SAND2000-1680
Unlimited Release
Printed August 2000

Dewarless Logging Tool – 1st Generation

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Abstract

This report focuses on Sandia National Laboratories' effort to create high-temperature logging tools for geothermal applications without the need for heat shielding.

One of the mechanisms for failure in conventional downhole tools is temperature. They can only survive a limited number of hours in high temperature environments. For the first time since the evolution of integrated circuits, components are now commercially available that are qualified to 225° C with many continuing to work up to 300° C. These components are primarily based on Silicon-On-Insulator (SOI) technology. Sandia has developed and tested a simple data logger based on this technology that operates up to 300° C with a few limiting components operating to only 250° C without thermal protection. An actual well log to 240° C without shielding is discussed. The first prototype high-temperature tool measures pressure and temperature using a wire-line for power and communication. The tool is based around the HT83C51 microcontroller.

A brief discussion of the background and status of the High Temperature Instrumentation program at Sandia, objectives, data logger development, and future project plans are given.

This work was sponsored by the U.S. Department of Energy, Office of Geothermal Technologies.

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1 BACKGROUND AND STATUS

Unshielded logging tools that operate indefinitely at temperatures up to 300° C are becoming possible. The benefits of unshielded logging tools are reduced cost, increased reliability, reduced diameters, and increased operating time inside of the well.

The Dewar is the single highest cost item in most geothermal logging tools. In 1996, the cost of a seven-foot Dewar was approximately \$10,000.00. Eliminating the Dewar reduces costs while increasing reliability. Conventional logging tools are designed with low-temperature components. These devices are not rated for temperatures above 125° C and have limited operating time within the wellbore. Tools not returned to the surface in time are destroyed and must be replaced. Increased downhole operating time also allows the well operator to place sensors downhole for continuous measurement while altering production strategies. This can lead to a better understanding of the geothermal reservoir dynamics.

This project was initiated in FY97. At that time, a very limited number of SOI devices were available for testing. They included an operational amplifier, a digital switch, the (HT83c51) microcontroller, and accompanying 32-kbyte of memory. In order to test the microcontroller with memory, a number of non-SOI devices had to be identified and oven tested. This was accomplished using parts from Sandia's 200° C technology list. This initial effort required solving a number of testing-related technical challenges. For example, conventional electronic board materials and lead attachment methods cannot be utilized above 250° C. For development purposes, machinable ceramic substrates were utilized with laser spot-welded interconnects.

In FY98 sufficient devices existed to design and test a simple memory-based temperature tool. This tool consisted of newly available SOI devices and qualified non-SOI components. One of the shortcomings that still existed was the lack of a suitable crystal oscillator for the processor. The initial tests were performed with a clock signal for the microcontroller external to the oven. A microcontroller-based circuit operating at 300° C while measuring the external room temperature was demonstrated at the 1998 High-Temperature Electronics Conference (HiTEC), sponsored in part by Sandia and the Air Force.

Also in FY98, a high-temperature electronics workshop was held. The workshop was well attended by companies including Honeywell, Halliburton, Endevco, Maurer Engineering, and KD Components. The consensus of the workshop was that 225° C Measurement-While-Drilling (MWD) tools were possible. Problem areas were identified and incorporated into Sandia's 1999 Annual Operating Plan (AOP).

In this fiscal year, many more components were available for testing. They included a clock oscillator, 5-volt regulator, 10-volt regulator, field-effect transistors (FET), 5-volt reference, and a strain-gage based pressure transducer. The testing revealed that all components functioned well to 250° C but many suffered above this temperature. Utilizing

these components, a complete pressure/temperature downhole tool that was capable of sustained operation at 250° C was designed and field-tested in a 240° C, 12,000 foot deep geothermal well for more than 56 hours and pressures up to 5000 psi. Keeping the maximum operating temperature for the tool below 250° C allowed the use of more conventional board material and interconnects. This tool was also demonstrated in an oven operating at 240° C at the Society of Petroleum Engineers (SPE) conference.

