U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Development of a HT Seismic Tool

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High Temperature Tools and Drilling

Overview

- Project Overview
  - Timeline
    - Project start date FY 2008, Project end date FY 2010
      - Currently 90% complete
      - 9 month funding delay in FY2009
  - Budget
    - Non ARRA project funded by DOE Geothermal total budget $1100k - FY08 $300k, FY09 $600k, FY10 $200k (field support)
  - Barriers
    - Funding delays
  - Partners
    - Pinnacle (Halliburton)
    - Harvey Mudd College

Why a Seismic Tool?

- EGS requires stimulation of drilled wells, most likely through hydraulic fracturing
  - Microseismic monitoring provides one method of real-time mapping of fractures
    - During creation of reservoir, monitoring helps to assess stimulation effectiveness and provides information necessary to properly create the reservoir
    - After reservoir is established, monitoring (with additional sensors such as pressure) can provide information on reservoir performance and evolution over time
- No HT seismic tool exists that will operate continuously at well temperatures > 125 -150° C

Project objective

- Design and fabricate and field test a high temperature (HT) Seismic Tool in an EGS application.
  - Seismic tools enable real-time mapping of fractures during well stimulation.
- Work with commercial partner in the development of the tool
  - Pinnacle Technologies (Halliburton)
  - Harvey Mudd College
- Develop two electronic designs:
  - 240 ºC SOI Tool (Continuous, 17000 hour life)
    - Three axis, 1 uG (based on electronics)/ 100 Hz seismic sensitivity (Honeywell 18 bit A/D converter, FPGA and EEPROM)
  - 210 ºC Tool (Continuous, 1000 hour life)
    - Three axis, 1 uG (based on electronics)/ 1000 Hz seismic sensitivity (Texas Components, Texas Instruments 24 bit A/D converter)

Scientific/Technical Approach

- Establish commercial partner early in the development stage
- Design hardware and electronics based on the needs of industry
- Apply experience from our previously developed and field tested tools such as our Silicon-on-Insulator (SOI) based well monitoring tools and low temperature (LT) seismic tools
- Utilize COTS (commercial-off-the-shelf) devices
- Determine possible barriers and alternative solutions

Scientific/Technical Approach

- **Milestones: (Note: Start of project May 2008)**
  - Selection of industry partner – June 2008 (complete)
  - Signal conditioning circuit design – August 2008 (complete)
  - Seismic sensor selection – August 2008 (complete)
  - Preliminary sensor/signal conditioning evaluation – September 2008 (complete)
  - Hardware clamping mechanism concept – September 2008 (complete)
  - Delay in funding of approximately 9 months (restart May 2009)
  - Finalized design for both 200C and 240C electronics – February 2009 (November 2009 complete)
  - Fabrication of clamping mechanism – April 2009 (January 2010 complete)
  - Lab evaluation of clamping mechanism – May 2009 (March 2010 complete)
  - Lab performance tests of both electronics packages – June 2009 (April 2010 complete)
  - Finalized hardware design – June 2009 (April 2010 complete)
  - Determine HT data link options – July 2009 (May 2010)
  - Fabrication and assembly of two tools – August 2009 (May 2010)
  - Perform initial field test – September 2009 (June 2010)
  - Preliminary field test in HT well (TBD) – November 2009 (August 2010)

Project Subtopics Include:

- Hardware design and development
  - Shear pin release
  - Clamping arm motor
  - Note: Clamping mechanism is critical to the success of the tool
- Sensor selection
  - Ideal sensor
  - HT options
    - Endevco piezoelectric accelerometer
    - Geospace geophone
- Electronics
  - Analog-to-Digital converter options

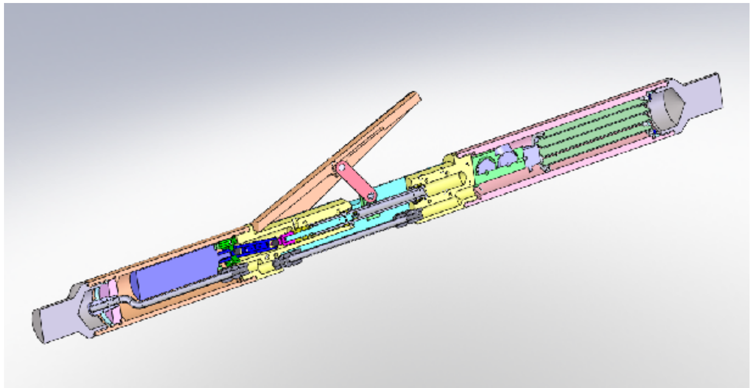
Accomplishments, Expected Outcomes and Progress

