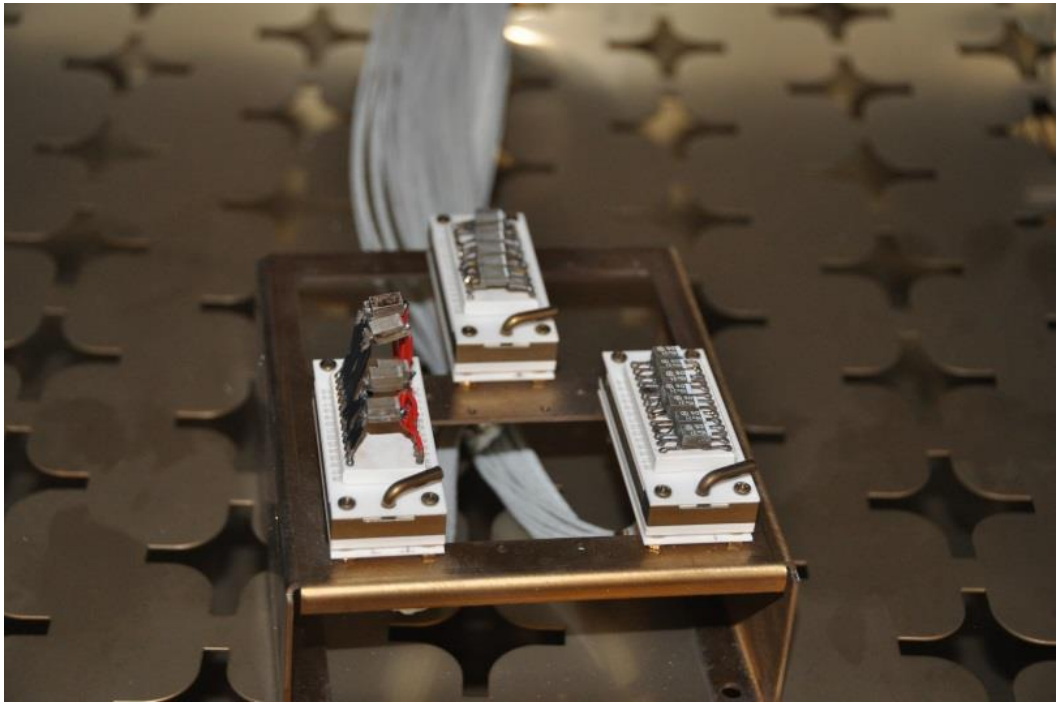


Evaluation of High Temperature Components for Use in Geothermal Tools

Project Officer: Lauren W.E. Boyd

Total Project Funding: $500k

May 12, 2015

This presentation does not contain any proprietary confidential, or otherwise restricted information.

Avery Cashion

Sandia National Laboratories

EGS: High Temp Tools, Drilling Systems

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

Project Objective

- Assist global geothermal tool development through independent high temperature component evaluation.
  - New HT component developers benefit from 3rd party evaluation of functionality and lifetime at temperature.
- Address the scarcity of COTS components rated for geothermal temperatures.
  - Public dissemination of beyond spec performance evaluations of select commercial components.
  - Helps developers who do not have the resources to dedicate to out-of-spec performance evaluation of expensive components.

Scientific/Technical Approach

- Component Selection
  - Open advertisement (FedBizOps) directed at HT component developers for 3rd party evaluation
  - Discussion with various end users and HT tool developers.
- Test Procedure Design (Unique for each component)
  - Internal discussions and communications with part developers
  - Once desired data is decided upon, test protocol is developed.
  - Where possible, equipment and processes are designed to enable future component tests

