Deeper, Smarter EM Drilling Technology

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For a number of reasons, primarily noise immunity and signal sensitivity, current electromagnetic telemetry systems are limited by operational depth and geological formation characteristics.

Recent developments in computational power and advanced computer algorithm techniques have produced data fusion technologies that can be employed to create rugged, commercially viable telemetry systems for energy exploration. Electromagnetic (EM) telemetry provides an ideal application area for data fusion methods. Recent testing of a newly developed system has demonstrated that information from multiple independent sources can be fused, in real-time, resulting in a marked increase in the ability to reject ambient environmental noise while extending operational capabilities.

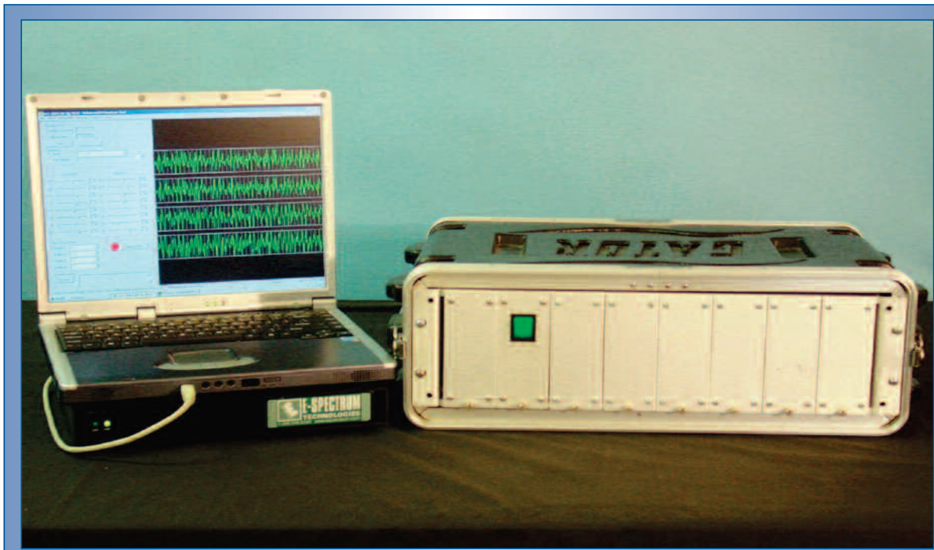

Figure 1. Data fusion receiver hardware platform

Data fusion for EM telemetry

To facilitate the development of high-tech drilling tools that will provide access to increasingly deeper energy resources, the U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory's Deep Trek project has collaborated with San Antonio, Texas-based E-Spectrum Technologies Inc. to develop an innovative two-way EM telemetry system for energy exploration applications. Based on the culmination of 3 years of research and development in the area of advanced EM telemetry communications, E-Spectrum has successfully tested the system in test wells and operational drilling environments with successful results. This data fusion-based EM telemetry system provides an EM tool capability that can benefit onshore and offshore oil and gas exploration operations for conventional and underbalanced drilling applications.

A key element of the new design is a data-fusion receiver, which enhances the system's ability to extract weak telemetry signals originating thousands of feet below the earth's surface. This data-fusion receiver adapts technologies used for interplanetary deep space navigation and missile guidance systems and makes them work in energy exploration applications. Every element of the system's design, from power efficiency to reliability, has been optimized to extend operational depth and improve noise immunity. The data fusion receiver apparatus and algorithms are patent-pending with awards anticipated during the second quarter this year.

Data fusion system development

The data fusion receiver is a key element of the EM telemetry system, with much of the system development focused on perfecting this new technology. Development efforts consisted of two fundamental areas: the development and tuning of the data fusion computer algorithms, and the design and construction of the data fusion receiver hardware platform.

The objective of the data fusion computer algorithm development was to generate and validate a set of innovative signal-processing algorithms that maximize the noise rejection capabilities of a high-sensitivity subterranean communications receiver. Within the context of the energy exploration market, developing a methodology that increases a subterranean telemetry receiver's noise rejection capability works to improve the signal-to-noise ratio resulting in a receiver capable of recovering the extremely weak electromagnetic field signals associated with deep drilling telemetry applications.

