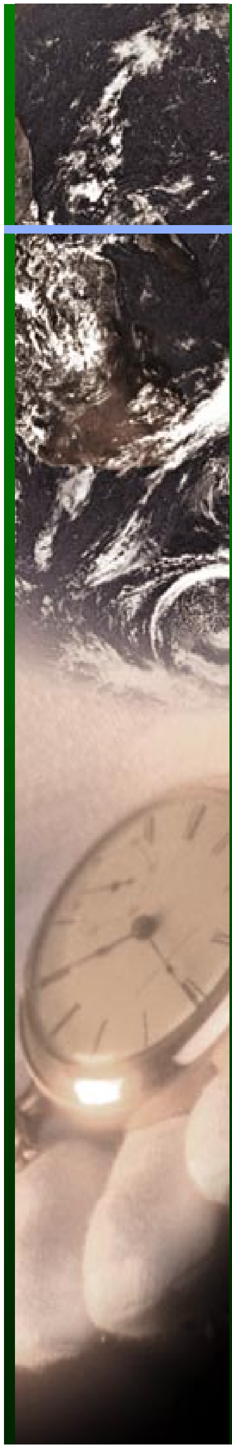

Thermal Performance of EV and HEV Battery Modules and Packs

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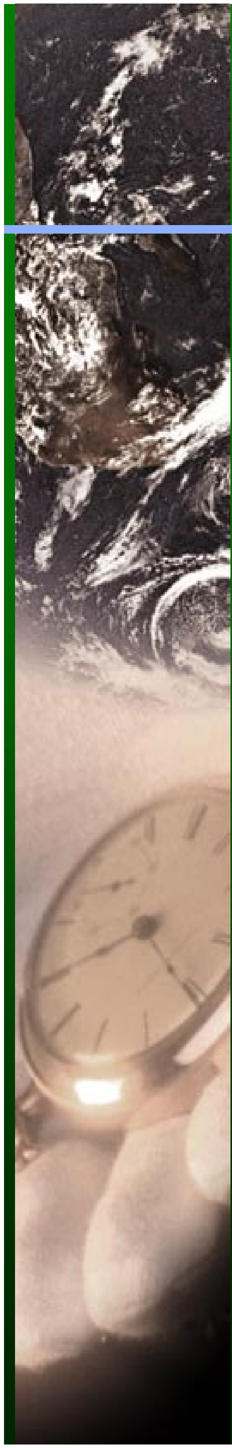

Acknowledgment

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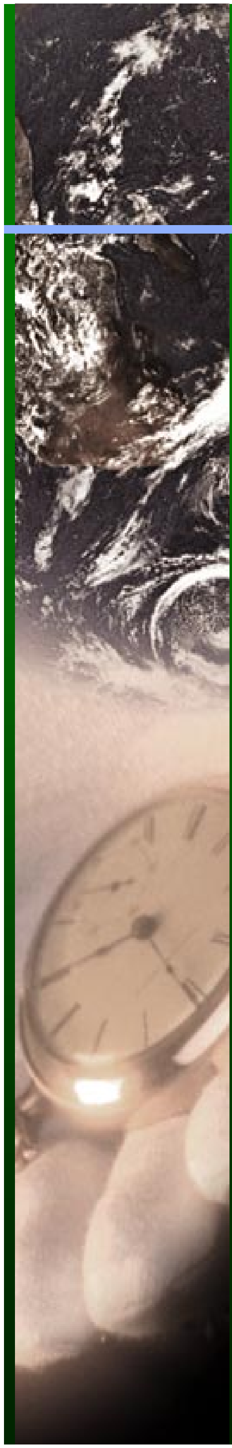
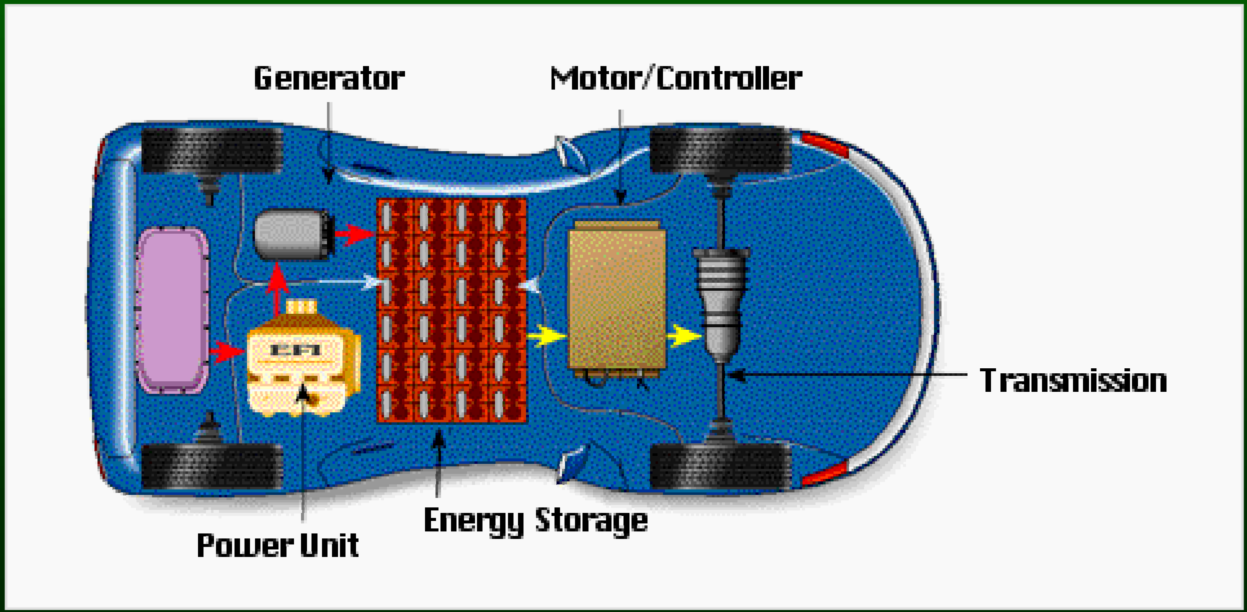


Presentation Outline

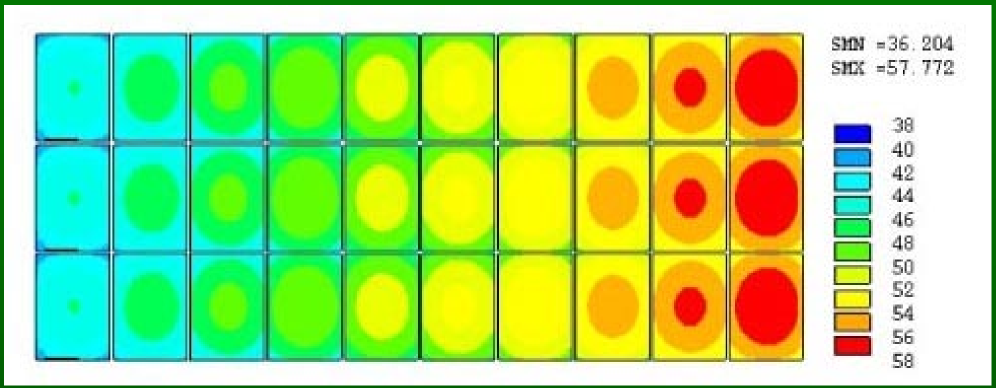
- Importance of thermal management
- Thermal management and analysis
- Typical results
- Thermal imaging
- Measuring heat generation
- Summary

Importance of Thermal Management

- HEV/EV performance and life-cycle cost is influenced by battery pack
- Temperature affects battery module/pack performance and life



