Progress report for contract DTRA01−99−C−0198

Background.

The seismic vault at Yreka, CA (YBH; AMS 189) is sited in an abandoned hard rock mining drift in the Klamath National Forest in northern California. YBH is the most thermally stable station in the Berkeley Digital Seismic Network (BDSN). The average annual temperature variation is of order 60 millidegrees Celsius. The remoteness of the site coupled with the exceptional thermal stability has reduced the culturally and thermally generated noise sources to the point that the dominant noise source recorded by the broadband seismographs is the local turbulence of the atmosphere at high frequencies (greater than ~3 mHz) and the Newtonian attraction of the atmosphere at low frequencies (less than ~3 mHz). At YBH, the seismic signals from a three−component set of Streckeisen STS−1 broadband seismometers (2.7 mHz − 5 Hz flat velocity proportional passband) are digitally recorded with a resolution of ~25+ bits (owing to the exceptional thermal stability) and at sampling rates of 0.01 Hz, 0.1 Hz, 1 Hz, and 20 Hz continuous and 80 Hz triggered). The pier temperature and the local atmospheric pressure are also digitally recorded via medium resolution (~22 bit) digitizers at a 1 Hz sampling rate (0 Hz − 0.4 Hz flat passband). The YBH vault also houses a geodetic GPS system and a strong motion accelerometer.

The use of cross−correlation techniques to compensate for the temperature and pressure effects on the seismic signals enables us to effectively reduce the power spectral density (PSD) of the background noise in both the seismic and the sub−seismic frequency bands and thus improve the weak signal detection capability of the broadband seismic instrumentation at YBH. Unlike infrasonic transducers that operate with a narrow passband (0.02 Hz − 4 Hz, say) and with high sensitivity for the CTBT monitoring system, we require that the infrasonic transducers have a flat passband response over the entire frequency band (0 Hz − 40+ Hz). We have researched the capabilities of commercially available barometric sensors and we selected a Druck PTX−1200 series Model 1240 barometric sensor for upgrading the microbarographic detection capability of the BDSN station at YBH because it has appropriate sensitivity and it is compatible with the existing systems.

Infrastructure and Operations.

The the existing infrastructure consists of: the sensors, datalogger, power, and communications equipment housed in the YBH hard−rock mine; a dedicated frame−relay connection, dial−up telephone, and 5% of the incoming Berkeley Seismological Laboratory (BSL) T1 line for digital telemetry; and the BSL data acquisition computers and facilities for data analysis, quality control and archiving. Security is provided via a locked bulkhead door at the mine entrance and a gated access road which is maintained by the US Forest Service. Internet access is provided via a private intranet utilizing the frame–relay telemetry. There are no BSL personnel at the remote (315 miles and 6 hours by vehicle from Berkeley) YBH site and it is only visited when the need arises for repair or upgrading of the equipment. YBH is scheduled for equipment upgrading in the spring of 2001 as weather and time permit.

The sensor data telemetered to BSL from YBH includes: a three–component set of Streckeisen STS–1 broadband seismometers (0.0027–5 Hz passband), a three–component Kinemetrics FBA–23 strong motion accelerometer (±2 g full scale); an Ashtech Z–X113 geodetic GPS receiver; a YSI 44031 thermistor (to sense seismic pier temperature); a Motorola MPX–2010 pressure transducer (to sense atmospheric pressure) (soon to be upgraded with a Druck PTX–1240 barometric sensor as discussed below); and a Quanterra GPS clock for an accurate time base. Additionally, the sensor temperature, datalogger temperature, broadband sensor mass position, clock quality, and telemetry through–put are utilized for status of health monitoring.

The operations personnel include the computing resource manager who maintains and upgrades the software on the datalogger and addresses communications problems, a research seismologist who performs station signal and noise analysis, a staff research associate who performs station quality control, and a principal development engineer who does station maintenance and upgrades. Routine data quality control procedures include weekly noise–level analysis, daily time corrections as needed, and routine reading of the data.

The partition inside the mine that houses the equipment at YBH will need to be expanded in spring 2001 to accommodate the planned instrumentation upgrade which includes the installation of VSAT's.

Current Efforts.

