PROGRESS REPORT

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Ground-based Monitoring R and E Technology Report

Evaluation of the Kinemetrics/Quanterra Q330HR Remote Seismic System For IRIS/GSN

Q330HR /GainX1 Configuration

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Abstract

Sandia National Laboratories has tested and evaluated the Kinemetrics/Quanterra Q330HR remote seismic system for IRIS/GSN applications. The test results included in this report were for response to static and dynamic input signals, data time-tag accuracy, and seismic application performance. Most test methodologies used were based on IEEE Standards 1057 for Digitizing Waveform Recorders and 1241 for Analog to Digital Converters; others were designed by Sandia specifically for seismic application evaluation and for supplementary criteria not addressed in the IEEE standards. When appropriate, test instrumentation calibration is traceable to the National Institute for Standards Technology (NIST).

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1 Executive Summary

Objectives:
The objectives of this work were (1) to evaluate the overall technical performance of the Kinemetrics/Quanterra Q330HR 6-channel remote seismic system and measure the distortions introduced by the high-resolution digitizers and (2) evaluate the technical performance of the Q330HR for IRIS GSN STS-1, KS54000, STS-2, and CMG-3TB seismic applications. The result of this evaluation can be compared to relevant IRIS application requirements or specifications.

Description:
The Q330HR remote seismic system was built by Quanterra, Harvard, MA, and was configured for 6-channel operation. Q330HR/A (Channels 1-3) are high resolution (26-bit) and Q330HR/B (Channels 4-6) are standard resolution (24-bit).For these tests the Q330HR was configured to acquire 6 channels of data in combinations of simultaneous acquisition streams at 200, 100, 40, 20, 1 and 0.1 samples per second. Quanterra provided Willard-HR configuration/data acquisition software for the Q330HR digitizer. It operated on a PC and communicated with the Q330HR through a LAN Ethernet connection. Data were acquired in real-time on the PB14F Bailer in Mini-SEED flat-file records. The Q330HR tested was set to the preamplifier gain of X1 (0dB). Testing was performed in a seismic vault for temperature stability.

1.1 Q330HR- 200SPS Digitizer Evaluation Summary:

Static Performance:
Q330HR/A DC accuracy errors were within 3.5% for nominal and 0.07% for full-scale. DC offset was less than 3/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 1.86 µV RMSfor a bandwidth of 0.1 to 100 Hz. The Maximum Potential Dynamic Range was better than 137.7 dB.

Broadband Dynamic Performance:
Q330HR/A Bandwidth measured –3 dB at 74.4 Hz with a relative attenuation of –130 dB at the Nyquist.

Timing Performance:
The Q330HR/A time-tagged the data to better than 1.2 microseconds.

Seismic Application Performance:
Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low-Earth Noise Model (LNM) between 0.01 and 60.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

1.2 Q330HR- 100SPS Digitizer Evaluation Summary:

Static Performance:
Q330HR/A DC accuracy errors were within 4% for nominal and 0.06% for full-scale. DC offset was less than 3.0/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 0.96 µV RMS for a bandwidth of 0.1 to 50 Hz. The Maximum Potential Dynamic Range was better than 143.4 dB

Q330HR/B DC accuracy errors were within 4% for nominal and 0.06% for full-scale. DC offset was less than 7.3/0.32 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 3.5 µV RMS for a bandwidth of 0.1 to 50 Hz. The Maximum Potential Dynamic Range was better than 132.1dB.

Broadband Dynamic Performance:
Q330HR/A Bandwidth measured –3 dB at 43.14 Hz with a relative attenuation of –90 dB at the Nyquist.

Q330HR/B Bandwidth measured –3 dB at 43.14 Hz with a relative attenuation of –90 dB at the Nyquist.

Timing Performance:
The Q330HR/A time-tagged the data to better than 1 microsecond.

<u>Seismic Application Performance:</u>
Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 50.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

Q330HR/B Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 22.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

1.3 Q330HR- 40SPS Digitizer Evaluation Summary:

<u>Static Performance:</u>
Q330HR/A DC accuracy errors were within 4% for nominal and 0.08% for full-scale. DC offset was less than 7.3/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 0.58 µV RMS for a bandwidth of 0.01 to 20 Hz. The Maximum Potential Dynamic Range was better than 147.7 dB. The Q330HR/A/B will hard clip at an input of > +/- 35 Volts.

Q330HR/B DC accuracy errors were within 4% for nominal and 0.08% for full-scale. DC offset was less than 7.3/0.32 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 2.6 µV RMS for a bandwidth of 0.01 to 20 Hz. The Maximum Potential Dynamic Range was better than 134.5 dB.

<u>Tonal Dynamic Performance:</u>
The Q330HR/A Total Harmonic Distortion (THD) was better than –117.5 dB. Crosstalk between channels was better than –152 dB. CMR is better than -85 dB at 1 Hz. Common Mode Voltage up to +/- 8 Volts was tolerated by the Q330HR/A. Common Mode Voltages over +/-8 Volts resulted in erratic behavior.

The Q330HR/B Total Harmonic Distortion (THD) was better than - 94.5 dB. Crosstalk between channels was not observable.

<u>Broadband Dynamic Performance:</u>
Q330HR/A Bandwidth measured –3 dB at 16.31 Hz with a relative attenuation of –85 dB at the Nyquist. RTF indicated channel to channel timing is better than 0.11 microseconds. Timing between the Q330HR/A and Q330HR/B was better than 0.56 microseconds.

Q330HR/B Bandwidth measured –3 dB at 16.31 Hz with a relative attenuation of –85 dB at the Nyquist. RTF indicated channel to channel timing is better than 0.11 microseconds.

<u>Timing Performance:</u>
The Q330HR/A time-tagged the data to better than 1 microseconds.

The Q330HR/B time-tagged the data to better than 29 microseconds.

<u>Seismic Application Performance:</u>
Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 20.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 9.0 Hz when used with a Streckeisen STS-2 Low Gain seismometer.

Q330HR/B Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 20.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

1.4 Q330HR- 20SPS Digitizer Evaluation Summary:

Static Performance:
Q330HR/A DC accuracy errors were within 3.5% for nominal and 0.08% for full-scale. DC offset was less than 2.9/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 0.51 µV RMS for a bandwidth of 0.01 to 10 Hz. The Maximum Potential Dynamic Range was better than 148.8 dB. The Q330HR/A/B will hard clip at an input of > +/- 35 Volts.

Tonal Dynamic Performance:
The Q330HR/A Total Harmonic Distortion (THD) was better than –118.0 dB.

The Q330HR/B Total Harmonic Distortion (THD) was better than - 94.5 dB.

Broadband Dynamic Performance:
Q330HR/A Bandwidth measured –3 dB at 8.62 Hz with a relative attenuation of –85 dB at the Nyquist.

Timing Performance:
The Q330HR/A time-tagged the data to better than 2.4 microseconds.

Seismic Application Performance:
Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 10.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 10.0 Hz when used with a Guralp CMG-3TB seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 10.0 Hz when used with a Streckeisen STS-1 seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 7.0 Hz when used with a Geotech KS54000 seismometer.

1.5 Q330HR- 1SPS Digitizer Evaluation Summary:

Static Performance:
Q330HR/A DC accuracy errors were within 4% for nominal and 0.08% for full-scale. DC offset was less than 7.3/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 0.62 µV RMS for a bandwidth of 0.001 to 0.5 Hz. The Maximum Potential Dynamic Range was better than 147.1 dB.

Q330HR/B DC accuracy errors were within 4% for nominal and 0.08% for full-scale. DC offset was less than 7.3/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 1.7 µV RMS for a bandwidth of 0.001 to 0.5 Hz. The Maximum Potential Dynamic Range was better than 137.4 dB.

Broadband Dynamic Performance:
Q330HR/A Bandwidth measured –3 dB at 0.39 Hz with a relative attenuation of –80 dB at the Nyquist.

Q330HR/B Bandwidth measured –3 dB at 0.39 Hz with a relative attenuation of –80 dB at the Nyquist.

Timing Performance:
The Q330HR/A time-tagged the data to better than 400 microseconds.

The Q330HR/B time-tagged the data to better than 600 microseconds.

Seismic Application Performance:
Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Streckeisen STS-1 seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Geotech KS54000 seismometer.

Q330HR/B Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Streckeisen STS-1 seismometer.

Q330HR/B Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.004 and 0.5 Hz when used with a Geotech KS54000 seismometer.

Q330HR/B Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Guralp CMG-3TB seismometer.

1.6 Q330HR- 0.1SPS Digitizer Evaluation Summary:

Static Performance:
Q330HR/A DC accuracy errors were within 0.55% for nominal. DC offset was less than 0.37 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 0.8 µV RMS for a bandwidth of 0.0001 to 0.05 Hz. The Maximum Potential Dynamic Range was better than 145.0 dB.

Broadband Dynamic Performance:
Q330HR/A Bandwidth measured –3 dB at 0.038 Hz with a relative attenuation of –120 dB at the Nyquist.

Timing Performance:
The Q330HR/A time-tagged the data to better than 1.32 milliseconds.

Seismic Application Performance:
Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.0001 and 0.05 Hz when used with a Streckeisen STS-1 seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.0001 and 0.05 Hz when used with a Geotech KS54000 seismometer.

1.7 Observations/Conclusion:

Initially the Q330HR exhibited errors in bit-weight as shown in the DCA test. Discussions with Quanterra indicated that the Q330HR self calibrated and set the bit weights appropriately. Using internal diagnostics, it was determined that the self-calibration on some channels was outside the correctable range. As the Q330HR operated over time, the self calibration circuitry was able to eventually correct the bit-weights. This was shown in the DCFS test performed at a later date.

2 Introduction

2.1 Scope

This Evaluation Report defines the process that was performed as part of the evaluation and testing of the Kinemetrics/Quanterra Q330HR Digitizing Waveform Recorder (DWR) as a remote seismic system for IRIS GSN application.

A digitizing waveform recorder can consist of a single channel element or multi-channel elements of geophysical digitizers/data acquisition systems. The DWR converts analog signals from the interfaced geophysical sensor(s) to a digital representation of this analog signal without introducing unacceptable distortions. It contains one or more High-Resolution Digitizers (HRD) to convert the analog signals to digital form. The digital samples are either stored on local recording media and/or sent to a central collection point for storage and/or analysis.

2.2 Objectives

The objectives of this work were (1) to evaluate the overall technical performance of the Kinemetrics/Quanterra Q330HR 6-channel remote seismic system and measure the distortions introduced by the high-resolution digitizers and (2) evaluate the technical performance of the Q330HR for IRIS GSN STS-1, KS54000, STS-2, and CMG-3TB seismic applications. The result of this evaluation can be compared to relevant IRIS application requirements or specifications.

3 Test and Evaluation Program

3.1 Test and Evaluation Background

Sandia National Laboratories (SNL), Ground-based Monitoring R&E Department has the capability of evaluating the performance of digitizing waveform recorders and analog-to-digital converters/high-resolution digitizers for geophysical applications.

3.2 Standardization/Traceability

Most tests are based on the Institute of Electrical and Electronics Engineers (IEEE) Standard 1057 for Digitizing Waveform Recorders [Reference 1] and Standard 1241 for Analog to Digital Converters [Reference 2]. The analyses based on these standards were performed in the frequency domain or time domain as required. When appropriate, instrumentation calibration was traceable to the National Institute for Standards Technology (NIST).

3.3 Test/Evaluation Process

3.3.1 Q330HR Testing

Testing of the Q330HR was performed from November through May, 2006, at the Sandia National Laboratories Facility for Acceptance, Calibration and Testing (FACT Site) and Albuquerque Seismic Labs (ASL) , Albuquerque, NM.

3.3.2 Q330HR General Digitizer Performance Tests

The following tests were conducted on the Q330HR. A detailed Test Plan Matrix is provided in the Test Data Sheet, Appendix I, Section 6.1. This is based on the basic set of tests as outlined in the Sandia Ground-based Monitoring R and E Technology Report: *Test Plan for the Evaluation of Digitizing Waveform Recorder Subsystems for Ground-based Geophysical Monitoring* [Reference 3].

Static Performance Tests

- DC Accuracy Nominal (DCA)
- DC Accuracy Full-Scale (DCFS)
- AC Clip (ACC)
- Input Terminated Noise (ITN)

Maximum Potential Dynamic Range (MPDR)

Tonal Dynamic Performance Tests

Total Harmonic Distortion (THD)

Crosstalk (CTK)

Common Mode Rejection ratio (CMR)

Broadband Dynamic Performance Tests

Modified Noise Power Ratio (MNPR)

Relative Transfer Function (RTF)

Analog Bandwidth (ABW)

Timing Tests

Time-Tag Accuracy (TTA)

Seismic Application Tests

Seismic System Noise (SSN)

As a comparison, some of the previous tests on a Quanterra Q680 are provided in Appendix II, Section 7.

3.4 Test Configuration and System Specifications

3.4.1 Q330HR Digitizer Description and Test Configuration

The Q330HR remote seismic system was built by Quanterra, Harvard, MA, and was configured for 6-channel operation. Q330HR/A (Channels 1-3) are high resolution (26-bit) and Q330HR/B (Channels 4-6) are standard resolution (24-bit). For these tests the Q330HR was configured to acquire 6 channels of data in combinations of simultaneous acquisition streams at 200, 100, 40, 20, 1 and 0.1 samples per second. Quanterra provided Willard-HR configuration/data acquisition software for the Q330HR digitizer. It operated on a PC and communicated with the Q330HR through a LAN Ethernet connection. Data were acquired in real-time on the PB14F Bailer in Mini-SEED flat-file records. The Q330HR tested was set to the preamplifier gain of X1 (0dB). Testing was performed in a seismic vault for temperature stability (Figure 3.4.1). The Q330HR description is shown on Test Data Sheet, Appendix I, Section 6.2.

Figure 3.4.1 Q330HR Testing in ASL Tunnel

3.4.2 Q330HR IRIS GSN Seismometer Application Parameters and Response

The IRIS GSN STS-1, KS54000, STS-2, and CMG-3TB responses are indicated in the Test Data Sheet, Appendix I, Section 6.3. The Q330HR gain configuration characteristics are shown on Test Data Sheet, Appendix I, Section 6.4.

4 Q330HR – Gain X1 Tests

4.1 Static Performance Tests

Static tests provide a constant or non time-varying stimulus to the DWR under test. The purpose of these tests is to determine specific parameters such as: gain (accuracy at nominal and full-scale), DC offset, short-term and long-term stability, relationship to quantizing noise floor, and correlated/uncorrelated spurious signals. The results of these tests include measurement of dynamic range and resolution.

4.1.1 DC Accuracy Nominal (DCA)

Purpose: The purpose of the DC accuracy test was to determine and verify the accuracy of the Q330HR. The bit-weight (LSB) of a non-gain-ranged digitizer is its resolution.

Configuration: The Q330HR inputs were connected to a +/- DC voltage source set to +/- 1 volt.

Evaluation: The DC gain (accuracy) of the Q330HR, DC offset, bit-weight (LSB)/resolution and counts/volt were measured.

Test Results are shown on the DCA/DCFS Test Data Sheet, Appendix I, Section 6.5.

4.1.2 DC Accuracy Full-Scale (DCFS)

Purpose: The purpose of the DC full-scale test was to determine and verify the accuracy of the Q330HR at full-scale. The full-scale value was used in calculating Maximum Potential Dynamic Range (MPDR).

Configuration: The Q330HR inputs were connected to a +/- DC voltage source set to +/- 20 volts.

Evaluation: The DC gain (accuracy) of the Q330HR, DC offset, bit-weight (LSB)/resolution and counts/volt at full-scale were measured.

Test Results are shown on the DCA/DCFS Test Data Sheet, Appendix I, Section 6.5.

4.1.3 AC Clip (ACC)

Purpose: The purpose of the AC clip test was to determine and verify the maximum signal or clip level of the Q330HR.

Configuration: The Q330HR inputs were connected to an AC voltage source set to 1 Hz. The amplitude of the sinusoid was increased until the value of hard clip was reached.

Evaluation: The AC clip voltage of the Q330HR was measured.

Test Results are shown on the ACC Test Data Sheet, Appendix I, Section 6.6.

4.1.4 Input Terminated Noise (ITN)

Purpose: The purpose of the input-terminated noise test was to verify the static parameters of the Q330HR. These static parameters are dominated primarily by the random noise generated within the digitizer and from other components within the digitizer package.

Configuration: The Q330HR inputs were terminated with 100 ohms. This value approximates the output impedance of the GSN application seismometers.

Evaluation: A power density spectrum (PDS) of the input-terminated noise provided a measure of the noise floor of the digitizer. RMS noise in the appropriate bandwidth, short-term and long-term stability, relationship to quantizing noise floor and correlated and uncorrelated spurious signals were measured.

Test Results are shown on the ITN/MPDR Test Data Sheet, Appendix I, Section 6.7.

4.1.5 Maximum Potential Dynamic Range (MPDR) Computation

Calculating the RMS value of the full-scale sinusoid (20 Volts) and dividing by the RMS value of the Input Terminated Noise (ITN) test data determined the Maximum Potential Dynamic Range (MPDR) of the Q330HR. The appropriate bandwidth was used.

Test Results are shown on the ITN/MPDR Test Data Sheet, Appendix I, Section 6.7.

4.2 Tonal Dynamic Performance Tests

Dynamic tests are those that provide a time-varying stimulus to the DWR under evaluation. The purpose of these tests is to determine the DWR performance when digitizing time-varying signals. Multitudes of tests are available to determine the DWR digitizer's self noise, deviation from ideal performance and conversion distortions.

Tonal tests are dynamic tests that use sinusoids as stimuli. Sine waves are the most popular signals for evaluating analog-to-digital converter performance because of the ease of generation and mathematical analysis. The DWR under test is asynchronously sampled with respect to the signal source for all tonal tests.

4.2.1 Total Harmonic Distortion (THD)

Purpose: The purpose of the total harmonic distortion test was to verify the linearity and to identify sources of non-linearities of the Q330HR.

Configuration: The Q330HR inputs were connected to an ultra-low-distortion oscillator. The amplitude of the oscillator was set to approximately one-half full scale (21.0 V peak to peak) for the Q330HR. The oscillator was set to a frequency (1.4 Hz) unrelated to the sample rate and with nine or more harmonics observable.

Evaluation: A power density spectrum provided a measure of the non-linearity of the Q330HR. THD was calculated by integrating the power density spectral peaks at the fundamental and all harmonics (up to nine) below the Nyquist frequency.

Test Results are shown on the THD Test Data Sheet, Appendix I, Section 6.8.

4.2.2 Crosstalk (CTK)

Purpose: The purpose of the crosstalk test was to determine the extent of crosstalk between channels on the multi-channel Q330HR.

Configuration: The Q330HR channel under test was terminated with 50 ohms. All other Q330HR inputs were connected to a large amplitude (20 volt peak-to-peak) sinusoidal (1 Hz) test signal.

Evaluation: A power density spectrum provided a measure of crosstalk. The ratio of test signal to crosstalk signal was calculated using integrated power density spectra around the signal frequency.

Test Results are shown on the CTK/CMR Test Data Sheet, Appendix I, Section 6.9.

4.2.3 Common-Mode Rejection Ratio (CMR)

Purpose: The purpose of the common-mode rejection test was to determine the ability of the Q330HR to reject a common-mode signal on differential inputs.

Configuration: The individual inputs of each channel of the Q330HR were connected to an isolated, large amplitude (16 Volts peak to peak), sinusoidal (1.1 Hz) test signal. The test generator common was connected to the signal reference on the Q330HR.

Evaluation: A power density spectrum provided a measure of the un-rejected common-mode signal. The ratio of test signal to common-mode signal is the common-mode rejection ratio.

Test Results are shown on the CTK/CMR Test Data Sheet, Appendix I, Section 6.9.

4.3 Broadband Dynamic Performance Tests

Dynamic tests are those that provide a time-varying stimulus to the DWR under evaluation. The purpose of these tests is to determine the DWR performance when digitizing time-varying signals. Multitudes of tests are available to determine the DWR digitizer's self noise, deviation from ideal performance and conversion distortions. Broadband tests are dynamic tests that use Gaussian pseudo-random signal generators as stimuli.

4.3.1 Modified Noise Power Ratio (MNPR)

Purpose: The purpose of the modified noise-power-ratio test was to determine the Q330HR performance compared to n-bit ideal digitizers. This test determined the performance of the Q330HR at all amplitudes from small signal to clip level.

Configuration: The Q330HR inputs were connected to a bandwidth-limited Gaussian signal generator. The bandwidth of the signal generator was set to avoid aliasing the Q330HR and to maximize the power within the passband. The signal generator output was varied from a low level to the Q330HR clip level.

Evaluation: Coherence analysis computation provided a noise-power-ratio value for each level of input signal to the Q330HR. These estimated noise power ratios were compared to the performance model of n-bit ideal digitizers.

MNPR Tests were not performed due to instrumentation problems.

4.3.2 Relative Transfer Function (RTF)

Purpose: The purpose of the relative transfer function test was to determine the relative phase between channels in the multi-channel Q330HR.

Configuration: The Q330HR inputs were connected to a bandwidth-limited Gaussian signal generator. The signal generator output amplitude was set to greater than one-half the full-scale range of the Q330HR.

Evaluation: Coherence analysis computation provided a measure of relative phase. Channel skew was calculated.

Test Results are shown on the RTF/ABW Test Data Sheet, Appendix I, Section 6.10.

4.3.3 Analog Bandwidth (ABW)

Purpose: The purpose of the analog bandwidth test was to verify the bandwidth of the Q330HR digital FIR filter.

Configuration: The Q330HR inputs were connected to a bandwidth-limited Gaussian signal generator. The signal generator output amplitude was set to greater than one-half the full-scale range of the Q330HR.

Evaluation: A power density spectrum provided a measure of the Q330HR digitizer bandwidth. The 3 dB point and relative attenuation at the Nyquist of the digital FIR filters were measured.

Test Results are shown on the RTF/ABW Test Data Sheet, Appendix I, Section 6.10.

4.4 Timing Tests

Geophysical digitizing waveform recorders utilize a Universal Time Code (UTC) source, typically GPS, to time-tag the digitizer data samples. The HRD internal clock is usually synchronized to or phase-locked to this UTC receiver. The following timing test determines the accuracy of this time-tag.

4.4.1 Time Tag Accuracy (TTA)

Purpose: The purpose of the time tag accuracy test was to verify the ability of the Q330HR digitizer to accurately time-tag the data samples with respect to the Q330HR inputs.

Configuration: The Q330HR inputs were connected to the One Pulse per Hour (PPH) output of an independent running GPS Timing Reference.

Evaluation: The time tags of the data from the digitizer were analyzed for correct time on the hour transition. Q330HR sample rate (samples per second/minute) was verified.

Test Results are shown on the TTA Test Data Sheet, Appendix I, Section 6.11.

4.5 Seismic Application Tests

Seismic application tests are those that provide a stimulus to the DWR or interpret data from the DWR that is related to a specific seismic application. The DWR selected for an application should match the characteristics of the interfaced seismometer and the expected seismic signals and background. Seismic applications can use all of the available bandwidth when interfaced to broadband seismic sensors or just a part of the available bandwidth when interfaced to long-period or short-period seismic sensors. The choice of system parameters is partially determined by the background that is expected at the location of the seismometer. A properly matched DWR/seismometer can resolve the expected seismic signals and backgrounds while nearly maximizing the system dynamic range.

4.5.1 Seismic System Noise (SSN)

Purpose: The purpose of the seismic system noise test was to determine ability of the Q330HR to resolve the expected seismic background using a specific seismometer. The Q330HR self-noise should be below the expected seismic background and the self-noise of the seismometer. The Q330HR was designed to interface to IRIS GSN STS-1, KS54000, STS-2, and CMG-3TB seismometers. For reference, the seismic background is the USGS Low-Earth Noise Model (LNM).

Configuration: The power spectral density results of the Input Terminated Noise (ITN) test were used to determine the seismic system noise of the Q330HR.

Evaluation: The system noise of the Q330HR was converted to ground motion spectral units using the mathematical model for IRIS GSN STS-1, KS54000, STS-2, and CMG-3TB responses. The results of these conversions were overlaid with the USGS Low Earth Noise Model (LNM) to demonstrate the ability of the Q330HR to resolve a very quiet seismic background. Seismometer sensor noise models were included when available.

Test Results are shown on the SSN Test Data Sheet, Appendix I, Section 6.12.

5 Summary

Objectives:
The objectives of this work were (1) to evaluate the overall technical performance of the Kinemetrics/Quanterra Q330HR 6-channel remote seismic system and measure the distortions introduced by the high-resolution digitizers and (2) evaluate the technical performance of the Q330HR for IRIS GSN STS-1, KS54000, STS-2, and CMG-3TB seismic applications. The result of this evaluation can be compared to relevant IRIS application requirements or specifications.

Description:
The Q330HR remote seismic system was built by Quanterra, Harvard, MA, and was configured for 6-channel operation. Q330HR/A (Channels 1-3) are high resolution (26-bit) and Q330HR/B (Channels 4-6) are standard resolution (24-bit).For these tests the Q330HR was configured to acquire 6 channels of data in combinations of simultaneous acquisition streams at 200, 100, 40, 20, 1 and 0.1 samples per second. Quanterra provided Willard-HR configuration/data acquisition software for the Q330HR digitizer. It operated on a PC and communicated with the Q330HR through a LAN Ethernet connection. Data were acquired in real-time on the PB14F Bailer in Mini-SEED flat-file records. The Q330HR tested was set to the preamplifier gain of X1 (0dB). Testing was performed in a seismic vault for temperature stability.

5.1 Q330HR- 200SPS Digitizer Evaluation Summary:
Static Performance:
Q330HR/A DC accuracy errors were within 3.5% for nominal and 0.07% for full-scale. DC offset was less than 3/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 1.86 µV RMSfor a bandwidth of 0.1 to 100 Hz. The Maximum Potential Dynamic Range was better than 137.7 dB.

Broadband Dynamic Performance:
Q330HR/A Bandwidth measured –3 dB at 74.4 Hz with a relative attenuation of –130 dB at the Nyquist.

Timing Performance:
The Q330HR/A time-tagged the data to better than 1.2 microseconds.

Seismic Application Performance:
Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low-Earth Noise Model (LNM) between 0.01 and 60.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

5.2 Q330HR- 100SPS Digitizer Evaluation Summary:
Static Performance:
Q330HR/A DC accuracy errors were within 4% for nominal and 0.06% for full-scale. DC offset was less than 3.0/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 0.96 µV RMS for a bandwidth of 0.1 to 50 Hz. The Maximum Potential Dynamic Range was better than 143.4 dB

Q330HR/B DC accuracy errors were within 4% for nominal and 0.06% for full-scale. DC offset was less than 7.3/0.32 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 3.5 µV RMS for a bandwidth of 0.1 to 50 Hz. The Maximum Potential Dynamic Range was better than 132.1dB.

Broadband Dynamic Performance:
Q330HR/A Bandwidth measured –3 dB at 43.14 Hz with a relative attenuation of –90 dB at the Nyquist.

Q330HR/B Bandwidth measured –3 dB at 43.14 Hz with a relative attenuation of –90 dB at the Nyquist.

Timing Performance:
The Q330HR/A time-tagged the data to better than 1 microsecond.

Seismic Application Performance:

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 50.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

Q330HR/B Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 22.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

5.3 Q330HR- 40SPS Digitizer Evaluation Summary:

Static Performance:
Q330HR/A DC accuracy errors were within 4% for nominal and 0.08% for full-scale. DC offset was less than 7.3/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 0.58 µV RMS for a bandwidth of 0.01 to 20 Hz. The Maximum Potential Dynamic Range was better than 147.7 dB. The Q330HR/A/B will hard clip at an input of > +/- 35 Volts.

Q330HR/B DC accuracy errors were within 4% for nominal and 0.08% for full-scale. DC offset was less than 7.3/0.32 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 2.6 µV RMS for a bandwidth of 0.01 to 20 Hz. The Maximum Potential Dynamic Range was better than 134.5 dB.

Tonal Dynamic Performance:
The Q330HR/A Total Harmonic Distortion (THD) was better than –117.5 dB. Crosstalk between channels was better than –152 dB. CMR is better than -85 dB at 1 Hz. Common Mode Voltage up to +/- 8 Volts was tolerated by the Q330HR/A. Common Mode Voltages over +/-8 Volts resulted in erratic behavior.

The Q330HR/B Total Harmonic Distortion (THD) was better than - 94.5 dB. Crosstalk between channels was not observable.

Broadband Dynamic Performance:
Q330HR/A Bandwidth measured –3 dB at 16.31 Hz with a relative attenuation of –85 dB at the Nyquist. RTF indicated channel to channel timing is better than 0.11 microseconds. Timing between the Q330HR/A and Q330HR/B was better than 0.56 microseconds.

Q330HR/B Bandwidth measured –3 dB at 16.31 Hz with a relative attenuation of –85 dB at the Nyquist. RTF indicated channel to channel timing is better than 0.11 microseconds.

Timing Performance:
The Q330HR/A time-tagged the data to better than 1 microseconds.

The Q330HR/B time-tagged the data to better than 29 microseconds.

Seismic Application Performance:
Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 20.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 9.0 Hz when used with a Streckeisen STS-2 Low Gain seismometer.

Q330HR/B Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 20.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

5.4 Q330HR- 20SPS Digitizer Evaluation Summary:

Static Performance:

Q330HR/A DC accuracy errors were within 3.5% for nominal and 0.08% for full-scale. DC offset was less than 2.9/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 0.51 µV RMS for a bandwidth of 0.01 to 10 Hz. The Maximum Potential Dynamic Range was better than 148.8 dB. The Q330HR/A/B will hard clip at an input of > +/- 35 Volts.

<u>Tonal Dynamic Performance:</u>
The Q330HR/A Total Harmonic Distortion (THD) was better than –118.0 dB.

The Q330HR/B Total Harmonic Distortion (THD) was better than - 94.5 dB.

<u>Broadband Dynamic Performance:</u>
Q330HR/A Bandwidth measured –3 dB at 8.62 Hz with a relative attenuation of –85 dB at the Nyquist.

<u>Timing Performance:</u>
The Q330HR/A time-tagged the data to better than 2.4 microseconds.

<u>Seismic Application Performance:</u>
Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 10.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 10.0 Hz when used with a Guralp CMG-3TB seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 10.0 Hz when used with a Streckeisen STS-1 seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 7.0 Hz when used with a Geotech KS54000 seismometer.

5.5 Q330HR- 1SPS Digitizer Evaluation Summary:

<u>Static Performance:</u>
Q330HR/A DC accuracy errors were within 4% for nominal and 0.08% for full-scale. DC offset was less than 7.3/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 0.62 µV RMS for a bandwidth of 0.001 to 0.5 Hz. The Maximum Potential Dynamic Range was better than 147.1 dB.

Q330HR/B DC accuracy errors were within 4% for nominal and 0.08% for full-scale. DC offset was less than 7.3/0.35 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 1.7 µV RMS for a bandwidth of 0.001 to 0.5 Hz. The Maximum Potential Dynamic Range was better than 137.4 dB.

<u>Broadband Dynamic Performance:</u>
Q330HR/A Bandwidth measured –3 dB at 0.39 Hz with a relative attenuation of –80 dB at the Nyquist.

Q330HR/B Bandwidth measured –3 dB at 0.39 Hz with a relative attenuation of –80 dB at the Nyquist.

<u>Timing Performance:</u>
The Q330HR/A time-tagged the data to better than 400 microseconds.

The Q330HR/B time-tagged the data to better than 600 microseconds.

<u>Seismic Application Performance:</u>

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Streckeisen STS-1 seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Geotech KS54000 seismometer.

Q330HR/B Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Streckeisen STS-1 seismometer.

Q330HR/B Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.004 and 0.5 Hz when used with a Geotech KS54000 seismometer.

Q330HR/B Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Guralp CMG-3TB seismometer.

5.6 Q330HR- 0.1SPS Digitizer Evaluation Summary:

Static Performance:
Q330HR/A DC accuracy errors were within 0.55% for nominal. DC offset was less than 0.37 milliVolts (see 1.7 Observations). The Input Terminated Noise was less than 0.8 µV RMS for a bandwidth of 0.0001 to 0.05 Hz. The Maximum Potential Dynamic Range was better than 145.0 dB.

Broadband Dynamic Performance:
Q330HR/A Bandwidth measured –3 dB at 0.038 Hz with a relative attenuation of –120 dB at the Nyquist.

Timing Performance:
The Q330HR/A time-tagged the data to better than 1.32 milliseconds.

Seismic Application Performance:
Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.0001 and 0.05 Hz when used with a Streckeisen STS-1 seismometer.

Q330HR/A Seismic Signal Noise (SSN) test indicated that the response corrected noises were at or below the USGS Low Earth Noise Model (LNM) between 0.0001 and 0.05 Hz when used with a Geotech KS54000 seismometer.

5.7 Observations/Conclusion:

Initially the Q330HR exhibited errors in bit-weight as shown in the DCA test. Discussions with Quanterra indicated that the Q330HR self calibrated and set the bit weights appropriately. Using internal diagnostics, it was determined that the self-calibration on some channels was outside the correctable range. As the Q330HR operated over time, the self calibration circuitry was able to eventually correct the bit-weights. This was shown in the DCFS test performed at a later date.

