2011 Summary Research Performance Report

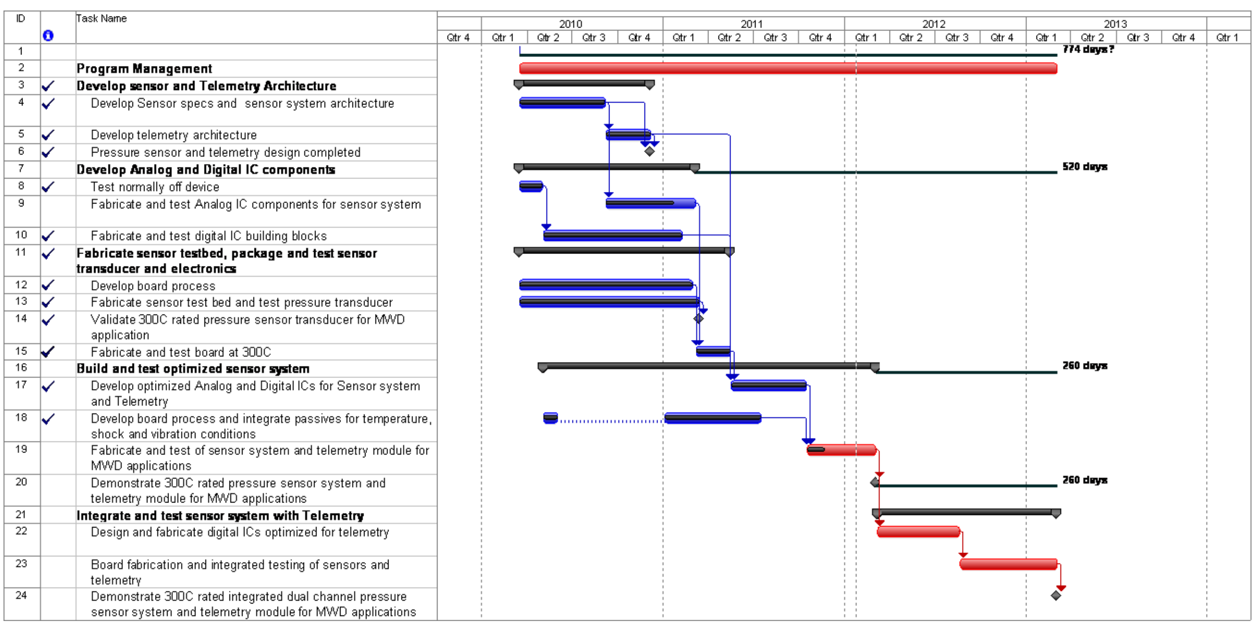
Federal Agency and Organization: DOE EERE – Geothermal Technologies Program

Recipient Organization: General Electric Company
Recipient Address: 1 Research Circle, Niskayuna, NY, 12309
Project Title: Pressure sensor and telemetry methods for measurement while drilling in geothermal wells
Project Period: 12/29/2009 to 1/31/2013

STATUS / ACCOMPLISHMENTS

Project Status Summary: The program is focusing on the development if SiC-based high temperature electronics and high temperature ceramic-based packaging. The developed building blocks, including active analog and digital ICs, passive components and method of their integration in a multi-chip module will be utilized to assemble a prototype of a pressure and temperature measurement systems multiplexed and integrated with the digital telemetry module for mud-pulsing transmission of data to the surface. Such tool rated to at least 300C and more than 400hours of continuous operation will be used in the measurement while drilling systems for geothermal and oil and gas applications where high temperatures are encountered in deep wells.
The key milestones and accomplishments by the end for year 2011 include: proof of feasibility of analog and digital components with their lifetime tested for more than 500 hours at 300C, demonstration of ceramic-based packaging capable to survive 300C, demonstration of a temperature sensor system, completion of the design of a pressure sensor system and demonstration of a prototype of the digital telemetry system.
The research in the last year of the program (2012) will focus on the optimization of the analog and digital SiC-based components and integration of them at higher complexity level in the optimized telemetry – sensor system prototype.

Status: The project is slightly behind in terms of both spending as of end of 2011. The delay is caused by the difficulties encountered in the fabrication lot resulting in poor yield requiring re-work. The gantt chart below overviews the tasks of the program and shows their status for the end of 2011 year.