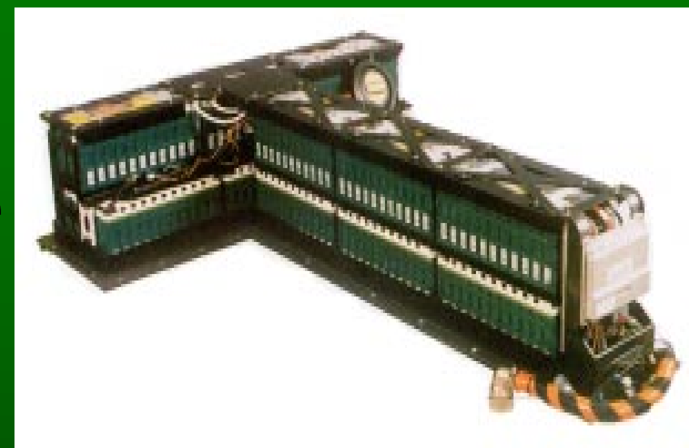
Importance of Thermal Management



- Uneven temperature distribution in a pack leads to unbalanced modules and reduced performance
- Pack thermal management is required, particularly for high power batteries in HEVs

Thermal Management System

- Desired attributes
  - Small temperature variation within a module and within a pack
  - Optimum temperature range for all modules



- Requirements
  - Compact, lightweight, and easy to package
  - Reliable and serviceable
  - Low-cost and low parasitic power

Thermal Analysis for Thermal Management

- Module/pack thermal analysis aids in designing better thermal management systems
- We used finite element analysis and heat transfer principles to obtain thermal performance
  - 2-D or 3-D
  - Steady-state or transient

Thermal Analysis of a Battery Pack

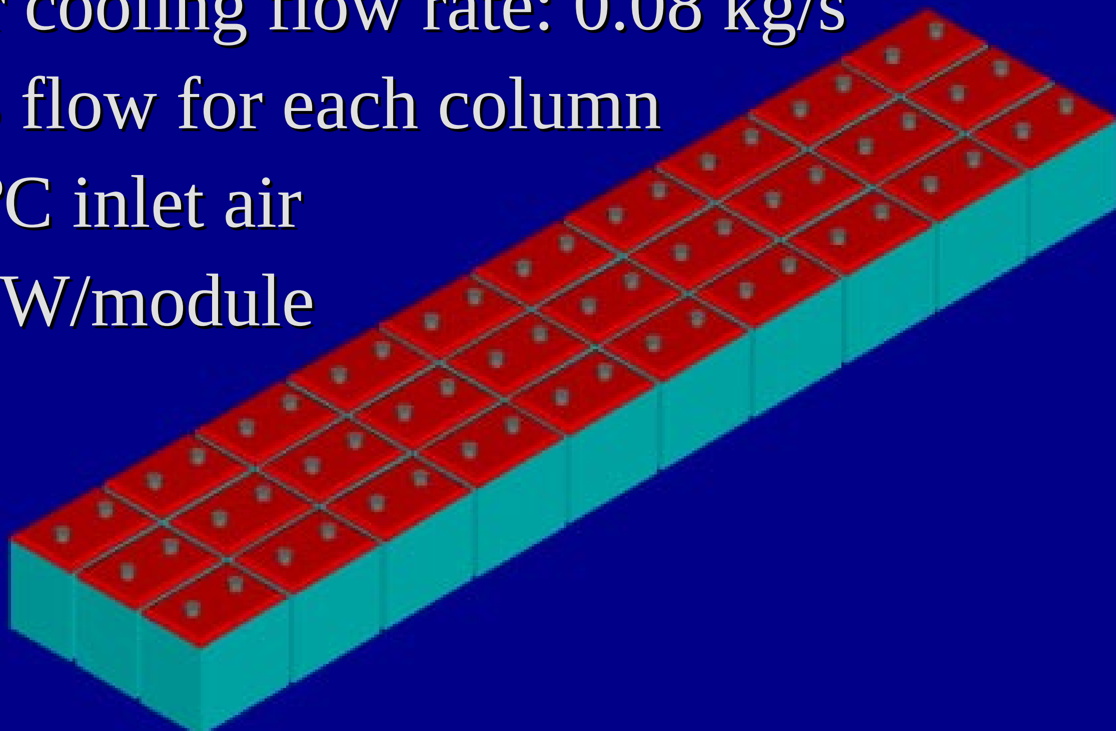
30 Modules

Air cooling flow rate: 0.08 kg/s

1/3 flow for each column

25ºC inlet air

35 W/module



Air circulated equally around each module

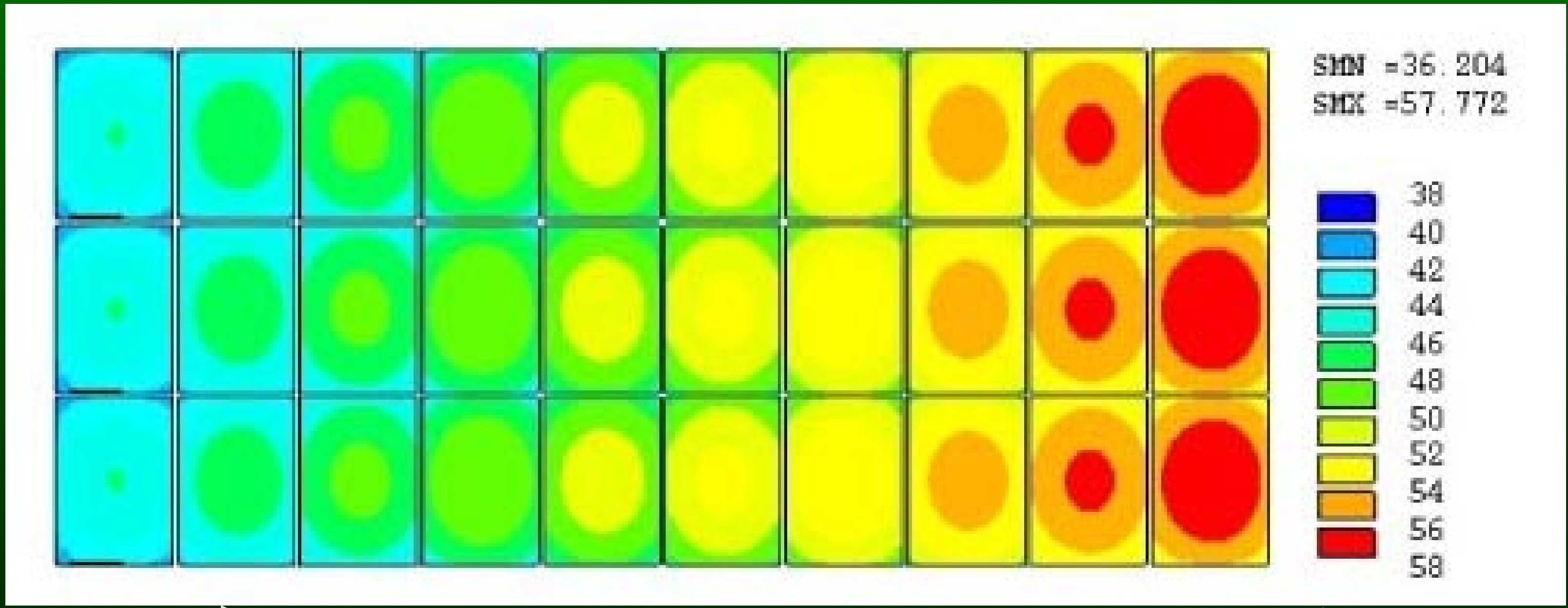
Air side heat transfer coefficient of 35 W/m^2K