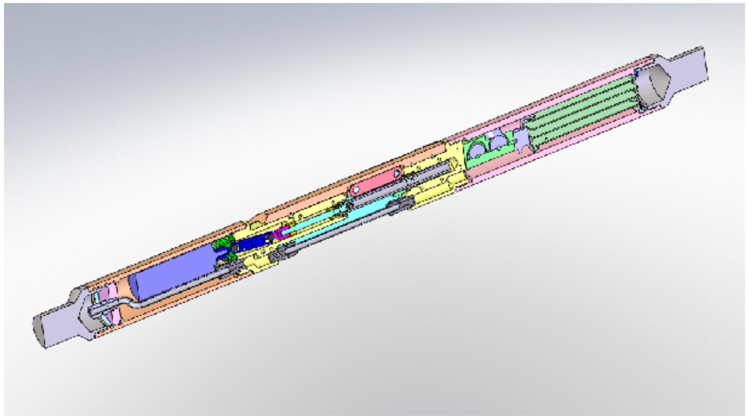
Low temperature Sandia-designed seismic tools

Prototype tool

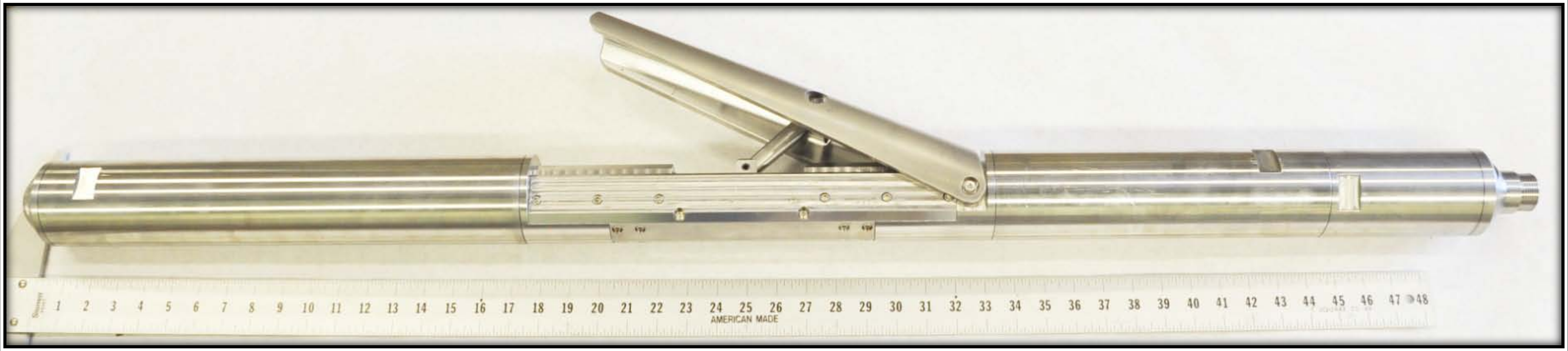
Commercialized tool

High temperature Sandia-designed seismic tools





Accomplishments, Expected Outcomes and Progress



- Design Highlights
  - All metal seals
  - Shear pin for emergency extraction
  - Stepper motor drive for arm
  - Electronics design for 240° C operation; exception is the high resolution 24 bit A/D (210° C; 1000 hrs)

