Robert Bosch India Drives ECU Temperatures Down

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Modern cars can contain upwards of 100 Electronic Control Units (ECUs) so the reliability of these units is critical to the reliability of the vehicle. ECUs can be found throughout a vehicle, often in hot, harsh environments, yet component temperatures must be kept within acceptable limits even when the ambient temperature is high, making optimizing their thermal performance a key element of the design challenge.

For this, Robert Bosch Engineering and Business Solutions needed a fast, accurate and robust simulation tool they could depend on, to explore different design options quickly and effectively, including the transient response to a time-varying power load, so they turned to Mentor Graphics' FloTHERM.

A product recently developed by the team was an ECU with various functions within the vehicle which result in a different thermal load on the unit. The ECU consists of PCB, components, thermal interface material, and metal housing. There are both active components (e.g. transistors, diodes etc.) and passive components (e.g. resistors, inductors, capacitor etc.) on the board in the ECU that generate heat during the operation. There must be a good conductive path (Figure 1) for heat to flow from components to the housing. Automotive components often contain a thermal slug, to spread the heat internally within the component. These can either be between the die and the top of the component (slug up), to assist heat removal from the top of the component, or between the die and the bottom of the component (slug down), to assist heat transfer into the PCB. Heat entering the housing by either route is dissipated to the external ambient by convection and radiation. The top cover is anodized to improve radiative heat transfer to the environment. Thermal simulation is used to predict the temperature of components and determine their thermal criticality.

The FloTHERM model of the ECU is shown in figure 2, with the housing acting as a

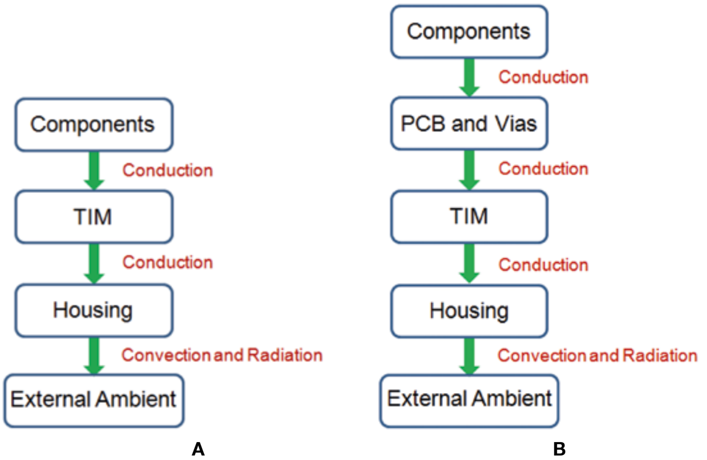

Figure 1. Heat Transfer Paths for (a) Slug-up and (b) Slug-down components

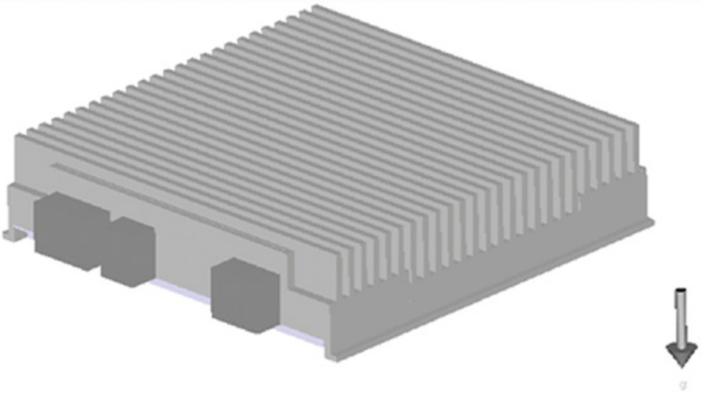

Figure 2. FloTHERM Model of ECU showing Finned Housing

heatsink to the surrounding air. The ECU is designed to be mounted either inside or outside of the vehicle, and the design has to operate under the worst case ambient condition.