Steady-State, 2-D Pack Results

Temperature distribution with air flow rate

Uniform heat generation of 35 W/module

Tmax,core = 58ºC, Tmin,core =40ºC



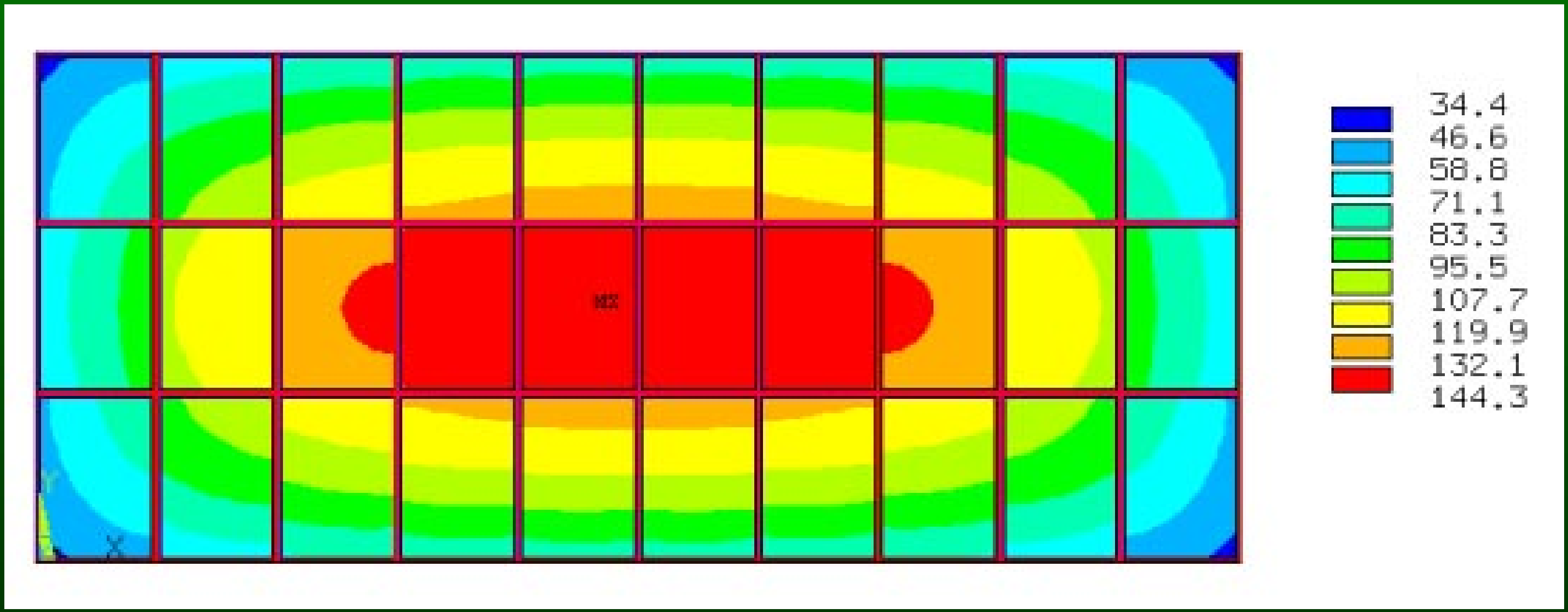
Air entering at 25ºC

Air leaving at 38ºC

Steady-State Closed Pack Results

Temperature distribution with no air flow

Tmax = 144ºC, Tmin =40ºC

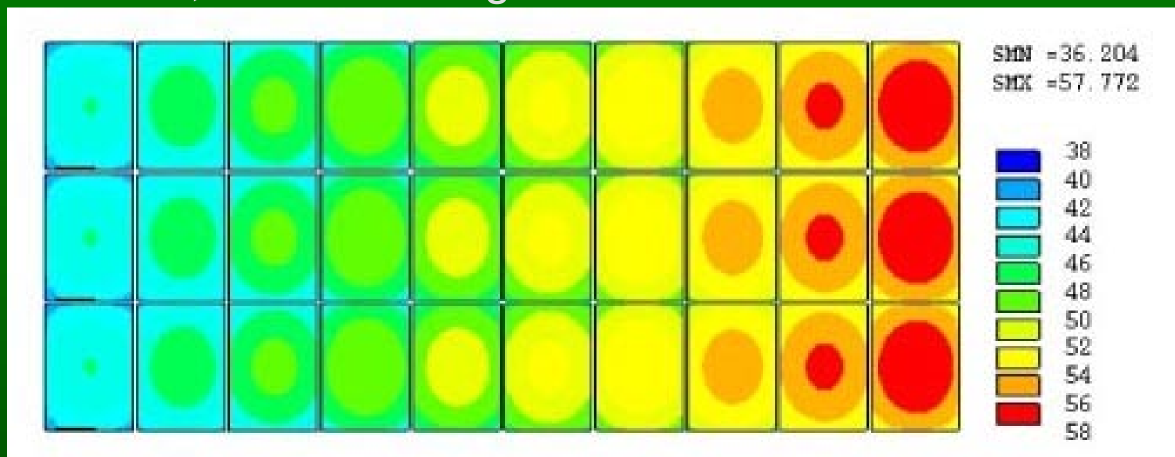


Assuming some heat loss from the sides

Uniform heat generation of 35 W/module

Steady-State, 2-D Pack Results

Air entering at 25ºC



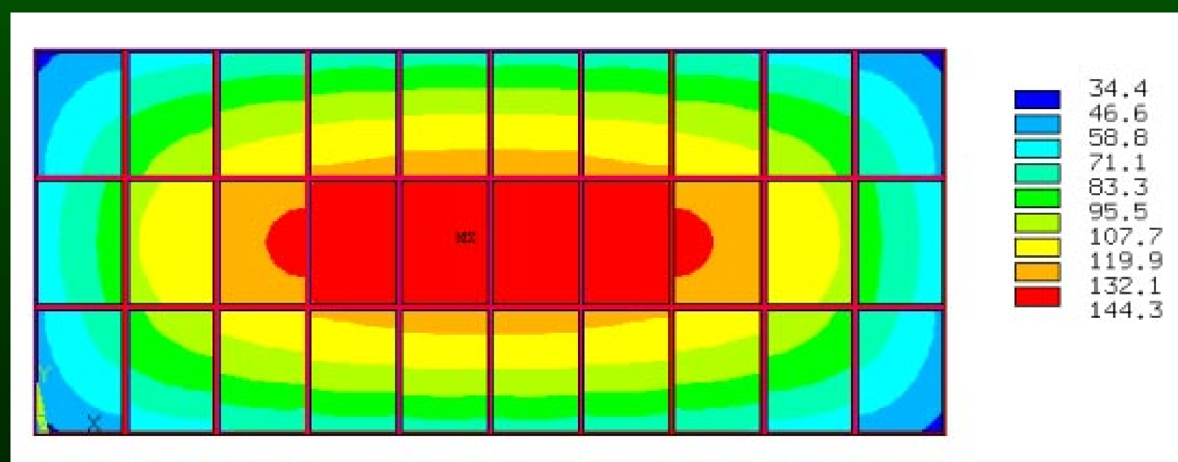
Open, with air flow

Tmax = 58ºC
Tmin =40ºC

