Component Testing for Nuclear Explosion Monitoring at the Facility for Acceptance, Calibration and Testing (FACT) Site

Seismological Instrumentation and Testing Symposium 2013 Albuquerque, NM

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Outline:

• FACT Site Overview

• Digitizer Testing at Sandia

• Infrasound Sensor Testing at Sandia

• Sandia CE Software Summary
  • Command and Control
  • Analysis
FACT Site Overview
FACT Site Overview

Tasked with hardware evaluation for US nuclear monitoring stations – digitizers, seismometers and infrasound sensors

• 2 ½ acres of property protection (fenced in area)

• 45 acres for deployment of up to ten subsystems and systems for evaluation purposes

• In 2011, received final approval for non-exclusive access to eight sites on 400 acres
1. Component Evaluation Support
   • Signal generation
   • Data acquisition
   • Minor fabrication

2. Storage/Workshop
   • Isolation pier
   • Temp chamber

3. Underground bunker
   • Component testing

4. Staging trailer
   • Unpacking/inventory
   • Storage

5. System testing
   • Data acquisition systems
Component Evaluation:

- Concrete structure
- DC and AC power
- GPS and Communication rack
- Patch Panel from CE support bldg. (signal transmission)
- GPS rebroadcaster
- Temperature stability
- Seismic Pier
- Infrasound Isolation Chamber
- HP3458A Voltage reference
Station configuration:

- Solar (85-135 Watt)
- Charge controller (Morning star PS-30)
- Radio (Afar)
- Custom power board
- CP 25 Infrasound sensor enclosure & porous hose wind-filter
- Seismic vault
- Smart24 digitizers

We provide a reference set of equipment for comparison to new systems designs.
400 acre FACT site Expansion

FACT Site (45 Acres)
Fenced Compound
Expansion (400 Acres)

Eight stations on 400 acres, one repeater site
Digitizer Testing at Sandia

- Test Equipment
- Requirements
- Overview of Tests Conducted by Sandia
- Examples
Digitizer Testing Support

Classic Signal generation
- ULDO classic: THD > -130 dB
- Sanford Research Systems DS360
- Time Tag equipment

Next Generation Signal Generator
- Quanterra SuperTonal – GPS time sync’ed signal generator
- Initial qualification testing (see MRR paper http://www.rdss.info/librarybox/mrr/MRR2012/PAPERS/07-06.PDF
- Command & Control
- High degree of frequency stability
- Not Amplitude calibrated

Calibrated HP3458A multi-meter (5)
FACT Site Overview

1.2. Minimum Requirements for Primary and Auxiliary Seismological Station Specifications

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Minimum Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor type</td>
<td>Seismometer</td>
</tr>
<tr>
<td>Station type</td>
<td>Three component or array</td>
</tr>
<tr>
<td>Position (with respect to ground level)</td>
<td>Borehole or vault</td>
</tr>
<tr>
<td>Three component station passband</td>
<td>Short period: 0.5 to 16 Hz plus long period: 0.02 to 1 Hz or broadband: 0.02 to 16 Hz.</td>
</tr>
<tr>
<td>Sensor response</td>
<td>Flat to velocity or acceleration over the passband</td>
</tr>
<tr>
<td>Array station passband</td>
<td>(Short period: 0.5 to 16 Hz)</td>
</tr>
<tr>
<td></td>
<td>Long period: 0.02 to 1 Hz</td>
</tr>
<tr>
<td>Number of sensors for new arrays</td>
<td>9 short period (one component) plus (1 short period (three component) plus 1 long period (three component))</td>
</tr>
<tr>
<td>Seismometer noise</td>
<td>≤10 dB below minimum earth noise at the site over the passband</td>
</tr>
<tr>
<td>Calibration</td>
<td>Within 5% in amplitude and 5° in phase over the passband</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>≥40 samples per second</td>
</tr>
<tr>
<td>System noise</td>
<td>≤10 dB below the noise of the seismometer over the passband</td>
</tr>
</tbody>
</table>

