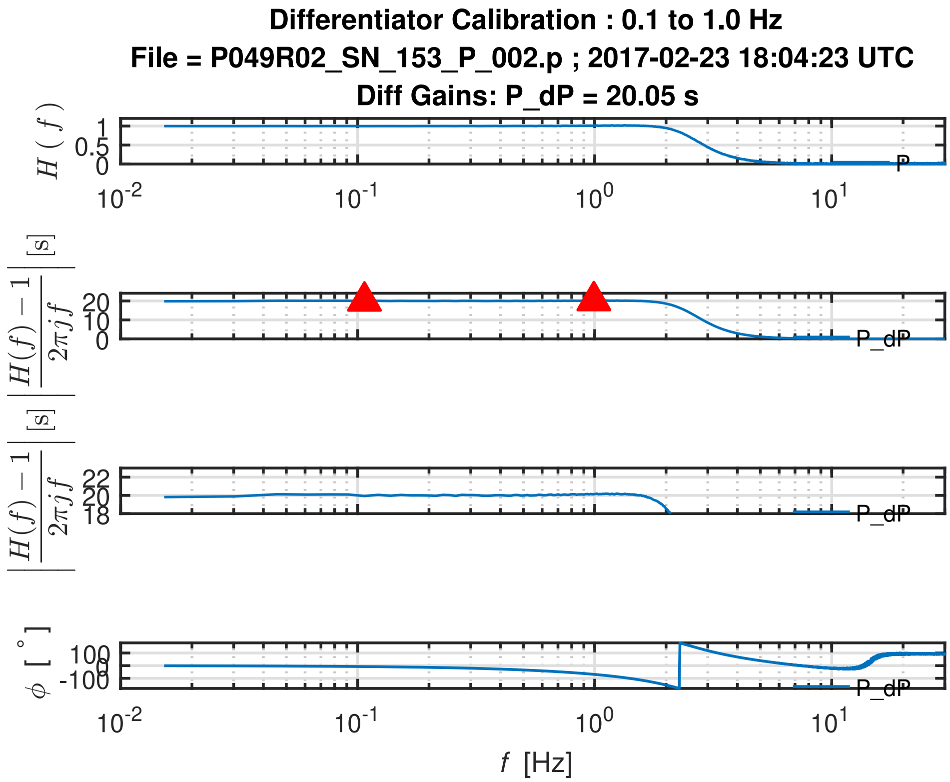

Figure 8: Transfer functions of pressure circuits. Upper panel: Pressure channel (P, ch10) with 2.5 Hz anti-aliasing filter. Second panel: Gain of pre-emphasized pressure channel (P_dP, ch11) relative to pressure (P, ch10). This channel is also low-pass filtered at 2.5 Hz. The gain of the differentiator that creates the pre-emphasized pressure signal is indicated in the figure and is the average gain over the frequency limits indicated by the red triangles. The output of the pre-emphasized pressure channel is $P + G_D \times \partial P/\partial t$ where P is the voltage from the pressure channel (ch10). Third panel: Same as second panel but with zoom-in view. Lower panel: The phase transfer function of the pre-emphasized pressure channel.