Uniform heat generation of 35 W/module

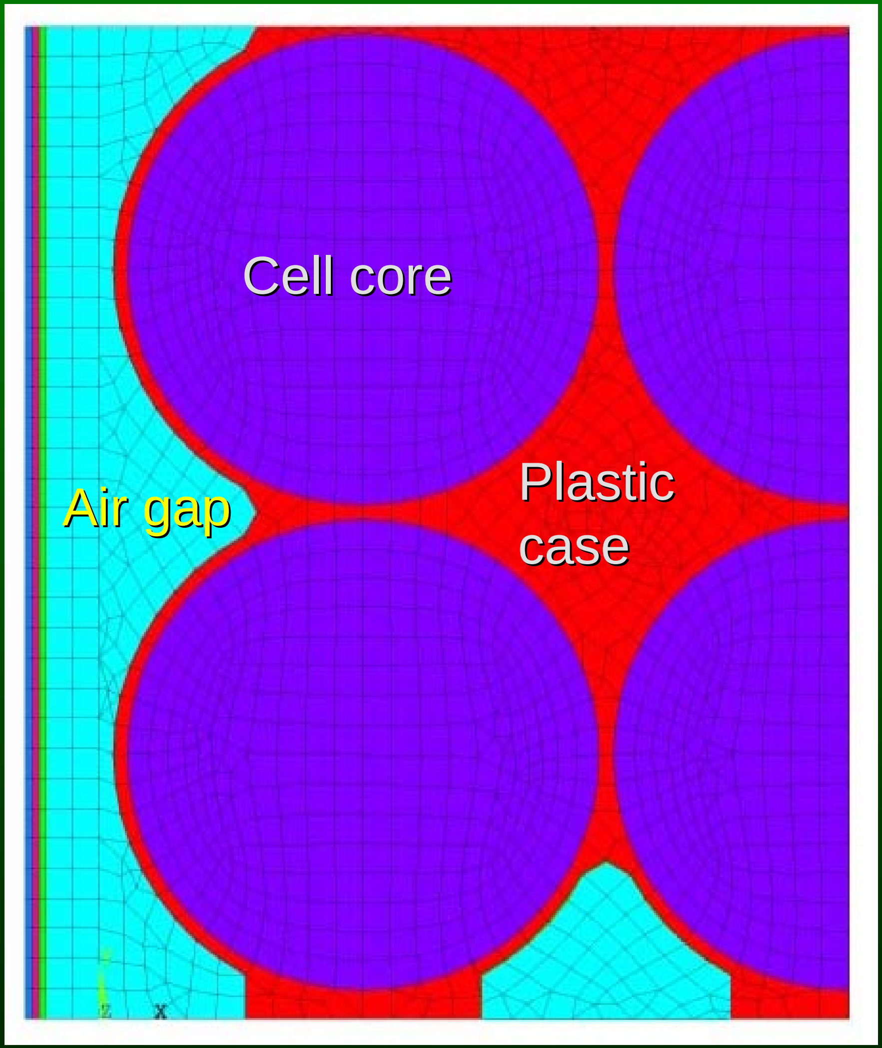
Closed, no flow

Tmax = 144ºC
Tmin =40ºC



Analyzing an HEV Module

- Spiral-wound
- Lead acid
- High power
- 12 cells , 24 V
- Analyzed 1/4 of module due to symmetry
- Air cooled at 25ºC

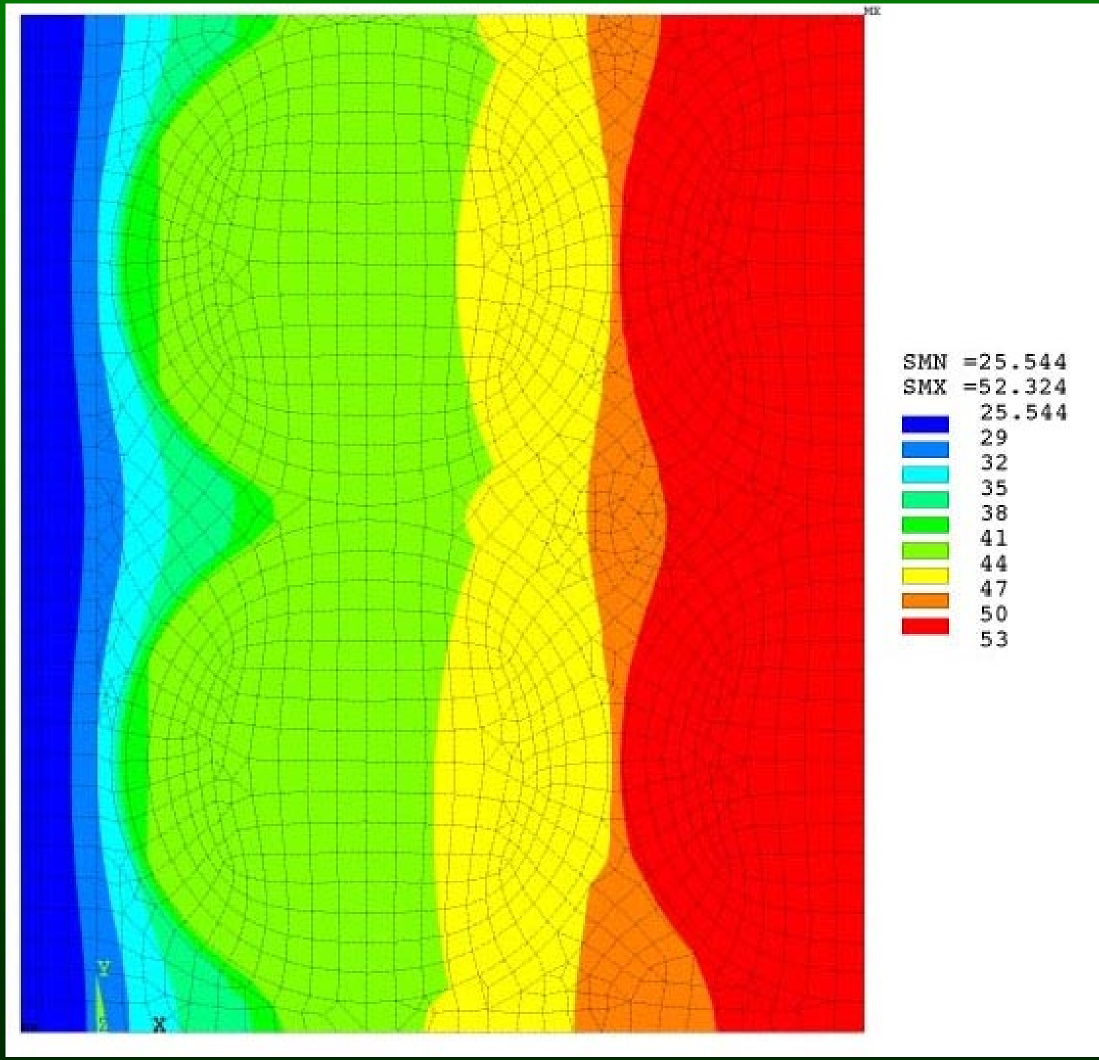


Thermal Performance of the HEV Module

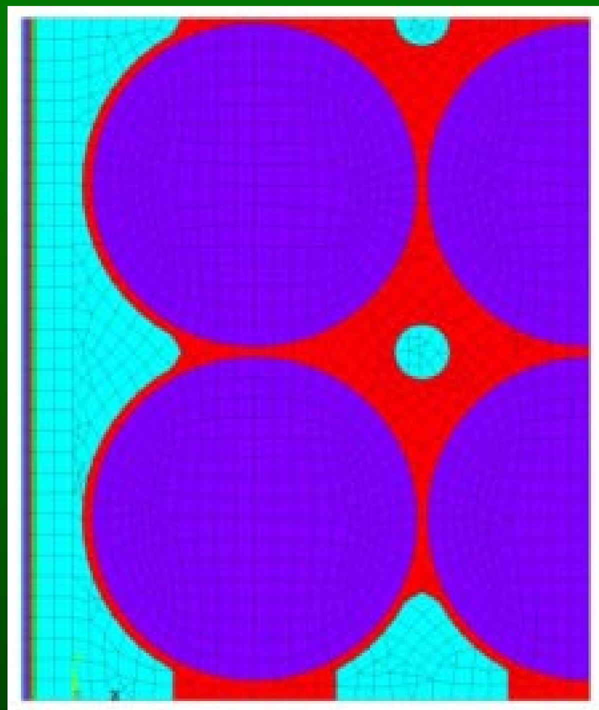
Steady State, 2-D

Tmax = 53ºC

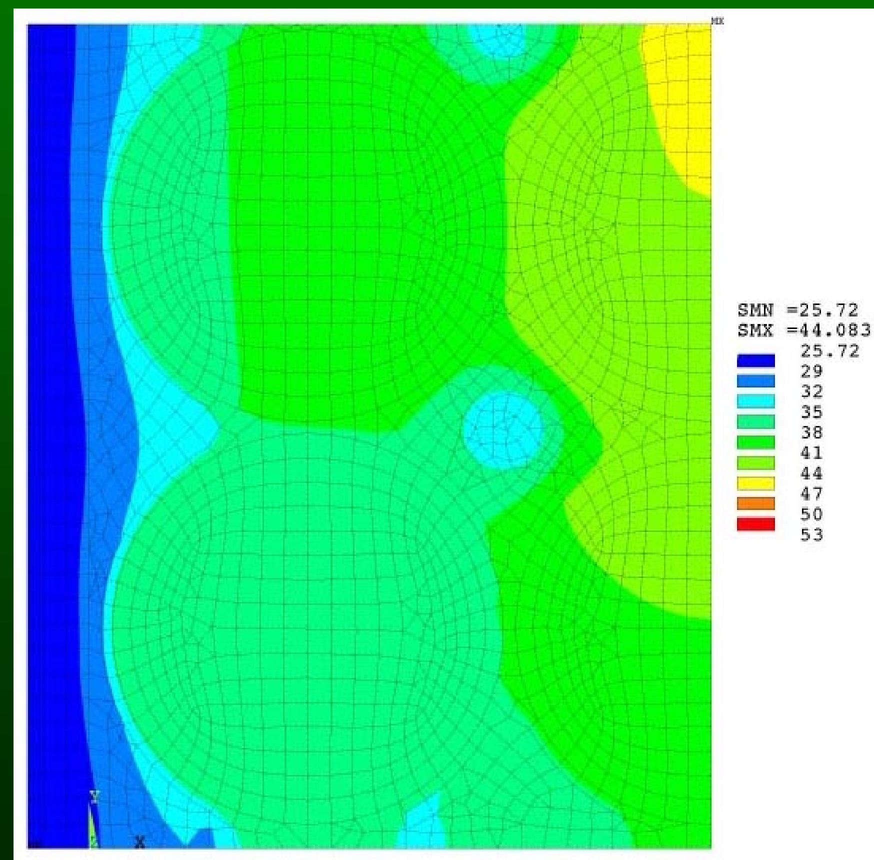
Delta Tcore = 13ºC



Thermal Performance of Module with Cooling Holes



Cooling holes were added.
Everything else remained the same.



