Sleeman Coherence to Determine Digital Recorder and Infrasound Sensor Noise Characteristics

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National Nuclear Security Administration

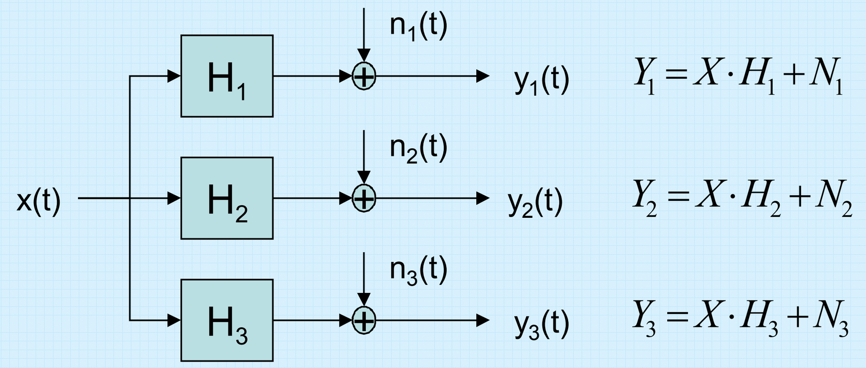
Proposed Research

•Determine noise for digital waveform recorder (DWR) and compare to independent estimate of DWR noise (i.e. Input Terminated Noise)

•Determine noise for infrasound sensor and compare to independent estimate of infrasound sensor noise (i.e. isolation chamber noise)

Three-Sensor Coherence Analysis

The three-sensor coherence analysis technique assumes that the three channels of data are all measuring a common signal. Each channel has its own response, H_i, and some amount of independent, incoherent noise, n_i.



Given just the outputs Y_i, the cross-power spectrums P_{ij} can be computed. Given the assumptions that the channels are all measuring a common signal and the noise for each channel is independent, the cross-power spectrums can be used to estimate the noise power spectrum (N_{ii}) and the channels' relative system response (H_j/H_k)

Relative System Response

$$P_{ij} = Y_i \cdot Y_j^* = P_{xx} \cdot H_i \cdot H_j^* + N_{ij} \quad \Rightarrow \quad \frac{P_{ji}}{P_{ki}} = \frac{H_j}{H_k} \quad (N_{ij} = 0 \text{ for } i \neq j)$$

Relative Gain $$abs\left(\frac{P_{ji}}{P_{ki}}\right) \quad (N_{ij} = 0 \text{ for } i \neq j)$$

Relative Phase $$angle\left(\frac{P_{ji}}{P_{ki}}\right) \quad (N_{ij} = 0 \text{ for } i \neq j)$$

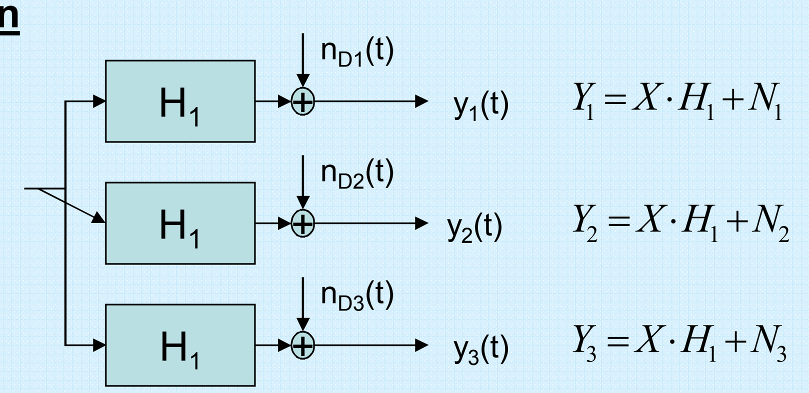
Channel Noise Spectra

$$\frac{P_{ii}}{P_{ji}} = \frac{H_i}{H_j} + \frac{N_{ii}}{P_{ji}} \quad \Rightarrow \quad N_{ii} = P_{ii} - P_{ji} \cdot \frac{P_{ik}}{P_{jk}}$$

Geotech Smart24 DWR

Test Configuration

Single Channel GS13(Vertical) as input x(t)*H(s) into three channels of Smart24 DWR.