Gantt chart showing rough estimate of progress. The tasks shown in red are in critical path.

Technical Results and Summary:

Pressure / Temperature / Telemetry System architecture

The development of the measurement system architecture was completed as a first step to identify and subdivide key system components, see Figure 1.

Figure 1. Measurement system architecture

The sensor and signal conditioning blocks are part of the analog sensor system module, where digital counter and multiplexer comprise the digital telemetry module capable to multiplex signal (frequency) inputs form pressure and temperature sensor and maybe scaled to larger sensors system set. Both modules are prototyped separately and integrated on the board level with the power switch (FET) and a mud pulsing solenoid for a complete measurement system.

SiC-based Integrated Circuits Development

Analog and digital SiC integrated circuits were developed in the course of the project, including operational amplifiers, counters, oscillators, shift registers, comparators and buffer amplifiers. A basic depletion and enhancement mode NMOS all-SiC transistor technology was developed along with transistor structures fabricated on SiC substrates and their models extracted for the circuit designer library. Figure 2 illustrates an example of the photograph of an operational amplifier and 8-bit counter circuit which have been proven to be functional at 300C.

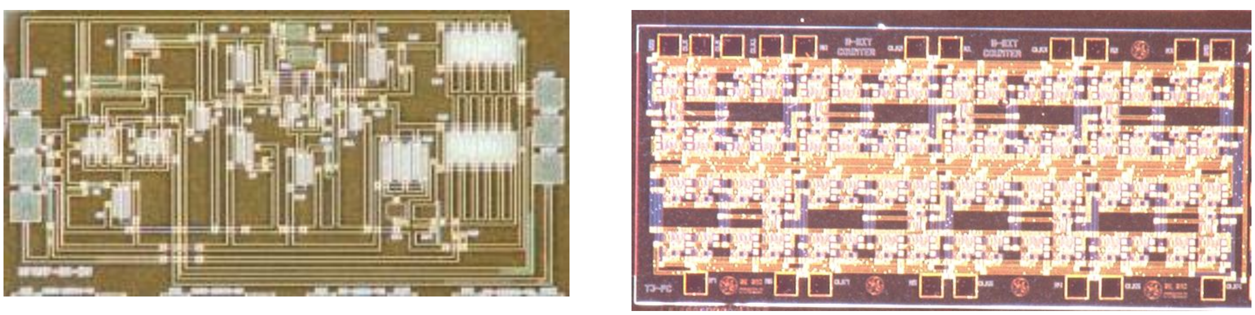
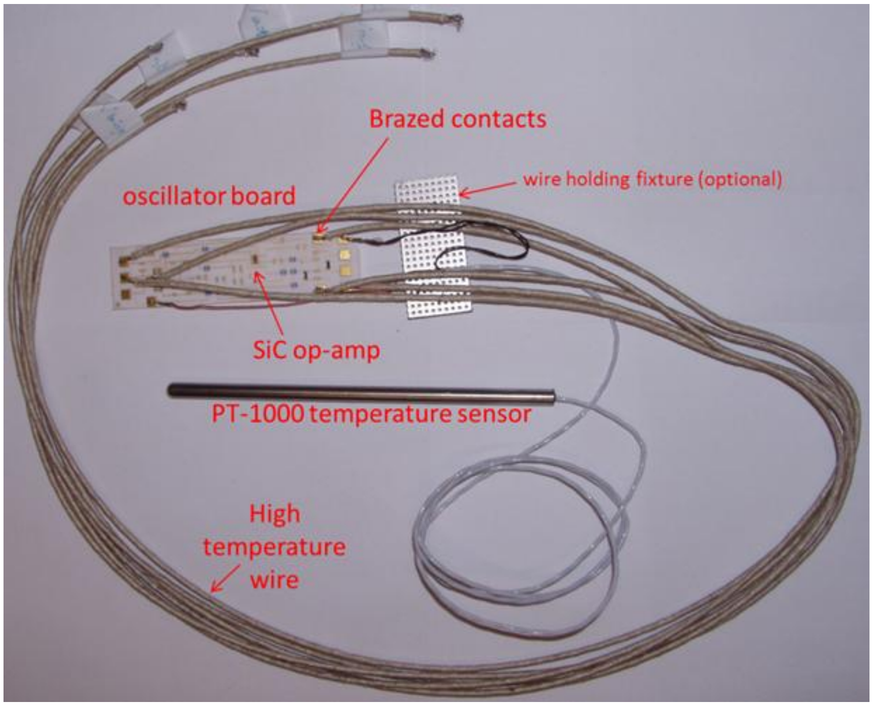


Figure 2. Photograph of the operational amplifier and 8-bit counter circuits.