The 3D thermal simulation in FloTHERM includes conduction, convection and radiation. The active components (transistors, diodes, etc.) are modeled in detail (with die, die-attach, die-pad/slug etc.), whereas the passive components that generate heat (resistors, inductors and capacitors) are modeled as lumped cuboids, unless the detailed model is available. The PCB is a multi-layer board constructed from copper and FR4. Each copper layer is modeled as a lumped cuboid with orthotropic thermal conductivity based on the percentage of copper coverage separated by FR4 layers. Appropriate surface emissivity is assigned to the components, PCB and housing to address radiative heat transfer. For the transient simulation the load profile vs. time is needed (Figure 3), where 100% thermal load corresponds to 43.0W. The FloTHERM simulation for the unit in natural convection showed that the maximum component temperature reached 162°C, well beyond the acceptable limits specified in vendor datasheets.

In the baseline design, the PCB does not have a contact with the bottom housing. Hence, heat transfer from the PCB to bottom of the housing is hampered by the absence of a proper thermal conduction path. Convection and radiation from the components and PCB to the housing is not as effective as direct thermal conduction. Bridging the gap between the bottom of the PCB and the housing without requiring a structural change is a challenge, making the thermal design harder.

To address this, Bosch's engineers, Ritwik Pattnayak and Dr. Laxmidhar Biswal, decided to make two changes to the design. The first was to add a metal heat spreader on the underside of the PCB, with a thin layer of thermal interface material in between, to spread the heat and pull down the maximum component temperature. A second change was to add a much thicker section of thermal interface material between the metal heat spreader and the bottom to provide more effective conduction heat transfer.

With the first improvement, the maximum junction temperature of the hottest component is 133°C (Figure 5a), a reduction of 31°C compared to the baseline design. The second modification reduced the maximum junction temperature of the component by a further 5°C to 127°C (Fig. 5b), giving

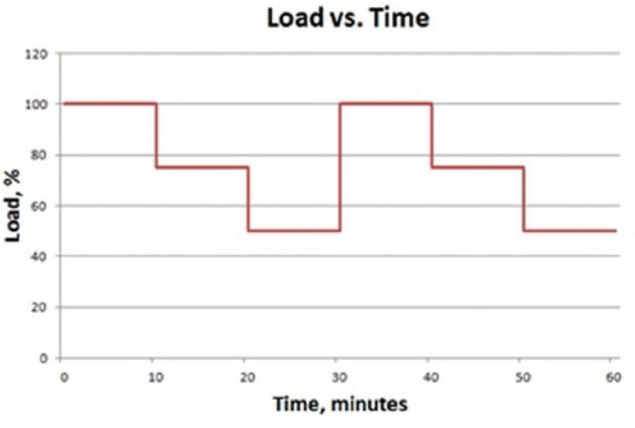

Figure 3. Power Load Profile for the ECU

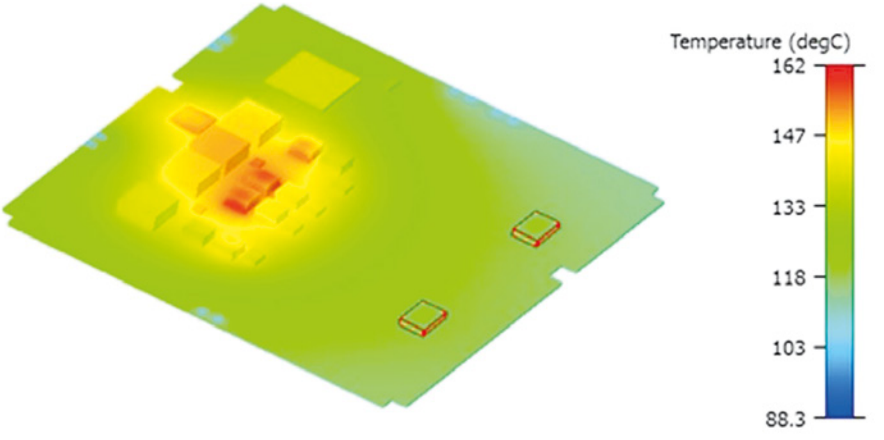

Figure 4. Temperatures of Components in Baseline model.