References:

1. IEEE Standard for Digitizing Waveform Recorders, IEEE Std. 1057-1994.

2. IEEE Standard for Analog to Digital Converters, IEEE Std. 1241-2001.

3. Kromer, Richard P., McDonald, Timothy S., Townsend, Toby O., Ground-based Monitoring R and E Technology Report, ‘Test Plan for the Evaluation of Digitizing Waveform Recorder Subsystems for Ground-based Geophysical Monitoring’, 26 February 2002.

6 Appendix I: Q330HR Test Data Sheets

6.1 Q330HR Test Data Sheet: Q330HR Test Plan Matrix

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Test Description: Define Q330HR Test Plan.

200 SPS	Q330HR Sensor A (Ch 1-3), 0dB Gain		
Test Type	**Channel 1 00-ELZ**	**Channel 2 00-ELN**	**Channel 3 00-ELE**
DCA	**TEST**	**TEST**	**TEST**
DCFS	**TEST**	**TEST**	**TEST**
ITN/MPDR	**TEST**	**TEST**	**TEST**
ABW	**TEST**	NA	NA
TTA	**TEST**	NA	NA
SSN	**TEST**	**TEST**	**TEST**

100 SPS	Q330HR Sensor A (Ch 1-3), 0dB Gain			Q330HR Sensor B (Ch 4-6), 0dB Gain		
Test Type	**Channel 1 00-HLZ**	**Channel 2 00-HLN**	**Channel 3 00-HLE**	**Channel 4 00-HHZ**	**Channel 5 00-HHN**	**Channel 6 00-HHE**
DCA	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
DCFS	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
ITN/MPDR	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
ABW	**TEST**	NA	NA	**TEST**	NA	NA
TTA	**TEST**	NA	NA	NA	NA	NA
SSN	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**

40 SPS	Q330HR Sensor A (Ch 1-3), 0dB Gain			Q330HR Sensor B (Ch 4-6), 0dB Gain		
Test Type	**Channel 1 00-SLZ**	**Channel 2 00-SLN**	**Channel 3 00-SLE**	**Channel 4 00-SHZ**	**Channel 5 00-SHN**	**Channel 6 00-SHE**
DCA	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
DCFS	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
ITN/MPDR	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
ACC	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
THD	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
RTF	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
ABW	**TEST**	NA	NA	**TEST**	NA	NA
TTA	**TEST**	NA	NA	**TEST**	NA	NA
SSN	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**

20 SPS	Q330HR Sensor A (Ch 1-3), 0dB Gain			Q330HR Sensor B (Ch 4-6), 0dB Gain		
Test Type	**Channel 1 00-BLZ**	**Channel 2 00-BLN**	**Channel 3 00-BLE**	**Channel 4**	**Channel 5**	**Channel 6**
DCA	**TEST**	**TEST**	**TEST**	NA	NA	NA
DCFS	**TEST**	**TEST**	**TEST**	NA	NA	NA
ITN/MPDR	**TEST**	**TEST**	**TEST**	NA	NA	NA
ACC	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
THD	**TEST**	**TEST**	**TEST**	NA	NA	NA
CTK	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
CMR	**TEST**	**TEST**	**TEST**	NA	NA	NA
ABW	**TEST**	NA	NA	NA	NA	NA
TTA	**TEST**	NA	NA	NA	NA	NA
SSN	**TEST**	**TEST**	**TEST**	NA	NA	NA

1.0 SPS	Q330HR Sensor A (Ch 1-3), 0dB Gain			Q330HR Sensor B (Ch 4-6), 0dB Gain		
Test Type	**Channel 1 00-LLZ**	**Channel 2 00-LLN**	**Channel 3 00-LLE**	**Channel 4 00-LHZ**	**Channel 5 00-LHN**	**Channel 6 00-LHE**
DCA	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
DCFS	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
ITN/MPDR	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**
ABW	**TEST**	NA	NA	**TEST**	NA	NA
TTA	**TEST**	NA	NA	**TEST**	NA	NA
SSN	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**	**TEST**

0.1 SPS	Q330HR Sensor A (Ch 1-3), 0dB Gain		
Test Type	**Channel 1 00-XLZ (1)**	**Channel 2 00-XLN (2)**	**Channel 3 00-XLE (3)**
DCA	**TEST**	**TEST**	**TEST**
ITN/MPDR	**TEST**	**TEST**	**TEST**
ABW	**TEST**	NA	NA
TTA	**TEST**	NA	NA
SSN	**TEST**	**TEST**	**TEST**

6.2 Q330HR Test Data Sheet: Q330HR Description

****

Test Description: Describe Q330HR under evaluation.

Q330HR Serial Number: 1550
Software: 1.74/1.11
QAPCHP: 10/101
GPS: Motorola M12/PLD: 4.9
Data Format Mode CH 1-3: 26-bit
Data Format Mode CH 4-6: 24-bit
Filter/Decimate Setup:
Linear Phase FIR 200/100/40/20/1/0.1 SPS

Input Impedance:

CH 1-3	**67.5K Ohms**
CH 4-6	**33.9K Ohms**

6.3 Q330HR Test Data Sheet: GSN Seismometer Responses

****

6.3.1 Streckeisen STS-1:

Test Description: Define STS-1 Seismometer Response.

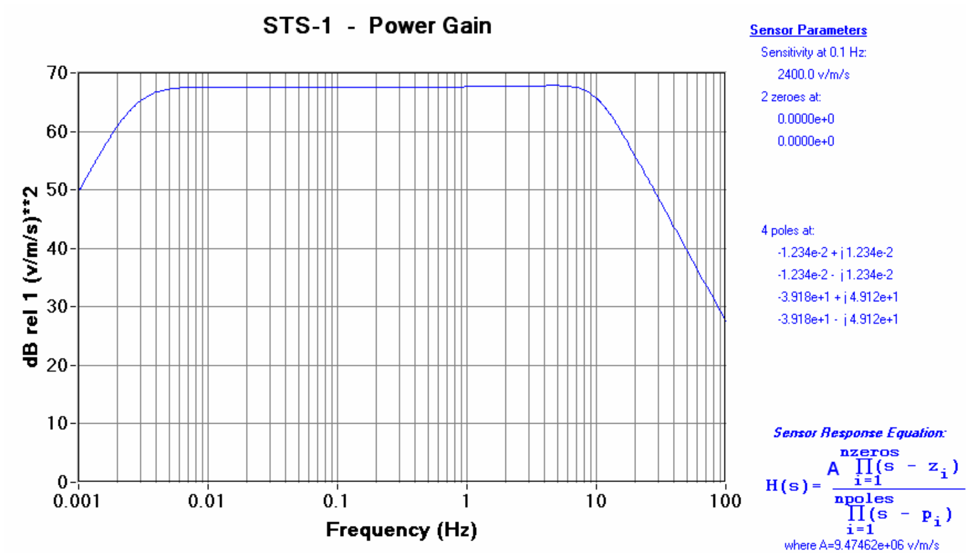


Figure 6.3.1 IRIS/GSN STS-1 Gain Plot

6.3.2 Streckeisen STS-2 High Gain:

Test Description: Define STS-2 Seismometer Response.

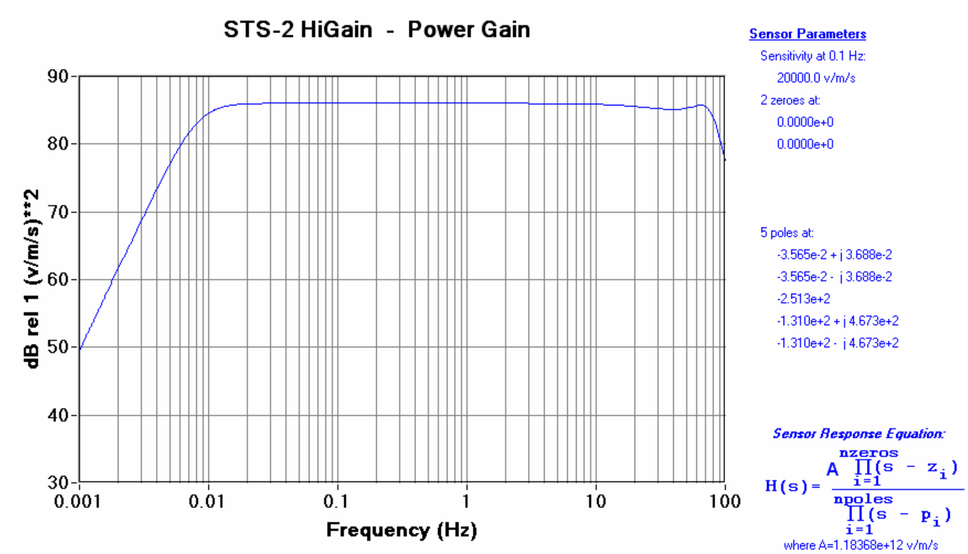
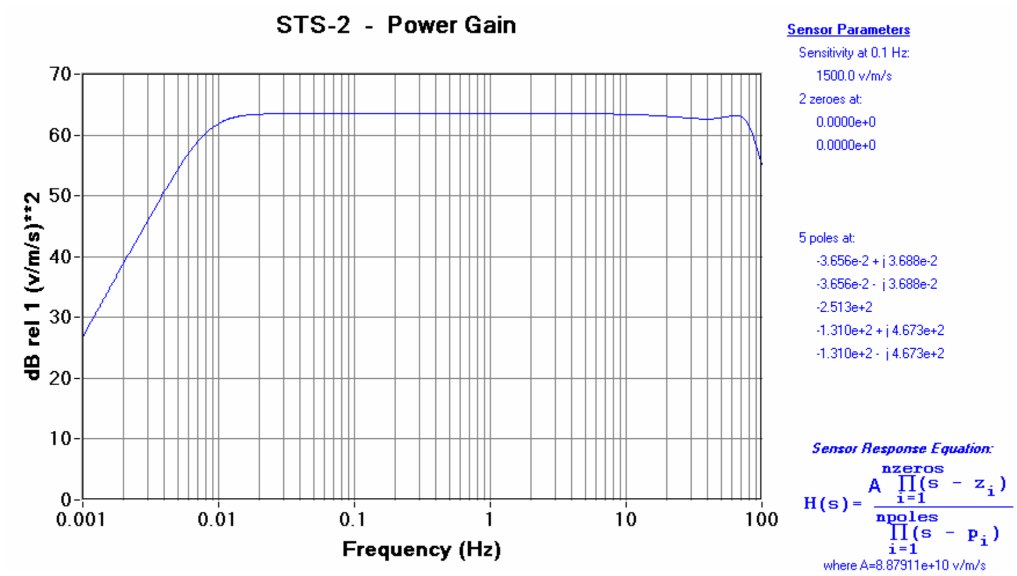


Figure 6.3.2 IRIS/GSN STS-2 High Gain Plot

6.3.3 Streckeisen STS-2 Low Gain:

Test Description: Define STS-2 Seismometer Response.

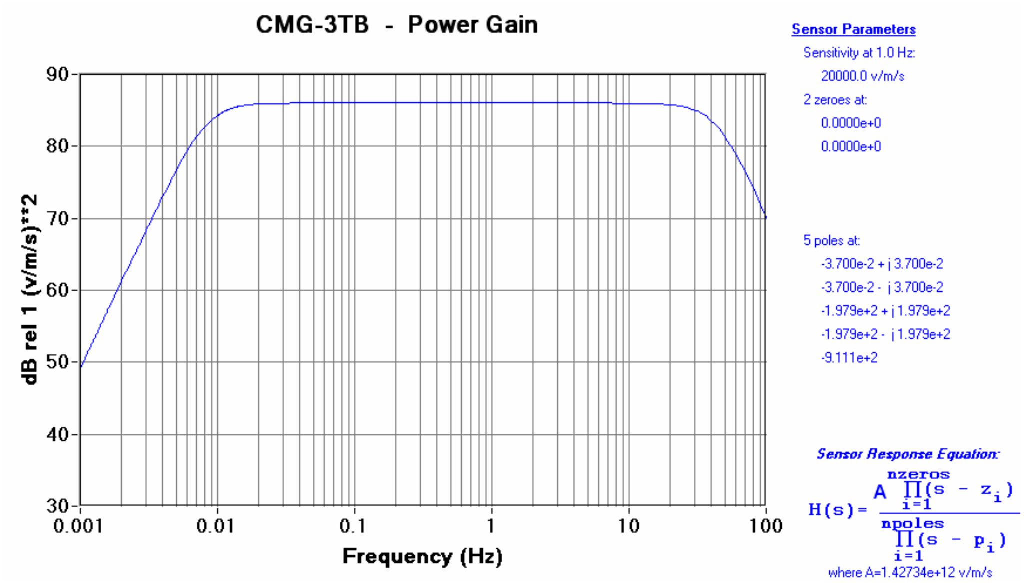


$$H(s) = \frac{A \prod_{i=1}^{nzeros} (s - z_i)}{\prod_{i=1}^{npoles} (s - p_i)}$$

Figure 6.3.3 IRIS/GSN STS-2 Low Gain Plot

6.3.4 Guralp CMG-3TB High Gain:

Test Description: Define CMG-3TB Seismometer Response.



$$H(s) = \frac{A \prod_{i=1}^{nzeros} (s - z_i)}{\prod_{i=1}^{npoles} (s - p_i)}$$

Figure 6.3.4 IRIS/GSN GMG-3TB Gain Plot

6.3.5 Geotech KS54000:

Test Description: Define KS54000 Seismometer Response.

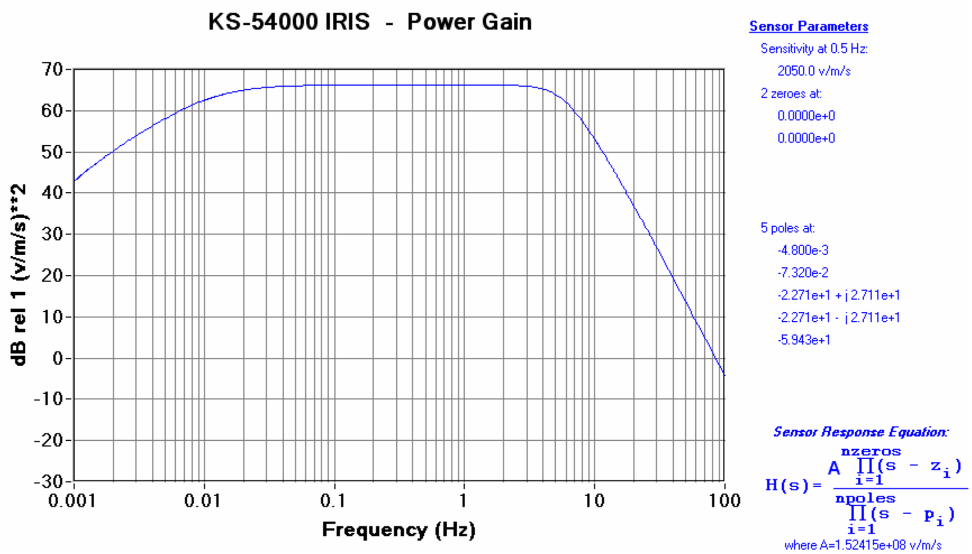


Figure 6.3.5 IRIS/GSN KS54000 Gain Plot

6.4 Q330HR Test Data Sheet: Q330HR Gain Configuration

Q330HR S/N: 1550 **Software Version: 1.74**

Q330HR Sample Rate: 200, 100, 40, 20, 1, 0.1 sps
****

Gain Configuration:

Q330HR/A Ch 1-3 is in 26-bit mode with gain=1.

Volts/Count for preamplifier gain=1 (per Quanterra) **0.596 µV/count**

Manufacturer Specified Nominal Volts/Count Based on Quanterra Q330HR Data Sheet.
Nominal Volts/Count: **0.5960464×10^{-6}**
Nominal Counts/Volt: 1677722
Maximum Data Range: 26 Bits (+/-counts) +/-20.0 V Differential

Q330HR/B Ch 4-6 is in 24-bit mode with gain=1.

Volts/Count for preamplifier gain=1 (per Quanterra) **2.384 µV/count**

Manufacturer Specified Nominal Volts/Count Based on Quanterra Q330HR Data Sheet.
Nominal Volts/Count: **2.384186×10^{-6}**
Nominal Counts/Volt: 419430
Maximum Data Range: 24 Bits (+/-counts) +/-20.0 V Differential

6.5 Q330HR Test Data Sheet: Test – Static/DCA/DCFS

Q330HR S/N: 1550 **Software Version: 1.74**

Q330HR Sample Rate: 200, 100, 40, 20, 1, 0.1 sps
Specified Nominal Volts/Count: CH1-3 0.596 x 10^{-6}
Specified Nominal Volts/Count: CH4-6 2.384 x 10^{-6}
****

DCA Test Description: Measure DC Accuracy and DC Full-Scale.

DCA- Specified Nominal Volts/Count, Ch1-3: 0.596x10^{-6}
DCA- Specified Nominal Volts/Count, Ch4-6: 2.384x10^{-6}
DCFS- Specified Full-Scale Volts: +/- 20.0V differential

6.5.1 Q330HR/A Sample Rate 200 sps:

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset mV
1	1.000	1676793	0.59638	-0.063	0.228
2	1.000	1736754	0.57579	3.511	-2.904
3	1.000	1677382	0.59617	-0.028	0.374

Table 6.5.1a DC Accuracy Nominal Results

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset µV
1	20.0	1676715	0.5964	-0.068	217.7
2	20.0	1676926	0.59633	-0.055	333.3
3	20.0	1677303	0.59619	-0.033	354.7

Table 6.5.1b DC Full-Scale Nominal Results

<u>Test Results:</u>
Tables 6.5.1a-b indicate that the Q330HR/A DC accuracy errors were within 3.5% for nominal and 0.07% for full-scale at 200 sps. DC offset was less than 3/0.35 milliVolts.

6.5.2 Q330HR/A Sample Rate 100 sps:

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset mV
1	1.000	1676845	0.59636	-0.06	0.228
2	1.000	1736807	0.57577	3.514	-2.904
3	1.000	1677433	0.59615	-0.025	0.374

Table 6.5.2a DC Accuracy Nominal Results

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset µV
1	20.0	1676767	0.59639	-0.065	214.1
2	20.0	1676977	0.59631	-0.052	337.5
3	20.0	1677355	0.59618	-0.030	352.9

Table 6.5.2b DC Full-Scale Nominal Results

Test Results:
Tables 6.5.2a-b indicate that the Q330HR/A DC accuracy errors were within 4% for nominal and 0.06% for full-scale at 100 sps. DC offset was less than 3.0/0.35 milliVolts.

6.5.3 Q330HR/B Sample Rate 100 sps:

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset mV
4	1.000	419255	2.38518	-0.049	-1.100
5	1.000	419567	2.38340	0.025	-1.492
6	1.000	436144	2.29282	3.977	7.3164

Table 6.5.3a DC Accuracy Nominal Results

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset µV
4	20.0	419222	2.38537	-0.057	317.3
5	20.0	419529	2.38362	-0.016	-83.4
6	20.0	419513	2.38371	-0.012	283.7

Table 6.5.3b DC Full-Scale Nominal Results

Test Results:
Tables 6.5.3a-b indicate that the Q330HR/B DC accuracy errors were within 4% for nominal and 0.06% for full-scale at 100 sps. DC offset was less than 7.3/0.32 milliVolts.

6.5.4 Q330HR/A Sample Rate 40 sps:

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset mV
1	1.000	1676602	0.59644	-0.075	0.228
2	1.000	1736555	0.57585	3.499	-2.904
3	1.000	1677190	0.59624	-0.039	0.374

Table 6.5.4a DC Accuracy Nominal Results

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset µV
1	20.0	1676523	0.59647	-0.079	224.9
2	20.0	1676734	0.59640	-0.067	328.0
3	20.0	1677112	0.59626	-0.044	350.6

Table 6.5.4b DC Accuracy Full-Scale Results

Test Results:
Tables 6.5.4a-b indicate that the Q330HR/A DC accuracy errors were within 4% for nominal and 0.08% for full-scale at 40 sps. DC offset was less than 2.9/0.35 milliVolts.

6.5.5 Q330HR/B Sample Rate 40 sps:

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset mV
4	1.000	419195	2.38552	-0.064	-1.100
5	1.000	419507	2.38375	0.011	-1.492
6	1.000	436080	2.29315	3.962	7.318

Table 6.5.5a DC Accuracy Nominal Results

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset µV
4	20.0	419161	2.38571	-0.072	314.9
5	20.0	419469	2.38397	0.001	-81.1
6	20.0	419452	2.38406	-0.002	281.3

Table 6.5.5b DC Accuracy Full-Scale Results

Test Results:
Tables 6.5.5a-b indicate that the Q330HR/B DC accuracy errors were within 4% for nominal and 0.07% for full-scale at 40 sps. DC offset was less than 7.3/0.32 milliVolts.

6.5.6 Q330HR/A Sample Rate 20 sps:

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset mV
1	1.000	1676653	0.59643	-0.071	0.228
2	1.000	1736608	0.57584	3.502	-2.904
3	1.000	1677241	0.59622	0.036	0.374

Table 6.5.6a DC Accuracy Nominal Results

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset µV
1	20.00	1676575	0.59645	-0.076	223.1
2	20.00	1676785	0.59638	-0.064	331.0
3	20.00	1677163	0.59624	-0.041	354.2

Table 6.5.6b DC Accuracy Full-Scale Results

<u>Test Results:</u>
Tables 6.5.6a-b indicate that the Q330HR/A DC accuracy errors were within 3.5% for nominal and 0.08% for full-scale at 20 sps. DC offset was less than 3.0/0.35 milliVolts.

6.5.7 Q330HR/A Sample Rate 1 sps:

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset mV
1	1.000	1676685	0.59641	-0.070	0.228
2	1.000	1736641	0.57582	3.504	-2.904
3	1.000	1677273	0.59621	-0.035	0.374

Table 6.5.7a DC Accuracy Nominal Results

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset µV
1	20.0	1676607	0.59644	-0.074	215.3
2	20.0	1676817	0.59637	-0.062	333.4
3	20.0	1677195	0.59623	-0.039	354.8

Table 6.5.7b DC Full-Scale Nominal Results

Test Results:
Tables 6.5.7a-b indicate that the Q330HR/A DC accuracy errors were within 3.5% for nominal and 0.08% for full-scale at 1 sps. DC offset was less than 3.0/0.35 milliVolts.

6.5.8 Q330HR/B Sample Rate 1 sps:

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset mV
4	1.000	419215	2.38541	-0.059	-1.100
5	1.000	419528	2.38363	0.015	-1.492
6	1.000	436102	2.29304	3.967	7.315

Table 6.5.8a DC Accuracy Nominal Results

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset µV
4	20.0	419182	2.38559	-0.067	322.1
5	20.0	419490	2.38384	0.007	-69.1
6	20.0	419473	2.38394	0.002	281.3

Table 6.5.8b DC Full-Scale Nominal Results

Test Results:
Tables 6.5.8a-b indicate that the Q330HR/B DC accuracy errors were within 4% for nominal and 0.07% for full-scale at 1 sps. DC offset was less than 7.3/0.32 milliVolts.

6.5.9 Q330HR/A Sample Rate 0.1 sps:

Channel	Test Input Volts	Counts/Volt	µVolts/Count	% Deviation from Nominal	DC Offset µV
1	1.000	1687082	0.59274	0.55	286.9
2	1.000	1687313	0.59266	0.56	366.9
3	1.000	1687665	0.59253	0.59	360.3

Table 6.5.9a DC Accuracy Nominal Results

Test Results:

Tables 6.5.9a-b indicate that the Q330HR/A DC accuracy errors were within 0.6% for nominal at 0.1 sps. DC offset was less than 0.37 milliVolts.

6.6 Q330HR Test Data Sheet: Test – Static/ACC

Q330HR S/N: 1550 **Software Version: 1.74**

Q330HR Sample Rate: 40, 20 sps
Specified Nominal Volts/Count: CH1-3 0.596 x 10^{-6}
Specified Nominal Volts/Count: CH4-6 2.384 x 10^{-6}
****

ACC Test Description: Measure the actual clip voltage of the Q330HR digitizers using a sinusoidal signal.

6.6.1 Q330HR/A Sample Rate 40 sps:

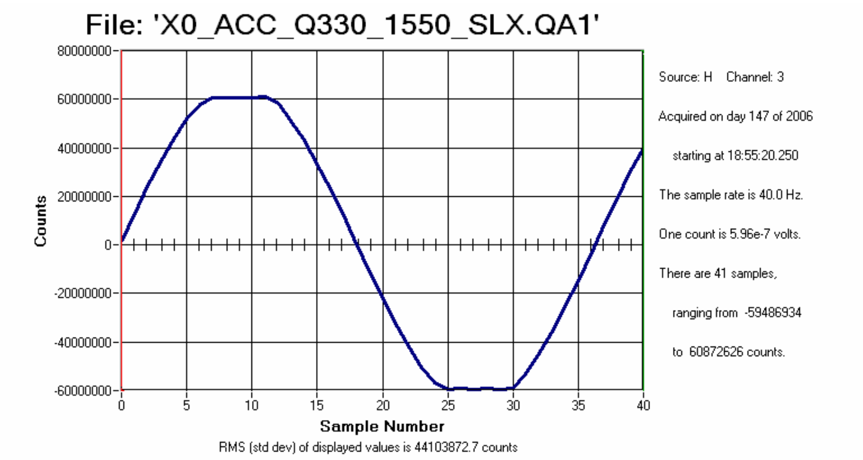


Figure 6.6.1 AC Clip Results

Channel	Positive Clip Voltage	Negative Clip Voltage
1	36.1	-35.4
2	36.6	-35.6
3	36.4	-35.7

Table 6.6.1 AC Clip Results

<u>Test Results:</u>
Figure 6.6.1 and Table 6.6.1 indicates that the Q330HR/A clip level is > +/-35 Volts

6.6.2 Q330HR/B Sample Rate 40 sps:

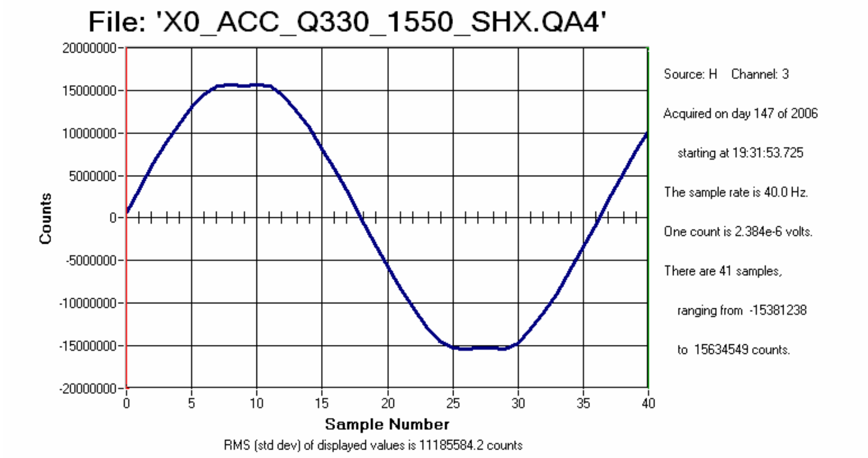


Figure 6.6.2 AC Clip Results

Channel	Positive Clip Voltage	Negative Clip Voltage
4	37.2	-36.5
5	36.6	-35.6
6	36.3	-35.6

Table 6.6.2 AC Clip Results

Test Results:
Figure 6.6.2 and Table 6.6.2 indicate that the Q330HR/B clip level is > +/-35 Volts

6.6.3 Q330HR/A Sample Rate 20 sps:

Channel	Positive Clip Voltage	Negative Clip Voltage
1	36.4	-35.5
2	36.6	-35.8
3	36.6	-35.8

Table 6.6.3 AC Clip Results

Test Results:
Table 6.6.3 indicates that the Q330HR/A clip level is > +/-35 Volts

6.6.4 Q330HR/B Sample Rate 20 sps:

Channel	Positive Clip Voltage	Negative Clip Voltage
4	37.3	-36.7
5	36.5	-35.8
6	36.2	-35.4

Table 6.6.4 AC Clip Results

<u>Test Results:</u>
Table 6.6.4 indicates hat the Q330HR/B clip level is > +/-35 Volts

6.7 Q330HR Test Data Sheet: Test – Static/ITN/MPDR

Q330HR S/N: 1550 **Software Version: 1.74**

Q330HR Sample Rate: 200, 100, 40, 20, 1, 0.1 sps
Specified Nominal Volts/Count: CH1-3 0.596 x 10^{-6}
Specified Nominal Volts/Count: CH4-6 2.384 x 10^{-6}
****

ITN Test Description: Measure Input Terminated Noise. Calculate Maximum Potential Dynamic Range using data from ITN Test.

6.7.1 Q330HR/A Sample Rate 200 sps:

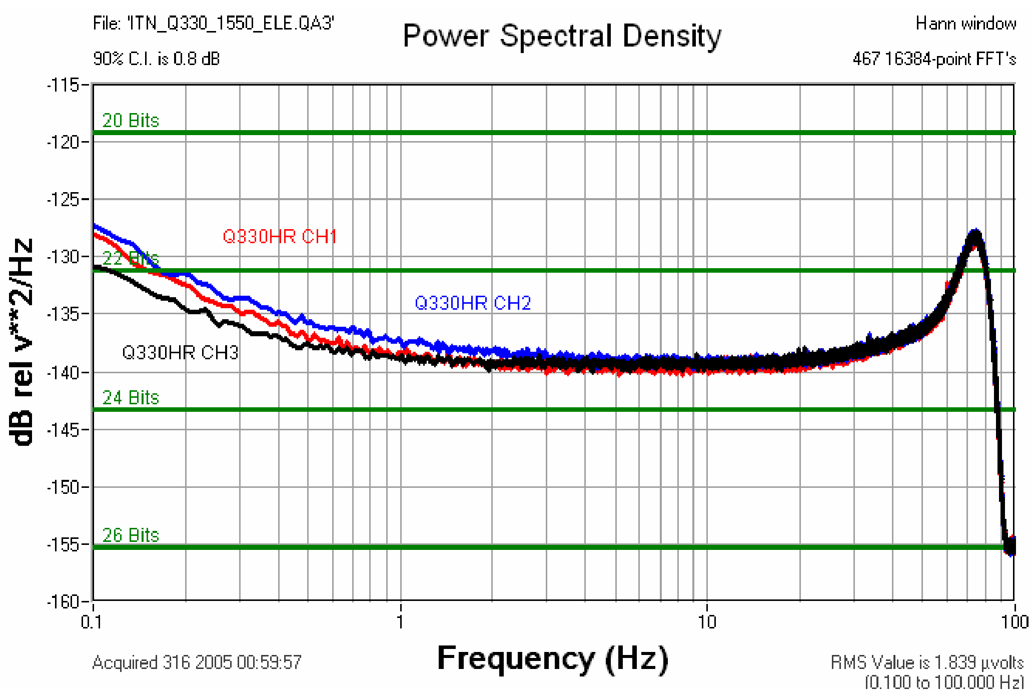


Figure 6.7.1 Q330HR 200SPS Channel 1-3 Input Terminated Noise

Channel	RMS Noise µV 0.1 to 100 Hz	RMS Full-Scale Volts	MPDR (dB)
1	1.805	14.14	137.9
2	1.861	14.14	137.6
3	1.839	14.14	137.7

Table 6.7.1 Q330HR 200SPS ITN/MPDR

<u>Test Results:</u>
Figure 6.7.1 and Table 6.7.1 indicate that the Q330HR/A has < 1.86 µV RMS noise at 200 sps. MPDR is better than 137.6 dB.

6.7.2 Q330HR/A Sample Rate 100 sps:

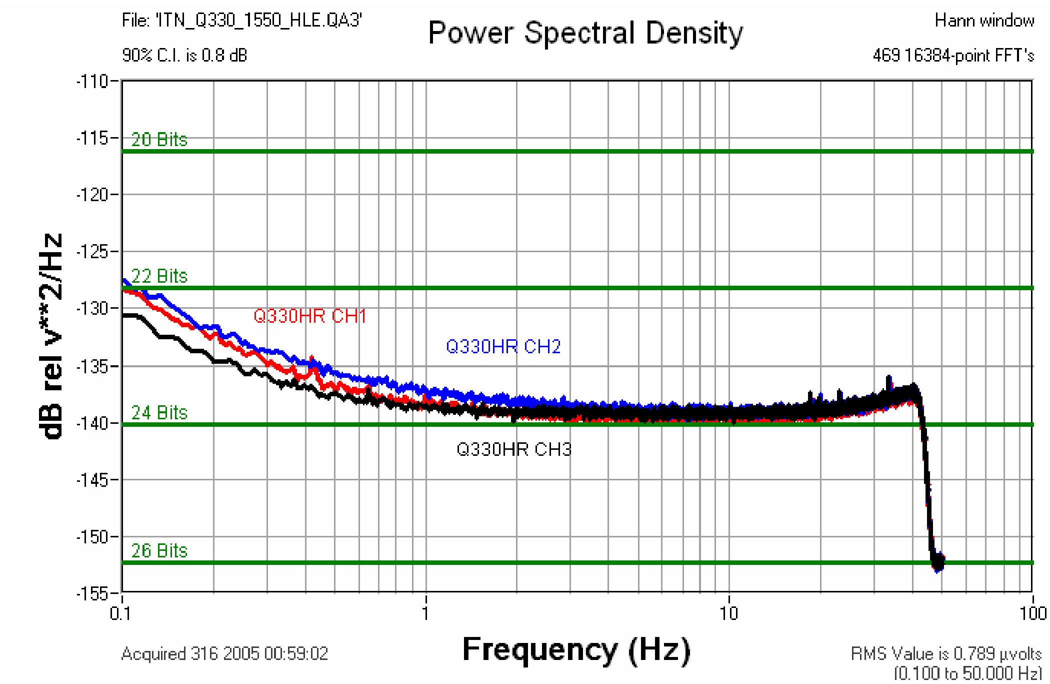


Figure 6.7.2 Q330HR 100SPS Channel 1-3 Input Terminated Noise

Channel	RMS Noise µV 0.1 to 50 Hz	RMS Full-Scale Volts	MPDR (dB)
1	0.774	14.14	145.2
2	0.960	14.14	143.4
3	0.790	14.14	145.0

Table 6.7.2 Q330HR 100SPS MPDR

Test Results:
Figure 6.7.2 and Table 6.7.2 indicate that the Q330HR/A has < 0.96 µV RMS noise at 100 sps. MPDR is better than 143.4 dB.