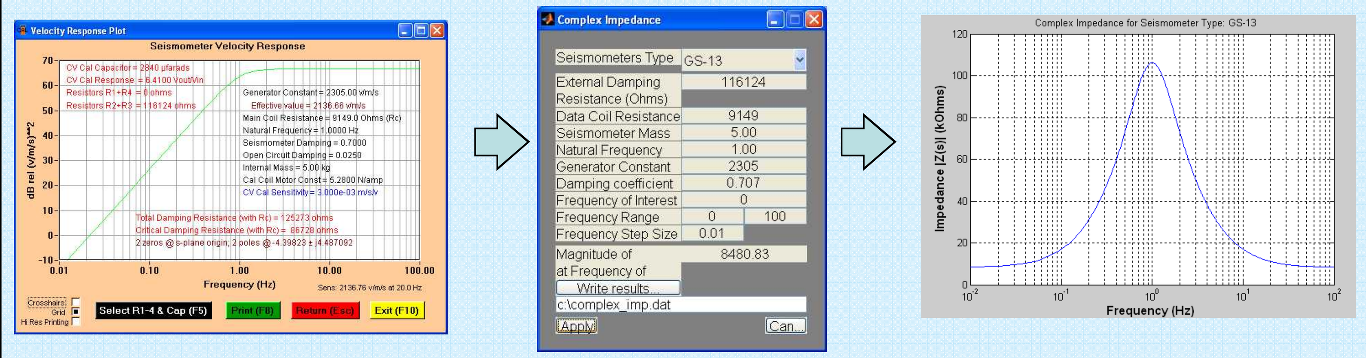


DWR Calibration of Voltage Output

Least Significant Bit (V/Ct)	Relative gain (dB)	Channel-to-Channel
4.08517E-07	0.011938	2-1
4.09079E-07	0.001272	2-3
4.09019E-07	0.010666	3-1

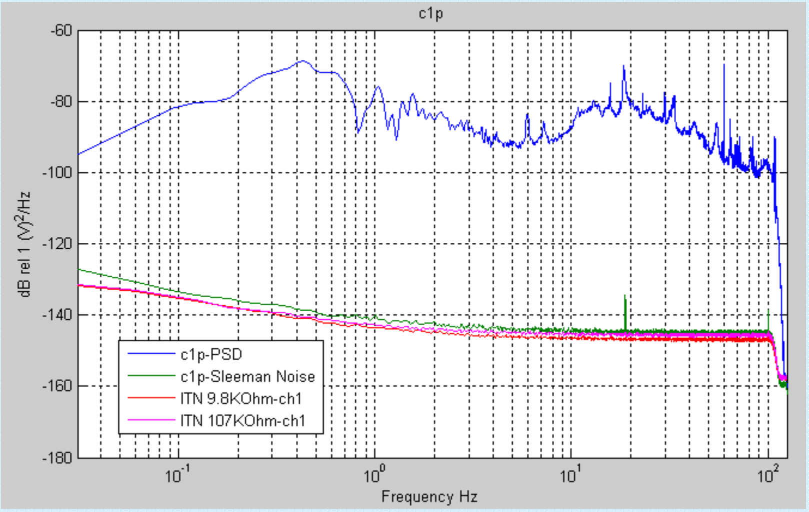
Each recorder used was voltage calibrated using one of three HP 3458A meters calibrated at Sandia's PSL.

Passive Seismometer and complex Impedance



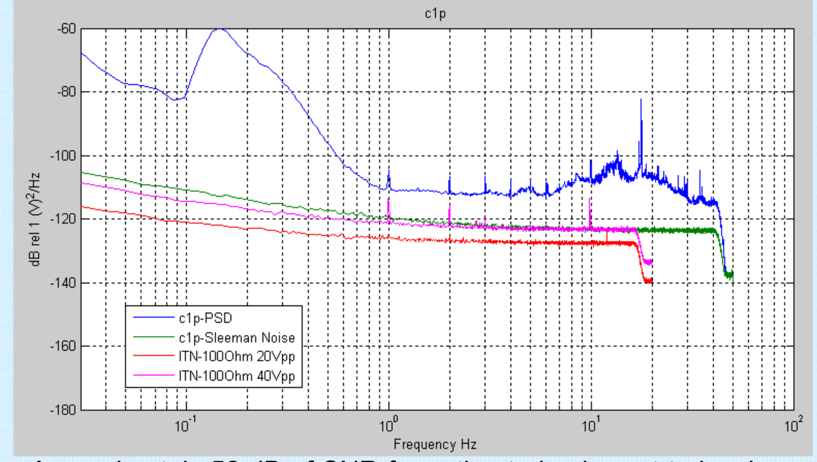
Digitizer Noise Estimates

Smart24 digitizer in 5Vpp ADC configuration. Sensor output from GS13 as input into Sleeman technique. Blue is the total power spectrum. Green is the digitizer channel c1p noise estimate. For comparison, ITN spectral results for a Smart24 digitizer in 5Vpp configuration and 9.8KOhm and 107KOhm terminations.