Tool Assembly

HT Stepper Motor

Electronics/Sensor Package

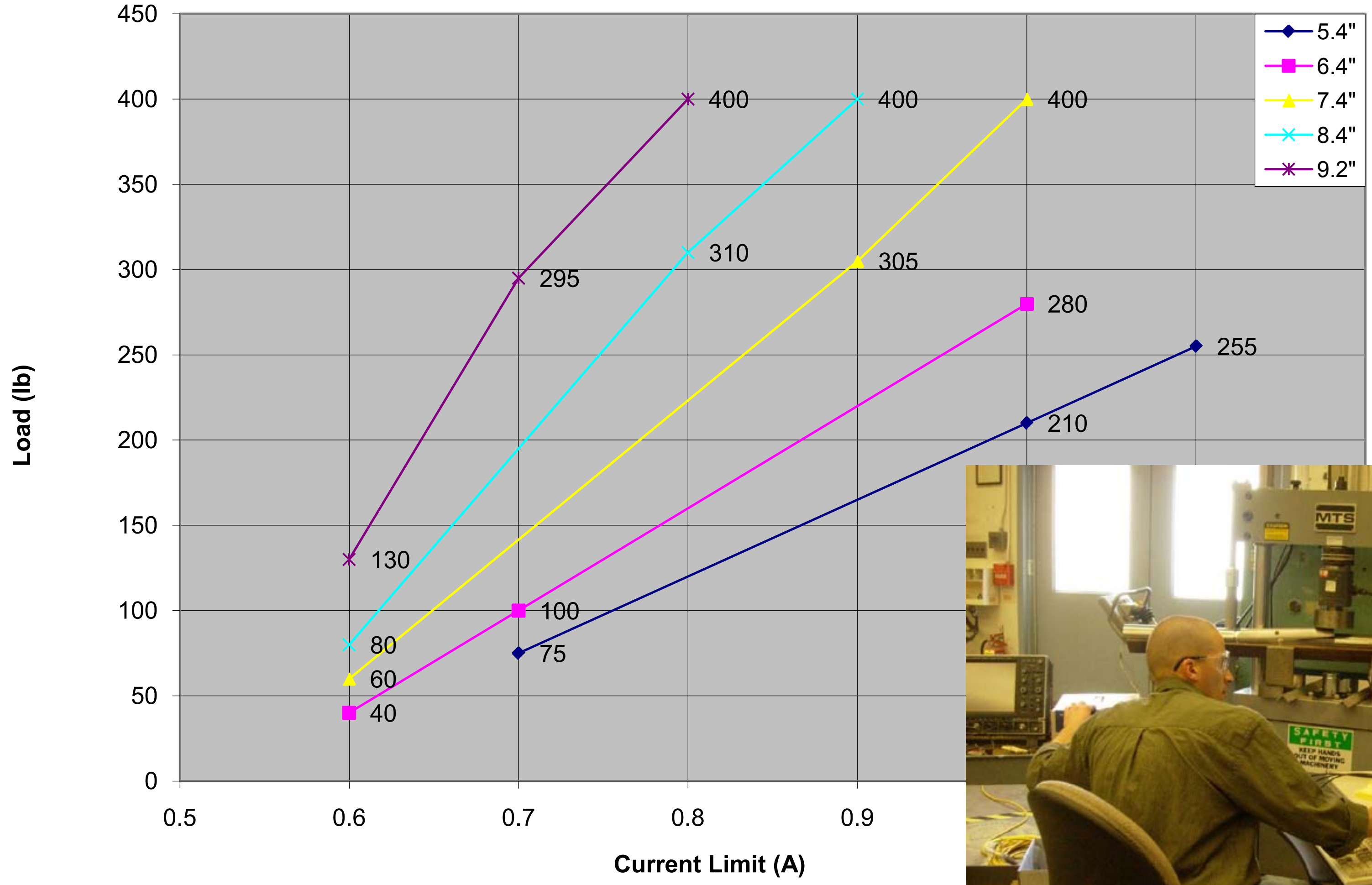
Electronics consists of five boards, two board sets are assembled and tested up to 200 – 240° C