6.7.3 Q330HR/B Sample Rate 100 sps:

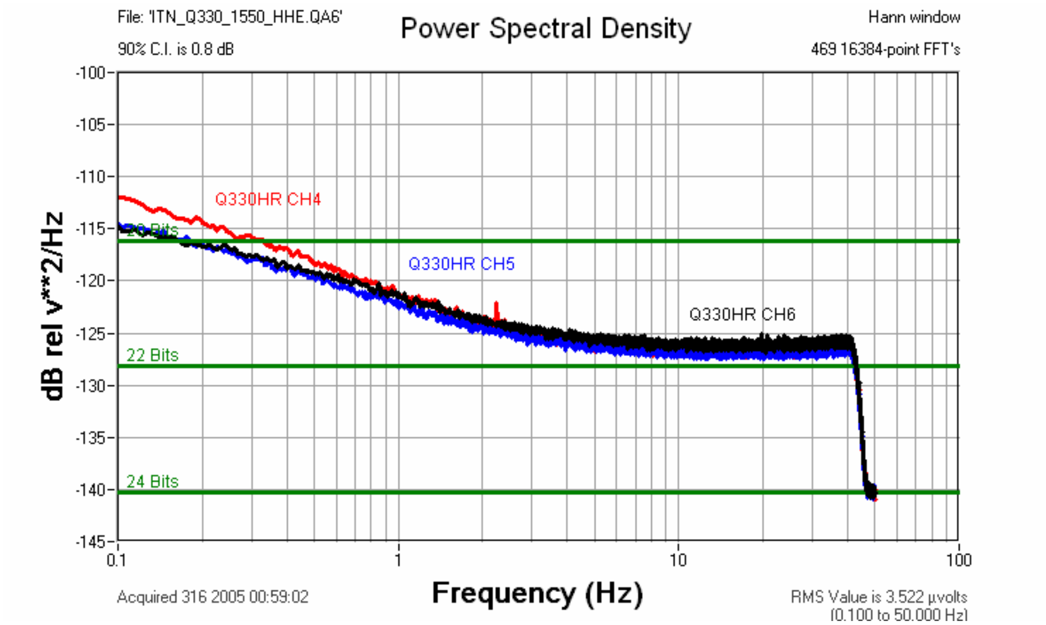


Figure 6.7.3 Q330HR 100SPS Channel 4-6 Input Terminated Noise

Channel	RMS Noise µV 0.1 to 50 Hz	RMS Full-Scale Volts	MPDR (dB)
4	3.441	14.14	132.3
5	3.252	14.14	132.8
6	3.522	14.14	132.1

Table 6.7.3 Q330HR 100SPS MPDR

Test Results:
Figure 6.7.3 and Table 6.7.3 indicate that the Q330HR/B has < 3.522 µV RMS noise at 100 sps. MPDR is better than 132.1 dB.

6.7.4 Q330HR/A Sample Rate 40 sps:

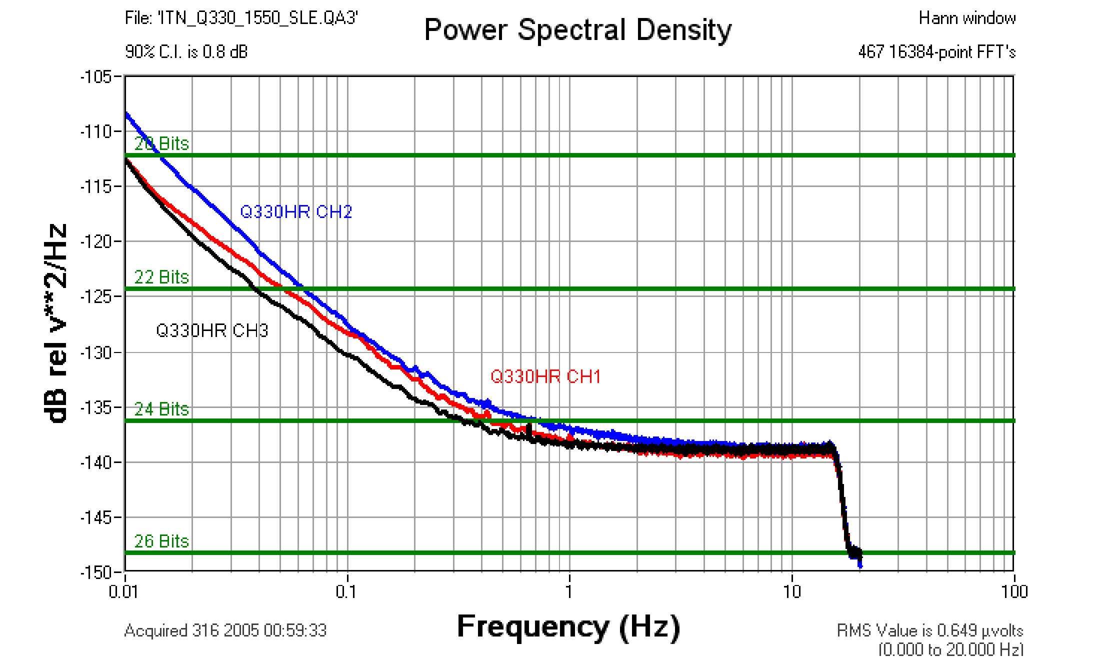


Figure 6.7.4 Q330HR 40SPS Channel 1-3 Input Terminated Noise

Channel	RMS Noise µV 0.01 to 20 Hz	RMS Full-Scale Volts	MPDR (dB)
1	0.521	14.14	148.7
2	0.583	14.14	147.7
3	0.513	14.14	148.8

Table 6.7.4 Q330HR 40SPS MPDR

<u>Test Results:</u>
Figure 6.7.4 and Table 6.7.4 indicate that the Q330HR/A has < 0.583 µV RMS noise at 40 sps. MPDR is better than 147.7 dB.

6.7.5 Q330HR/B Sample Rate 40 sps:

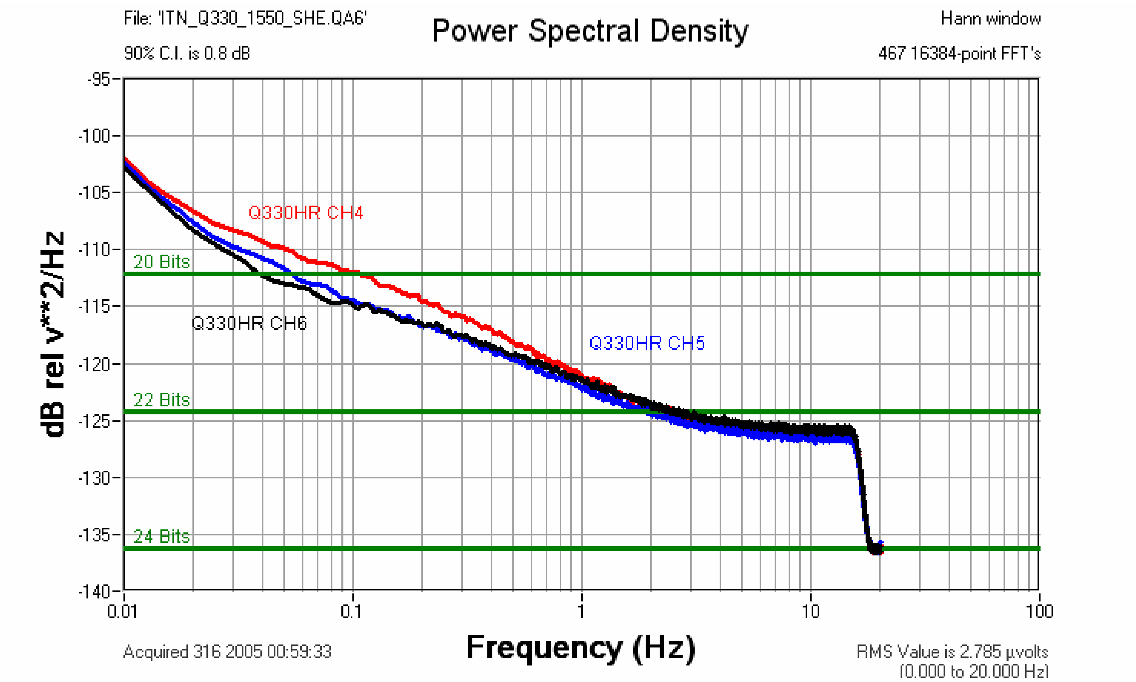


Figure 6.7.5 Q330HR 40SPS Channel 4-6 Input Terminated Noise

Channel	RMS Noise µV 0.01 to 20 Hz	RMS Full-Scale Volts	MPDR (dB)
4	2.655	14.14	134.5
5	2.416	14.14	135.3
6	2.543	14.14	134.9

Table 6.7.5 Q330HR 40SPS MPDR

Test Results:
Figure 6.7.5 and Table 6.7.5 indicate that the Q330HR/B has < 2.655 µV RMS noise at 40 sps. MPDR is better than 134.5 dB.

6.7.6 Q330HR/A Sample Rate 20 sps:

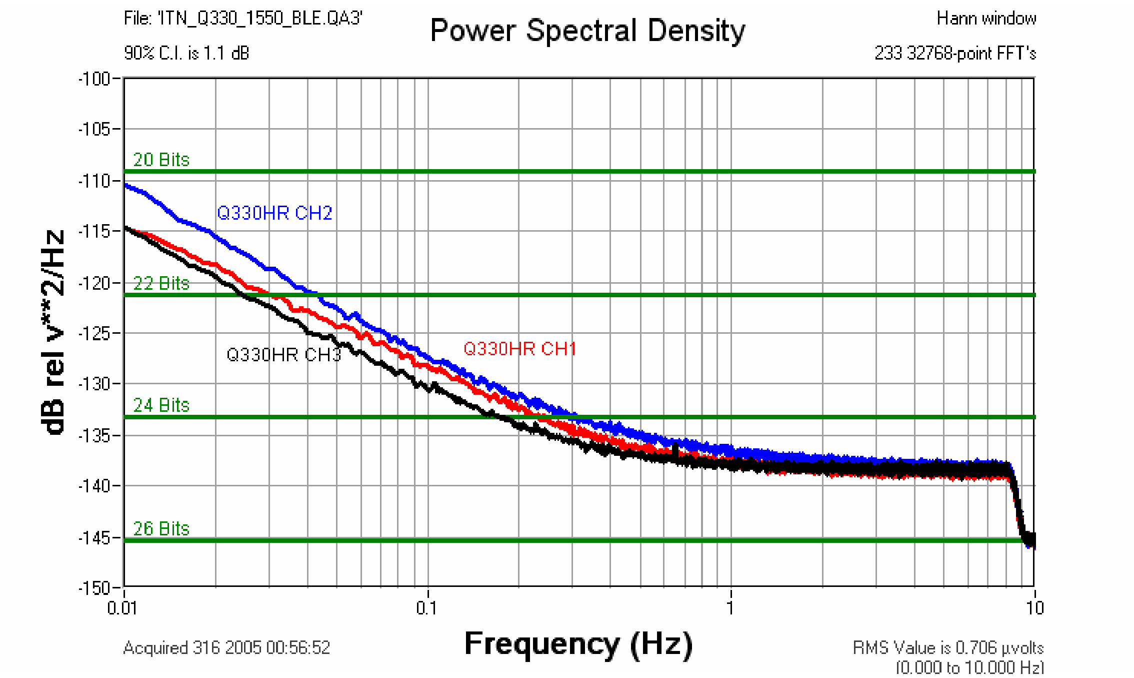


Figure 6.7.6 Q330HR 20SPS Channel 1-3 Input Terminated Noise

Channel	RMS Noise µV 0.01 to 10 Hz	RMS Full-Scale Volts	MPDR (dB)
1	0.440	14.14	150.1
2	0.514	14.14	148.8
3	0.424	14.14	150.5

Table 6.7.6 Q330HR 20SPS MPDR

Test Results:
Figure 6.7.6 and Table 6.7.6 indicate that the Q330HR/A has < 0.514 µV RMS noise at 20 sps. MPDR is better than 148.8 dB.

6.7.7 Q330HR/A Sample Rate 1 sps:

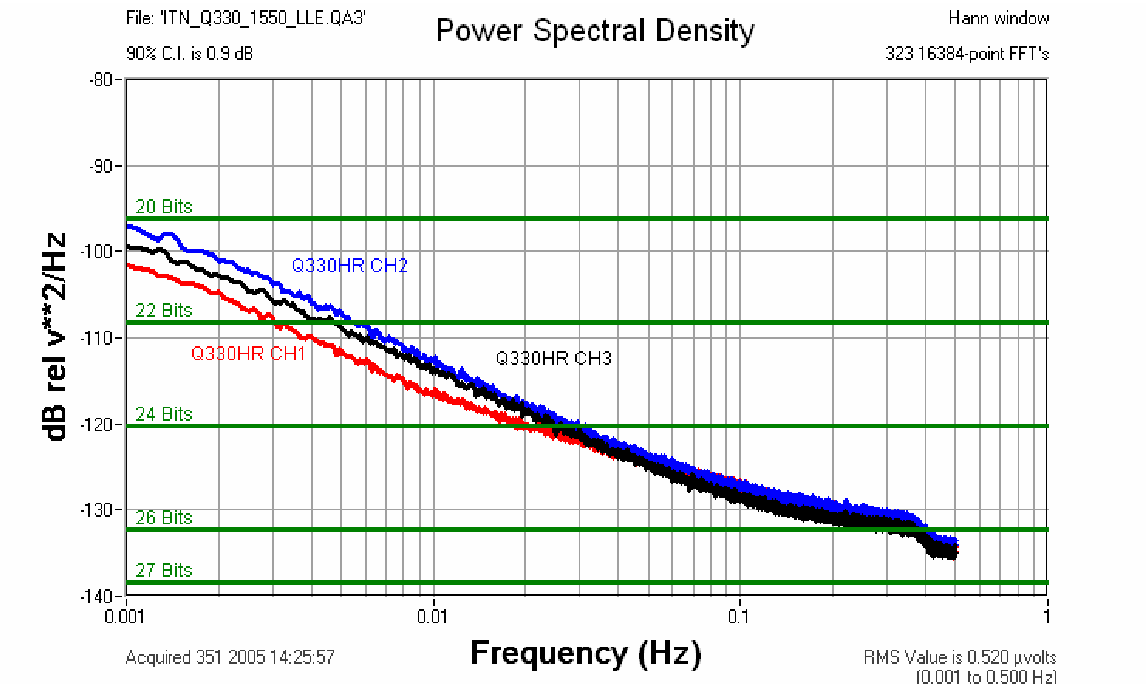


Figure 6.7.7 Q330HR 1SPS Channel 1-3 Input Terminated Noise

Channel	RMS Noise µV 0.001 to 0.5 Hz	RMS Full-Scale Volts	MPDR (dB)
1	0.428	14.14	150.4
2	0.623	14.14	147.1
3	0.520	14.14	148.7

Table 6.7.7 Q330HR 1SPS MPDR

Test Results:

Figure 6.7.7 and Table 6.7.7 indicate that the Q330HR/A has < 0.623 µV RMS noise at 1 sps. MPDR is better than 147.1 dB.

6.7.8 Q330HR/B Sample Rate 1 sps:

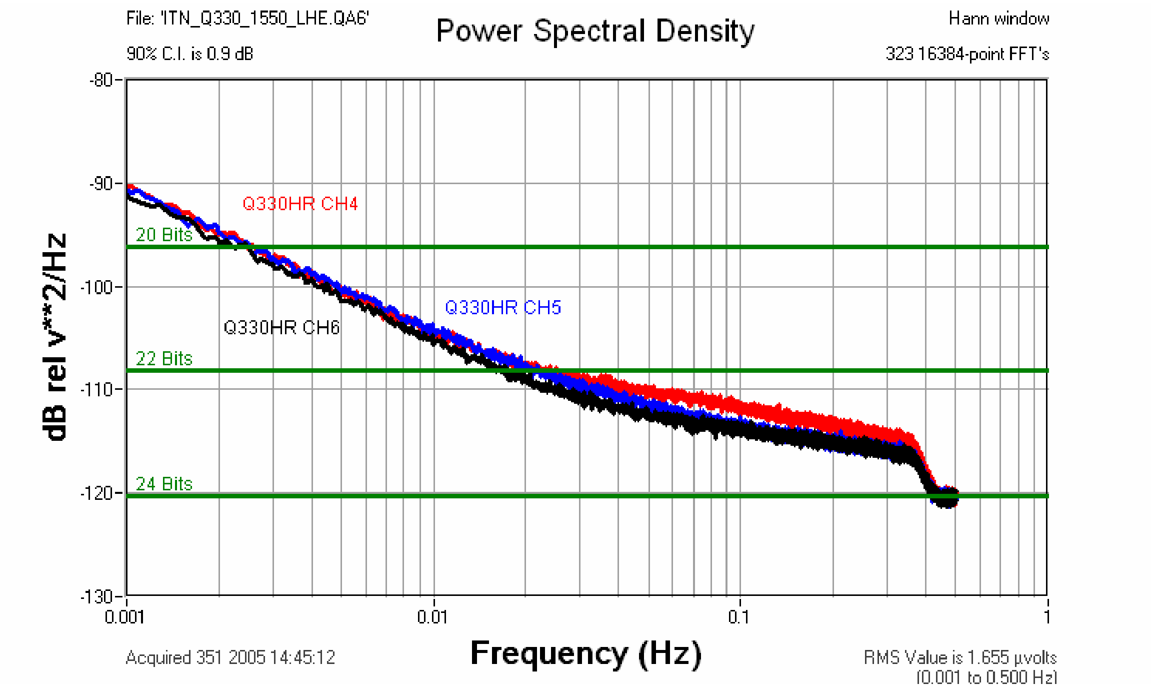


Figure 6.7.8 Q330HR 1SPS Channel 4-6 Input Terminated Noise

Channel	RMS Noise µV 0.001 to 0.5 Hz	RMS Full-Scale Volts	MPDR (dB)
4	1.915	14.14	137.4
5	1.766	14.14	138.1
6	1.655	14.14	138.6

Table 6.7.8 Q330HR 1SPS MPDR

Test Results:

Figure 6.7.8 and Table 6.7.8 indicate that the Q330HR/B has < 1.915 µV RMS noise at 1 sps. MPDR is better than 137.4 dB.

6.7.9 Q330HR/A Sample Rate 0.1 sps:

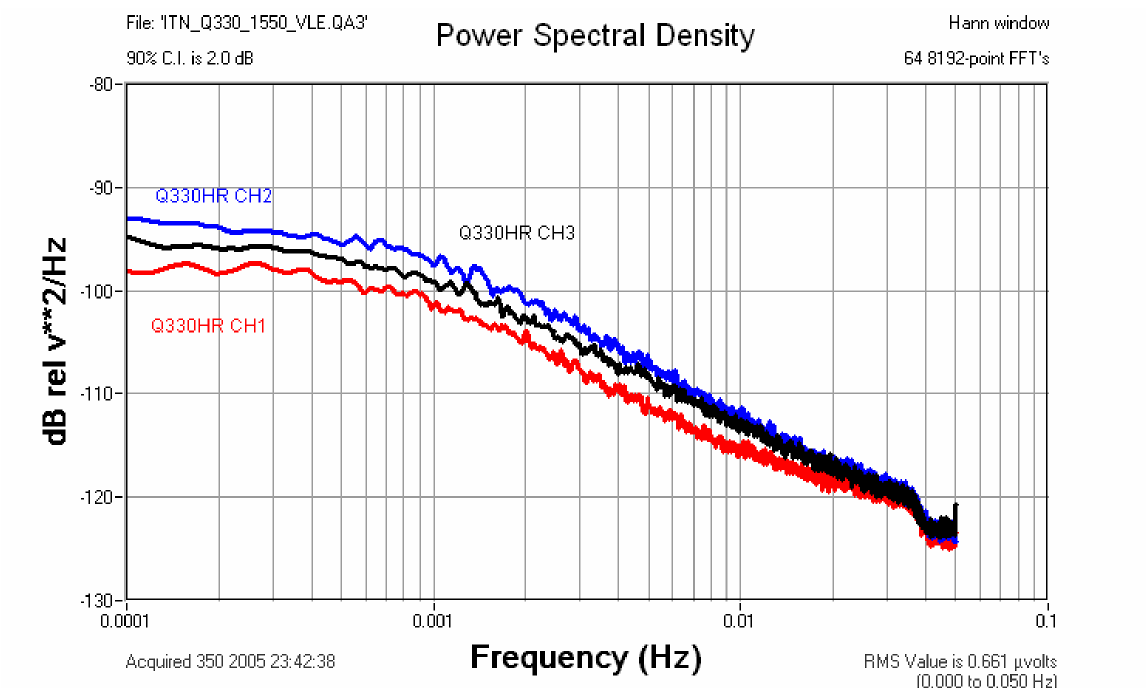


Figure 6.7.9 Q330HR 0.1SPS Channel 1-3 Input Terminated Noise

Channel	RMS Noise µV 0.0001 to 0.05 Hz	RMS Full-Scale Volts	MPDR (dB)
1	0.520	14.14	148.7
2	0.798	14.14	145.0
3	0.661	14.14	146.6

Table 6.7.9 Q330HR 0.1SPS MPDR

<u>Test Results:</u>
Figure 6.7.9 and Table 6.7.9 indicate that the Q330HR/A has < 0.798 µV RMS noise at 0.1 sps. MPDR is better than 145 dB.

6.8 Q330HR Test Data Sheet: Test – Dynamic Tonal/THD

Q330HR S/N: 1550 **Software Version: 1.74**

Q330HR Sample Rate: 40, 20 sps
Specified Nominal Volts/Count: CH1-3 0.596 x 10^{-6}
Specified Nominal Volts/Count: CH4-6 2.384 x 10^{-6}
****

THD Test Description: Measure the linearity of the Q330HR digitizers using Total Harmonic Distortion.

6.8.1 Q330HR/A Sample Rate 40 sps:

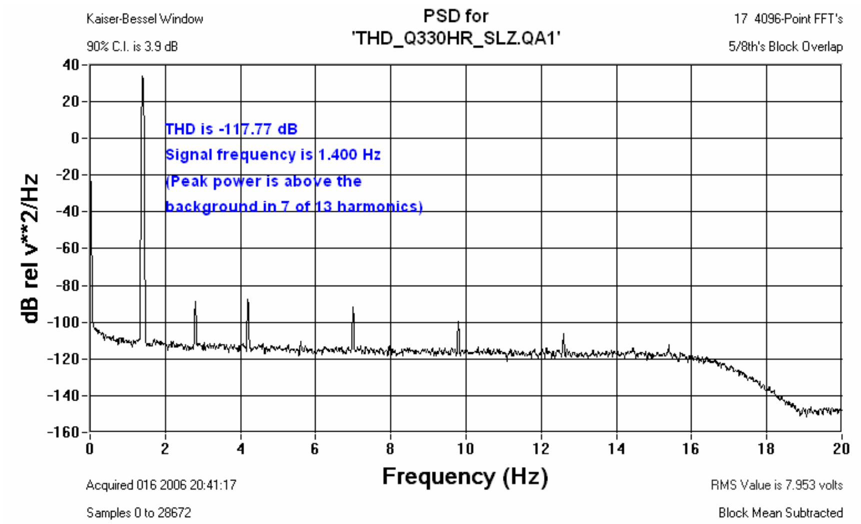


Figure 6.8.1 Q330HR Channel 1 Total Harmonic Distortion

Channel	THD (dB)
1	-117.8
2	-117.5
3	-117.8

Table 6.8.1 Q330HR 40SPS Channel 1-3 THD

Test Results:
Figure 6.8.1 and Table 6.8.1 indicate that the Q330HR/A Total Harmonic Distortion is better than -117.5 dB at 40 sps.

6.8.2 Q330HR/B Sample Rate 40 sps:

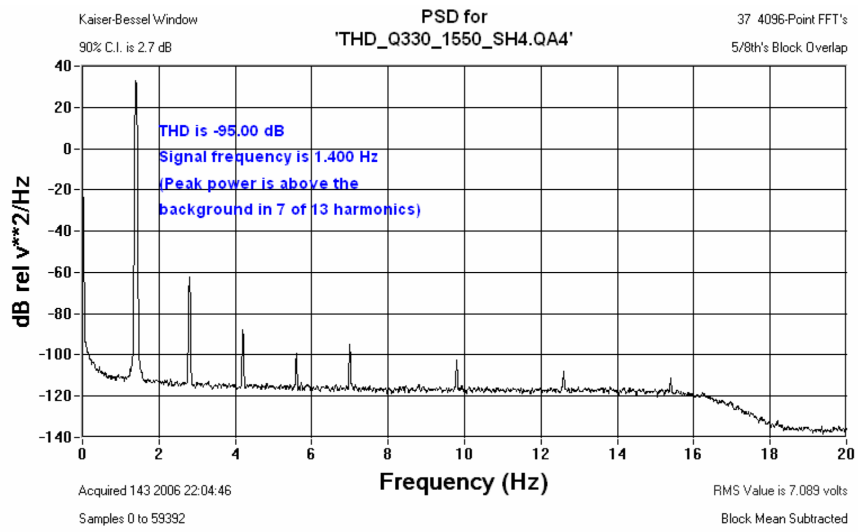


Figure 6.8.2 Q330HR Channel 4 Total Harmonic Distortion

Channel	THD (dB)
4	-95.0
5	-94.8
6	-94.5

Table 6.8.2 Q330HR 40SPS Channel 4-6 THD

Test Results:
Figure 6.8.2 and Table 6.8.2 indicate that the Q330HR/B Total Harmonic Distortion is better than -94.5 dB at 40 sps.

6.8.3 Q330HR/A Sample Rate 20 sps:

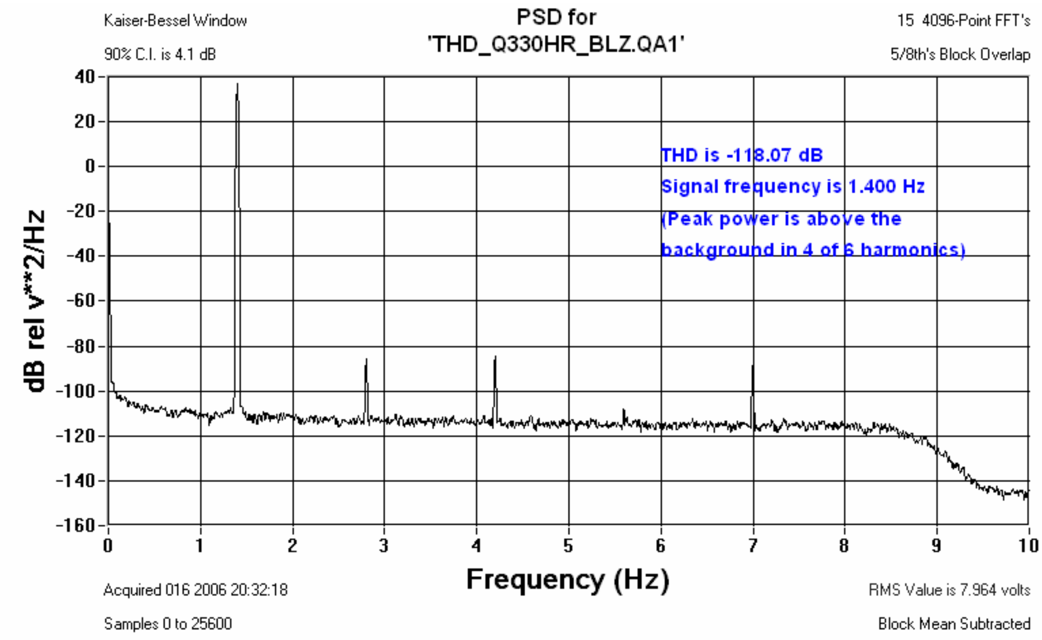


Figure 6.8.3 Q330HR Channel 1 Total Harmonic Distortion

Channel	THD (dB)
1	-118.1
2	-118.3
3	-118.0

Table 6.8.3 Q330HR 20SPS Channel 1-3 THD

Test Results:

Figure 6.8.3 and Table 6.8.3 indicate that the Q330HR/A Total Harmonic Distortion is better than –118.0 dB at 20 sps.

6.9 Q330HR Test Data Sheet: Test – Dynamic Tonal/CTK/CMR

Q330HR S/N: 1550 **Software Version: 1.74**

Q330HR Sample Rate: 40 sps
Specified Nominal Volts/Count: CH1-3 0.596 x 10^{-6}
Specified Nominal Volts/Count: CH4-6 2.384 x 10^{-6}
****

CTK/CMR Test Description: Measure the amount of digitizer channel-to-channel crosstalk. Measure the ability of the digitizer to reject common-mode signals.

6.9.1 Q330HR/A/B Sample Rate 40 sps:

Channel	RMS Input	RMS Crosstalk	Crosstalk
1	7.19	0.18 µV	-152 dB
2	7.19	0.13 µV	-155 dB
3	7.19	0.11 µV	-156 dB
4	7.19	0.0	Na.
5	7.19	0.0	Na.
6	7.19	0.0	Na.

Table 6.9.1a Q330HR/A/B 40SPS Channel 1-6 Crosstalk

Channel	RMS Input	RMS CM	CMR
1	6.16	319.2µV	-85.7 dB
2	6.16	41.5 µV	-103.4 dB
3	6.16	195.6 µV	-89.9 dB

Table 6.9.1b Q330HR/A 40SPS Channel 1-6 Common Mode Rejection

Test Results:
Table 6.9.1a indicates that the Q330HR/A/B Crosstalk is better than-150 dB at 40 sps.

Table 6.9.1b indicates that the Q330HR/A CMR is better than -85 dB at 1 Hz for 40 sps. Common Mode Voltage up to +/- 8 Volts was tolerated by the Q330HR/A/B. Common Mode Voltages over +/-8 Volts resulted in erratic behavior.

6.10 Q330HR Test Data Sheet: Test – Dynamic Broadband/RTF/ABW

Q330HR S/N: 1550 **Software Version: 1.74**

Q330HR Sample Rate: 200, 100, 40, 20, 1, 0.1 sps
Specified Nominal Volts/Count: CH1-3 0.596 x 10^{-6}
Specified Nominal Volts/Count: CH4-6 2.384 x 10^{-6}
****

RTF/ABW Test Description: Measure channel-to-channel relative phase and compute channel skew. Measure the bandwidth/corner frequency (–3 dB point) and attenuation at the Nyquist (20 Hz).