Approximately 72 dB of SNR for estimated coherent to incoherent energy from technique.

Smart24 digitizer in 40Vpp ADC configuration. Sensor output from STS2 low-gain seismometer as input into Sleeman technique. Blue is the total power spectrum. Green is the digitizer channel c1p noise estimate. For comparison, ITN spectral results for a Smart24 digitizer in 40Vpp and 20Vpp configurations; terminated with 100Ohm terminations.



Approximately 52 dB of SNR for estimated coherent to incoherent energy from technique.

Quanterra Q330HR DWR

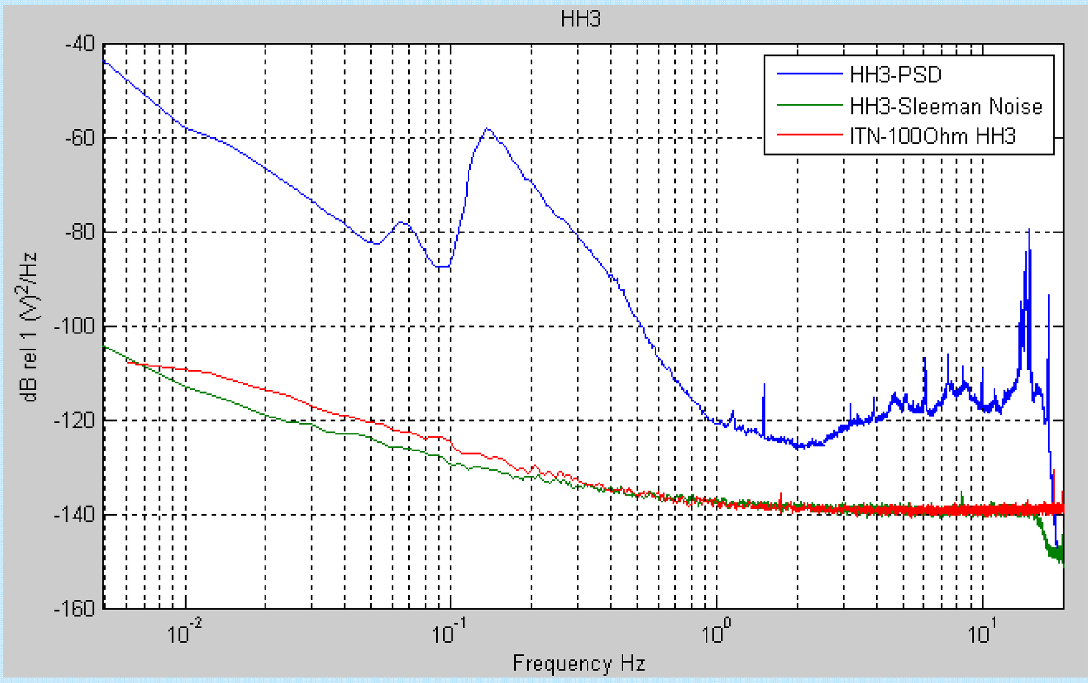
DWR Calibration of Voltage Output

Least Significant Bit (V/Ct)	Relative gain (dB)	Channel-to-Channel
5.96407E-07	-0.00335	2-1
5.96177E-07	0.00218	2-3
5.96027E-07	-0.00553	3-1

Each recorder used was voltage calibrated using one of three HP 3458A meters calibrated at Sandia's PSL.

