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Geotech Smart24 Data Acquisition System Input Terminated Noise Seismic Response Adjusted Test: Streckeisen STS2-Low and High Gain, Guralp CMG3T and Geotech GS13 Seismometers

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Abstract

Sandia National Laboratories has tested, evaluated and reported on the Geotech Smart24 data acquisition system with active Fortezza crypto card data signing and authentication in SAND2008-. One test, Input Terminated Noise, allows us to characterize the self-noise of the Smart24 system. By computing the power spectral density (PSD) of the input terminated noise time series data set and correcting for the instrument response of different seismometers, the resulting spectrum can be compared to the USGS new low noise model (NLNM) of Peterson (1996), and determine the ability of the matched system of seismometer and Smart24 to be quiet enough for any general deployment location. Four seismometer models were evaluated: the Streckeisen STS2-Low and High Gain, Guralp CMG3T and Geotech GS13 models. Each has a unique pass-band as defined by the frequency band of the instrument corrected noise spectrum that falls below the new low-noise model.

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1 Executive Summary

Objective:

The objective of this work was to evaluate the static performance of the Geotech Smart24 digitizer with Fortezza PCMCIA crypto card actively implementing the signing of data packets for its possible application with four seismometer models: the Streckeisen STS2-Low and High Gain, Guralp CMG3T and Geotech GS13. The results of this evaluation were compared to the USGS New Low Noise Model (NLNM) to determine the sensor's effective passband (frequencies at which the instrument corrected input terminated noise spectrum is at or below the NLNM) when matched with the Smart24 data logger. Four frequencies, 0.02, 0.1, 1.0 and 10 Hz, were chosen to make individual measurements of the amount of separation above or below the NLNM.

Description:

Smart24 digitizers used in certain applications need to have the capability to be configured to collect data from either an infrasound or seismic application. The one requirement for some sites is to have the capability to sign outgoing data packets. The Smart24 digitizer supports the use of a Fortezza PCMCIA Crypto Card for the purpose of data signing and authentication. For a seismic application the configuration is 40 Vpp ADC Board, LSB of $3.271e-6$ V/count, three active channels and sampled at 40 sps. Digitizer testing focused on characterization of one unit serial number s1224 with a single ADC board serial number 1724, and one would expect that other Geotech Smart24 with Fortezza PCMCIA crypto cards to perform in a like manner.

The central recording facility at FACT uses the Geotech GeoHub software suite run on a standard PC for acquisition and data archiving the test data. The GeoHub system was designed for network and array operators to allow greater control in data acquisition, data concentration and distribution for data archiving via its flexible communication protocol. The basic data transmission path from the data loggers to database starts at the Smart24 with a RJ45 Ethernet connection to the FACT internal LAN. The PC running the GeoHub software was connected to the same LAN. The Smart24 and GeoHub communicate via fixed IP addresses. All test data were acquired in near real-time in CSS 3.0 flat-file database records in S4 format.

Testing was performed in a seismic vault for temperature stability. The Smart24 tested was set to the gain of 1, required for seismic or infrasound applications.

1.1 Smart24 w/Fortezza 40sps and 40Vpp ADC Board - Digitizer Evaluation Summary:

Static Performance:

The input terminated noise was less than 0.97 counts RMS for the 0.02 to 20 Hz application band. The Maximum Potential Dynamic Range was better than 133.0 dB.

Application Performance STS2 low gain:

When the ITN spectrum for the Smart24 was corrected for a Streckeisen STS2 low gain seismometer the resulting spectrum was at or below the USGS LNM minimum-earth noise model between 0.01 and 1 Hz.

The ITN-correct noise was approximately 2.151 nm/s RMS for the 0.02 to 20 Hz application band.

Application Performance STS2 high gain:

When the ITN spectrum for the Smart24 was corrected for a Streckeisen STS2 high gain seismometer the resulting spectrum was at or below the USGS LNM minimum-earth noise model between 0.01 and 17 Hz.

The ITN-correct noise was approximately 0.1614 nm/s RMS for the 0.02 to 20 Hz application band.

Application Performance Guralp CMG 3T:

When the ITN spectrum for the Smart24 was corrected for a Guralp CMG-3T seismometer the resulting spectrum was at or below the USGS LNM minimum-earth noise model between 0.01 and 1.3 Hz.

The ITN-correct noise was approximately 1.604 nm/s RMS for the 0.02 to 20 Hz application band.

Application Performance Geotech GS13:

When the ITN spectrum for the Smart24 was corrected for a Geotech GS13 seismometer the resulting spectrum was at or below the USGS LNM minimum-earth noise model between 0.15 and 1.2 Hz.

The ITN-correct noise was approximately 214.1 nm/s RMS for the 0.02 to 20 Hz application band.

1.2 Conclusions:

The four seismometers evaluated for the matched performance with the Smart24 showed variability between the portion of each sensor's pass-band falling at or below the USGS low noise model. The sensor's sensitivity will affect the amount above, at or below the compared reference model, we used the USGS NLNM. This point is clearly shown by comparing the results between the STS2 low and high gain seismometers. Their response poles and zeros (i.e. shape in amplitude and phase) are the same, but their sensitivities differ by 22.5 dB (dB relative to 1 (v/m/s)^2). The effect of higher sensitivity extends the portion at or below the USGS NLNM from 1 Hz to 17 Hz. The differences observed between the Streckeisen STS2 low-gain, Guralp and Geotech are driven by the differences in their response models. When selecting a seismometer to match with the Smart24 for a particular end use application a properly matched data-logger and sensor should resolve the expected seismic signals and backgrounds while nearly maximizing the systems dynamic range.

2 Introduction

2.1 Scope

This Evaluation Report defines the activities that were performed as part of the evaluation of the Geotech Smart24 configured with a Fortezza Crypto PCMCIA Card describes the results of the testing.

2.2 Objectives

The objective of this work was to evaluate the overall technical performance of the Geotech Smart24 digitizer while the Fortezza Card is enabled and signing data outbound data packets. Basic digitizer characterization includes determining LSB, DC offset, noise, dynamic range, time-tag accuracy, channel-to-channel cross-talk, total harmonic distortion and the calibrator's performance. The results of this evaluation were compared to relevant application requirements or specifications of the Smart24 provided by the manufacturer.

3 DWR 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 [Reference 1] for Digitizing Waveform Recorders 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 DWR Test/Evaluation Process

3.3.1 SMART24 Testing

Testing of the Smart24 w/Fortezza, serial number s1224, digitizer was performed between October 2007 and February 2008, at the Sandia National Laboratories Facility for Acceptance, Calibration and Testing (FACT Site), Albuquerque, NM. The unit arrived with one 20 Vpp ADC board installed, serial number 1360. The ADC board has an input range of 20 Volts peak-to-peak (Vpp). Testing the performance of a 40 Vpp ADC board, required that Sandia provide one for testing. The 40 Vpp ADC used for testing was serial number 1724 procured November 2007.

The Smart24 allows up to four data customer profiles to be configured. We configured profile #3 for testing at FACT. Configuration of the profile consisted of setting the peak-to-peak voltage, sample rate and channel naming convention. For both ADC board tested at 20sps data was labeled as c1s –channel 1, c2s – channel 2 and c3s – channel 3; the 40 sps data was labeled as BDF – channel 1, c2p – channel 2 and c3p – channel 3.

3.3.2 SMART24 General Digitizer Performance Tests

The following tests were conducted on the Smart24 as described in the test plan: *Test Definition and Test Procedures for the Evaluation of Digitizing Waveform Recorders* [Reference 3].

The tests selected provide a high level of characterization for IMS when evaluating digitizers for seismic or acoustic applications.