We have been testing the Druck PTX–1240 barometric sensor and various configurations of the associated hardware interface in the BDSN Byerly Seismic Vault at Berkeley to determine the optimal configuration and the performance. The transducer, housing, and support electronics are shown in Figure 1 and a close up of the transducer and circuit board is shown in Figure 2. The transducer housing shown in Figure 1 is designed to be installed inside the YBH vault in a manner that provides good thermal coupling to the rock in order to achieve adequate thermal stability and the housing will be connected to a manifold that leads to the exterior of the vault where it will be connected to a noise reduction system of permeable hoses. A close up of the transducer mount

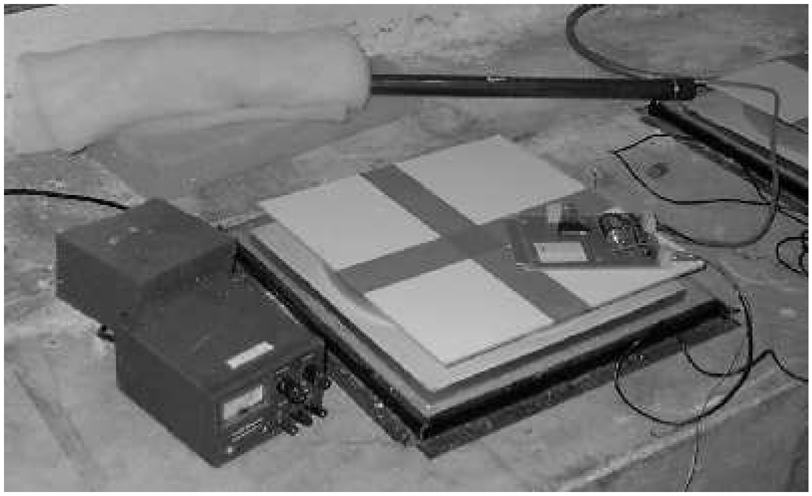

Figure 1. Photograph of test setup used to determine the calibration and performance of the Druck PTX−1240 barometer. Shown are the power supply (left foreground), the interface circuit (right center on cardboard; a schematic of which is shown in Figure 2), and the transducer manifold (copper pipe at top with insulation on left over transducer end). Not shown is the Quanterra Q4120 data logger which samples the transducer signal at 1 and 100 samples per second with 24 bit integer resolution.

Figure 2. Close up of the Druck PTX−1240 transducer (mounted inside pipe and union joint) and the transducer electronics test board. The Druck transducer sensing port has been closed off with a length of 3/8" pipe to facilitate measurement of the sensor self noise (see Figure 6).

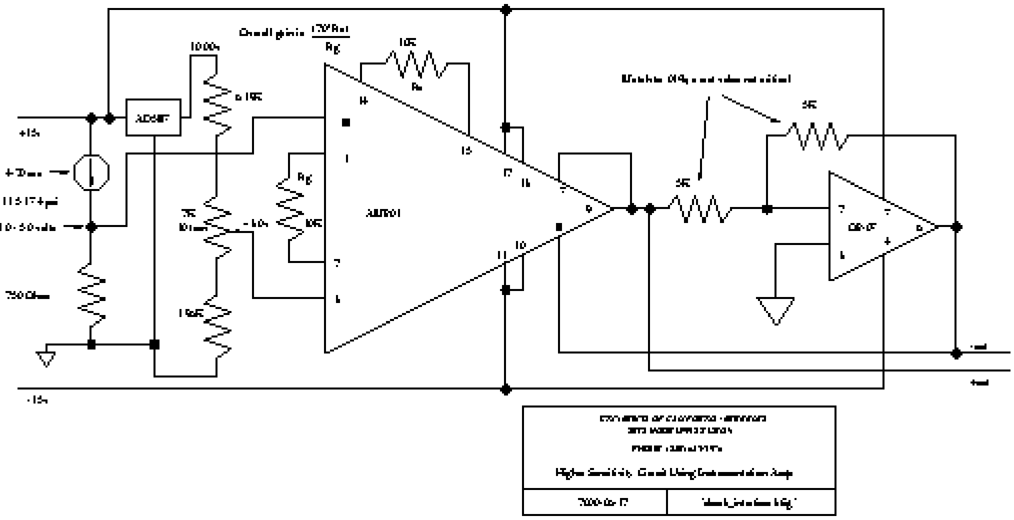

Figure 3. Schematic diagram of transducer electronics.

