



Microhole Coiled Tubing Bottom Hole Assemblies Final Scientific / Technical Report

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Principal Author: Don Macune

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GE Energy

13000 Executive Dr.
Sugar Land, TX 77478
USA

832-615-4569

don.macune@ge.com

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Final Scientific and Technical Report

*Don Macune
Ultima Labs, a Sondex Company of GE Energy
Sugar Land, Texas*

Abstract

The original objective of the project, to deliver an integrated 3 1/8" diameter Measurement While Drilling (MWD) and Logging While Drilling (LWD) system for drilling small boreholes using coiled tubing drilling, has been achieved. Two prototype systems have been assembled and tested in the lab. One of the systems has been successfully tested downhole in a conventional rotary drilling environment. Development of the 3 1/8" system has also lead to development and commercialization of a slightly larger 3.5" diameter system. We are presently filling customer orders for the 3.5" system while continuing with commercialization of the 3 1/8" system. The equipment developed by this project will be offered for sale to multiple service providers around the world, enabling the more rapid expansion of both coiled tubing drilling and conventional small diameter drilling.

The project was based on the reuse of existing technology whenever possible in order to minimize development costs, time, and risks. The project was begun initially by Ultima Labs, at the time a small company (~12 employees) which had successfully developed a number of products for larger oil well service companies. In September, 2006, approximately 20 months after inception of the project, Ultima Labs was acquired by Sondex plc, a worldwide manufacturer of downhole instrumentation for cased hole and drilling applications. The acquisition provided access to proven technology for mud pulse telemetry, downhole directional and natural gamma ray measurements, and surface data acquisition and processing, as well as a global sales and support network. The acquisition accelerated commercialization through existing Sondex customers. Customer demand resulted in changes to the product specification to support hotter (150 deg. C) and deeper drilling (20,000 psi pressure) than originally proposed. The Sondex acquisition resulted in some project delays as the resistivity collar was interfaced to a different MWD system and also as the mechanical design was revised for the new pressure requirements. However, the Sondex acquisition has resulted in a more robust system, secure funding for completion of the project, and more rapid commercialization.

In October, 2007 Sondex was acquired by General Electric. This also resulted in some additional project delays as Ultima Labs was relocated to a nearby existing GE facility. GE remains fully committed to commercialization of the resulting products.

The resulting downhole system now in production consists of a mud pulser, probe-based directional and gamma sensors, and resistivity collar with multiple depths of investigation. A near bit sensor with wireless communications to the MWD/LWD system above the mud motor remains under development. The surface system consists of a mud pulse detection and depth tracking system with PC-based software for mud pulse message decoding, real time log plotting, and processing of memory data from the resistivity collar at the end of the job.

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Executive Summary

This project has resulted in the development of a 3 1/8" diameter system for measurement and logging while drilling. The system can be used for both coiled tubing drilling and conventional drilling with jointed drillpipe. Two prototypes have been built and tested in the lab. One of the prototypes has been tested successfully while drilling using jointed pipe. The 3 1/8" tools are now being actively marketed to potential customers. The 3 1/8" development has also led to the development of a slightly larger 3.5" diameter system to meet customer demand. The 3.5" system development was funded internally without DOE assistance. The 3.5" system is currently in production with first deliveries scheduled for the end of 2008.

The main subsystems are as follows, beginning at the bottom of the bottom hole assembly and moving upward:

- Near Bit Sub, including inclination, natural gamma ray, bore & annular pressure, weight on bit (WOB) & torque on bit (TOB) and shock measurements and battery. Located between the mud motor above and drill bit below. Measurement data is transmitted via a wireless telemetry link ("Short Hop") around the mud motor to the Shorthop Transceiver Sub above, and also stored in local memory.
- Short Hop Transceiver Sub. A short (<6 ft) sub located between the mud motor below and Resistivity collar above. It includes an antenna on the outer diameter, electronics, and an electrical connection in the bore to the Resistivity collar above for power and communications.
- Resistivity Collar. This collar is approximately 10 feet long and includes five antennas on the outer diameter for the propagation resistivity measurements at multiple depths of investigation and also includes most of the resistivity electronics.
- Probe-based Measurement While Drilling (MWD) directional sensors and batteries. The directional sensors and batteries for the Short Hop Transceiver Sub, Resistivity Collar, Directional Measurements, and Mud Pulser are packaged in 1.75" diameter probes located in the bore of a non-magnetic drill collar (NMDC) above the Resistivity Collar. Also present is a probe directly above the Resistivity Collar including memory for resistivity data and a communications interface to the MWD system above. The system was also tested with a 1.75" natural gamma ray probe. The natural gamma ray probe provides gamma ray data when the system is operated without the Near Bit Sub.
- Mud Pulser. The Mud Pulser is located in a short sub (< 3 ft.) directly above the NMDC housing the MWD probes. It is used to transmit data in real time via the mud column at a rate of approximately 1 bit / second.
- Surface System for Mud Pulse Decoding, Depth Tracking, Log Plotting, and Memory Data Processing.

The project was based on the reuse of existing technology whenever possible to minimize development cost, time, and effort. In the Near Bit Sub, the bore and annular pressure measurements, WOB & TOB measurements, and Short Hop telemetry system had all previously been developed and tested in larger system diameters – e.g. 6.75". The Near Bit gamma measurement was developed especially for this project. In the Resistivity collar, electronics from larger collar sizes (4.75" and 6.75") were repackaged to fit in the smaller 3.13" diameter collar. For the MWD directional sensors, mud pulser, and surface

system, existing technology from Sondex was incorporated into the system following the acquisition of Ultima Labs by Sondex. This minimized the development effort for these components.

The specification and performance goals for the product evolved over the life of the project. Initially, the goal was to minimize manufacturing cost by designing only for reduced temperatures (<125 deg. C) and pressures (<5000PSI) expected in shallow (<5000 ft.) coiled tubing drilling environments. However, initial customer demand has been for tools rated to conventional MWD / LWD tool limits: 150 deg. C and 20,000 PSI. After the acquisition of Ultima Labs by Sondex, we decided to redesign existing components for the higher pressure and temperature ratings. The primary change was to increase the pressure ratings of mechanical seals in the system. Unfortunately this led to schedule delays due to long lead times for custom mechanical components. However the resulting product will have a much broader market than the original concept and will be more reliable.

The primary challenge to completing the project was availability of design and manufacturing resources, particularly for custom machined mechanical parts. As the price of crude rose steadily over the duration of the project competition for these resources increased. Internally at Ultima Labs the project had to compete with continuing obligations to existing customers. Externally Ultima Labs was competing with other firms for access to mechanical design resources, specialty steel materials, and custom machining resources. During most of the project we were both behind schedule and under budget while waiting on resources to become available. At the end of the project we were still behind schedule but were able to complete the project with the original financial aid awarded from DOE.

