Automotive Electronics in Extreme Environments

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Automotive Companies

NSF Center for Advanced Vehicle and Extreme Environment Electronics

A National Science Foundation Center

The Center for Advanced Vehicle and Extreme Environment Electronics (CAVE3) at Auburn University is dedicated to working with industry in developing and implementing new technologies for the packaging and manufacturing of electronics with special emphasis on the cost, harsh environment and reliability requirements of the vehicle industry.

Center personnel work directly with the member companies to identify challenges and opportunities for new materials, processes and approaches to the production of electronics. The member companies select the research projects. Semi-annual project reviews, visits, monthly updates and frequent phone calls maintain a close interaction between the industrial members and Center researchers. CAVE3 currently has 30 members teamed up with Auburn representing material, component, equipment and electronics assembly companies.

Researcher Spotlight

Prognostic health management (PHM) is a method for assessing the reliability of a system by monitoring the system in real time as it is used in the field. As the system wears out, but before failure, information that facilitates decision making about the future use of the system is delivered to the user. Learn more about this exciting technology here.

News

Call for Papers for IEEE PHM Conference, June 2012

Mechanical engineering professor appointed to National Academies committee

New mechanical engineering building opens with state of the art facilities

Awards

CAVE3 Student Wins Best Poster Award at IPACK 2011

Center faculty named IEEE fellow

CAVE3 Faculty Guest Editor for Special Issue of SME Journal of Electronic Packaging on PHM

CAVE3 at Auburn University

NSF Center for Advanced Vehicle and Extreme Environment Electronics

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CAVE3 Facts

- Started in 1999
- Located on Auburn University Campus
- Phase-III NSF-Center
- Research Focus on Harsh Envts
- 17-Faculty (Engr & Sciences)
- 53-Students
- 15-Laboratories
2002
CAVE3 Responsible for extracting infield modules with upto 175,000 miles on the odometer to develop revised qualification guidelines for thermal cycling for 1000 cycles down from 3000 cycles.

2003
CAVE3 Responsible for proving use of large BGAs in automotive modules on metal-backed substrates.
## Traditional Automotive Electronic Systems

<table>
<thead>
<tr>
<th>Category</th>
<th>Example Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine &amp; Power Train</td>
<td>EFI (electronic fuel injection), ECU (engine control unit), TCU (transmission control unit), KCS (knock control system), cruise control, cooling fans</td>
</tr>
<tr>
<td>Chassis &amp; Safety</td>
<td>Active 4-wheel steering, active control suspension, ABS (anti-lock brake system), TRC (traction control system), VSC (vehicle stability control), air bag system</td>
</tr>
<tr>
<td>Comfort &amp; Convenience</td>
<td>Preset steering wheel position, climate control, power seat, power windows, door lock control, mirror controls</td>
</tr>
<tr>
<td>Displays &amp; Audio</td>
<td>Radio (AM, FM, satellite), CD player, TV and DVD player, cellular phone, navigation system, instrument cluster</td>
</tr>
<tr>
<td>Signal Communications &amp; Wiring Harness</td>
<td>Communications bus, starter, alternator, battery, diagnostics</td>
</tr>
</tbody>
</table>

Core-Functionality Systems Enabled by Electronics

Driving Assists
• Antilock Braking System
• Traction Control System
• Park Distance Controls
• Power steering
• Power braking
• Electronic Stabilization Programme
• Adaptive Cruise Control
• Electronic Brake Force Distribution
• Rain Sensors

Safety Systems
• Airbags
• Emergency Braking System
• Early Crash Sensors
• Brake Disc Wipers
• Active Rollover Protection System

Navigation & Communication
• GPS
• Parking assist

Engine Control
• ECUs
• Electronic Fuel Injection
• Powertrain Control Module

Propulsion Systems
• Hybrid Engines
• Regenerative Braking

Source: Actel pioneering new markets for FPGAs in automobiles, EE TIMES
Flexible Electronics in Automotive Applications

Ref: The future is flexible in the automotive world, SmartKem, 2016

Courtesy of IDTechEx, Flexible and Printed Electronics in the Automotive Industry, Feb 17, 2016
How self-driving cars see the road

Autonomous vehicles rely on a host of sensors to plot their trajectory and avoid accidents.

- **Multi-domain controller**
  Manages inputs from camera, radar, and LiDAR. With mapping and navigation data, it can confirm decisions in multiple ways.

- **Camera**
  Takes images of the road that are interpreted by a computer. Limited by what the camera can “see”.

- **Radar**
  Radio waves are sent out and bounced off objects. Can work in all weather but cannot differentiate objects.

- **LiDAR**
  Light pulses are sent out and reflected off objects. Can define lines on the road and works in the dark.