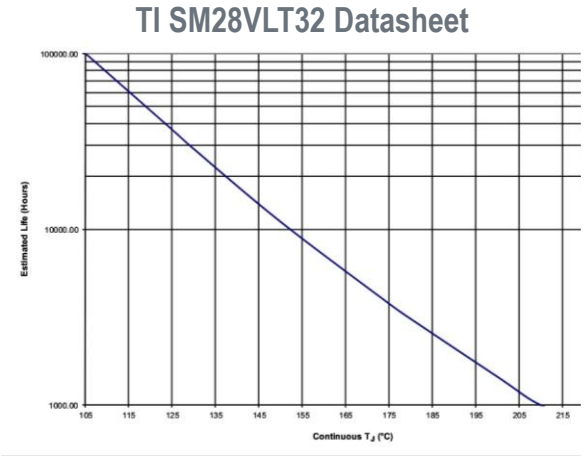
Scientific/Technical Approach

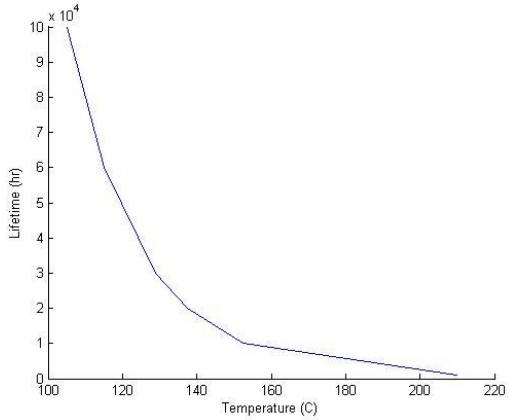
- Reporting
  - COTS component evaluations are made public through publication and/or presentation at relevant conferences
  - Prototype component evaluations are shared and discussed with the developers. Public dissemination strategies vary.

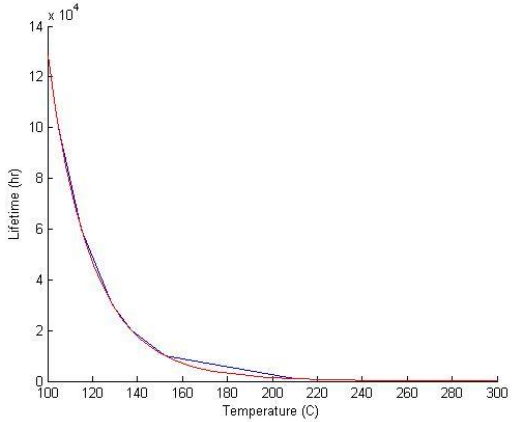
Texas Instruments HT Flash Memory

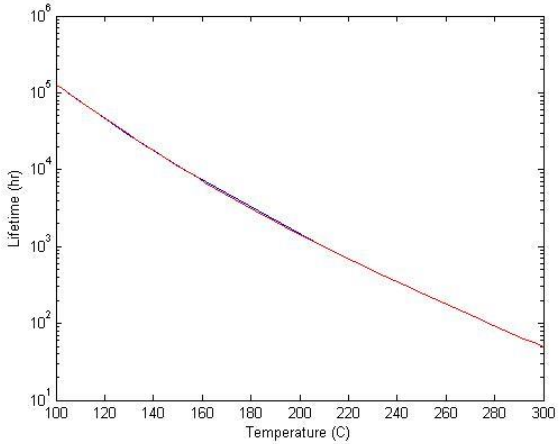
"The predicted operating lifetime vs. junction temperature is based on reliability modeling and available qualification data."