Discussion

The combined Measurement While Drilling (MWD) – Logging While Drilling (LWD) system consists of the following subsystems, beginning at the bottom of the BHA:

- *Near Bit Sub.* Includes inclination, natural gamma ray, bore & annular pressure, weight on bit (WOB) & torque on bit (TOB), and shock measurements and battery.

Located between the mud motor above and drill bit below. Measurement data is transmitted via a wireless telemetry link (“Short Hop”) around the mud motor to the Short Hop Transceiver Sub above, and also stored in local memory.

- *Short Hop Transceiver Sub.* A short (<6 ft) sub located between the mud motor below and Resistivity collar above. It includes an antenna on the outer diameter, electronics, and an electrical connection in the bore to the Resistivity collar above for power and communications.

- *Resistivity Collar.* This collar is approximately 10 feet long and includes five antennas on the outer diameter for the propagation resistivity measurements at multiple depths of investigation and also includes most of the resistivity electronics.

- *Probe-based Measurement While Drilling (MWD) Directional Sensors and Batteries.*

The directional sensors and batteries for the Short hop Transceiver Sub, Resistivity Collar, Directional Measurements, and Mud Pulser are packaged in 1.75” diameter probes located in the bore of a non-magnetic drill collar (NMDC) directly above the Resistivity Collar. Also present is a Memory Probe directly above the Resistivity Collar including memory for resistivity data and a communications interface to the MWD system above. The system was also tested with a 1.75” natural gamma ray probe. The natural gamma ray probe provides gamma ray data when the system is operated without the Near Bit Sub.

- *Mud Pulser.* The Mud Pulser is located in a short sub (< 3 ft.) directly above the NMDC housing the MWD probes. It is used to transmit data in real time via the mud column at a rate of approximately 1 bit / second.

- *Surface System for Mud Pulse Decoding, Depth Tracking, Log Plotting, and Memory Data Processing.*

Development of each subsystem will be described separately.

Near Bit Sub

The Near Bit Sub is a compact, highly integrated measurement system for providing measurements at the bit. The Near Bit Sub is designed to work with any mud motor and should be as short as possible to maintain the steering behavior of the bottom hole assembly (BHA). It has a standard API 2 3/8" regular pin connection on top and box connection on bottom. Make-up length is 36".

Measurements made by the Near Bit Sub include:

- Natural Gamma Ray. Putting the sensor close to the bit optimizes the measurement for geosteering.
- Inclination. Putting this sensor close to the bit allows the directional driller to drill more accurate boreholes.
- Torque on Bit (TOB). When drilling with coiled tubing and a mud motor, all torque to the bit is delivered by the mud motor. The Near Bit Sub is the only location in the BHA where TOB can be measured directly.
- Weight on Bit (WOB). When drilling horizontal or highly directional wells a downhole WOB measurement (vs. uphole) is the only reliable method to determine actual weight on bit.
- Annular and Bore Pressure. Annular pressure is required for Managed Pressure Drilling operations, which improve recovery in depleted reservoirs. Both Bore Pressure and Annular Pressure are required for corrections to the TOB and WOB measurements.
- Shock. Shock measurements can inform the driller of drilling conditions which can damage the downhole instrumentation or result in loss of the BHA. Shock is typically most extreme at the bit.

The Near Bit sub also includes a wireless communications link ("Short Hop") to a transceiver sub above the mud motor, connected to the MWD/LWD system. The wireless link is bidirectional, allowing the Near Bit Sub to be reconfigured by the MWD system above. Data sent by the wireless link is transmitted to the surface while drilling via mud pulse telemetry. Additional data is stored in non-volatile memory in the Near Bit Sub. This memory is downloaded via a dump port at the end of the job. The Near Bit Sub also includes batteries to power the measurement and Short Hop electronics.

Status

The Near Bit Sub has not been tested downhole. It was not ready in August 2008 when we field tested the MWD and resistivity collar. Electronics and sensors for the Near Bit Sub are ready for downhole test. We are currently waiting on delivery of custom mechanical components to complete assembly and begin system testing.

Development of Near Bit Sub Components

Natural Gamma Ray Measurement: Generally either sodium iodide (NaI) crystals or Geiger Mueller (GM) tubes are used downhole while drilling for detecting natural gamma rays. Sodium iodide crystals are much more sensitive than GM tubes, but must be used with a photomultiplier tube for converting the photons resulting from scintillation in the crystal to electrical pulses which are then counted. The NaI crystal must be carefully mated to the PMT. The resulting NaI/PMT assembly can be long (8-12 in.), fragile, expensive, and have a long lead time.

Geiger Mueller tubes are short (~3" min.), rugged, inexpensive, and more available. The GM tubes yield a relative large electrical pulse output directly (without a photomultiplier) which can be counted with a simple comparator / counter circuit. The disadvantage to the GM tubes is that they are much less sensitive than the NaI/PMT combination. Typically an array of GM tubes is required to achieve the same count rate as a single NaI crystal.

As the Near Bit Sub needed to be short and also be able to withstand a very high level of shock and vibration just behind the bit, we decided to use an array of GM tubes. Eight GM tube are mounted in a "Gatling Gun" arrangement around the bore of the Near Bit Sub. The total length of the GM tube array is three inches.

The GM tubes require a 700V power supply. Also, the GM pulse output must be converted to a logic level prior to counting. The 700V power supply and pulse processing circuitry are located on a single printed circuit board 2" wide x 5" long. The same board also includes a DC-DC converter to convert the battery voltage to lower voltages required by the remainder of the Near Bit Sub circuitry. Pulses are counted

using a microcontroller with eight separate pulse counting inputs. Using separate inputs allows a bad GM tube to be easily recognized and identified. Also, separate counting will allow for azimuthal gamma ray measurements under favorable conditions.

Azimuthal capability is not currently supported but could be added in the future via a firmware upgrade. The GM electronics and GM array have been tested in the lab to 150 deg. C. The electronics and sensor array are ready for field test.

Inclination: Inclination is measured downhole using either a single accelerometer or an array of three accelerometers. Three accelerometers provide greater accuracy, especially around zero degrees inclination. Historically quartz-based accelerometers have been used for measurement while drilling. They are rugged and very accurate (+/-1mg typ.) but also large and power – hungry (180mW typ.). Silicon-based accelerometers (MEMS) have been available for the last 10-20 years. They are much smaller and use considerably less power (3.5mW typ.) but are not as accurate (+/-25mg typ.) as the quartz-based accelerometers.

Conventional MWD directional measurements using very accurate quartz-based accelerometers must support extended reach applications approaching 30,000 feet in measured depth. Extreme accuracy is required to achieve an acceptable error in geometrical placement of the well. For the Microhole borehole profiled by the DOE of less than 5000 ft. measured depth, a simple geometrical analysis shows that the same absolute error can be achieved for a 5000 ft. borehole using a less accurate sensor as can be achieved in a 30,000 ft. borehole using quartz-based accelerometers. Thus the MEMS devices appear well-suited to a reduced accuracy application. We have tested MEMS devices over temperature from two different vendors. One of the devices has been selected for the initial prototype.