During this fiscal year, Sandia also formed an industry advisory panel to evaluate and guide the direction of the high-temperature electronics technology. The newly formed panel is called HiTED, High-Temperature Electronics Downhole. HiTED membership presently consists of five members from industry and two university professors.

This ongoing unshielded logging tool project is evolving with the developing high-temperature industry.

2 OBJECTIVES

The objective of the high-temperature instrumentation program is twofold. The objectives are: 1) identify and assist the high-temperature-component industry in creating electronics for geothermal applications and 2) assist geothermal companies in the development of *NEW* high-temperature instruments. These new high-temperature instruments will operate at a lower cost and higher reliability without the aid of a heat-shielding Dewar.

These objectives are possible with Silicon-On-Insulator (SOI) technology. This technology was developed in part at Sandia National Labs for radiation hardened electronics used in weapon applications. SOI is now being commercially produced by Honeywell's Solid State Electronics Center (SSEC) and Allied Signal for operation at 225° C. Many of these devices continue to operate well above 225° C, several were tested to temperatures as high as 315° C, with reduced performance and shortened operational life. Tools built utilizing this technology have the capability to stay in high temperature wells for extended time without temperature-related tool failures. This capability has a high potential for greatly altering geothermal drilling and logging.

2.1 Technical Objectives

The technical objectives are listed below:

- Test and evaluate SOI devices, as they become available.
- Test and evaluate high-temperature sensors, as they become available.
- Design a pressure/temperature Dewarless downhole tool.
- Develop uphole and downhole software for the P/T tool.

- Field-test a Dewarless P/T tool.
- Form an industry advisory panel to evaluate and guide the direction of the high-temperature electronics technology program.

2.2 Expected Outcomes

The expected outcomes are summarized below:

- Cost-saving reliable high temperature tools. Although the geothermal industry views high-temperature instrumentation as critical, it is difficult to show direct cost savings. Specialized tools can provide substantial cost savings during drilling. An example of such a tool is the core-tube data logger (CTDL). This tool enables the driller to obtain valuable information about bottom hole temperatures, pressures and hole inclination without loss of rig time. The data is virtually free information that will help guide the drilling process. Utilizing this information may lead to better decisions concerning the well being drilled and the need for additional wells. It has been estimated that this type of tool could eliminate the need of one well in ten. The Sandia developed CTDL has been in high-demand and is an extremely reliable tool. Converting the CTDL to a Dewarless tool utilizing high temperature electronics is within reach.
- Stimulate the growth of the high-temperature industry by publishing test data on new high-temperature components, new high-temperature logging tool circuits, and new high-temperature packaging.
- Demonstrate that a useful Dewarless downhole tool can be designed for sustained operation at 240° C.

3 APPROACH

The Sandia approach is simple: "Adapt and expand high-temperature electronics technology to downhole applications". The aircraft industry has been providing the driving force for the commercial production of SOI circuits. The aircraft industry needs high-temperature electronic engine controllers. The components needed for electronic engine controllers are nearly identical to the components needed for a simple logging tool.

Geothermal applications will require features and components not necessary for aircraft. For example, special batteries and narrow tubular packaging must be developed for unshielded geothermal logging tools. Once new high-temperature designs are demonstrated for geothermal wellbore applications, the geothermal industry will gain never-before-realized instrumentation capabilities that will lead to new approaches in well logging and reservoir characterization.

Sandia has tested a number of components to 300° C and built a complete pressure/temperature logging tool that was oven tested to 250° C and successfully wellbore tested to 240° C. As the high-temperature electronic industry matures, so will performance at higher temperatures toward the target temperature for geothermal applications of 300° C.

4 Data Logger Development

Data Logger Development can be sub-divided into 4 categories. They are: 1) Components Tested, 2) First Generation Dewarless Data Logger, 3) High Temperature Sensors, and 4) Power sources.

4.1 Components Tested

Several newly available components were evaluated up to 300° C. They included the SOI 5-volt regulator, SOI 10-volt regulator, SOI 5-volt reference, SOI FET, clock oscillator, and a strain-gage pressure transducer. Also, a more detailed analysis was performed on the SOI operational amplifier.