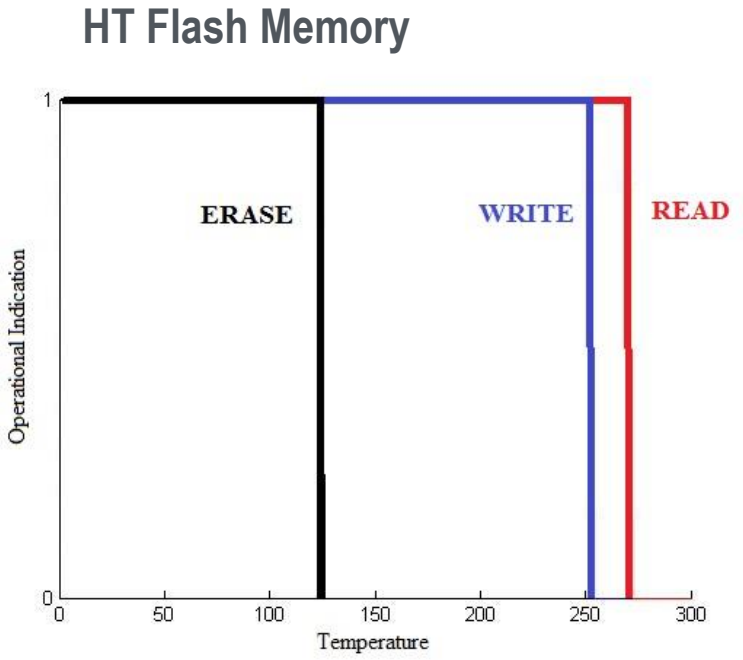
MATLAB Fit and Extrapolation



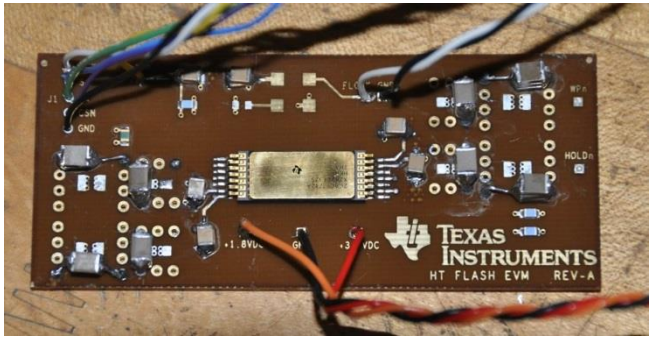




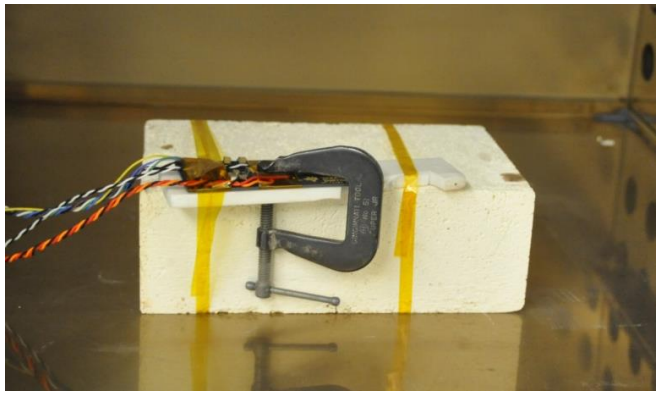




- Verified Read/Write functionality for 1000hr test @ 225˚ C
- 1000hr test at 240˚ on-going
- Determined maximum temperatures for individual functions
- Chip can recover functionality after short exposures to 300˚ C



Modification for 300C exposure

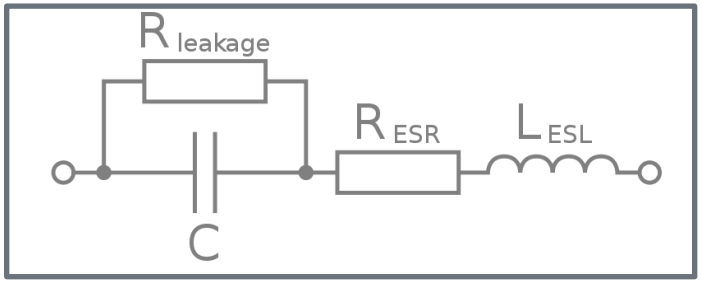


Mechanically secured

Accomplishments, Results and Progress

Capacitor Testing

Ideal Capacitor

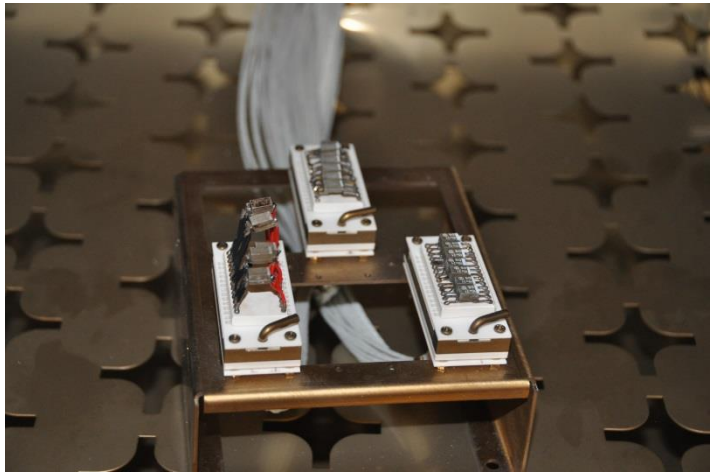


Real Capacitor

$$|Z| = \sqrt{ESR^2 + \left(\frac{1}{2\pi f C}\right)^2} \qquad \theta = \tan^{-1}\left(\frac{(1/2\pi f C)}{ESR}\right)$$

$$C = \frac{1}{2\pi f |Z| \sin\theta} \qquad ESR = |Z| \cos\theta$$

- Ceramic ZIF sockets for simultaneous HT evaluation of commercial capacitors
- Switch matrix enables multiple parallel tests using a single LCR/ESR Meter
- MatLab Control Interface



Accomplishments, Results and Progress

COTS Solid Tantalum Capacitor Testing (1000hrs @ 260° C)