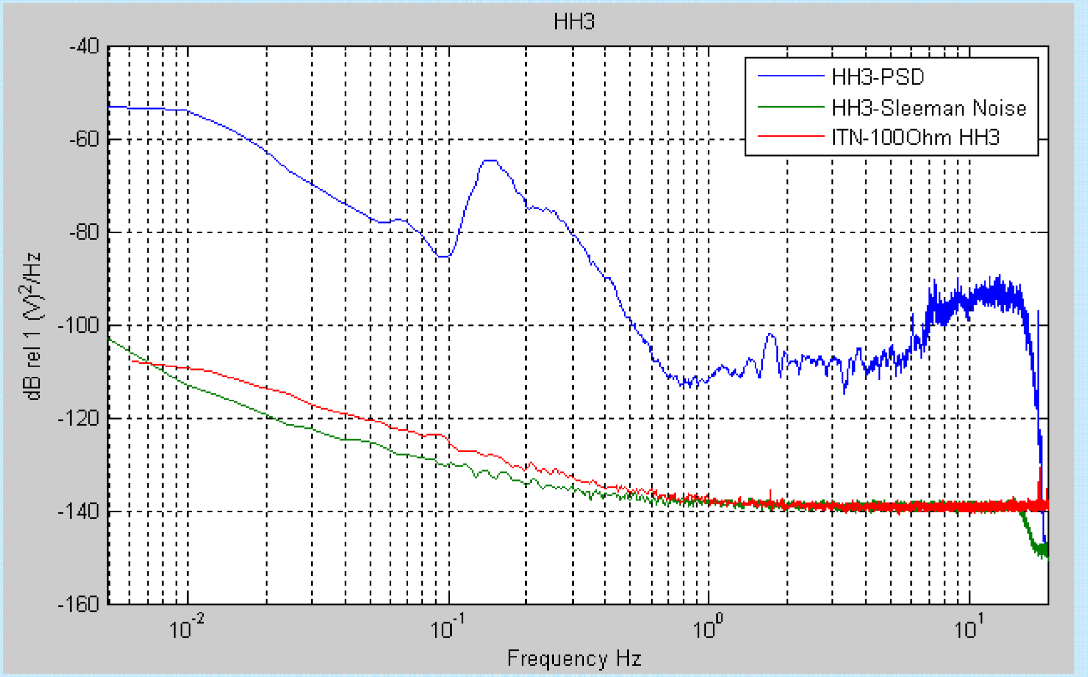
Digitizer Noise Estimates

Q330HR digitizer in 40Vpp ADC configuration. Sensor output from vertical component of STS2 low-gain as input into Sleeman technique. Blue is the total power spectrum. Green is the digitizer channel c1p noise estimate. For comparison, ITN spectral results for a Q330HR digitizer in 40Vpp configuration and 100 Ohm termination.



Approximately 71 dB of SNR for estimated coherent to incoherent energy from technique.

Q330HR digitizer in 40Vpp ADC configuration. Sensor output from easting component of STS2 low-gain as input into Sleeman technique. Blue is the total power spectrum. Green is the digitizer channel c1p noise estimate. For comparison, ITN spectral results for a Q330HR digitizer in 40Vpp configuration and 100 Ohm termination.

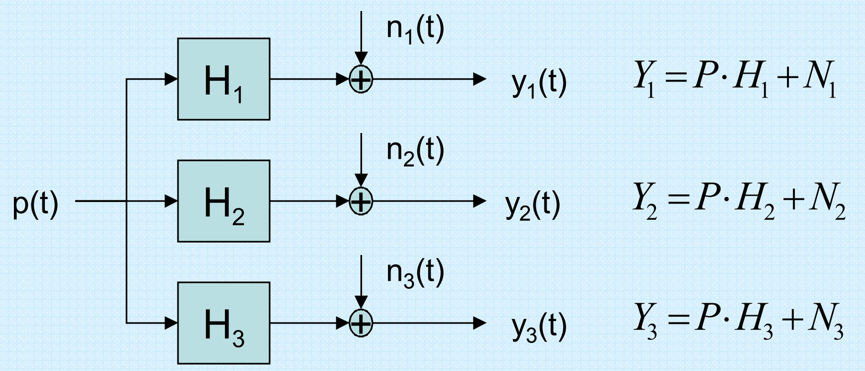


Approximately 68 dB of SNR for estimated coherent to incoherent energy from technique.