6.10.1 Q330HR/A Sample Rate 200 sps:

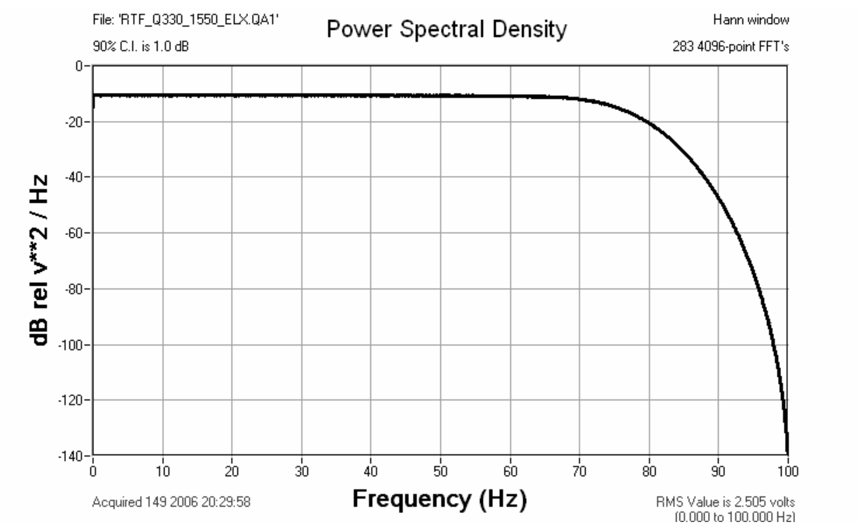


Figure 6.10.1a Response of the Q330HR to Broadband Noise

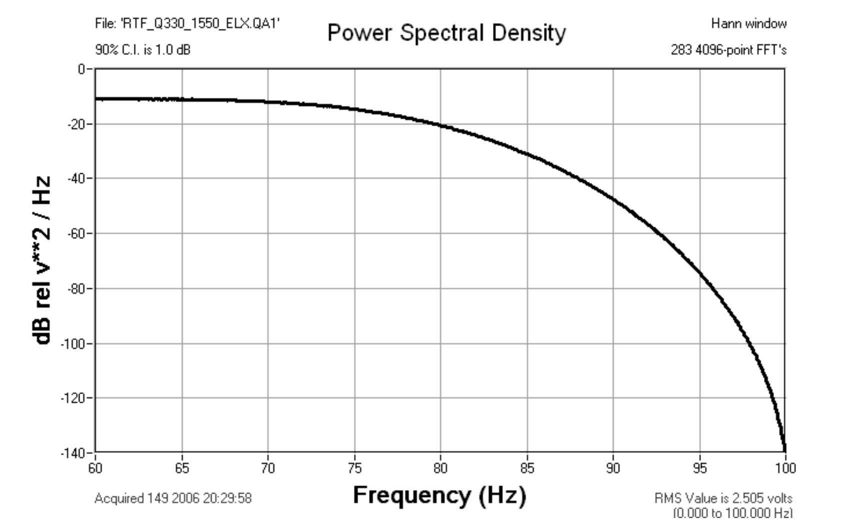


Figure 6.10.1b Response of the Q330HR to Broadband Noise

<u>Test Results:</u>

Figures 6.10.1a-b indicate that the Q330HR/A –3dB point is at 74.4 Hz with a relative attenuation of -130 dB at the Nyquist.

6.10.2 Q330HR/A Sample Rate 100 sps:

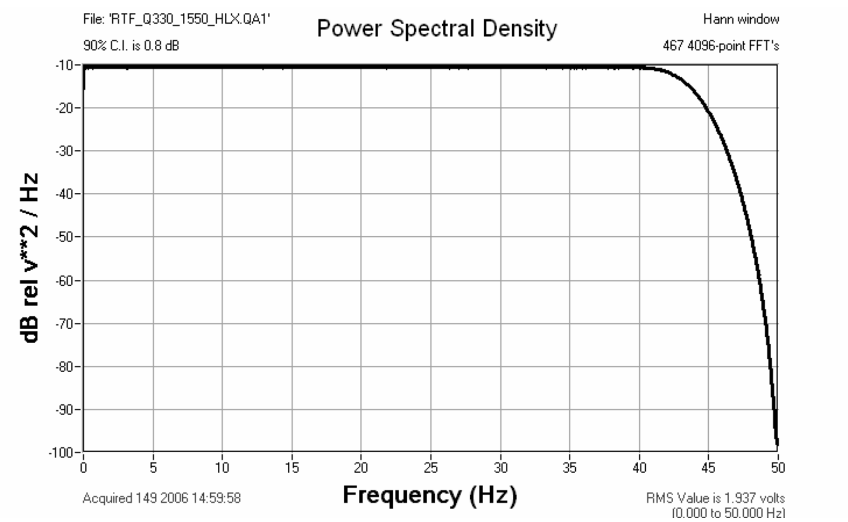


Figure 6.10.2a Response of the Q330HR to Broadband Noise

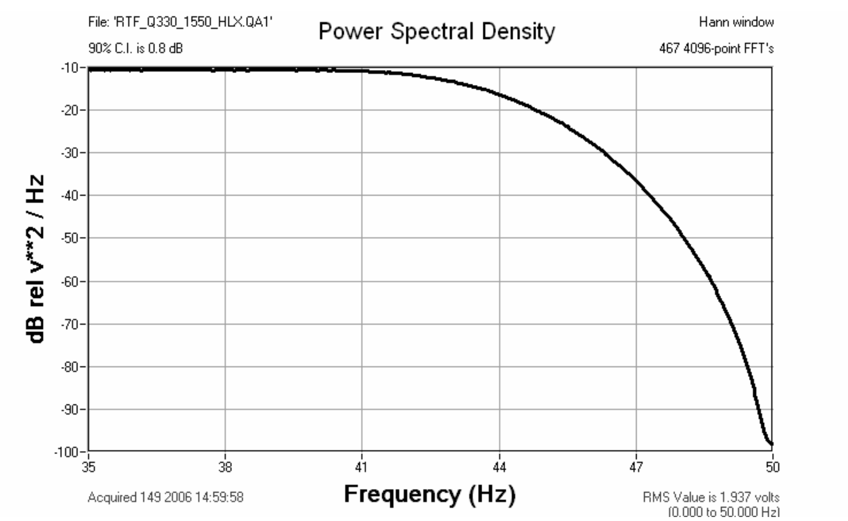


Figure 6.10.2b Response of the Q330HR to Broadband Noise

<u>Test Results:</u>
Figures 6.10.2a-b indicate that the Q330HR/A –3dB point is at 43.14 Hz with a relative attenuation of 90 dB at the Nyquist.

6.10.3 Q330HR/A/B Sample Rate 40 sps:

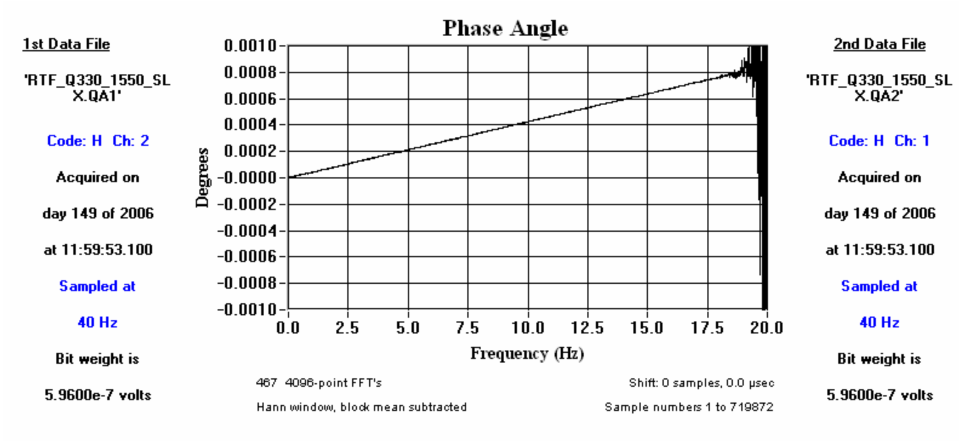


Figure 6.10.3a Q330HR 40SPS Channel 1-2 Relative Phase/Skew

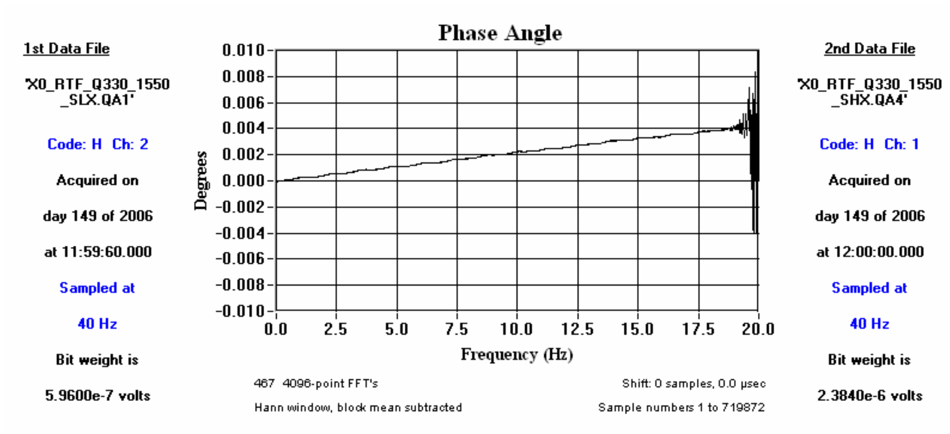


Figure 6.10.3b Q330HR 40SPS Channel 1-4 Relative Phase/Skew

Channel	Relative Phase @ 10 Hz	Channel Skew (Microseconds)
1-2	0.0004	0.11
1-3	0.0003	0.083
2-3	-0.0001	-0.027
4-5	-0.0003	-0.083
4-6	0.0001	0.027
5-6	0.0004	0.11
1-4	0.002	0.56

Table 6.10.3 Q330HR 40SPS Channel Relative Phase/Skew

Test Results:
Figure 6.10.3a-b and Table 6.10.3 indicate that the Q330HRA/B has less than 0.56 microseconds of channel to channel skew.

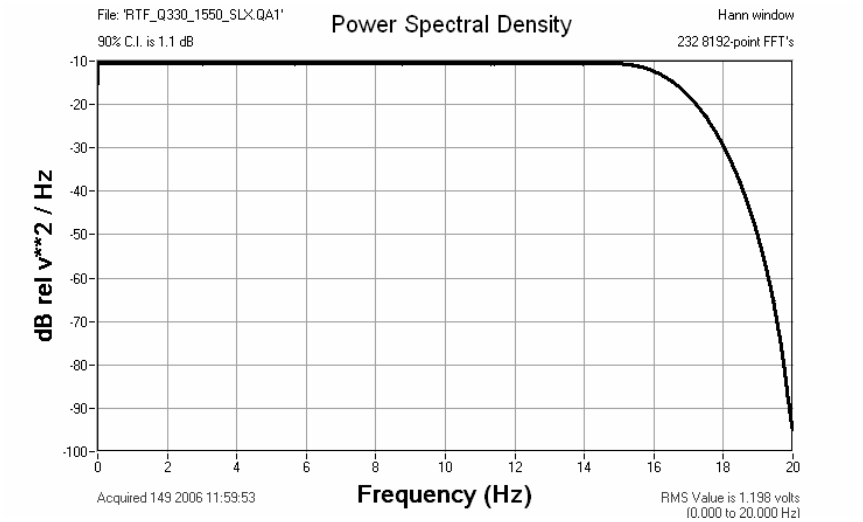


Figure 6.10.3c Response of the Q330HR to Broadband Noise

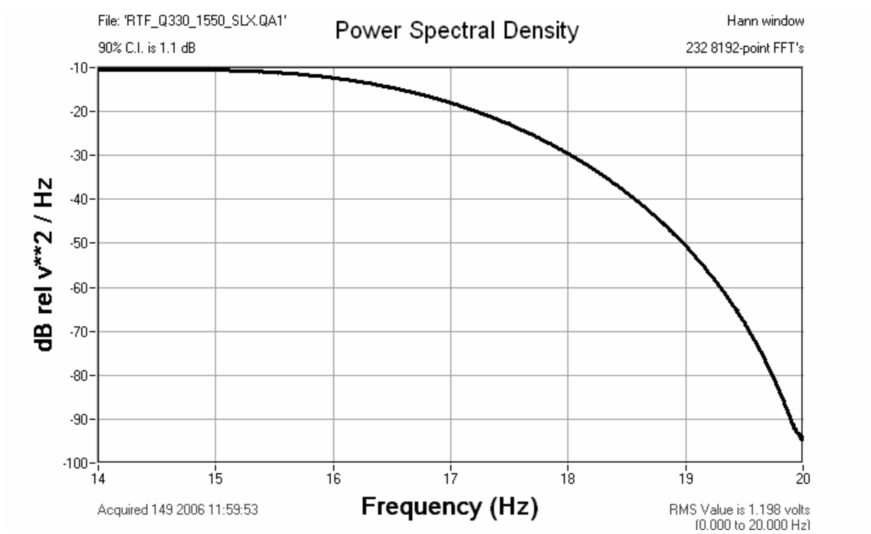


Figure 6.10.3d Response of the Q330HR to Broadband Noise

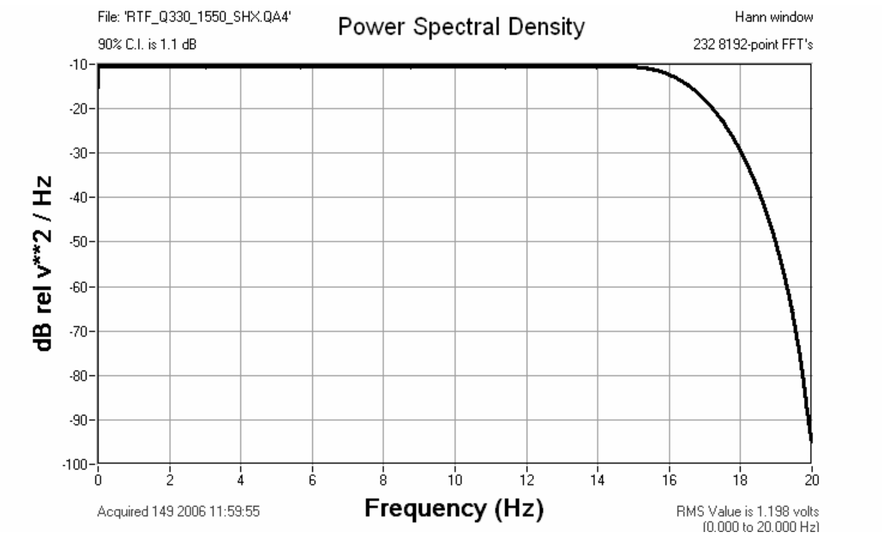


Figure 6.10.3e Response of the Q330HR to Broadband Noise

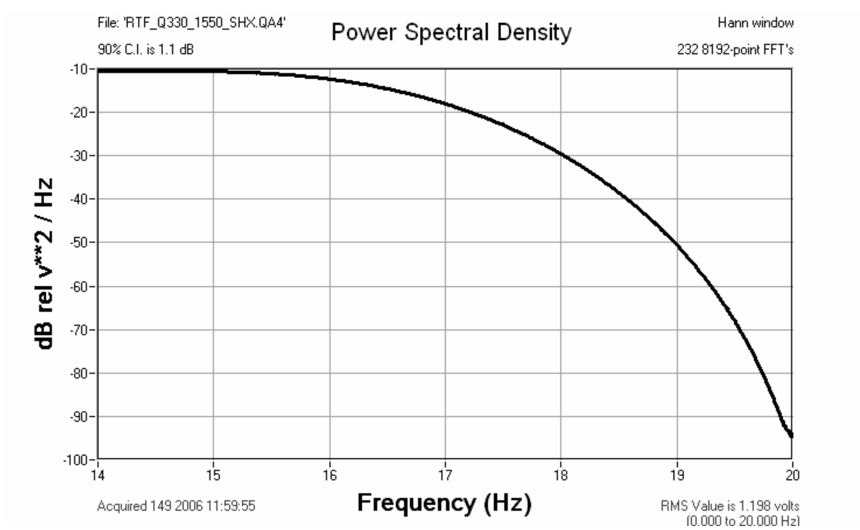


Figure 6.10.3f Response of the Q330HR to Broadband Noise

Test Results:

Figures 6.10.3c-f indicate that the Q330HR/A/B –3dB point is at 16.31 Hz with a relative attenuation of 85 dB at the Nyquist.

6.10.4 Q330HR/A Sample Rate 20 sps:

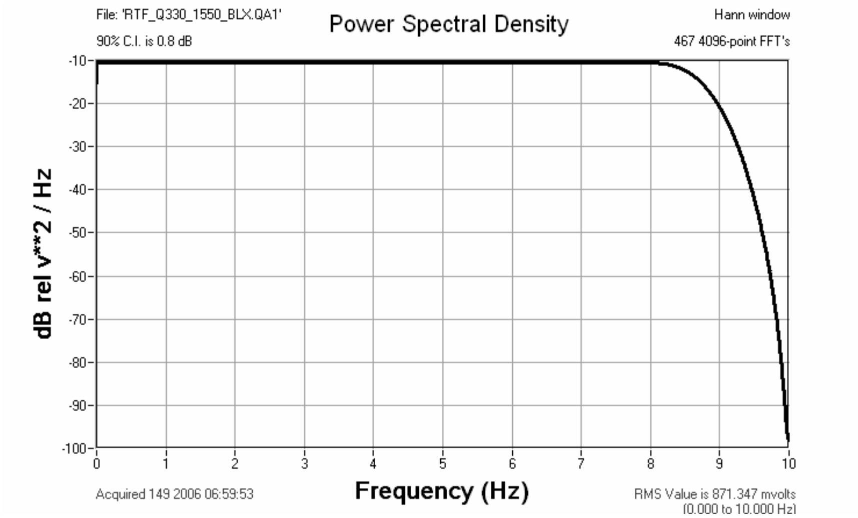


Figure 6.10.4a Response of the Q330HR to Broadband Noise

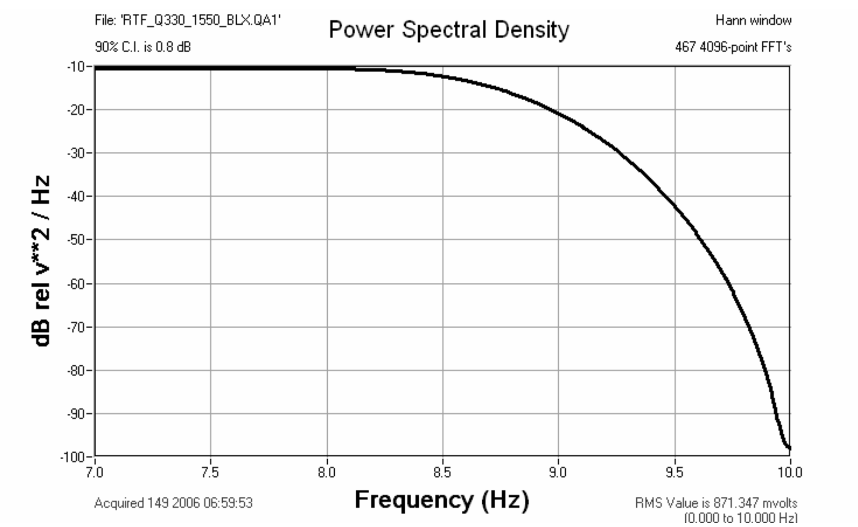


Figure 6.10.4b Response of the Q330HR to Broadband Noise

<u>Test Results:</u>
Figures 6.10.4a-b indicate that the Q330HR/A –3dB point is at 8.62 Hz with a relative attenuation of 85 dB at the Nyquist.

6.10.5 Q330HR/A/B Sample Rate1 sps:

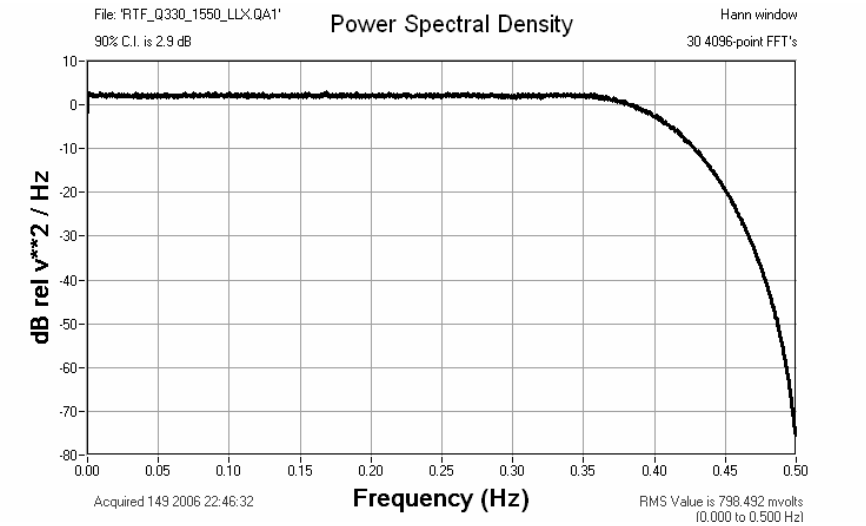


Figure 6.10.5a Response of the Q330HR to Broadband Noise

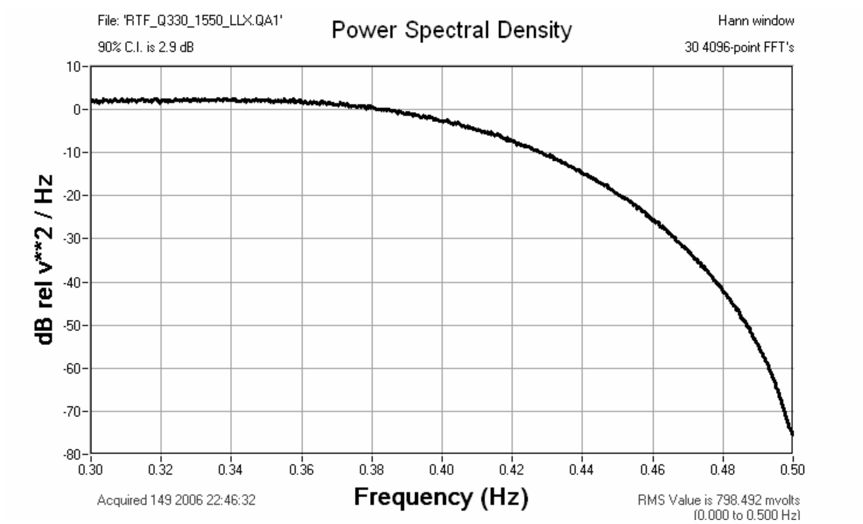


Figure 6.10.5b Response of the Q330HR to Broadband Noise

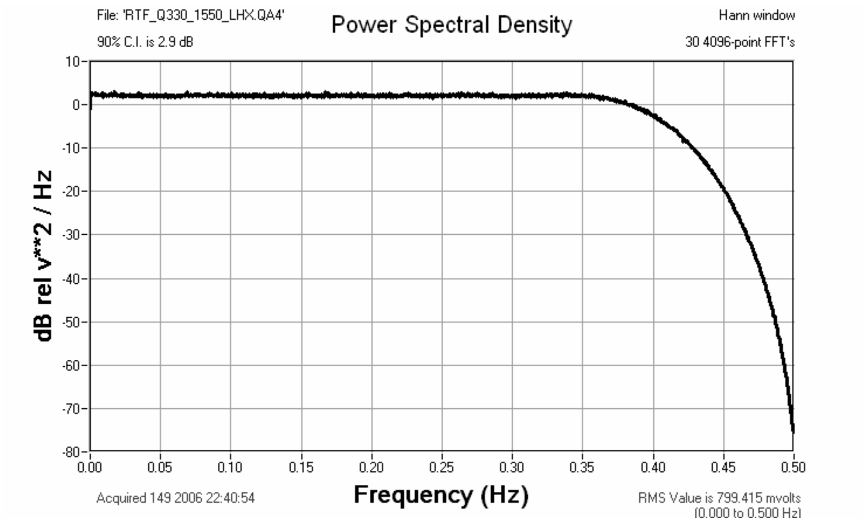


Figure 6.10.5c Response of the Q330HR to Broadband Noise

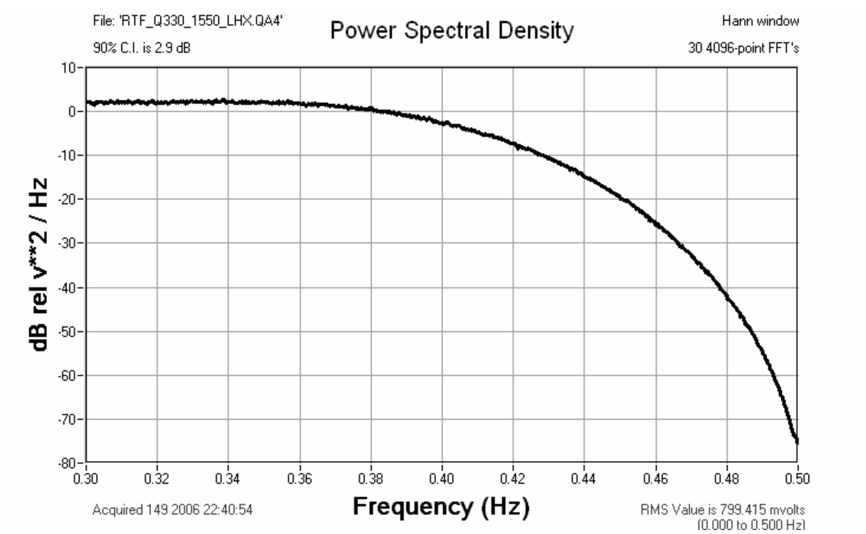


Figure 6.10.5d Response of the Q330HR to Broadband Noise

Test Results:

Figures 6.10.5a-d indicate that the Q330HR/A/B –3dB point is at 0.39 Hz with a relative attenuation of 80 dB at the Nyquist.

6.10.6 Q330HR/A Sample Rate 0.1 sps:

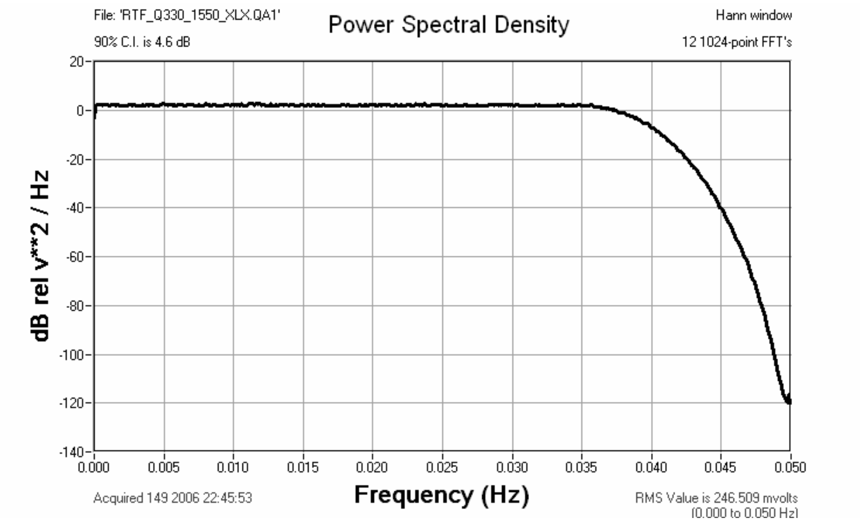


Figure 6.10.6a Response of the Q330HR to Broadband Noise

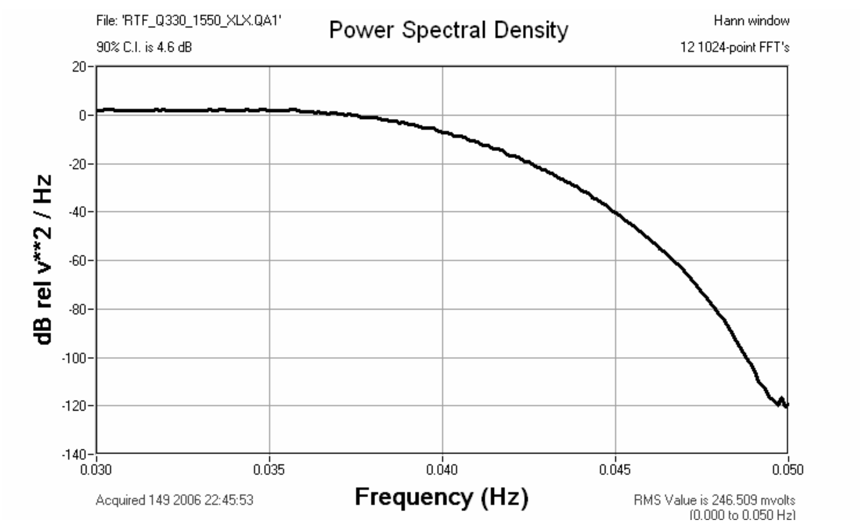


Figure 6.10.6b Response of the Q330HR to Broadband Noise

Test Results:

Figures 6.10.6a-b indicate that the Q330HR –3dB point is at 0.0381 Hz with a relative attenuation of 120 dB at the Nyquist.

6.11 Q330HR Test Data Sheet: Test – Timing/TTA

Q330HR S/N: 1550 **Software Version: 1.74**

Q330HR Sample Rate: 200, 100, 40, 20, 1, 0.1 sps
Specified Nominal Volts/Count: CH1-3 0.596 x 10^{-6}
Specified Nominal Volts/Count: CH4-6 2.384 x 10^{-6}
****

TTA Test Description: Determine the accuracy of the time-tags of the Q330HR data samples.

6.11.1 Q330HR/A Sample Rate 200 sps:

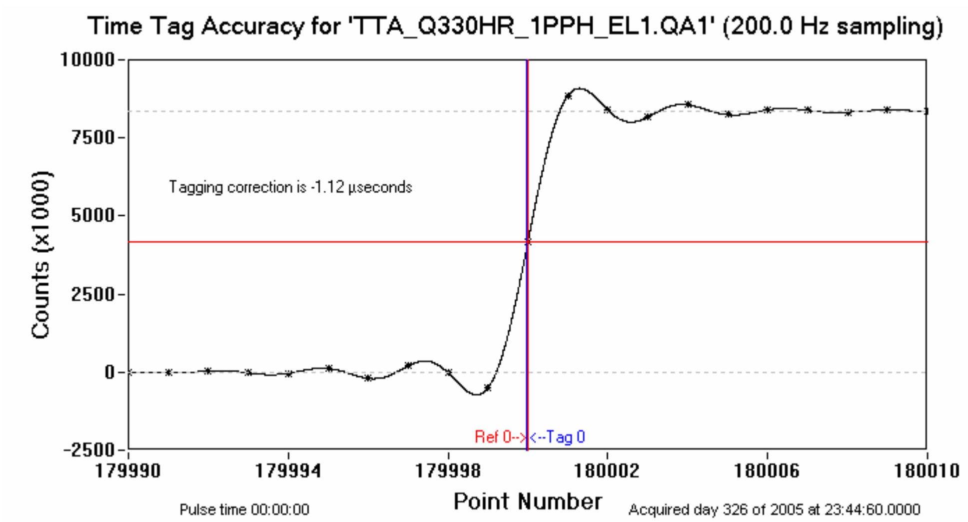


Figure 6.11.1 Q330HR Time-Tag Accuracy

<u>Test Results:</u>
Figure 6.11.1 indicates with a continuous powered GPS, the Q330HR can time-tag data samples to within 1.2 microseconds for 200 sps.

6.11.2 Q330HR/A Sample Rate 100 sps:

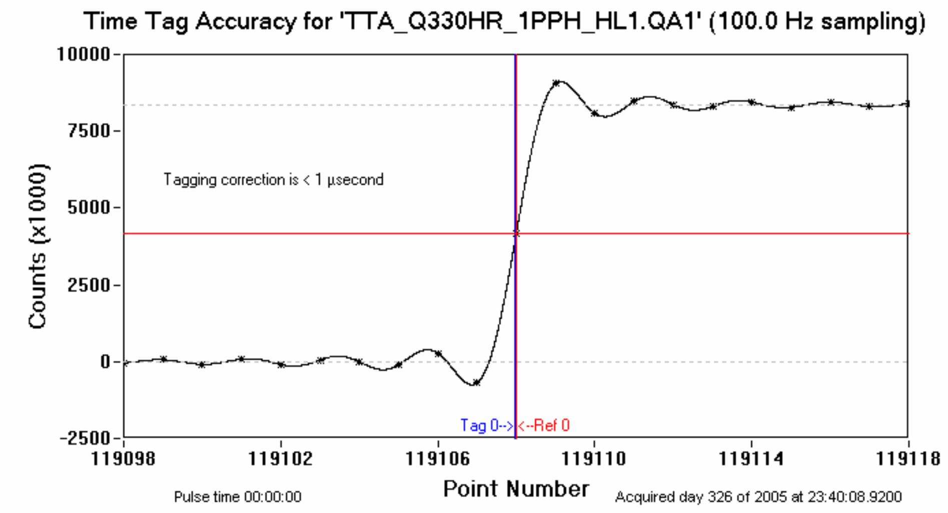


Figure 6.11.2 Q330HR Time-Tag Accuracy

Test Results:

Figure 6.11.2 indicates that with a continuous powered GPS, the Q330HR/A can time-tag data samples to within 1 microsecond for 100 sps.

6.11.3 Q330HR/A Sample Rate 40 sps:

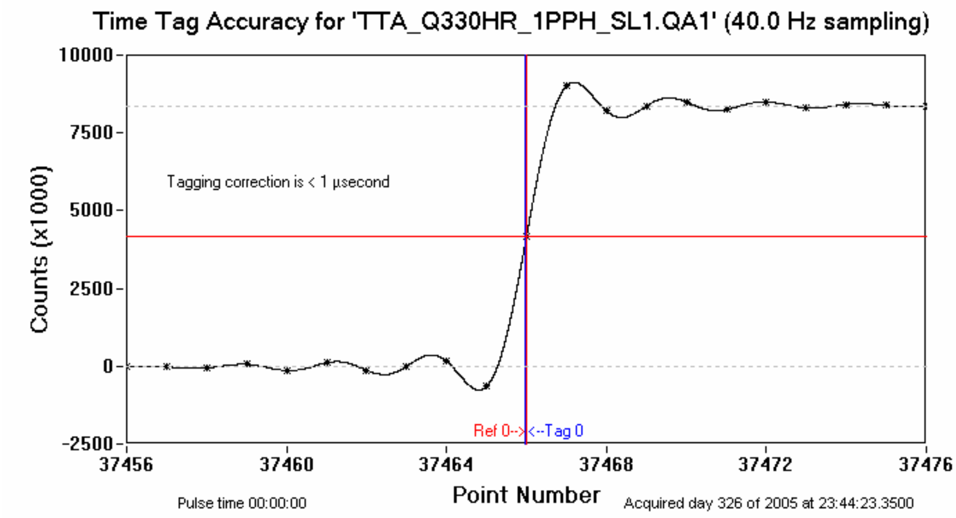


Figure 6.11.3 Q330HR Time-Tag Accuracy

<u>Test Results:</u>
Figure 6.11.3 indicates that with a continuous powered GPS, the Q330HR/A can time-tag data samples to within 1 microsecond for 40 sps.