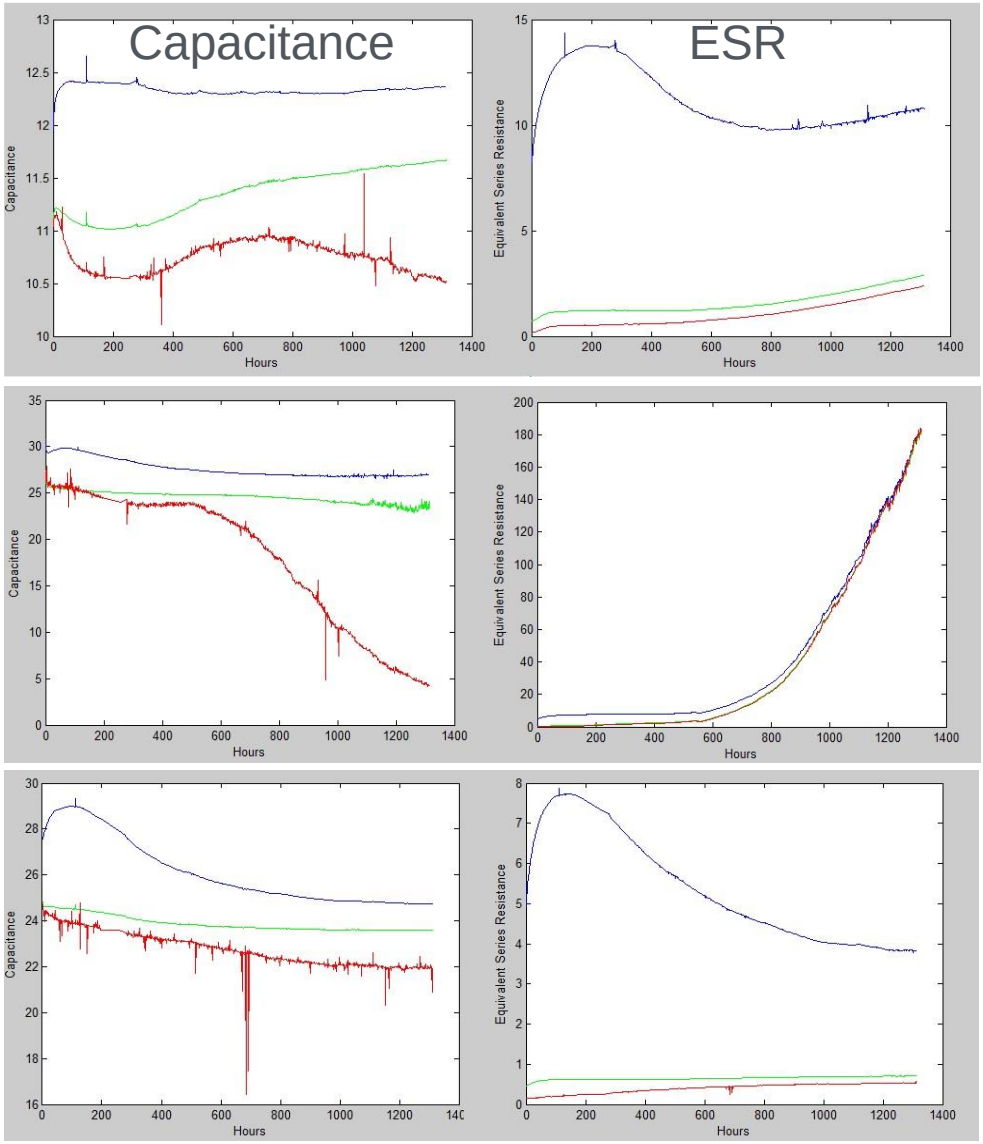
Blue – 100Hz
Green – 1kHz
Red – 10kHz

- All caps are evaluated beyond temperature spec
- ESR and Capacitance lifetime performances vary with excitation frequency