Error Angle (deg.)	Error @ 5000 ft.	Error @ 25,000 ft.
.1	8.7 ft.	44 ft.
.5	44 ft.	218 ft.
1	87 ft.	436 ft.

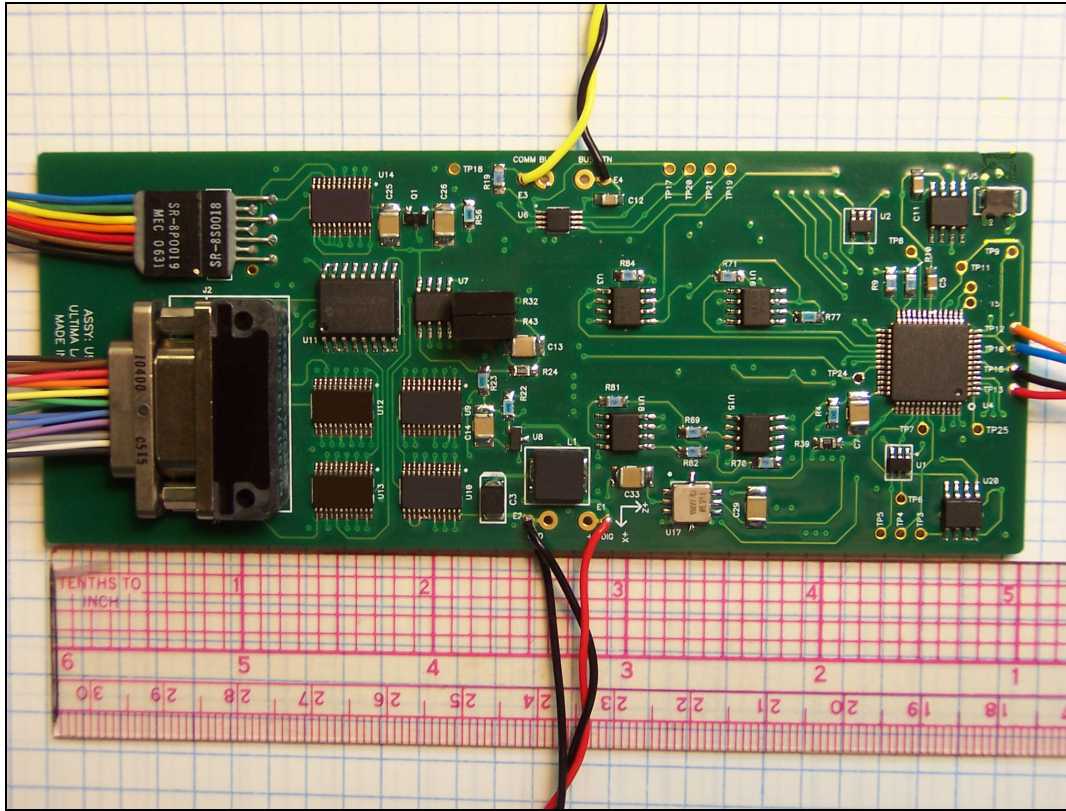
Simple Geometrical Analysis of Error vs. Measured Depth

Bore and Annular Pressure: The Bore and Annular Pressure measurements use a piezoresistive sensor accurate to within 1% of the full scale rating of 15,000PSI. Accuracy can be improved by characterizing the gauges over temperature and pressure. Electronics from an earlier downhole development were repackaged into a new printed circuit board designed to fit in the Near Bit Sub.

Weight on Bit and Torque on Bit: These measurements use foil strain gauges bonded to the load-bearing member of the Near Bit Sub. The foil gauges are connected to signal conditioning circuitry and analog to digital converters. The design is based on an earlier system used in a 6.75" collar.

Shock: A two axis shock measurement is included in the Near Bit Sub. The measurement is designed to measure peak shocks up to +/- 50g. The "raw" outputs of the accelerometers are also available for digitization and processing. The shock accelerometers are mounted on the Measurement Interface PCB. The shock data can be transmitted uphole in real time to inform the driller of harmful downhole conditions, allowing the driller to take corrective action prior to damaging the downhole equipment or losing the BHA.

Acquisition electronics for the Inclination, Bore and Annular Pressure, Weight on Bit and Torque on Bit, and Shock measurements are all located on the Near bit Measurement Interface printed circuit board, shown below.



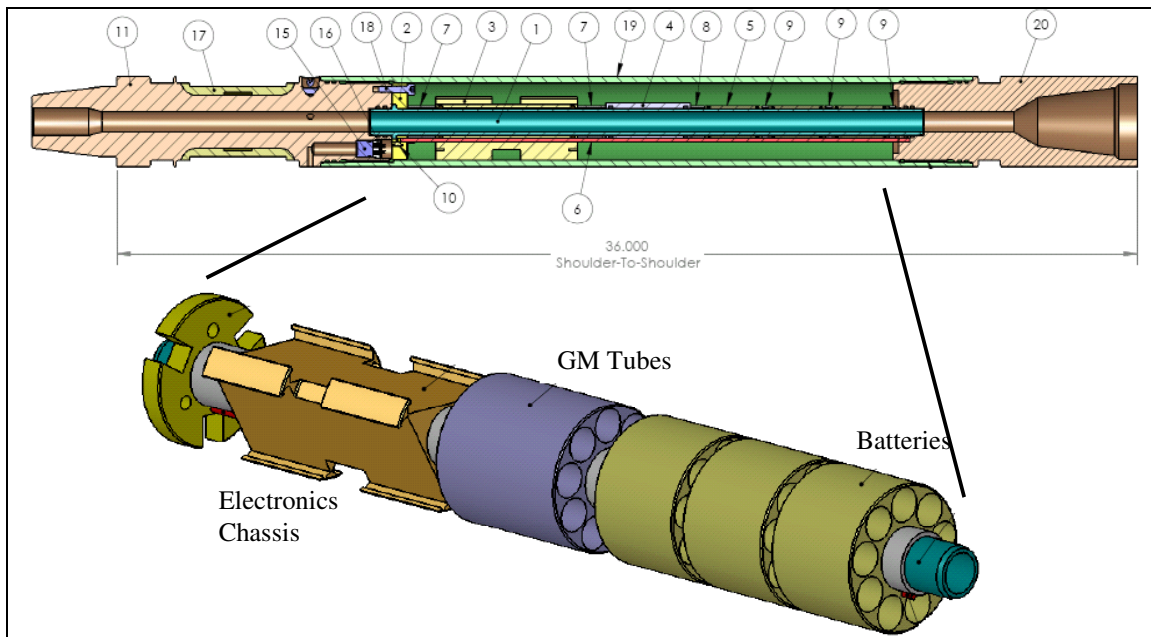
Near Bit Measurement Interface PCB (Actual Size)

Short Hop Transceiver: The Short Hop Transceiver is based on a prior design proven in a larger rotary steerable tool application. The prior design required a digital signal processor (DSP), microcontroller, and field programmable gate array (FPGA). The FPGA used in the original design is now obsolete. Also, new versions of the DSP are now available which include the functionality of the microcontroller. The Short Hop Transceiver for the Near Bit Sub was redesigned to eliminate the obsolete FPGA and microcontroller. The resulting printed circuit board is 2" x 5" long and about 25% smaller in area than the original design. The Short Hop Transceiver PCB connects to the Short Hop Antenna wound on the outer diameter of the Near Bit Sub.