6.11.4 Q330HR/B Sample Rate 40 sps:

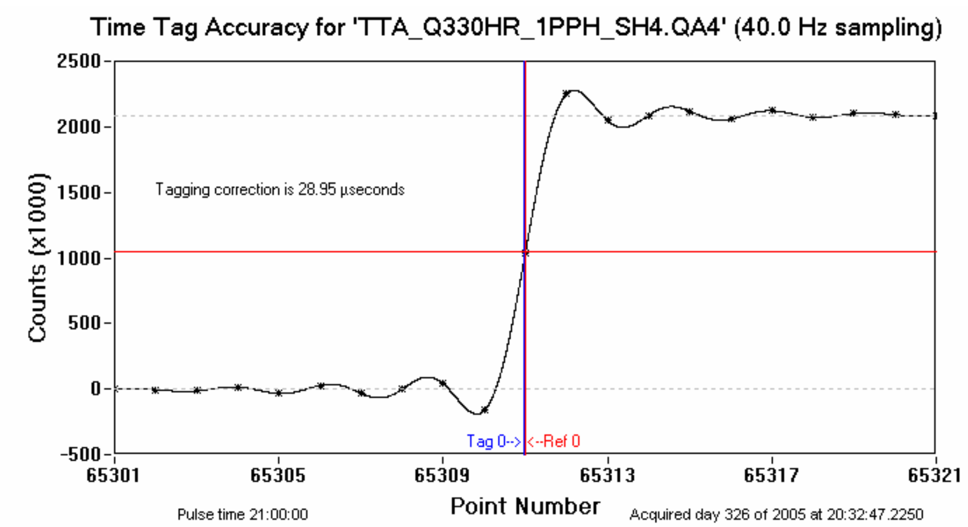


Figure 6.11.4 Q330HR Time-Tag Accuracy

<u>Test Results:</u>
Figure 6.11.4 indicates that with a continuous powered GPS, the Q330HR/B can time-tag data samples to within 29 microseconds for 40 sps.

6.11.5 Q330HR/A Sample Rate 20 sps:

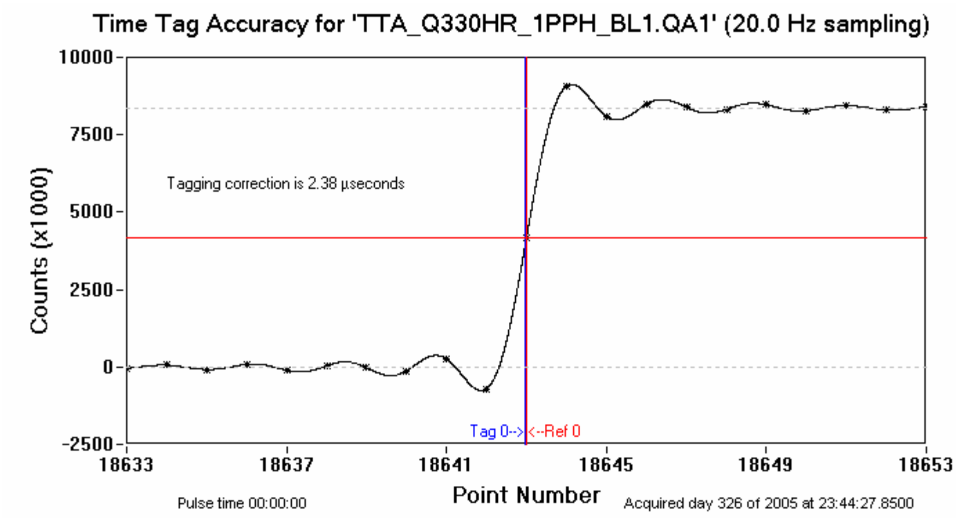


Figure 6.11.5 Q330HR Time-Tag Accuracy

<u>Test Results:</u>
Figure 6.11.5 indicates that with a continuous powered GPS, the Q330HR can time-tag data samples to within 3 microseconds for 20 sps.

6.11.6 Q330HR/A Sample Rate 1 sps:

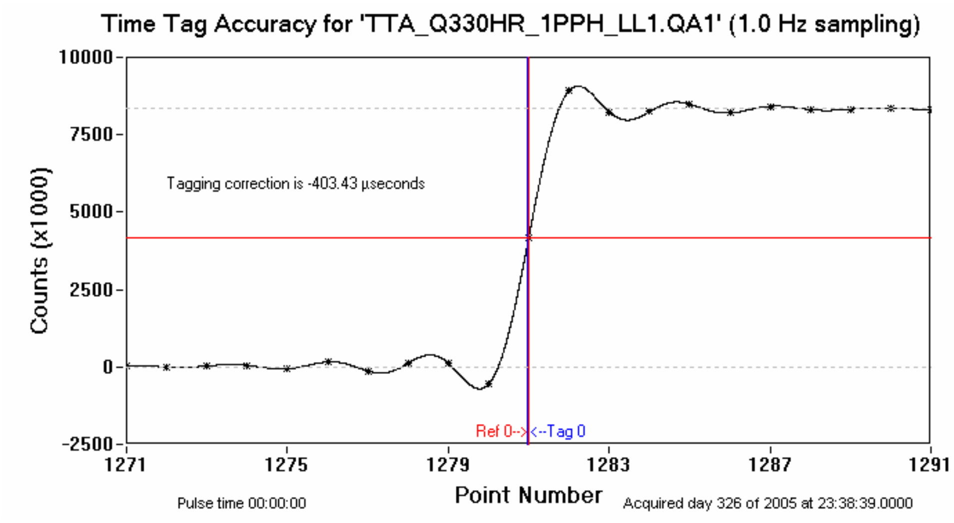


Figure 6.11.6 Q330HR Time-Tag Accuracy

<u>Test Results:</u>
Figure 6.11.6 indicates that with a continuous powered GPS, the Q330HR/A can time-tag data samples to within 400 microseconds for 1 sps.

6.11.7 Q330HR/B Sample Rate 1 sps:

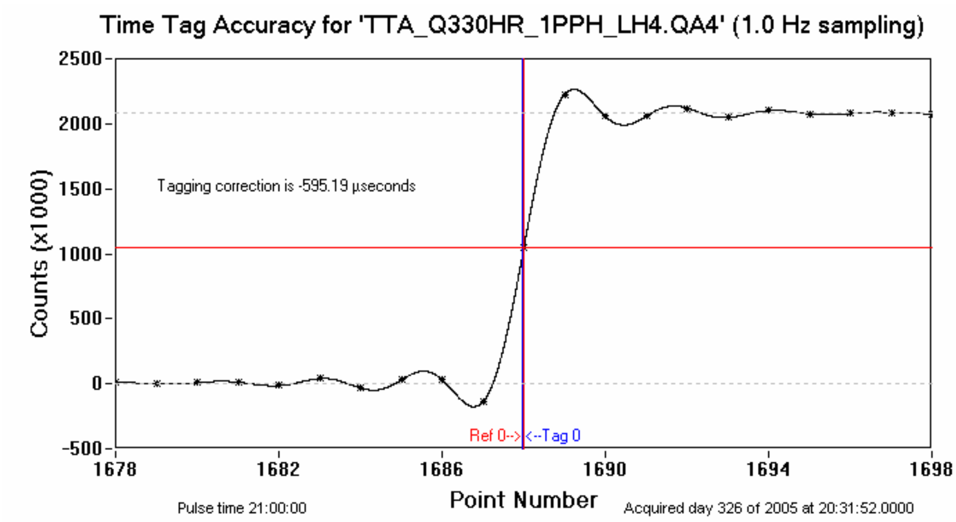


Figure 6.11.7 Q330HR Time-Tag Accuracy

<u>Test Results:</u>
Figure 6.11.7 indicates that with a continuous powered GPS, the Q330HR/B can time-tag data samples to within 600 microseconds for 1 sps.

6.11.8 Q330HR/A Sample Rate 0.1 sps:

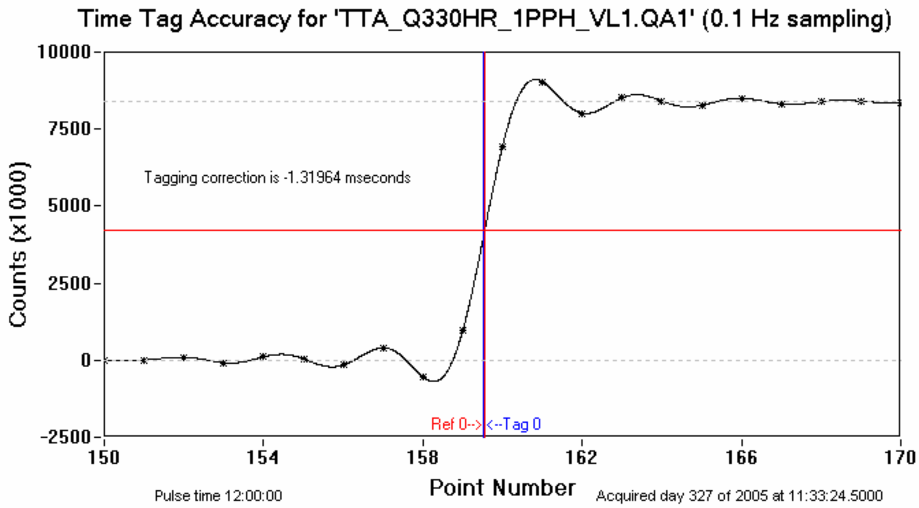


Figure 6.11.8 Q330HR Time-Tag Accuracy

<u>Test Results:</u>
Figure 6.11.8 indicates that with a continuous powered GPS, the Q330HR/A can time-tag data samples to within 1.32 milliseconds for 0.1 sps.

6.12 Q330HR Test Data Sheet Test – Seismic/SSN

Q330HR S/N: 1550 **Software Version: 1.74**

Q330HR Sample Rate: 200, 100, 40, 20, 1, 0.1 sps
Seismometer Application CH1-3: STS-1, STS-2, CMG-3TB, KS54000
Seismometer Application CH4-6: STS-2, CMG-3TB
****

SSN Test Description: Determine ability of the Q330HR to resolve the expected seismic background using the appropriate seismometer.

6.12.1 Q330HR/A Sample Rate 200 sps/STS-2 High Gain:

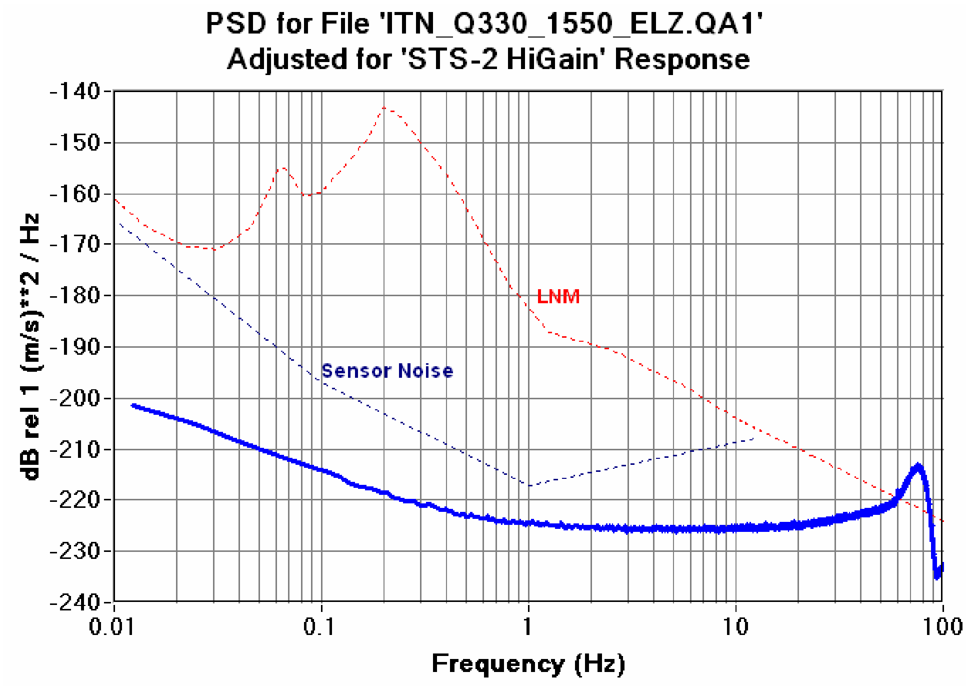


Figure 6.12.1a Q330HR 200SPS CH1 Seismic System Noise STS-2 High Gain

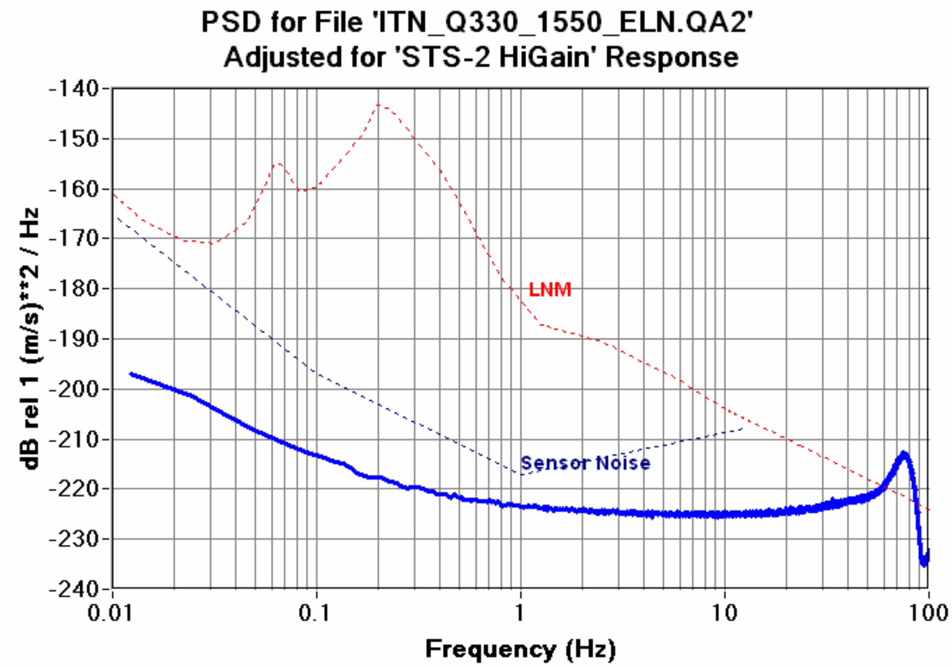


Figure 6.12.1b Q330HR 200SPS CH2 Seismic System Noise STS-2 High Gain

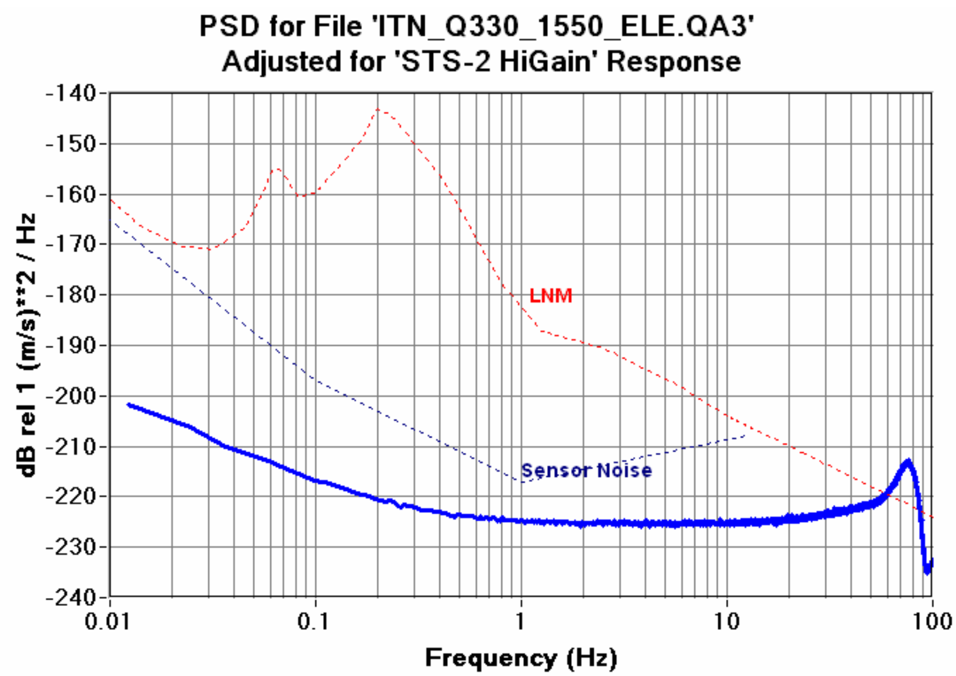


Figure 6.12.1c Q330HR 200SPS CH3 Seismic System Noise STS-2 High Gain

Test Results:

Figures 6.12.1a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 60.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

6.12.2 Q330HR/A Sample Rate 100 sps/STS-2 High Gain:

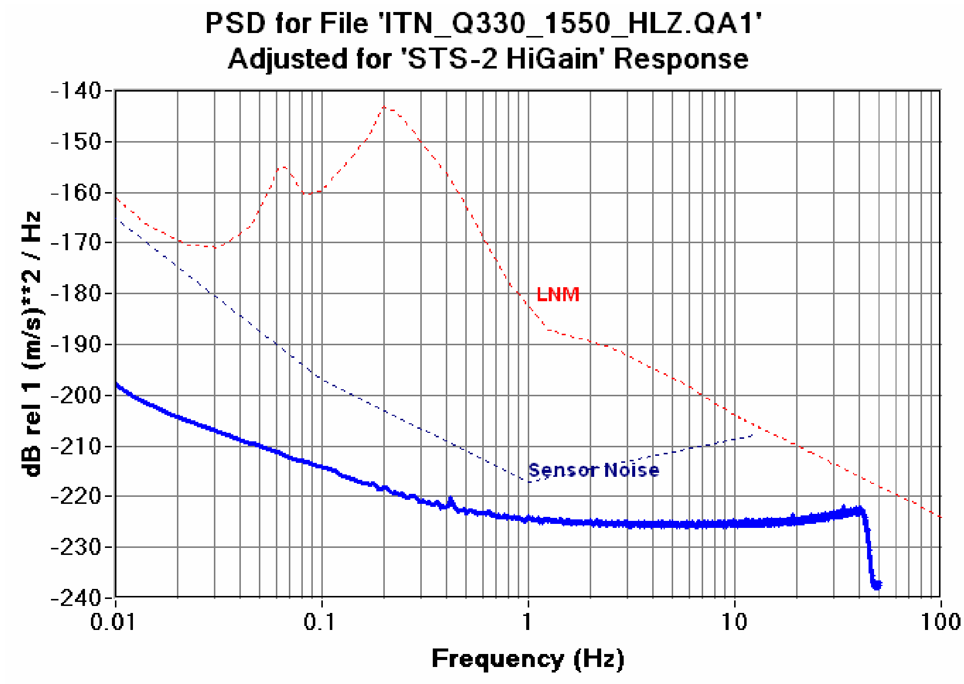


Figure 6.12.2a Q330HR 100SPS CH1 Seismic System Noise STS-2 High Gain

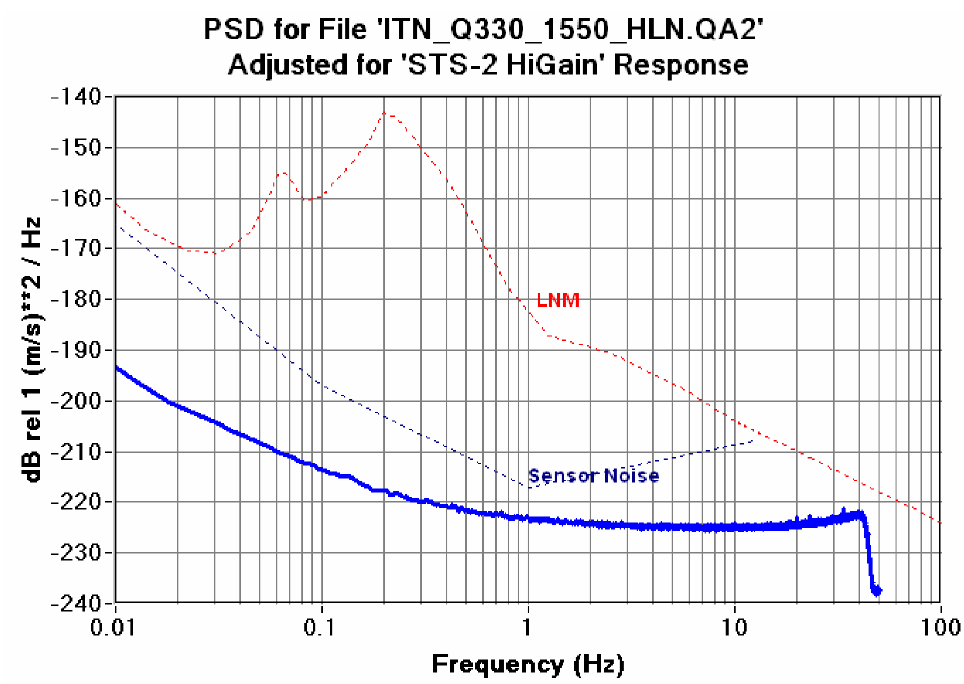


Figure 6.12.2b Q330HR 100SPS CH2 Seismic System Noise STS-2 High Gain

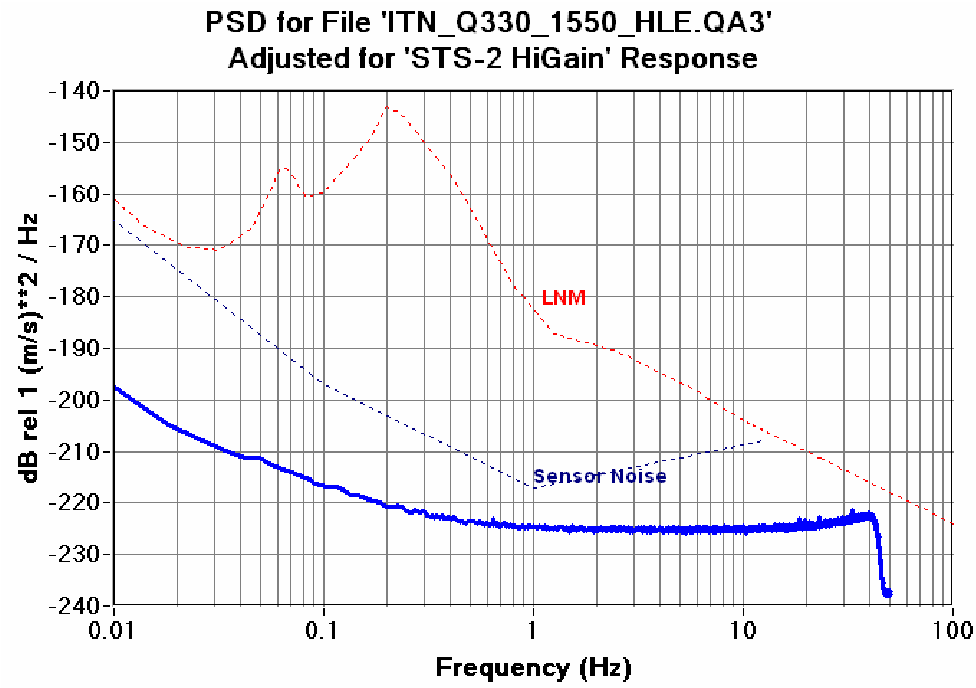


Figure 6.12.2c Q330HR 100SPS CH3 Seismic System Noise STS-2 High Gain

<u>Test Results:</u>
Figures6.12.2a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 50.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

6.12.3 Q330HR/B Sample Rate 100 sps/STS-2 High Gain:

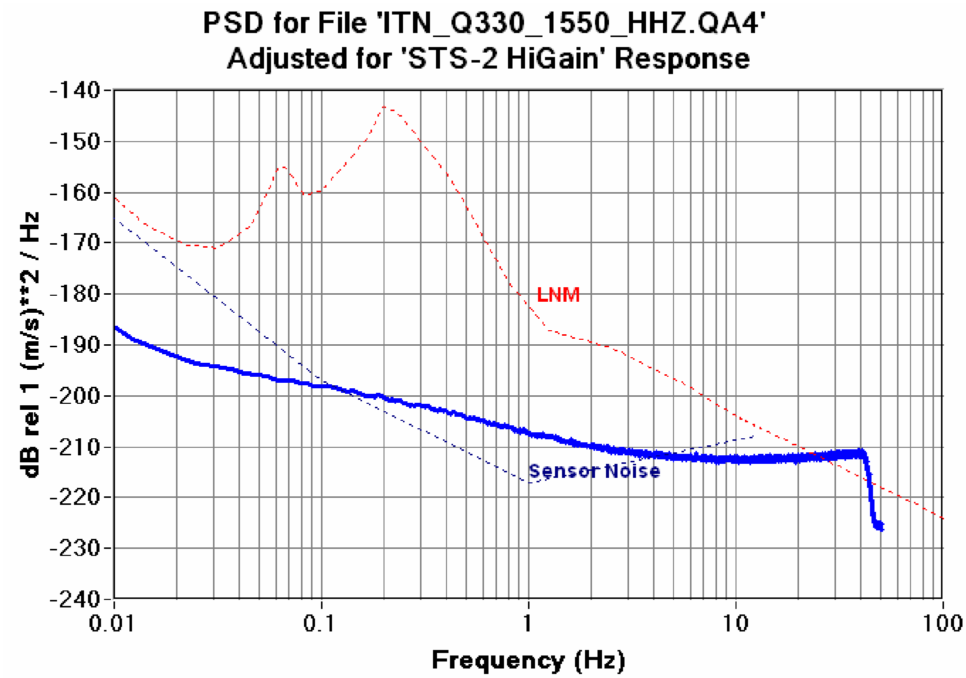


Figure 6.12.3a Q330HR 100SPS CH4 Seismic System Noise STS-2 High Gain

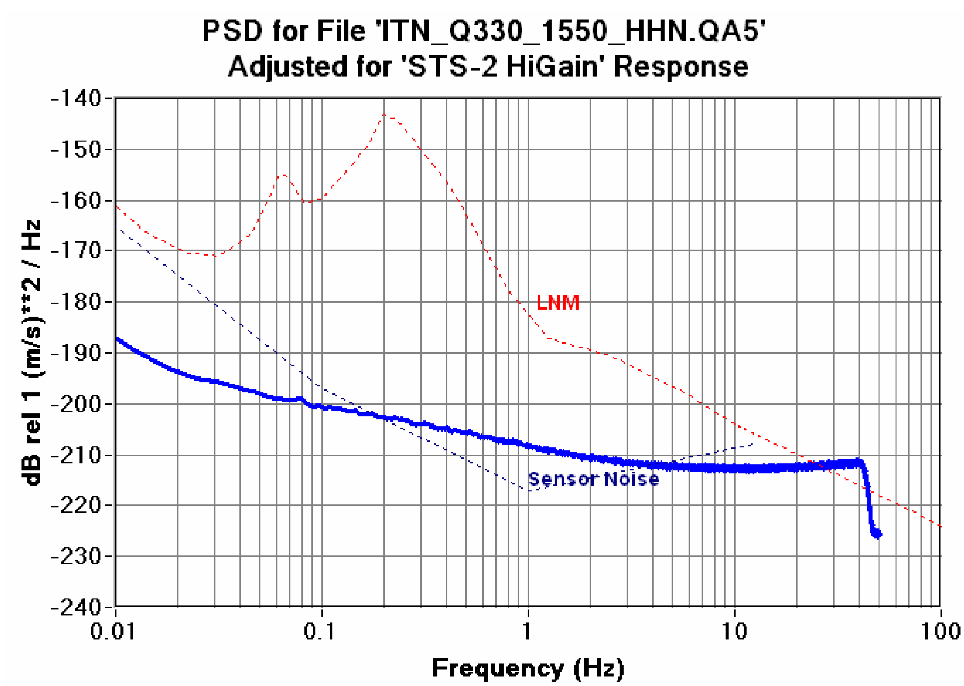


Figure 6.12.3b Q330HR 100SPS CH5 Seismic System Noise STS-2 High Gain

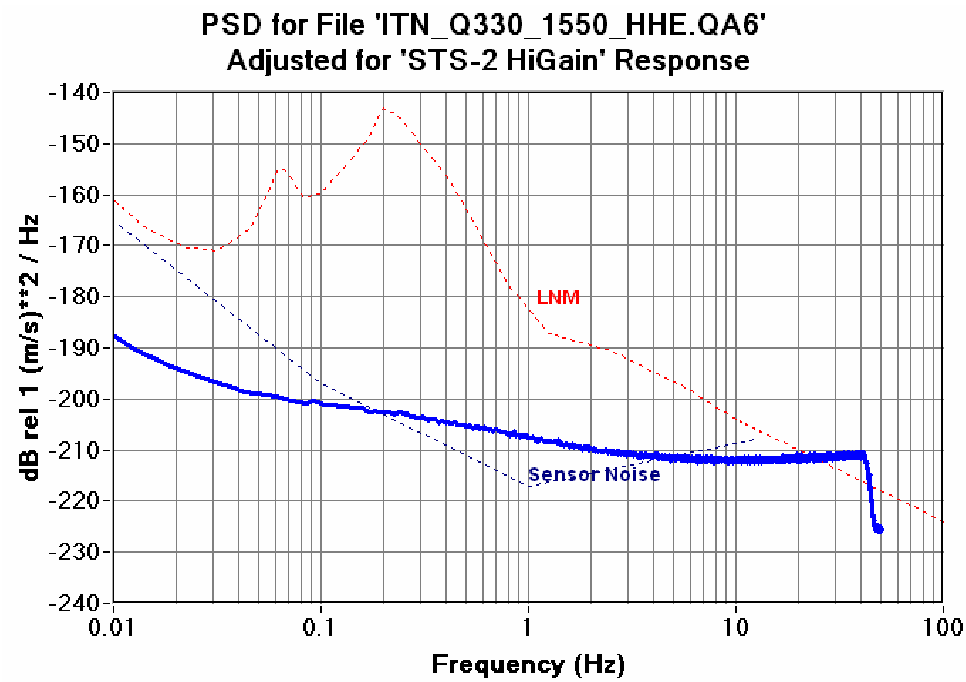


Figure 6.12.3c 330HR 100SPS CH6 Seismic System Noise STS-2 High Gain

<u>Test Results:</u>

Figures 6.12.3a-cicate that the response corrected noises of the Q330HR/B were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 22.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