The data fusion receiver hardware platform was designed to maximize electronic signal

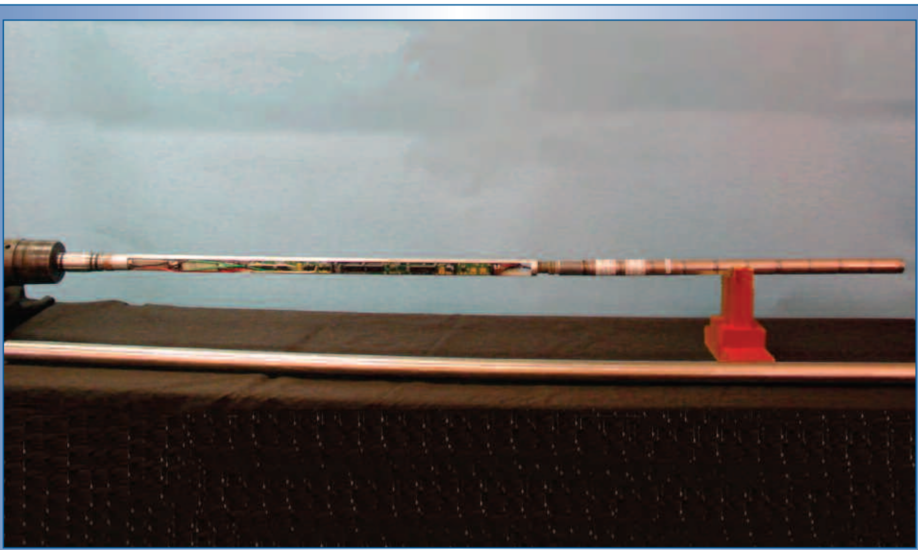

Figure 2. Downhole tool power amplifier and receiver assembly

sensitivity, employing techniques adopted from biomedical sensing devices. It also was critical the data fusion receiver be computationally efficient, rugged and compact to satisfy the requirements of the oil and gas market.

The receiver platform (Figure 1) developed during the Deep Trek project consists of two primary components: an ultra low-noise signal conditioning unit and a Windows-based notebook computer.

The ultra-low noise signal-conditioning unit accommodates up to four electric-field signal channels and up to 12 magnetic-field signal channels for a total of 16 real-time receive-input channels.

A Windows-based, personal computer-architecture computer provides an industry standard platform for digitizing the incoming signal channel. It also provides the run-time processing platform for the data fusion and demodulation engines. The computer also hosts the data fusion receiver's graphical user interface (GUI) application, the primary function of which is to provide the operator-interface for display of the data received from the downhole tool. This data can be real-time information from the tool sensors, such as tool-face information for measurement-while-drilling (MWD) applications; or diagnostic information about the "health" of the tool, such as battery voltages and gap antenna impedance. The GUI application also allows the operator to format downlink commands to the downhole tool to configure the tool for telemetry uplinks or query it for real-time health/diagnostic information. Additional GUI functionality includes the ability to display multiple incoming/receive antenna waveforms, allowing the operator to select any four of the 16 incoming waveforms for real-time display.

The data fusion receiver application also allows the user to save the incoming real-time waveform data to the hard drive to facilitate post-processing analysis of the raw temporal-waveform data. The receiver application also keeps an electronic log of all uplinks received from the tool and all downlinks sent to the tool. This log is time stamped and can be used to facilitate the post-processing of the raw waveform data archived to the hard drive.

High-efficiency PA development

The high-efficiency power amplifier (PA) employs a robust architecture to provide increased power-delivery efficiency in a compact, rugged mechanical package. Increasing transmission efficiency results in a greater transfer of available energy from the transmitter's principal power source to the transmission media. The maximization of energy transfer is especially critical downhole, where the transmitter's principal power source is typically a battery. Efficient coupling of magnetic field energy into the low impedance transmission media present at the PA transmitting antenna results in a maximum amount of field energy remaining at the receive antenna after transit through the earth's strata. Increased field energy at the receive antenna equates to increased recoverable signal amplitude; thus, the overall receiver signal-to-noise ratio is improved resulting in increased operational depth capability.

Two separate high-efficiency PA systems have been developed: a downhole tool power amplifier and a surface power amplifier. The downhole tool PA is compact, rugged and uses a solid-state switched-output driver circuit topology to efficiently convert battery-stored energy into magnetic field energy. For maximum operational flexibility, the downhole PA can be reconfigured while deployed in-hole via a two-way, EM-based, communications link to the surface. Additionally, the downhole tool PA electronic-assembly was sized to fit in a 1¼-in. inside diameter (max) pressure vessel to allow integration into a working drillstring.

