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A High Speed, High Temperature Datalink for Geothermal Applications

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ABSTRACT

Many phases in the construction of a geothermal well or engineered reservoir are enhanced through the use of tools that provide real time data feedback. Drilling diagnostic tools, seismic monitoring tools, and televiewers are among the tools that can provide this type of feedback. In order to achieve their full potential, these tools require communication rates over 500 kbps along 15,000 feet of single conductor wireline. However, current high temperature wireline communication techniques prevent tools from transmitting at these rates. For example, Sandia's high temperature televiewer is limited to less than 11 kbps over 15,000 feet of single conductor wireline. In addition, Sandia's recently developed high temperature seismic tool can transmit at 200 kpbs, but only over multiconductor cables less than 5,000 feet in length. Sandia, in collaboration with Harvey Mudd College, has shown that data rates can be increased by a factor of two with minimal modification to current high temperature downhole electronics.

Traditional techniques to increase wireline communication speeds include advanced digital signaling and/or modulation schemes that are difficult to implement with high temperature electronics. Therefore, this new high speed communication system places the majority of the computational burden on the uphole receiver, which can be designed around state-of-the-art electronics. The uphole receiver utilizes a combination of equalization to overcome distortion caused by the wireline and correlation to recover corrupted data to achieve a demonstrated data rate exceeding 400 kbps. This method has the advantage of working over industry standard single conductor wireline with existing high temperature tools. Communication speed can be easily modified for a given application by changing a single crystal oscillator in the downhole electronics.

This paper includes details on the methodology of the developed high speed datalink. Design details for both the uphole and the downhole electronics are discussed. Lab tests demonstrating reliable operation up to 400 kbps are also presented.

Downhole Data Transmission

The goal of this project is to increase the communication rates from high temperature downhole tools to 500 kbps over single conductor wireline. Data transmission schemes from Sandia's high temperature tools have typically been limited in their capability for two main reasons. First, the lack of high temperature, high density field programmable gate arrays (FPGAs) limits the complexity of the digital signaling used to transmit data to the surface. Second, the desire to utilize single conductor wireline in as many situations as possible in order to minimize cable costs requires an encoding scheme that contains the clock and data in the same signal.

For these reasons, Sandia's high temperature tools, utilize Manchester encoding, which can be seen in Figure 1, to transmit sensor data to the surface. The digital zeros and ones are represented by either a high-to-low or low-to-high transition in the middle of each bit period. The downhole electronics create the Manchester signal through a simple exclusive OR operation of the original data with the clock, which requires minimal hardware usage in a FPGA. In addition, because there is a guaranteed transition of the signal during each bit period, the clock signal can be recovered by the receiver without having to transmit it separately.

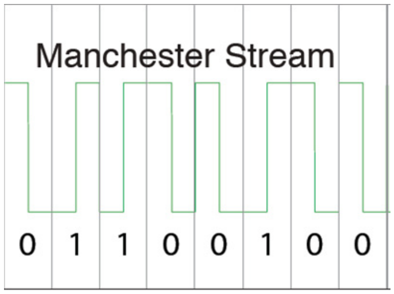

Figure 1.

Cable Characteristics

Single conductor logging cable presents a non-ideal transmission channel to the downhole electronics. Figure 2 shows a plot of magnitude and phase versus frequency for 5000 ft. of

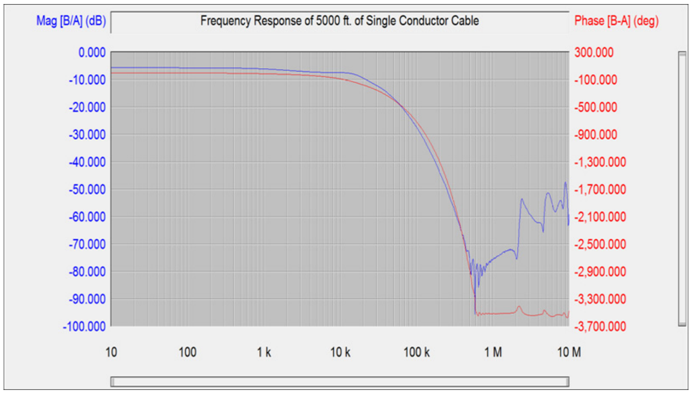

Figure 2.

single conductor logging cable. As can be seen in the plot, both magnitude and phase vary significantly as frequency is increased.