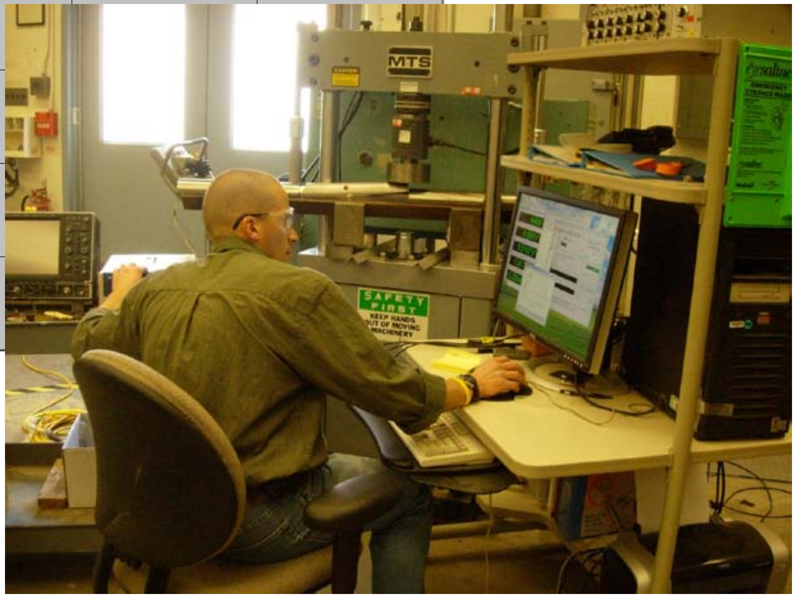
Clamp Arm Drive Motor Selection

- DC motor
  - Easy to use, and directly compatible with industry.
  - HT motor not currently available; Could be designed but was not within our timeframe and budget
- AC motor
  - Speed control more difficult than DC motor
  - Torque is limited (size restrictions)
  - HT motor not currently available; Could be designed
- Stepper motor
  - Control is difficult using HT components
  - Torque is adequate
  - Suitable for HT operation

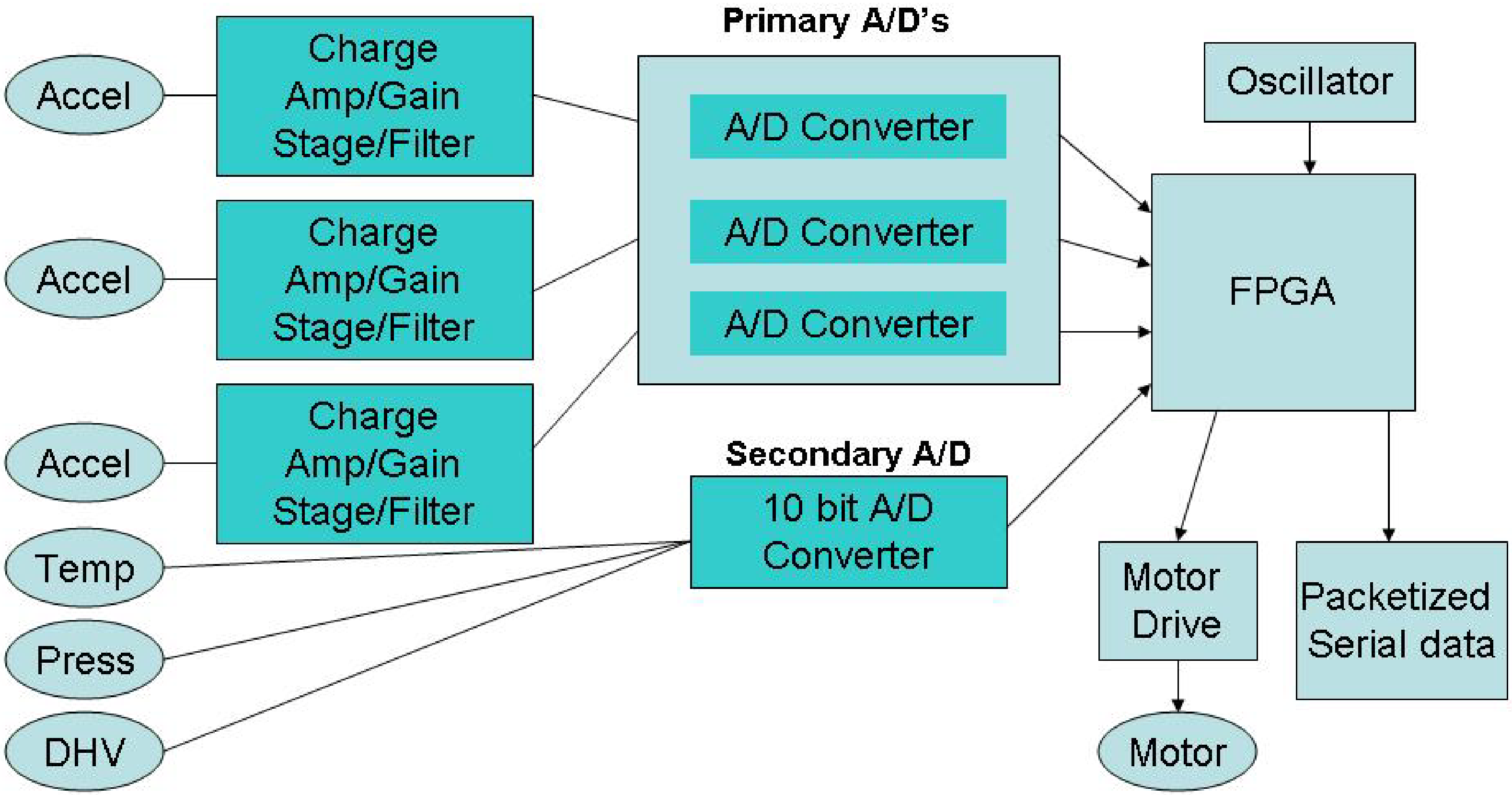
Accomplishments, Expected Outcomes and Progress