Infrasound Sensor Testing – Microbarometer

Test Configuration

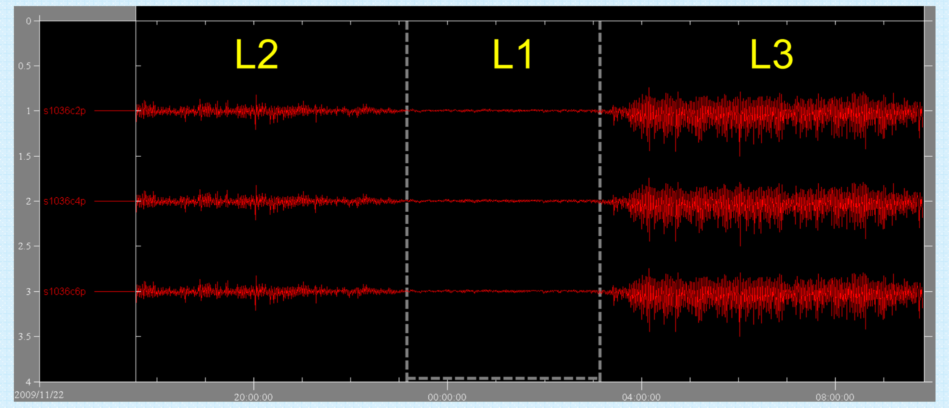
Three Channels differential pressure data as input p(t) into three channels of Smart24 DWR.



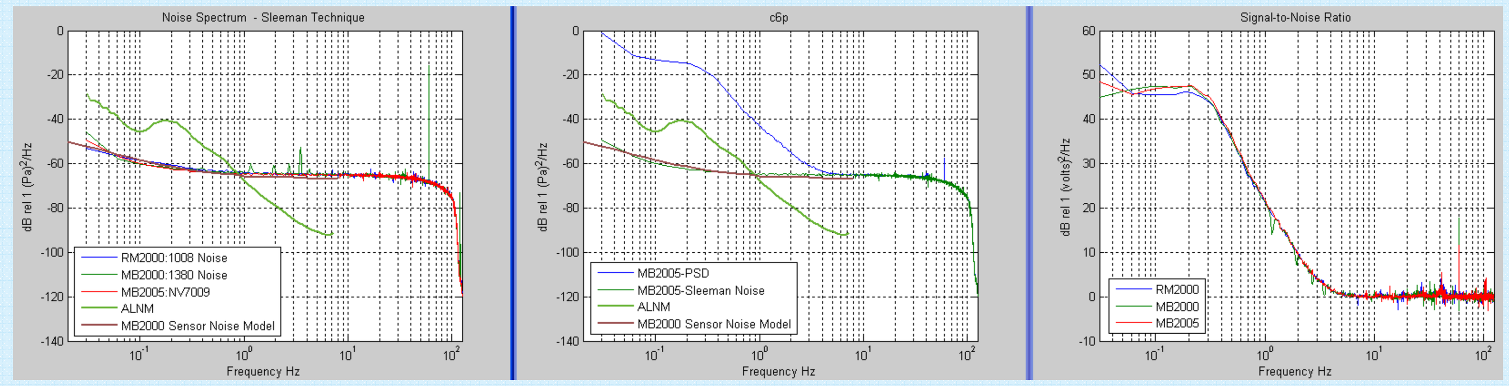
DWR Calibration of Voltage Output

Least Significant Bit (V/Ct)	% deviation from nominal LSB	Sensor	Sensitivity (V/Pa)	Calib (Pa/Ct)
3.25506E-06	-0.46%	RM2000	0.0867	3.754E-05
3.25496E-06	-0.46%	MB2000	0.100	3.269E-05
3.26939E-06	-0.02%	MB2005	0.097	3.350E-05

Each recorder used was voltage calibrated using one of three HP 3458A meters calibrated at Sandia's PSL.



Three channels of acoustic data showing three levels of activity. Each of the three background levels were processed using the Sleeman technique.



