Heat Flux Measurement

Practical Applications for Electronics

Heat flux sensors are practical measurement tools which are useful for determining the amount of thermal energy passed through a specific area per unit of time. Heat flux can be thought of as the density of transferred power, similar to current through a wire or water through a pipe. Measuring heat flux can be useful, for example, in determining the amount of heat passed through a wall or through a human body, or the amount of transferred solar or laser radiant energy to a given area. In a past article [1] we learned how heat flux sensors operate and how they can be calibrated. But how can heat flux sensors be used for electronics design? This article highlights several practical uses of the heat flux sensor in the design of electronics systems. See Figure 1 for a simplified layout of a heat flux transducer.

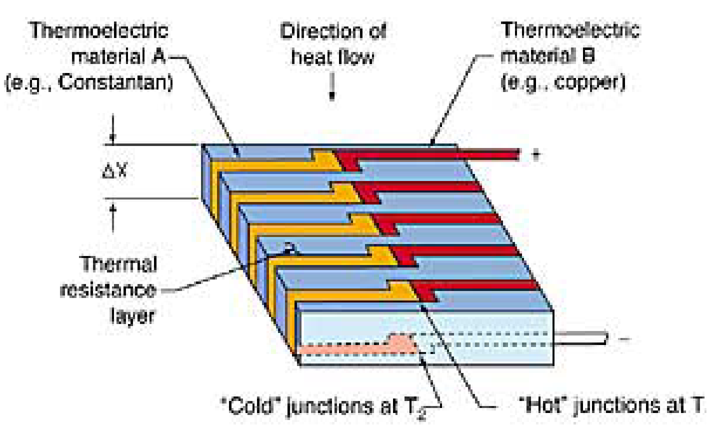


Figure 1. Thermopile-type of Heat Flux Transducer [2].

All circuit boards generate heat and that heat must be convected to the ambient. JEDEC values for a particular component may be known, as well as the resistance of the board and solder connections; the resistance at the interface of the component and board to the ambient are not easily known and are dependent on the flow characteristics. While analytical or CFD methods can at best predict the heat transfer coefficient at a particular area, often for complex systems with uneven or sparsely populated components these methods are not accurate and may not be useful. For those components which generate power, but may not need the use of a separate heatsink, the heat flux gage can be experimentally used to determine the heat transfer coefficient on the component surface or the compact thermal response on the board (e.g. how much heat is conducted into the PWB).

Affixing a thin heat flux sensor to the top of a component will yield two separate values which are useful in determining the convection heat transfer coefficient. If the heat flux can be measured from the top of the component to the ambient, airstream and if the temperature at the top of the component and of the ambient airstream is measured, then the convection coefficient can be calculated.

$$\dot{q}=h\bullet(T_S-T_A)$$

Where:
$\dot{q}$ = Heat flux, or transferred heat per unit area
h = Convection heat transfer coefficient
T_S = Temperature at the surface of the solid/fluid boundary
T_A = Ambient airstream temperature

Azar and Moffet [3] evaluated a simulated board under forced convection, populated with 12 heated aluminum blocks aligned in a grid of 3 by 4, with 4 blocks lined in the direction of airflow with attached sensors to measure surface temperature and heat flux. The ambient airstream temperature was estimated based on the power output of upstream objects and compared with the inlet air temperature. The objective of the experiment was to determine the effect of uniform and non-uniform powering of the simulated components under forced convection. Complex flow structures form in the region of the simulated components, such as vortices and wakes, and this in turn affects components downstream or aside of the component of interest. Thermal gradients along the board, due to conduction heat transfer through the board, add to the complexity of analyzing such a system. Because of these complexities, it often becomes necessary to use experimental devices to find the heat transfer properties of a particular device within the particular flow scheme, whether simulated or tested in-situ.