Stepper Motor Performance at 190°C





Block Diagram of Electronics



Two high resolution A/D converters have been evaluated with acceptable results. (Texas Components TX424 and the newly available Texas Instruments ADS1278)

Seismic Sensor Selection

- Seismic sensor desired specifications
  - Resonant frequency > 3 KHz
  - Operational frequency range - DC to 2 KHz
  - Maximum operating temperature range > 240° C
  - Sensitivity > 50ug
  - Low cross-axis sensitivity
  - Shock survivability > 5000 g
- Seismic sensor options
  - Geophone
    - Best suited for detecting low frequency events (<100 Hz)
    - Prone to cross-axis sensitivity issues
    - Rated to 200° C with limited life
    - Shock limit approximately 500g
  - Accelerometer
    - Resonant frequency > 10kHz
    - Operational frequency range - 1Hz to 3 kHz respectively
    - Maximum operating temperature range – 260° C
    - Sensitivity – 1000 pC/g
    - Shock limit approximately 1000g

Accomplishments, Expected Outcomes and Progress

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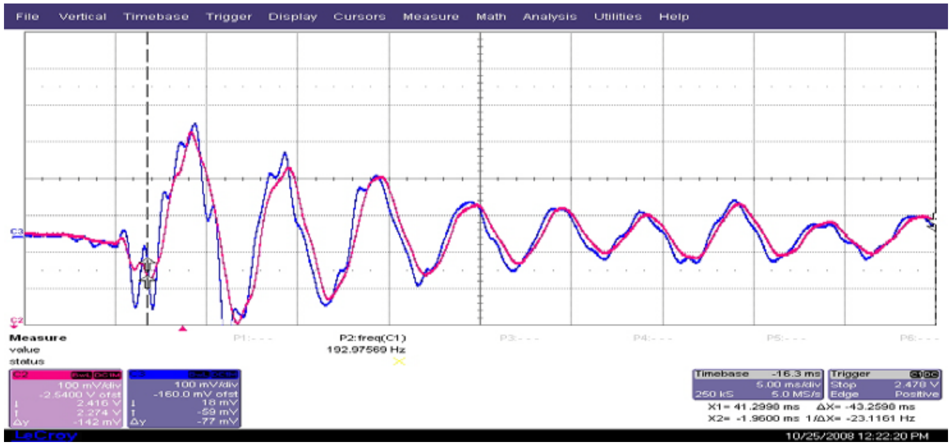
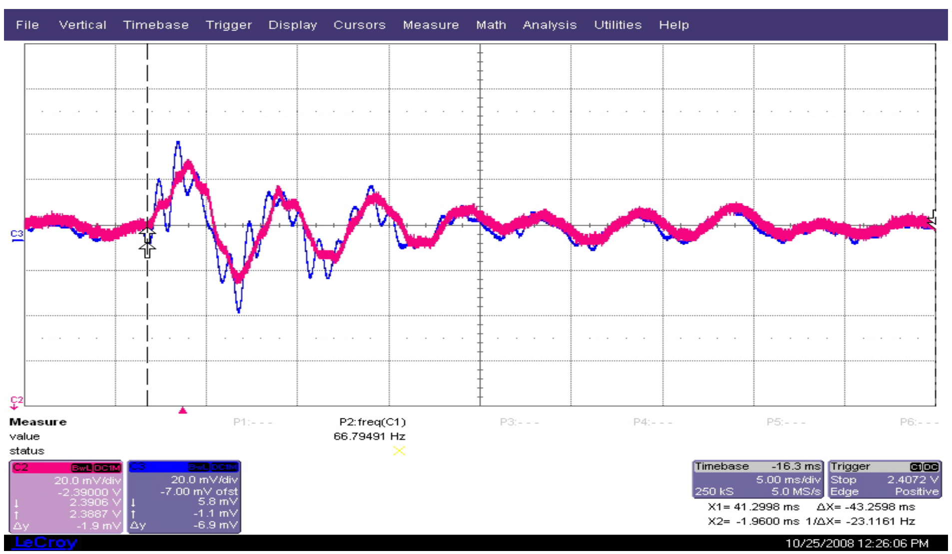
Vibration Response of LT and HT Sensors