is shown in Figure 2. The interface shown in Figure 3 is designed with a bias circuit to null the long term average atmospheric pressure and with a gain of 40 to achieve the desired sensitivity. A sample recording from the test system is shown in Figure 4. By comparing the long–period signals from the test system with the barometric pressure recorded hourly (with 10 Pa resolution) at nearby National Data Buoy Center (URL: http://www.ndbc.noaa.gov) buoys at San Francisco (#46026; 53 km W) and at Half Moon Bay (#46012; 69 km SW), we empirically determined that the sensitivity of the Druck PTX–1240 pressure sensor (recorded by the Quanterra 4120 data logger at 100 samples per second, scaled by a factor of 16, FIR LP filtered, and decimated to 1 sample per second) is (91 ± 3) µPa/count. When the Druck pressure transducer is installed at YBH and recorded at 1 sample per second, the anticipated sensitivity is (1.46 ± 0.05) mPa/count. The pressure inferred from the Motorola MPX–2010 silicon pressure transducer signal is shown as the dashed line in Figure 4. The compliance of this sensor is obviously attenuated at long periods and it is likely that the reference port seal on the Motorola transducer is leaking with a time constant of order one hour. This is consistent with the roll–off in the phase coherency between the two transducers at frequencies below ~0.1 mHz as shown in Figure 5. The Motorola transducer is housed within the insulating urethane foam box that surrounds the BKS broadband seismic sensors and which has been sealed via gluing to minimize convective heat transfer. The roll–off in the phase coherency at high frequencies (> 0.05 Hz) as shown in Figure 5 is due to degradation of the signal recorded by the Motorola MPX–2010 sensor owing to its self noise level and its being located within the sealed insulating foam box the surrounds the broadband seismometers. The estimated pressure background noise PSD in the Byerly Seismic Vault, as inferred from the Druck PTX–1240