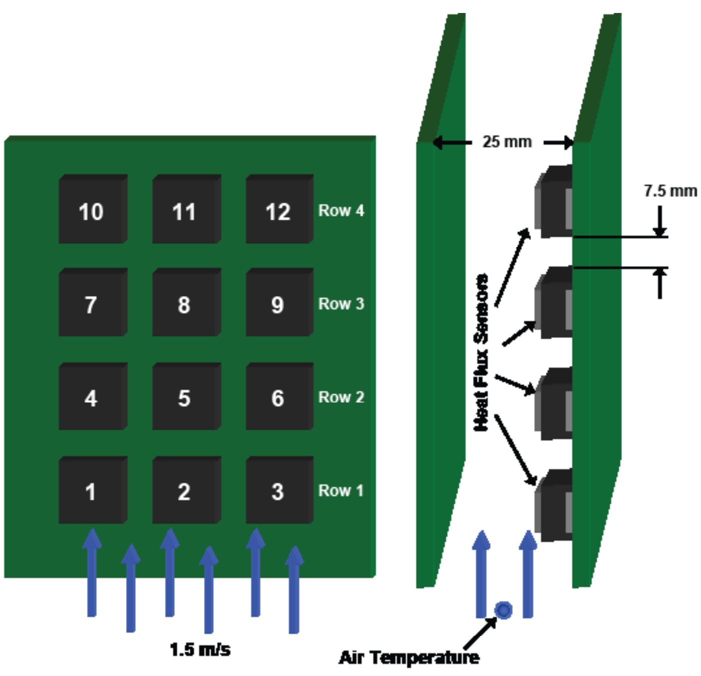
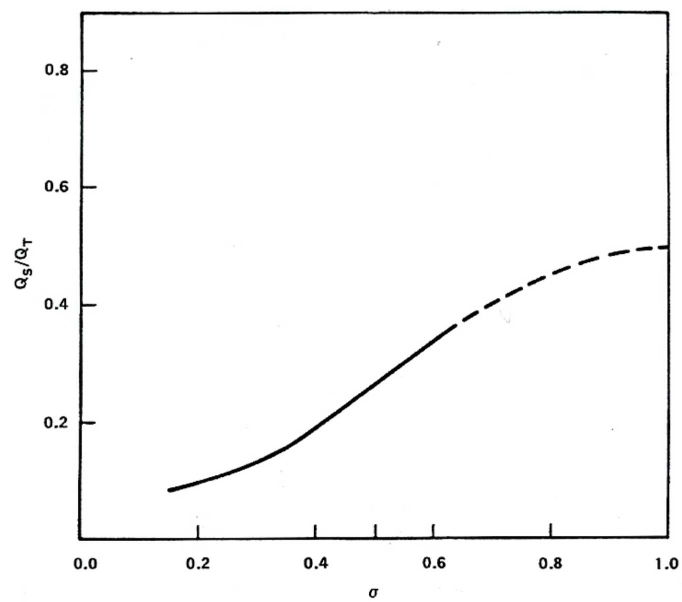


Figure 2. Azar and Moffet Experimental Configuration [3].

Using a heat flux sensor can be useful for lower powered systems under natural convection scenarios. Under forced convection, the heat lost to convection off the top of a component can often be significantly higher than the heat lost to the board, particularly if the board is densely populated and the temperature of the board reaches close to the temperature of the device. Under natural convection situations, often the balance of heat lost to convection and heat lost through the board becomes more even and it therefore is of even greater interest to the designer to understand the quantity of heat dispersed through convection.

Experiments done by Smith W. [4] alluded to the effect of board density on the heat transfer coefficient. In these experiments, thin film heat flux sensors are affixed to DIP devices which populate a board. The total heat generation of the board is kept constant, so the removal of components from a densely populated board only increases the heat generation per component. The results of this particular experiment highlight an increase in the ratio of heat lost through convection from the surface of the component



as board density increases and individual device power decreases.

Figure 3. Smith Experiment: Surface Heat Flow vs. Board Density [4].

Where:

Q_s/Q_t = the ratio of total heat flow through device surface to total heat generation

σ = the ratio of total device surface area to total board area

For a board of constant power, the balance of heat transfer vs. board population can be shown below in Figure 4. The conclusion is that for a populated board of devices in natural convection there occurs some specific board density where the net heat transfer coefficient at the component surface is at a minimum.