50 mg vibration test

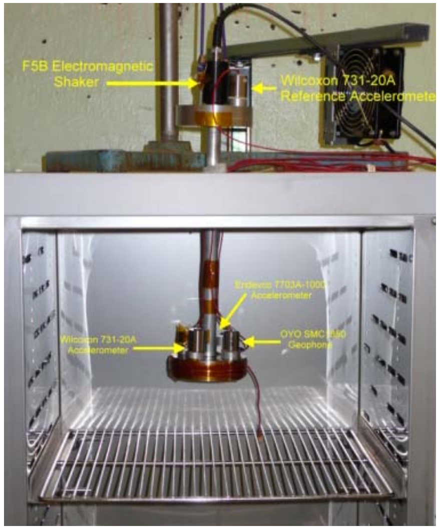


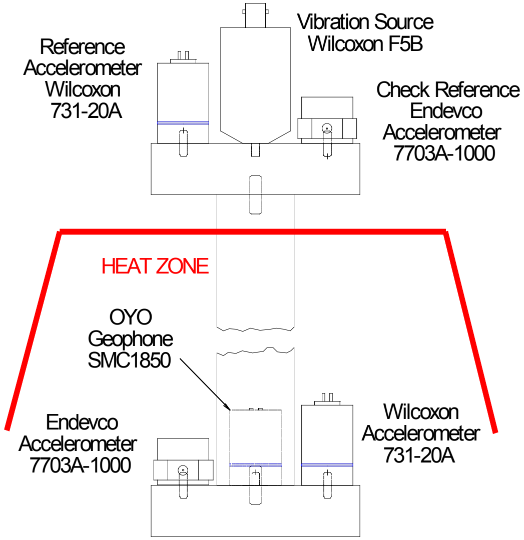
4mg vibration test

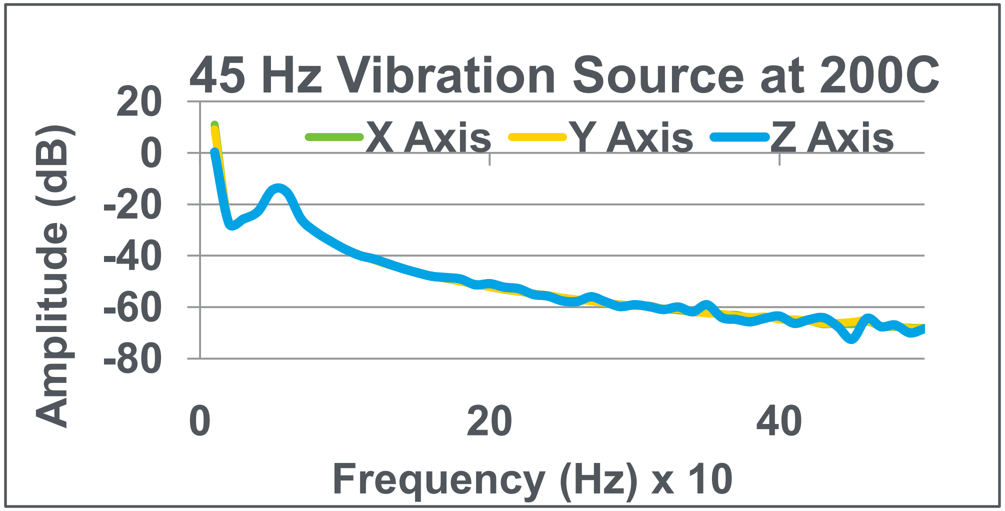
The graphs at the left compare the output of a low temperature seismic sensor to the HT seismic sensor with the HT signal conditioning circuits