Source: Delphi

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How Google is shaping the rules of the driverless road, Paul Ingrassia, Alexandria Sage and David Shepardson, Reuters, April 26, 2016
Automotive Temperature Extremes

Combustion Chamber: < 500°C
- Pressure Sensors

Engine Compartment: < 150°C
- Power Train Control
- Motor Control
- Transmission Control

Exhaust System: < 800°C
- Exhaust Sensors

Engine, Transmission: < 200°C
- Engine-mounted ECUs
- Integrated TCUs
- Shift-by-Wire

Wheel Mounted Components: < 300°C
- Brake-by-Wire
- Steer-by-Wire

# Automotive Temperature Extremes

## TABLE II

**AUTOMOTIVE TEMPERATURE EXTREMES (DELPHI DELCO ELECTRONIC SYSTEMS) [3]**

<table>
<thead>
<tr>
<th>Location</th>
<th>Typical Continuous Max Temperature</th>
<th>Vibration Level</th>
<th>Fluid Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>On engine</td>
<td>140°C</td>
<td>Up to 10Grms</td>
<td>Harsh</td>
</tr>
<tr>
<td>On transmission</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At the engine (intake manifold)</td>
<td>125°C</td>
<td>Up to 10Grms</td>
<td>Harsh</td>
</tr>
<tr>
<td>Underhood (near engine)</td>
<td>120°C</td>
<td>3 – 5Grms</td>
<td>Harsh</td>
</tr>
<tr>
<td>Underhood (remote location)</td>
<td>105°C</td>
<td>3 – 5Grms</td>
<td>Harsh</td>
</tr>
<tr>
<td>Exterior</td>
<td>70°C</td>
<td>3 – 5Grms</td>
<td>Harsh</td>
</tr>
<tr>
<td>Passenger compartment</td>
<td>70-80°C</td>
<td>3 – 5Grms</td>
<td>Benign</td>
</tr>
</tbody>
</table>

Automotive Operational Temperatures

Ambient Temperature Characterization

Temperature Instrumentation

Death Valley Gradient Ascent w/ Trailer
GCW=12,500 Outside Temp - 130° C

Mountain Punch Cycle
Highway
Hot Soak
City
Brake Load
Warm Start
City Driving

Automotive Operational Temperatures

- Max temperature increase for integrated electronics (organic PCB)
  - 16.6° C from ambient to power resistor
    - $\theta_{JA} \approx 26°$ C/W (2512 resistor)
  - 7.9° C from ambient to 3.3V regulator
    - $\theta_{CA} \approx 20°$ C/W (4x4mm QFN)
  - 4.1° C from ambient to solenoid driver
    - $\theta_{CA} \approx 3°$ C/W (bare die)

R. Thompson, Proc. SMTA/CAVE Workshop
Harsh Environment Electronics, Dearborn, MI,
Vehicle Speed Influences Under-Hood Ambient Temperature

Under Hood Ambient Temperature Profile
1 Year Interval Modeled

Component Challenges for Automotive Electronics

• Most common automotive packages: SOIC, TSSOP, SOT, TQFP, and QFN (growing)
• Traditional challenges still exist around 150°C/Grade 0 reliability
  • Materials: metallurgy, delamination, board level reliability
  • Thermal: max temperature, usage profiles, overtemp protection
• New challenges anticipated
  • Higher voltage & isolation
  • Lead free materials
  • New electrical current paths
• Change is complex
  • When is a new technology “automotive ready”?
  • What are the true standards and requirements?

Ref: Romig, M., IPACK2017-74398
Al pad with barrier: joint stability at high temperature

Au/Al after 66h at 300C

New pad metallurgy after 500h at 300C

In this example the absence of joint degradation with the new pad finishing is showed

Transition to Cu WB and Ag WB

Bonding Wire Shipment Share by Type

Source: SEMI
Oxidation of Cu-Al intermetallics during operation at high temperature and high humidity may cause oxidation of IMC, followed by crack initiation, and eventual failure.
Problem: Rapid Assessment of Propensity for Tin Whisker Formation in Platings

Tensile Stress

Compressive Stress
Problem: Measure High Strain-Rate Properties of SAC Alloys at Strain Rate of 1-100 sec$^{-1}$

**Graph:**
- **X-axis:** Strain ($\epsilon_{yy}$) from 0 to 0.02
- **Y-axis:** Stress ($\sigma_{yy}$) from 0 to 100 MPa
- **Graphs (a) through (d):**
  - 30 DAYS @ 25C + 10/sec @ 25C
  - 30 DAYS @ 25C + 35/sec @ 25C
  - 30 DAYS @ 25C + 50/sec @ 25C
  - 30 DAYS @ 25C + 75/sec @ 25C

**Legend:**
- 0.09375
- 0.0875
- 0.08125
- 0.075
- 0.06875
- 0.0625
- 0.05625
- 0.05
- 0.04375
- 0.0375
- 0.03125
- 0.025
- 0.01875
- 0.0125
- 0.00625
- 0

**Elasticity:**
- SAC105 30 Days Aging at 25C
CREEP

Example Data – Aging at 100 °C
The Time Duration Before the Cross-Over Depends on the Composition of the SAC Alloy and the Aging Temperature. Increased Silver Content Increases the Aging Time Required Before the Cross-Over Occurs.
Wire Harnesses in Automobiles

“About 50 MCUs are found in mid-priced cars, almost 140 in high-end models. This cabling—and the harnesses involved—makes up the third heaviest and costliest component in a car, right behind the chassis and engine.... and with more features being added each new model year, the harnesses are getting bigger and heavier. The average is now about 100 kilograms”

It Takes a Lot of Wiring to Keep a Modern Vehicle Moving (Witness this Bentley’s Harness), J. P. Huffman, Car and Driver, May 23, 2016.
Fewer Wires, Lighter Cars, Kathy Pretz, The Institute, 12 April 2013

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In-Mold Electronics

Applications
Controls in automobiles and domestic appliances.