Steady State

Tmax = 44ºC

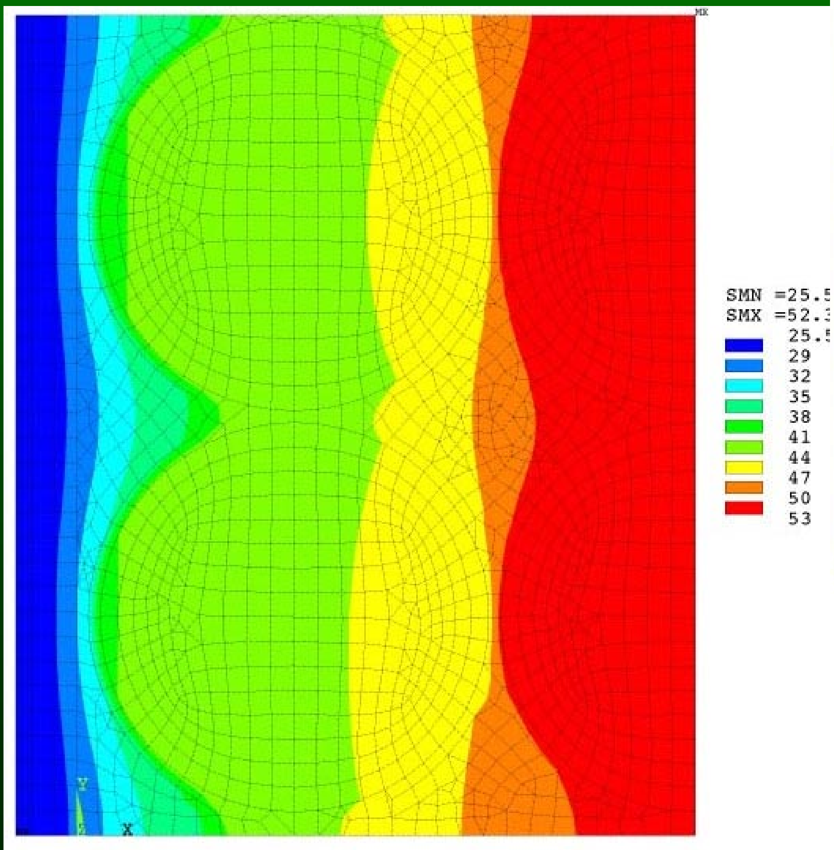
Delta Tcore = 9ºC

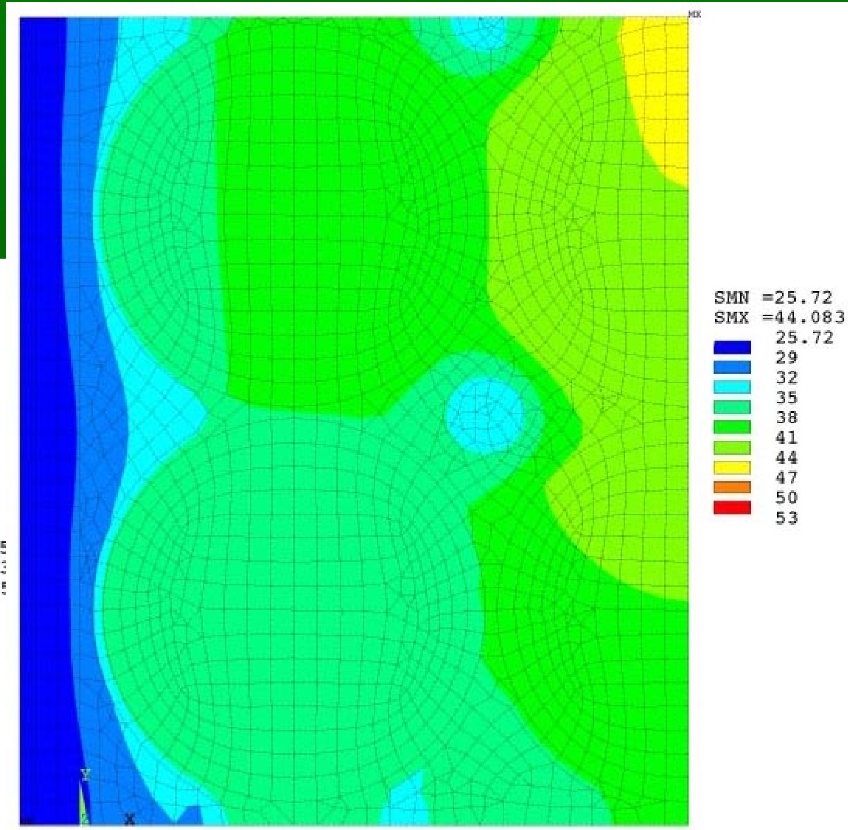
Thermal Improvement by Adding Cooling Holes

No Holes

Tmax = 53ºC

Delta Tcore = 13ºC





With Holes

Tmax = 44ºC

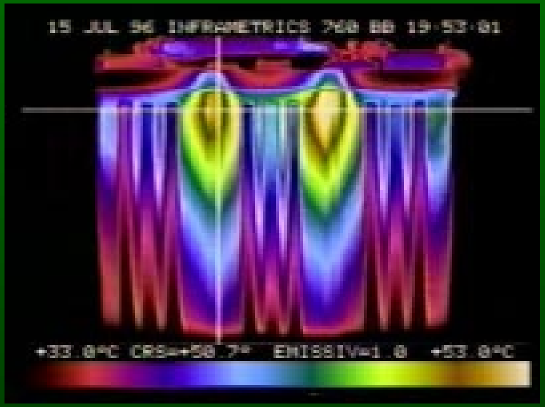
Delta Tcore = 9ºC

Optima HEV Modules Use Cooling Holes

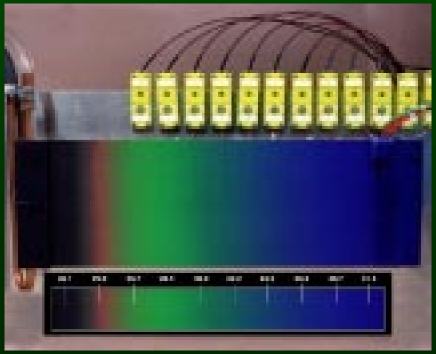
Thermal Imaging

Useful methods to obtain information on thermal behavior of battery modules and packs for model validation and diagnostics

➤Infrared Thermography



➤ Liquid Crystal Thermography (temperature-sensitive paint)



Infrared Thermal Imaging

Measuring infrared radiation from an object and converting its surface temperature readings

- Wide range
- Accurate
- High resolution
- Non-intrusive
- Need IR-transparent materials

