2017 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGIES OFFICE

SAND2017-10999R

Summary: High Temperature High Speed Data Link

1. Enhanced High Temperature/High Speed Data Link for Logging Cables

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- Subcontractors and/or Participating Organizations: Harvey Mudd College (Claremont, CA)

- Project Start and End Date: 10/2009 – 09/2018

2. Project Objectives and Purpose

New generations of high-temperature (HT) sensors and electronics are enabling increased measurement speed and accuracy allowing collection of more accurate and relevant data by downhole tools. Unfortunately, this increased capability is often not realized due to the bottleneck in the uplink data transmission rates due to poor signal characteristics of HT wireline.

The objective of this project is to enable the high transmission rate of raw data from downhole tools such as acoustic logging tools and seismic measurement devices to minimize the need for downhole signal processing. To achieve this objective, Sandia has undertaken the effort to develop an asymmetric high-temperature (HT), high-speed data link system for downhole tools capable of operating at temperatures of 210°C while taking advantage of existing wireline transmission channels. Current data rates over HT single-conductor wireline are limited to approximately 200 kbps. The goal system will be capable of transmitting data from the tool to the surface (uplink) at rates of > 1Mbps over 5,000 feet of single-conductor wireline as well as automatically adapt the data rate to the longer wirelines by adapting modern telecommunications techniques to operate on high temperature electronics. The data rate from the surface to the tool (downlink) will be significantly smaller but sufficient for command and control functions. While 5,000 feet of cable is the benchmark for this effort, improvements apply to all lengths of cable.

3. Project Timeline (with milestones and/or decision points, as applicable)

Due to gaps in funding, this project was split into two distinct phases. During the first phase (FY10/FY11), Sandia partnered with Harvey Mudd College to investigate an uphole solution to the data rate bottleneck. The initial approach combined Manchester data encoding with an uphole equalization filter to compensate for signal distortion created by the HT wireline. This approach resulted in an increase of the data rate up to 400kbps and fulfilled the initial goals of the project.

The second phase of the project (FY13-FY18) was initially focused on refining the original approach to further increase data rates. However, initial testing showed that data transmission above 400kbps was not practical due to the size of the equalization filter that would be required downhole. In FY14, a new approach was developed which leveraged the original idea but also included an orthogonal-frequency-division multiplexing (OFDM) technique used in the telecom industry. The OFDM technique has been shown to facilitate high data rates over a 5000 ft wireline in the laboratory but implementation downhole requires development of a HT transceiver package. The necessary new electronics can be described by three key modules: digital signal processor, digital to analog converter, and line drive circuitry. In FY15 an HT digital to analog converter and an HT line driver were developed and tested up to 250°C. A high data rate of 3.8Mbps (greatly exceeding the 1Mbps goal) was demonstrated over a 5000 ft single conductor wireline using a combination of the developed HT and standard temperature electronics. A further funding gap in FY16 slowed progress but in FY17 some funds were transferred from another project. In FY17, critical functions

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including the fixed point fast fourier transform were implemented on a novel HT microcontroller capable of operation up to 300°C. FY18 will focus on implementing the entire protocol on an HT processor and integrating the electronics into a HT electronics module.

4. Technical Barriers and Targets

- Develop a communication approach capable of transmitting data from the tool (uplink) at rates of > 1Mbps over 5,000 feet of single-conductor wireline to improve data quality provided by existing and future tools.
- Develop downhole HT electronic transceiver compatible with the new approach which can be easily incorporated with existing and future tools

Both of these challenges are difficult to achieve due to limitations of single-conductor wireline and scarcity of HT electronics. The single-conductor wireline is very commonly used for downhole logging tools. As such, the wireline is primarily designed for working tension and power transmission, while the parameters required for high speed (HS) data transmission (impedance) are secondary. These design tradeoffs cause the wireline to have poor bandwidth properties, which change depending on the overall length and proportion of the wireline deployed in the well.

HT electronics are required downhole to enable HS data transmission over single-conductor wireline. However the number of available HT components is multiple orders of magnitude smaller than the number of the standard temperature electronics. This limits the techniques used and requires much longer design times to implement necessary functionality.