The voltage regulators continued to function at 300° C. Their performance suffered significantly above 275° C but it was quite usable to this temperature. This is shown in Figure 1 and Figure 2. The voltage reference's maximum operating temperature is 250° C. Above this temperature the output rolls off sharply. The results are shown in Figure 3. The FET was tested with satisfactory results to 300° C.

The crystal oscillator results are inconclusive due to the limited number of oscillators that were available for testing. To date, Sandia has evaluated four batches of crystals manufactured for operation to 300° C with mixed results. The first two batches failed due to lead attachments separating internal to the oscillator. The last two batches have worked up to 250° C for several days. Exposures of 300° C appear to significantly limit the life of the oscillator. Also, the oscillators are load sensitive. A minimum load of 200 ohm and 50pf must be maintained to ensure the oscillator will continue to oscillate at the elevated temperatures. The oscillator also exhibits a sharp frequency shift of greater than 10 % between 30 and 150° C (depending on the oscillator tested). The oscillator manufacture is aware of the shortcomings and will continue to improve their oscillator design based on the feedback Sandia provides to them. They feel the frequency shift could be lowered below the anticipated operating range of the oscillator in future devices and may be able to achieve an oscillator with a temperature stability of ± 400 PPM or better over the temperature range of ambient to 300° C. The crystal test results are shown in Figure 4 and Figure 5.

The strain-gage pressure transducer worked well up to 300° C. The offset voltage varies considerably over the temperature range. This is an undesirable attribute and will increase the complications of calibrating the unit, but is quite adequate to demonstrate the pressure/temperature tool concept.

The SOI operational amplifier was further evaluated to determine the bandwidth at various gains and to determine the offset voltage error at temperatures up to 300° C. It was determined the bandwidth is suitable for most geothermal applications. The offset voltage was quite large and will need to be kept in mind when designing circuits with this operational amplifier. Second generation devices will improve analog performance. The operation amplifier test results are shown in Figure 6 and Figure 7.

4.2 First Generation Dewarless Data Loggers

Two memory-based data loggers were designed and built. The first design was a data logger capable of storing and transmitting temperature information. The second design was a data logger capable of storing and transmitting three temperature channels and a pressure channel.

The first data logger design used a machinable ceramic substrate as the board material and mechanical lead attachment with laser spot-welded connections to ensure reliable performance. This design incorporated a field-programmable-gate-array (FPGA) with SOI components. The FPGA limited the maximum continuous operating temperature to 200° C with short excursions to 225° C. A photo of this board is shown in Figure 8.

The goal is to ultimately design a geothermal logging tool that will operate continuously at 300° C which will require the use of non-conventional board assemblies such as the ceramic board concept. The FPGA circuit design utilized in the ceramic board data logger, has paved the way for working with Honeywell in FY00 to develop a qualified 300 C Application Specific Integrated Circuit (ASIC). This needed component will have similar functionality to the FPGA and would replace the mil-spec devices that are currently required. The developed ASIC will enable a data logger to be designed using only qualified high-temperature components.

The ceramic board data logger was tested in a geothermal well in August 1999. It performed satisfactorily up to 200° C, but experienced intermittent difficulties above this temperature. Post-test evaluation revealed the specific crystal oscillator Sandia used for this test required more of a load than previously tested oscillators to reliably sustain oscillation above 200° C. The temperature data correlated with the previous temperature well profile and the ceramic board assembly performed well in the downhole field test.

The second data logger design used more conventional board material and high-temperature solder for the connections. A photo of this board is shown in Figure 9. This design incorporated tested mil-spec and SOI components, which would allow continued operation up to 250° C. A block diagram of this design is shown in Figure 10. Utilizing