IR Thermal Image of an HEV Module

1st Generation Prototype

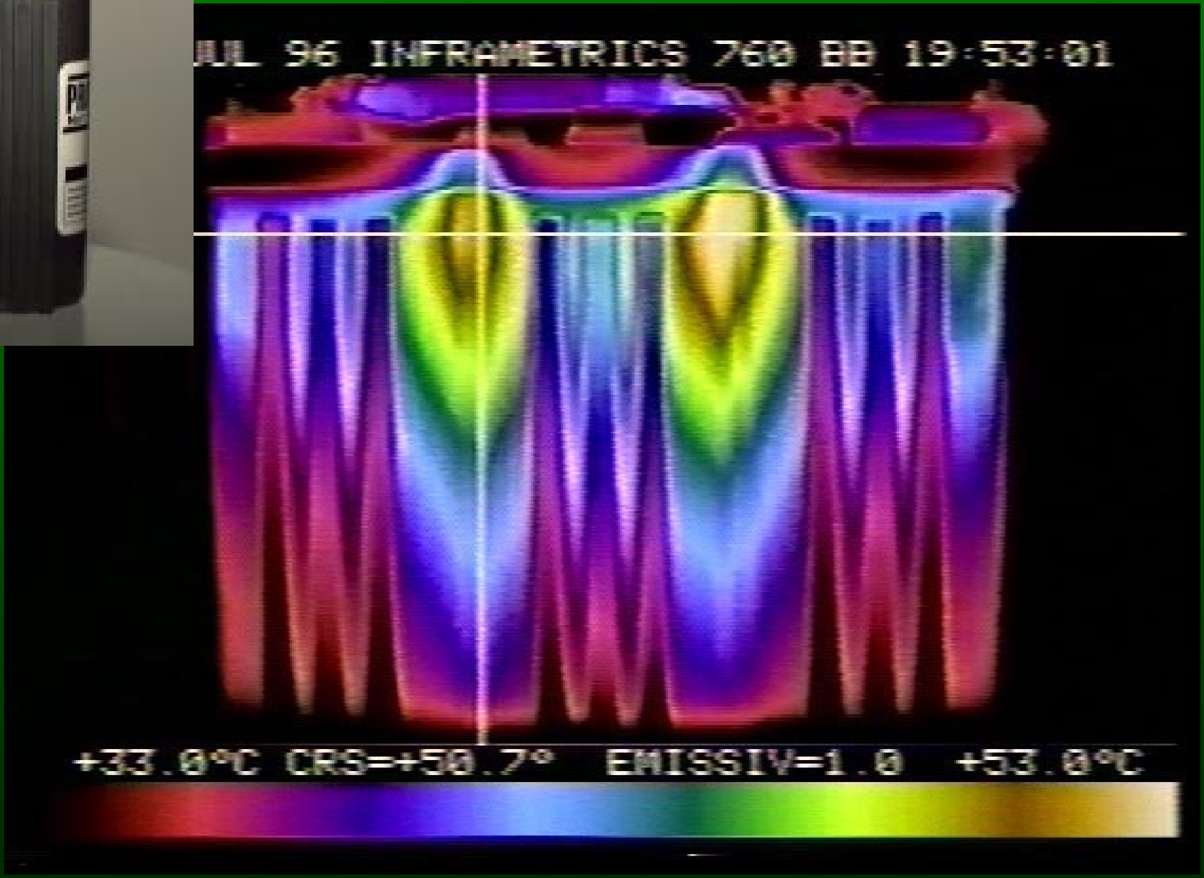
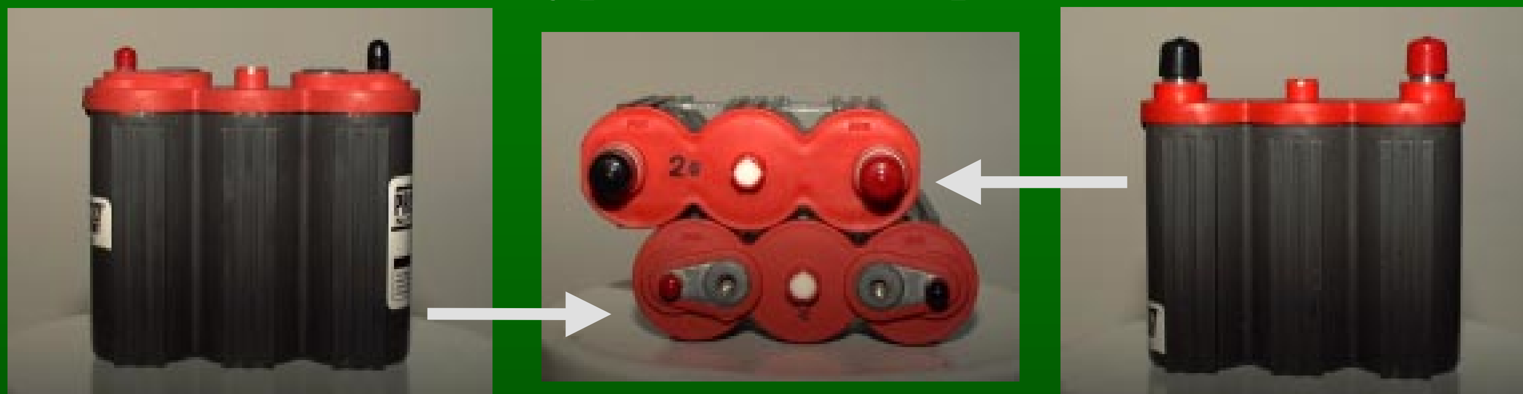
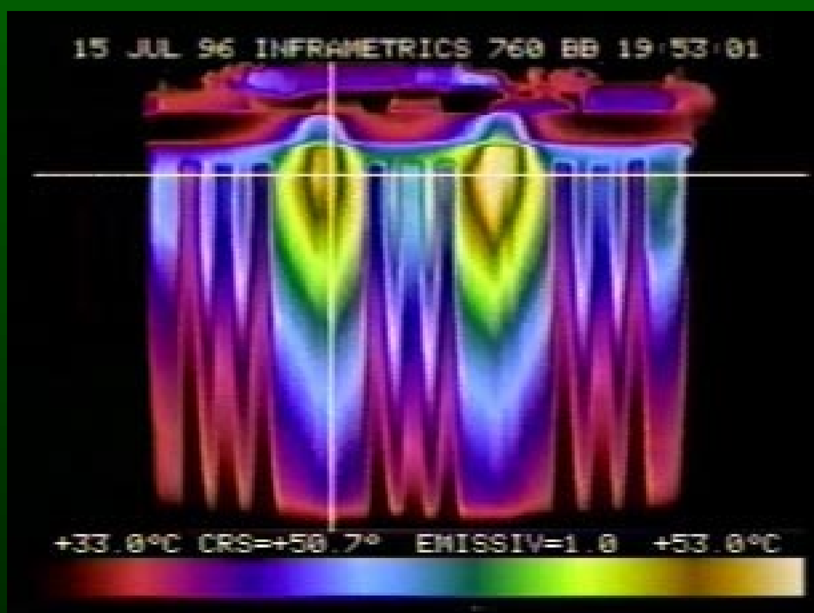