Smart24 w/Fortezza 40Vpp and 40sps Configuration

- Static Performance Tests
 - Input Terminated Noise (DWR-ITN)
- Seismic Sensor Application Tests
 - DWR Seismic System Noise Test (DWR-SSN)

3.4 Test Configuration and System Specifications

3.4.1 Smart24 Digitizer Description and Test Configuration

The SMART24 digitizers under evaluation were manufactured by Geotech Instrument, LLC of Dallas, TX. The SMART24 was designed to be a high resolution 24-bit data acquisition system. The SMART24 was configured to acquire a primary data stream at 40 samples per second (sps) and a secondary data stream at 20 sps. The system under test used GeoHub™ data acquisition software for the SMART24 digitizers. GeoHub operated on a PC running Windows XP and communicated with the SMART24 digitizers through an Ethernet connection. Data were acquired in real-time in CSS 3.0 flat-file records. Waveform data were archived in “s4” data format.

DWR testing was performed in a seismic vault for temperature stability.

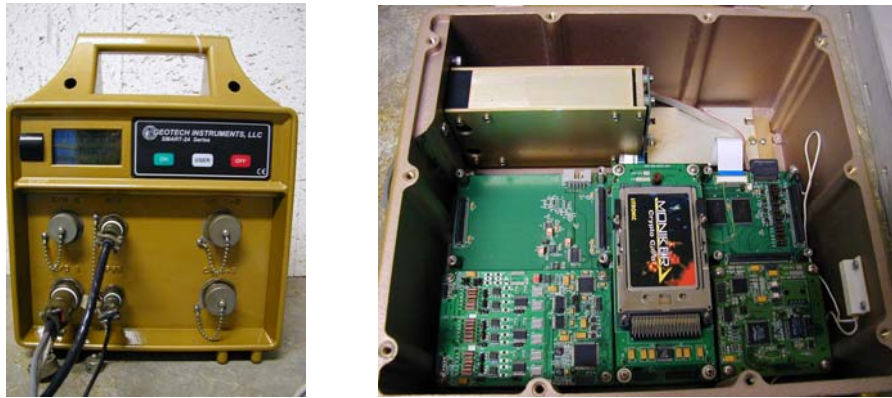


Figure 3.4.1 Smart24 w/Fortezza Card used for testing in FACT Vault. Illustrating the unit as viewed from the front and inside after removing back plate.

3.4.2 Seismic Sensor Application Test Parameters and Response

The four different seismometers were evaluated the Streckeisen STS2-Low and High Gain, Guralp CMG3T and Geotech GS13; their average theoretical amplitude and phase response as indicated in the Test Data Sheets, Appendix I, Sections 6.1-4, respectively.

4 DWR – SMART24 Tests

4.1 Static Performance Tests

Static tests provide a constant or non time-varying stimulus to the DWR under evaluation. The purpose of these tests is to determine specific parameters such as: gain (accuracy at nominal, full-scale and over-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 Input Terminated Noise (DWR-ITN)

Purpose: The purpose of the input-terminated noise test was to verify the static parameters of the SMART24. These static parameters are dominated primarily by the random noise generated within the digitizer and from other components within the digitizer package.

Configuration: The SMART24 Port 1 inputs were terminated with 100 ohms external resistors.

Evaluation: A power density spectrum (PDS) of the input-terminated noise provided a measure of the noise floor of the SMART24. RMS noise in the 0.02 to 20 Hz bandwidth for 40 sps data, short term and long-term stability, relationship to quantizing noise floor and correlated and uncorrelated spurious signals were measured.

Test Results:

DWR Serial Number: 1224, ADC board: 1724 ITN/MPDR Test Data Sheet, Appendix I, Section 6.5.

4.2 DWR Seismic Sensor Application Tests

Sensor application tests are those that provide a stimulus to the DWR or interpret data from the DWR that is related to a specific sensor application. The DWR selected for an application should match the characteristics of the interfaced sensor and the expected sensor 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 sensor. A properly matched DWR/sensor can resolve the expected seismic signals and backgrounds while nearly maximizing the system dynamic range.

DWR Seismic System Noise (DWR-SSN)

Purpose: The purpose of the seismic system noise test is to determine ability of the DWR to resolve the expected seismic background using a specific seismometer. The DWR self-noise should be below the expected seismic background and the self-noise of the seismometer.

Configuration: The DWR inputs are terminated with the equivalent output impedance of the application sensor. For typical active sensors this is 50-100 ohms. For complex impedance sensors, a range of values may be appropriate.

Evaluation: For a specific sensor application, convert the system noise of the DWR to ground motion using the application seismometer response mathematical model. The result of this computation can be overlaid with the USGS Low Earth Noise Model or a site specific seismic background to demonstrate the ability of the DWR to resolve the local seismic background.

Test Results:

DWR Serial Number: 1224 40sps SSN-STS2 LG Test Data Sheet, Appendix I, Section 6.6.

DWR Serial Number: 1224 40sps SSN-STS2 HG Test Data Sheet, Appendix I, Section 6.7.

DWR Serial Number: 1224 40sps SSN-CMG3T Test Data Sheet, Appendix I, Section 6.8.

DWR Serial Number: 1224 40sps SSN-GS13 Test Data Sheet, Appendix I, Section 6.9.

5 Summary

Objective:

The objective of this work was to evaluate the static performance of the Geotech Smart24 digitizer with Fortezza PCMCIA crypto card actively implementing the signing of data packets for its possible application with four seismometer models: the Streckeisen STS2-Low and High Gain, Guralp CMG3T and Geotech GS13. The results of this evaluation were compared to the USGS New Low Noise Model (NLNM) to determine the sensor's effective passband (frequencies at which the instrument corrected input terminated noise spectrum is at or below the NLNM) when matched with the Smart24 data logger. Four frequencies, 0.02, 0.1, 1.0 and 10 Hz, were chosen to make individual measurements of the amount of separation above or below the NLNM.

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5.1 Smart24 w/Fortezza 40sps and 40Vpp ADC Board - Digitizer Evaluation Summary:

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When the ITN spectrum for the Smart24 was corrected for a Streckeisen STS2 low gain seismometer the resulting spectrum was at or below the USGS LNM minimum-earth noise model between 0.01 and 1 Hz.

The ITN-correct noise was approximately 2.151 nm/s RMS for the 0.02 to 20 Hz application band.

Application Performance STS2 high gain:

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Application Performance Guralp CMG 3T:

When the ITN spectrum for the Smart24 was corrected for a Guralp CMG-3T seismometer the resulting spectrum was at or below the USGS LNM minimum-earth noise model between 0.01 and 1.3 Hz.

The ITN-correct noise was approximately 1.604 nm/s RMS for the 0.02 to 20 Hz application band.

Application Performance Geotech GS13:

When the ITN spectrum for the Smart24 was corrected for a Geotech GS13 seismometer the resulting spectrum was at or below the USGS LNM minimum-earth noise model between 0.15 and 1.2 Hz.

The ITN-correct noise was approximately 214.1 nm/s RMS for the 0.02 to 20 Hz application band.

5.2 Conclusions:

The four seismometers evaluated for the matched performance with the Smart24 showed variability between the portion of each sensor's pass-band falling at or below the USGS low noise model. The sensor's sensitivity will affect the amount above, at or below the compared reference model, we used the USGS NLNM. This point is clearly shown by comparing the results between the STS2 low and high gain seismometers. Their response poles and zeros (i.e. shape in amplitude and phase) are the same, but their sensitivities differ by 22.5 dB (dB relative to 1 (v/m/s)²). The effect of higher sensitivity extends the portion at or below the USGS NLNM from 1 Hz to 17 Hz. The differences observed between the Streckeisen STS2 low-gain, Guralp and Geotech are driven by the differences in their response models. When selecting a seismometer to match with the Smart24 for a particular end use application a properly matched data-logger and sensor should resolve the expected seismic signals and backgrounds while nearly maximizing the systems dynamic range.

