WHITE PAPER

INSIGHTS FROM CONNECTED MOBILITY:

Thermal Management for Tomorrow's Vehicle

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INTRODUCTION

The automotive industry is undergoing an exciting transformation in connectivity as the need for higher speed and for more compute power is changing the game. Changes, updates and improvements are occurring nearly every day, with automakers in a race to deliver the latest safety and communication features and optimal functionality to consumers.

These trends are only accelerating and the car of the (near) future will be more connected than ever before — and that is creating a tremendous demand for both processing power and the ability to transmit vast amounts of high-speed data in new automotive designs.

The race is on—and not unlike the PC race witnessed over the last decade or so. In that market, it was a tough competition to see who was able to deliver the most powerful laptop, in the smallest size, with the lightest weight and, most importantly, with all of the functionality to quickly and easily handle digital data files growing in both size and complexity.

In the automotive market, the design challenges go beyond simply delivering processing power and high-speed data transfer. Design engineers must also safely manage heat generated by those processes in the confines of tight vehicle packaging requirements, as well as ambient temperature fluctuations, while adhering to stringent safety and reliability standards of the automotive industry.

That, indeed, is a challenge.

In considering specific design issues facing automakers and their suppliers, the challenges related to thermal management can be broken down into two basic areas of focus:

1. *Understanding the increasing demands on electronic components to ensure that the device design will generate the least amount of heat*
2. *Designing enclosures that will help manage heat and optimize cooling in these extreme temperatures, often enclosed, harsher environments*

Addressing these challenges is no simple feat and it all begins with proper electrical and enclosure designs to provide efficient and cost-effective thermal management.

Module Definition and Recent Advancements

As consumer electronics have proliferated, so too has the need for higher performance automotive networks, media modules and more powerful chargers to meet the needs of the devices that drivers and passengers connect to the car and for the networks that will support the advanced safety features of the vehicles of the future. Concurrently, forward-thinking automakers are clamoring for a more streamlined and powerful automotive network solution capable of handling copious amounts of data being generated within today's vehicles. As a result, important advances have been made in automotive electronic components and devices, which are increasingly technically advanced but require innovative thermal management strategies to dissipate the heat generated.

Before we address the various design methods aimed at managing thermal issues, let's be clear on a few definitions and the basic frameworks within which automotive designers operate:

Media modules

Automotive media modules enable the integration of multiple I/O port connection types, such as USB, HDMI, Ethernet, and SD memory cards, in order to meet end-system requirements for seamless communications to the ever-increasing number of devices that customers use to create the connected vehicle. Media modules make it possible to connect to the car and deliver the charging power needed to keep us connected.

Based on decades of experience pioneering solutions for consumer-facing devices, Molex engineers understand the unique connectivity requirements and are able to navigate and design for even the most stringent automotive standards. Our customers rely on that deep expertise to fully understand what they need and design the best module solutions.

Molex multi-port media hubs offer the most advanced smart charging support

Features and benefits: USB-A and Type C interfaces, USB 2.0 and 3.1 support, BC 1.2, MFI, Type C and PD charging protocols, Apple CarPlay, Android Auto and CarLife host sharing support, SD card, cascading hub support and LED lighting

Chargers

With the exploding growth of in-vehicle infotainment, automobiles are being designed with multiple chargers as well as various charger types incorporating both USB-A and Type C interfaces.

For more demanding applications, Molex designs custom in-vehicle smart chargers that follow a device's profile and provide the maximum power and most efficient charging process defined by that device's manufacturer. They also have built-in protective circuitry to protect devices from shorts and overcurrent conditions. Ultimately, the added safety protection and engineering assure a more robust charger and a fast, effective charge for drivers and passengers.

During the design phase, Molex specifies and engineers chargers to meet the full range of requirements set by the automotive customer's packaging and power requirements. Through thermal modeling and analyzing the environmental requirements, and later verifying performance in a lab, charger interfaces are fully validated to meet the demands of the customer's performance and packaging needs.

Our thermal solutions for chargers take into account the complete range of variables that challenge engineers — whether it is mechanical, electrical or software — with the goal being to achieve optimal thermal and power performance. Additionally, Molex employs the latest automotive technologies and thermal design advances in order to create efficient and cost-effective solutions in the smallest possible form factors.