The Short Hop Transceiver board also includes eight Mbytes of non-volatile memory for storing measurement data. The Near Bit Sub will acquire much more data than can be transmitted to the surface via the slow mud pulse telemetry link. All data acquired by the

Near Bit Sub will be stored in the memory and available for downloading and processing at the end of the job. Data can be accessed via a dump port in the side of the collar.

The resulting Near Bit Electronics system, include all acquisition, communications, and power supplies fits on a three board set, 2"x5" each. The three boards are mounted on a triangular chassis with a flow tube down the middle for mud flow from the surface to the bit. The boards are the Gamma / Power Supply, Measurement Interface, and Short Hop Transceiver.



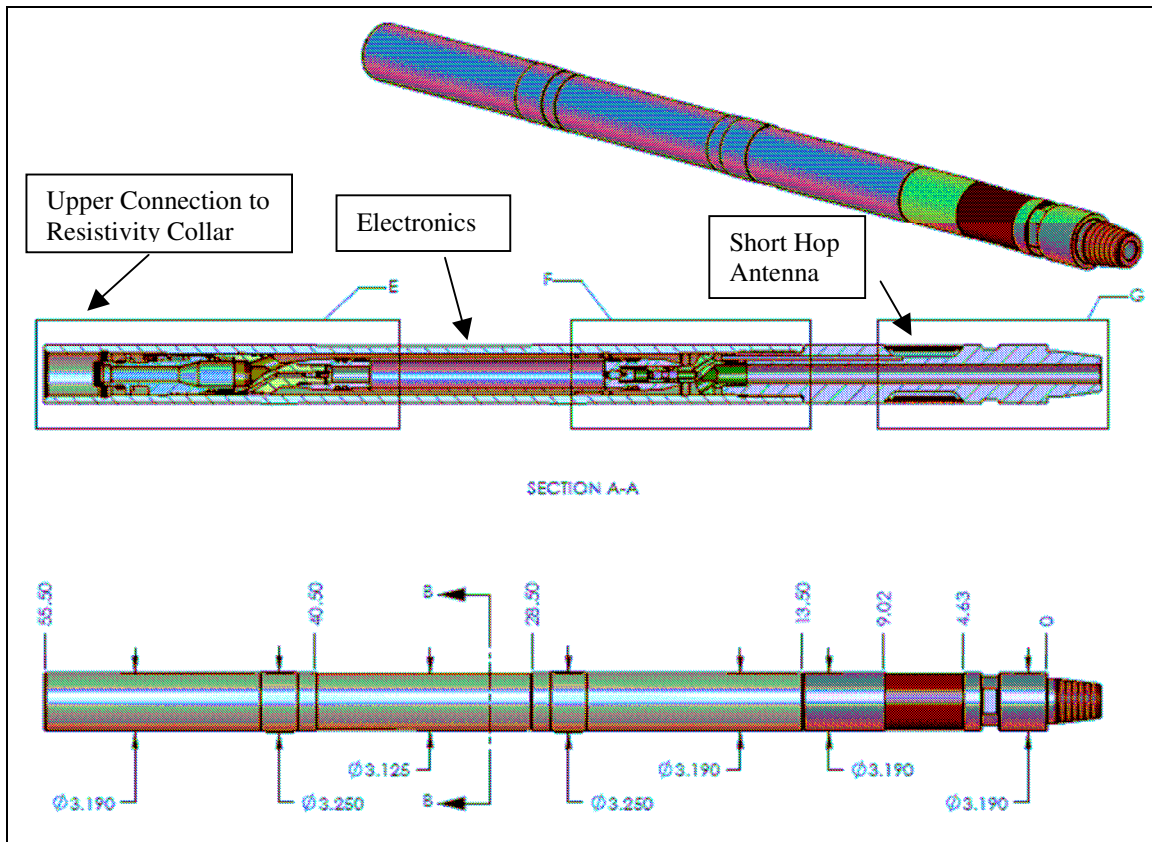
Near Bit Assembly

The Gamma / Power Supply PCB includes a microprocessor for counting the gamma pulses. The microprocessor includes a serial interface for communications. The Measurement Interface PCB also includes a microprocessor with serial communication interface. Both boards communicate via the serial communications interface to the Short Hop Transceiver. Firmware has been developed for transferring the data between boards.

Short Hop Transceiver Sub

The Short Hop Transceiver Sub is located above the top of the mud motor and attaches to the bottom of the Resistivity Collar. The sub replaces a lower saver sub used in larger

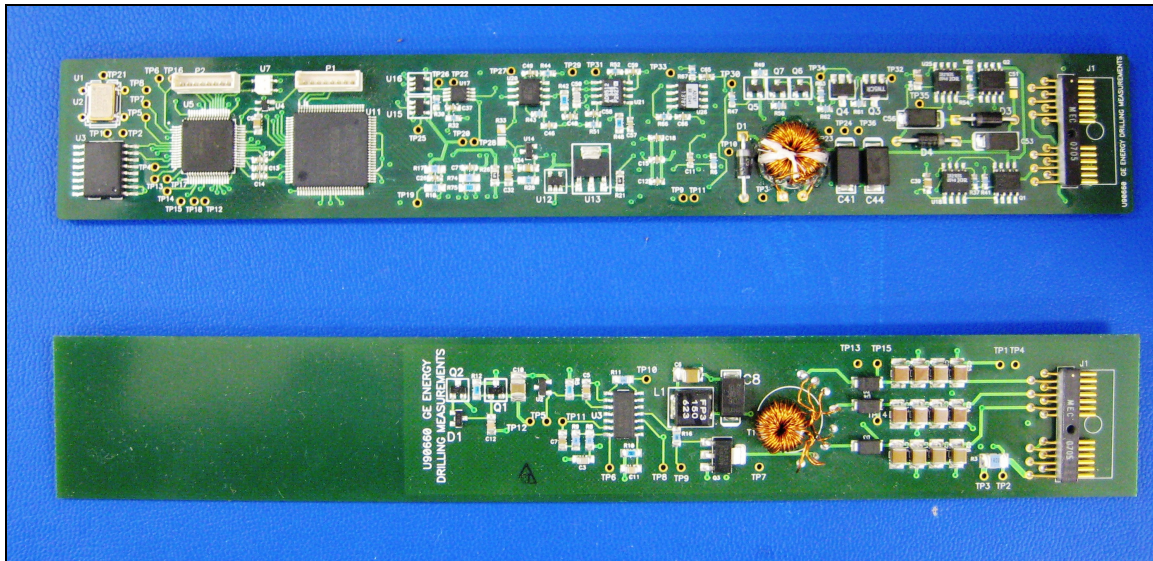
diameter tools, and includes an antenna wound on the outer diameter and electronics housed in a probe in the bore of the sub. The modular design of the lower end of the Resistivity Collar and Transceiver Sub allow the sub to be easily removed when operating the system without the Near Bit Sub, as was done on the initial field test in August, 2008.