more conventional board assembly techniques eased the integration of additional data channels and allowed Sandia to demonstrate a prototype pressure/temperature tool. This tool successfully logged a 240° C, 12000 foot geothermal well. It successfully operated within the well for more than 56 hours at temperatures greater than 225° C (up to 240° C) and pressures up to 5000 psi. This type of long-term tool exposure to extreme environments is not possible with conventional logging tools. The prototype tool was also compared to a conventional Dewared Tool. While the prototype high-temperature PT Tool was designed more for functionality than absolute accuracy, it did provide a favorable well profile. As indicated in Figure 11, the temperature data correlates with the Dewared tool. As expected from oven tests, the pressure data contained false pressure gradients. Several factors influenced the results including the limited component choices for the pressure transducer interface circuit and temperature gradients that existed between the pressure transducer and the temperature compensation circuit. The next generation tool will include a high-temperature analog-to-digital converter that just recently became available. This device will enable the accuracy of the temperature and pressure measurements to increase significantly.

After approximately 56 hours of exposure, the wireline cablehead experienced a small leak, shorting the cablehead conductors and leaking into the tool. The tool was evaluated after the test and it was determined two components had failed due to the leak. After their replacement, the tool was again functional. The development of HT SOI electronics will push the evolution of improved downhole hardware for long-term deployment.

The test results were conveyed to the high-temperature industry through the High-Temperature Electronics Downhole (HiTED) panel.

4.3 High-Temperature Sensors

High-temperature sensors can be categorized in three sections: readily available, soon to be available, may never be available.

4.3.1 Readily Available: Many geothermal sensors are already available for high-temperature applications. These sensors have always been in direct contact with the wellbore environment in conventional logging tools. Examples of direct contact sensors are the temperature and spinner sensors. Recently, additional new pressure sensors and accelerometers have become available for new high-temperature applications.

4.3.2 Soon to be Available: We are aware of several companies currently working on high-accuracy, high-temperature pressure and inclination sensors. There is reasonable evidence that magnetometers and collar counters can be produced to perform at 300° C. Magnetometers and collar counters are examples of sensors that could be developed by taking the older low temperature design and substituting high-temperature materials to enable high temperature operation.

- 4.3.3 **May Never be Available:** Sensors such as Sodium Iodide [NaI(Tl)] using photon multipliers are used for gamma spectroscopy. This sensor will require a technology breakthrough in order to operate above 200° C.

4.4 Power Sources

A downhole tool has two sources for power: wire-lines or batteries. Both are concerns at 300° C. High-temperature wire-lines are expensive and have a limited life. Commercially available batteries have limited operation to only 200° C.

Sandia developed thermal batteries are considered the best option. Thermal batteries use molten salt technology. At room temperature, thermal batteries are inactive. Only when the battery salts have been melted will the battery become active. Most thermal batteries become active at temperatures above 300° C.

Our battery development effort is aimed at closing the gap between the starting temperature of thermal batteries and the upper limitation of conventional batteries. Work is ongoing to develop a thermal battery with useful power production below 50° C and upper temperature limitation near 300° C. Such batteries give the tool designer the option of using them in memory tools, which can be deployed on slick-line cable or conventional wire-line.

5 Future Plans

Sandia's objectives in FY00 will be to evaluate and report on commercial activities to produce new high-temperature components and to develop Dewarless tool designs deployable within the geothermal wellbore and transfer this technology to the geothermal industry. Sandia will also support DOE's Small Business Innovated Research program to help small businesses develop new devices such as high-value capacitors, voltage references, pressure and inclination sensors and new high-temperature logging tools such as a pressure/temperature tool.

The FY00 objectives include working with Honeywell to develop an Application Specific Integrated Circuit (ASIC) that will be packaged and programmed for geothermal applications. This component is needed to overcome the shortcomings and lack of availability of mil-spec components Sandia is presently using. With the addition of this ASIC, a tool can be designed using only qualified high-temperature components. This will result in a reliable tool capable of sustained temperatures of 250° C with many of the components including the ASIC qualified to 300° C. The ASIC also will greatly enhance the capabilities of the developed tool by providing several new features such as precision counters, FM data transmission, and increased memory capacity beyond 64k bytes. It will also provide firmware that will serve as a basic data logger. Sandia has consulted various

geothermal tool companies for specific needs that could be incorporated into the design of the ASIC. The resulting ASIC will be essentially an enhanced 8051 based controller, which can be used as the basic building block for a variety of high-temperature applications. These enhancements would not be possible without the development of a high-temperature ASIC and are needed to design a practical downhole tool. The developed ASIC will be made available to the high temperature instrumentation industry.