Molex smart charger solutions

Features and benefits: Automotive qualified USB-A, Type C interfaces and BC 1.2, Apple MFI Type C, QC 3.0/4.0 and PD charging protocols with optional LED halo lighting I and covers

Ethernet gateway and switches

A truly autonomous vehicle requires the highest level of security, prioritization, reliability and performance. Legacy automotive bus systems, such as CAN, don't have the speed to deliver information fast enough for the vehicle to perform safely and reliably. According to a 2018 McKinsey Report[1], automotive Ethernet solutions are a key enabler and represent the future of in-vehicle and V2X connectivity. The Molex 10G multi-zone Ethernet network platform is an industry-leading solution capable of handling all of the combined in-vehicle connectivity demands.

Molex is at the forefront of Ethernet technology and the first in the industry to provide 10G speeds in an integrated automotive platform. Combining the company's long history and expertise in design and manufacturing for the networking, industrial and datacom markets along with expertise from 20 years of software develoment and integration in the industrial market, Molex developed the innovative Ethernet platform to meet the mechanical size, electrical layout, thermal demands and software requirements of the connected vehicle.

Demand continues to increase

As early as 2025, according to estimates[2], more than 85% of all new cars will be classed as "connected" and there will be more than 470 million connected vehicles on roads in Europe, the United States and China. The staggering number of connected vehicles — along with the increasing level of connectivity — is already creating a data explosion. A McKinsey & Company report estimates that connected cars create up to 25GB of data per hour, while autonomous cars are expected to create upwards to 500 GB of data per hour (equivalent to 4,000 GB of data per day). That data will come from sensors and cameras, sonar and radar, LIDAR and GPS systems, and a host of safety, security and infotainment.

According to a report by Intel, one self-driving car will burn through approximately the same amount of data as 3,000 people.

Automotive connectivity components — modules, chargers, switches and gateways — will be expected to move and process that data in near real-time. That extraordinary demand for processing power requires extraordinary measures to manage the resulting thermal energy that's created.

Managing Heat and Optimizing Cooling

Approaches to Cooling Systems and Design

With the advent of autonomous driving, automakers are essentially putting the equivalent of a super computer or enterprise network switch in the vehicles of the future. Minimizing heat generation and determining the best strategies for dissipating heat are both critical design components. Ideally, a natural convection cooling method is the most cost-effective solution to dissipate thermal energy because it does not rely on additional components, either active or passive.

Currently, the industry is widely using liquid-cooled solutions to offset the heat being generated. While effective, liquid cooled methods generate additional costs and processing (pumps, fluid – ethylene glycol or something similar to prevent freezing and a closed system to transfer the fluid.) Using liquid cooling to offset heat in an autonomous vehicle is not practical or probable long-term and that – along with the need to shrink the size – create the need for more and better thermal designs.

In addition to specifying cooling methods, R&D engineers must also address a myriad of other challenges inherent to automotive design, including:

- Mounting and other mechanical requirements
- Space constraints
- Customization and application-specific design parameters
- Materials and components available today (and their ability – or inability – to handle the heat that will be generated by tomorrow's systems). Most ICs are designed for IT computer room environments which do not meet the requirements of the automotive industry thereby increasing the challenges for thermal cooling that is critical to end product reliability.

[1] Burkacky, Ondrej. "Rethinking car software and electronics architecture." McKinsey & Company – Automotive & Assembly (February 2018)

[2] "470 Million Connected Vehicles On the Road by 2025." ITSdigest (February 2018)

Simulating and Validating Design Innovations for Thermal Management

To begin, it is essential to have a full understanding of automotive products and impact of the design on thermal management, including the basics such as the solution function, location, etc., and to consider and plan for things such as:

- Vehicle space constraints
- Power level and dissipation number for each component and location
- Materials available for use
  Including maximum material temperatures and location of each (end user contact surfaces vs. installation contact surfaces)
- Type of air flow, if any
  Including in surrounding components, ducts, harnesses, etc.
- Costs

Simulation and validation tools

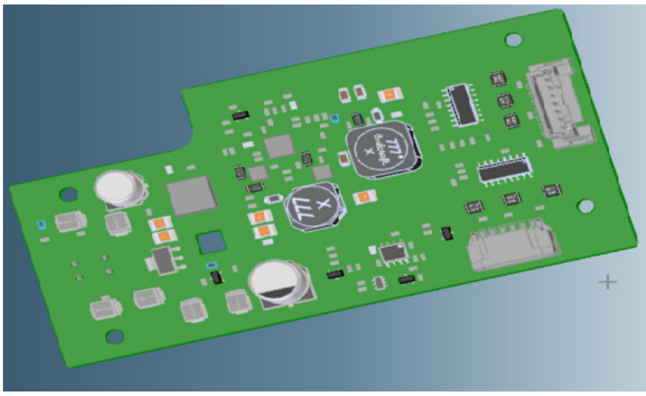
Simulation and validation of thermal design models are crucial steps in producing an accurate and credible design, and assist with anticipating and solving problems in the overall automotive design. To accomplish that, Molex employs a variety of processes and uses a variety of tools in order to achieve the highest level of accuracy and precision. Additionally, Molex has the capability to run a comprehensive range of in-house tests and simulations in the company's state-of-the-art labs.