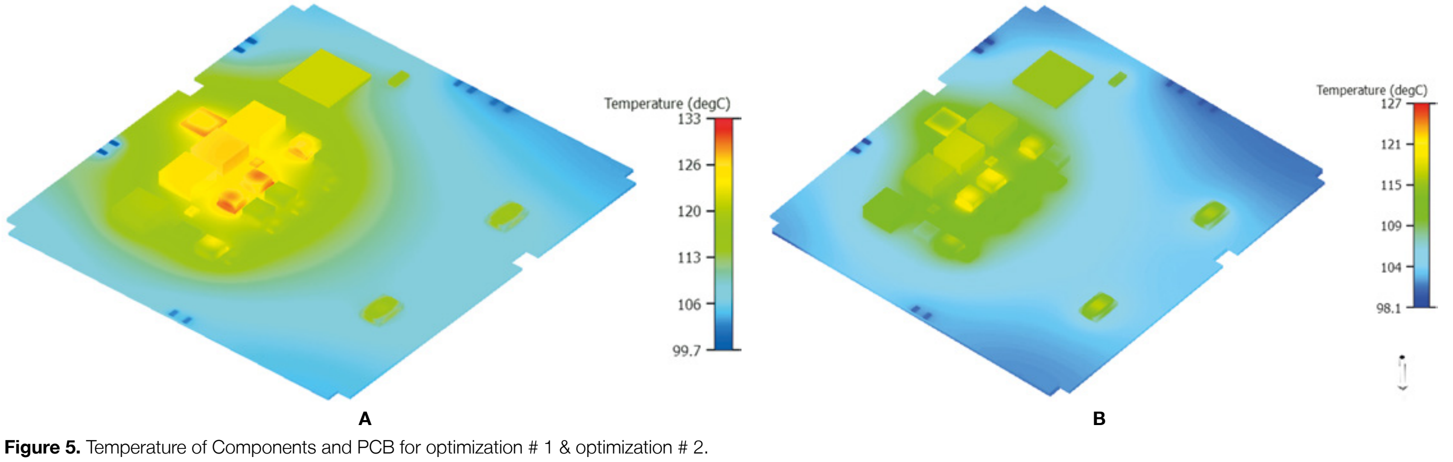

Figure 5. Temperature of Components and PCB for optimization # 1 & optimization # 2.

a total reduction of 35°C is achieved in comparison to the baseline design.

To account for the variation in load power for the system, the sensitivity of the response of individual components to different power levels was tested. Two components were chosen for this, D1600 and V1907. The D1600 component is a slug up design and interfaced with the top finned housing via thermal interface material. Because of lower thermal impedance of the thermal interface material and finned top housing, junction-to-ambient thermal impedance is relatively low, below 5K/W. V1907 is a slug-down component and interfaced with bottom housing via PCB, Thermal Vias, TIM, Heat Spreader and TIM. Due to several layers of materials between the component, bottom housing and associated thermal impedance, junction-to-ambient thermal impedance of 'V1907' is relatively very high in comparison to the slug-up component 'D1600'. This latter component was simulated in FloTHERM to obtain its transient response at 100%, 75%, and 50% power loads. Plotting these temperature responses normalized the applied power to give a graph of dynamic thermal impedance, Zth, the data almost mirror each other as shown in figure 6.

As the data line almost mirror one another, engineers at Bosch were able to derive an analytical model for dynamics thermal resistance (Zth,j-a) of all heat dissipating components from the FloTHERM simulation. This model could then be used to predict the temperature of the components for different power dissipations and external ambient, without having to run a full 3D thermal simulation for each scenario.

The results of the design optimizations were checked with a prototype using a thermal chamber, shown in figure 7. The experiment was conducted for the specified ambient, and at an air speed of 0.6ms-1, with the velocity of the airflow over the ECU measured with an anemometer. Thermocouples were placed on the components of interest to measure their temperature.

The comparison of the simulated temperatures against the experimental measurements showed a good correlation, confirming the robustness and reliability of the FloTHERM model. The outcome of this work was that the design optimizations in FloTHERM overcame the thermal bottleneck and reduced component temperatures by 35°C from the baseline design, resulting in an acceptable operating temperature of components. Using analytical models derived from FloTHERM results, Robert Bosch Engineering and Business Solutions have been able to predict junction temperature of component at any load for a given design and time duration or operational time duration of the ECU for the desired junction temperature. This has delivered a significant saving in time.