5. Technical Approach

- To achieve our goal of creating the high speed HT HS Data Link, we focused on changing the underlying data encoding scheme. We have been able to increase the existing data transmission rate by employing an OFDM technique used by the telecom industry which enables transmission of multiple data streams simultaneously at different frequencies. This technique allows for correction of cable distortion at each frequency independently. However, this new approach to the problem increases complexity of the downhole transmitter by requiring significantly more computation to encode/decode the data, and a digital to analog converter (DAC) to generate the required waveform.
- To further increase the reliability of the data, a robust point to point link protocol is in development. The protocol will enable use of the data link for a variety of tools with little to no changes by hiding all the complexity from the tool. The protocol will automatically detect and correct transmission errors, allow for data buffering and retransmission as well as provide feedback as to the quality of the link.
- The HTHS data link system will comprise of two major components: a downhole HT transceiver and a low-temperature uphole transceiver. The uphole transceiver will consist of COTS National Instruments hardware and a computer running custom software to decode the data. While the hardware of the uphole transceiver is relatively simple due to the availability of standard temperature components, the downhole transceiver will consist of a more complex design involving HT electronic components. It will consist of three major parts: digital signal processor (DSP), custom designed DAC, and custom designed line driver (power amplifier) capable of driving high capacitance wireline.
- The prototype system will be tested in the laboratory at 210°C with various wirelines to demonstrate robustness of the HT high-speed data link system developed.

6. Technical Accomplishments

- Data encoding – Adapted the OFDM technique to efficiently use available bandwidth and minimize wireline distortion.

- DAC – Completed and tested a custom designed HT 12-bit DAC. The converter uses a 16-bit resistor ladder where the lower four bits are reserved for tuning the overall performance. The DAC seamlessly integrates with the HT DSP.
- Line Driver – Designed and tested a custom designed line driver. The line driver effectively integrates with the DAC and allows driving the benchmark 5000ft wireline between 1kHz-200kHz with minimal distortion.
- Downhole Transceiver – Successfully demonstrated the DAC + Line Driver system working in the laboratory setting with the 5000ft wireline. The maximum speed achieved under optimal conditions was ~3.8Mbps, however after integrating the link protocol, the overall performance decreases while reliability increases (the resulting speed will be >1Mbps).
- Link Protocol - Demonstrated adaptive protocol capable of modifying data rate over independent OFDM channels in response to increased data error rates.

7. Challenges to Date

- DAC – Due to the nature of the resistor ladder, DAC calibration is necessary to maintain a proper output. To mitigate this challenge, a feedback system will be implemented using a HT analog to digital converter (ADC)
- Line Driver – This was not envisioned as the part of the initial OFDM design and was necessitated by the lack of appropriate HT components capable of buffering a broadband signal generated by the DAC.
- Lack of SPICE Models for HT components caused much longer development time for the line driver as there was no good way to explore the design space and each design had to be built and tested.
- Funding gaps and personnel turnover caused the project to run longer than expected. The project is continuing from a transfer of funding from another project.

8. Conclusion and Plans for the Future

We have developed a prototype HTHS data link system which is capable of transmitting >1Mbps over 5000ft of single-conductor wireline. Preliminary testing showed that the system will be able to adapt to wirelines of different lengths and qualities. For the remainder of FY18 we are planning to focus on the adaption of the protocol onto a high temperature processing device and the integration of the hardware into a single HT prototype. In addition we are hoping to find a suitable partner which will be interested in using our HTHS data link in the field.

9. DOE Geothermal Data Repository

- Preliminary performance of HT datalink
- Designs and documentation of developments

10. Other Dissemination of Research

- Describe any communication, press, outreach, or collaborations that have come from this project.

11. Publications and Presentations, Intellectual Property (IP), Licenses, etc.

- Article publication and presentation at the High Temperature Electronics Network (Cambridge, UK), 2017
- Sandia National Laboratories Technical Advance filed in 2017