Image taken after a large current peak during HEV cycling

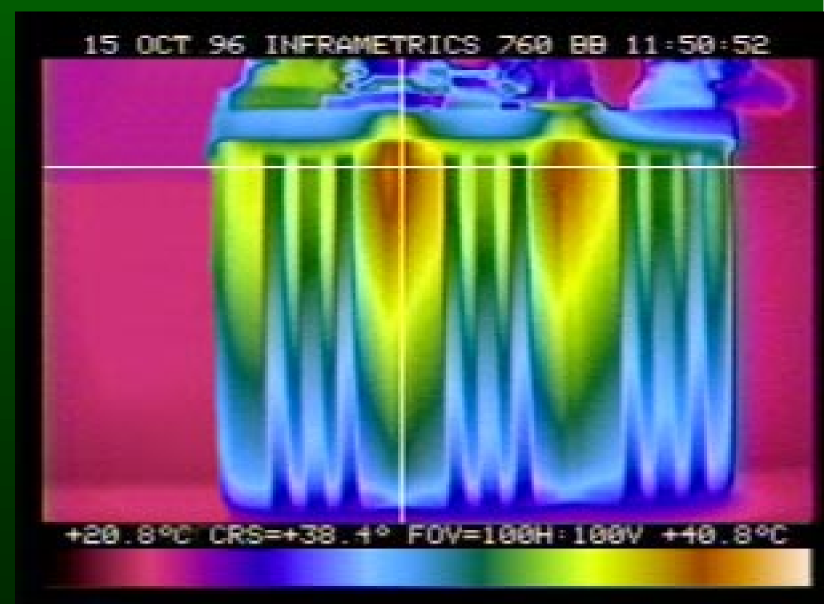
IR Thermal Images for Diagnostics

1st Generation Prototype | Improved Next Generation



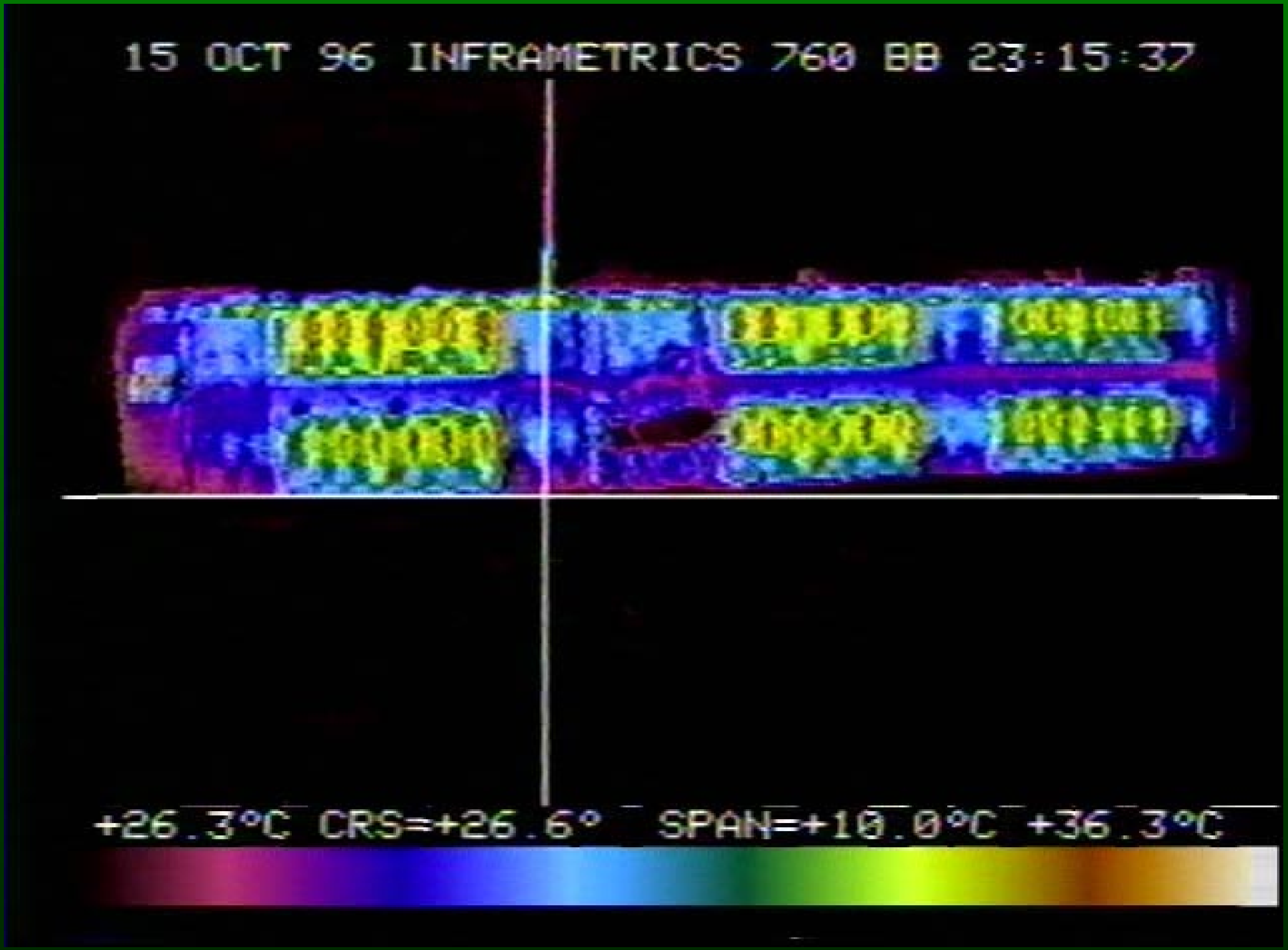


Tmax = 53ºC



Tmax = 41ºC

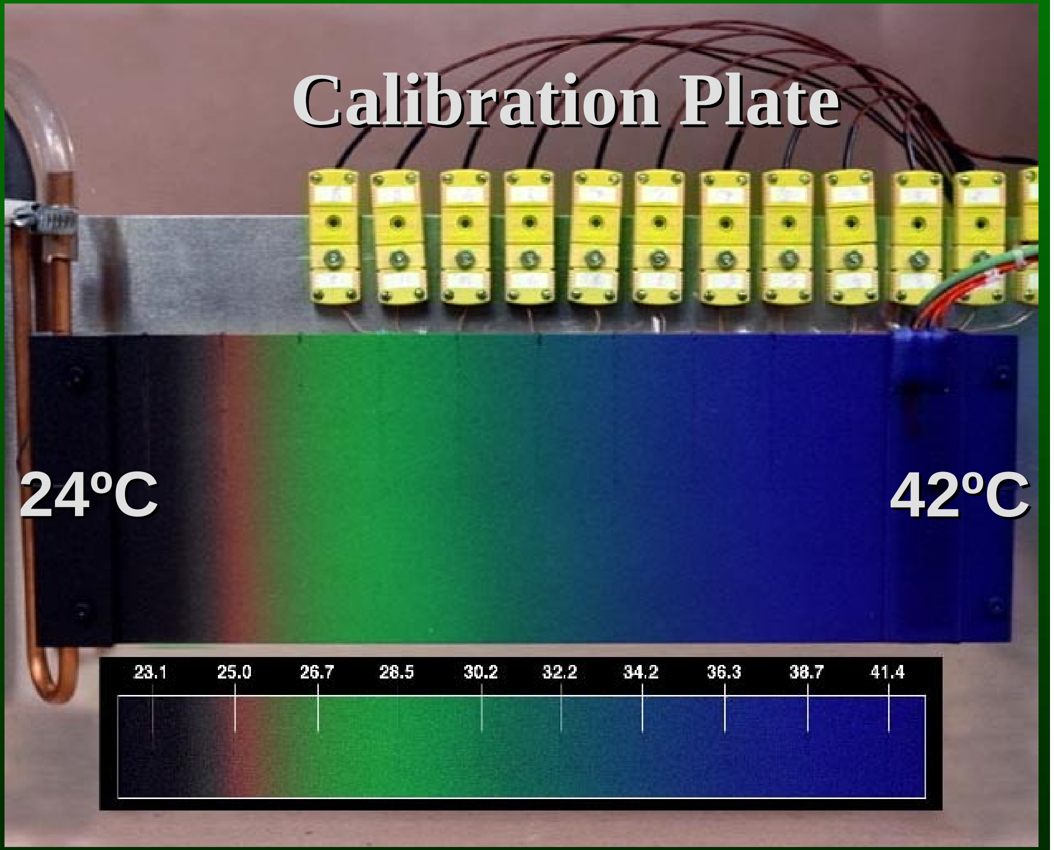
IR Thermal Image of a Battery Pack



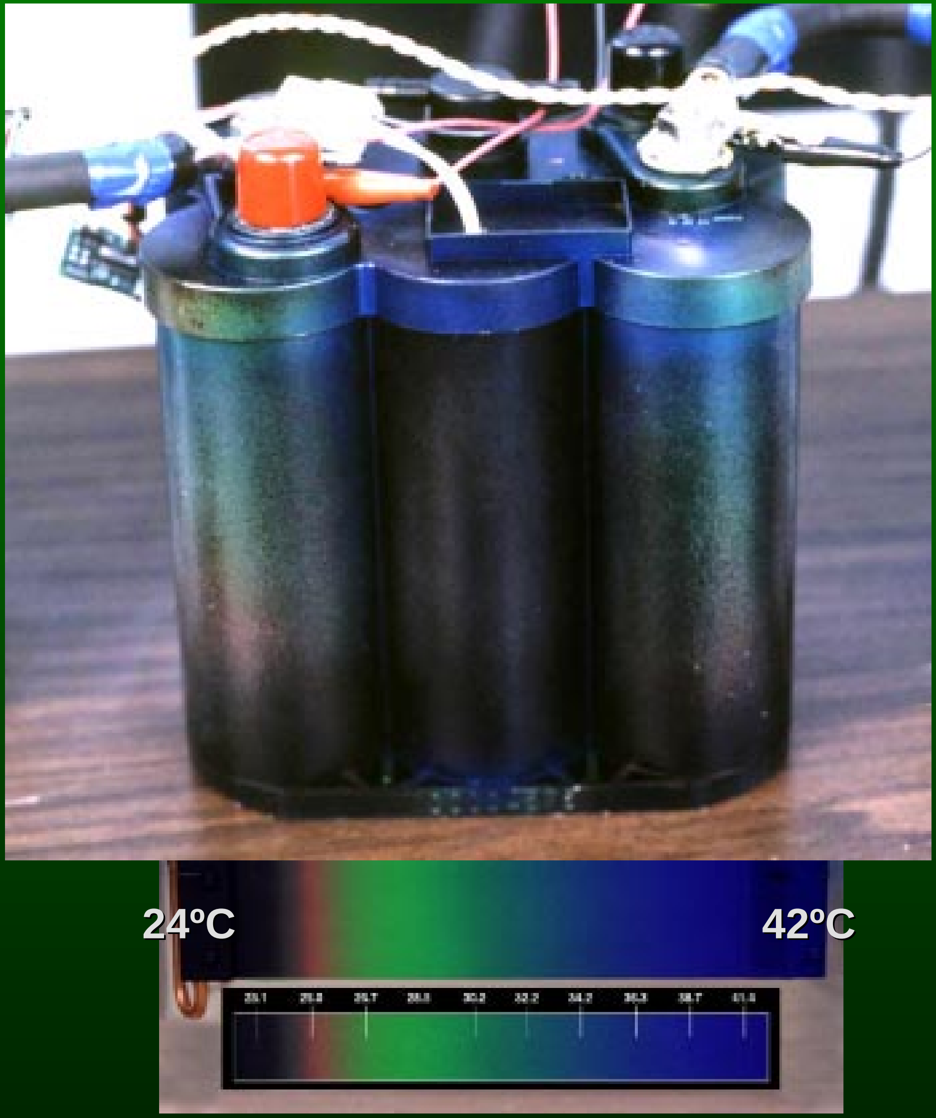
Liquid Crystal Thermal Imaging

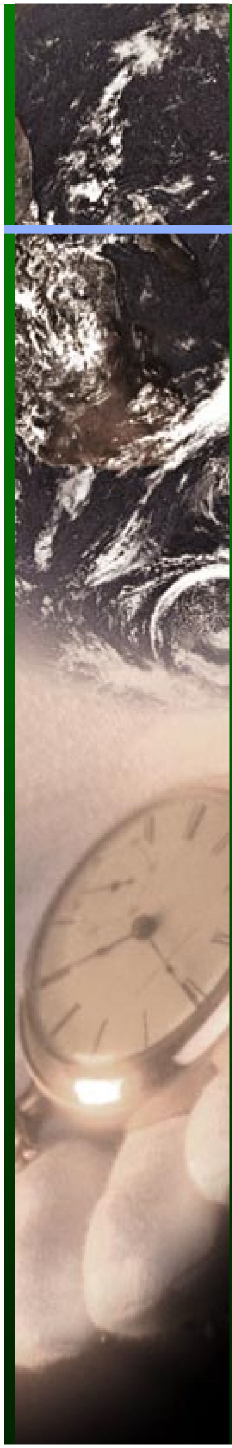
Painting an object's surface with a temperature-sensitive liquid crystal material

- Specified range
- Relatively accurate
- Non-intrusive
- Can be seen through any transparent material



LC Thermal Image of a Module





Battery Heat Generation Measurement

- To properly design a pack's thermal management system, accurate data on heat generation from modules under various charge/discharge profiles are needed
- We are using a calorimeter and a cycler to measure heat generation from large modules under any battery cycling profile

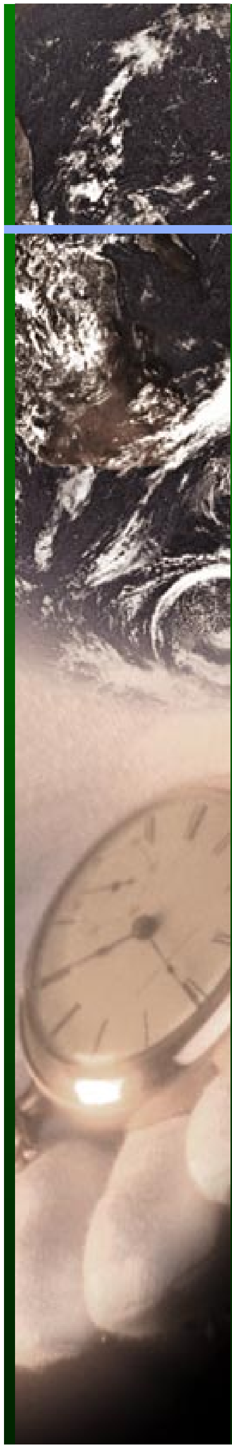
Battery Calorimeter for Large Modules