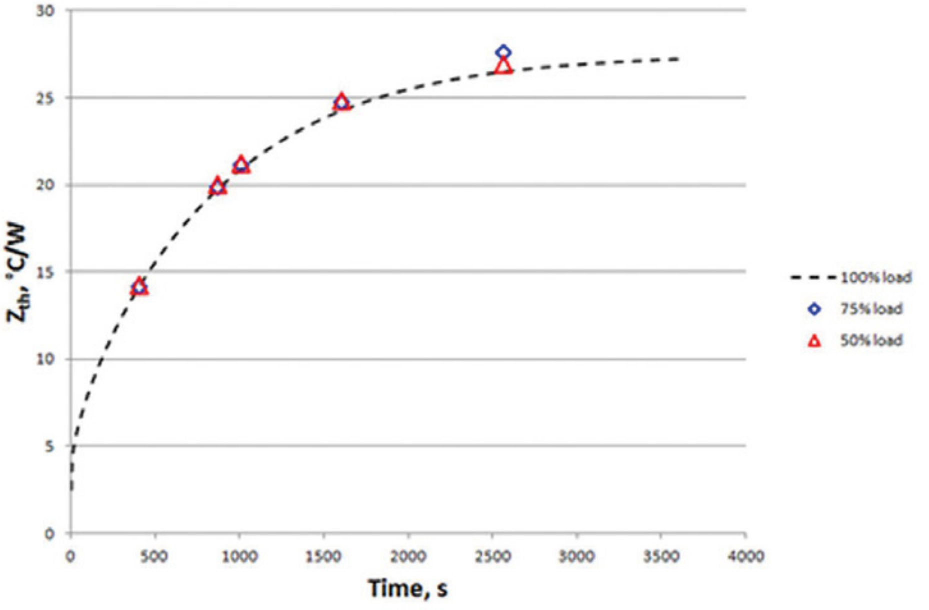

Figure 6. Comparison of dynamic thermal impedance (Zth) of 'V1907' for different loads

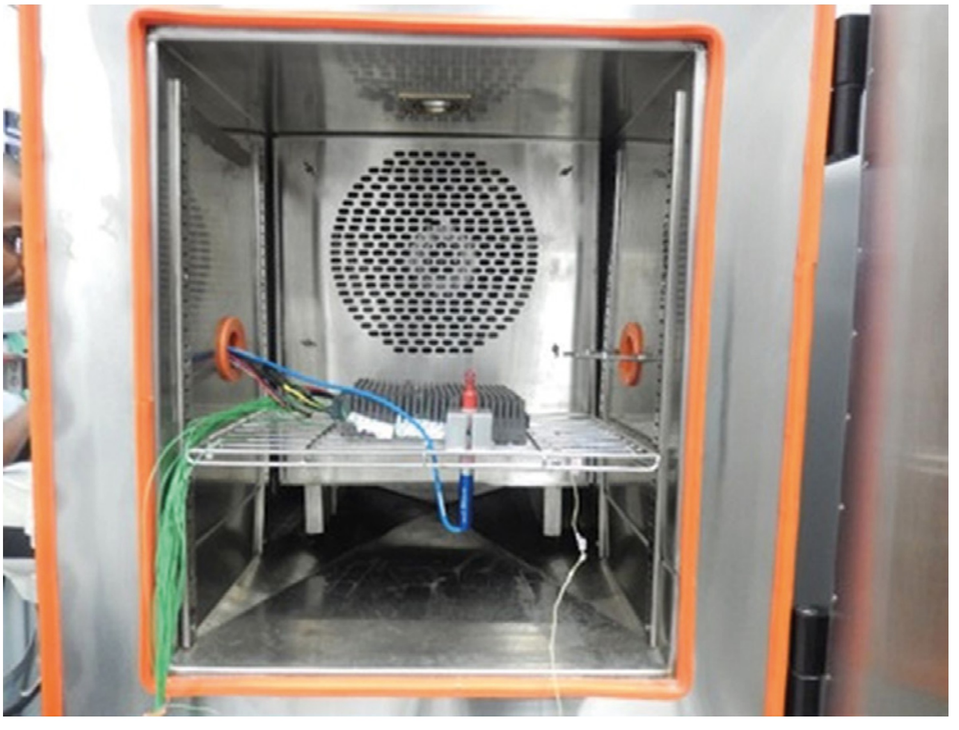

Figure 7. Thermocoupled ECU and Anemometer in the Thermal Chamber

Acknowledgement:

This work "Thermal design and analysis for high power automotive electronic product" by Ritwik Alok Pattnayak & Dr. Laxmidhar Biswal, PhD, FIE, CEng (Robert Bosch Engineering and Business Solutions, India), was first published at NAFEMS' World Congress in San Diego, 21-24 June 2015, www.nafems.org