Effects of Aging Hardware on Data Quality

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Abstract

For over twenty years broadband seismometers have been used for nuclear explosion monitoring at teleseismic distances. Short period seismometers have also been used to improve resolution at higher frequencies (> 1 Hz) over regional distances. At the time of installation, a calibration process is implemented to determine the proper scale factor between digital counts and ground motion for the seismic subsystem (seismometer and digital waveform recorder). This scale factor is called "calib" and is applied at a single period called "calper." Under this framework, the instrument response model is stored in a Frequency Amplitude Phase (FAP) format, which normalizes the response to unity at the "calper." The two hardware components at a site that are used to construct the "calib" are the digital waveform recorder (DWR) and the seismometer of interest. The digital waveform recorder has an associated scale factor from counts to volts and the seismometer scale factor between volts and ground motion (valid in the flat portions of the instruments' respective passbands). Under proper calibration, the relative gain between co-located broadband and short period seismometers should be 0 dB across their common passband as defined in their FAP files.

Recently, data from eleven stations with co-located broadband and short period seismometers have been analyzed for their relative gains using a common time window and their most recent "calib" scale factors. The relative gains vary between 0.4 and 2.0 dB at 1 Hz, which translates into a 4.7 to 26% amplitude scaling difference between the seismometers at 1 Hz. One complicating factor is the "calper" at 1 Hz for the short period seismometer. For a GS21 short period seismometer, the 1 Hz "calper" is the low frequency corner of the GS21. The "calper" is not in the flat portion of the response file of the GS21 seismometer.

The Sandia National Laboratories Facility for Acceptance, Calibration and Testing (SNL FACT) was tasked with assisting our customer in determining the reason for the amplitude scaling differences. The possible areas of potential scaling problems are 1) DWR bit-weight scale factor errors (volts per count), 2) the seismometer output sensitivity scale factor errors (volts per ground motion), 3) a combination of DWR bit-weight and seismometer sensitivity scale factor errors (ground motion per count), or 4) internal changes to either seismometer that may have affected the response parameters near 1 Hz. Another possible issue with the hardware components may be the change in self-noise level.

The SNL FACT site will be receiving and testing instrumentation from a recently decommissioned station with the same (or similar) equipment, known as a "hot-spare". The site had a significant up-time of fifteen years and exhibits the same amplitude scaling problem observed in the other Global Seismic Network stations. Results of this work will be available in the coming year.

Problem

There are a few fundamental problems that need to be assessed when analyzing data from instruments that have been installed for any period of time.

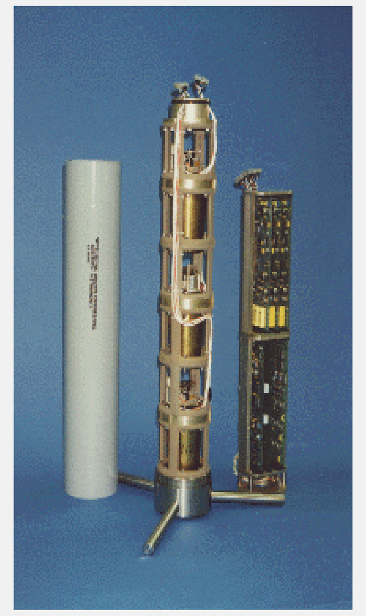
1) How well the components are characterized prior to the installation. For example, how does each component vary from their nominal values.
2) Are these values being reported in the same manner for each installation? For example, at what frequencies does the FAP get created and for what resolution.
3) How do these values compare to the nominal values, first reported values and subsequently reported values over the life span of the sensor installation.

Instrumentation

The 11 stations are configured with co-located GS21 and KS54000 seismometers with Science Horizons borehole digitizers.