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., Hart, Darren M. and J. Mark Harris (2007), 'Test Definition and Test Procedures for the Evaluation of Digitizing Waveform Recorders, SAND2007-5037.
4. Peterson, J., Hutt, C.R., and L.G. Holcomb (1980), Test and Calibration of the Seismic Research Observatory, U.S. Geological Survey Open File Report: 80-187.

6 Appendix I: DWR Test Data Sheets

6.1 Seismometer Test Data Sheet: STS2 – Low Gain Seismometer Response

Streckeisen STS2: (Low Gain) 1500 v/m/s

Bandwidth: 0.02 to 20 Hz for 40 SPS Broadband Application

Test Description: Define Streckeisen STS2 Seismometer Velocity Response.

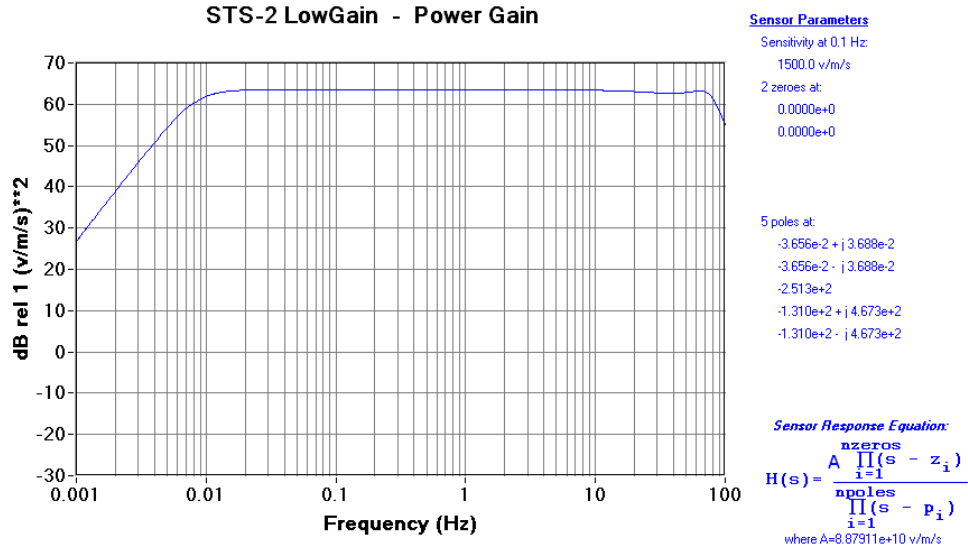


Figure 6.1.1 STS2 Low Gain Amplitude Plot

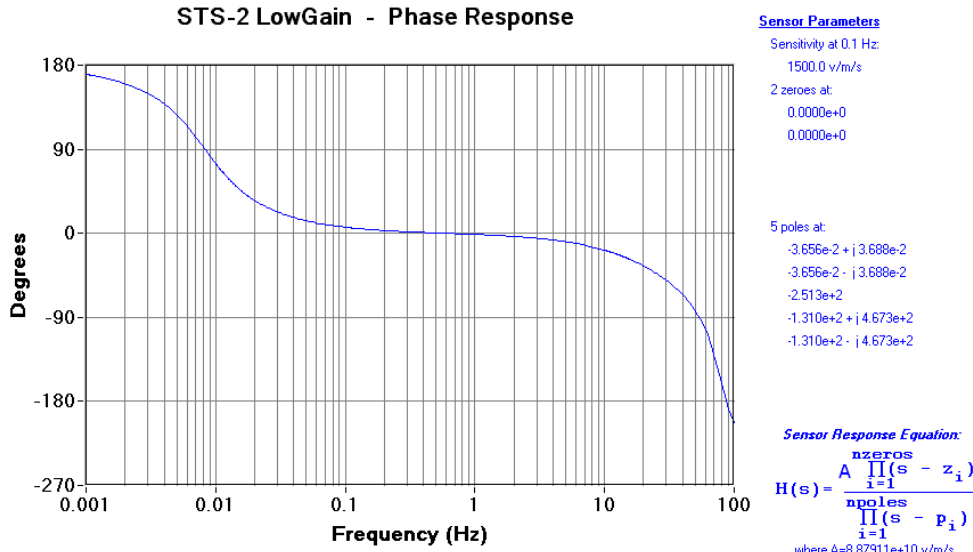


Figure 6.1.2 STS2 Low Gain Phase Plot

6.2 Seismometer Test Data Sheet: STS2 – High Gain Seismometer Response

Streckeisen STS2: (High Gain) 20,000 v/m/s
 Bandwidth: 0.01 to 20 Hz for 40 SPS BB Application

Test Description: Define Streckeisen STS2 Seismometer Velocity Response.