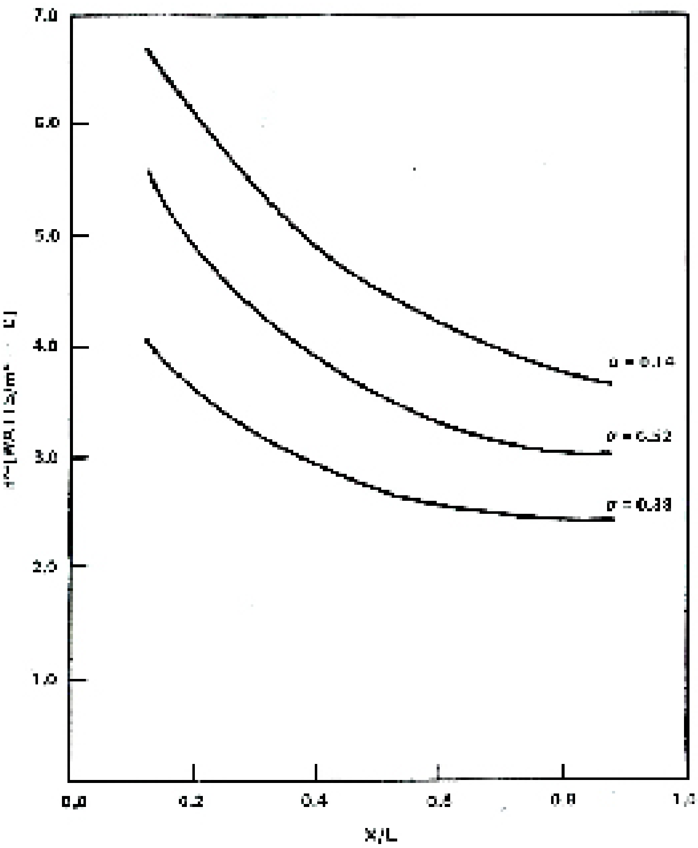


Figure 4. Smith Experiment: Convection Coefficient vs Nondimensional Distance Along Board. [4].

Where:

h = convection coefficient at the surface of the device

X/L = nondimensional distance along board.

σ = the ratio of total device surface area to total board area

On one hand, if a board were to be sparsely populated, a greater percentage of heat can be transferred to the board due to larger thermal gradients; however since the overall surface area of the sum of devices decreases, to some extent the heat transfer coefficient must increase to reflect a balance. As the number of components decreases, the power generation increases per component, and the larger resulting temperature gradients in the region around the component yield more convective flow and thus an increase in the heat transfer coefficient. On the other hand, if the board becomes more densely populated, the proportion of heat transferred through the surface, as compared to through the board increases, and the overall increase in heat transferred through the surface yields increased flow and heat transfer at an individual component surface. The heat flux sensor was important in this particular experiment in order to study this phenomenon which was relative to the particular board and chassis design.

While heat flux sensors are particularly useful for experimental simulations, one should be careful in their use. Since the heat flux sensor is not completely discrete in geometry and conductive resistance, an experiment should compensate or allow for interference, which can be caused by the sensor. It is important to be wary of the effects the introduction of the sensor may have on experiments. Since the sensor has some inherent thermal resistance, conduction through the material of the sensor and also across its interface, an experiment should recognize or compensate for additional conductive resistance [5]. For a device with a certain junction to case thermal resistance, for example, a designer could affix a heater to a heat flux sensor with equivalent resistance to the device for a particular simulation.

Since the sensor also has some geometry as well, (and cannot ever be truly 100% discrete) a designer should not allow the sensor to disturb the flow regime in which it is being placed [5]. Usually this can mean simply creating a recess of equivalent thickness to immerse the sensor within and thus mount the sensor flush with the surface in which it is embedded.

In conclusion, the use of a heat flux gauge is an important and useful tool for the electronics designer. In particular, by using a heat flux gauge, it is possible to experimentally determine the heat transfer coefficient at a certain location on the electronics board where it would have had to be simply predicted or estimated previously. Due to the complexity of many electrical systems as well as the irregular nature of many boards, often analytical or CFD methods are not accurate and the best approach is empirical techniques. The use of the heat flux sensor can give results, which as seen particularly in [2, 3], would be difficult to calculate using analytical or numerical simulations. However, like most other instruments, it is important to use the sensor correctly and carefully to decrease the errors within a system and increase the reliability.

References:

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