Advantages
By removing bulky physical switches, significant cost and weight savings can be achieved.

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>COMPOSITION</th>
<th>PRODUCT CODE</th>
<th>FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Mold Electronics</td>
<td>Silver</td>
<td>ME60x</td>
<td>Formable conductors</td>
</tr>
<tr>
<td>In-Mold Electronics</td>
<td>Dielectric</td>
<td>ME77x</td>
<td>Formable dielectric, UV and solvent cure</td>
</tr>
<tr>
<td>In-Mold Electronics</td>
<td>Transparent</td>
<td>ME801</td>
<td>Formable transparent conductor</td>
</tr>
<tr>
<td>In-Mold Electronics</td>
<td>Silver</td>
<td>ME901</td>
<td>Conductive adhesive for LED attach</td>
</tr>
<tr>
<td>OLED Lighting</td>
<td>Silver</td>
<td>9169</td>
<td>Bus lines, good adhesion to ITO</td>
</tr>
<tr>
<td>OLED Lighting</td>
<td>Silver</td>
<td>PE410</td>
<td>Ink-jet nano-Ag for bus and grid lines</td>
</tr>
<tr>
<td>LED Lighting</td>
<td>Silver</td>
<td>502x/5064H</td>
<td>High conductivity signal lines</td>
</tr>
<tr>
<td>LED Lighting</td>
<td>Dielectric</td>
<td>5056</td>
<td>Flexible solder mask and white reflector</td>
</tr>
<tr>
<td>LED Lighting</td>
<td>Ag/Cu</td>
<td>CB230</td>
<td>Solderable contact pad</td>
</tr>
</tbody>
</table>

Ref: Courtesy of DuPont

NSF Center for Advanced Vehicle and Extreme Environment Electronics
Engine Control Module

Reference:
Toyota Electronic Throttle Webinar, March 12, 2010
On-Board Diagnostics

OBD-II Connector and Fault Codes Explained,
Kiril Mucevski, May 12, 2015

OBD-II Code Reader

Trouble Code SubSystem
B – Body
C – Chassis
P – Powertrain
U – Network Communication

Affected SubSystem
1 – Secondary Air Injection System
2 – Fuel System
3 – Ignition System
4 – Exhaust Monitoring System
5 – Idle Speed Control or Cruise Control
6 – Input / Output Signal from ECU
7 and 8 – Transmission System

Type of Code
0 – Standardized Code (ISO/SAE)
1 – Manufacturer Specific Code

Specific Code (Exact Problem)
02 – indicates for misfire detected in the 2nd cylinder
Overview of Prognostic Health Management for Systems @CAVE3
cave³ Prognostics Framework

Leading Indicators of Failure

Thermo-mechanics

Interrogation of Latent Damage

Redeployment Decisions

Damage Progression

$ t = 0, 1, 2, 3, \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots T-1, T, T+1, \ldots \ldots \ldots \ldots$

Shock and Vibration

Feature Extraction and Damage Assessment

Damage Pre-Cursors

System Self-Load

Physics-Based Models

Multiple Sensor Data

Condition Diagnosis

Damage Progression

Remaining Useful Life

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Problem: Remaining Useful Life Assessment of Board Assembly Under Vibration @CAVE3

Kalman Filter Based RUL
Problem: Prognostication of PBGA Assembly Anomalies and Fault Mode Classification @CAVE3

Karhunen Loéve Transform

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Battery Technology in EV

Battery in a Tesla S Model chassis. The 85kWh battery has 7,616 type 18650 cells in parallel/serial configuration.

Source: Tesla Motors

Battery Technology in EV

Driving range as a function of battery performance. A new EV battery only charges to about 80% and discharges to 30%. As the battery ages, more of the usable battery bandwidth is demanded, which will result in increased stress and enhanced aging.

Prognostication of SOC for Batteries @CAVE3

Data Logger

Work Station

NI Labview Environment

Source Meter

Load

Temperature of the Battery

Voltage of the Battery

Current of the Battery

Charge Profile Control Signal

Selection Signal

Discharge Profile Control Signal

Lithium Battery

Environmental Chamber

Current Transducer

5V 2.5V

Uc Vref Vout


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Effect of Environment on SOC

Battery Capacity and Normalized Capacity

Normalized Capacity vs Cycle Number at Different Test Condition

Summary and Conclusions

• Proliferation of electronics in automotive platforms requires the survivability assurance of advanced semiconductor packaging in harsh environments.

• Mitigation of risk with the use of new material, interface and assembly architectures requires design of damage tolerant structures in addition to advancements in understanding of failure mechanisms and acceleration factors.