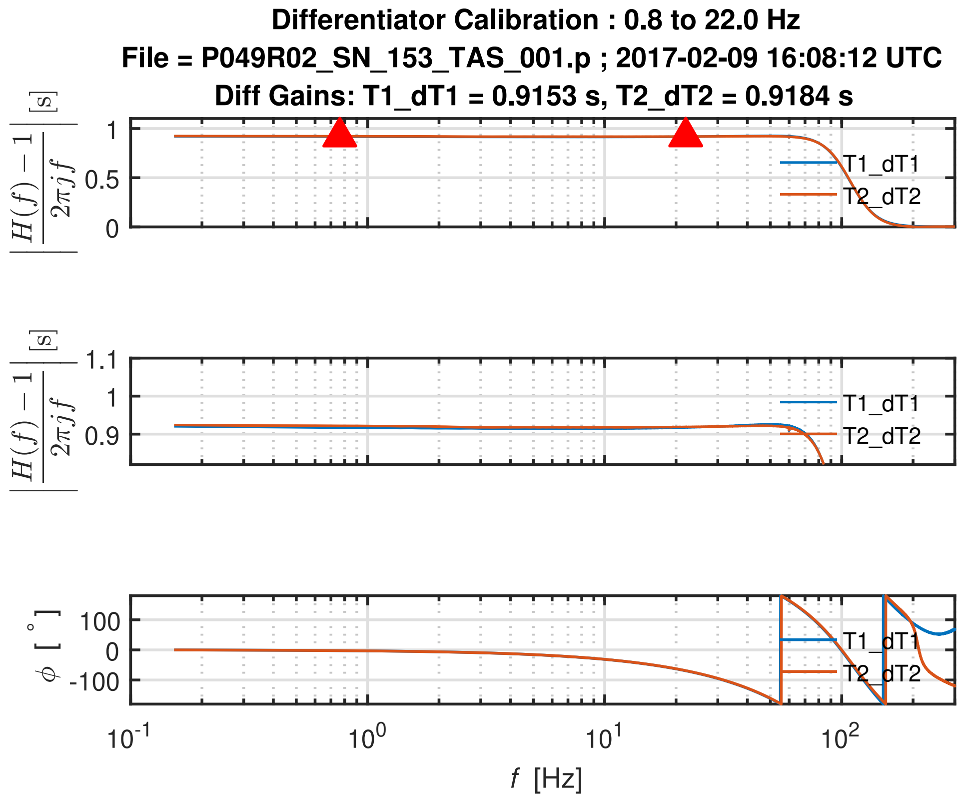

Figure 9: Transfer functions of the pre-emphasized thermistor circuits, relative to that of an ideal differentiator. The gains of the differentiators are indicated in the title and represent the mean gain between the frequency limits indicated by the red triangles. Upper panel: Gain with respect to frequency. Middle panel: Same but with zoom-in view. Lower panel: phase with respect to frequency.

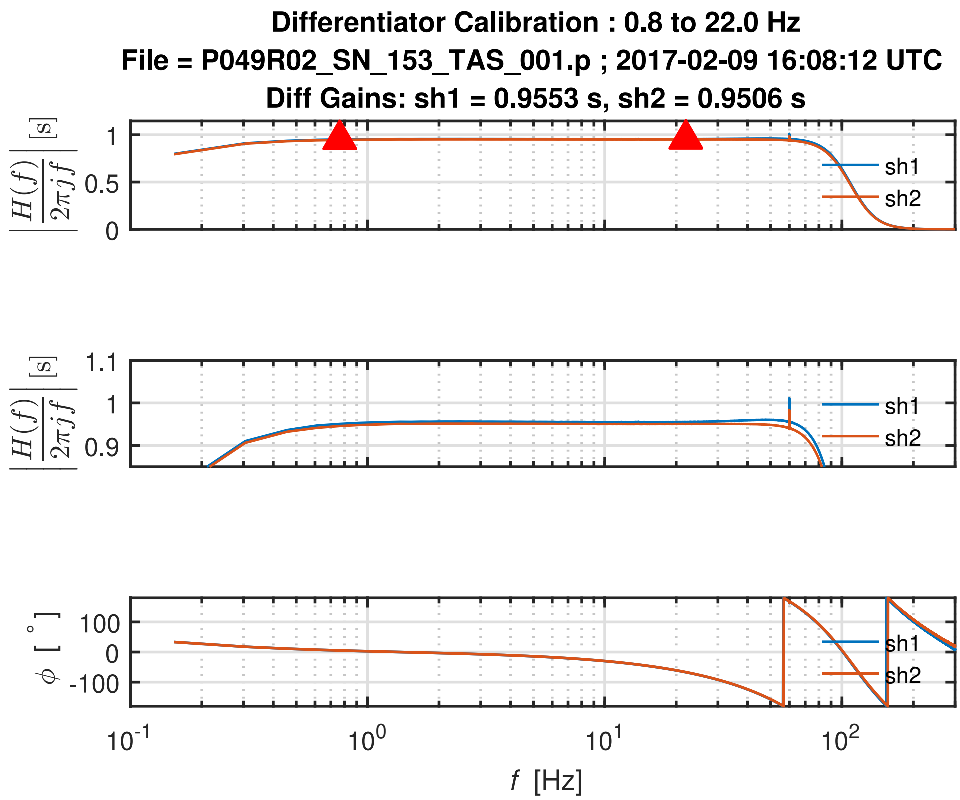

Figure 10: Transfer functions of the shear probe circuits, relative to that of an ideal differentiator. The charge-transfer amplifier responds only to AC signals and has its half-power response at 0.1 Hz. The gains of the differentiators are indicated in the title and represent the mean gain between the frequency limits indicated by the red triangles. Upper panel: Gain with respect to frequency. Middle panel: Same but with zoom-in view. Lower panel: phase with respect to frequency.