Predicting thermal performance requires knowledge of heat generation from full-size modules.

A High Power Battery Cycler

- Cycling modules in the calorimeter
- Capable of simulating any driving power profile
- Up to 530 amps

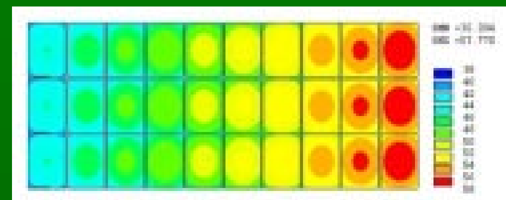
A Unique Calorimeter/Cycler for EV/HEV Batteries

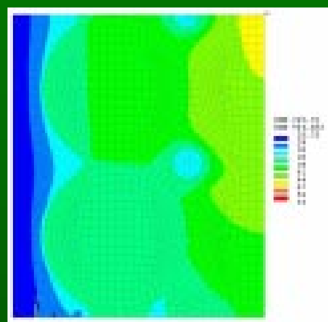


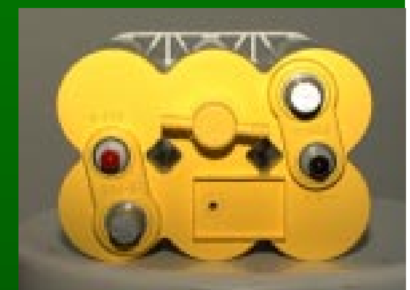
Summary

- Thermal management can improve performance and life cycle for EV/HEV battery packs.
- Thermal analysis is needed to properly design a battery module and pack thermal management system.
- Thermal imaging can be used to evaluate temperature distribution within modules/packs.
- A calorimeter/cycler is used to obtain heat generation data from modules and verify analytical predictions.

For Questions and Information







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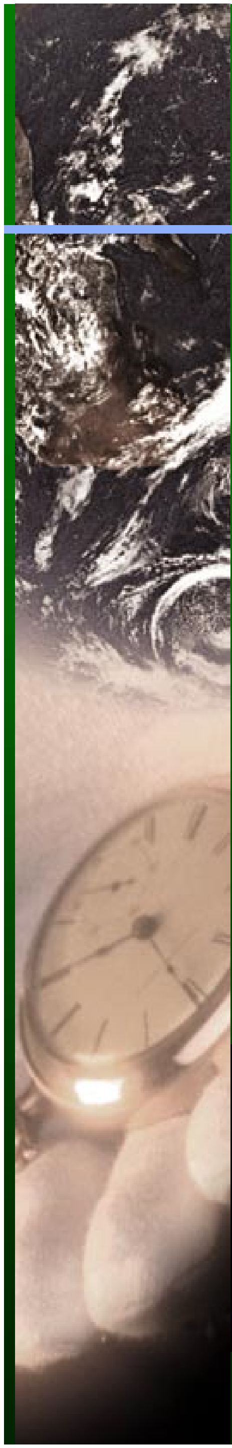

or visit our
Battery Thermal Management Web Site
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