Vishay Capacitor

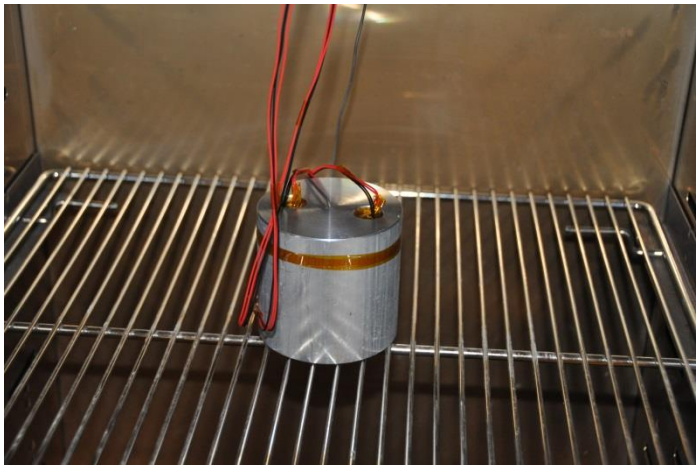
Kemet Capacitor

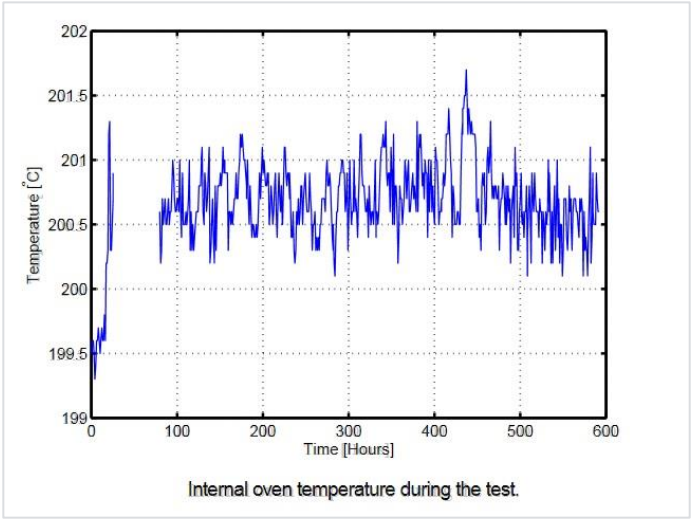
AVX Capacitor



FASTCAP SYSTEMS

Novel HT Ultracapacitor Test (500hr @ 200° C)

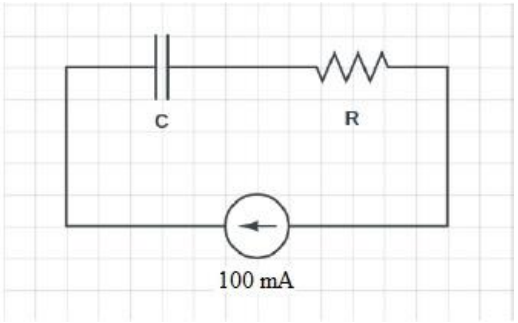


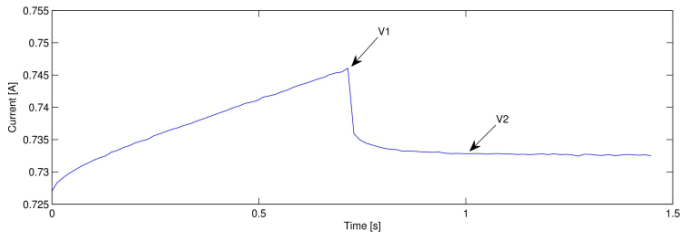


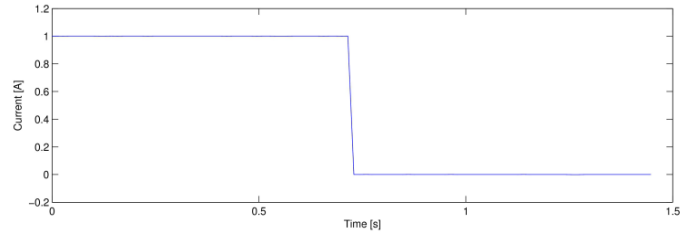
Internal oven temperature during the test.

$$ESR = \frac{\Delta V}{I} = \frac{V_1 - V_2}{0.1A}$$

$$C = \frac{2 * E}{V^2}$$



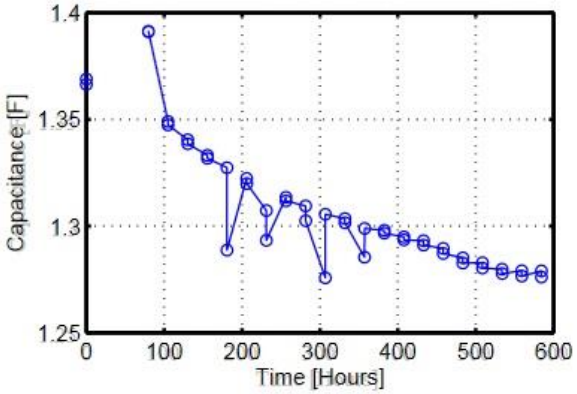




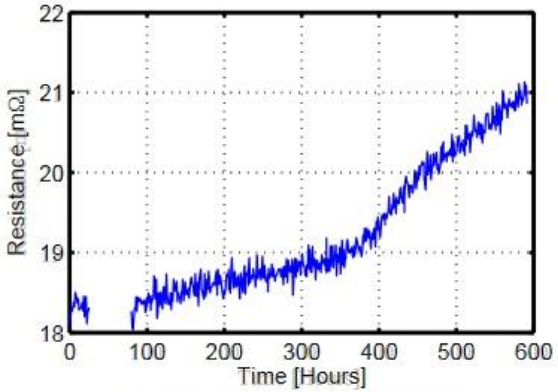
Example data from a commercial capacitor