Upper Short Hop Transceiver Sub Assembly

The electronics consists of two PCB's – a power supply and transceiver PCB. The Transceiver PCB for the Short Hop Sub is very similar to the Transceiver PCB for the Near Bit Sub, except for the form factor. Both PCB's in the upper sub are 1.2 wide x 8" long. Power is supplied to the Transceiver Sub from the lower end of the Resistivity Collar. The Transceiver Sub and Resistivity Collar share power from batteries in probes above.

The Transceiver PCB communicates with the Memory Probe via a single wire multi-drop serial communications bus shared with the Resistivity electronics. Data received from the Near Bit Sub is transferred to the Memory Probe. There it is either passed on to the MWD system for transmission to the surface via mud pulse telemetry or stored in memory.



Short Hop Transceiver Sub Electronics

Status

Electronics for the Short Hop Transceiver Sub have been built and tested in the lab. We are still waiting on long lead time custom mechanical parts to complete the assembly.

Resistivity Collar

The Resistivity Collar uses the same antenna array spacing as 4.75" and 6.75" collars developed and commercialized by Ultima Labs. The array provides compensated resistivity measurements from three different transmitter-receiver spacings: 18", 27", and 36". Operating at two frequencies (400KHz and 2MHz) and using both phase difference and attenuation measurements, 12 different compensated resistivity measurements are available. The patented array and compensation method eliminates three antennas and reduces the length of the array by >40% when compared to the most widely used compensation method.

Status

Two Resistivity Collars have been built and tested in the lab. Both collars were deployed on a field test at the Gas Technology Institute Catoosa Drilling Test Facility outside of Tulsa, OK in August, 2008. One of the collars was tested downhole successfully, providing both real time data while drilling and memory data after the job.

Based on initial success of the 3 1/8" Resistivity Collar development, a slightly larger 3.5" version has been designed and is now in production. The 3.5" collar uses the same electronics and mechanical concepts as the 3 1/8" collar. The 3.5" collar allows for greater mud flow and additional strength for drilling slightly larger hole sizes used by the customer.

Development of the Resistivity Collar

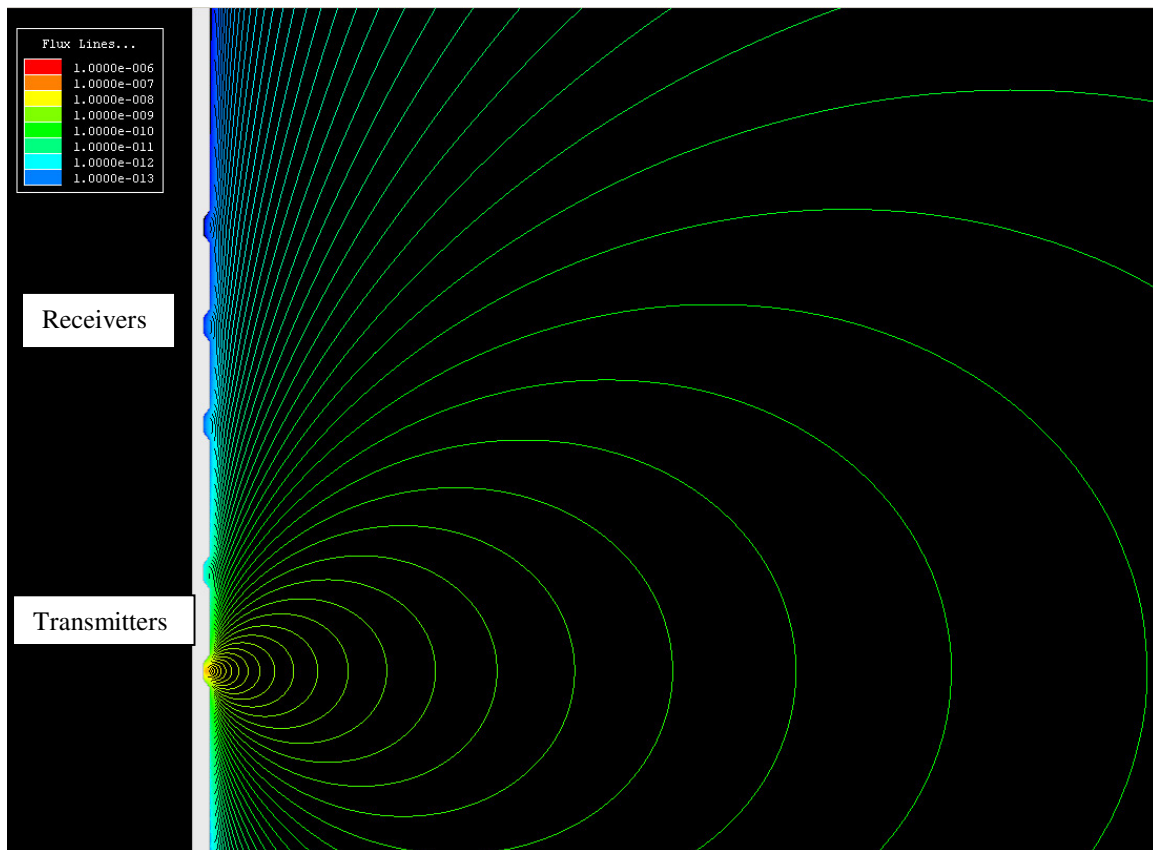
The main challenges in downsizing from existing 4.75" and 6.75" designs to the 3 1/8" size were design of the antennas and packaging of the electronics.

Antennas & Electromagnetic Modeling: As the diameter of the antennas is reduced from larger diameters the efficiency of the antennas decreases. Efficiency for a transmitter / receiver pair is determined in part by the ratio of receiver voltage to transmitter current. This ratio is called transimpedance, since the resulting units are $V/I = Z$ (ohms). The receiver voltage must be well above the thermal noise of the system over the resistivity range of interest to generate a usable measurement. The receiver voltage increases with the transmitter current. However, transmitter current is limited by capacity of the batteries and temperature rise in the transmitter electronics.