6.12.4 Q330HR/A Sample Rate 40 sps/STS-2 High Gain:

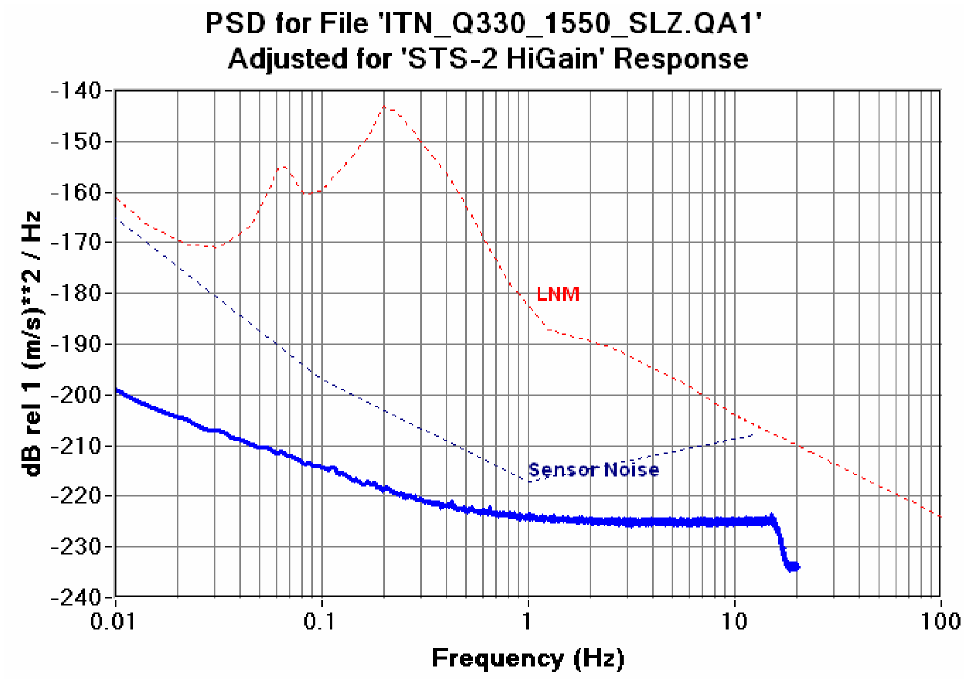


Figure 6.12.4a Q330HR 40SPS CH1 Seismic System Noise STS-2 High Gain

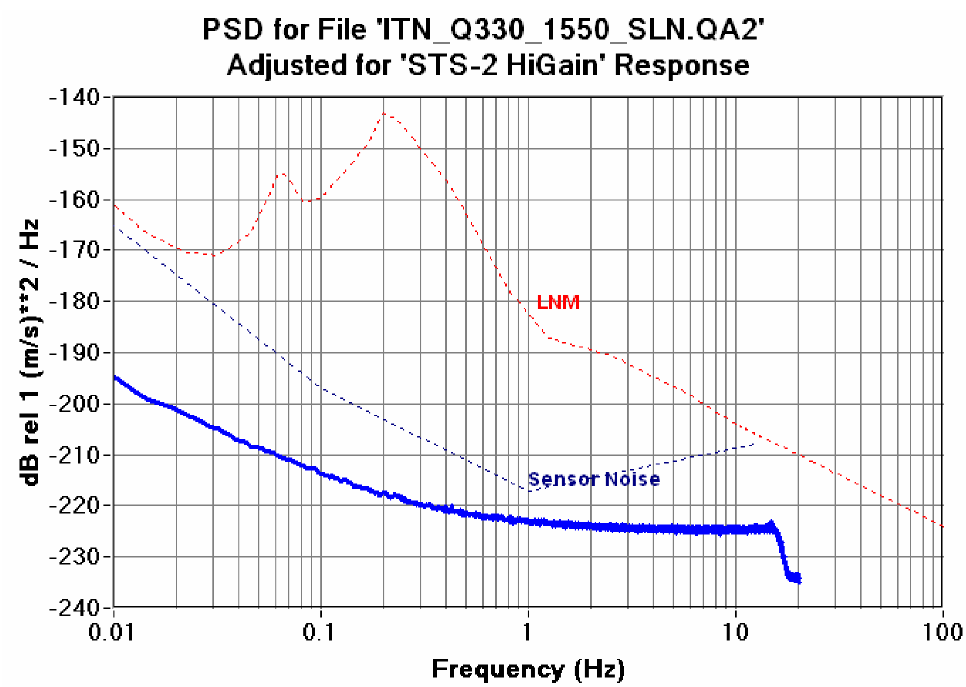


Figure 6.12.4b Q330HR 40SPS CH2 Seismic System Noise STS-2 High Gain

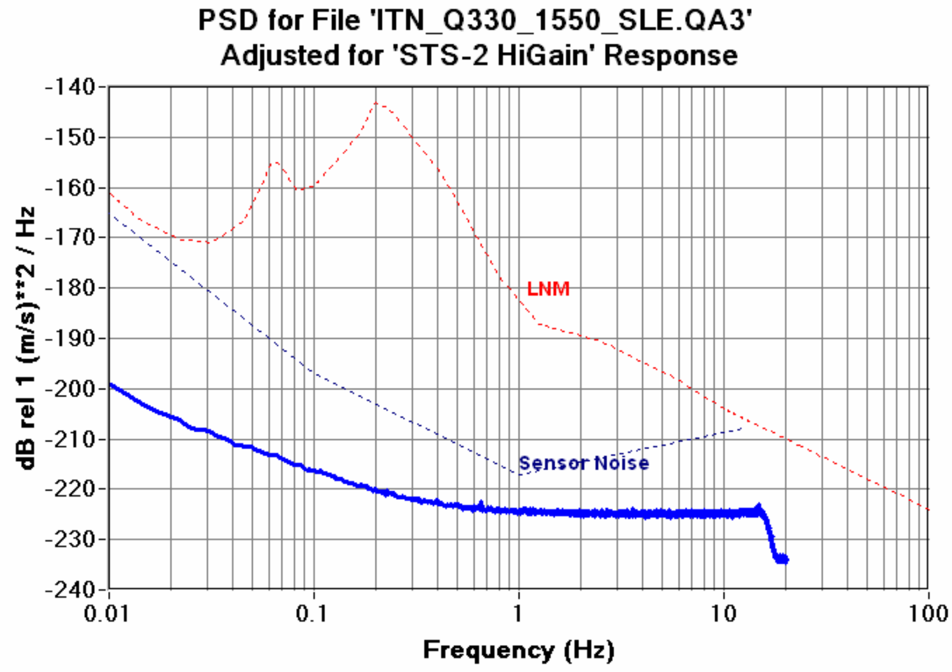


Figure 6.12.4c Q330HR 40SPS CH3 Seismic System Noise STS-2 High Gain

Test Results:

Figures 6.12.4-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 20.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

6.12.5 Q330HR/A Sample Rate 40 sps/STS-2 Low Gain:

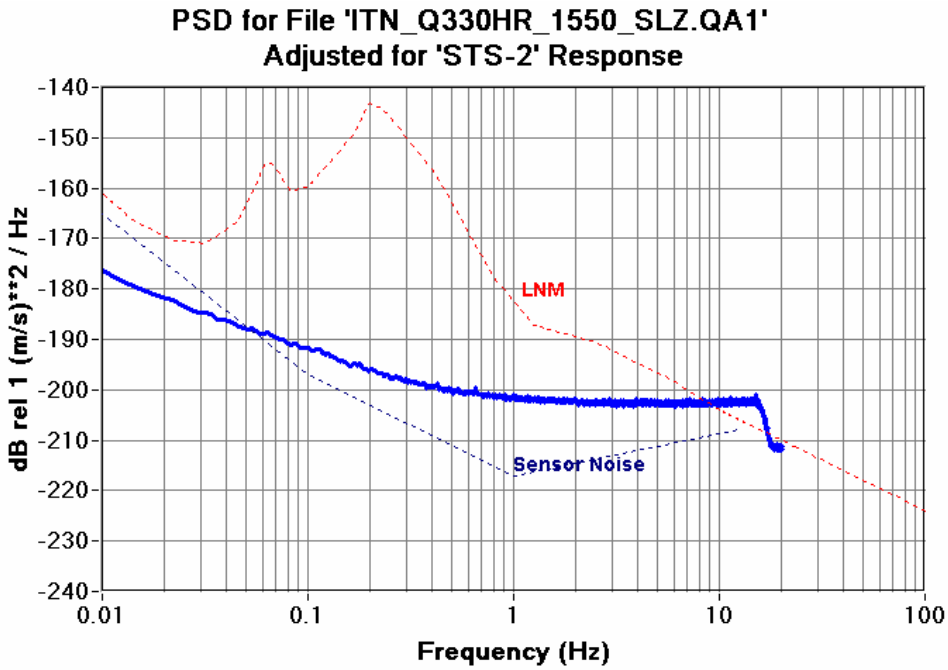


Figure 6.12.5a Q330HR 40SPS CH1 Seismic System Noise STS-2 Low Gain

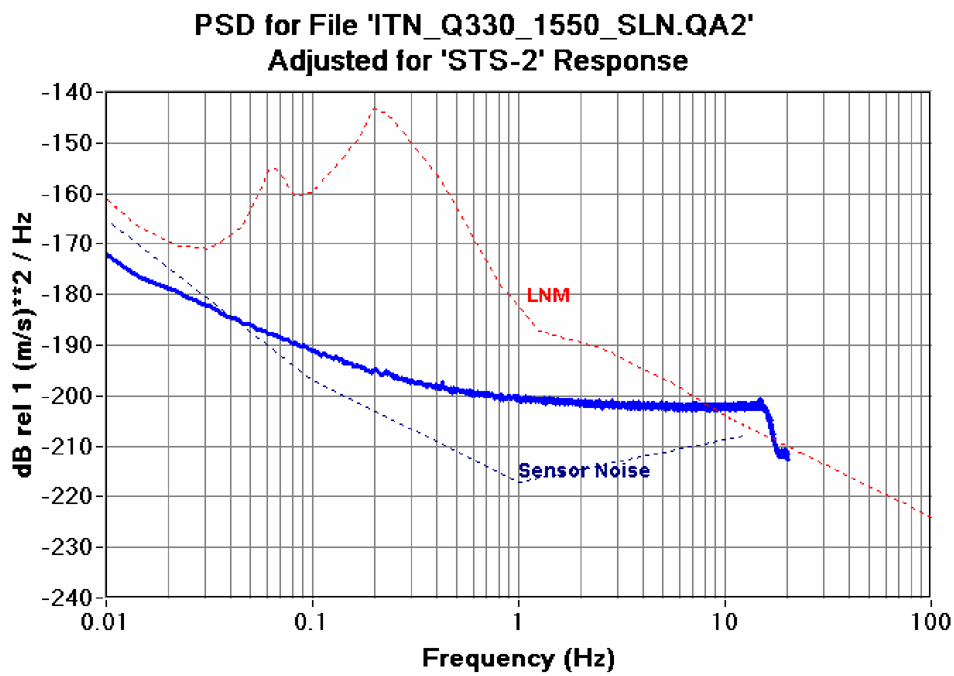


Figure 6.12.5b Q330HR 40SPS CH2 Seismic System Noise STS-2 Low Gain

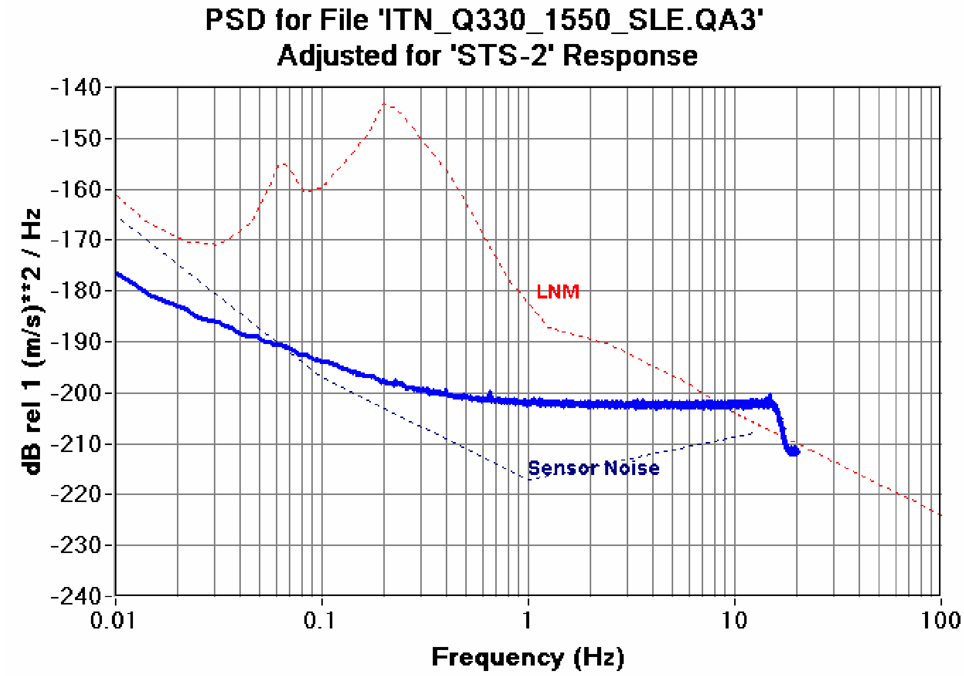


Figure 6.12.5c Q330HR 40SPS CH3 Seismic System Noise STS-2 Low Gain

Test Results:

Figures 6.12.5a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 20.0 Hz when used with a Streckeisen STS-2 Low Gain seismometer.

6.12.6 Q330HR/B Sample Rate 40 sps/STS-2 High Gain:

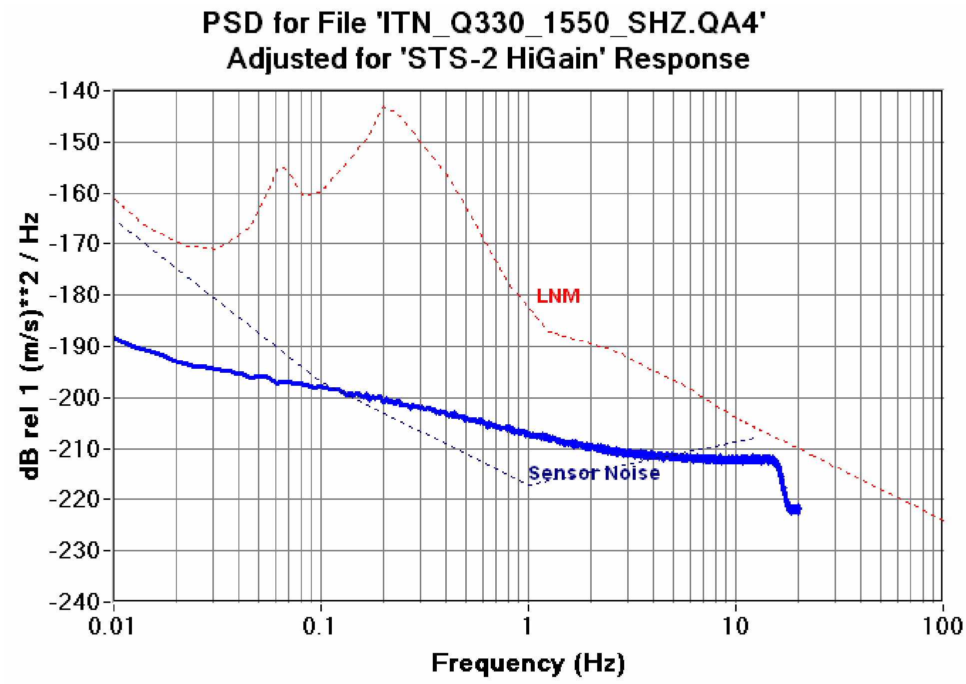


Figure 6.12.6a Q330HR 40SPS CH4 Seismic System Noise STS-2 High Gain

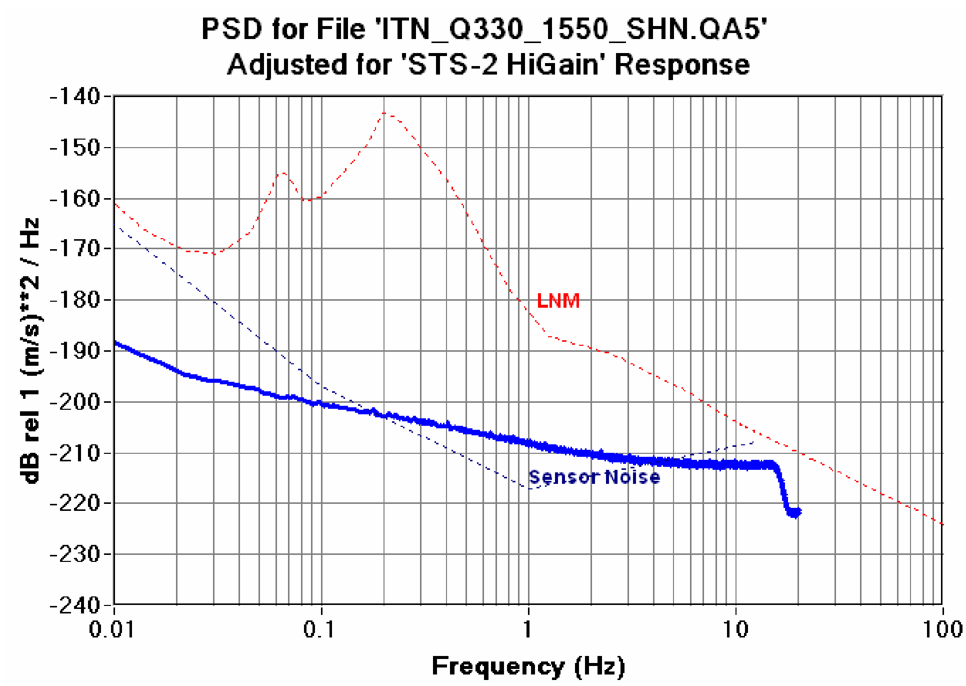


Figure 6.12.6b Q330HR 40SPS CH5 Seismic System Noise STS-2 High Gain

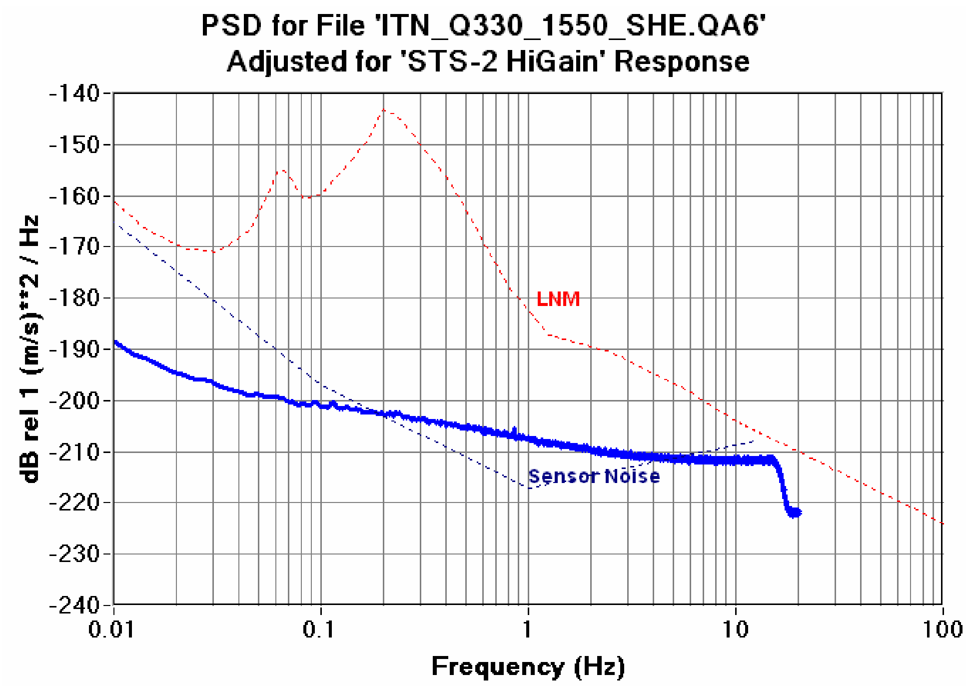


Figure 6.12.6c Q330HR 40SPS CH6 Seismic System Noise STS-2 High Gain

Test Results:
Figures 6.12.6a-c indicate that the response corrected noises of the Q330HR/B were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 20.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

6.12.7 Q330HR/A Sample Rate 20 sps/STS-2 High Gain:

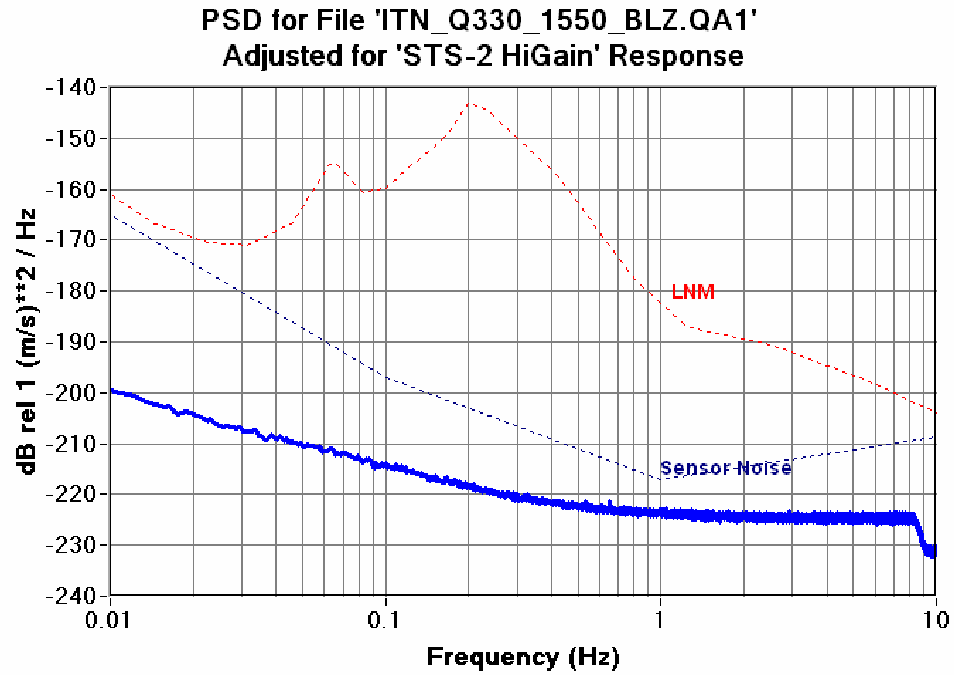


Figure 6.12.7a Q330HR 20SPS CH1 Seismic System Noise STS-2 High Gain

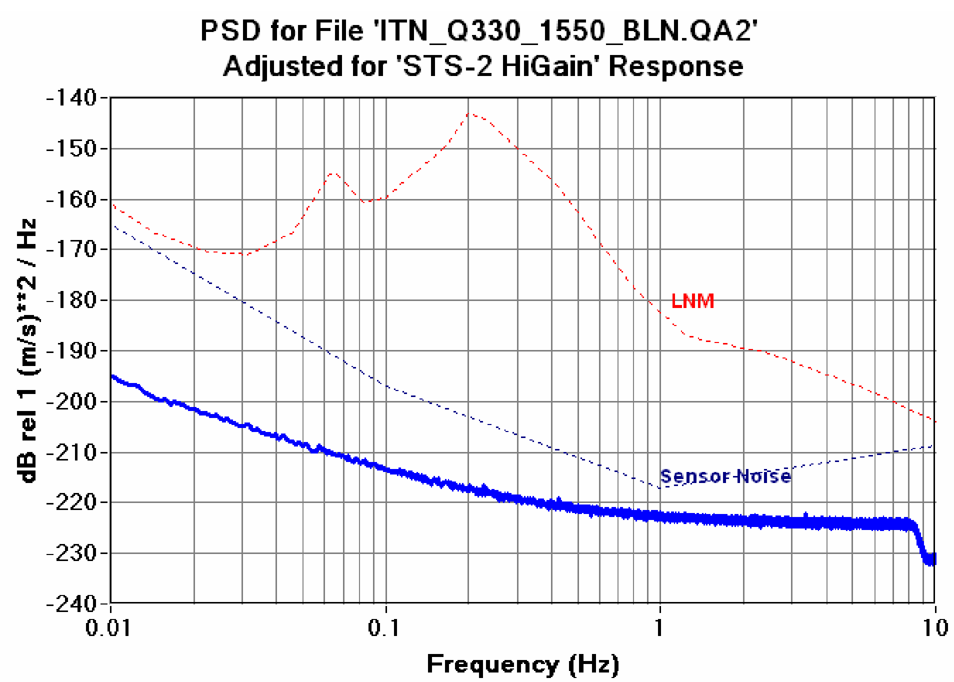


Figure 6.12.7b Q330HR 20SPS CH2 Seismic System Noise STS-2 High Gain

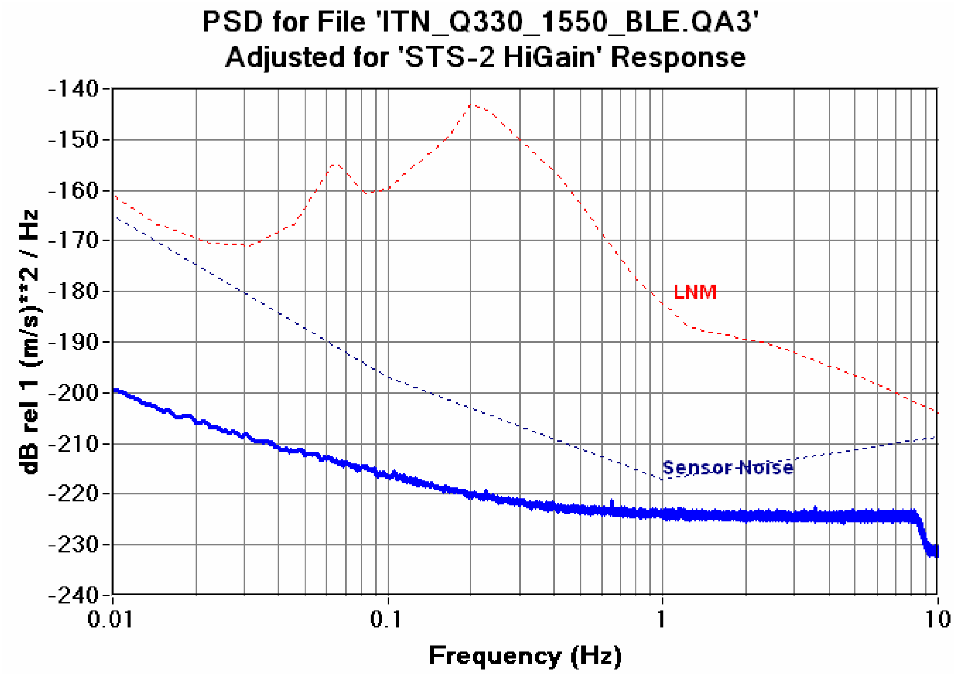


Figure 6.12.7c Q330HR 20SPS CH3 Seismic System Noise STS-2 High Gain

Test Results:

Figures 6.12.7a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.01 and 10.0 Hz when used with a Streckeisen STS-2 High Gain seismometer.

6.12.8 Q330HR/A Sample Rate 20 sps/CMG-3TB:

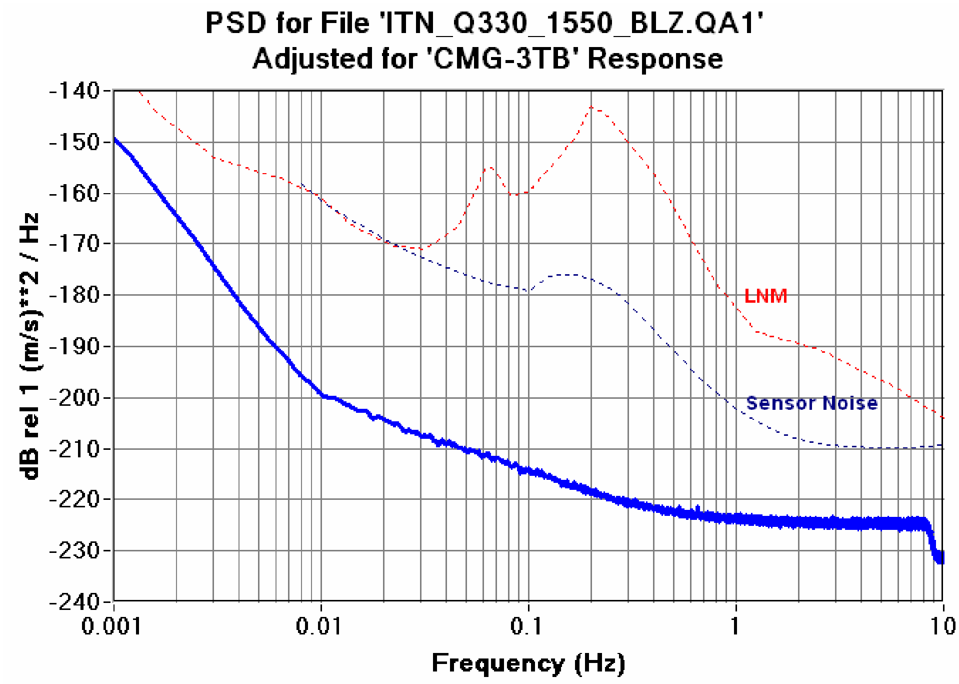


Figure 6.12.8a Q330HR 20SPS CH1 Seismic System Noise CMG-3TB

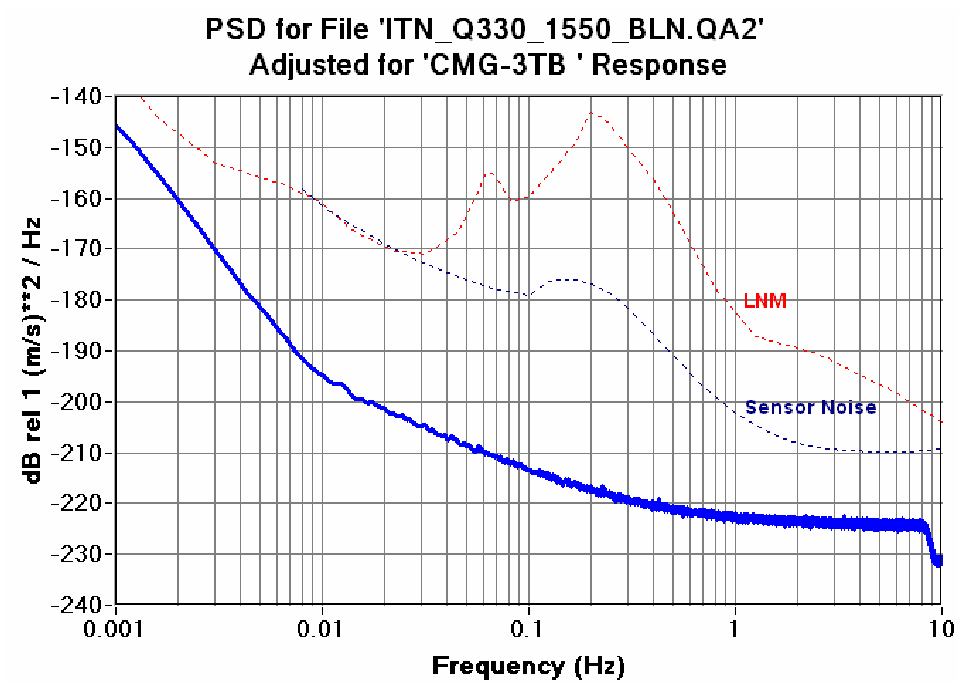


Figure 6.12.8b Q330HR 20SPS CH2 Seismic System Noise CMG-3TB

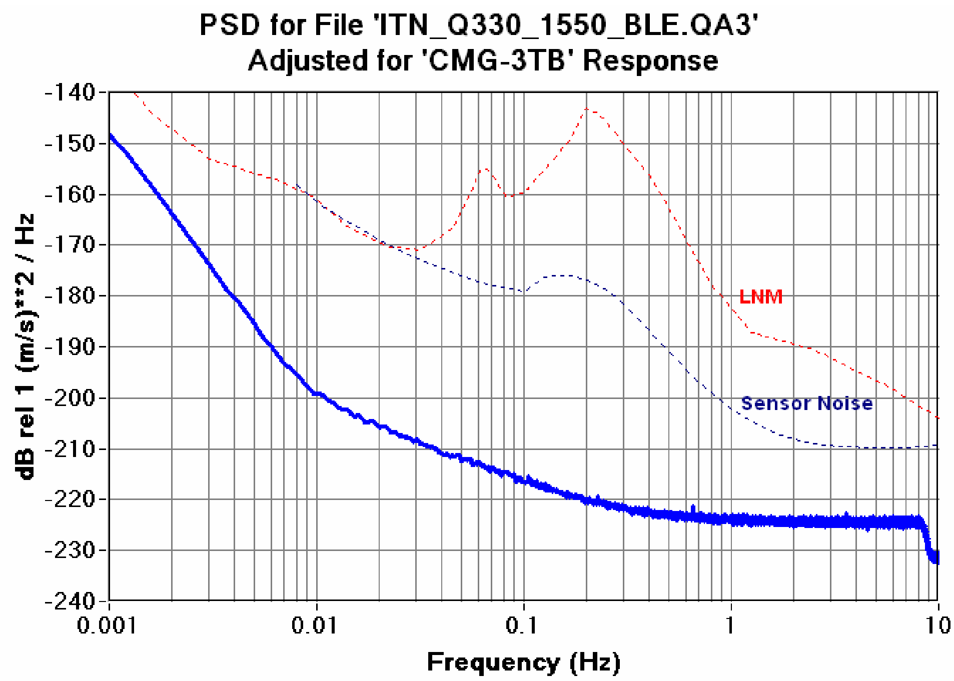


Figure 6.12.8c Q330HR 20SPS CH3 Seismic System Noise CMG-3TB

<u>Test Results:</u>
Figures 6.12.8a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 10.0 Hz when used with a Guralp CMG-3TB seismometer.