Accomplishments, Results and Progress

FastCAP Results



Capacitance for cell UHT2014032602

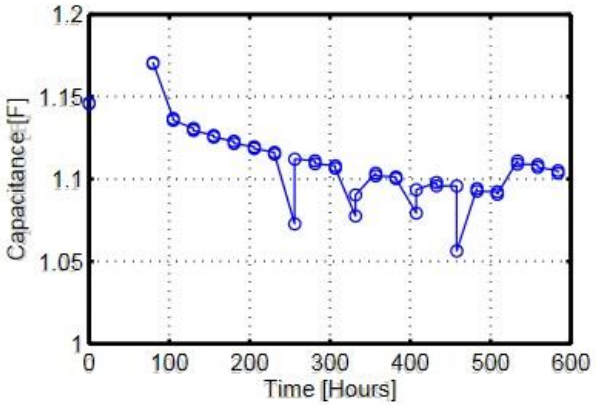


ESR for cell UHT2014032602

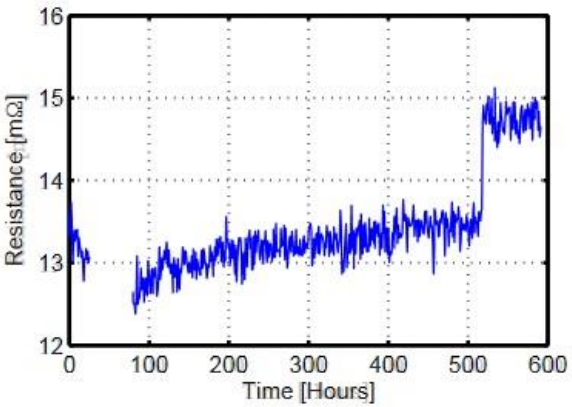
Cell 1

Initial Capacitance: 1.368F
Final Capacitance: 1.278F
% Cap Change: -6.56%

Initial ESR: 18.1mΩ
Final ESR: 20.86mΩ
% ESR Change: +15.23%



Capacitance for cell UHT2014032102



ESR for cell UHT2014032102

Cell 2

Initial Capacitance: 1.146F
Final Capacitance: 1.104F
% Cap Change: -3.63%

Initial ESR: 13.57mΩ
Final ESR: 14.66mΩ
% ESR Change: +8.02%

(Full SAND report posted on FastCAP website)

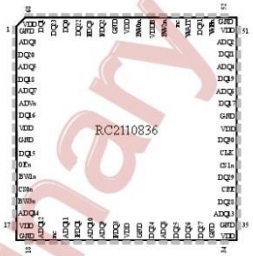
HT-RAM Testing

RelChip

RC2110836
8Kx36 Microcontroller RAM

FEATURES

- 8K x 36 Random Access Memory
- 5 volt Operation
- 3.4 volt Battery Back Up
- Fully Static Design
- Wide Operating Temperature Range
- Parity and Burst Mode Options
- RC10001 Compatible