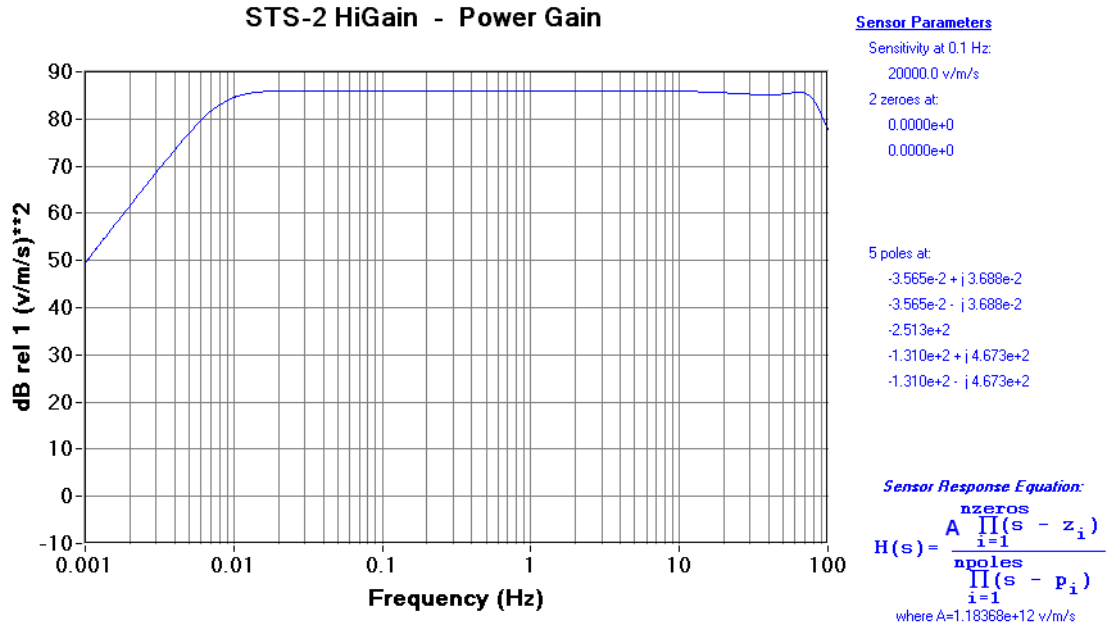


Figure 6.2.1 STS2 High Gain Amplitude Plot

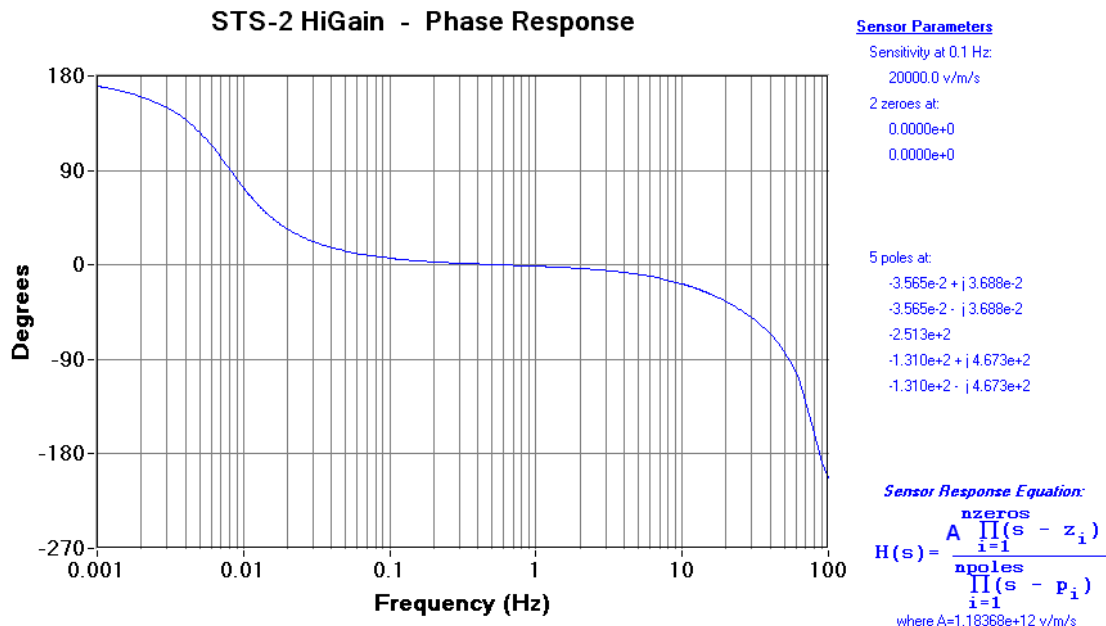


Figure 6.2.2 STS2 High Gain Phase Plot

6.3 Seismometer Test Data Sheet: CMG3T Seismometer Response

Guralp CMG3T: 2000 v/m/s

Application Bandwidth: 0.02 to 20 Hz for 40 SPS Broadband Application

Test Description: Define Guralp CMG3T Seismometer Velocity Response.

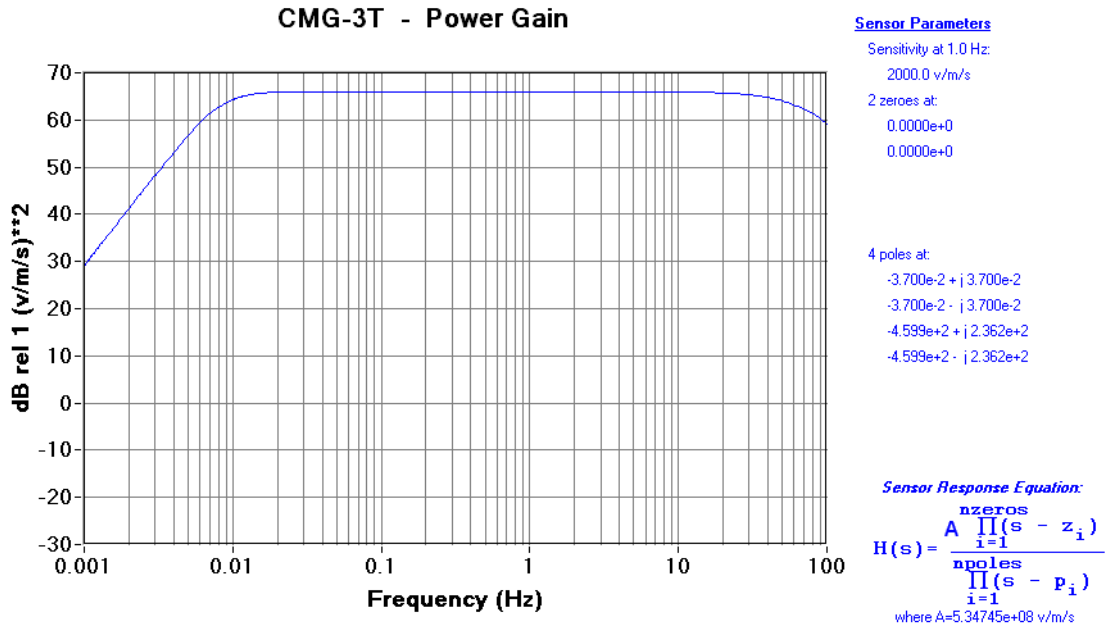


Figure 6.3.1 CMG3T Amplitude Plot

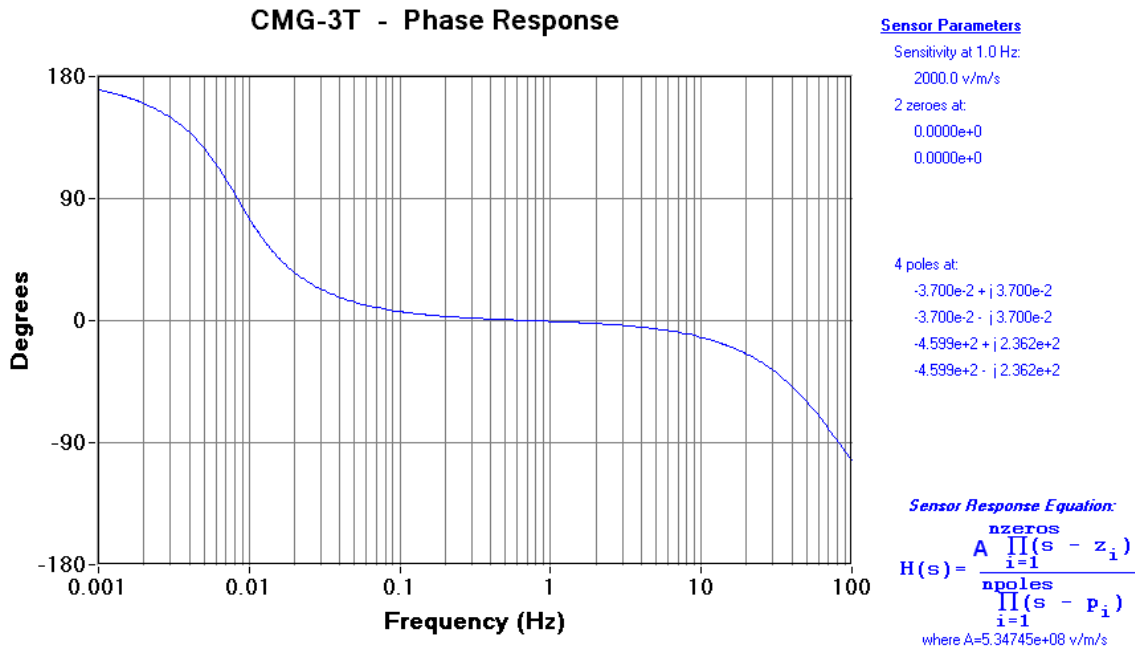


Figure 6.3.2 CMG3T Phase Plot

6.4 Seismometer Test Data Sheet: GS13 Seismometer Response

Geotech GS13 DSS: 2100 v/m/s

Application Bandwidth: 0.02 to 20 Hz for 40 SPS Broadband Application

Test Description: Define Geotech GS13 Generic Seismometer Velocity Response.