Antennas for propagation resistivity measurements are formed by wrapping a coil of wire around an insulating material mounted around the outer diameter of the collar. The antenna efficiency is determined in part by the electromagnetic area of the antenna coils. This area is determined by the cross section of the insulating material. The area can be increased by removing more of the collar material and making the insulating area thicker. However, this reduces the strength of the collar - there is a tradeoff between antenna

efficiency and collar strength. The antenna designer and mechanical designer must negotiate a compromise between antenna efficiency and collar strength.

Electromagnetic modeling was used to determine the expected transimpedance of the final compromise prior to machining the collar and building the first prototypes. This minimized design risk and eliminated the need to build and test prototypes solely to verify the antenna performance.



Electromagnetic Model of Two Transmitters and Three Receivers

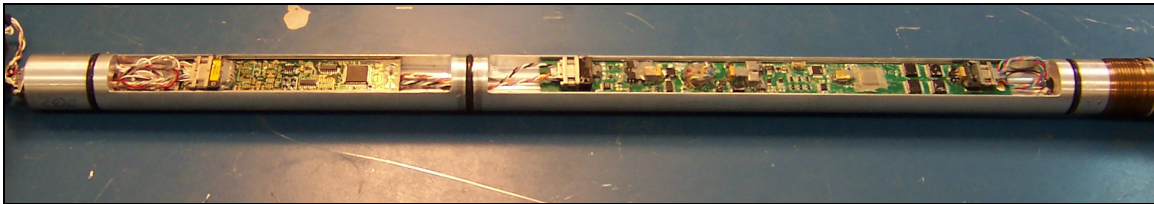
Electronics: In the larger tool sizes the electronics for the resistivity measurement consists of nine different printed circuit boards. All nine boards are mounted in the same collar with the antennas, leaving additional room for an optional gamma sensor. There are four boards at the bottom of the larger collars for the receiver measurements, each 5.5" long, and five boards at the top for the transmitter, signal processing, memory, and

communications interface to the MWD system above. The boards at the top are 12" long, except for the communications interface measuring 6" long.

After shrinking the collar to 3 1/8" dia. there is only room for six printed circuit boards in the collar. At the bottom, the four 5.5" long boards for the receivers were combined into three 12" long boards. At the top, the 12" long Memory PCB and shorter Communications Interface PCB were relocated to the 1.75" diameter Memory Probe in the bore of a non-magnetic drill collar above the Resistivity Collar, with the remainder of the probe-based MWD system. For the Transmitter Electronics, two 12" long boards were redesigned to work more efficiently and also provide power for the remainder of the collar-based electronics. The Acquisition PCB was modified to include a temperature sensor which had previously been on the Memory PCB.

Memory Probe

As discussed in the prior section, two circuit boards housed in the Resistivity Collar in larger tool sizes were relocated to a 1.75" diameter probe located immediately above the resistivity collar. The Memory Probe now houses the Memory PCB and Communications Interface PCB. The same Memory Probe is used with both 3 1/8" and 3.5" Resistivity Collars.



Memory Probe Electronics Installed in Chassis

Status

Two Memory Probes have been built and tested in the lab. Both probes were deployed on a field test at the Gas Technology Institute Catoosa Drilling Test Facility outside of Tulsa, OK in August, 2008. One of the Memory Probes was tested downhole

successfully with the Resistivity Collar, providing both real time data while drilling and memory data after the job.

Based on results of the lab testing and assembly of the first two units, the hardware used for mounting the printed circuit boards to the chassis is in revision. The connection between the bottom of the Memory Probe and top of the CPR Collar is being revised to allow easier assembly of the BHA at the rig. Six additional units based on the revised design are planned for assembly prior to the end of 2008. These units will be shipped with 3.5" Resistivity Collars.

Development of the Memory Probe and Memory Probe Electronics

Moving the Memory PCB into a probe above the Resistivity Collar required some changes to the distribution and control of power to the Resistivity electronics. In larger collar sizes the Memory PCB provides power to the Receiver and Acquisition electronics via a DC-DC converter which converts the battery voltage to lower voltages required by the electronics. This requires a large number of interconnects from the Memory PCB to the Receiver and Acquisition electronics. To simplify the mechanical interface between probe and collar, these low voltage interconnects were eliminated. The lower voltages for the Receiver and Acquisition electronics are now provided by a DC-DC converter on a different circuit board in the collar. The DC-DC converter is powered from the battery voltage, which is controlled by a switch on the Memory PCB. The switch allows the Resistivity Collar and Short Hop Transceiver Sub to both be powered down when not needed. The resulting interface between Memory Probe and Resistivity Collar is only three signals: Power (switched battery voltage), Communications (single wire multi-drop master / slave protocol) and Ground.

Downsizing of the existing larger collar design to 3 1/8" and 3.5" diameter also required redesign of the electronic hardware and firmware used to communicate and download memory data from the tool. The larger tool sizes use a 10 pin pressure bulkhead mounted in the side of the collar between the transmitter and receiver antennas. At the surface the field engineer plugs into the pressure bulkhead ("dump port") with a cable connected to the surface interface box to configure tool parameters prior to the job and download the

memory data after the job. The existing 10 pin pressure bulkhead is approximately 1” in diameter – far too large to be used in a 3” diameter collar. A smaller pressure bulkhead is required.

To support the use of a smaller bulkhead the signal count required for communicating with the tool was reduced from seven to one. This allowed the use of a three pin bulkhead at the dump port of approximately 0.35” diameter.

At the same time the signal count was reduced, the effective data rate for memory dumping was increased by approximately 10X. Previously about 40 minutes were required to download a full 16Mbyte data set. With the new protocol the dump time is reduced to about 4 minutes. This represents a significant savings in rig time.

During redesign to minimize the communications signal count and increase the memory data transfer rate, we also converted the digital system (microcontroller, flash memory, and interface IC’s) from +5V parts to +3.3V parts. The +5V parts are becoming obsolete.

Another function of the Memory PCB is battery switching. To achieve 250+ hours of battery capacity, two stacks of 10 “DD” lithium batteries are required. To maximize battery utilization, the two stacks are wired separately and connected to a battery switch on the Memory PCB. The purpose of the battery switch is to insure that the first stack is almost fully depleted before the second stack is enabled. If the job lasts less than ~125 hours, the second stack is not used at all. Also if the job is expected to last less than 250 hours, a partially depleted stack can be installed as the primary stack and fully depleted prior to switching in the second pack. In this way partially depleted packs can be fully utilized prior to disposal. The Battery Switch circuitry was reused from the larger collar electronics.

No change was required to the Communications Interface PCB previously used in larger tool sizes.

