2015 Geothermal Technologies Office Peer Review Summary: Evaluation of High Temperature Components

1. Evaluation of High Temperature Components for Use in Geothermal Tools

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Participating Organizations: FastCAP Systems (Boston, MA), RelChip (Provo, UT), XREL Semiconductor (Grenoble, France)
Project Start and End Date: 10/2013 – 09/2020

2. Project Objectives and Purpose

The objective of this project is to perform independent evaluation of high temperature components to determine their suitability for use in high temperature geothermal tools. Development of high temperature components has been increasing rapidly due to demand from the high temperature oil and gas exploration and aerospace industries. Many of these new components are at the late prototype or first production stage of development and could benefit from third party evaluation of functionality and lifetime at elevated temperatures. In addition to independent testing of new components, this project recognizes that there is a paucity of commercial-off-the-shelf COTS components rated for geothermal temperatures. As such, high-temperature circuit designers often must dedicate considerable time and resources to determine if a component exists that they may be able to knead performance out of to meet their requirements. This project aids tool developers by characterization of select COTS component performances beyond published temperature specifications. The process for selecting components includes public announcements of project intent (e.g., FedBizOps), direct discussions with candidate manufacturers, and coordination with other DOE funded programs.

3. Project Timeline (with milestones and/or decision points, as applicable)

This project was initially funded in FY14 to advertise the program, communicate with high temperature component developers that may be interested, and perform evaluation and reporting of a component identified as having high potential benefit to geothermal tool development. Starting in FY15, the project is funded for testing and reporting on 4 components with a stretch goal of a 5th component. Assuming out-year funding, this project adopts a multi-year plan:

FY14 – Sandia began project planning and initiating communications with developers and end users to start component selection. A solicitation was issued to FedBizOps announcing the program to a wide audience. An evaluation of FastCAP ultracapacitors was performed and results were subsequently presented and published by FastCAP at GRC 2014.

FY15 – Four components have been tested this year so far (4th on-going). Development of test hardware and software for a fifth component is well underway and testing is scheduled to begin in May. Additional FastCAP components are scheduled for test in April. A high temperature vibration unit has been designed for testing resilience of components to mechanical vibration at temperature.

FY16 – Evaluation of several types of COTS capacitors at temperatures above specification are planned using the capacitor test station developed in FY15. Work with component developers will continue and parts will be tested as they become available. Pressure-at-temperature and vibration-at-temperature test capabilities will be pursued.

FY17-FY20 – Tests of important components will continue to be conducted and the results shared publicly through the GDR and presentations/publications.

[1] Sandia National Laboratories is a multi-program laboratory operated and managed by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2015-xxxx.

4. Technical Barriers and Targets

The number of components this project can evaluate per year is limited by factors such as time necessary to test, facilities available, lead times on nonstandard materials and pre-commercial parts, and experimental design time. The aging standard we are striving for is 1000hrs (~42 days) per component at temperature. Depending on the component, the complexity and time of the experiment set-up varies. For small and simple components like capacitors, we can test many different types at once in a single oven using a switch matrix. For components like high temperature RAM chips, tests can be more complicated (i.e. PCB design/fabrication, firmware/software development, supporting hardware and custom circuitry, debugging, etc.). Additionally, the higher the temperatures of the test, the more difficulties are introduced with material selection (PCB substrates, solders, etc.). Finally, some components show little sign of aging before complete failure. As such, determination of the approximate maximum temperature where a 1000hr test is successful can require multiple 1000hr tests at increasing temperatures.

The limited supply and/or high cost of each component and associated test equipment can make achieving high statistical significance with performance evaluation data difficult. In this program, we endeavor for a minimum of 3 samples for each experimental test of a component. The time and expense of each component evaluation is in fact part of the impetus for this program as it can be a large barrier to high temperature circuit designers that need to operate beyond the limits of manufacturer specifications and do not have the resources to dedicate to out-of-spec performance evaluation of expensive components.

5. Technical Approach

The technical approach for the HT component evaluation program can be separated into three key tasks:

Component Selection – Components are selected for testing in this program through open advertisement and by discussion with various component developers and end users.

Test Design/Procedure – Each component has its own associated challenges and often unique test protocol to be developed. We attempt to design test procedures such that a geothermal tool designer will be provided with the most practical dataset of expected component performance information. Internal discussions and communication with developers are used to determine what tests are most useful. Once we have decided what data is to be collected from a specific device, the test protocol is developed. Where possible, we also attempt to design test stations such that more components of a similar type (i.e. capacitors) can be tested in the future with minimal recurring overhead.