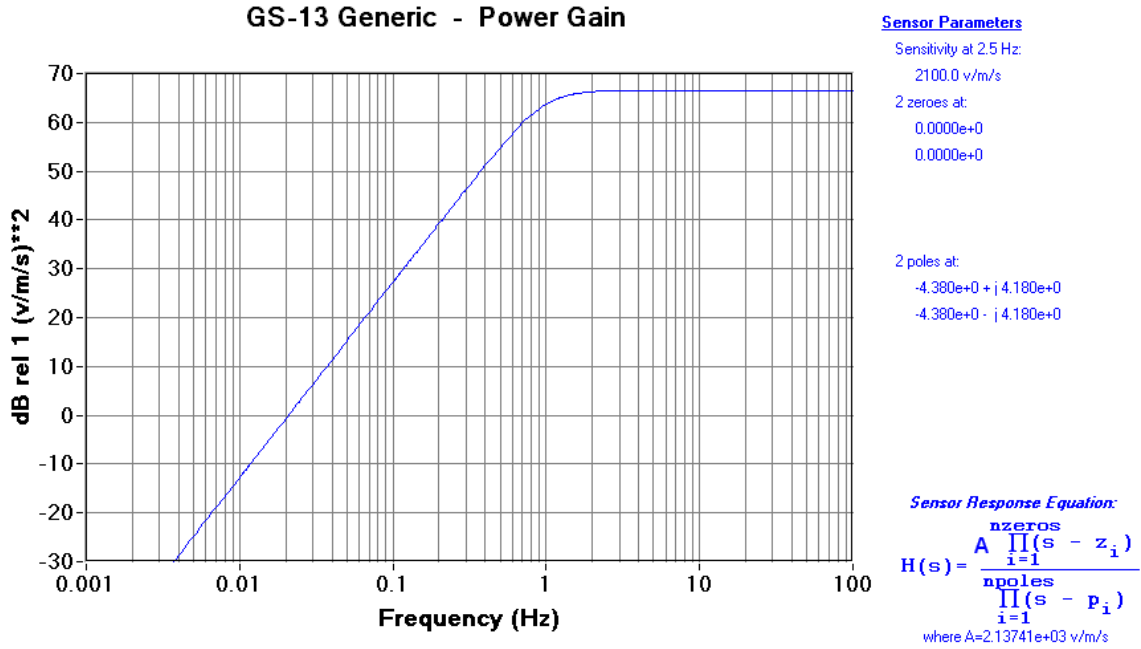


Figure 4.1.1 GS13 Generic Gain Plot

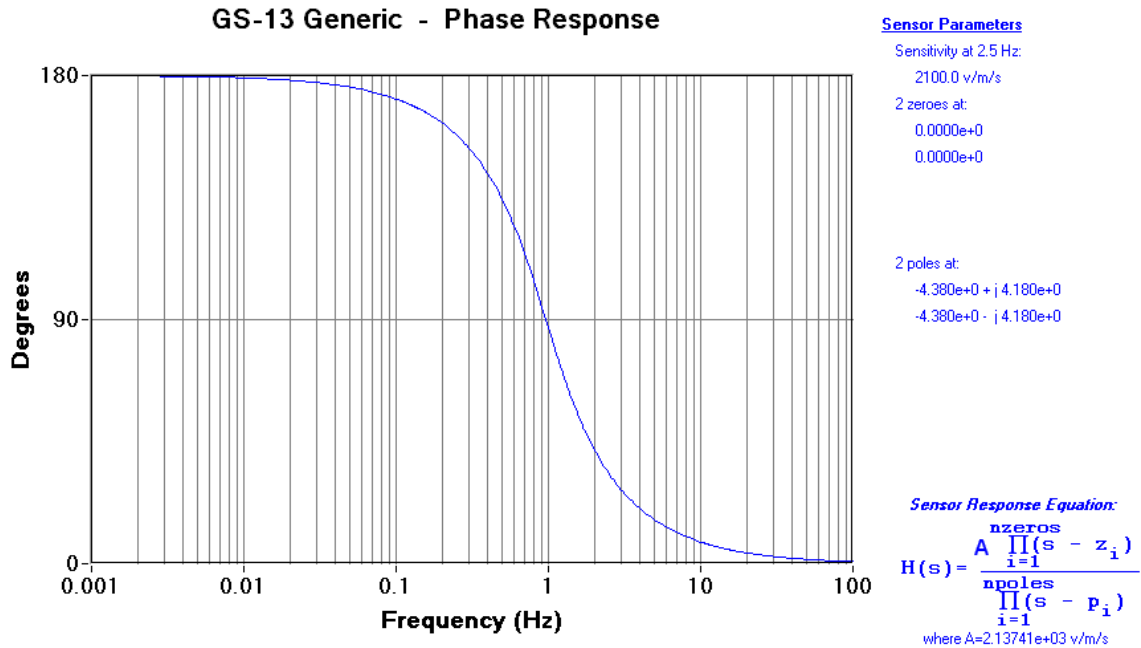


Figure 4.1.2 GS13 Generic Phase Plot

6.5 SMART24 Test Data Sheet: 40 Vpp ADC Test – Static/ITN/MPDR

Smart24 S/N: 1224

Firmware Revision: 1.38

Authentication: Enabled

CH 1-3: Single Three Channel 40 Vpp ADC Board - S/N 1724

Smart24 Sample Rate: 40sps

ITN Test Description: Measure Input Terminated Noise.