PCB Modeling Improves Accuracy

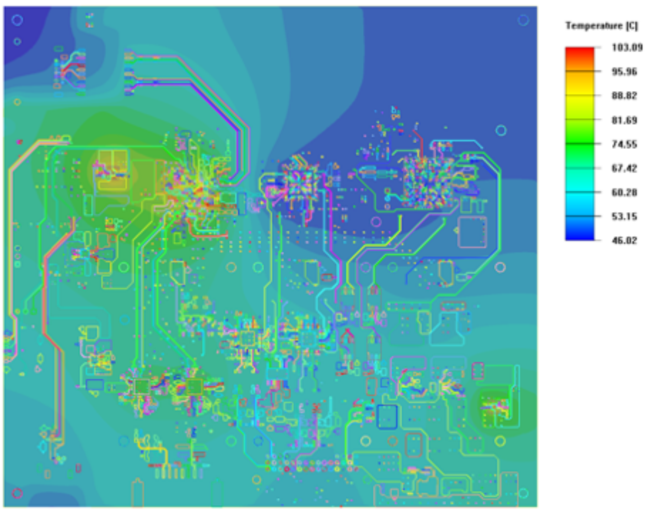
Accuracy is absolutely critical when designing a board and, with the advancements in technology, design requirements are becoming tighter and more stringent than ever. Detailed test and simulations are performed iteratively until simulation results correlate with empirical data. Modeling provides both security and peace of mind that the design is going to function properly before ever making it to the manufacturing floor. Molex employs the following steps for every solution its engineers test:

Modeling

- Capturing the physics accurately
- Power levels
- Component placement
- PCB layout (copper layout)

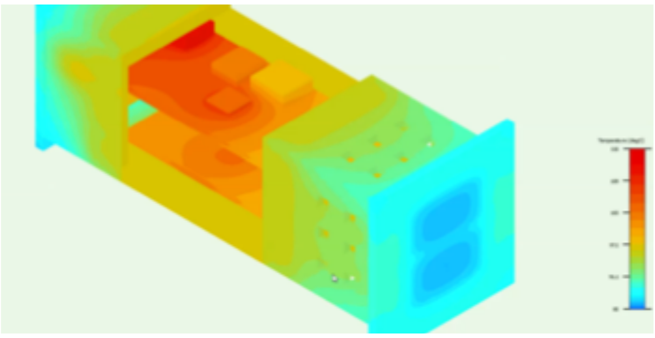


Copper is an excellent conductor of heat, therefore, modeling the heat in the copper traces provides detail and accuracy



Temperature plotting

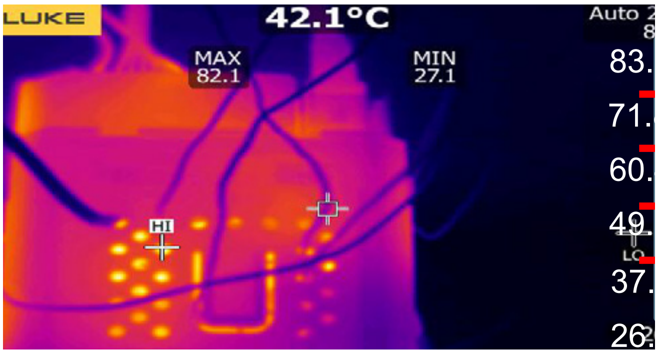
- Temperature plotting helps identify hotspots and other areas of concern



Transient simulations, testing and validation

Thermal margins vs. data sheet ratings

- Lab vs. in-situ monitoring and performance



Impact of automotive host system on module design

In addition to accurate modeling of the solution, consideration must be given as to where and how it is packaged within the vehicle, as that can also have significant impact on the effectiveness and overall cost of the design. For example, if a component is planned to be packaged near the HVAC ducting, climate can be a significant factor. Additional considerations include:

- **Module heat locations and internal heat spreading**
  Obviously, both how and where modules are packaged can have both advantages and disadvantages. Modules generate heat so design measures are needed to mitigate the impact. Many Molex solutions, for example, feature embedded modules, whereby the module interface is embedded in the dashboard of the vehicle and the actual module is located elsewhere so heat can be more easily vented or dissipated.