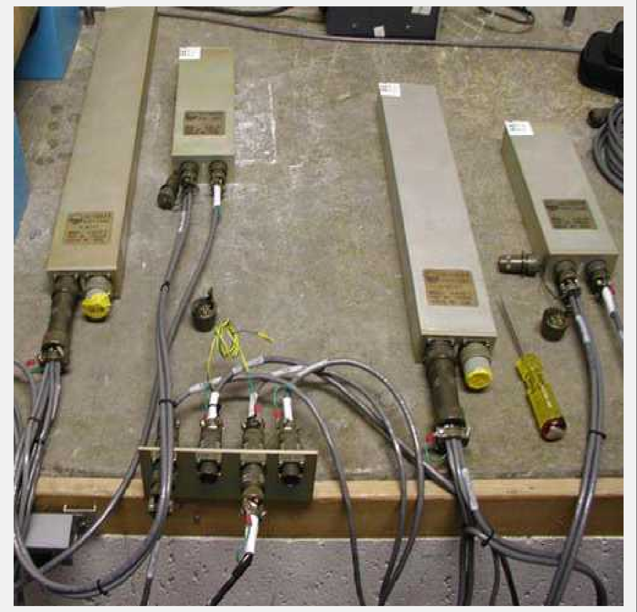
Seismometer –manufacturer, model, and design	DWR – manufacturer, model
Geotech KS54000 broadband (acceleration / velocity)	Science Horizons AIM24S3
Geotech GS21 short period	Science Horizons AIM24S1

GS21 Short Period Borehole Seismometer



KS54000 Broadband Borehole Seismometer

GS21 and KS54000 images courtesy Geotech Instruments



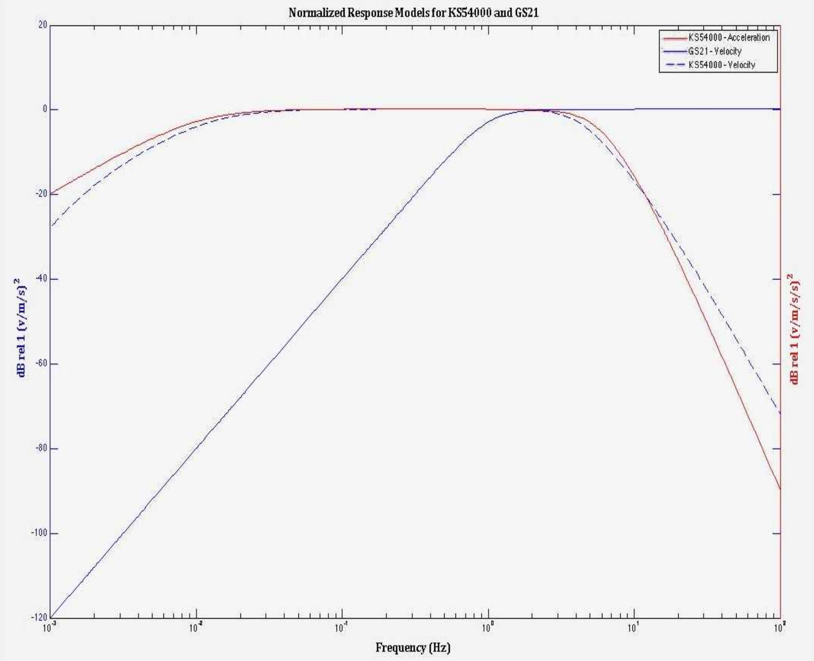
Science Horizons AIM24S Borehole Digitizer.

AIM24S Image from SNL FACT Site

Nominal Configurations

Each seismometer and digitizer ship with their own nominal values for bit-weight and sensitivity. Using the these two values one can calculate the calib at 1 Hz. The following tables shows the nominal bit-weights and sensitivities from the KS54000 paired with the AIM243S and the GS21 paired with the AIM 24S1.