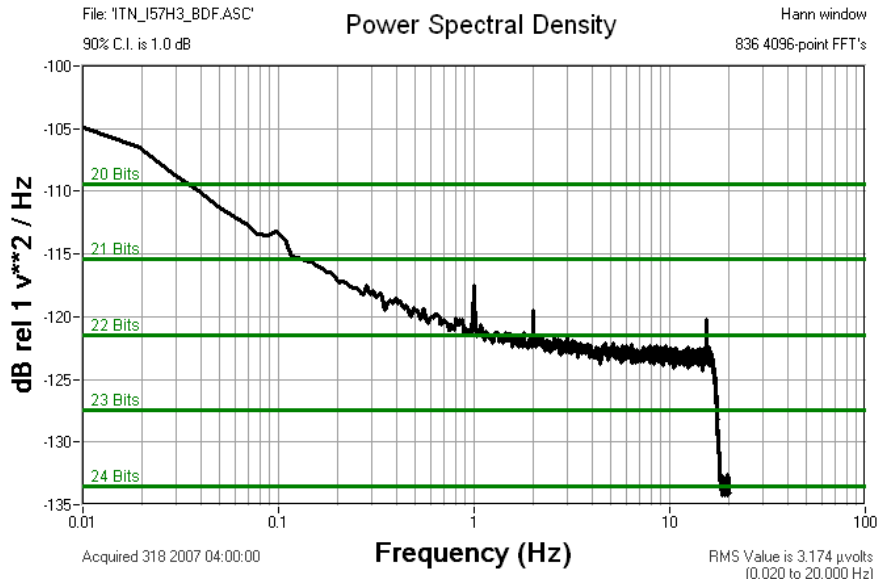


Figure 6.5.1 SMART24 Channel BDF Input Terminated Noise

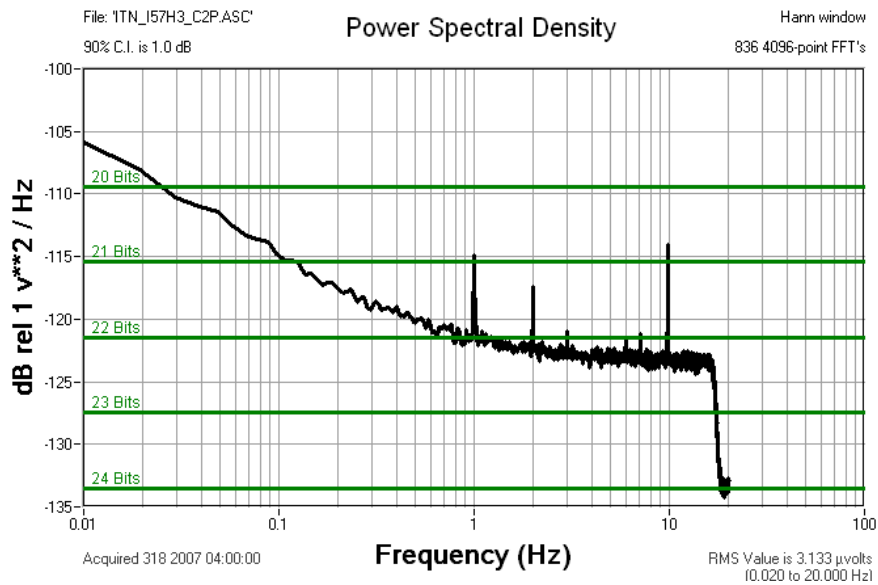


Figure 6.5.2 SMART24 Channel C2P Input Terminated Noise

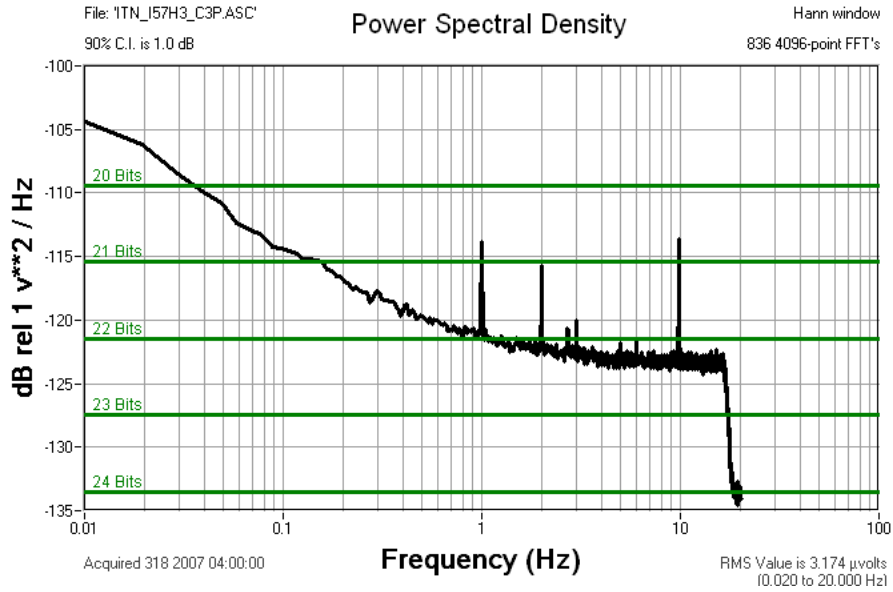


Figure 6.5.3 SMART24 Channel C3P Input Terminated Noise

Channel	RMS Noise μ V 0.02 to 20 Hz	Counts RMS
BDF	3.174	0.968
C2P	3.133	0.956
C3P	3.174	0.967

Table 6.5.1 SMART24 40sps RMS Noise

Test Results: Figures 6.5.1-3 and Table 6.5.1 indicate that the SMART24 has < 0.97 counts RMS noise.

MPDR Test Description: Compute Maximum Potential Dynamic Range using data from ITN Test.

Channel	RMS Noise μ V 0.02 to 20 Hz	RMS Full-Scale Volts	MPDR
BDF	3.174	14.14	133.0
C2P	3.133	14.14	133.1
C3P	3.174	14.14	133.0

Table 6.15.2 SMART24 40sps MPDR

Test Results: Table 6.5.2 indicates that the SMART24 Maximum Potential Dynamic Range is greater than 133.0 dB.

6.6 SMART24 Test Data Sheet: Seismic System Noise Test

Smart24 S/N: 1224

Firmware Revision: 1.38

Authentication: Enabled

CH 1-3: Single Three Channel 40 Vpp ADC Board - S/N 1724

Smart24 Sample Rate: 40sps

Seismometer Application (CH 1-3): Streckeisen STS2 1500 (2*750) V/m/s @ 0.1 Hz

SSN Test Description: Determine ability of the Smart24 to resolve the expected seismic background using a Streckeisen STS2 Low Gain velocity seismometer.

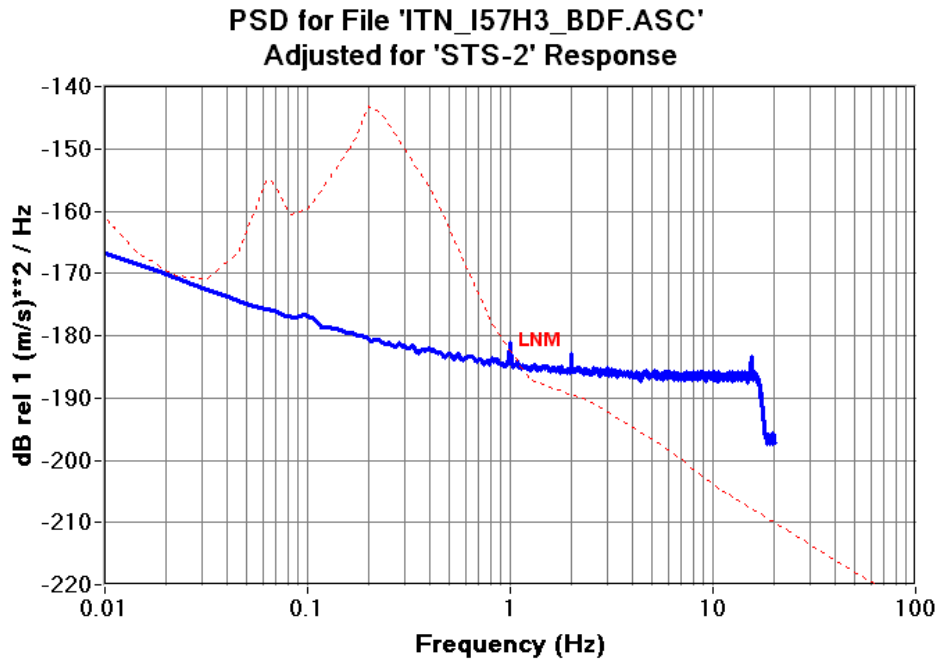


Figure 6.6.1 SMART24 SSN relative to a STS2 low gain seismometer.

Test Results: Figures 6.6.1 indicates that the noise of the average of the individual component, a Smart24, was at or below the USGS LNM minimum-earth noise model between 0.01 and 1 Hz when used with a Streckeisen STS2 low gain seismometer. The Smart24 components were ~1 db below the USGS LNM at 0.02 Hz, 27 db below at 0.1 Hz, 0 db below at 1 Hz and 15 dB above at 10Hz.

Channel	RMS Noise (nm/s) 0.02 to 20 Hz
CH1	2.151

Table 6.6.1 Smart24 RMS Noise meters/second

Test Results: Figure 6.6.1 and Table 6.6.1 indicate that the Smart24 has less than 2.151 nm/s RMS noise when corrected for the STS2 low gain seismometer response shown in Section 6.1.

BLDR Test Description: Compute Bandwidth Limited Dynamic Range using data from SSN Test.