Signal distortion resulting from reduced magnitude and phase shift in the received signal can be observed in Figure 3. The received amplitude is much less than the transmitted amplitude and the varying degree of phase shift for different frequency components results in distortion of the signal. This distortion causes the loss of sharp edges that digital circuits require for proper operation. In order to overcome this distortion more complex equalization techniques must be used to recover the data.

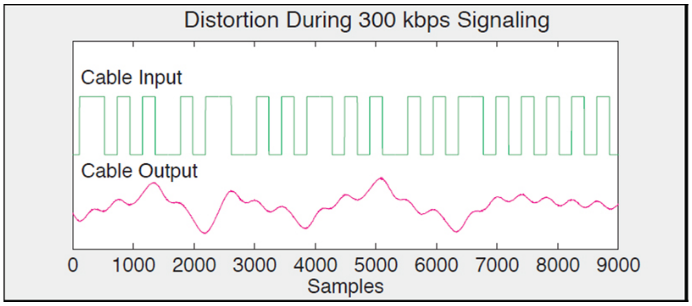

Figure 3.

Receiver Design

Utilizing an equalizer based receiver architecture to restore data signals transmitted though a logging cable has been previously demonstrated by (R.S. Sherratt, 1998). This system takes advantage of the fact that the cable can be modeled as a transfer function with a discreet number of poles. In order to reverse the effects of the cable, these poles are compensated by zeros at the same frequencies as the poles in the equalizer, which was implemented using operational amplifier circuits in the analog domain. This system was able to transmit at data rates of 100 kbps.[1]

The new system developed by Sandia and Harvey Mudd College, described below, uses a more advanced cable model and equalizer in order to reach data rates of 400 kbps, which begins to approach speeds that may allow enhanced use of televiewers and seismic tools.

A block diagram of the receiver is given in Figure 4. The transmitted signal enters the system and passes through an analog font end. This block performs three operations on the signal, all in the analog domain. First, a simple filter removes the 26 VDC bias from the data signal. Second, an amplifier increases the signal amplitude in order to utilize the full range of the analog-to-digital converter. The amplifier is implemented using an Analog Devices ADRF6510, which also performs an anti-alias filtering operation on the data. Finally, the analog front end samples the signal using an Analog Devices AD9254 14-bit, 150 MSPS analog-to-digital converter.

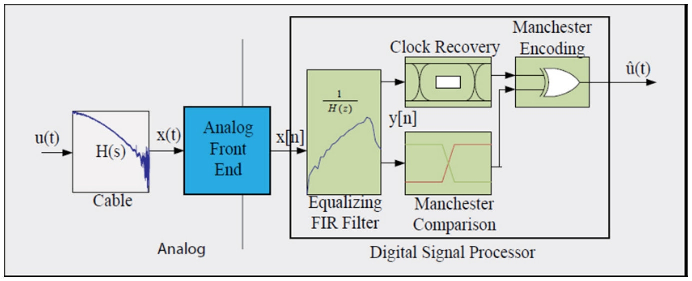

Figure 4.

Once the signal has been transferred into the digital domain it passes into the digital signal processor block that performs equalization and clock and data recovery. All of these functions are realized using a single Altera Cyclone III FPGA.

The equalizer is implemented using a 720 tap finite impulse response filter to invert the response of the cable and undo the effects of distortion. Filter coefficients are generated for a given cable through a pre-processing operation. The system measures a cable's frequency response using a pseudorandom bit sequence as an input. Then, through a series of MATLAB operations generates the filter coefficients to be loaded into the FPGA. A plot showing the input and output of the equalizer is shown in Figure 5. Note that the equalizer cannot recreate the sharp edges of the cable input signal, but does recreate the high-to-low and low-to-high transitions necessary for recovery of the original signal.