- **Inlet and laminar airflow and temperature**
  The ambient temperature is usually read without any airflow so, as a result, testing is performed in an enclosed environment, representing the actual condition of the vehicle and generating more accurate results. Within the vehicle, these types of components are typically packaged in areas with ducts or harnesses or other types of packing constraints.

- **Placement of components**
  The placement of various components can affect thermal design performance and consideration must be given to design decisions such as assembly direction, flow characteristics, resistance and coolant effects — to name a few.

- **Enclosure thermal management**
  Outside faceplates must have a lower temperature, as that's where users interact with the module so it must not be too hot to the touch. This surface will act as a heat sink and steps must be taken to isolate this portion of the modules. If not done properly, these surfaces can reach temperature of 100 degrees C. Molex engineers utilize board layout, heat spreaders and other methods to make sure these surfaces meet industry requirements.

It's important to note that any and all changes to even a single component within a vehicle can result in intended or unintended system-level changes. Making a change to the PCB layout can cause a change to the overall system.

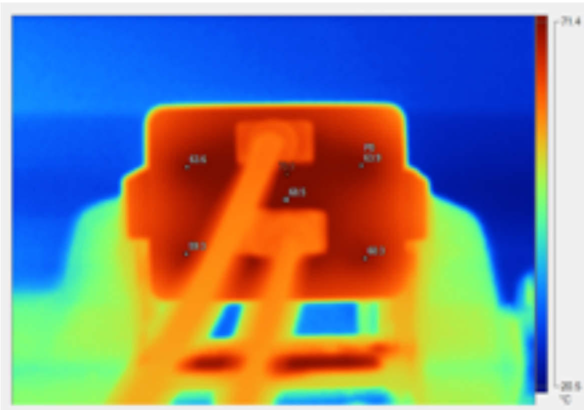
Thermal Results and Ratings

Case Study #1: Safer power module

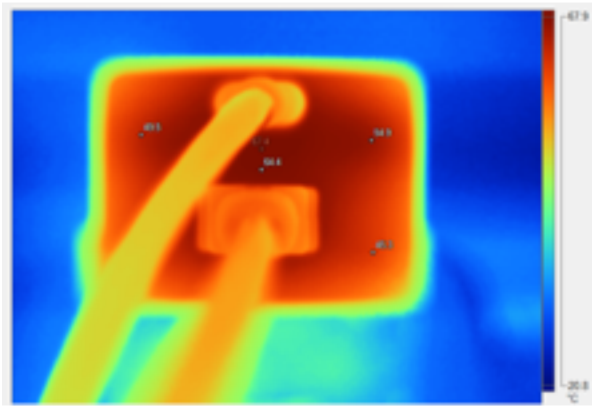
Another top-tier automaker challenged Molex to reduce the interface temperature for one of its modules, specifying that the module needed two USB charging ports and each port needed to be capable of delivering 60W of power. Additionally, the customer interaction (front-facing) surface temperature could not exceed 60 degrees Celsius.

In-depth thermal study and testing helped Molex identify and implement changes at the board level to reduce the customer interface temperature. As a result of the changes, it is now safe to touch the accessible area while the module continuously outputs power at the maximum level.

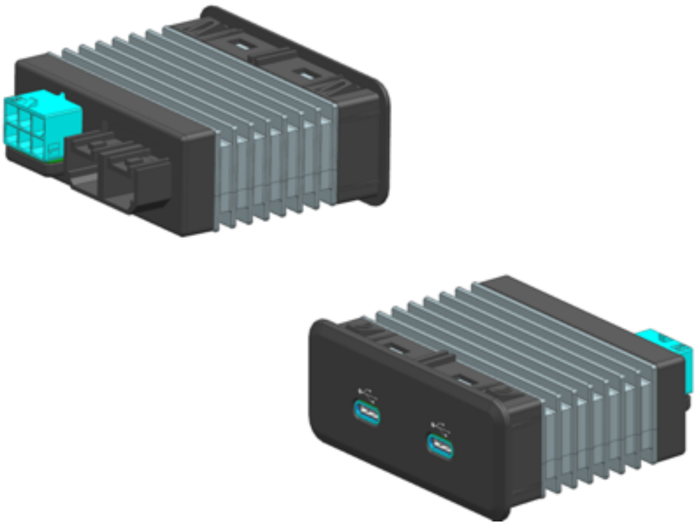
Before changes to PCB (image below): The challenge was to meet the front face temperature specification not to exceed 60 degrees Celsius. Initially, the component was registering a temperature of 68-69 degrees Celsius.



After changes to PCB (image below): In order to decrease the front face temperature, Molex engineers reconfigured the PCB layout and were able to bring the module within spec without any sacrifice in power.