6.12.9 Q330HR/A Sample Rate 20 sps/STS-1:

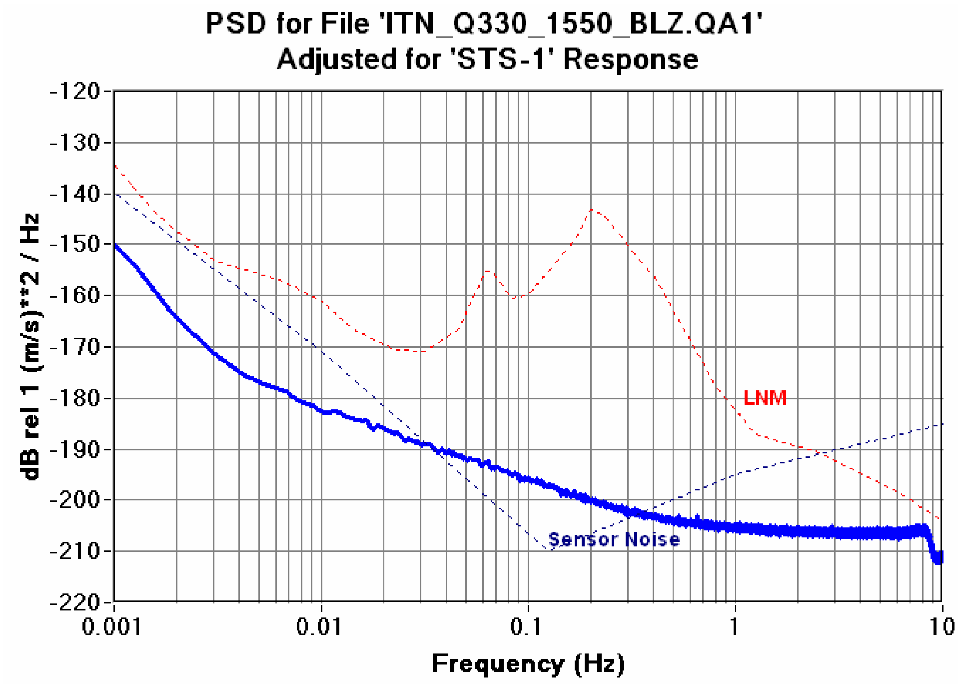


Figure 6.12.9a Q330HR 20SPS CH1 Seismic System Noise STS-1

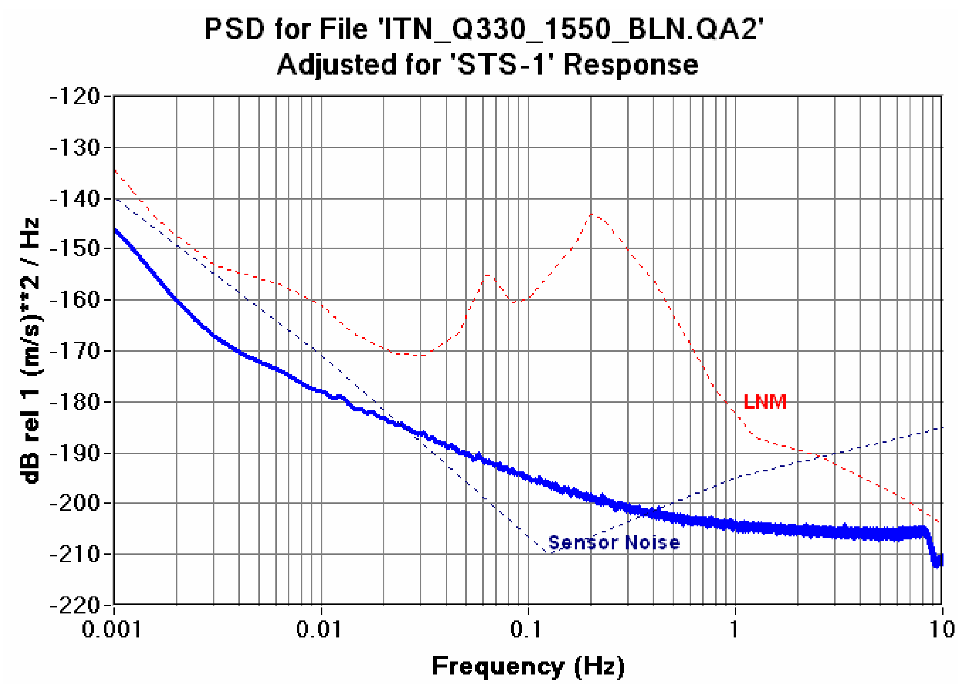


Figure 6.12.9b Q330HR 20SPS CH2 Seismic System Noise STS-1

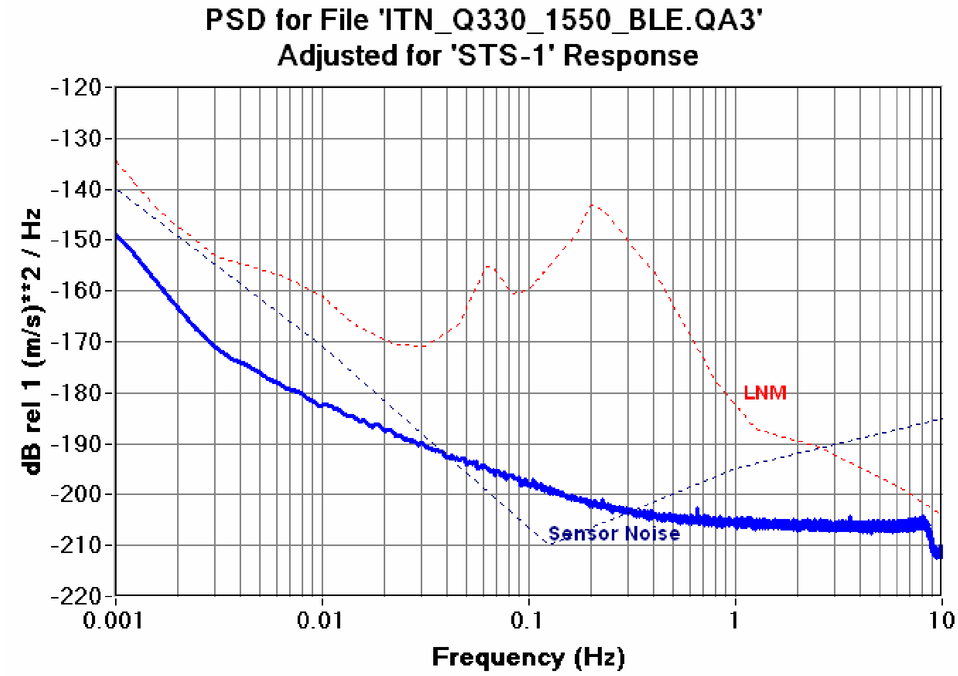


Figure 6.12.9c Q330HR 20SPS CH3 Seismic System Noise STS-1

<u>Test Results:</u>

Figures 6.12.9a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 10.0 Hz when used with a Streckeisen STS-1 seismometer.

6.12.10 Q330HR/A Sample Rate 20 sps/KS54000:

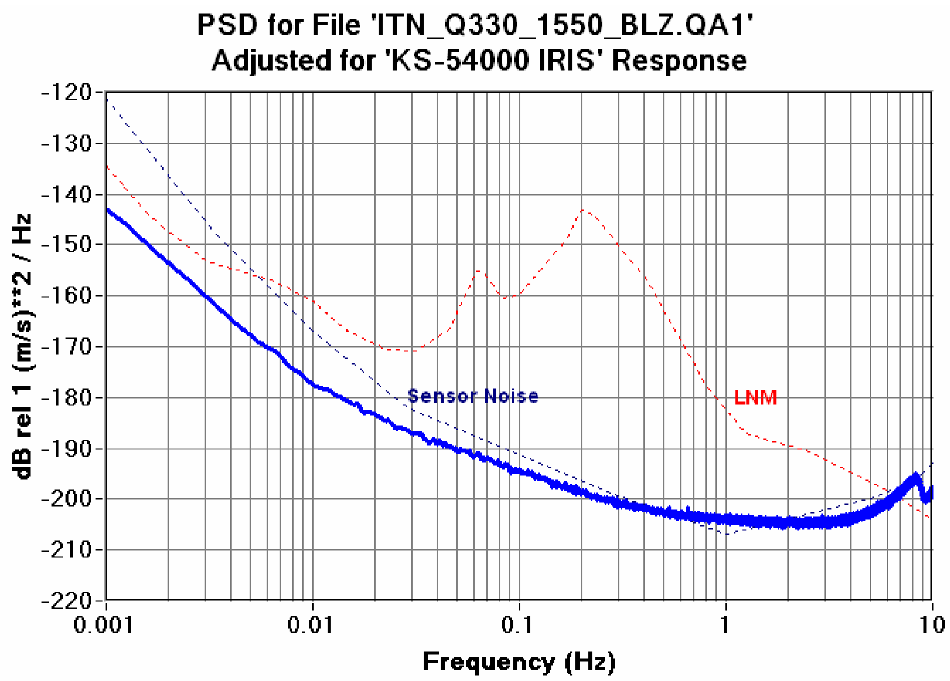


Figure 6.12.10a Q330HR 20SPS CH1 Seismic System Noise KS54000

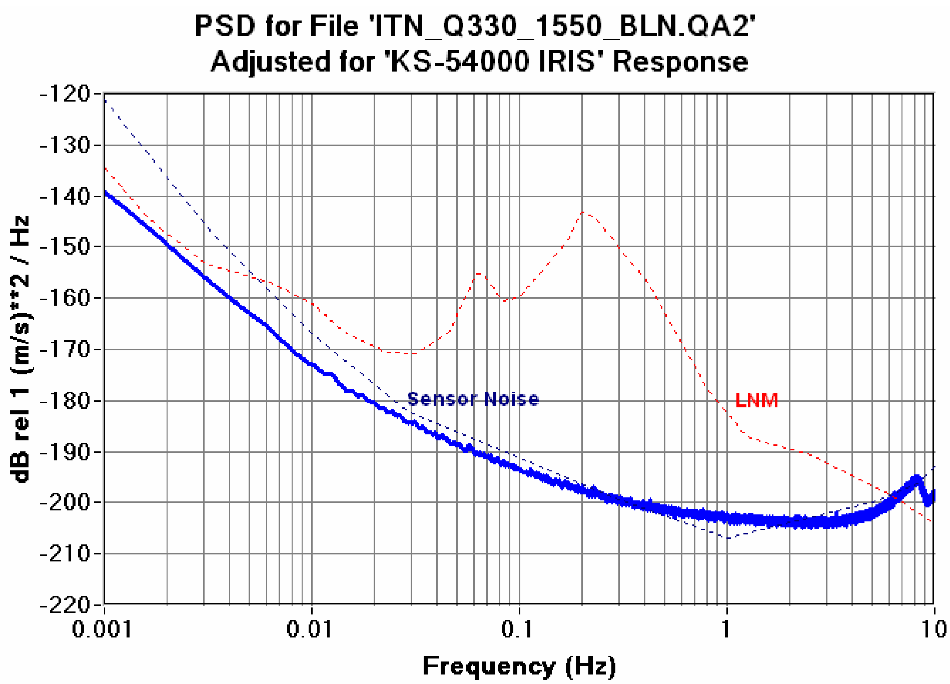


Figure 6.12.10b Q330HR 20SPS CH2 Seismic System Noise KS54000

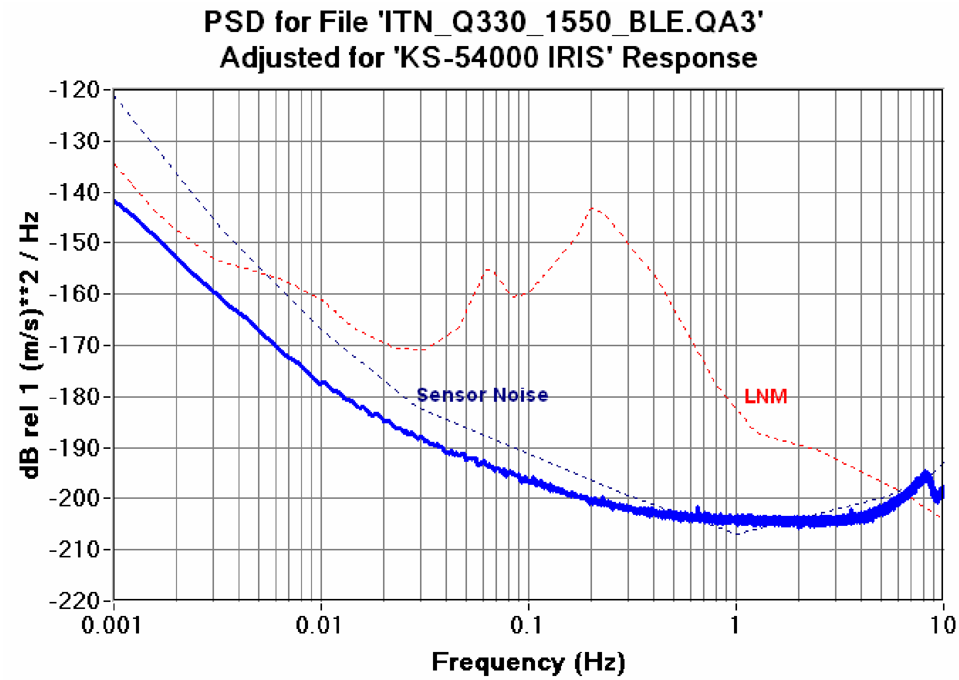


Figure 6.12.10c Q330HR 20SPS CH3 Seismic System Noise KS54000

<u>Test Results:</u>
Figures 6.12.10a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 7.0 Hz when used with a Geotech KS54000 seismometer.

6.12.11 Q330HR/A Sample Rate 1 sps/STS-1:

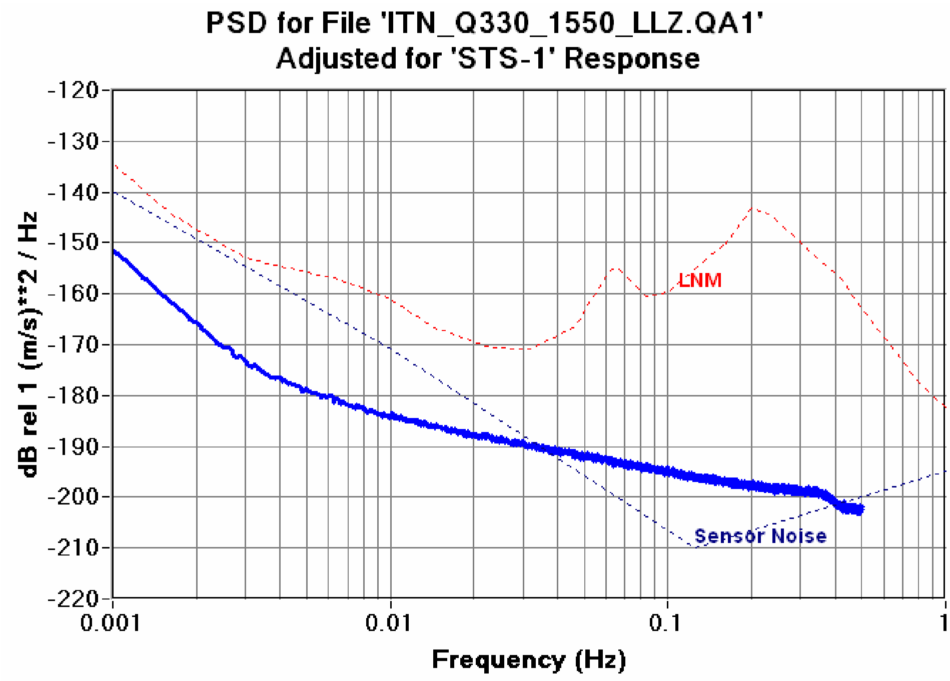


Figure 6.12.11a Q330HR 1SPS CH1 Seismic System Noise STS-1

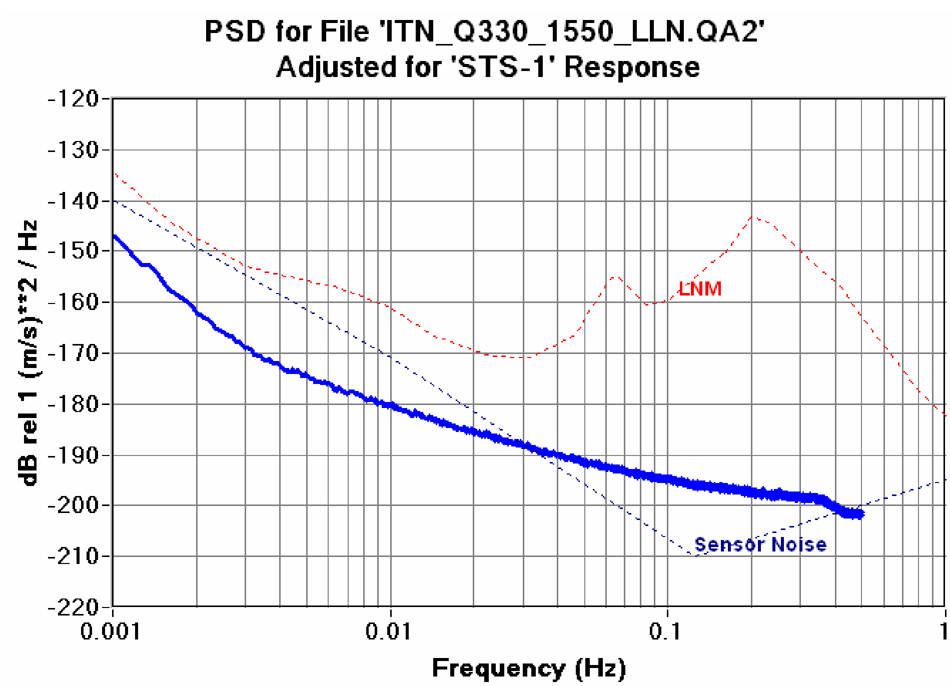


Figure 6.12.11b Q330HR 1SPS CH2 Seismic System Noise STS-1

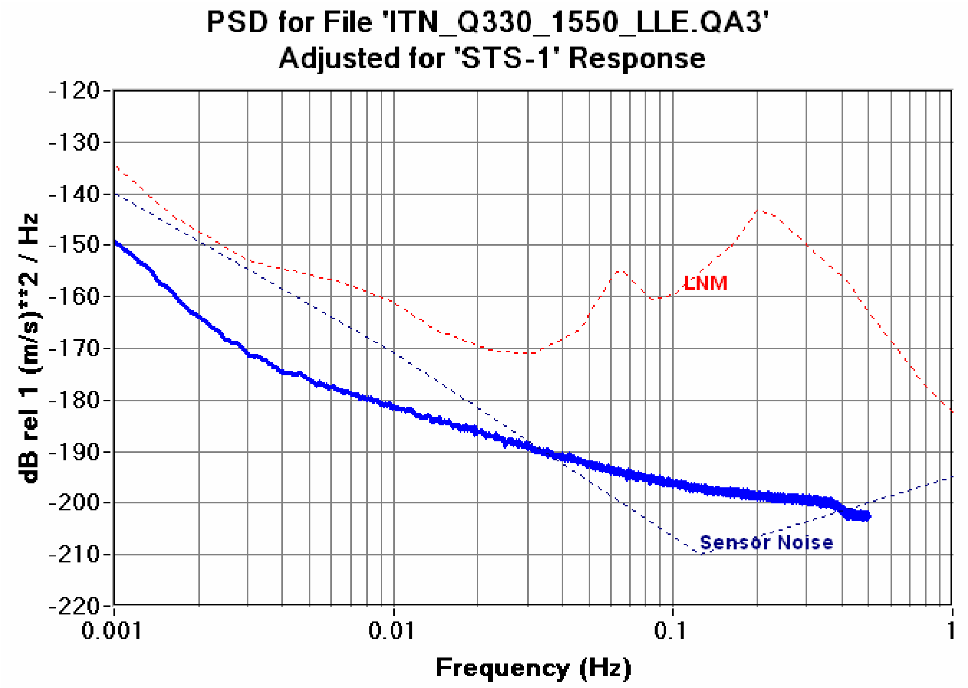


Figure 6.12.11c Q330HR 1SPS CH3 Seismic System Noise STS-1

<u>Test Results:</u>

Figures 6.12.11a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Streckeisen STS-1 seismometer.

6.12.12 Q330HR/A Sample Rate 1 sps/KS54000:

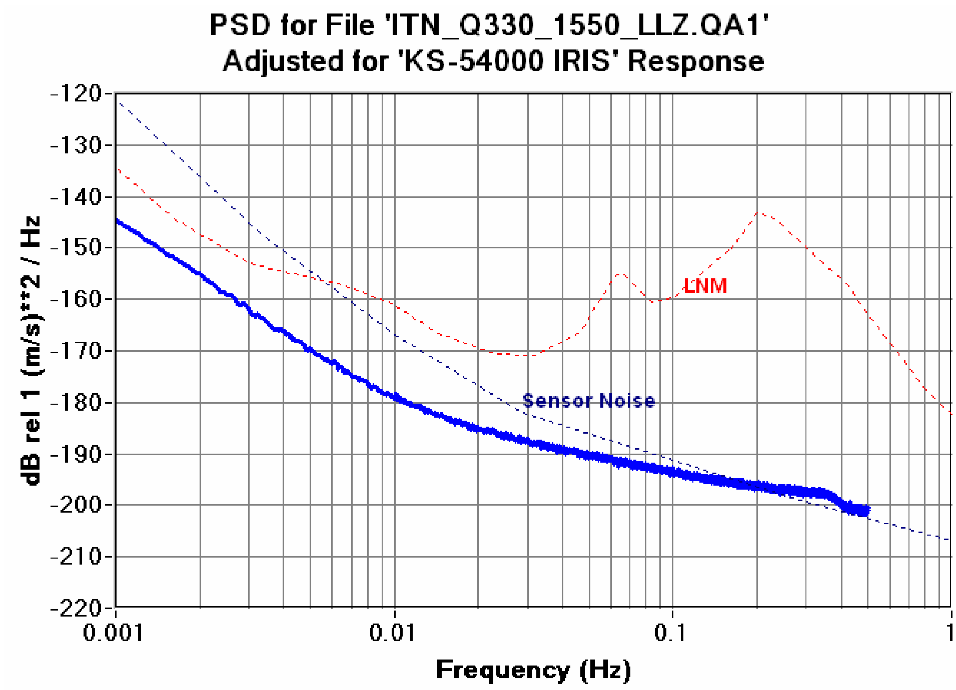


Figure 6.12.12a Q330HR 1SPS CH1 Seismic System Noise KS54000

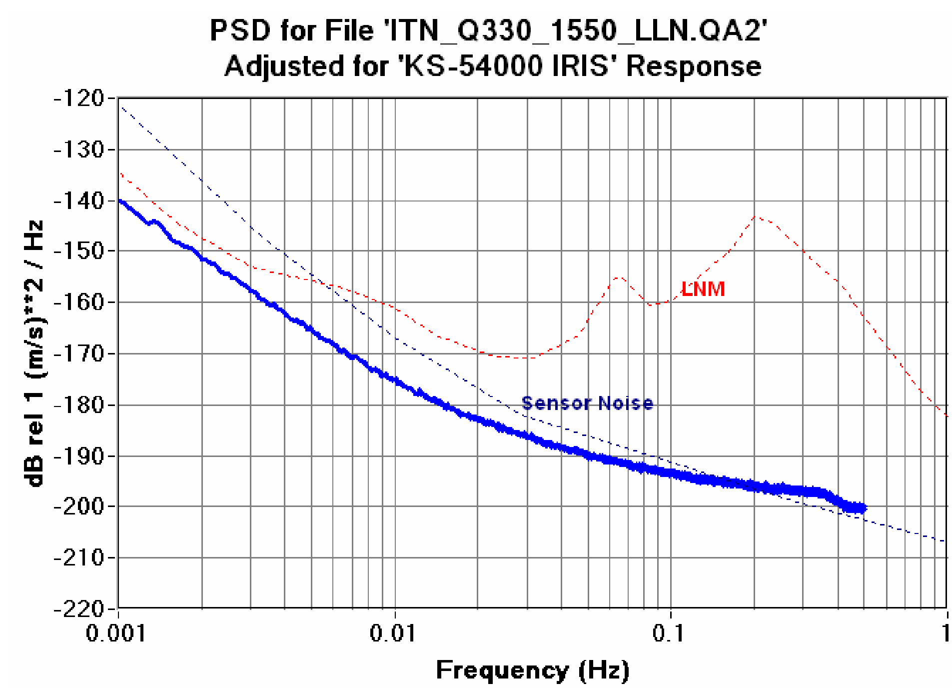


Figure 6.12.12b Q330HR 1SPS CH2 Seismic System Noise KS54000

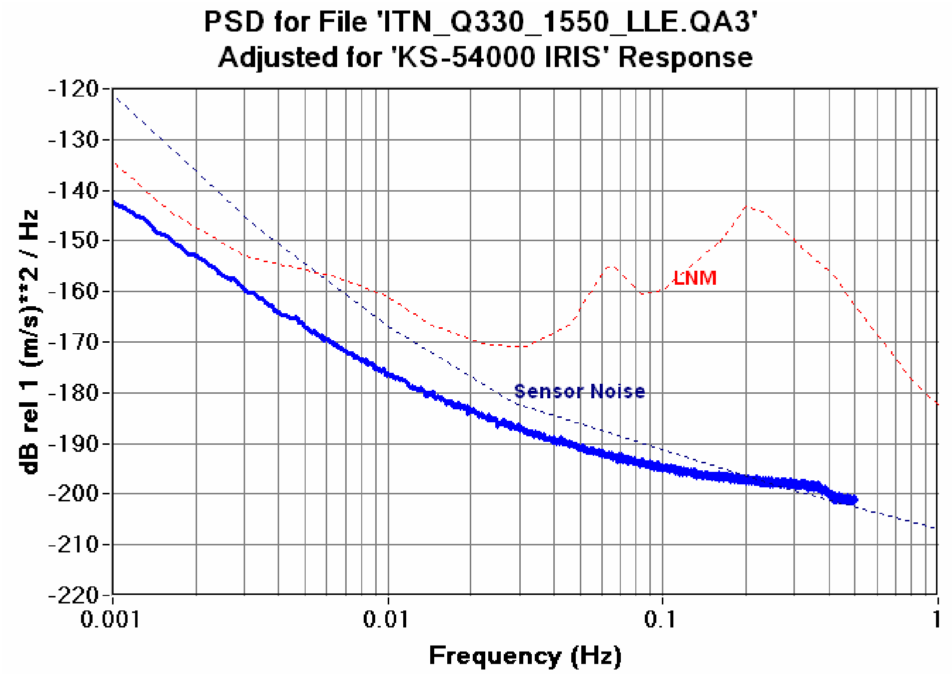


Figure 6.12.12c Q330HR 1SPS CH3 Seismic System Noise KS54000

<u>Test Results:</u>

Figures 6.12.12a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a KS54000 seismometer.

6.12.13 Q330HR/B Sample Rate 1 sps/STS-1:

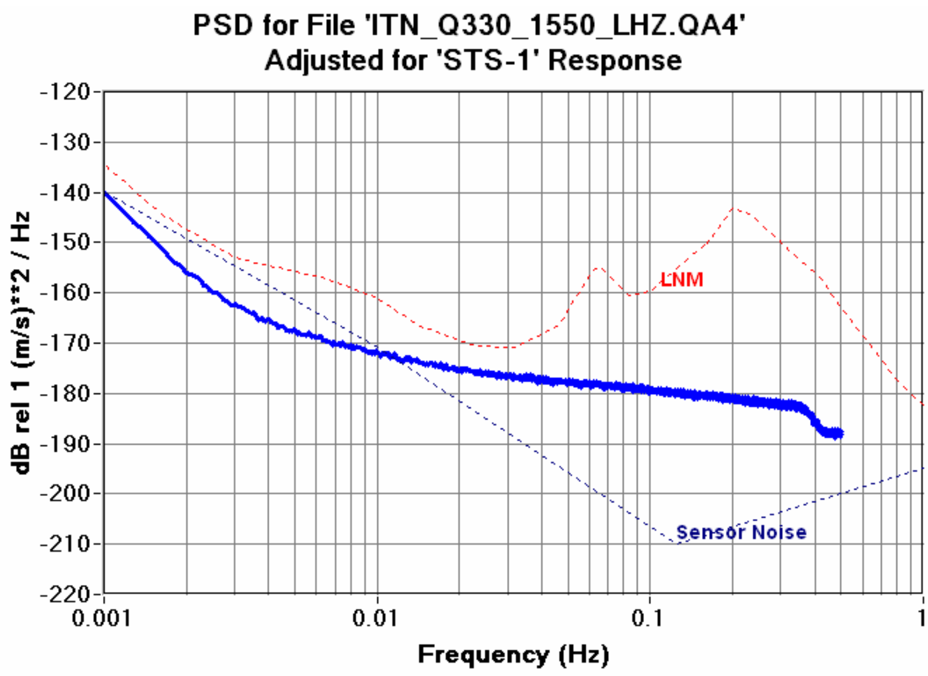


Figure 6.12.13a Q330HR 1SPS CH4 Seismic System Noise STS-1

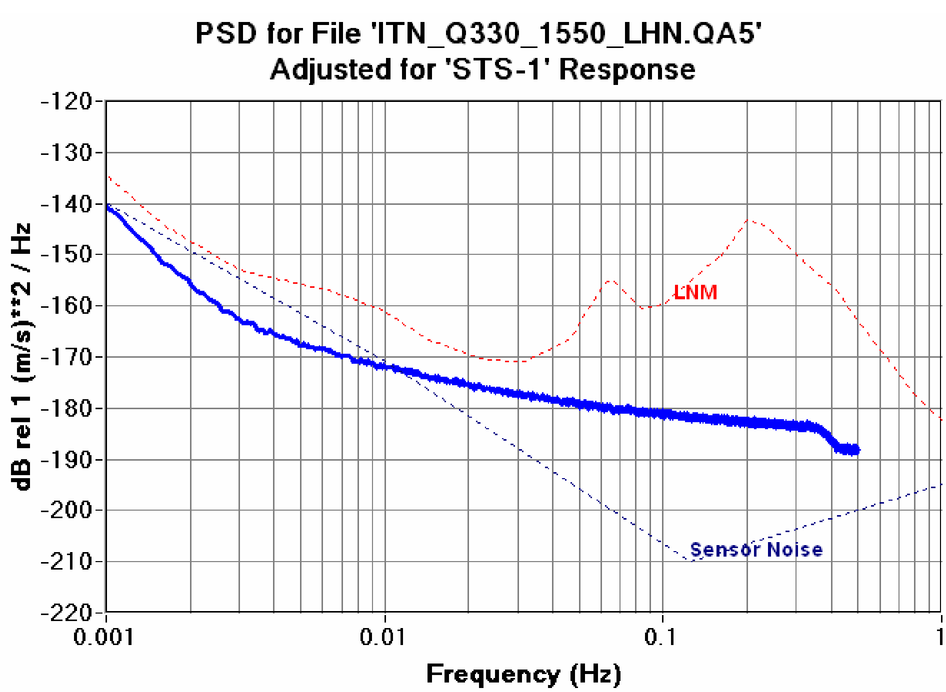


Figure 6.12.13b Q330HR 1SPS CH5 Seismic System Noise STS-1

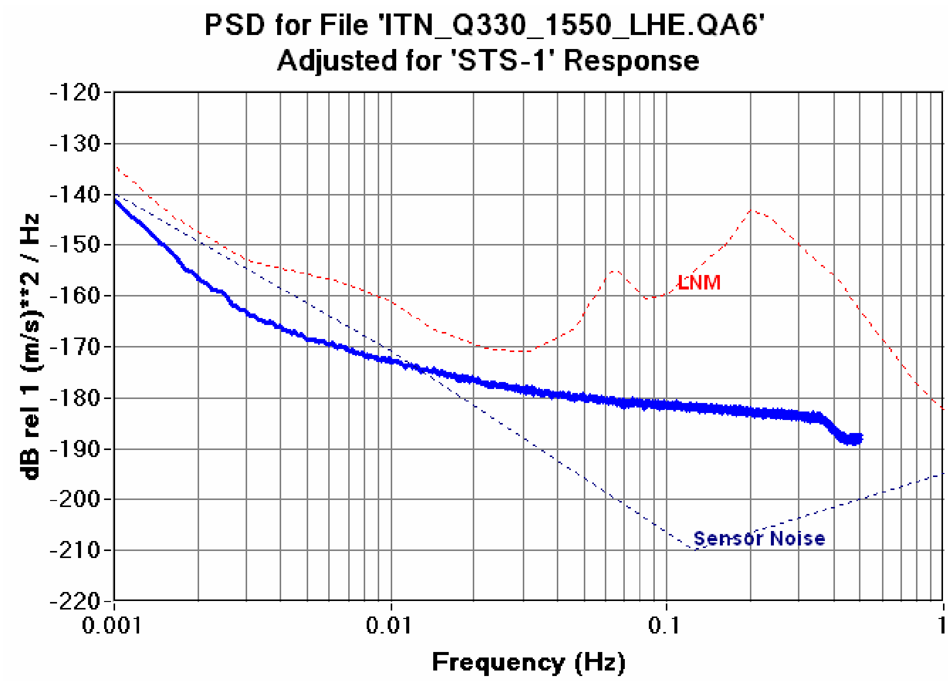


Figure 6.12.13c Q330HR 1SPS CH6 Seismic System Noise STS-1

<u>Test Results:</u>

Figures 6.12.13a-c indicate that the response corrected noises of the Q330HR/B were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Streckeisen STS-1 seismometer.