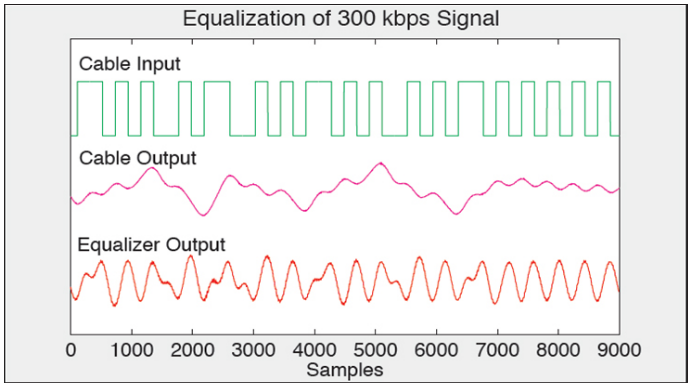

Figure 5.

After the signal passes through the equalizer it enters into the clock and data recovery module. The data recovery is performed through a correlation receiver that correlates the signal during each bit period with both a high-to-low and low-to-high reference signal. The receiver assigns either a zero or a one to the bit based on the higher correlation value. A phase locked loop takes a reference clock running at the system data rate together with the recovered data to synchronize the output clock and data. A correlator output plot is shown in Figure 6.

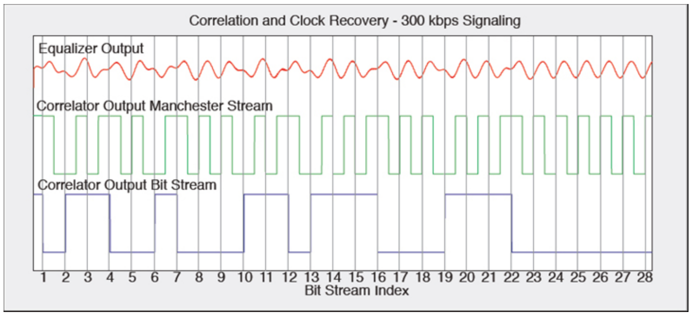

Figure 6.

Test Results

The uphole receiver system was tested over 5000 ft. of single conductor logging cable with a 10-bit pseudorandom bit sequence used as the data input. Equalizer filter coefficients were generated for data rates of 100 kbps, 200 kbps, 300 kbps, and 400 kpbs. Once the coefficients were generated, the digital signal processing code was complied and loaded onto the FPGA. The system was then run at each data rate for multiple hours. Bit error rates were measured using a custom built bit error checker in the FPGA. As can be seen in Figure 7, the system exhibits low bit error rates for data rates up to 400 kpbs.

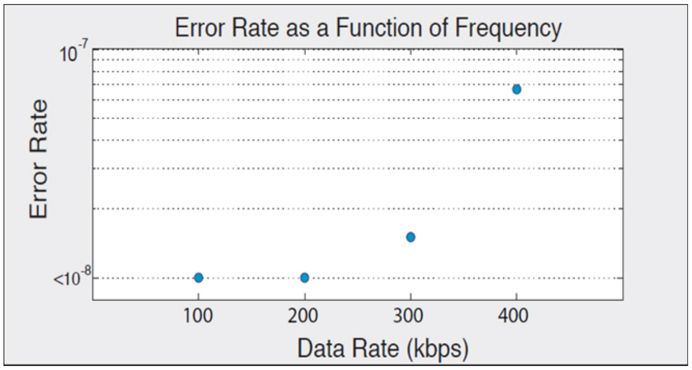

Figure 7.

Conclusions

An uphole receiver capable of interfacing with industry standard single conductor logging cable has been designed and demonstrated. This receiver is designed to optimize the data received from Sandia's standard high temperature data encoding scheme. Testing has shown that the system is currently capable of operating with sufficiently low bit error rates at speeds up to 400 kpbs, which is two times faster than current Sandia receiver systems. With modifications to the equalizer filter length data rates up to 600 kbps can be expected.

References

Sherratt, R. (1998). Using Modeling Tools to Optimise the Calculation and Subsequent Reduction of Cable Distortion Parameters with Application to Oil Well Logging Systems. *The Use of Systems Analysis and Modelling Tools: Experiences and Applications (Ref. No. 1998/413), IEE Colloquium on* (pp. 13/1-13/6). IEE.

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