The next year effort will focus on improving fabrication processes yield and robustness as those were identified as critical for project success, reduction of future electronic system cost and enabling system scalability to higher functionality.

Temperature Sensor System Prototype

The key component of the high temperature sensor system is the active SiC-based component – operational amplifier. The program focuses on the development of SiC operational amplifier circuits, high temperature ceramic substrates and off-eutectic Au-Sn die attach packaging. High temperature passive components have been selected and screened for high temperature functionality in addition to the development of ceramic-based high temperature packaging and die attach methods. A high temperature prototype of a temperature-to-frequency converter system has been developed and tested at 300⁰C. The lifetime of all system components has been evaluated and shown in the table next to the picture of the prototype, Figure 3. Similar approach was adopted to realize a pressure to frequency converter system.



Lifetime test summary, 300⁰C	
SiC operational amplifier	>1,000 hours
resistors	1010 hours
capacitors	17,000 hours
ceramic board	very little degradation
die attach and bonding	>1,500 hours

Figure 3. Integrated temperature sensor system

The developed prototype is the resistance to frequency converter (oscillator), where the sensor element is a temperature sensitive resistor (PT-1000). High temperature insulated wires were brazed to the contact pads of the assembled sensor system board. PT-1000 temperature sensor was attached to the resistive feedback loop of the oscillator using the same high temperature brazing process.
Temperature sensor system has been tested to obtain calibration curve of oscillation frequency versus temperature, Figure 4. All the components used to assemble temperature system were proved to survive 300⁰C long term test for at least 1,000 hours.

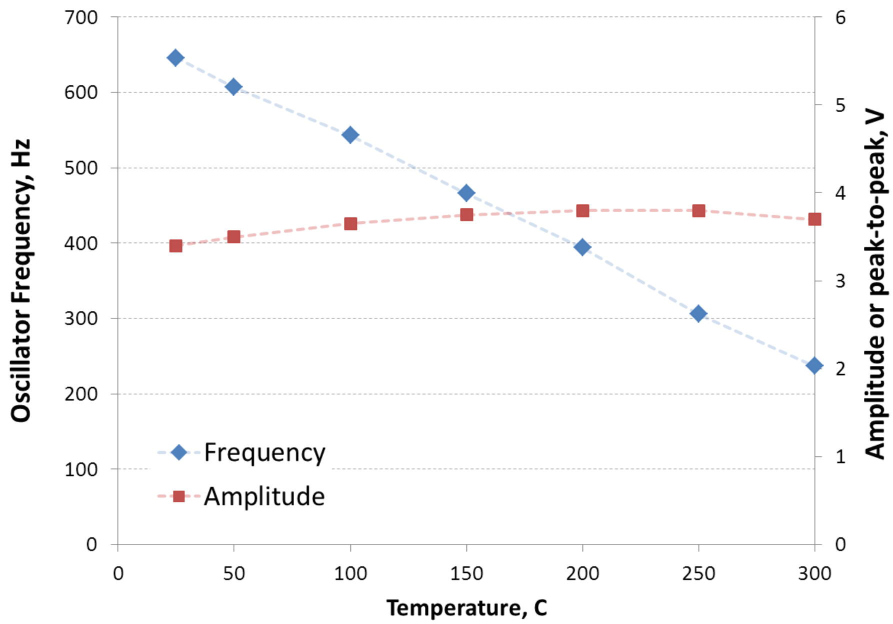


Figure 4. Frequency versus temperature test of SiC-based temperature sensor prototype

The developed prototype is a unique demonstration of SiC and high temperature packaging technology which will be extended in the future to other high temperature electronic systems and is expected to greatly impact the development of down-hole tools for geothermal exploration and well monitoring.

