INTEGRATED SEISMIC SENSOR/DIGITIZER EVALUATION

Richard P. Kromer and Darren M. Hart

Sandia National Laboratories

Sponsored by National Nuclear Security Administration
Office of Nonproliferation Research and Development
Office of Defense Nuclear Nonproliferation

Contract No. DE-AC04-94AL85000

ABSTRACT

Sandia National Laboratories have tested and evaluated an integrated seismic sensor/digitizer from Science Horizons Inc. (SHI), Melbourne, FL. A Geotech GS21 single component short-period vertical borehole seismometer was integrated with a SHI AIM24-S1/GS21 modified borehole digitizer. The integrated seismometer/digitizer concept may provide a lowered system noise due to the elimination of long analog cables (up to 100 m), digitizer cable harness, and potentially quieter pre-amplifier design.

The modified SHI AIM24-S1/GS21 digitizer was compared to a standard configuration AIM24-S1/GS21 digitizer with a 30-m analog cable for self-noise measurement comparison. A sensor impedance simulator was used as a digitizer load.

OBJECTIVE

Introduction

The Air Force Technical Applications Center (AFTAC) is tasked with monitoring compliance of existing and future nuclear test treaties. To perform this mission, AFTAC uses several different monitoring techniques to sense and monitor nuclear explosions, each designed to monitor a specific domain (e.g. space, atmosphere, underground, oceans, etc.) Together these monitoring systems, equipment and methods form the United States Atomic Energy Detection System (USAEDS). Some USAEDS seismic stations may be included in the International Monitoring System (IMS). Some of these monitoring systems are deployed in extremely quiet locations that challenge the performance of the digitizing waveform recorder (DWR).

Some Sensor Sub-Systems (SSS) built for AFTAC applications use passive sensors such as the Geotech GS21, 23900, GS21a and GS13. These sensors are typically installed in a borehole at up to 100 meters depth. A DWR is typically installed at the top of the borehole in a Wellhead Terminal Unit (WTU). A long analog cable connects the seismometer output to the DWR input through an Interface Box (IB). The sensor impedance is terminated using a programmable resistance in the DWR. The DWR provides an internal preamplifier to set the seismic signal level appropriate to the application.

A set of tests has been developed to (1)determine if the long analog cable contributes noise to the separated sub-system and (2)determine if an integrated sensor/DWR can lower sub-system noise.

Evaluations Performed

Evaluations include determination of the GS21seismometer impedance model, construction of a seismometer impedance simulator and tests to determine sensor sub-system performance.

Tests included:

- DWR Seismic Sensor Application Tests
  - Seismic System Static Performance Tests
  - DWR Seismic System Noise (DWR-SSN)
- Sensor Sub-Systems Seismic Sensor Application Tests
  - Sensor Sub-Systems Seismic System Static Performance Tests
  - Sensor Sub-Systems Seismic System Noise (SS-SSN)

RESEARCH ACCOMPLISHED

Determination of Seismometer Impedance Model

The complex impedance of a seismometer can be modeled using equation 1.

$$Complex\_impedance(\omega) = \frac{R_1 + \left\lfloor \frac{R_2 * G_c{}^2}{M} \right\rfloor * \omega}{\omega^2 + 2 * D_c * \omega_0 + \omega_0{}^2} \qquad \text{Equation 1}$$

Where

$R_1 = \dfrac{R_{DC} * R_{ED}}{R_{DC} + R_{ED}}$ and $R_2 = \left[\dfrac{R_{ED}}{R_{DC} + R_{ED}} \right]^2$, R_{ED} is the external damping resistor (ohms), R_{DC} is the data coil resistor (ohms), M is the seismometer mass (kg), D_c is the seismometer damping coefficient, G_c is the seismometer generator constant (V/m/s), ω_0 is the natural frequency (radians/second) of the seismometer. These parameter values for the seismometers used in this study are shown in Table 1.

Table 1. List of seismometer parameters used to calculate complex impedance.

Seismometer Type	Generator Constant (V/m/s)	External Damping Resistor (ohms)	Damping Coefficient	Data Coil Resistance (ohms)	Natural Frequency (Hz)	Seismometer Mass (kg)
GS21	458.0	4255	0.707	467	1.0	5.0

The complex impedance plot for the GS21 seismometer is shown in Figure 1. The plot shows at low and high frequencies the seismometer impedance is approximately equal to R_1 (~420 ohms) and the seismometer impedance rises to the value of the external damping resistance at the natural frequency of the seismometer.