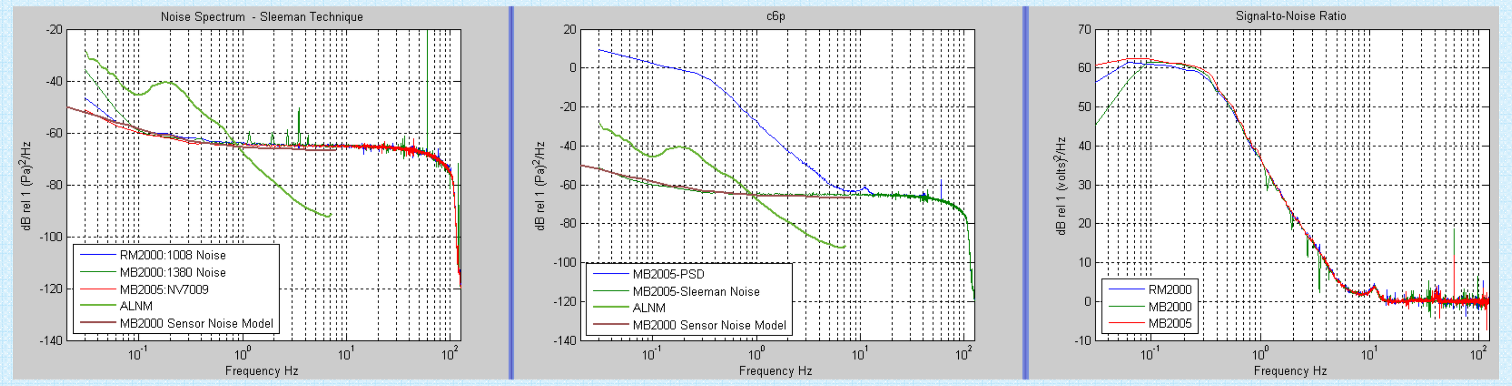
Results of processing acoustic background level L1. L1 is characterized by background signals varying from (~) +0.5 to -0.5 Pa.

Acoustic background level variations:

•Approximately 46 dB of SNR for estimated coherent to incoherent energy for L1 region of background.

•Approximately 61 dB of SNR for estimated coherent to incoherent energy for L2 region of background.

•Approximately 73 dB of SNR for estimated coherent to incoherent energy for L3 region of background.



Results of processing acoustic background level L2. L2 is characterized by background signals varying from (~) +3 to -4 Pa.

Results:

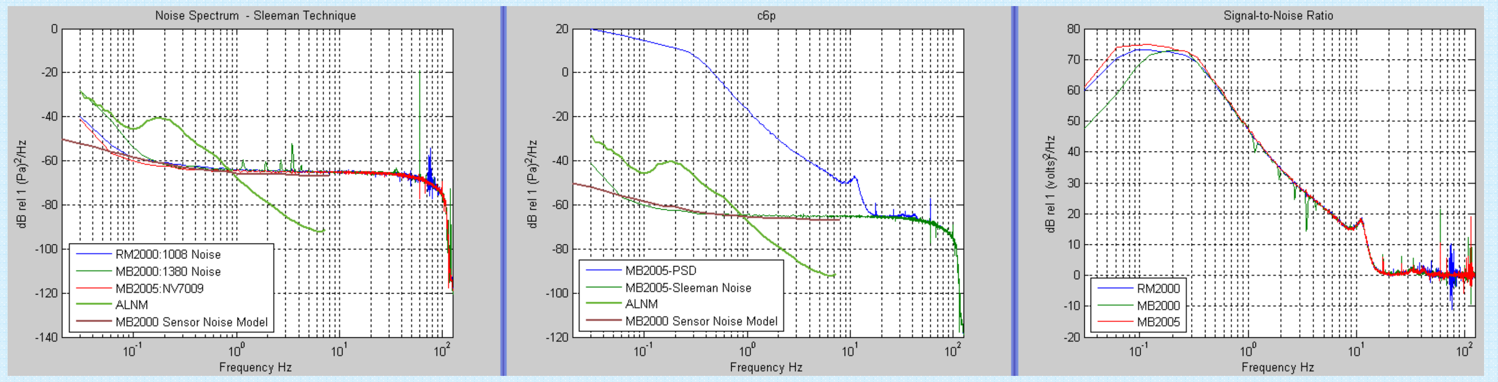
Noise estimates are independent of signal level processed for this brand of infrasound sensor.

New test design to capture higher frequency (>12Hz) signals.

Interesting aspect of test configuration is the resulting wind-noise reduction filter response of the inlet hose used in this experiment. Table 4 lists the filter characteristics.

BNL	-3dB from maximum SNR	Roll-Off Rate (dB/decade)	+3db from minimum SNR	
L1	0.35	38	3.6	
L2	0.34	46	11.4	
L3	0.33	39	16.5	

Table 4. Wind-noise reduction filter characteristics for 20 m conduit.



Results of processing acoustic background level L3. L3 is characterized by background signals varying from (~) +5 to -15 Pa.

References:

Sleeman, R., A. van Wettum, and J. Trampert (2006). **Three-channel correlation analysis: A new technique to measure instrumental noise of digitizers and seismic sensors, *Bull. Seism. Soc Am.*** 96: 258–271.

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