Pressure Sensor System Prototype Development

The development of the pressure sensor system is utilizing the knowledge and experience gained during the temperature to frequency converter development. Operational amplifiers of the same kind have been used to design and simulate system performance. The design of the pressure to frequency conversion circuit is based on an amplifier-integrator-comparator design. The pressure sensor is a wheatstone bridge based sensor in which the mismatch of resistance in the two legs of the sensor provide a voltage differential indicative of the pressure. The amplifier stage amplifies this voltage differential to a level more suitable for the subsequent circuits to operate on. The amplified voltage differential is then integrated by the integrator stage providing a either a positive or negative going ramp depending on the polarity of the amplified signal. The comparator stage with built in hysteresis coverts that ramp into a level (either positive or negative) which is then fed back to the pressure sensor as the excitation signal. The output of the comparator is designed such that when the threshold is reached, the comparator switches output causing the pressure sensor to have an excitation of the opposite polarity. That ultimately causes the integrator to integrate a signal of that opposite polarity, and once the comparator threshold is reached, the polarity is switched again. The result is an alternating switching between positive and negative signals where the rate of switching is a function of the amplified voltage differential out of the pressure sensor. Hence the circuit provides a frequency output that is indicative of the sensed pressure. A block diagram of the approach is shown below in Figure 5.

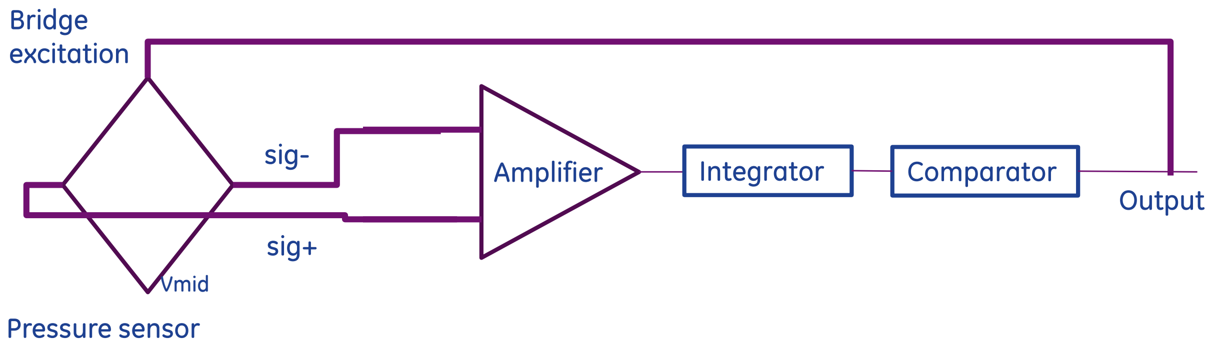


Figure 5. Block diagram of the pressure measurement module.

The assembly of the pressure to frequency converter prototype board is currently in progress. Wire-bonding of SiC analog parts has been selected, but will be replaced by flip-chip process once the design is proven and evaluated for reliability at high temperature. Wire-bonded components allow easy access for failure analysis in case of failures.

Telemetry System Prototype development

First prototype of a digital board has been assembled and tested at 300C for more than 500 hours without failures, proving feasibility and robustness of SiC-based digital components and developed packaging.

The board comprised two 4-bit counters and a data latch which were designed and fabricated at GE Global research. Photograph of the assembled board is shown in Figure 6.