Battery Probes for Resistivity Collar and Upper Short Hop Transceiver Sub

After the acquisition of Ultima Labs by Sondex in September, 2006 we decided to adapt existing 1.75" dia. probes used for batteries in the Sondex Measurement While Drilling system to power the Resistivity Collar, Memory Probe, and optional Upper Short Hop Transceiver Sub. The Sondex MWD system requires +/-17V system power supplied by two stacks of 5 "D" or "DD" lithium cells providing approximately 3.4V / cell. The Resistivity electronics require a single +34V supply voltage. Only a simple change to the harness was required to convert the existing probes from +/-17V to +34V.

A single battery probe contains a pack of 5 "DD" cells. At least two battery probes are required to power the Resistivity Collar and Memory Probe. Two battery probes provide about 125 hours of operation. Two additional battery probes can be added to achieve 250 hours of operation. The +34V output voltages of each pair of battery probes is connected separately to the input of the Battery Switch on the Memory PCB in the Memory Probe (see discussion of the Battery Switch above).

Status

We purchased four battery probes at cost from Sondex for the field testing with the Resistivity Collars. These were used during the August 2008 Field Test.

Measurement While Drilling (MWD) Subsystem

After the acquisition of Ultima Labs by Sondex in September, 2006 we decided to adapt the existing 1.75" diameter MWD system already available from Sondex. The MWD system includes standard directional measurements using high accuracy quartz-based accelerometers for inclination and magnetometers for azimuth and a separate battery probe. Also included is a telescoping housing which adjusts the length of the probe-based MWD subsystem to match the length of the non-magnetic drill collar and also allows the probes to be more easily connected to the top of the Resistivity Collar during make up on the rig floor. No additional design engineering was required, as larger size Resistivity Collars had already been interfaced and tested with the MWD system.

The MWD system also includes a Gamma probe option. The Gamma probe uses an industry-standard sodium iodide crystal with photomultiplier. When operated without the optional Near Bit Sub with Gamma, the conventional Gamma probe is installed directly above the Memory Probe for the Resistivity Collar. The Gamma probe includes through wiring for the battery voltages to the Memory Probe.

The Directional Probe controls the communications bus to the Memory Probe and optional Gamma probe below. It queries the Memory Probe and Gamma Probe when data is to be sent to the surface via the mud pulser. The Directional Probe translates the data received over the communications bus to the pulse sequence used for the Mud Pulser. Prior to the job, the user specifies which Resistivity data is to be sent in real time and specifies the message formats for Resistivity, Gamma, and Directional data.

Firmware in both the Directional Probe and Memory Probe for communication between the two had previously been developed for larger collar sizes and was used without modification.

Status

Two Directional Probes and two Telescoping Housings have been procured at cost from Sondex. These were used during the August 2008 Field Test.

Mud Pulser

After the acquisition of Ultima Labs by Sondex in September, 2006 we decided to adapt the existing 3.13" Mud Pulser already available from Sondex. The Mud Pulser shares the same battery as the Directional Probe. It generates a positive mud pulse to transmit data.

Status

Two 3 1/8" Mud Pulsers and associated electronics have been procured at cost from Sondex. These were used during the August 2008 Field Test.



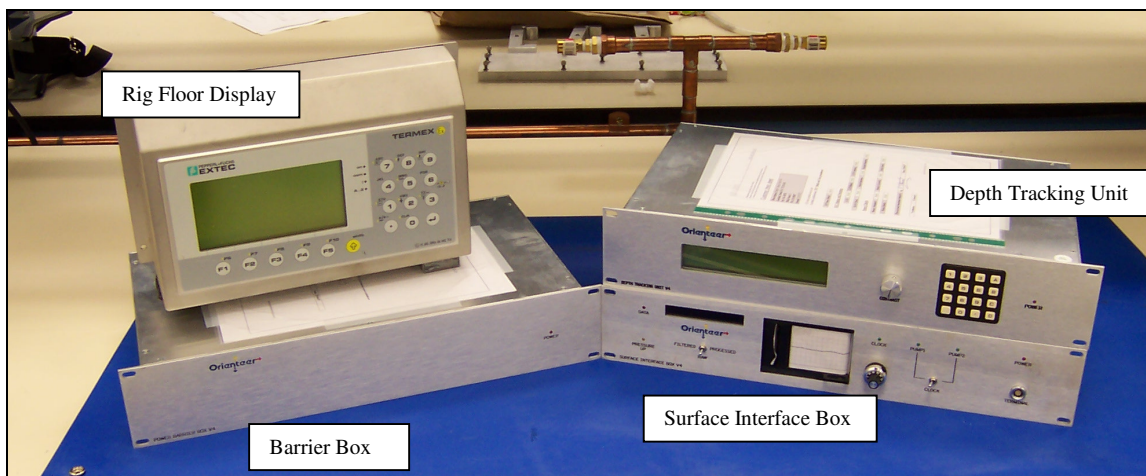
MWD, Gamma, and Memory Probes shown in Order of Assembly. Mud Pulser is on top, Memory Probe is on bottom.

Surface System

After the acquisition of Ultima Labs by Sondex in September, 2006 we decided to adapt the existing Surface System already available from Sondex. The Surface System includes pressure transducers and signal processing for decoding the mud pulse waveform and also transducers for tracking bit depth. The system includes a laptop computer running software for plotting a log in real time of the mud pulse data.

Status

Two Surface Systems have been procured at cost from Sondex. These were used during the August 2008 Field Test.



Surface System

Field Test Results

The project received a final extension in November, 2007. The final extension included a requirement for field test. Project delays were due primarily to delivery of custom machined parts – in particular the Resistivity Collar. We received delivery of the first Resistivity Collar in March 2008 and began final assembly and test.

Two Resistivity Collars, Memory Probes, and MWD systems were ready for field test in August, 2008. At that time, we were still waiting on mechanical components for the Near Bit Sub and Upper Short Hop Transceiver Sub. As we were proceeding rapidly with commercialization of the Resistivity Collar, we decided to field test the Resistivity Collar / MWD combination without the Near Bit Sub and Upper Short Hop Transceiver Sub. We added a Gamma Probe (borrowed from the Sondex Engineering Group in Aberdeen) to the MWD system to replace the Gamma measurement in the Near Bit Sub. (The 3.5” Resistivity Collars have been sold in this configuration.)

We reserved the last week of August for testing at the Gas Technology Institute Catoosa Drilling Test Facility (<http://www.gtcatooosa.com/>) outside of Tulsa, OK. The Catoosa facility is well suited for testing the 3 1/8” BHA. There are numerous existing boreholes with both directional data and openhole formation evaluation data to compare. The facility has both large and small drilling rigs and an experienced crew.

The goals for the test were as follows:

- Make up the BHA on location using typical rig equipment and verify recommended make-up procedures and equipment.
- Log a section of existing open hole while tripping in to the bottom. Verify performance of mud pulse telemetry system and surface system for generating a real time log. Verify resistivity measurement while tripping in.
- Drill as many hours as possible to verify mechanical integrity of BHA and also verify resistivity measurements while drilling.