- Resolution: 18 dB below the minimum local seismic noise
- Dynamic range: >120 dB
- Absolute timing accuracy: ≤10 ms
- Relative timing accuracy: ≤1 ms between array elements
- Operation temperature: 10°C to 45°C
- State of health: Status to be transmitted to the International Data Centre; clock, calibration, vault and/or borehole status, telemetry
- Delay in transmission to the International Data Centre: ≤5 min
- Data frame length: Short period: ≤10 s; long period: ≤30 s
- Buffer at the station or National Data Centre: ≥7 days
- Data availability: >98%
- Timely data availability: >97%
- Mission capable arrays: ≥80% of the elements should be operational
- Precision on station location: ≤100 m absolute for stations (World Geodetic System 84) ≤1 m relative for arrays
- Elevation above sea level: ≤20 m
- Seismometer orientation: <3°
- Data format: Group of Scientific Experts format
- Data transmission: Primary station: continuous
- Auxiliary station: segmented

- For existing Global Telemetered Seismic Network stations, upgrading needs further consideration.
- For a one component element of telemetered arrays, the upper limit is 8 Hz.
- In the case of noisy sites or when increased capability is required, the number of sensors could be increased.
- This can be achieved by a single broadband instrument.
- This applies to three component and regional arrays. For existing telemetered arrays, 40 samples per second are necessary for three component sensors but 20 samples per second are suitable for other sensors.
- Temperature range to be adapted for some specific sites.
- Procedure for buffering to ensure minimum loss of data and single point failure should be addressed in the International Monitoring System Operational Manual.

Sensor Requirements

Digitizer Requirements
# Sandia – Digitizer Testing Capabilities

## Tests used in Digitizer Evaluation
- AC Accuracy
- AC Clip
- Analog Bandwidth
- Common Mode Rejection
- Cross-talk
- DC Accuracy
- Input Impedance
- Input Shorted Offset
- Input Terminated Noise
- Modified Noise Power Ratio
- Power
- Relative Transfer Function
- Total Harmonic Distortion

## Input Terminated Noise
- Infrasound System Noise
- Seismic System Noise
- Rotational Seismic System Noise

## Timing Tests
- Time-Tag Accuracy
- Time-Tag Statistics
- Time-Tag Drift

## Calibrator Tests
- Sine Calibrator Amplitude
- Sine Calibrator Current
- Sine Calibrator Frequency
- Calibrator Output THD
- Calibrator Loopback THD
Example: DC Accuracy
- DC source generator
- Calibrated Voltage Meter

Top waveform: HP3458A meter
Bottom waveform: Digitizer channel
Example: Input Terminated Noise
- **Static/Passive Test**
- Differential input of digitizer is terminated with input Impedance of matched sensor
Example: Seismic System Noise

- ITN data
- Sensor Response Model
  - STS2-High Gain 20,000 V/m/s
  - STS2-Low Gain 1,500 V/m/s

Compare result to requirement for system noise...≤ 10 dB below seismometer noise across passband

Dark Blue = High Gain, Dark Red = Low Gain
Infrasound Sensor Testing
at Sandia

- Test Equipment
- Overview of Tests Conducted by Sandia
- Examples
FACT Site Overview

Sandia – Infrasound Testing Capabilities

Acoustic Test Chamber
- Use Comparison Calibration Technique
  - Reference Sensor MB2000
- Primary Test Chamber
  - Volume (~330 L)
  - Pressure range < 6 Pa Peak
  - Tonal frequency band ~0.02 to 14 Hz
  - Acoustic White Noise band ~0.01 up to 200 Hz
- Six channel acquisition (5 test + 1 reference)
- PSL calibrated - Vaisala PTU303 – P, T, RH% *
Acoustic Test Chamber
- Use Comparison Calibration Technique
  - Reference Sensor MB2000
- Secondary Test Chamber
  - Volume (~50 L)
  - Pressure range 0.01 to Pa 100 Pa Peak
Acoustic Test Manifold
• Use Comparison Calibration Technique
  • Reference Sensor MB2000
• Secondary Test Chamber
  • Volume (~35 L)
  • Pressure range 0.01 to Pa 100 Pa Peak
  • Part of transportable testbed
    • IS56, IS59, Chaparral Physics (UAF)
• Six primary channels of data acquisition
• Two ports for reference microphones and Viasala
Martec MB2000 Primary Reference

Martec MB2005 Secondary Reference

Power: MB2000 = 4 watts and MB2005 = 1.6 watts @ 12V

Sensitivity: MB2000 100 mV/Pa and MB2005 97.6 mV/Pa

Noise: -64 dB rel 1 Pa^2/Hz ~ 0.7 mPa rms (0.5-2 Hz)

Full-scale Pressure: 107 Pa (zero to peak)