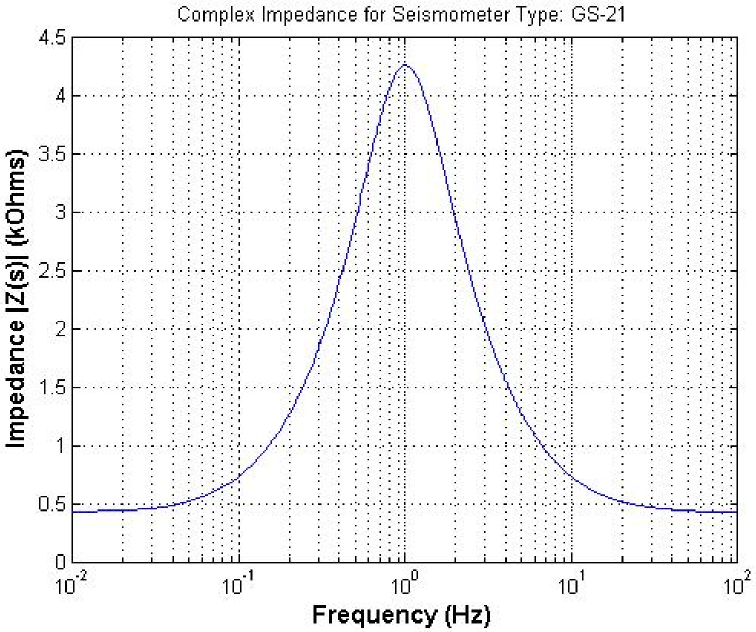


Figure 1. GS21 Complex Impedance.

Table 2. Impedance terminators used to model GS21 seismometer's complex impedance. X's indicate impedance values used to model specific seismometers complex impedance. For this report the best and worst case impedances were used (XX).

Impedance Termination (ohms)	402	1050	1500	2100	2500	3010	3480	4420
GS-21	**XX**	X	X	X	X	X	X	**XX**

Construction of Seismometer Impedance Simulator

A Seismometer Impedance Simulator was constructed using parts of an old seismometer. Changeable resistor terminations are installed on the inside. This simulator, shown in Figure 2, was used in place of the seismometer.

Figure 2. Sensor Impedance Simulator with interchangeable loads.

Evaluation of AFTAC Typical Sensor Sub-System and Alternative Integrated Sensor Sub-System

An AFTAC Typical Sensor Sub-System consists of a Geotech GS21 sensor installed at the bottom of a borehole and connected to a DWR installed in a WTU. Analog signals from the seismometer are connected by borehole cable to the WTU Interface Box and distributed to the DWR installed at the top of the borehole. This is shown in Figure 3, left.

The Alternative Integrated Sensor Sub-System consists of a Geotech GS21 sensor directly integrated to a DWR installed at the bottom of a borehole. Digital signals from the integrated DWR/seismometer are connected by borehole cable to the WTU breakout box. This is shown in Figure 3, right.

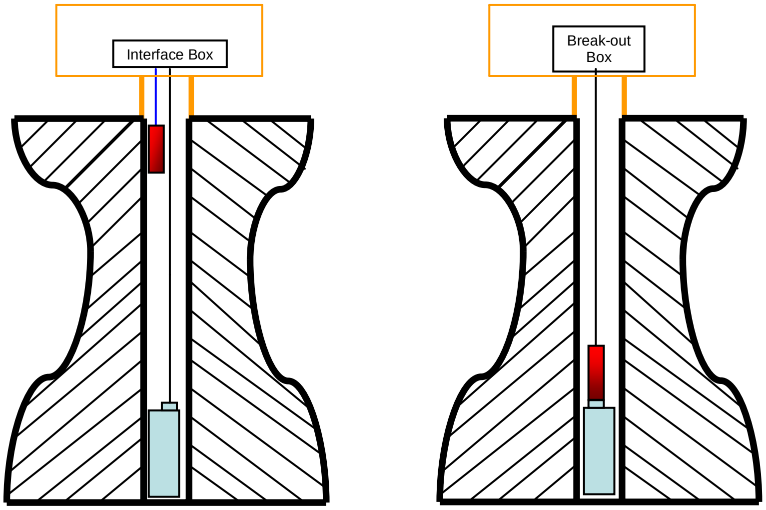
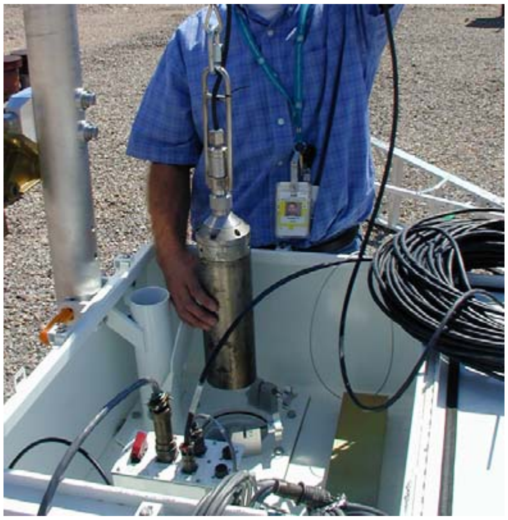