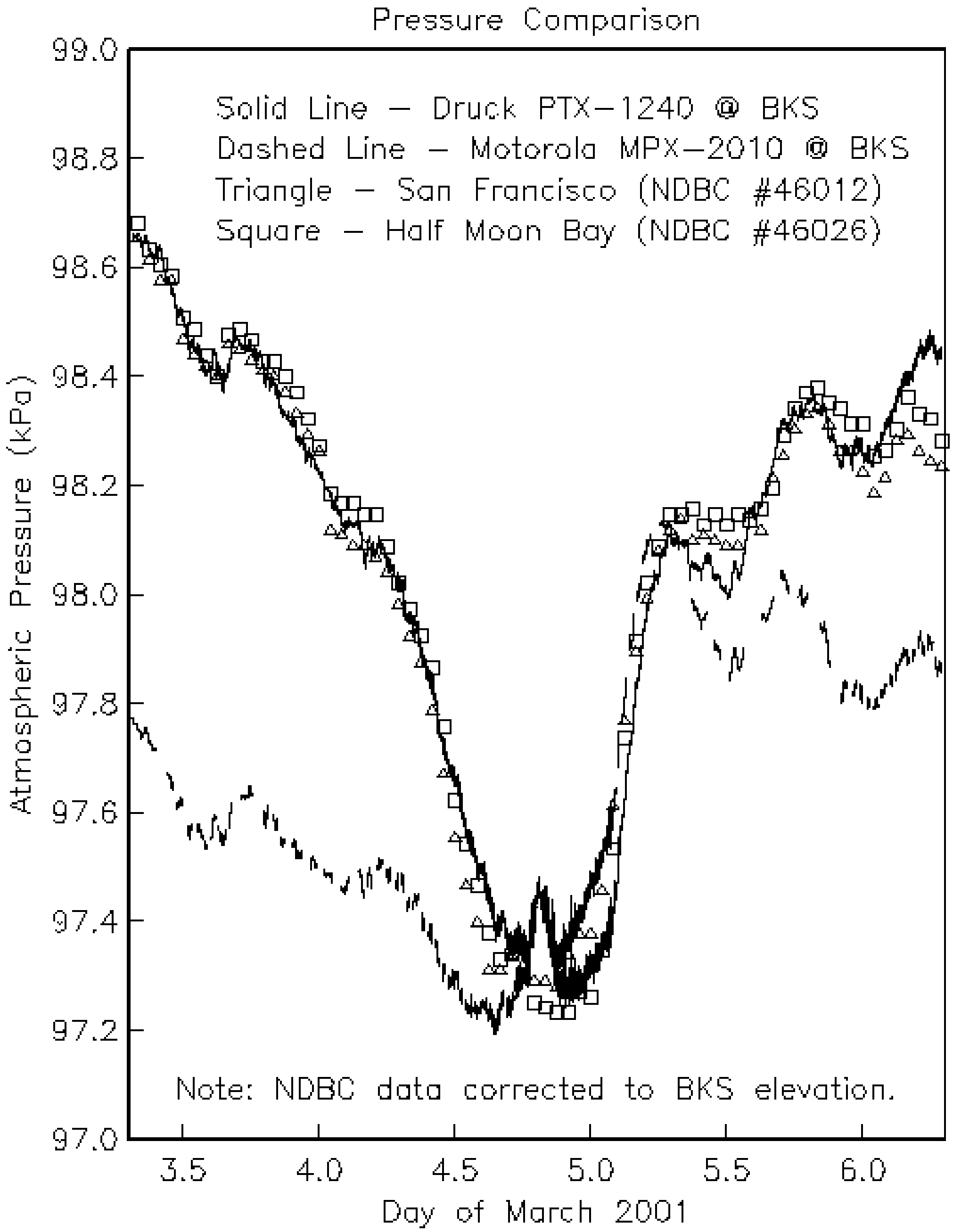

Figure 4. Comparison of atmospheric pressure variation at the Byerly Seismic Vault (BKS) over a four day interval measured at two NDBC stations and by two sensors in the Byerly Seismic Vault. For comparison, the sea level NDBC buoy pressure data have been corrected to the 276 m BKS elevation using the standard formula (where z is the elevation above mean sea level in meters):