Sensor Type	Channel	RMS Noise (m/s) 0.02 to 20 Hz	RMS Full-Scale Voltage (V)	RMS Full-Scale Velocity (m/s)	BLDR (dB)
STS2 low gain	BDF	2.151e-9	14.1421	0.0094	132.8

Table 6.6.2 Smart24 RMS Noise meters/second

Test Results: Table 6.6.2 indicates that the Smart24 Maximum Bandwidth Limited Range is greater than 132 dB when corrected for the STS2 low gain seismometer shown in Section 6.1.

6.7 SMART24 Test Data Sheet: Seismic System Noise Test

Smart24 S/N: 1224

Firmware Revision: 1.38

Authentication: Enabled

CH 1-3: Single Three Channel 40 Vpp ADC Board - S/N 1570

Smart24 Sample Rate: 40sps

Seismometer Application (CH 1-3): Streckeisen STS2 20,000 V/m/s @ 0.1 Hz

SSN Test Description: Determine ability of the Smart24 to resolve the expected seismic background using a Streckeisen STS2 High Gain velocity seismometer.

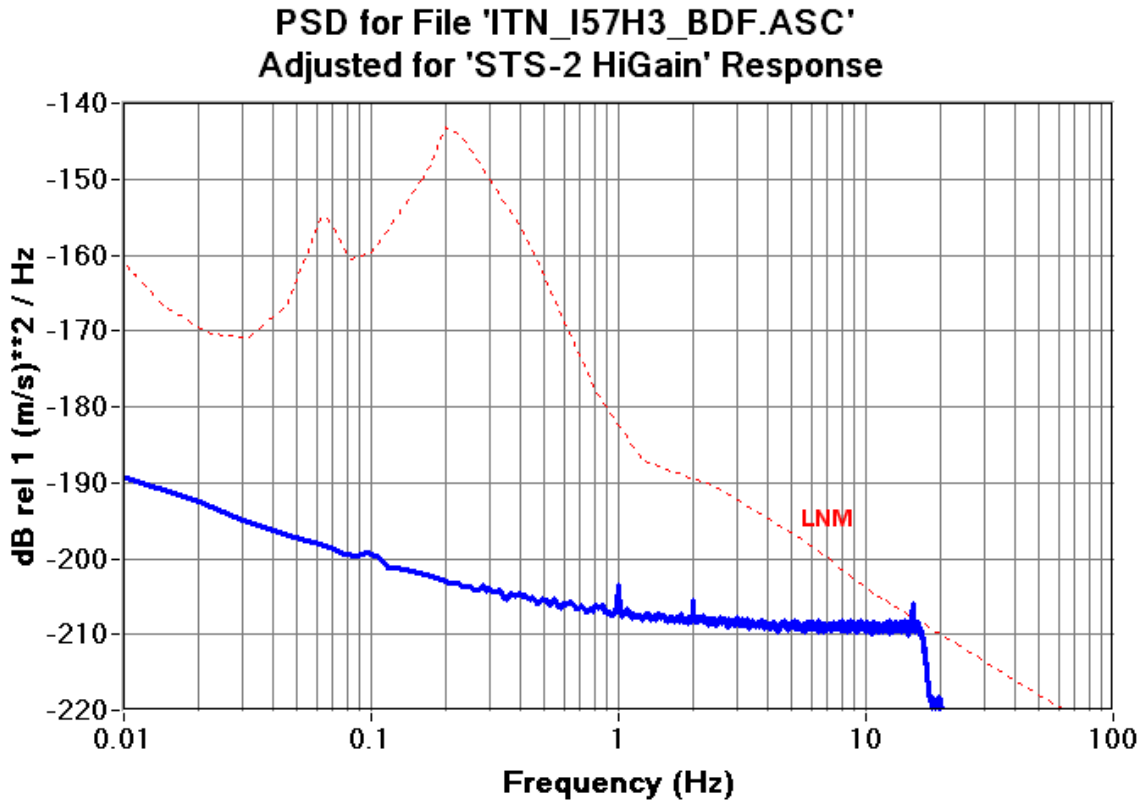


Figure 6.7.1 SMART24 SSN relative to a STS2 high gain seismometer.

Test Results: Figure 6.7.1 indicates that the noise of the average of individual component, a Smart24, was at or below the USGS LNM minimum-earth noise model between 0.01 and 17 Hz when used with a Streckeisen STS2 high gain seismometer. The Smart24 components were ~23 db below the USGS LNM at 0.02 Hz, 39 db below at 0.1 Hz, 24 db below at 1 Hz and 5 db below at 10Hz.

Channel	RMS Noise (nm/s) 0.02 to 20 Hz
CH1	0.1614

Table 6.7.1 Smart24 RMS Noise meters/second

Test Results: Figure 6.7.1 and Table 6.7.1 indicate that the Smart24 has less than 0.161 nm/s RMS noise when corrected for the STS2 high gain seismometer response shown in Section 6.2.

BLDR Test Description: Compute Bandwidth Limited Dynamic Range using data from SSN Test.

Sensor Type	Channel	RMS Noise (m/s) 0.02 to 20 Hz	RMS Full-Scale Voltage (V)	RMS Full-Scale Velocity (m/s)	BLDR (dB)
STS2 high gain	BDF	1.614e-10	14.1421	7.071e-4	132.8

Table 6.7.2 Smart24 RMS Noise meters/second

Test Results: Table 6.7.2 indicates that the Smart24 Maximum Bandwidth Limited Range is greater than 132 dB when corrected for the STS2 high gain seismometer shown in Section 6.2.

6.8 SMART24 Test Data Sheet: Seismic System Noise Test

Smart24 S/N: 1224

Firmware Revision: 1.38

Authentication: Enabled

CH 1-3: Single Three Channel 40 Vpp ADC Board - S/N 1570

Smart24 Sample Rate: 40sps

Seismometer Application (CH 1-3): Guralp CMG3T 2000 V/m/s @ 1 Hz

SSN Test Description: Determine ability of the Smart24 to resolve the expected seismic background using a Guralp CMG3T velocity seismometer.