Seismometer/DWR	Nominal Bit-Weight (μV/count)	Seismometer sensitivity (V/m/s/s)	Seismometer sensitivity (V/m/s)	Seismometer sensitivity (V/m)	Calib (nm/count) @ 1 Hz
KS54000acc/AIM24S3	3.815	15000	94247.8	592176	0.006442
KS54000vel/AIM24S3	3.815	4775	30000	188495	0.02024
GS21vel/ AIM24S1	0.023073	46.486	292.08	1835.19	0.0126



It is important to note that comparisons between these two systems are fundamentally difficult because there is a very limited frequency band that overlaps between both systems. The flat portion of one is in the roll-off of the other and likewise. The figure to the left shows the normalized responses for the GS21 in velocity at 10 Hz and the KS54000 in velocity and acceleration at 1 Hz. The GS21 cannot be compared to the 54000 at 1 Hz because that it is already in its roll-off.

Received Data

The table below shows sample meta-data from 11 stations with the co-located Science Horizons GS21/KS54000 configuration. The meta-data were obtained from the instrument response files. The bit-weights and sensitivities listed are calculated from the sample data received.

Station	Channel	Sensor	Calib (nm/Count)	Bit-weight (counts/volt)	Calper (seconds)	Sensitivity (V/m/s) or (V/m/s/s)
ABKAR	SHZ(01)	GS21vel	0.0118	43340701	1	311.2
	BHZ(31)	KS54000acc	0.00645	262144	1	14981.0
BOSA	SHZ(01)	GS21vel	0.01224	43340701	1	300.0
	BHZ(B)	KS54000vel	0.02014	262144	1	30145.4
BURAR	SHZ(08)	GS21vel	0.01335	43340701	1	275.1
	BHZ(31)	KS54000acc	0.00628	262144	1	15386.5
CPUP	SHZ(01)	GS21vel	0.01223	43340701	1	300.3
	BHZ(B)	KS54000acc	0.00635	262144	1	15216.9
DBIC	SHZ(01)	GS21vel	0.01169	43340701	1	314.1
	BHZ(B)	KS54000vel	0.0203	262144	1	29907.8
KKAR	SHZ(02)	GS21vel	0.01231	43340701	1	298.3
	BHZ(31)	KS54000acc	0.00613	262144	1	15763.0
LBTB	SHZ(01)	GS21vel	0.01294	43340701	1	283.8
	BHZ(B)	KS54000vel	0.02049	262144	1	29630.5
LPAZ	SHZ(01)	GS21vel	0.01232	43340701	1	298.1
	BHZ(B)	KS54000vel	0.02065	262144	1	29400.9
MKAR	SHZ(05)	GS21vel	0.01037	43340701	1	354.1
	BHZ(31)	KS54000acc	0.00675	262144	1	14315.2
PLCA	SHZ(01)	GS21vel	0.01234	43340701	1	297.6
	BHZ(B)	KS54000vel	0.02149	262144	1	28251.6
VNDA	SHZ(01)	GS21vel	0.01436	43340701	1	255.7
	BHZ(B)	KS54000vel	0.02044	262144	1	29702.9