Support for converting existing tool designs to high temperature is also being considered. Many tools lend themselves for such a conversion. Examples include 1) pressure/temperature tool, 2) fluid/steam sampling tool, 3) core-tube data logger, and 4) casing inspection tool. Geothermal companies have requested assistance for this type of support. For example, Welaco has requested assistance in modifying their casing inspection tool to increase the operating temperature to 300° C. This converted tool could be used to log more than 1000 aging geothermal wells within the US. The information gleaned from this type of tool may be critical in developing strategies for increasing the life of these wells.

6 REFERENCES

1. McCluskey, P.F., Grzybowski, R. and Podlesak, T: "High Temperature Electronics", CRC Press, ISBN 0-8493-9623-9
2. Swenson, Gregg and Ohme, Bruce. (1996). "HTMOSTM: Affordable High Temperature Product Line", Third International High Temperature Electronics Conference (HITEC), Vol 2, pp 89-94.
3. Normann, Randy A. and Guidotti, Ronald A. (1996). "A Study of the Use of High-Temperature Electronics and Batteries to Avoid the Use of Dewars for Geothermal Logging", Geothermal Resources Council, Vol 20, pp 509-513.
4. Franco, R.J. and Sleaf, G.E. (1994), "CMOS Devices and Design Methodology for 200°C Circuits", Sec International High Temperature Electronics, June 5-10, 1994.

Figure 9. The prototype polyimide Pressure/Temperature Data Logger board is shown in this picture. This board was used to successfully log a 240° C, 12000 foot geothermal well. It successfully operated within the well for more than 56 hours.

Figure 10. Block diagram of the prototype pressure/temperature data logger.

Figure 11. Temperature/Pressure plot comparing a conventional Dewared logging tool with the prototype Dewarless logging tool.

Appendix A

The schematic for the Dewarless data logger utilizing the polyimide as the board material follows.

Title		8051 PCB
Size	Document Number	8051 po lym de
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Appendix B

The following page is the parts list for the Dewarless Data Logger utilizing polyimide as the board material.

Item	Quantity	Reference	Part
1	13	C1,C2,C4,C5,C6,C7,C8,C9, C10,C11,C12,C13,C14	.1uF
2	1	C3	10uF
3	3	C15,C16,C17	1000PF
4	1	R1	50
5	1	R2	1K
6	12	R3,R13,R14,R15,R26,R27, R28,R31,R34,R37,R38,R42	100K
7	1	R4	2K
8	1	R5	1.2K
9	4	R6,R7,R11,R12	50K
10	1	R8	20K
11	1	R9	500
12	14	R10,R18,R19,R20,R21,R22, R23,R24,R30,R32,R35,R39, R40,R44	7.5K
13	1	R16	10K
14	1	R17	4K
15	2	R25,R36	5K
16	3	R29,R41,R43	70K
17	1	R33	150K
18	1	TP1	BAT_IN
19	1	TP2	5VOUT
20	1	TP3	10VOUT
21	1	TP4	RESET
22	1	TP5	EX+
23	1	TP6	GND
24	1	TP7	5V
25	1	TP8	EX-
26	1	TP9	mux_power
27	1	TP10	10V
28	1	TP11	+V1
29	1	TP12	P1_4_OUT
30	1	TP13	+V2
31	1	TP14	TX_OUT
32	1	TP15	TXD
33	1	TP16	PROG_RUN
34	1	TP17	RXD
35	1	TP18	P1_4
36	1	TP19	GND2
37	1	U1	HTOSC
38	1	U2	HTVREG
39	1	U3	HT83C51
40	1	U4	54AC373
41	2	U6,U5	HT6256
42	3	U7,U8,U12	VN0104N5
43	2	U13,U9	HT1204
44	1	U10	54AC04
45	2	U15,U11	HT1104
46	1	U14	54AC08

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