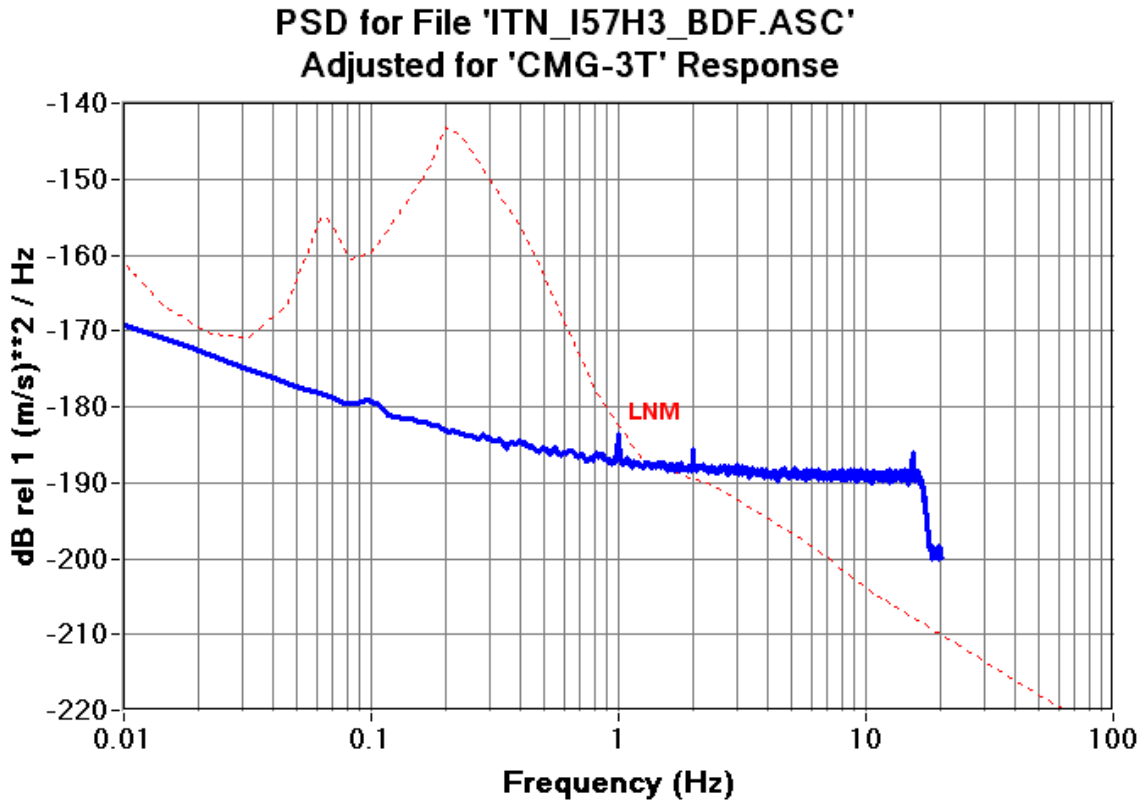


Figure 6.8.1 SMART24 SSN relative to a Guralp CMG3T seismometer.

Test Results: Figure 6.8.1 indicates that the noise of the average of the individual component, a Smart24, was at or below the USGS LNM minimum-earth noise model between 0.01 and 1.3 Hz when used with a Guralp CMG3T seismometer. The Smart24 components were ~3 db below the USGS LNM at 0.02 Hz, 20 db below at 0.1 Hz, 4 db below at 1 Hz and 14 dB above at 10Hz.

Channel	RMS Noise (nm/s) 0.02 to 20 Hz
CH1	1.604

Table 6.8.1 Smart24 RMS Noise meters/second

Test Results: Figure 6.8.1 and Table 6.8.1 indicate that the Smart24 has less than 1.604 nm/s RMS noise when corrected for the Guralp CMG 3T seismometer response shown in Section 6.3.

BLDR Test Description: Compute Bandwidth Limited Dynamic Range using data from SSN Test.

Sensor Type	Channel	RMS Noise (m/s) 0.02 to 20 Hz	RMS Full-Scale Voltage (V)	RMS Full-Scale Velocity (m/s)	BLDR (dB)
Guralp CMG 3T	BDF	1.604e-9	14.1421	0.007071	132.9

Table 6.8.2 Smart24 RMS Noise meters/second

Test Results: Table 6.8.2 indicates that the Smart24 Maximum Bandwidth Limited Range is greater than 132 dB when corrected for the Guralp CMG 3T seismometer shown in Section 6.3.

6.9 SMART24 Test Data Sheet: Seismic System Noise Test

Smart24 S/N: 1224 Firmware Revision: 1.38
 Authentication: Enabled
 CH 1-3: Single Three Channel 40 Vpp ADC Board - S/N 1570
 Smart24 Sample Rate: 40sps
 Seismometer Application (CH 1-3): Geotech GS13 Generic 2100 V/m/s @ 2.5 Hz

SSN Test Description: Determine ability of the Smart24 to resolve the expected seismic background using a Geotech GS13 velocity seismometer.

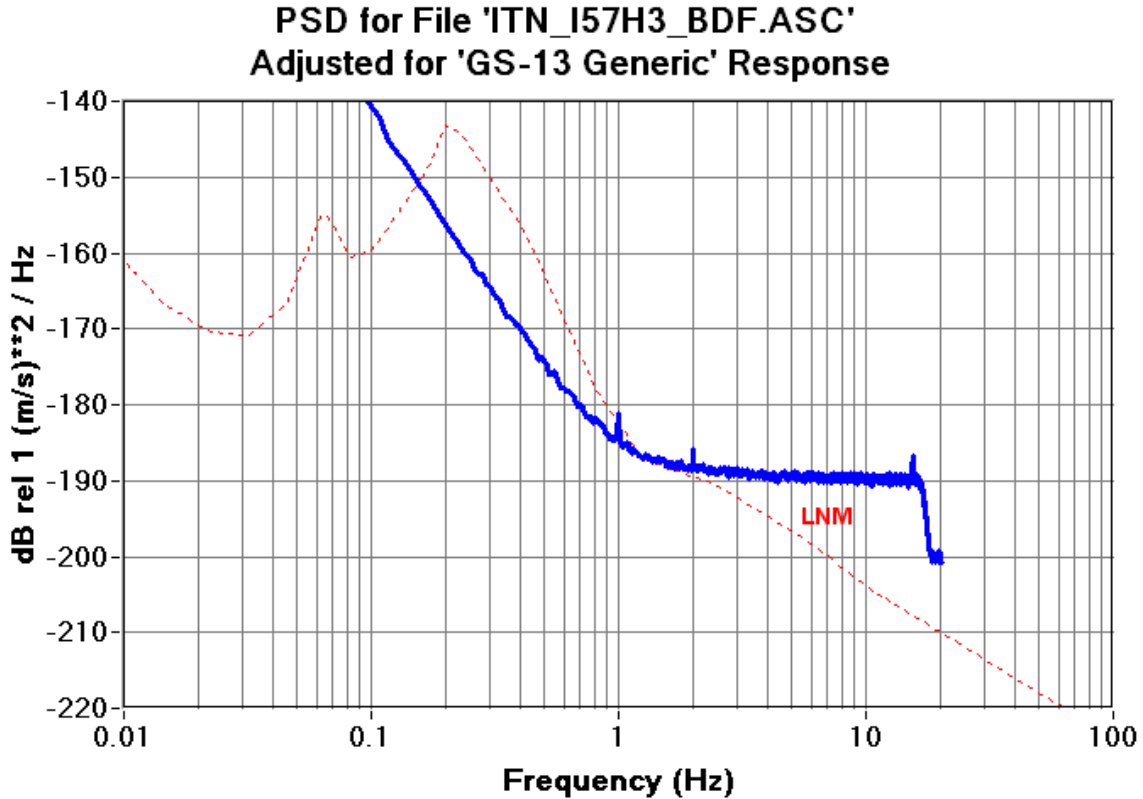


Figure 6.9.1 SMART24 SSN relative to a Geotech GS13 seismometer.

Test Results: Figures 6.9.1 indicates that the noise of the average of the individual component, a Smart24, was at or below the USGS LNM minimum-earth noise model between 0.15 and 1.2 Hz when used with a Geotech GS13 seismometer. The Smart24 components were ~40 db above the USGS LNM at 0.02 Hz, 13 db above at 0.1 Hz, 3 db below at 1 Hz and 9 dB above at 10Hz.

Channel	RMS Noise (nm/s) 0.02 to 20 Hz
CH1	214.1

Table 6.9.1 Smart24 RMS Noise meters/second

Test Results: Figures 6.9.1 and Table 6.9.1 indicate that the Smart24 has less than 214.1 nm/s RMS noise when corrected for the GS13 seismometer response shown in Section 6.4.

BLDR Test Description: Compute Bandwidth Limited Dynamic Range using data from SSN Test.

Sensor Type	Channel	RMS Noise (m/s) 0.02 to 20 Hz	RMS Full-Scale Voltage (V)	RMS Full-Scale Velocity (m/s)	BLDR (dB)
Geotech GS13 DSS	BDF	214.1	-	-	-

Table 6.9.2 Smart24 RMS Noise meters/second

Test Results: Table 6.8.2 indicates that the Smart24 Maximum Bandwidth Limited Range is greater than N/A dB when corrected for the generic GS13 seismometer shown in Section 6.4.



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