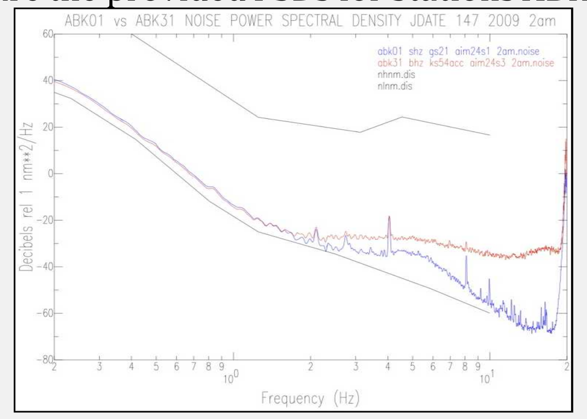
Response File Summary

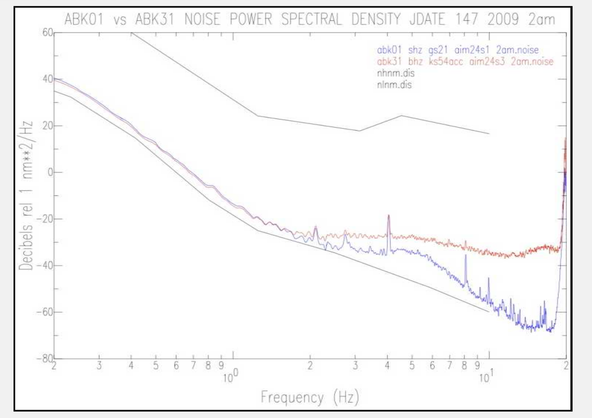
The table below shows a summary of the response files indicating the calibrated passbands, low frequency variability in the short period seismometers, and little to no consistency in resolution between short period and broadband FAP Files

Station	Channel	Sensor	Low Frequency Limit (Hz)	High Frequency Limit (Hz)	Resolution (# Samples in FAP File)
ABKAR	SHZ(01)	GS21vel	0.1025	20	4075
	BHZ(31)	KS54000acc	0.0098	20	2047
BOSA	SHZ(01)	GS21vel	0.163	19	55
	BHZ(B)	KS54000vel	0.01	19	80
BURAR	SHZ(08)	GS21vel	0.1172	20	1018
	BHZ(31)	KS54000acc	0.01	19	70
CPUP	SHZ(01)	GS21vel	0.33	19	40
	BHZ(B)	KS54000acc	0.009	20	2047
DBIC	SHZ(01)	GS21vel	0.102	20	4075
	BHZ(B)	KS54000vel	0.0098	20	2047
KKAR	SHZ(02)	GS21vel	0.102	20	4075
	BHZ(31)	KS54000acc	0.0098	20	2047
LBTB	SHZ(01)	GS21vel	0.1025	20	4075
	BHZ(B)	KS54000vel	0.0098	20	2047
LPAZ	SHZ(01)	GS21vel	0.335	19	40
	BHZ(B)	KS54000vel	0.0098	20	2047
MKAR	SHZ(05)	GS21vel	0.01	20	262
	BHZ(31)	KS54000acc	0.0098	20	2047
PLCA	SHZ(01)	GS21vel	0.0098	20	4094
	BHZ(B)	KS54000vel	0.01	19	1899
VNDA	SHZ(01)	GS21vel	0.1025	20	4075
	BHZ(B)	KS54000vel	0.01	19	70

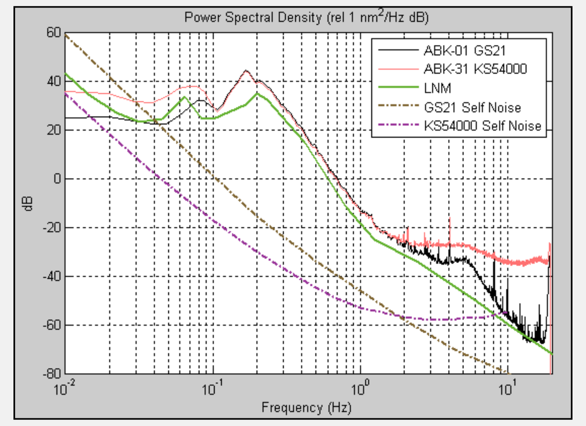
Power Spectral Density Plots

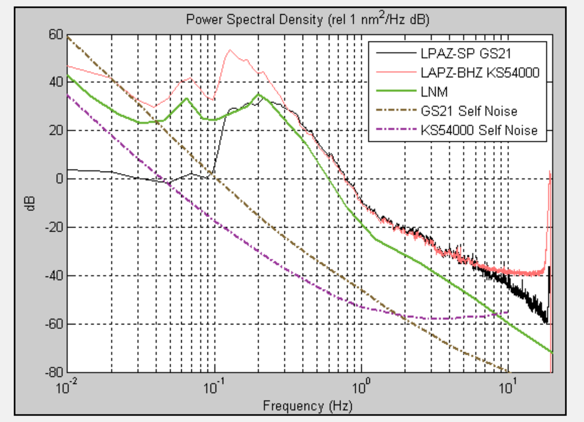
Power spectral density plots were provided for each of the 11 stations. Below are the provided PSDs for stations ABKAR and LPAZ for 0.2 to 20 Hz.