Reporting – The overall goals of this project are to both make component evaluation results available to the wide public audience and to assist developers of new components by providing third party verification of function. Results obtained from tests of COTS components are shared through posting to the GDR and through publication/presentation at relevant conferences. For pre-commercial components, Sandia works with the component developer to determine the public dissemination strategy.

6. Technical Accomplishments

Technical accomplishments have been achieved on the following tasks comprising the technical approach:

Component Selection – Sandia has participated in extensive discussions with three component developers interested in the Sandia HT component evaluation program; FastCAP Systems, RelChip, and XREL Semiconductor. FastCAP ultracapacitors have been tested and reported. RelChip has provided engineering samples of a novel high temperature RAM chip which we will be testing at 300°C in the near term. And finally, through conversations with XREL Semiconductor, several XREL parts have been acquired for testing in the near future. Additionally, four COTS components were selected for their potential in geothermal electronics packages (a Flash memory module made by Texas Instruments and 3 types of tantalum capacitors.)

Test Design/Procedure and Reporting - Performed evaluation of FastCAP ultracapacitors which was presented and published at GRC 2014 by FastCAP and published internally in a SAND report. Three types of COTS tantalum capacitors have been evaluated for a 1000hr test at the geothermally relevant temperature of 260°C. High temperature printed circuit boards and ceramic sockets have been acquired to enable the development of a robust capacitor test station that allows testing 21 capacitors simultaneously. Commercial flash memory modules made by Texas Instruments

(SM28VLT32) have been tested for short duration performance at temperatures up to 300°C as well as for 1000hr duration at 225°C. Duration tests are ongoing for 3 flash modules at 240°C. Results of tantalum capacitors and commercial flash evaluation will be presented at HiTEN 2015 in July.

Vibration Testing – A revised vibration at temperature station has been designed for performing military specification vibration testing in an oven environment. Component evaluation for this station is planned for FY16.

7. Challenges to Date

- Mismatched thermal expansion rates between conductive trace work and standard high temperature printed circuit board substrate materials can lead to delamination and shorting of traces at temperatures approaching 300°C.
- The supporting electronics for each device under test must either be located outside the oven (far from the device under test and thus noise sensitive) or inside the oven (introducing potential failure modes apart from the device under test)

8. Conclusion and Plans for the Future

To date, this program has evaluated a range of high temperature components that have been selected for their potential in geothermal tool development. Since the beginning of this project in 10/2013, several interested component developers have been identified, components with high potential utility have been selected for testing, and results of five component evaluations have been made publicly available through conference presentations and/or uploading to the GDR. The team has worked with a small business (FastCAP) to evaluate their novel high temperature ultracapacitor technology which shows promise for downhole electrical energy storage applications. A commercial flash memory module has been successfully tested at temperatures and durations exceeding manufacturer specification. Three types of tantalum capacitors have been evaluated above manufacturer specification with tracking of key parameter degradation over time such as equivalent series resistance and capacitance. The evaluations of the flash memory and the tantalum capacitors will be presented in July 2015 at the International Conference and Exhibition on High Temperature Electronics Network (HiTEN). Printed circuit board substrate materials have been tested for reliability in high temperature testing. Work is underway with another component developer, RelChip to test a pre-commercial RAM module they designed for 300°C operation. Parts developed by XREL Semiconductor have been acquired and are scheduled for testing in near term 2015. Future plans include testing more commercial high temperature components for determination of effectiveness in geothermal applications and broadening our test capabilities to include vibration+temperature and pressure+temperature evaluations.

9. DOE Geothermal Data Repository

- Evaluation data of a high temperature COTS flash memory module SM28VLT32 for a duration test at 225°C, A. Cashion, Sandia National Laboratories, submitted on 8/29/2014.
- Results of initial tests of three different types of tantalum capacitors at 260°C, G. Cieslewski, Sandia National Laboratories, submitted on 9/2/2014.

Publications and Presentations, Intellectual Property (IP), Licenses, etc.

- Conference presentation and proceedings publication at International High Temperature Electronics Network (HiTEN 2015). *High-Temperature Component Evaluation of Commercial Flash Memory for Enhancement of Geothermal Tool Development*
- Conference presentation and proceedings publication at International High Temperature Electronics Network (HiTEN 2015). *Evaluation of Tantalum Capacitors at Geothermal Temperatures*
- SAND Report (SAND2014-15282). *Evaluation of FastCap's High-Temperature Ultracapacitors.*
- Conference presentation and transactions publication at Geothermal Resources Council (GRC 2014) by FastCAP Systems of results from this project. *Downhole Power Source for Geothermal Drilling and Well Development Enabled by a Novel Extreme High Temperature (200°C+) Ultracapacitor*