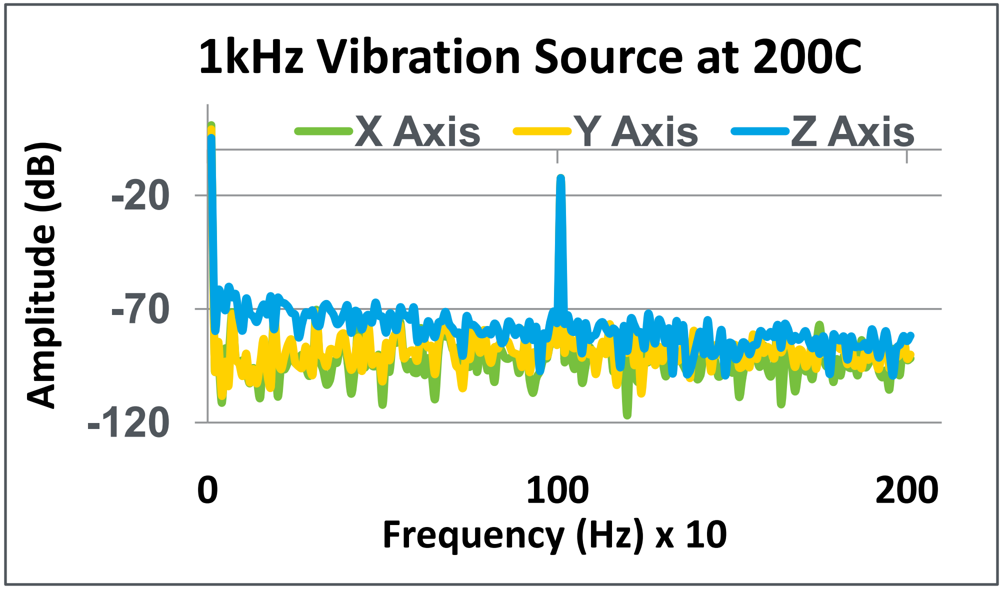
Even in an open (unshielded) setup, it is evident that an acceleration level of less than 2mg can easily be detected. In a shielded setup, one would expect a factor of approximately 50 – 100 improvement in sensitivity.