Figure 3. A cartoon drawing of the two deployment configurations tested in this study. The boxes in red represent the digitizer, light blue boxes represent the seismometer and the orange objects represent the WTU. The drawing on the left is the typical deployment configuration. The drawing on the right shows the alternative configuration where the digitizer is directly connected to the seismometer.

Evaluation of AFTAC Typical Sensor Sub-System using Science Horizons AIM24S1 DWR separate from Geotech GS21 Short-period Vertical Borehole Seismometer (Figure 4).

Components of AFTAC Typical SSS



Installation of Sensor Simulator in WTU Borehole

Installation of DWR in WTU Borehole

Figure 4. Installation of AFTAC Typical Sensor Sub-System

The following tests were conducted on the AFTAC Typical SSS DWR.

DWR Seismic Sensor Application Tests
- Seismic System Static Performance Tests
- DWR Seismic System Noise (DWR-SSN)

The following tests were conducted on the AFTAC Typical SSS.

Sensor Sub-Systems Seismic Sensor Application Tests
- Sensor Sub-Systems Seismic System Static Performance Tests
- Sensor Sub-Systems Seismic System Noise (SS-SSN)

DWR Seismic System Noise (DWR-SSN) Test

Purpose: The purpose of the DWR seismic system noise test was 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.

Configuration: The DWR sensor input connector was terminated with the equivalent output impedance of the application sensor. For the GS21 comparison purposes, the range of values was chosen to approximate the minimum (402 ohms) and maximum (4.4 K ohms) impedance.

Evaluation: For GS21 sensor application, the system noise of the DWR was converted to ground motion using the GS21 seismometer response mathematical model. The results of this computation were overlaid with the USGS New Low Earth Noise Model (NLNM) to demonstrate the ability of the DWR to resolve the local seismic background.

Sensor Sub-System Seismic System Noise (SS-SSN) Test

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

Configuration: The SSS Sensor Simulator at the sensor end of the SSS sensor cable was terminated with the equivalent output impedance of the application sensor. For the GS21 comparison purposes, the range of values was chosen to approximate the minimum (402 ohms) and maximum (4.4 K ohms) impedance.

Evaluation: For GS21 sensor application, the system noise of the SSS was converted to ground motion using the GS21 seismometer response mathematical model. The results of this computation were overlaid with the USGS New Low Earth Noise Model (NLNM) to demonstrate the ability of the DWR/SSS to resolve the local seismic background. Comparisons were made between the two configurations.

Results: DWR-SSN and SS-SSN results are shown in Figure 5. There were no appreciable differences between the two test configurations.