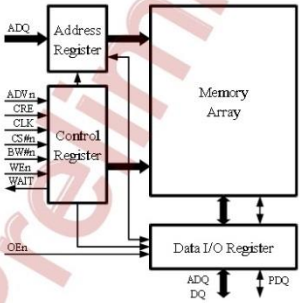
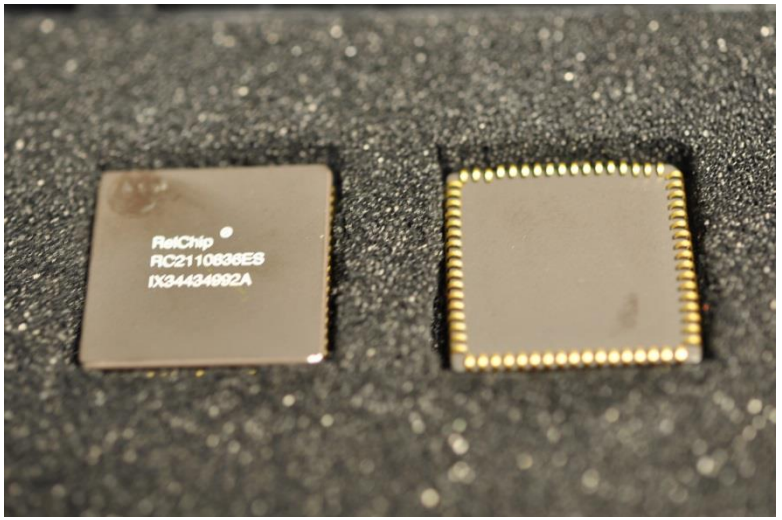
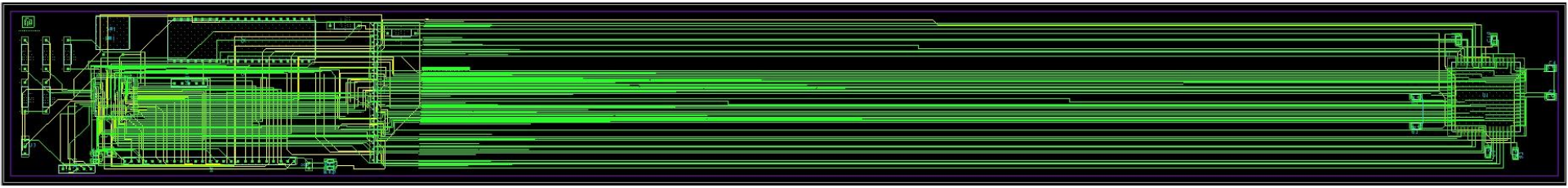


Figure 1: Block Diagram

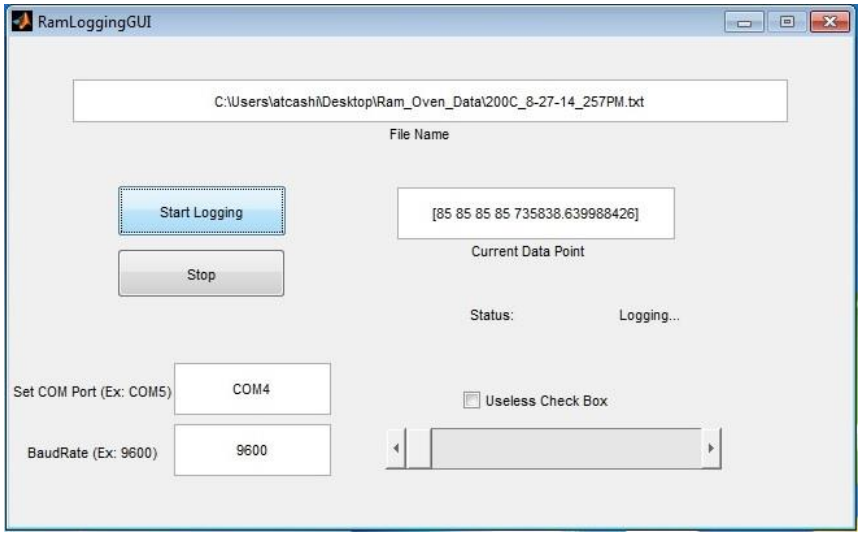
Preliminary





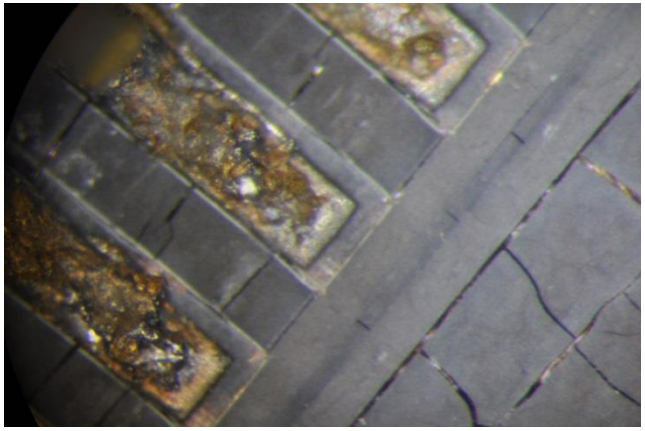
HT-RAM

- Tests on-going
- Initially, the test PCB failed before the RAM at 280° C
- Reconfiguration in process