6.12.14 Q330HR/B Sample Rate 1 sps/KS54000:

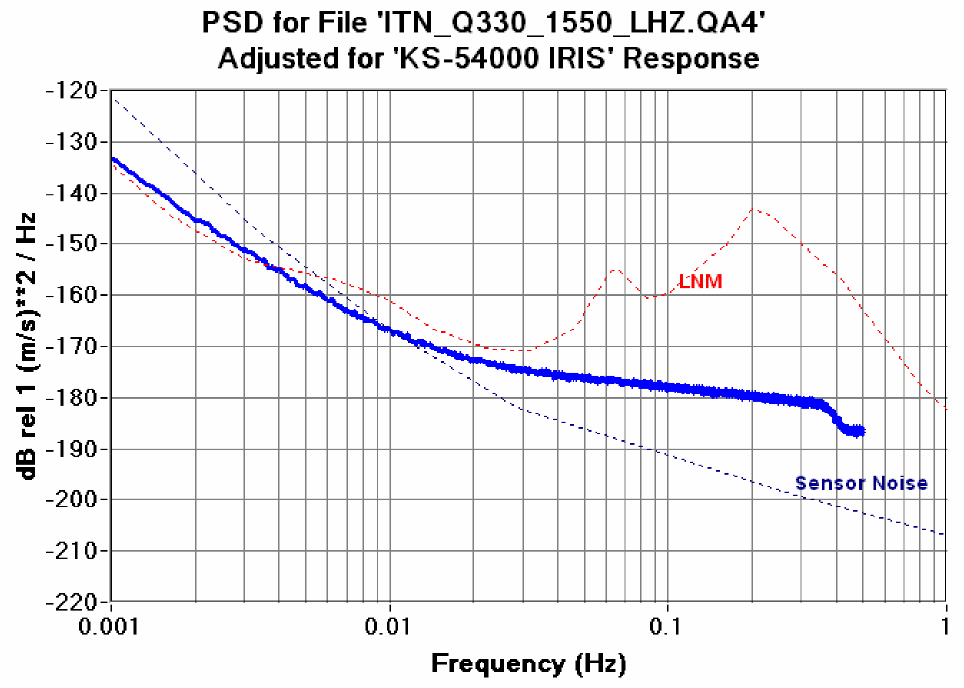


Figure 6.12.14a Q330HR 1SPS CH4 Seismic System Noise KS54000

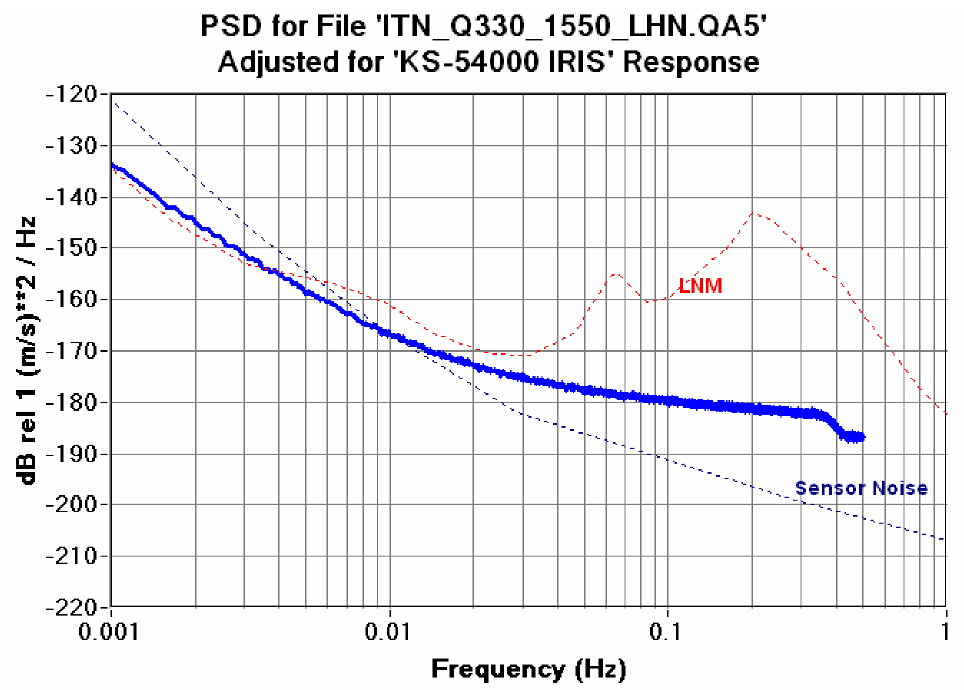


Figure 6.12.14b Q330HR 1SPS CH5 Seismic System Noise KS54000

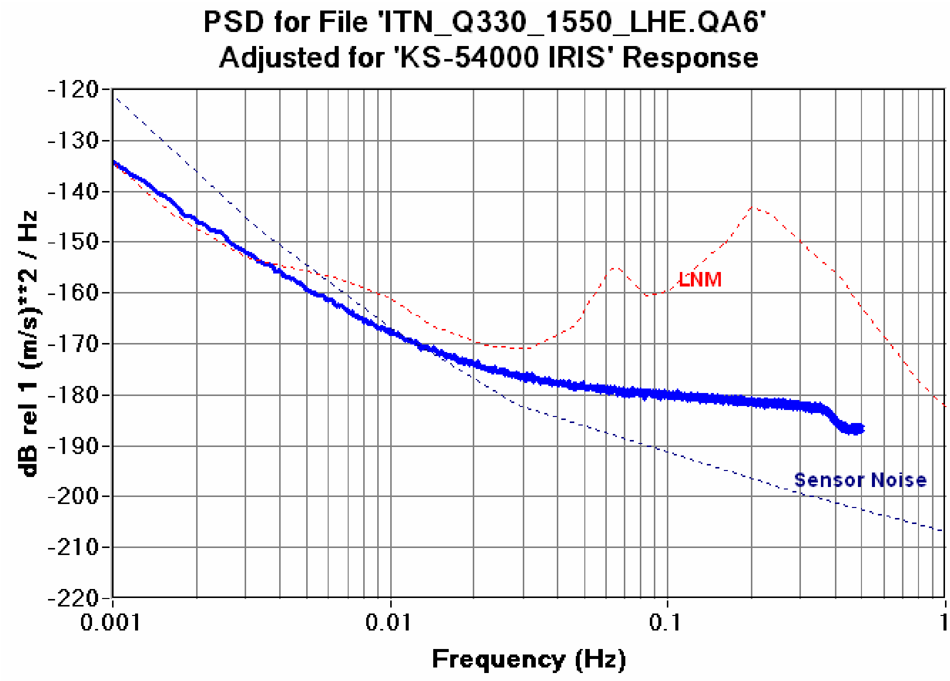


Figure 6.12.14c Q330HR 1SPS CH6 Seismic System Noise KS54000

<u>Test Results:</u>
Figures 6.12.14a-c indicate that the response corrected noises of the Q330HR/B were at or below the USGS Low Earth Noise Model (LNM) between 0.004 and 0.5 Hz when used with a KS54000 seismometer.

6.12.15 Q330HR/B Sample Rate 1 sps/CMG-3TB:

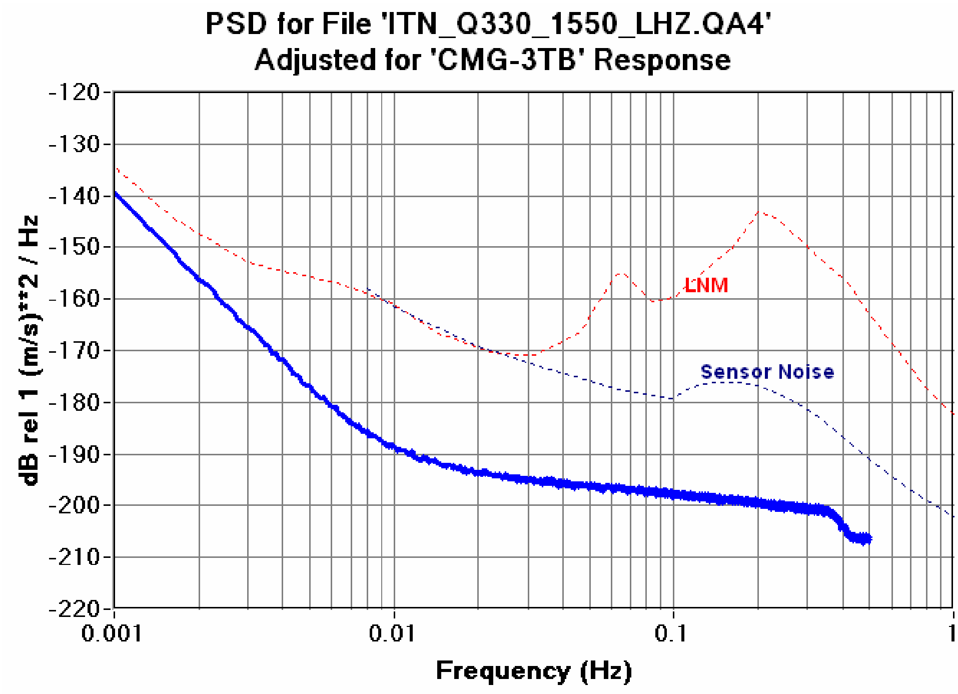


Figure 6.12.15a Q330HR 1SPS CH4 Seismic System Noise CMG-3TB

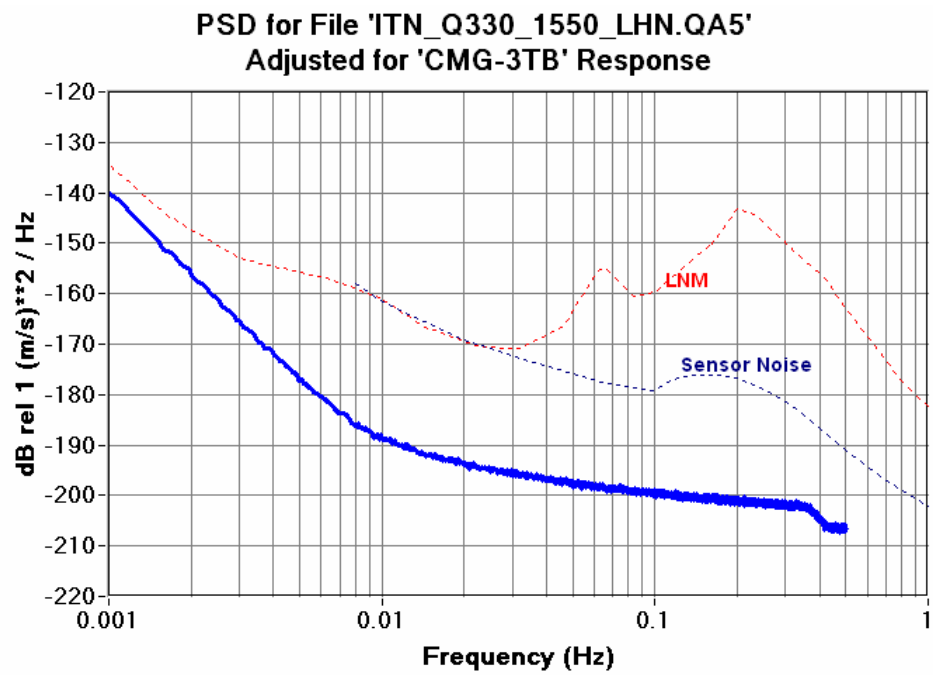


Figure 6.12.15b Q330HR 1SPS CH5 Seismic System Noise CMG-3TB

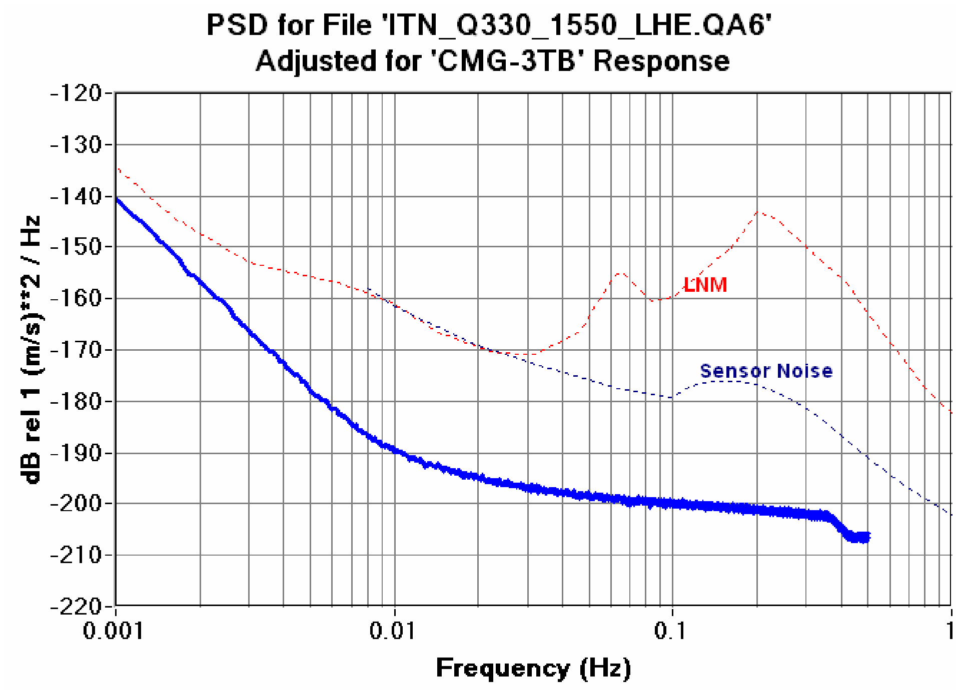


Figure 6.12.15c Q330HR 1SPS CH6 Seismic System Noise CMG-3TB

<u>Test Results:</u>
Figures 6.12.15a-c indicate that the response corrected noises of the Q330HR/B were at or below the USGS Low Earth Noise Model (LNM) between 0.001 and 0.5 Hz when used with a Guralp CMG-3TB seismometer.

6.12.16 Q330HR/A Sample Rate 0.1 sps/STS-1:

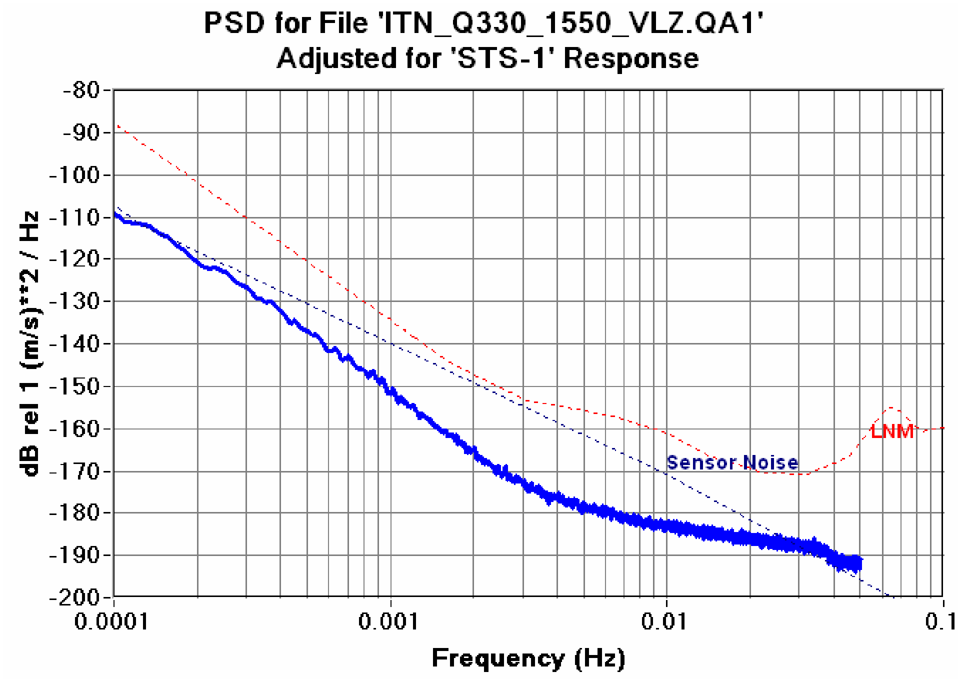


Figure 6.12.16a Q330HR 0.1SPS CH1 Seismic System Noise STS-1

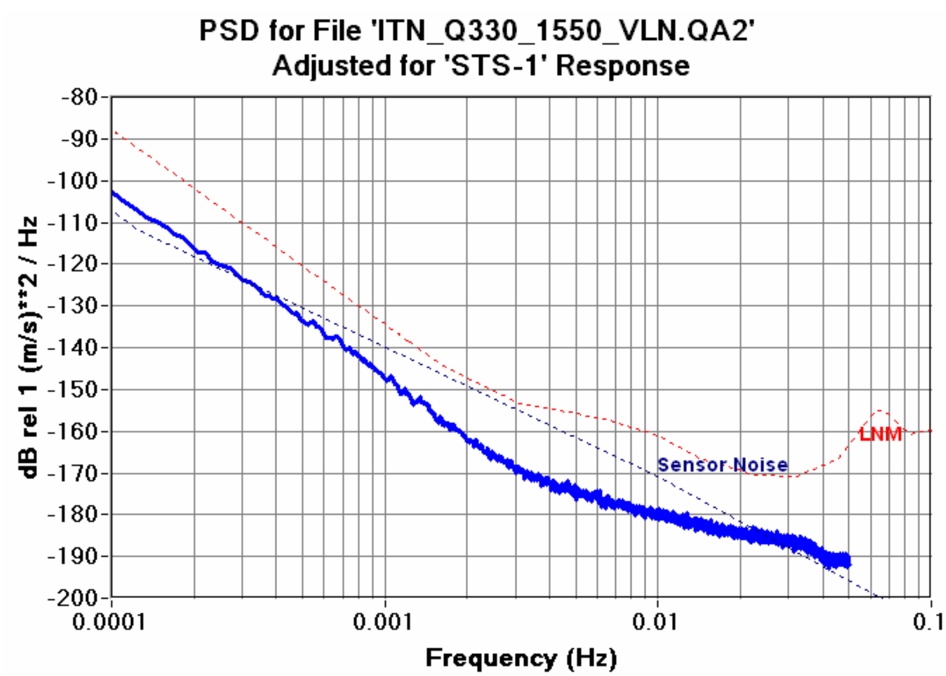


Figure 6.12.16b Q330HR 0.1SPS CH2 Seismic System Noise STS-1

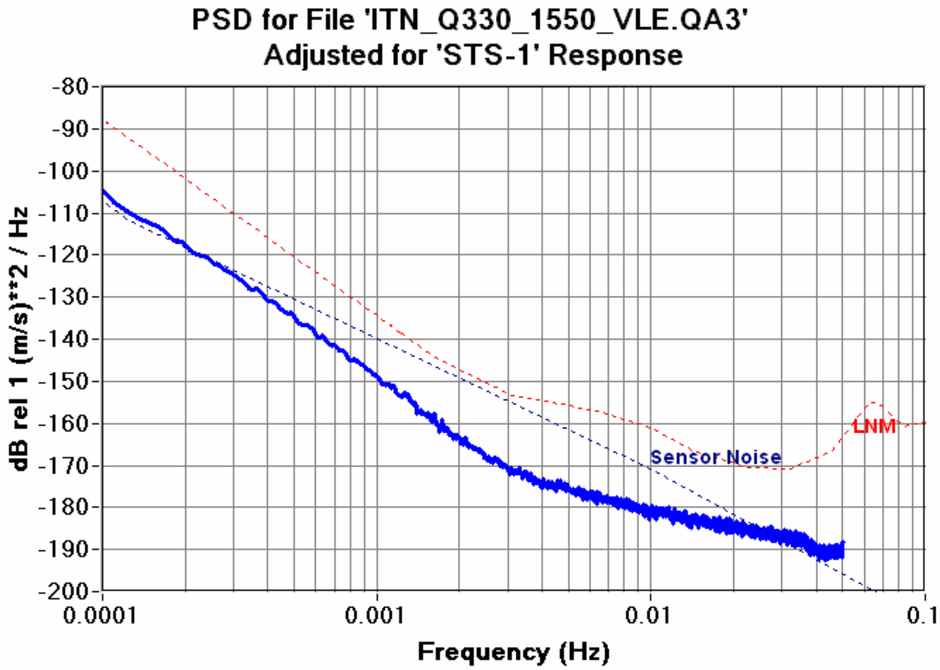


Figure 6.12.16c Q330HR 0.1SPS CH3 Seismic System Noise STS-1

Test Results:

Figures 6.12.16a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.0001 and 0.05 Hz when used with a Streckeisen STS-1 seismometer.

6.12.17 Q330HR/A Sample Rate 0.1 sps/KS54000:

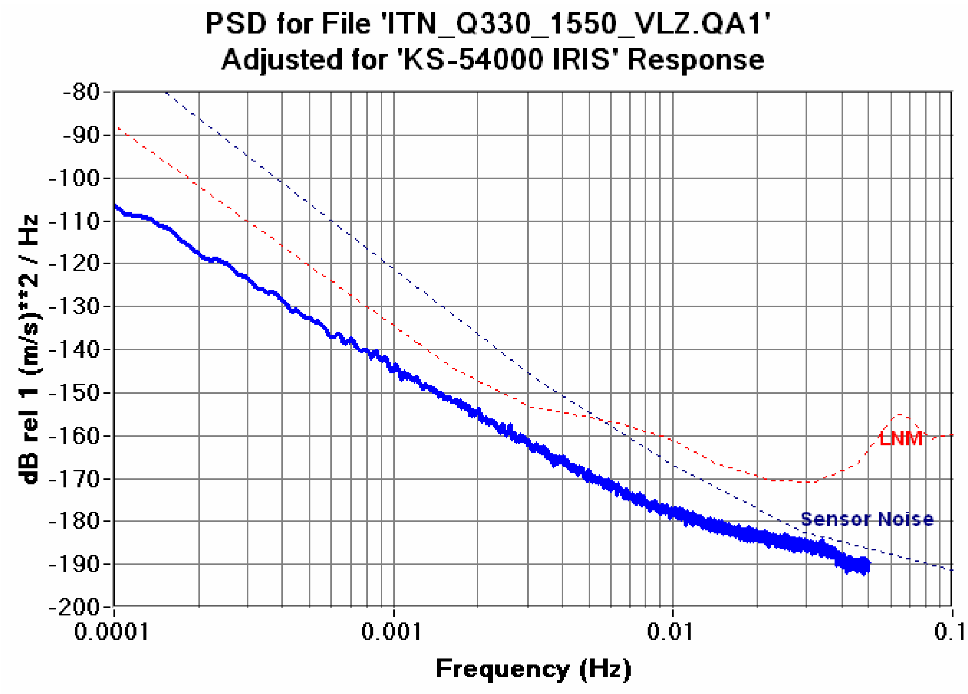


Figure 6.12.17a Q330HR 0.1SPS CH1 Seismic System Noise KS54000

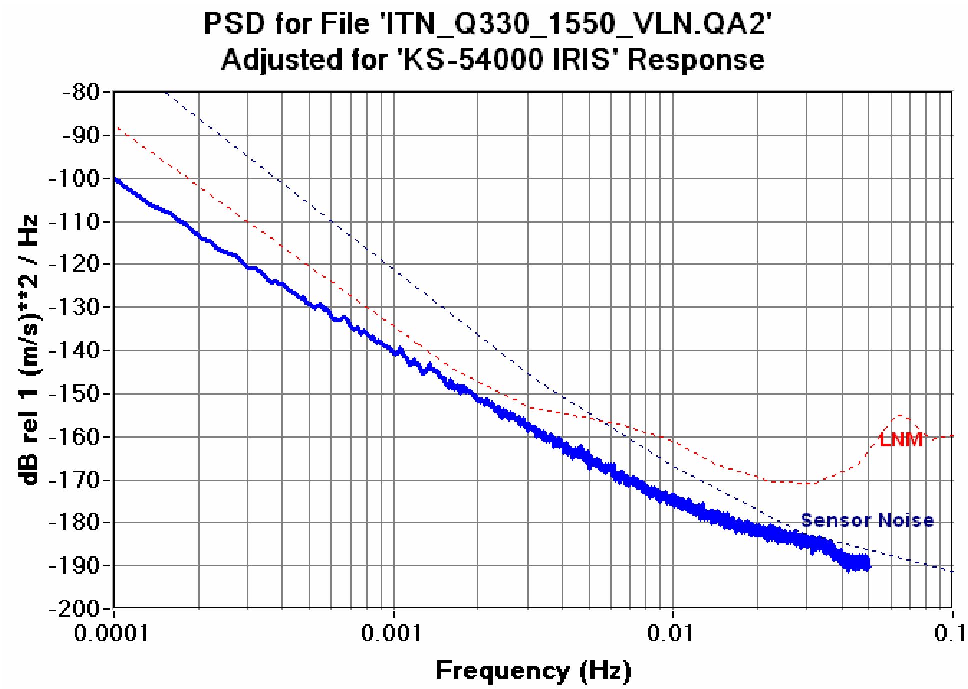


Figure 6.12.17b Q330HR 0.1SPS CH2 Seismic System Noise KS54000

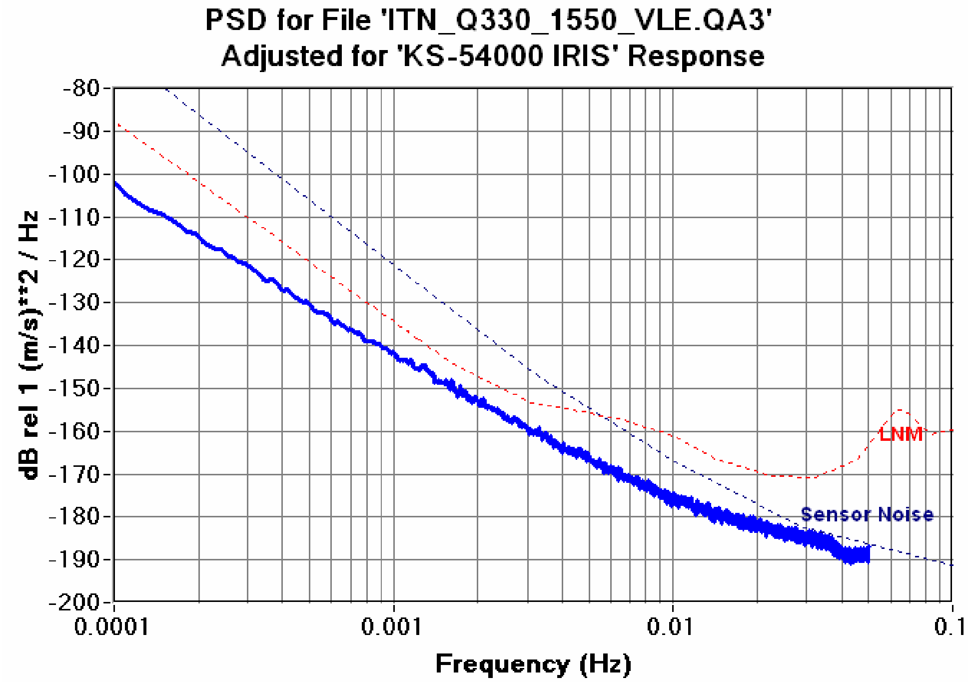


Figure 6.12.17c Q330HR 0.1SPS CH3 Seismic System Noise KS54000

Test Results:

Figures 6.12.17a-c indicate that the response corrected noises of the Q330HR/A were at or below the USGS Low Earth Noise Model (LNM) between 0.0001 and 0.05 Hz when used with a KS54000 seismometer.

7 Appendix II: Q680 Information

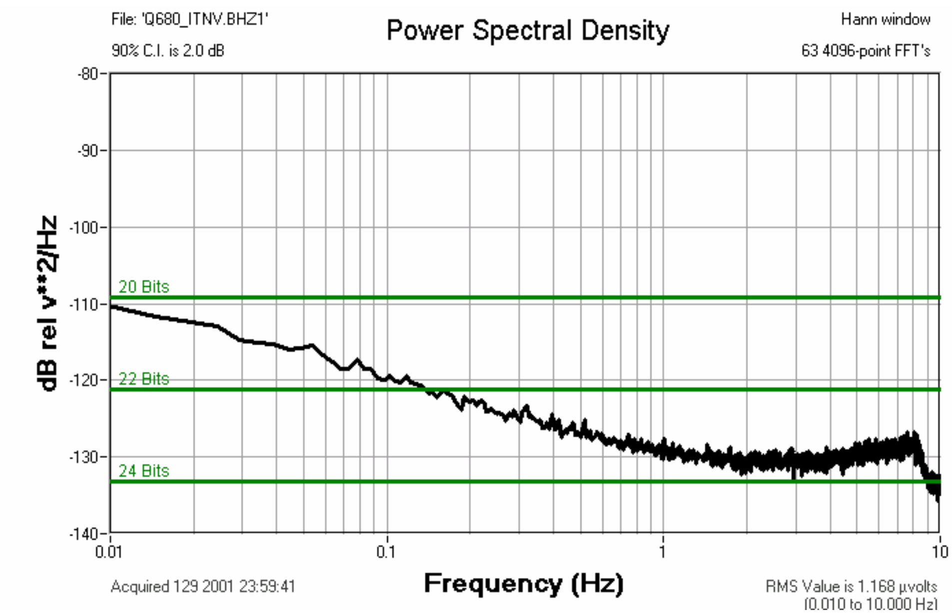
Historical Data from Earlier Report

7.1 Q680 Test Data Sheet: Test – Static/ITN

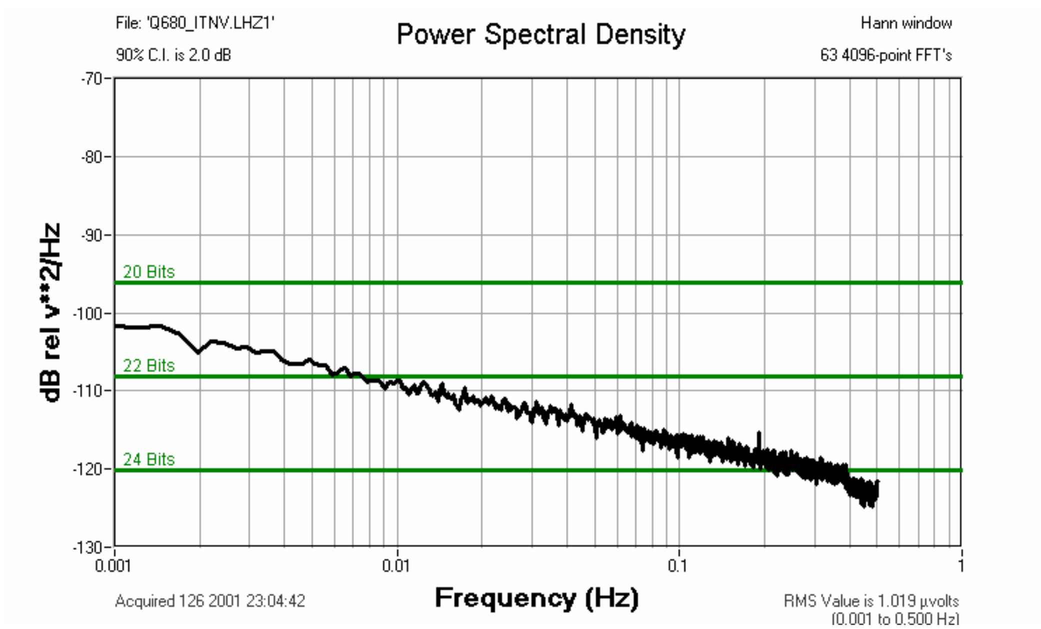
Q680 S/N: 1550
****

ITN Test Description: Measure Input Terminated Noise.

7.1.1 Q330HR Sample Rate 20 sps:



7.1.2 Q680 Sample Rate 1 sps:

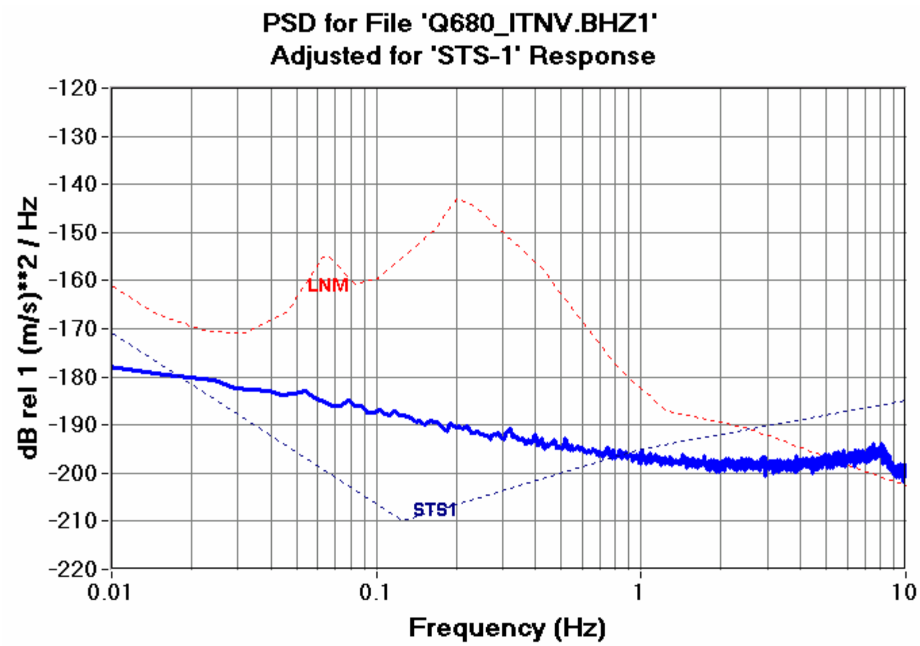


7.2 Q330HR Test Data Sheet Test – Seismic/SSN

Q680 S/N: 1550
****

SSN Test Description: Determine ability of the Q680 to resolve the expected seismic background using a Streckeisen STS-1.

7.2.1 Q680 Sample Rate 20 sps:



7.2.2 Q680 Sample Rate 1 sps: