Phase Change Material Transient Heatsink

Daniel Canuto, Kegan Dellinger, Joseph Rivera
Florida State University, Tallahassee, FL 32310

Motivation

Our project's sponsor, Unison Industries, designs and produces electrical products for the jet engine industry. Among these products are ignition units and power regulators that contain power semiconductors whose proper operation requires that they be maintained below a certain operational limit. However, because these devices are kept close to the engine itself (Fig. 1), the ambient temperature is already near the aforementioned limit. Thus, these semiconductors are highly sensitive to both electrical overloads during operation and transient thermal conditions in the ambient environment. Consequently, **Unison tasked our team with designing a highly-reliable, low-weight, compact heatsink that would make their semiconductors more robust against varying operational conditions**.

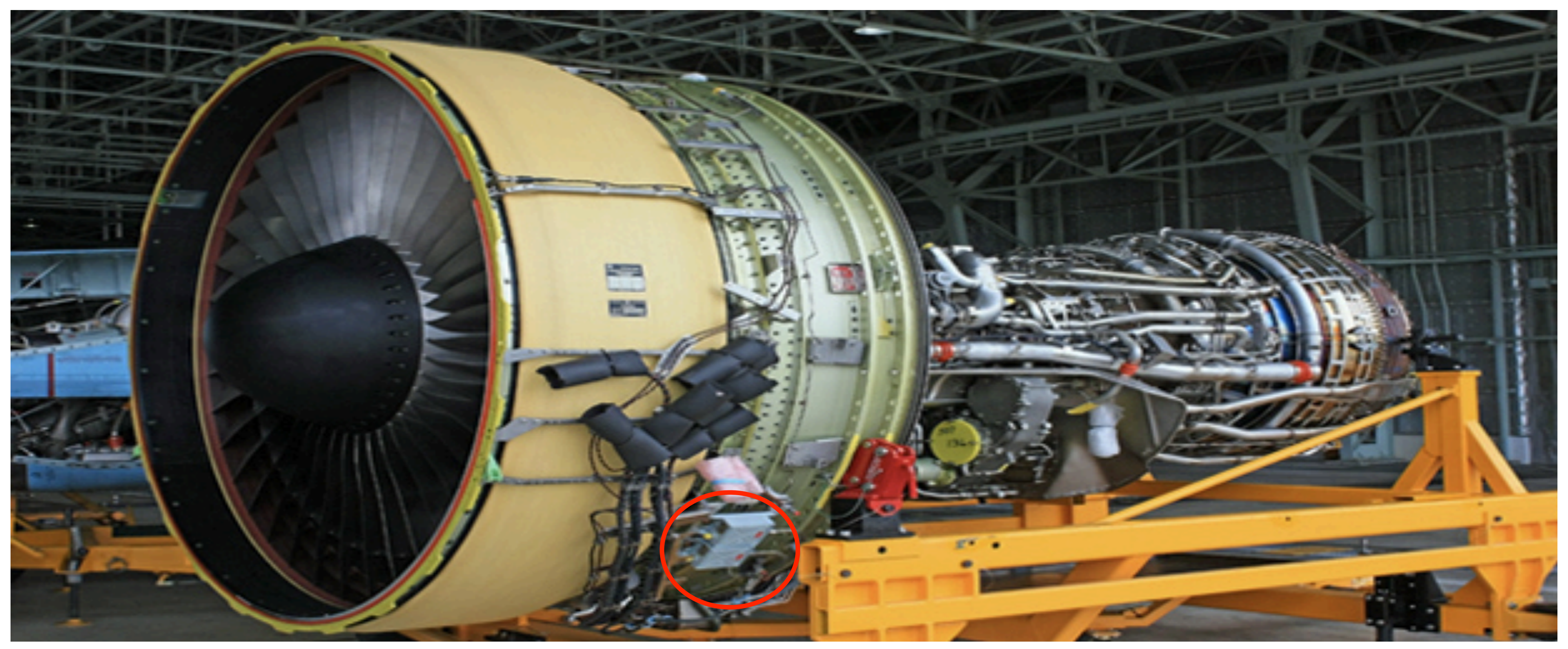

Fig. 1. Typical jet engine using Unison products. Ignition unit is circled.

Design Testing and Analysis

To rapidly iterate through various prototype designs, and to identify the design parameters most critical to our heatsink's operation, we developed a simulation of our heatsink in COMSOL. Fig. 4 displays the semiconductor's specified duty cycle and predicted temperature (assuming an ambient temperature of 110°C, and indicated that our design would be able to handle the required semiconductor duty cycle. However, the model also predicted that the solder would exceed its thermal absorption capacity after about 7 minutes, as indicated by the rise in the rate of temperature increase shown at the bottom of Fig. 4. However, from the experimental results displayed in Fig. 5, it is clear that our prototype outperformed the expectations set forth from the simulation. In the case of 1W dissipation from the semiconductor (simulated in the experiment by a ceramic resistor), there was found to be a steady-state temperature just above 117°C, while **in the case of a 2W overdrive, the heatsink was able to keep the resistor from exceeding 125°C for nearly 15 minutes (3 times its performance specification)**. Still, tests run without the heatsink (Fig. 6) suggest that the resistor could be run indefinitely at 2W without causing a temperature difference greater than 15°C. This result indicates either that a heatsink may not be necessary for this application, or that our test environment (i.e., lab oven) needed more careful control.

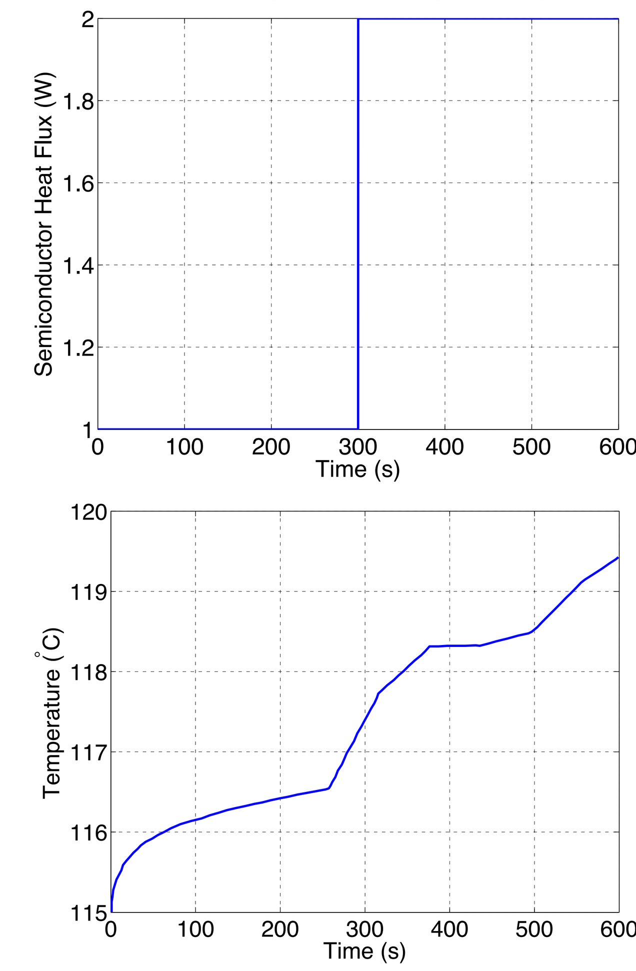

Fig. 4. Computational setup. Top is the semiconductor's duty cycle, while the bottom is its predicted temperature.

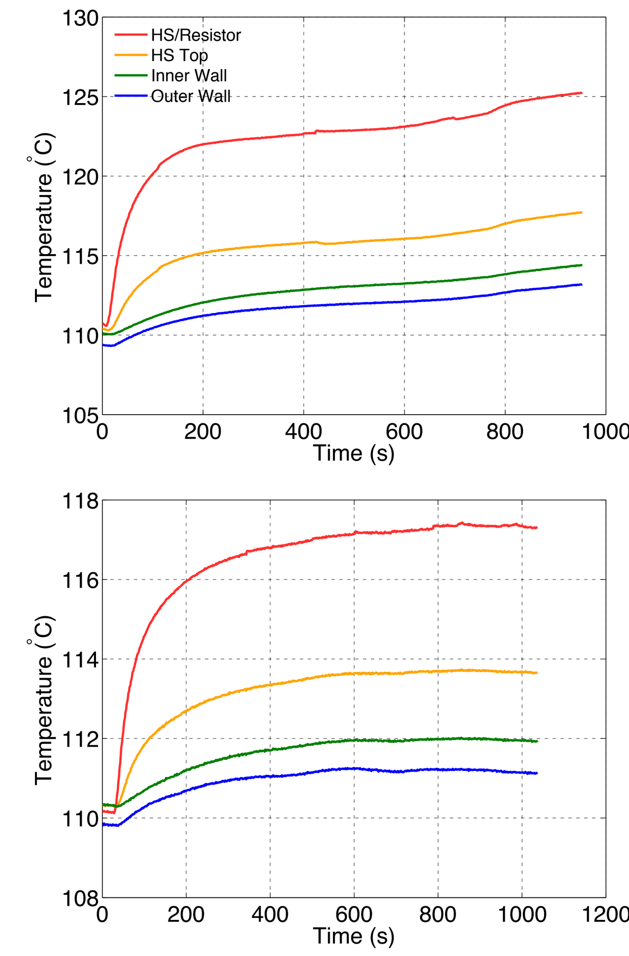

Fig. 5. Temperature history with heatsink. Top is resistor set to 2W, while the bottom is set to 1W.

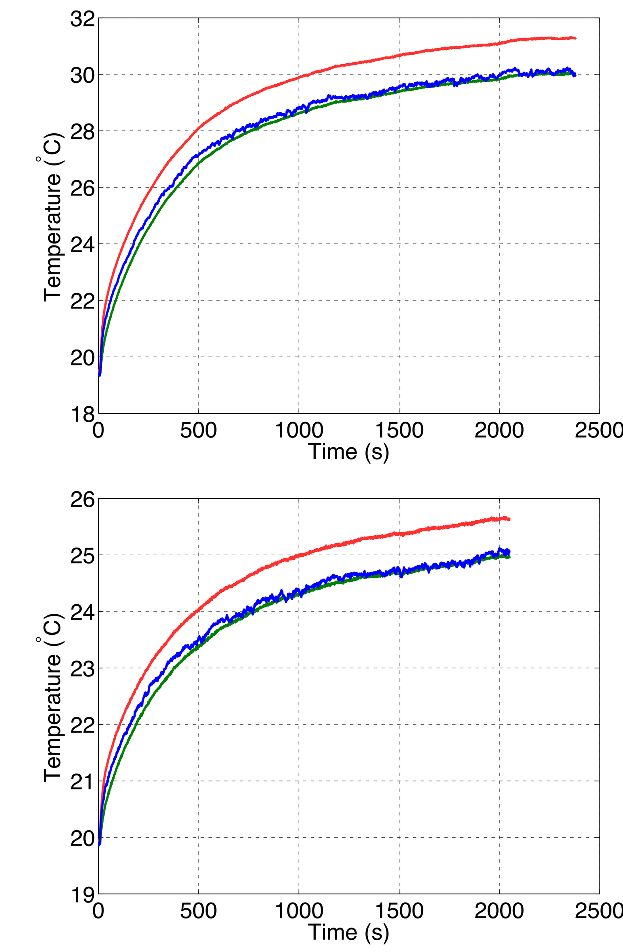

Fig. 6. Temperature history without heatsink. Top is resistor set to 2W, while the bottom is set to 1W.

Design Concept

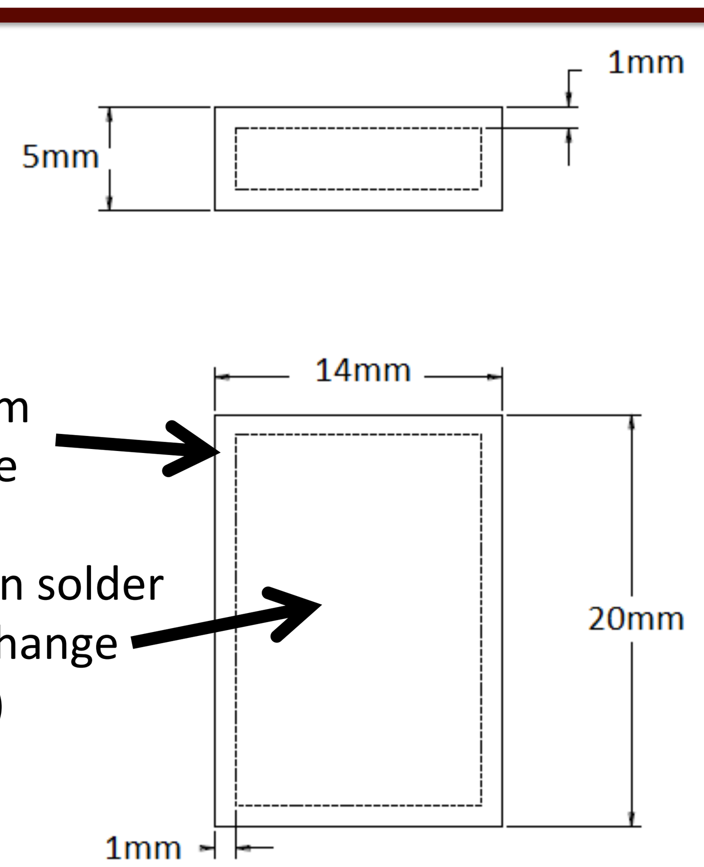

Fig. 2. Heatsink geometry.

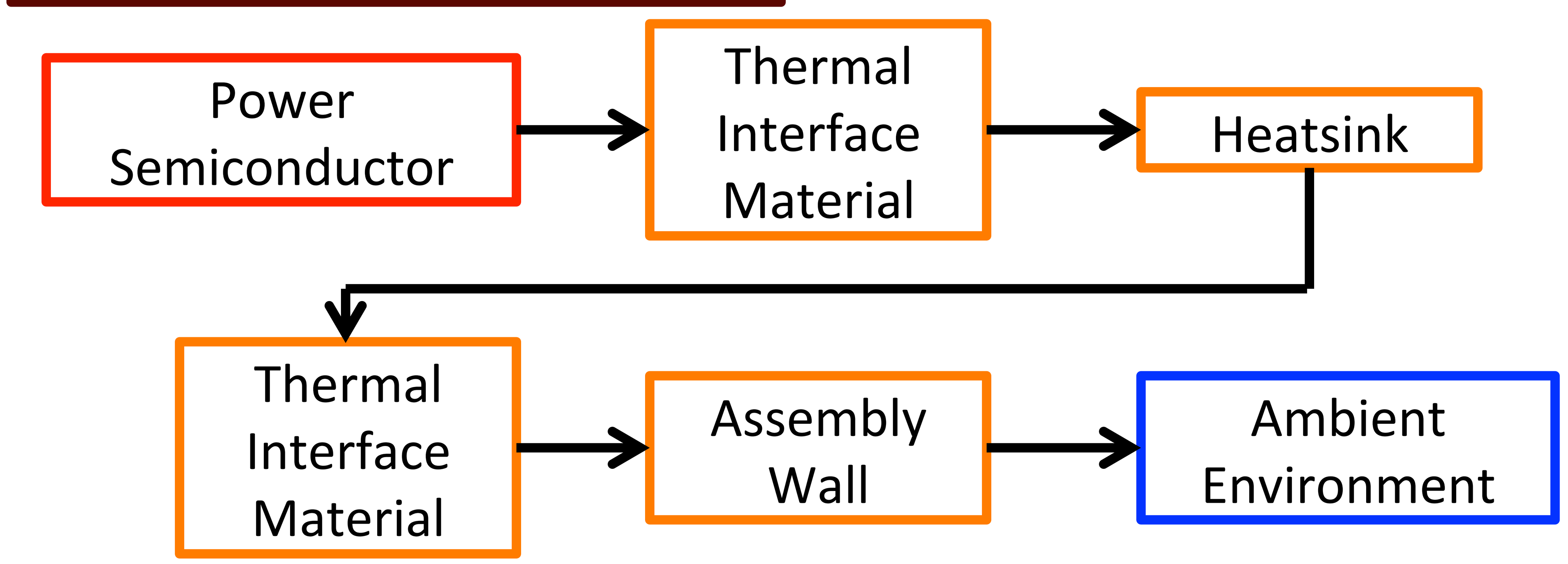

Fig. 3. High-level heat transfer schematic.

Our design concept (Fig. 2) is a thermal system's equivalent of an electrical capacitor: as a capacitor can temporarily store electrical energy for later discharge, **our heatsink temporarily stores thermal energy in the latent heat of a solder whose melting temperature (118°C) is slightly below the operational limit of the semiconductor (125°C)**. The solder was selected as a phase-change material because it had the highest specific heat and thermal conductivity among all materials found that melt within the specified temperature range. By placing the heatsink between the semiconductor and the outer wall of the ignition unit or power regulator assembly (Fig. 3), it essentially **acts as a safety valve, minimizing thermal resistance during normal operating conditions, but also allowing the semiconductor to cope with short periods of electrical overload or thermal transients**.

Future Work

If this project is carried on by future senior design teams, several improvements and extensions could be made. Specifically:

- **Refined boundary and initial conditions for the COMSOL model** to achieve better matching with experimental data
- Sourcing of a **lab oven with more reliable temperature control and faster preheating** to reduce experimental time and improve accuracy/reliability of data
- A **test bed with an adjustable mounting system** so that heatsinks of varying geometry can be tested
- Identification or development of a **less costly phase change material** (the solder constituted roughly 80% of our expenditures)
- Development of a **faster, more easily replicated method for prototype fabrication**

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