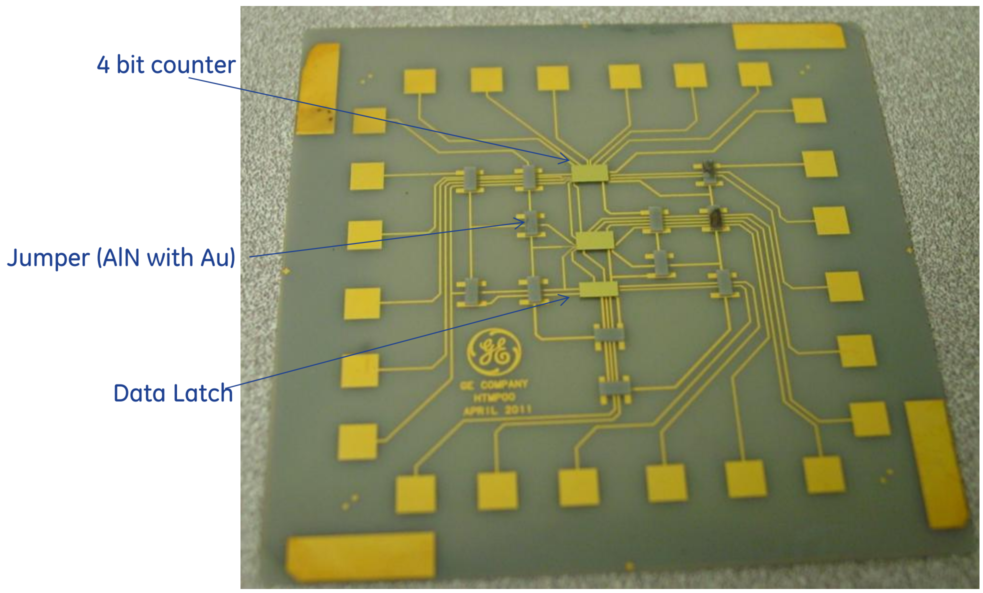


Figure 6. Photograph of AlN high-temperature digital board comprising of two 4-bit counters and data latch. 4-bit counters and data latch die are attached by a flip-chip process.

The second generation digital components were fabricated and are planned to be integrated in the second generation prototype of the telemetry system by mid-year of 2012. The second generation prototype will digitize input frequency signal and serialize it into the bit-stream to be transmitted by the mud pulsing solenoid through the buffer amplifier.

Pressure Sensor selection and stability test

The evaluation of Paine electronics pressure sensors was completed by conducting long term stability testing at 300C and constant applied pressure of 35bars with the decision of satisfactory sensor performance.

Figure 7 shows the offset drift of sensor output demonstrated 5.1e-4 mV/hour drift equivalent to a 0.6% full-scale change over 400 hours span. The feasibility of sensor drift less than 1% over target 400 hours has been proven making it suitable for use in the down-hole pressure system.

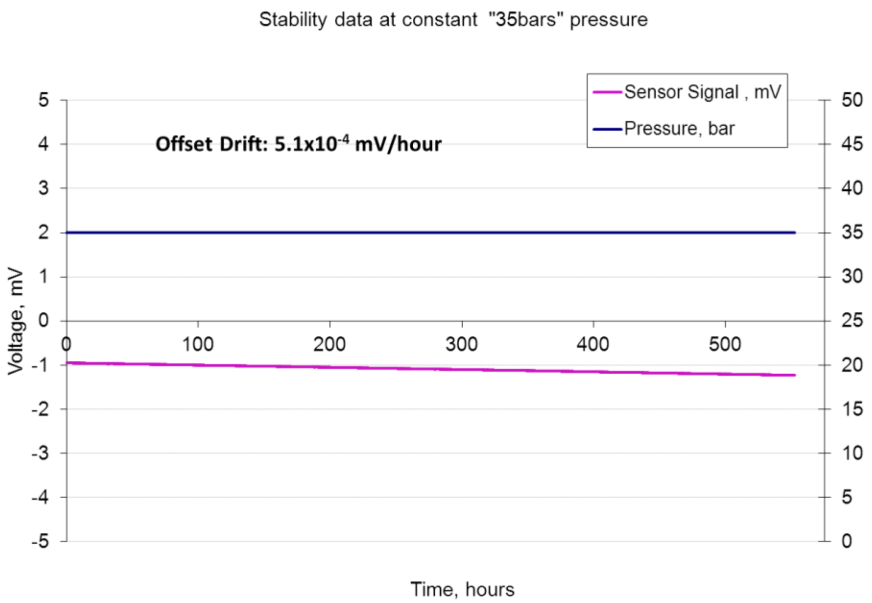


Figure 7. Paine electronics Sensor offset drift during long term test.

The high pressure high temperature (20,000psi) version of Paine electronics pressure sensors will be utilized in the final assembly of the pressure to frequency converter prototype. Unlike existing commercially available high temperature solutions for the temperature sensors (PT series), the low drift pressure sensor element was found to be a critical component not readily available.