Vibration Response at 200° C









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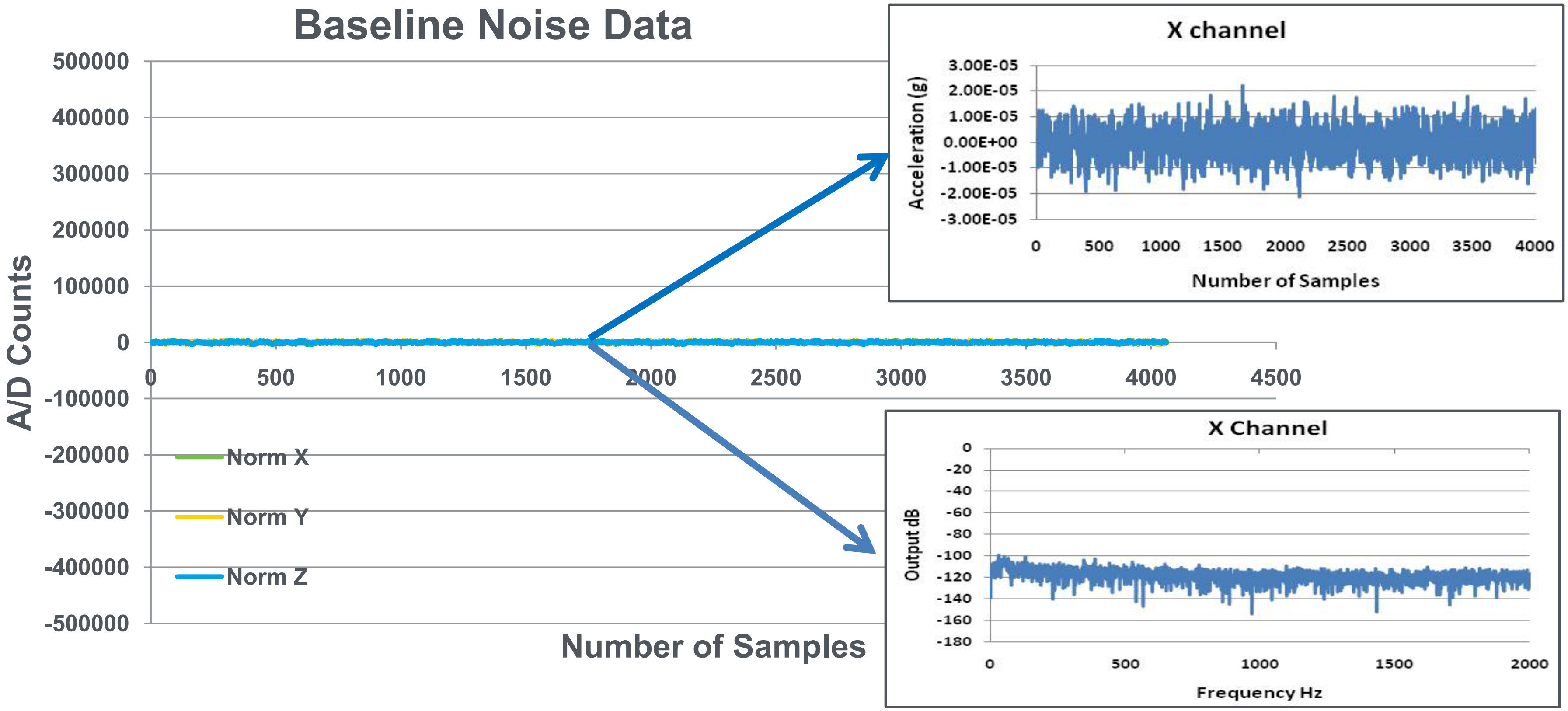
Electronics Noise Evaluation (Charge amp, Filter and A/D converter)



Project Management/Coordination

- Schedule
  - Schedule based on previously discussed milestones
  - Currently 90% complete
- Application of resources
  - Sandia Geothermal department – hardware and electronics design
  - Uhltronics – seismic sensor and noise evaluation
  - Physical Solutions – Analog-to-Digital converter evaluations
  - Harvey Mudd College – high speed data link
- Project Integrated
  - HT seismic tools are needed to help map fractures when developing EGS reservoirs. As such, this tool is aligned with DOE Geothermal program objectives
- Coordination with industry
  - Investigating fielding of tool with Pinnacle

Future Directions

- Critical milestones (remainder of FY10)
  - Deploy tools
    - Initial field test
      - Function test, 15000 feet of cable, in-tool data logger
        - In-tool data logger
    - Fielding in geothermal well
      - Single tool test, 5000 feet of cable
  - Determine high speed data link options
    - Increased capability required for
      - Deployment depths > 5000 feet
      - Multiple tools
    - High speed data link critical; path forward:
      - DOE funded fiber optic driver under development (Sandia - new project)
      - DOE funded HT fiber optic cable under development

Summary

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- HT seismic tool has been designed and lab tested
  - Individual boards tested to 200/240C
  - Complete assembly testing to 200C
  - Motor drive load evaluations to 200C
- Design highlights include:
  - Hardware
    - Shear pin release
  - Electronics
    - High speed high resolution measurements
    - SOI based electronics (exception is A/D converter and FPGA)
      - SOI A/D and FPGA/EEPROM required for 17000 hour life
- First field deployment scheduled for June
- Completion of project (FY10)
  - Final milestone for project - Fielding of the tool in a geothermal well

Publications and Presentations

- Henfling, J. A., J. Greving, F. Maldonado, D. Chavira, Y. Polsky, J. Uhl, 2010, *Development of a HT Seismic Downhole Tool,* World Geothermal Congress, Bali, Indonesia.

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