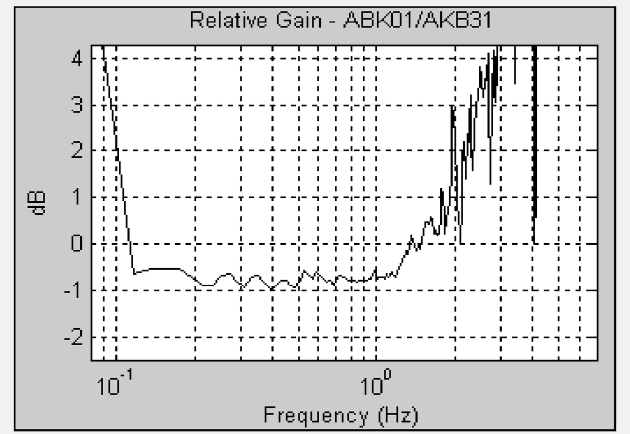


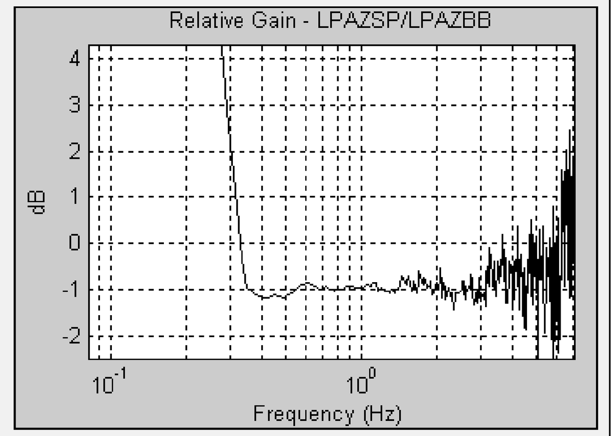
We re-created the PSD plots to verify the data scaling from counts to nanometers was correct for both stations. Below are the PSDs for stations ABKAR and LPAZ for 0.01 to 20 Hz. By plotting the PSDs below 0.2 Hz we can see that the two sensors separate at both high and low frequencies, leaving only a narrow range of overlap.





We also calculated the relative gain between the short period GS21 and the broadband KS54000. This allows us to calculate the difference in gain in dB for each station.