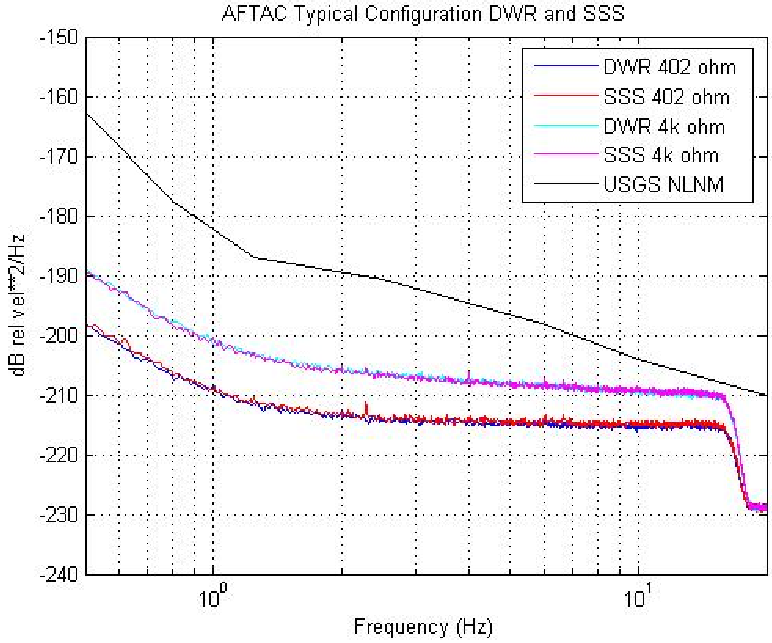
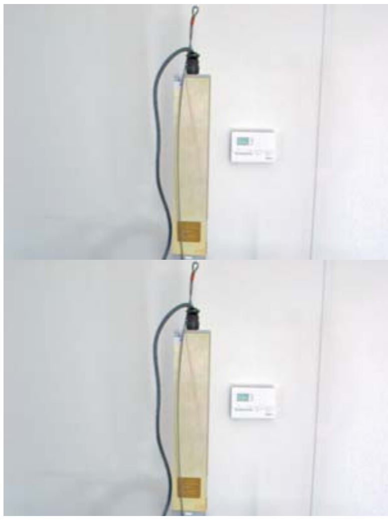


Figure 5. DWR Seismic System Noise (DWR-SSN) Test and Sensor Sub-Systems Seismic System Noise (SS-SSN) Test Results.

Evaluation of Alternative Integrated Sensor Sub-System using Science Horizons AIM24S1 DWR integrated with Geotech GS21 Short-period Vertical Borehole Seismometer (Figure 6).



Components of Alternative Integrated SSS

Installation of Integrated Sensor Simulator with DWR in WTU Borehole

Figure 6. Installation of Alternative Integrated Sensor Sub-System.

The following tests were conducted on the Alternative Integrated SSS.

Sensor Sub-Systems Seismic Sensor Application Tests
- Sensor Sub-Systems Seismic System Static Performance Tests
- Sensor Sub-Systems Seismic System Noise (SS-SSN)

Sensor Sub-System Seismic System Noise (SS-SSN) Test

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

Configuration: The Alternative Integrated SSS DWR/Sensor Simulator was terminated with the equivalent output impedance of the application sensor. For the GS21 comparison purposes, the range of values was chosen to approximate the minimum (402 ohms) and maximum (4.4 K ohms) impedance.

Evaluation: For GS21 sensor application, the system noise of the SSS was converted to ground motion using the GS21 seismometer response mathematical model. The results of these computations were overlaid with the USGS New Low Earth Noise Model (NLNM) to demonstrate the ability of the DWR/SSS to resolve the local seismic background.

Results: SS-SSN results are shown in Figure 7.

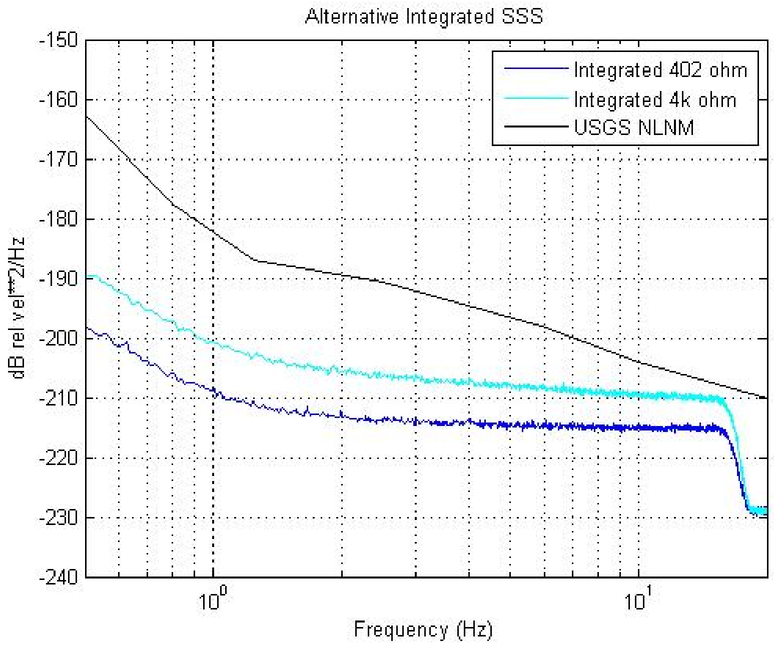


Figure 7. Alternate Integrated Sensor Sub-Systems Seismic System Noise (SS-SSN) Test Results.