Dynamic Range: 104 dB

Passband: 0.02 – 10 Hz
Sandia – Infrasound Testing Capabilities

Tests used in Infrasound Evaluation

- Power
- Single Frequency / Single Amplitude
- Single Frequency / Increasing Amplitude
- Multiple Frequency / Single Amplitude
- Static Noise
- Dynamic Noise
  - Broadband signal (Analysis – Holcomb (1989) or Sleeman (2006))
- Response Verification
- Total Harmonic Distortion
- Inter-Modulation Distortion (two-tone)
FACT Site Overview

Sensor:
Low Gain: 0.02 V/Pa
High Gain: 0.1 V/Pa
Output(V): +/- 10

13 dB difference in Voltage in noise.

When converted by response to Pa, the Pa noise is the same.

<table>
<thead>
<tr>
<th>Waveform</th>
<th>Noise (mPa rms) 0.02-4 Hz</th>
<th>Full-Scale (Pa)</th>
<th>DR 0.02-4 Hz</th>
<th>Noise (mPa rms) 0.5-2 Hz</th>
<th>Full-Scale (Pa)</th>
<th>DR 0.5-2 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB2005 HG</td>
<td>2.60</td>
<td>100</td>
<td>89.3 dB</td>
<td>1.16</td>
<td>100</td>
<td>96.0 dB</td>
</tr>
<tr>
<td>MB2000 LG</td>
<td>2.90</td>
<td>500</td>
<td>102.9 dB</td>
<td>1.13</td>
<td>500</td>
<td>110.0 dB</td>
</tr>
</tbody>
</table>
FACT Site Overview

Sensor:
- Low Gain: 0.4 V/Pa
- High Gain: 2.0 V/Pa
Output(V): +/- 18

20 dB difference in Voltage in noise.

When converted by response to Pa, the Pa noise is 5 dB higher for HG.

<table>
<thead>
<tr>
<th>Waveform</th>
<th>Noise (mPa rms)</th>
<th>Full-Scale (Pa)</th>
<th>DR 0.02-4 Hz</th>
<th>Noise (mPa rms)</th>
<th>Full-Scale (Pa)</th>
<th>DR 0.5-2 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS HG</td>
<td>1.37</td>
<td>9</td>
<td>73.3 dB</td>
<td>0.72</td>
<td>9</td>
<td>78.9 dB</td>
</tr>
<tr>
<td>IS LG</td>
<td>0.63</td>
<td>45</td>
<td>94.1 dB</td>
<td>0.29</td>
<td>45</td>
<td>100.1 dB</td>
</tr>
</tbody>
</table>
Infrasound Sensors Evaluated
• Chaparral 2.2, 2.5, 25, 50 and 50A
• IML SS and ST
• Miltec
• NCPA (IRIS-PASSCAL)
• Hyperion Technology Group
• infraNMT (modified for CVO/HVO)
• PCB Piezotronics
• Paroscientific, Inc.
FACT Site Overview

Sandia CE Analysis
Software Summary
CE Software Update

• CE Analysis software upgrade
  – TALENT (Test and AnaLysis EvaluatioN Tool)
  – Standardization, with traceability and database archive of test results
  – Models (e.g. site background, sensor noise), Instrument Response (pole-zero), Procedures and Test Plan tools
  – Support testing at Pinedale Seismic Research Facility (PSRF)
  – Digitizer and Infrasound testbed automation

• CE Testbed Automation
  – Leverage basic capability of Smart24 Calibrator
  – SAC 2012 (Smart24 Automated Calibrator)
  – Prototype Command Control for Infrasound Testbed
  – Queue test sequences and control when queue is executed
Component Evaluation Software Support

Component Evaluation Software:

Smart24 Auto Calibrator (SAC)
- Automation of Infrasound Testbed
- Allows connection to Smart24 Digitizer; then uses DAC to generate test signals.
- Define custom test sequences
- Allows test sequences to be queued
- Delay start
Component Evaluation Software Support

Component Evaluation Software: Test Analysis and Evaluation Tool: (TALENT)

- Designed to be a single, standard interface to all test configuration, metadata, parameters, waveforms, and results generated during the course of testing.
- Table of Contents (LHS)
- Menus
- Desktop (RHS)

Notable Features:
- Instrument Response models
- Reference models (either noise of site background)
Component Evaluation Testing and Analysis Algorithms

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