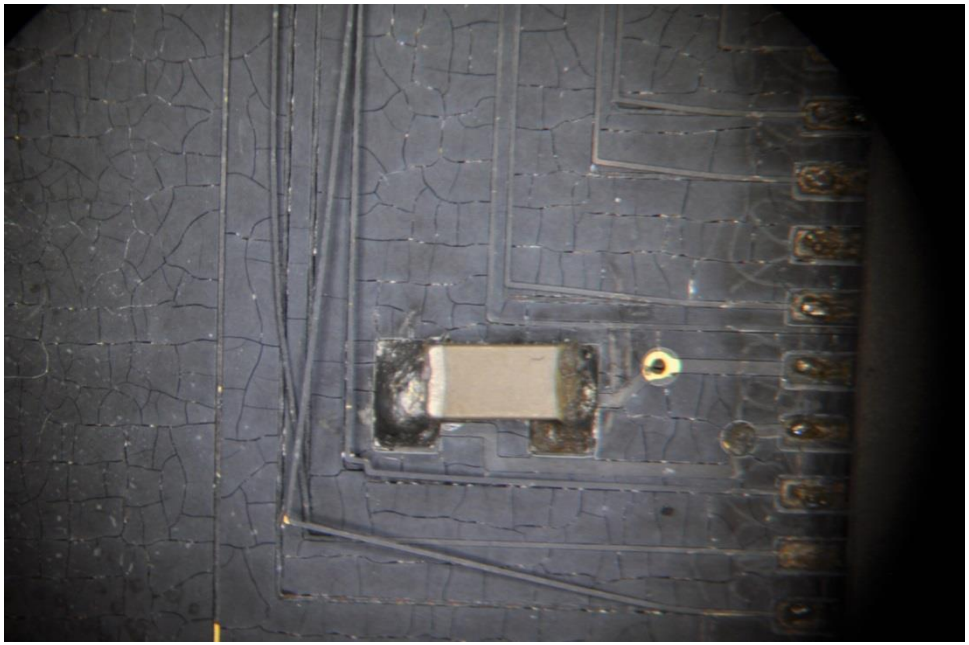


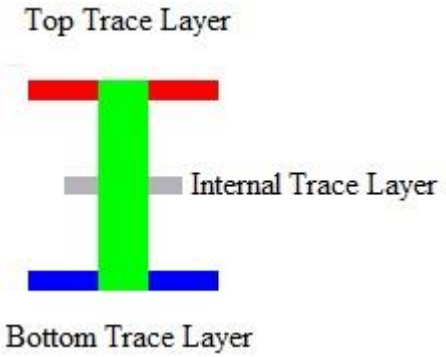
RelChip PCB Failure

Damaged Solder Joints



Delaminated and shorted traces





New PCBs have been developed with:

- **Matched thermal expansion rates between copper and substrate**
- **Trace work routed on internal layers**

Accomplishments, Results and Progress

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
FY(14) Issue a solicitation for Sandia HT Evaluation program	FedBizOps Solicitation Issued	2014
FY(14) Perform and make public a performance evaluation of a component deemed to have high potential value to geothermal tool designers.	Worked with FastCAP Systems to perform 3rd party verification. Results published/presented by FastCAP at GRC 2014.	2014
FY(15) Perform and make public performance evaluations of 4 components with a stretch goal of a 5th component.	3 types of COTS capacitors and a COTS Flash module have been evaluated and are scheduled for conference presentation.	04/2015
FY(15) Issue another open solicitation and communicate with component developers that are interested in the program.	Two companies, XREL Semi and Relchip have provided parts for Sandia evaluation. Tests will continue with more FastCAP parts.	Ongoing
FY(15) Present results at relevant conferences	Results of the three capacitor tests and the HT Flash evaluation will be presented at HiTEN 2015.	07/2015 Scheduled

Future Directions

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Milestone	Status & Expected Completion Date
- Results of four commercial off the shelf components will be presented at the High Temperature Electronics Network	On-Track 7/15
- The RelChip Silicon-On-Insulator RAM modules will be tested at 300C with the new Rogers 3000 PCBs.	On-Track 9/30/15
- Evaluation plan will be developed and tests will commence of more components from FastCAP Systems	On-Track 9/30/15
- In FY16, Tests of important components will continue to be conducted and the results shared publicly through the GDR and presentations/publications.	9/30/16

Summary

- High temperature tool developers suffer from a lack of components rated for geothermal temperatures.
- This project evaluates components to determine their suitability for use in high temperature geothermal tools.
- This project is assisting component developers with evaluation of new parts with high potential utility in geothermal tools.
- Evaluations are performed of commercial components beyond manufacturer temperature specifications to inform tool designers of expected performance.