Comparison of AFTAC Typical Sensor Sub-System and Alternative Integrated Sensor Sub-System Seismic System noise

Sensor Sub-System Seismic System Noise (SS-SSN)

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

Configuration: The Alternative Integrated SSS DWR/Sensor Simulator was terminated with the equivalent output impedance of the application sensor. For the GS21 comparison purposes, the range of values was chosen to approximate the minimum (402 ohms) and maximum (4.4 K ohms) impedance.

Evaluation: For GS21 sensor application, the system noise of the SSS was converted to ground motion using the GS21 seismometer response mathematical model. The results of these computations were overlaid with the USGS New Low Earth Noise Model (NLNM) to demonstrate the ability of the DWR/SSS to resolve the local seismic background.

Results: SS-SSN results are shown in Figure 8. There were no appreciable differences between the two test configurations.

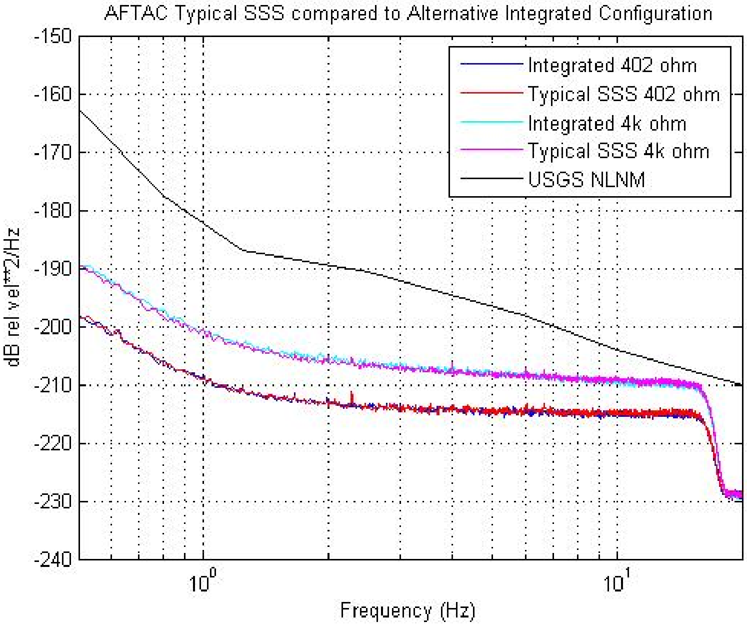


Figure 8. Comparison of Seismic System Noise (SS-SSN) between AFTAC Typical Sensor Sub-System and Alternate Integrated Sensor Sub-Systems.

CONCLUSIONS

Evaluation of AFTAC Typical Sensor Sub-System

The DWR seismic system noise was not degraded or increased by installation into an AFTAC Typical SSS installation for either sensor impedance. SSS seismic system noise was equivalent to within 0.2 dB.

Evaluation of Alternative Integrated Sensor Sub-System

The Alternative Integrated SSS seismic system noise was measured without difficulty.

Comparison of AFTAC Typical Sensor Sub-System and Alternative Integrated Sensor Sub-System

The Alternative Integrated SSS seismic system noise was not improved over the AFTAC Typical SSS installation for either sensor impedance.

The pickup of unwanted electronics noise can be a problem when separating a passive seismometer like the Geotech GS21 and the application DWR with up to 100 meters of cable. The AFTAC Typical installation technique for this configuration including power, cable interconnection and radio communications does not appear to contribute electronics noise to the SSS.

The DWR/Seismometer tested is the least affected impedance match. Other passive sensors can have impedances to greater than 100K ohms. This series of tests could be applied to these sensors to confirm rejection of unwanted electronics noise.

RECOMMENDATIONS

The present generation of AFTAC DWR components have inherent rejection of common mode electronics noise of up to the analog power supply voltages (+/- 12 volts). The next generation of low power DWR component technology utilizes electronics components shared with the cell phone and similar industry. The typical power supply voltages are +/- 3 volts or even lower. These components will not have the electronic noise rejection of the present technologies.

The use of the alternative integrated technique should continue to be evaluated as next-generation electronics components become more common in DWR design. This design might require more integrated functions into the DWR/SSS design such as internal GPS, integrated power systems and direct digital communication to the downhole integrated sub-system.