Trehu-Oregon LC4x4 Generalized Response and Calibration Factor

These calculations are for the generalized case and assume the signal is in the sensor frequency range giving a flat response. Frequency response ranges are indicated.

SENSOR RESPONSE INFO:

For the Differential Pressure Gauge (DPG) sensitivity:
Using measurements from strain gauge full scale outputs, the average is about 57 mv/7e3 PA. (FSO is 75e-3V/7e3PA). According to Cox *et al* there is a mechanical attenuation factor due to the compressibility of the oil and the compliance of the chamber. They estimate this as 0.86. Willoughby *et al* say they measured the response and deduced this factor as 0.924. Using a value of 0.9 is suggested until a better value can be determined. Thus the STAGE 1 gain should be 5.7e-2*0.9/7e3 or:

S(DPG) = 7.3 µV/Pa -or- (7.3e-6 V/Pa)
flat response: 0.002 Hz (500 sec) to ~30+ Hz

Frequency response information:

Parameter	Nominal Value	Units
Zeros (1)	0	Rad/s
Poles (1)*	-0.012568	Rad/s
Normalization	1	
Normalization Frequency	0.3	Hz

** Single Pole @ (1/-79.57).*

For the High-Tech Hydrophone sensitivity:
For the custom High-Tech Hydrophone (HTI-90-U) the manufacturer calibration files give a sensitivity of -182.7 dB re 1V/µPa. This hydrophone loses ~2 dB in sensitivity per ~6000m in depth (10,000 psi) so for typical ocean depth around 3km we correct ~1 dB and use -183.7 dB re 1V/µPa. Using amplitude spectra throughout (e.g. X[db] =20*log10[X/Xref]), this gives S(hyd-HTI) = 10**(-183.7/20) * 1V/µPa = .653 mV/Pa (@ 3000m water depth). Thus:

S(hyd-HTI) = 0.653 mV/Pa -or- (6.53e-4 V/Pa)
flat response: 0.05 Hz to 7.5 kHz (@ 3000m depth)

Frequency response information:

From Brian Spychalski at High Tech Inc. (personal communication: June 03, 2014):
1: HPF at input of preamp created by ceramic element 12.8nF (nom.) and 300 meg ohm resistor (0.04Hz)
2: There is another HPF at opamp set at 0.02Hz.
3: LPF at opamp is set at 7.5KHz.

Parameter	Nominal Value	Units
Zeros (2)	0 0	Rad/s
Poles (3)	-24.127431 -0.1256637 -47124	Rad/s
Normalization	47124	
Normalization Frequency	500	Hz

For the Trillium-240-OBS seismometer sensitivity:
the manufacturer quotes 1196.5 V*s/m over +/-20V for a full differential signal. SIO-4x4-LP uses only a single-sided input to the A/D, effectively halving the sensitivity, thus:

S(T240-ss) = 598.25 V/m/s *flat response: 0.004167 Hz (240 sec) to 35 Hz*

Trillium 240 OBS Seismometer Frequency response information:
(From Trillium 240 OBS User Guide - page 10)

Table 3-2 Poles and zeroes

	Parameter	Nominal values	Units
z_n	Zeroes	0 0 –108 –161	rad/s
p_n	Poles	–0.01815 ±0.01799i –173 –196 ±231i –732 ±1415i	rad/s
k	Normalization factor	2.316 x 10^9	
S_{sensor}	Passband sensitivity at 1 Hz	1196.5	V·s/m
f_0	Normalization frequency	1	Hz

**NOTE: Sensor sensitivity listed in Table 3-2 is for full differential response; SIO uses single sided input (halving this number to 598.25 V*s/m).