Understanding the basic principles of heat transfer and better cross-functional coordination led to the development of an automotive-grade module (seen below) that can simultaneously deliver power in two ports up to a total of 120 watts.



Case Study #2: Robust power delivery

Molex is actively pushing suppliers to make power supply components automotive-qualified based on thermal simulation and test data at various operating conditions. We recently developed a power delivery solution capable of 120W total output on two USB-C type ports. In this case, the power dissipation of components, which is input for thermal simulations, could only be calculated for one input voltage and current condition, as the ICs were newly developed.

As such, the efficiency of active components and the system was not completely known for a wide range of operating voltage, ambient temperature and various power outputs, all of which would drive the final mechanical design for safe operation and power performance.

To overcome these issues, Molex used one set of WCCA values to develop correlations between simulation and test by measuring temperatures using infra-red imagery and thermocouple data for the open PCB. Mechanical packaging was optimized using correlations from simulation DOE and tests covering various combinations of output power values and input voltages. Reduced efficiency at lower input voltages were identified and accounted for via rigorous testing to achieve safe and optimal power performance.

A Unique Vantage Point

Today, data integrity and processing power are essential to support the development of intelligent and autonomous vehicles and Molex stands uniquely qualified to support the exciting era of connectivity in the automotive industry.

Molex has pioneered cables, connectors, switches, media modules, gateways and other high-speed, high-bandwidth solutions as well as thermal strategies for high-density networking applications in diverse industries — from data-intensive supercomputing, hyperscale and enterprise data centers to telecommunications to rugged industrial and automotive.

A Proven Engineering Protocol

Additionally, Molex has developed a rigorous engineering protocol that is the proven foundation for developing leading thermal management solutions. Improper thermal management can lead to poor performance, reliability issues, shortened product life and safety concerns.

Molex brings many decades of experience in thermal design and providing innovative solutions to meet the challenges of thermal management in the connected vehicle of the future.

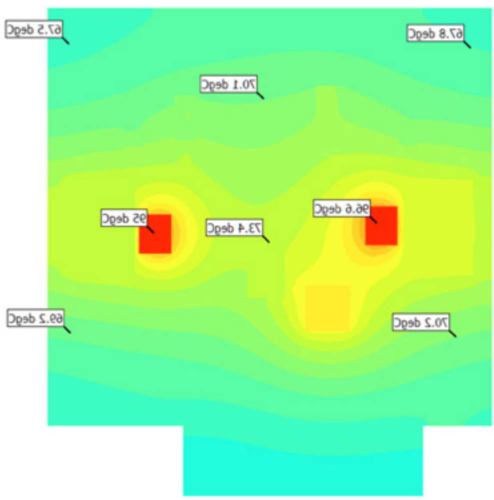
Case Study:

Molex recently developed a power delivery solution that is capable of 120W total output on two USB-C type ports. While electronic component manufacturers are developing newer power supply components, Molex is pushing the suppliers to make them automotive qualified based on the thermal simulation and test data at various operating conditions.

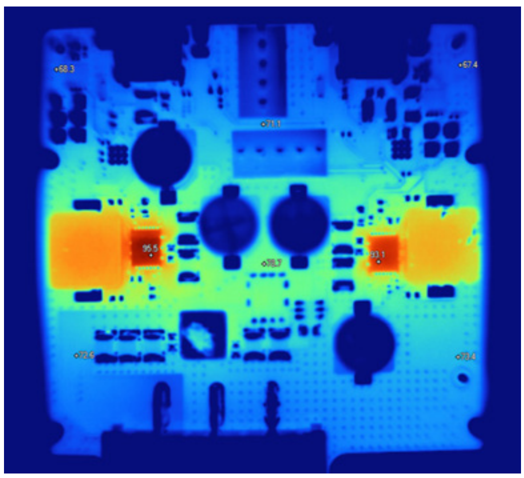
Power dissipation of components which is input for thermal simulations could only be calculated for one input voltage and current condition as the IC’s are newly developed.

Efficiency of active components and system is not completely known for wide range of operating voltage, ambient temperature and various power outputs which would drive the final mechanical design for a safe operation. Molex used one set of WCCA values to develop correlations between simulation and test by measuring temperatures using infra-red imagery and thermocouple data for open PCB. Pictures below show correlations between simulation and test data for open PCB. Mechanical packaging was optimized using correlations from simulation DOE and test covering various combination of output power values and input voltages. Reduced efficiency at lower input voltages were identified and accounted for through rigorous testing. Molex developed has automotive grade power delivery solution based on thorough thermal design.

Temperature Contour Plot from Simulation



IR Images of Open PCB



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