The downhole tool PA and receiver assembly consists of printed circuit boards mounted in a rigid backbone. Each circuit board is designed to utilize SOIC components provided by Honeywell. The components are designed for extended temperature range operation to 225°C and are provided in thru-hole style integrated circuit packages.

The power source for the downhole electronic assembly consists of a battery pack constructed from a series of high-temperature (200°C), lithium-thionyl-chloride batteries arranged in an axial configuration (shown in the right-hand portion of Figure 2). The battery pack is assembled with insulators between each cell to prevent shorting during drilling operations and act as mini shock absorbers to absorb vibration. The entire

PA/receiver/battery assembly is contained within a 1¼-in. ID screw-on pressure housing (shown in the foreground of Figure 2).

The downhole tool PA/receiver assembly provides the following capabilities:

- 15 W (max) delivered power: programmable via the EM downlink (eight adjustment settings);
- 2 Hz to 10 Hz adjustable uplink carrier frequency: programmable via the EM downlink (five adjustment settings);
- ability to measure received signal strength of the downlink and report via EM uplink;
- ability to measure gap-antenna impedance and report via EM uplink;
- ability to perform real-time system-health diagnostics and report status via EM uplink; and
- ability to record up to 30 minutes of time domain waveforms from the gap antenna.

The surface power amplifier (Figure 3), housed in a compact ruggedized chassis, allows downlink command-communications with the downhole tool.

Its electronics utilize the same basic solid state, switched output driver circuit topology as the downhole tool PA; however, the surface PA is capable of generating 1,000 Wrms of power to the load. In addition, the surface PA features safety interlocks so power delivery to the load is disabled if an abnormal impedance condition is sensed on the PA outputs. This interlock feature helps protect against the safety hazard caused by broken, loose or improperly connected antenna wires.

The surface PA provides an RS-232 serial communications interface to a laptop or desktop computer so information can be exchanged with the data fusion receiver. The serial communications link is used to relay the operator-downlink command packet to the PA for formatting and subsequent downlink transmission to the downhole tool. The surface PA also performs internal health/diagnostic functions such as measurement of the transmission antenna load impedance and the monitoring of various internal system-health metrics. This data is reported to the data fusion receiver GUI application via the RS-232 serial communications interface.

Field testing

Seven separate field tests have been conducted to validate the Deep Trek data fusion system. Field testing has consisted of two types of test protocols: test-well performance and field-noise recordings. The performance tests were conducted in commercial test well facilities, ranging in maximum depth from 2,000ft to 5,000ft. All test wells were completely cased and topped by fully equipped drilling-rig platforms. The casing in each well was constructed from a ferrous material (steel), which extended the entire length of the structure and strongly attenuated the electromagnetic waves broadcast from inside the bottom of the well to the surface. Testing at a depth of 4,944ft using the lowest possible downhole transmission power setting of less than 1.7 W resulted in consistent successful data transmission in the presence of strong rotational noise. Using industry developed models, this data can be extrapolated to estimate a typical functional operational depth in excess of 13,000ft in the presence of drilling noise.

A field test was conducted in February in a 9,517-ft well being drilled in North Texas. The data fusion receiver was deployed as part of the MWD telemetry support equipment for the top-drive drilling rig being used to drill the well. The receiver was able to decode EM telemetry uplinks from the bottom of the well throughout the 10 days the rig was operational. This operational profile included the successful recovery of uplinks while sliding and drilling. Test results were excellent despite portions of the well including a geological formation (the Lower Barnett) known to be unfavorable to EM transmission.

These field test results show using data fusion technology provides a measurable advantage over existing EM systems and should facilitate the development of high-tech drilling tools that will provide access to increasingly deeper energy resources. E-Spectrum Technologies is seeking industry partners to collaborate in introducing these technologies to energy exploration markets.

For more information about E-Spectrum's EM telemetry or data fusion technologies, contact Jeff Gabelmann at (210) 696-8848 ext. 238, or via email *at jgabelmann@espectech.com* ✧

Figure 3. Surface power amplifier