$$P(z) = P_o[1-0.02255z\}^{5.256}.$$

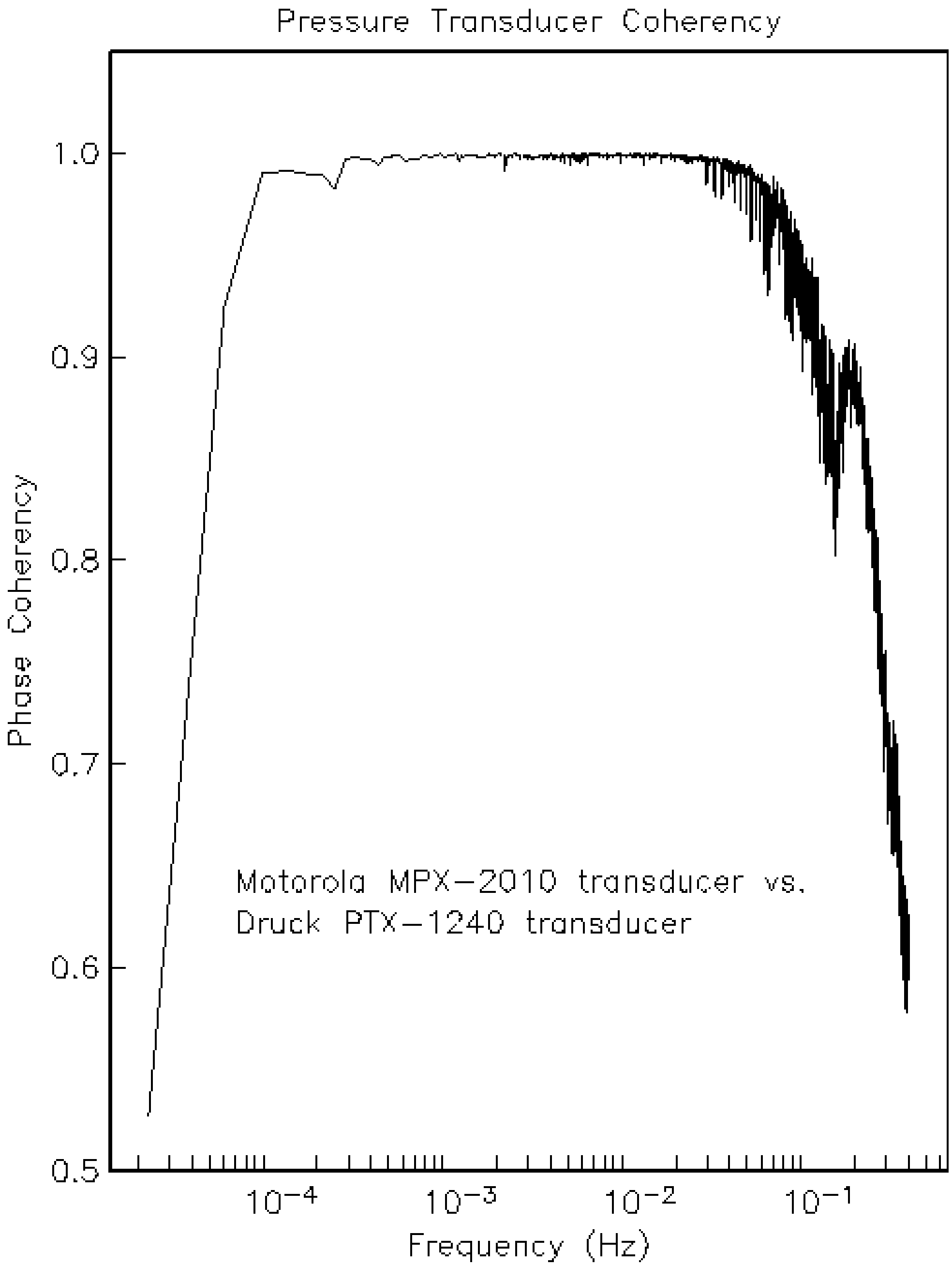

Figure 5. Phase coherency between Druck PTX−1240 and Motorola MPX−2010 pressure transducers co−sited in the Byerly Seismic Vault. The coherency falls off at low frequencies due to a problem with the Motorola sensor and at high frequencies due to differences in pressure admittance between the two sensors owing predominantly to degradation on the signal−to−noise level in and the placement of the Motorola sensor within the sealed urethane foam box which surrounds the broadband seismic sensors.