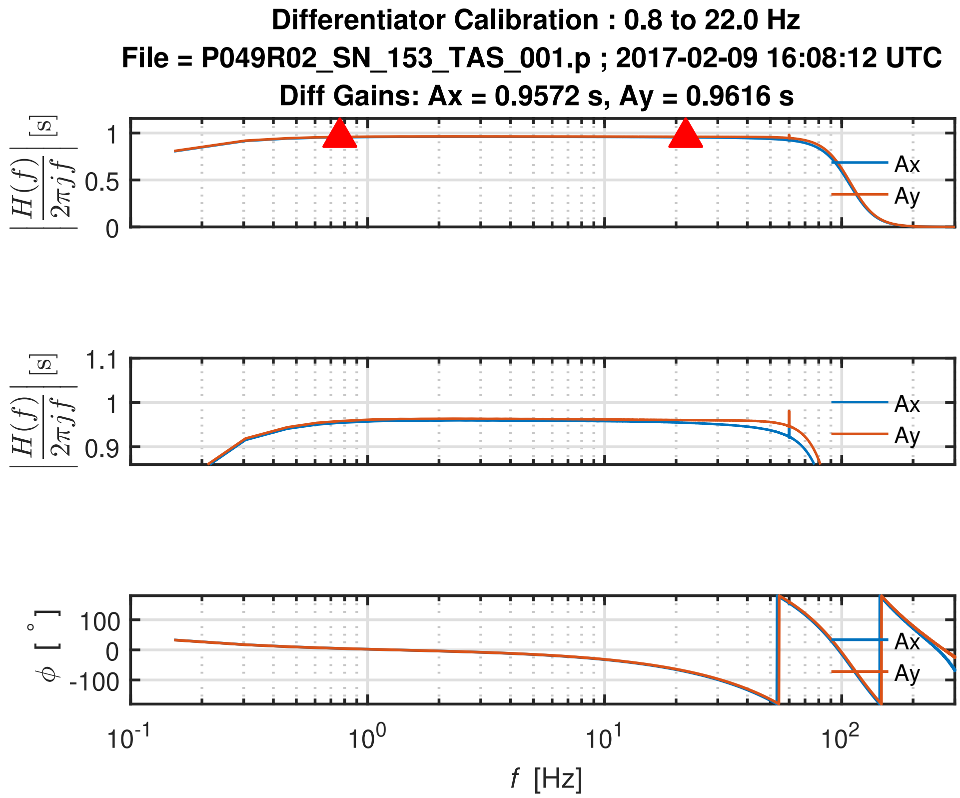

Figure 11: Transfer functions of the piezo-accelerometer circuits, relative to that of an ideal differentiator. The charge-transfer amplifier responds only to AC signals and has its half-power response at 0.1 Hz. The gains of the differentiators are indicated in the title and represent the mean gain between the frequency limits indicated by the red triangles. Upper panel: Gain with respect to frequency. Middle panel: Same but with zoom-in view. Lower panel: phase with respect to frequency.

7 ASTP Output Noise Spectra

Noise measurements were taken by using test thermistor probes of 3000 Ω resistance and open-circuit test shear probes. The piezo-accelerometers were disconnected from the inputs to the board. The pressure transducer was disconnected from the board, and the differential input to the ASTP board was shorted to the reference voltage.

All measurements are given in terms of counts from the 16-bit analog-to-digital converter, on the ASTP board. One count equals 62.5 µV. All spectra have the property that the integral from zero to the Nyquist frequency equals the signal variance.