For the Trillium-40 seismometer sensitivity:
the manufacturer quotes 1553 V*s/m over +/-8V for a full differential signal. SIO-LC4x4 uses only a single-sided input to the A/D, effectively halving the sensitivity, thus:

S(T40-ss) = 776.5 V/m/s *flat response: 0.025 Hz (40 sec) to 50 Hz*

Trillium 40 Seismometer Frequency response information:
(From Trillium 40 User Guide - page 40)

Table 9-1 Ground motion response nominal parameters

Symbol	Parameter	Nominal Values	Units
z_n	Zeros	0 0 –68.8 –323 –2530	rad/s
p_n	Poles	–0.1103 ±0.1110i –86.3 –241 ±178i –535 ±719i	rad/s
k	Normalization factor	1.104x 10^5	$(rad/s)^2$
f_0	Normalization frequency	1	Hz
S	Ground motion sensitivity at f_0	1553	V·s/m

**NOTE: The passband sensitivity listed in Table 4-2 is for full differential response, SIO uses single sided input (halving this number to 776.5 V*s/m).

For the L28LB seismometer sensitivity:
Transduction constant --> 1.57 * sqrt(R-coil) V/m/s with R-coil = 630 ohm nominally this gives 39.53 V/m/s. SIO uses 70% coil current damping, (R-shunt-ss = (7860+51) ohm single-sided, divide by 2 to effective R-shunt damping for differential signal), thus R-shunt-diff = 3956 ohm, which gives:

S(L28) = 34.10 V/m/s *flat response: ~4.5 Hz and above*

Frequency response information (for a damped oscillator):
Two zeros at 0, two poles at $\omega_0\left(\delta \pm i\sqrt{1-\delta^2}\right)$ where $\delta = 0.701$ (damping value).

Parameter	Nominal Value	Units
Zeros (2)	0 0	Rad/s
Poles (2)	19.820 +/- i*20.164	Rad/s
Normalization	-1	
Normalization Frequency	4.5	Hz

ELECTRONICS RESPONSE INFO:

The sensitivity of the A/D is as follows:
With reference filter voltage of V-filt = 100 ohm the voltage range is +/- 2.47 V,
max counts over this range are –Vref = –6,100,300 to +Vref = 6,102,081.
This gives S(a/d) = 4.94 / 12,202,381 = 0.405 x 10**-6 V/count = 0.405 microV/count, or:

S(a/d) = 0.405 µV/count -or- (4.05e-7 V/count)

Note: A/D reaches full 24-bit range (i.e. -8388608 to 8388607) @ overvoltage of +/- 3.3 V. However, the response in this overvoltage range is roughly nonlinear.
Note2: If V-filt = 10 ohm the voltage range is +/- 2.50 V → S(a/d) = 0.410 microV/count.

PRE-AMP GAIN INFO:
Pre-amp gain settings for sensor/channel on all LC4x4 OBS deployments are:
gain(DPG) = 64
gain(hyd-HTI) = 1
gain(T240-ss) = 0.102
gain(T40-ss) = 0.200
gain(L28) = 64

Note: To keep the Trillium on scale at the A/D input (max +/- 2.47 V), signal form the Trillium seismometers output are attenuated using an analog voltage divider on the pre-amp board:
V-T240-div = R-T240-gnd-eff / (R-T240-sig + R-T240-gnd-eff) = 795 / (6980 + 795) = 0.102
V-T40-div = R-T40-gnd-eff / (R-T40-sig + R-T40-gnd-eff) = 1746 / (6980 + 1746) = 0.200

TOTAL SYSTEM RESPONSE INFO:
Total system response then becomes: S(total) = S(a/d)/[S(sensor)*gain]

LC4x4 Generalized Total System Response:

LC4x4-LP units:

DPG pressure response	**= 0.867 mPa/count**	*(500 sec to ~30+ Hz)*
	= 8.67e-4 Pa/count	
Trillium-240-OBS Velocity response	**= 6.637 (nm/s)/count**	*(240 sec to 35 Hz)*
	= 6.637e-9 (m/s)/count	
Trillium-40-OBS Velocity response	**= 2.608 (nm/s)/count**	*(40 sec to 50 Hz)*
	= 2.608e-9 (m/s)/count	

LC4x4-SP units:

Hydro-HTI pressure response	**= 0.620 mPa/count**	*(~0.05 Hz to 7.5 kHz)*
	= 6.20e-4 Pa/count	
L28 Velocity response	**= 0.186 (nm/s)/count**	*(~4.5 Hz and above)*
	= 1.86e-10 (m/s)/count	