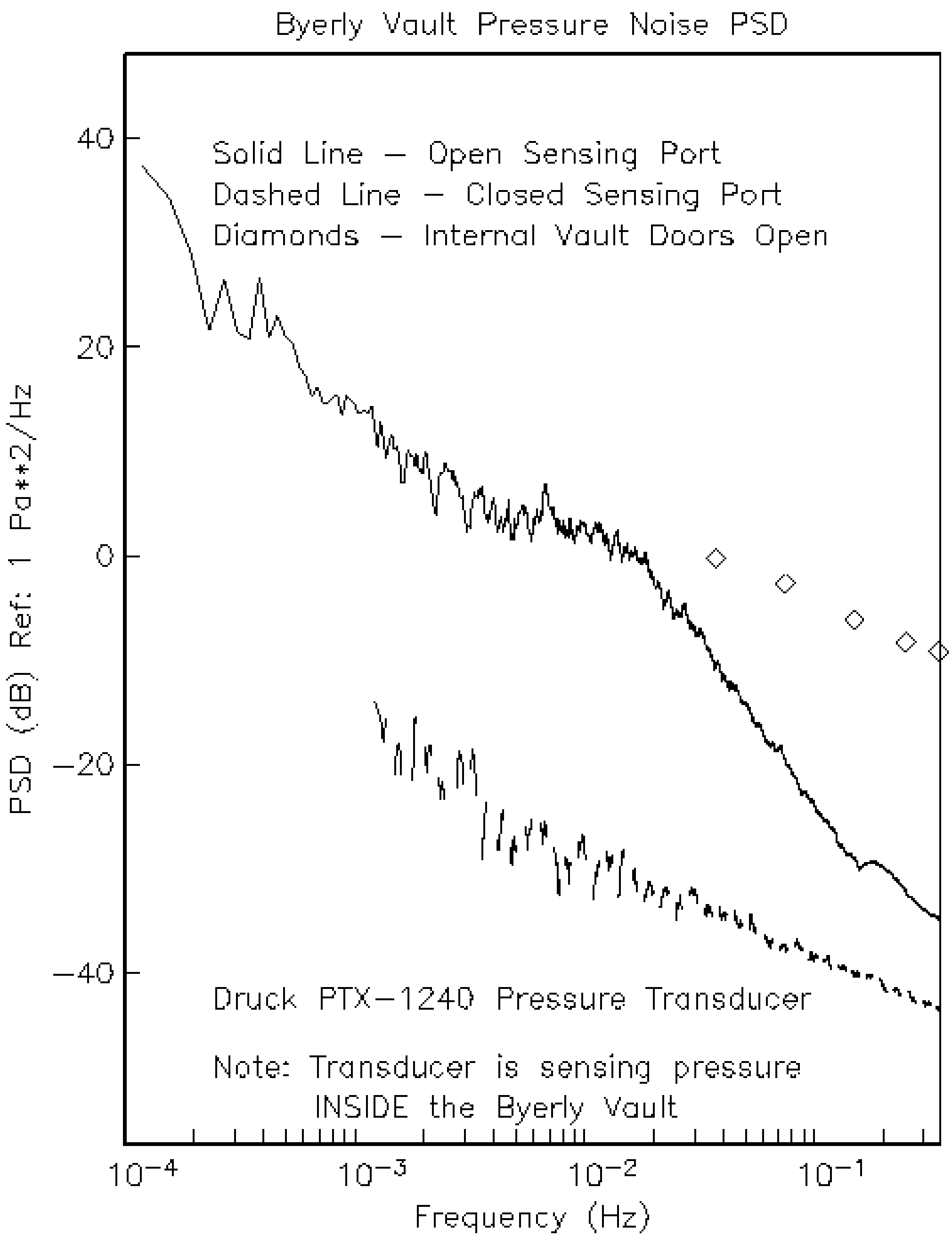

Figure 6. Estimates of the Power Spectral Density (PSD) of the atmospheric pressure measured using the Druck PTX_1240 barometer inside the Byerly Seismic Vault. The upper curve is the measured with an open sensing port which is sensing the pressure inside the vault. The lower curve is measured with the sensing port closed off, with a short length of capped pipe as shown in Figure 2, in order to estimate the self noise of the pressure sensor. The corner at 0.02 Hz is due to restricted air flow in the vault and opening the internal doors raised the pressure noise PSD to the level indicated by the diamonds.

pressure transducer recording, is shown in Figure 6. The noise floor of the Druck sensor system, as indicated by the dashed line, is −44 dB when extrapolated to 1 Hz or about 20 dB higher than the IMS sensor noise requirement. It appears that a large fraction of the self noise is due to the characteristics of the interface between the pressure transducer and the digitizer and we are exploring ways of reducing this noise floor.

The pressure data recorded at the BDSN broadband seismic stations is available on−line at the Northern California Earthquake Data Center via URL: http://quake.geo.berkeley.edu. The pressure, recorded at 1 sample per second, is the LDS data stream. Likewise, the seismic pier temperature is available as the LKS data stream.

Future Plans.

We plan to install the Druck PTX−1240 barograph when YBH is visited for the VSAT and associated instrumentation upgrade circa May 2001 as weather and time permits. The goal is to house the pressure sensor and associated electronics inside the hard rock mining drift for thermal stability and to connect the pressure sensor to a manifold which leads outside the vault to a noise reduction system of permeable hoses near the adit to sense the ambient atmospheric pressure.

At present, a medium resolution (~21 bit) digitizer board installed in the Quanterra Q935 data logger is recording internal vault pressure and seismic pier temperature at a 1 Hz sampling rate. The encouraging results of the Druck PTX−1240 sensor tests obtained using a high resolution (24+ bit) digitizer in the Byerly Vault indicate that we need to install a high resolution (24+ bit) digitizer board in the Quanterra Q935 data logger at YBH to record the atmospheric pressure with adequate resolution.

We have concentrated on the performance of the pressure transducer in the lower frequency bands that are of interest for seismic noise reduction using cross correlation methodologies to remove the pressure correlated component of the seismic background noise. An available spare channel on the high resolution digitizer board would allow the recording of a second pressure channel. Thus the possibility exists to also record a second channel from the pressure transducer with filtration and amplification to obtain a 0.02 Hz − 8 Hz bandwidth (sampled at 20 Hz) and a ~0.4 mPa LSB resolution as specified in the CTBT recommendations for infrasound stations.