We used a small truck-mounted workover rig for rotary drilling at the Catoosa facility. The workover rig has limited capability compared to a full size drilling rig but was

adequate for the task at hand. The capabilities for lifting and making up BHA's were similar to that expected at a coiled tubing drilling operation.

We selected an existing wellbore with 7" casing to 523' and 4 1/8" openhole to about 1300'. This would allow us to log several hundred feet of openhole prior to beginning drilling. Once reaching the bottom, we planned to drill until the system failed or we ran out of time. The hole was vertical at the top, deviated to about 18 deg. at about 680', and returned to near vertical (8 deg. deviation) at 1250'. Maximum dog leg severity was about 20 deg. per 100 ft between 600' and 700'. This deviation and dogleg severity would put some stress on the Resistivity Collar but significantly less than the specification limit.

For the resistivity measurement the most interesting zone is from around 1220' to 1320'. The lowest resistivities (2-3 ohmm) in the well are encountered just above 1275' and some of the highest resistivities (50-70 ohmm) are just below, with a sharp transition in between.

The drilling operation relied on a very simple mud system consisting of a small tank with two compartments for gravity segregation of solids from the return line. In this system solids are allowed to simply settle to the bottom of the tank while cleaner fluid is pumped from the top of the tank. Drilling is stopped every few hours to empty solids from the bottom of the tank.

Three development personnel from the Ultima Labs design group in Sugar Land, Texas and two field engineers from the Sondex Customer Support Group in Aberdeen, Scotland were assigned to carry out the test. The equipment and test team arrived in Tulsa on Sunday evening, August 24, 2008. A summary of each day's activities follows. Unlike a normal drilling operation, activities at the Catoosa Test Facility are limited to 12 hours / day, from 7 a.m. to 7 p.m.

Monday: Set up Surface System. Found that rotary encoder required for measuring depth would not work properly with the draw works on this particular rig. Decided to continue, using a combination of manual inputs and Depth Tracking Unit simulation

software utility to track depth. Made up BHA. Found that Probe String had to be aligned very accurately with Resistivity Collar below to make up the connection from Memory Probe to the CPR Collar. Configured MWD system to transmit four uncompensated resistivity measurements plus gamma. Directional surveys were transmitted on a “pumps on” event. Ran BHA into casing below two collars (about 60’). Performed shallow test to verify mud pulse telemetry operation. Gamma data read 0. Since the primary purpose of the test was to verify CPR operation and we did not have a spare gamma probe, we decided to continue without a working gamma probe. By the end of the working day the bit was at the bottom of casing at ~500 ft.

Tuesday: Continued tripping into hole through existing openhole section at ~180 ft./hr (3 ft./min) beginning around 500 ft. We marked the pipe in the draw works at 1 foot intervals and instructed the driller to lower the pipe at a rate of 1 foot every 20 seconds. Beginning about 750 ft. we were able to begin simulating depth using the Depth Tracking Unit simulation software utility. Log data is available from this depth to total depth of the well (TD). The drillstring was rotated at 60-80 RPM while tripping in. BHA was rotated through region of maximum dogleg severity from 600’-700’ without problem. Directional data (inclination only) and resistivity data agreed well with prior surveys and openhole logs. Azimuthal measurements were not usable due to magnetic drill collars used in the BHA. Mud pulse height occasionally degraded during the day indicating possible plugging of the mud pulser. Pulse height was restored by cleaning out the mud pit and pumping clean fluid. At the end of the day we had reached about 1200’. We picked up the BHA 60’ off the bottom of the hole to minimize the risk of getting stuck overnight.

Wednesday: Continued tripping into existing openhole at ~180 ft./hr. Reached bottom around 11a.m. and began drilling at 20-40RPM and 5000-6000 lbs Weight on Bit. Rate of penetration decreased to 5-10 ft./hr. Drilled for the remaining of the day. At end of day circulated drilling mud for ~30 minutes to return solids to surface and pulled up 120 ft. This would allow us to re-log the most interesting resistivities from 1220-1320 ft.

Thursday: Tripped in at 180 ft/hr until back on bottom ~10:00 a.m. Continued drilling. Around 16:00 ROP dropped to zero when we encountered a very hard formation known at Catoosa as ‘The Wall’. Decided to terminate drilling and pull up 60-120 ft after circulating to remove solids from hole. As outside temperatures were in the high 90’s, we decided to wait until morning to begin tripping out of BHA to avoid overheating of the rig crew.

Friday: Tripped BHA out of hole. While disassembling BHA found that Telescoping Housing of MWD system had been damaged, most like during disassembly as it had been operating properly downhole. This failure mode has been seen previously and is being addressed outside of this project. Also found that high-speed communications link for downloading resistivity data did not work. Problem traced to damaged connector in the Memory Probe. Otherwise all downhole equipment appeared in good condition.

After returning to Houston we downloaded the resistivity memory data and generated a resistivity log. The resistivity log agreed well with existing wireline data. More detailed inspection of the resistivity collar showed no unexpected wear or damage – the collar could have been used immediately for another job.

As a result of the field test, we have decided to revise the connection between Memory Probe and top of the Resistivity Collar to make the connection easier to make up while the system is hanging vertically in the draw works. This change will be incorporated into the Memory Probes and 3.5” Resistivity Collars.

We achieved all goals for the test. We were able to make up and disassemble the BHA at the rig using typical rig equipment. We generated both realtime and memory logs which agreed well with available wireline logs of the formation. We also drilled successfully with no downhole failures or significant wear to the BHA components.



Making up BHA – 1st
Day of Test. Resistivity
Collar Hanging in
Derrick.



Making up BHA
– 1st Day of Test.
Connecting
Memory Probe to
Top of Resistivity
Collar



Simple Gravity Segregation Mud System



Surface System for Depth Tracking and Mud Pulse Decoding

Commercialization Status and Plans

Since the acquisition of Ultima Labs by Sondex in September, 2006 the Sondex sales organization has been actively promoting the 3.13” Resistivity Collar and MWD system globally. Initial orders have been received for a slightly larger 3.5” Resistivity Collar and MWD system. The slightly larger system will use the same Resistivity electronics, Memory Probe, and MWD Probes as tested with the 3.13” system. The Resistivity Collar will be 3.5” in diameter and will have a larger bore to accommodate the higher mud flowrate required by the customer. The Mud Pulser will be changed to a negative-pulse type rated for the higher flow rates, also. We are presently filling orders for the 3.5” system and expect to begin deliveries prior to the end of 2008.

The 3.13” Resistivity Collar has also been displayed at the GE Energy booth at the 2008 Society of Petroleum Engineers Russian Oil and Gas Technical Conference and Exhibition, 28-30 October, 2008.