Models for the thermistor and shear channel noise are shown by the thin black lines and acceptable ranges, i.e. within a factor of two of the model, are represented by the grey bands[6].

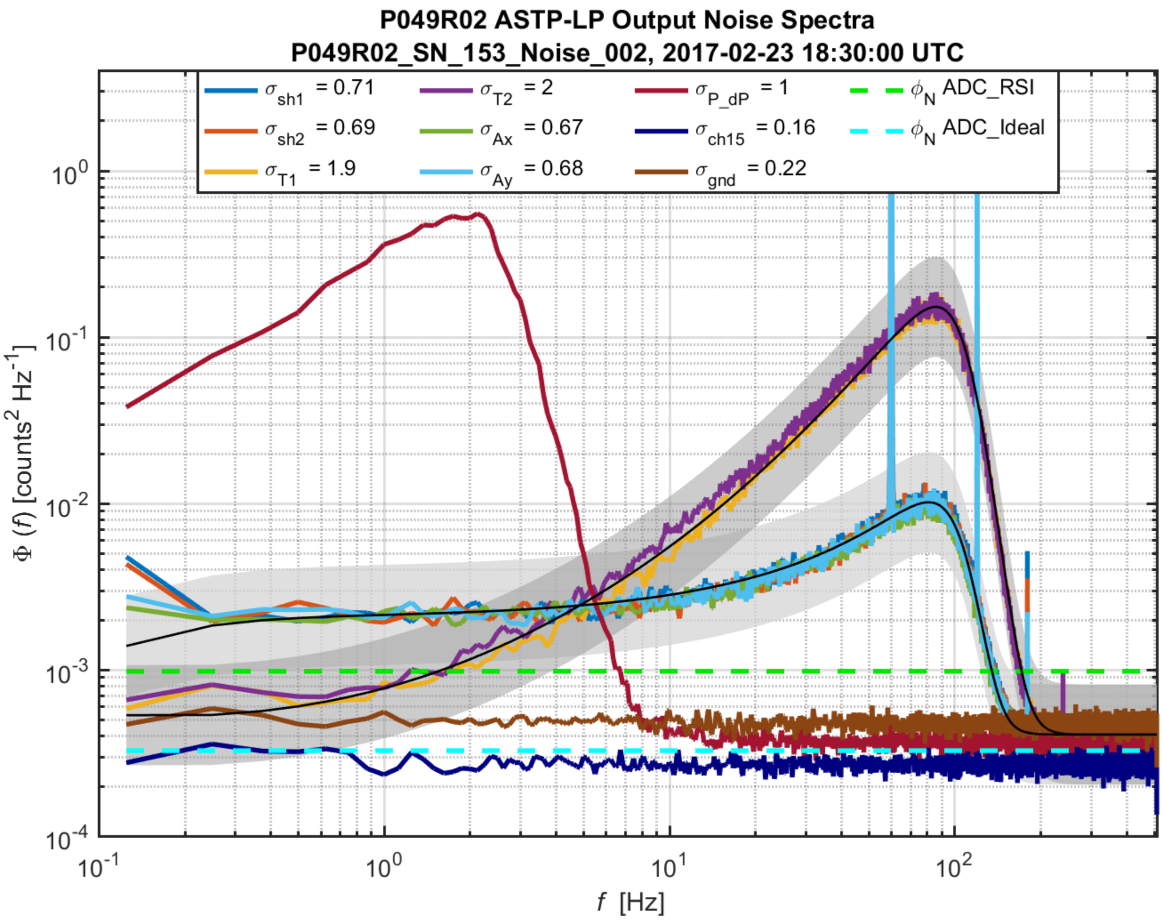

Figure 12: Output noise spectra of the ASTP board. The thin black lines and grey bands correspond to the modelled noise and acceptable noise ranges, respectively. GND (ch0) is a hard-wired virtual ground and ch15 is the reference channel. The two horizontal dashed lines show the quantization (or sampling) noise of an ideal converter (cyan) and the typical performance of the RSI converters (green), when a sample rate of 512 Hz is used. The standard deviations (σ) are for the 0–100 Hz band.

— End of Report —

[6] The details of these noise models are found in Technical Note 040 (thermistor) and 042 (shear), available from the downloads section of Rockland Scientific's website.