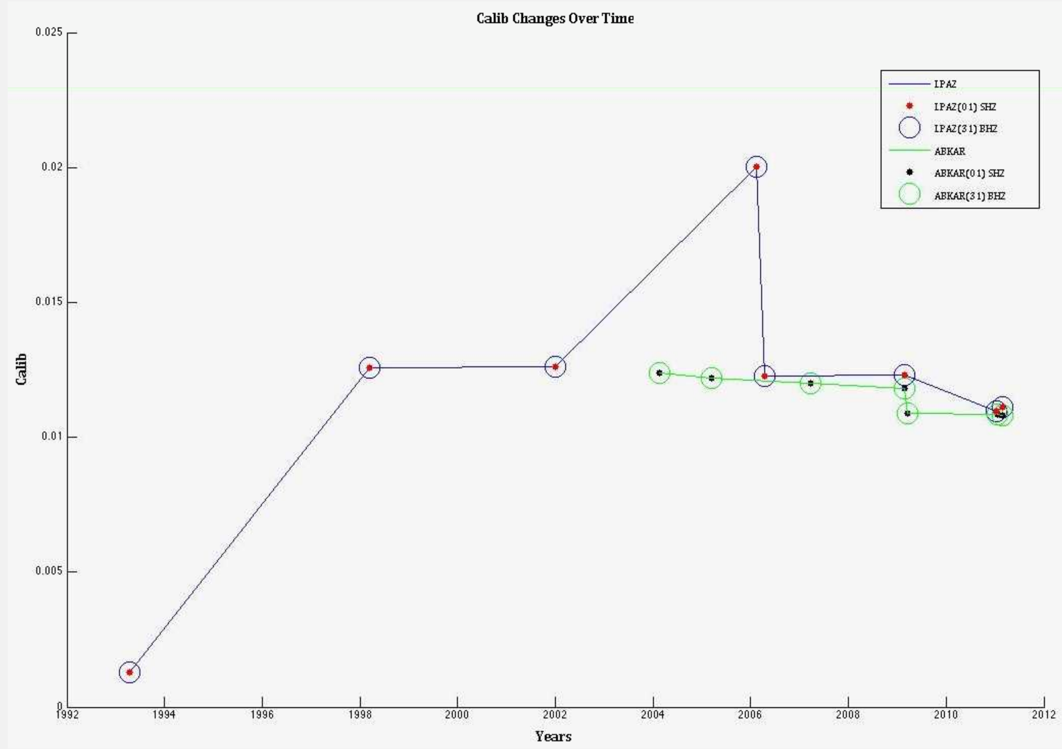
Station ABKAR has a moderate agreement between both sensors, showing a gain difference of 0.5 to 0.98 dB between 0.102 and 1.0 Hz. This translates into a 6-12%. Difference in amplitude scaling across this narrow band. Station LPAZ had an average gain difference of 1 dB between 0.4 and 3 Hz.

Station	0.1 Hz	1 Hz	Station	0.1 Hz	1 Hz
ABKAR	0.5 dB	-0.7 dB	LBTB	1.6 dB	-0.6 dB
BOSA	10 dB	-1.2 dB	LPAZ	-30 dB	-1 dB
BURAR	4 dB	-2 dB	MKAR	-3 dB	-0.4 dB
CPUP	30 dB	-1 dB	PLCA	-1 dB	1 dB
DBIC	2.6 dB	-1 dB	VNDA	-3.8 dB	-1.9 dB
KKAR	-1 dB	-1 dB			

The table to the left shows relative gain results in dB relative to 1 nm^2 /Hz between the 11 broadband and short period seismometer stations for 0.1 and 1 Hz.

Calib and Calper Over Time

The figure below shows 'calib' values from stations LPAZ and ABKAR for both SHZ and BHZ. This is a small sampling of 'calib' values from the installation date of each system to present. This shows that the 'calib' values are changing over time, and at both stations, changing dramatically within the same year (2006 for LPAZ and 2009 for ABKAR). To understand how the 'calib' values were changing we



found the average 'calib' values from both systems and found the percent change for each sample. Values ranged from 2.2% to 62% for ABKAR and 4.5% to 88.8% for LPAZ. It will be necessary to look at a higher resolution of 'calib' values to determine how and why they are changing over time. With such a small sampling of data it is difficult to draw any conclusions as to the inconsistency of these observations.

Conclusions

In comparing the relative gain scaling between co-located seismometers it is necessary to know the limitations in calibration passband when comparing a broadband seismometer to a short period seismometer. The main limitation we observed was the passband of the calibration in the FAP file. The KS54000/SHI system noise appears to limit how we can interpret the performance between the co-located seismometers above 2 Hz. Currently, little or no standardization exists in how FAP files are generated. The FAP file resolution and calibration frequencies are not the same for all seismometers of a common response type; e.g., short-period. Obtaining a complete system that has been running for an extended period of time may allow us to determine which components are the primary cause of the observed scaling differences between co-located short-period GS21/SHI systems and broadband KS54000/SHI systems.

Recomendations

In order to reduce the confusion from long term installations, a tool needs to be developed to produce standard FAP response files. The FAP files need to contain the same resolution and common low frequency starting point regardless of who writes the file.

References

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