Convective Cooling of Electronic Components

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Introduction

Continued miniaturization and increased multi-functionality of electronic circuits increases the power density and device operating temperatures. To maintain long-term performance, device temperature must be maintained below specific limits thus improved mechanisms of heat dissipation are needed. Many applications use passive cooling approaches that emphasize the importance of optimizing heat sink design to maximize heat dissipation by natural convection.

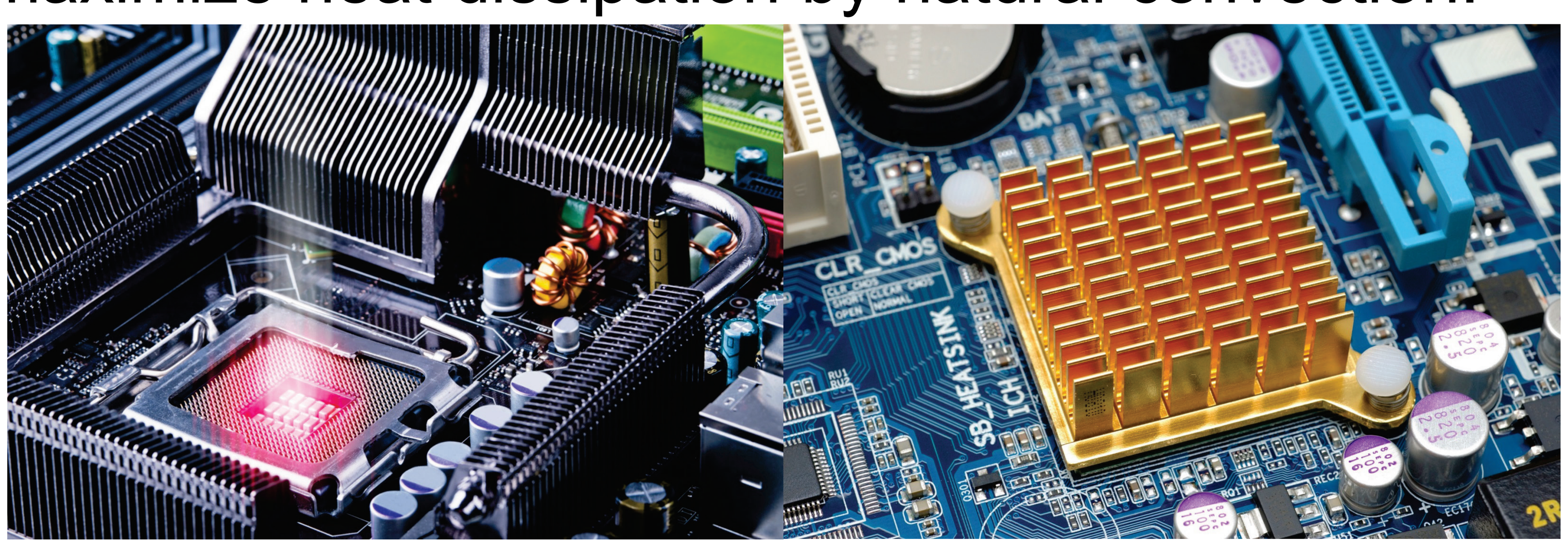

Figure 1. Thermal dissipation by passive heat sinks

Computational Methods

Ambient temperature air is heated by thermal transfer across the solid-air interface. The hot air has a lower density and rises under the buoyancy forces created. Heat transfer from the heat sink into the surrounding environment has been analyzed through a combination of conduction, convection and radiation. Heat flow in the solid domain is described using:

$$\rho\, c_p \frac{\partial T}{\partial t} = \nabla \cdot (\lambda \nabla T)$$

Surface to surface radiation effects are represented by:

$$q_r = \varepsilon_{emis}\left(G_m + F_{amb}\sigma\, T_{amb}^4 - \sigma\, T^4\right)$$

Heat transfer in the solid domain is coupled with fluid flow in the surrounding air domain represented by conservation of mass, momentum and energy:

$$\nabla \cdot (\rho\, \mathbf{u}) = 0$$

$$\rho\, \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p + \nabla \cdot \left(\eta\left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right) - \frac{2}{3}\eta(\nabla \cdot \mathbf{u})\mathbf{I}\right) + \rho\, \mathbf{g}$$

$$\nabla \cdot (-k\nabla T) = Q - \rho\, c_p \mathbf{u}$$

To limit computational requirements, a unit cell analysis was used to predict the effect of heat sink geometry on heat dissipation. In addition the significance of including heat transfer from the tips of the plate-fins was investigated.

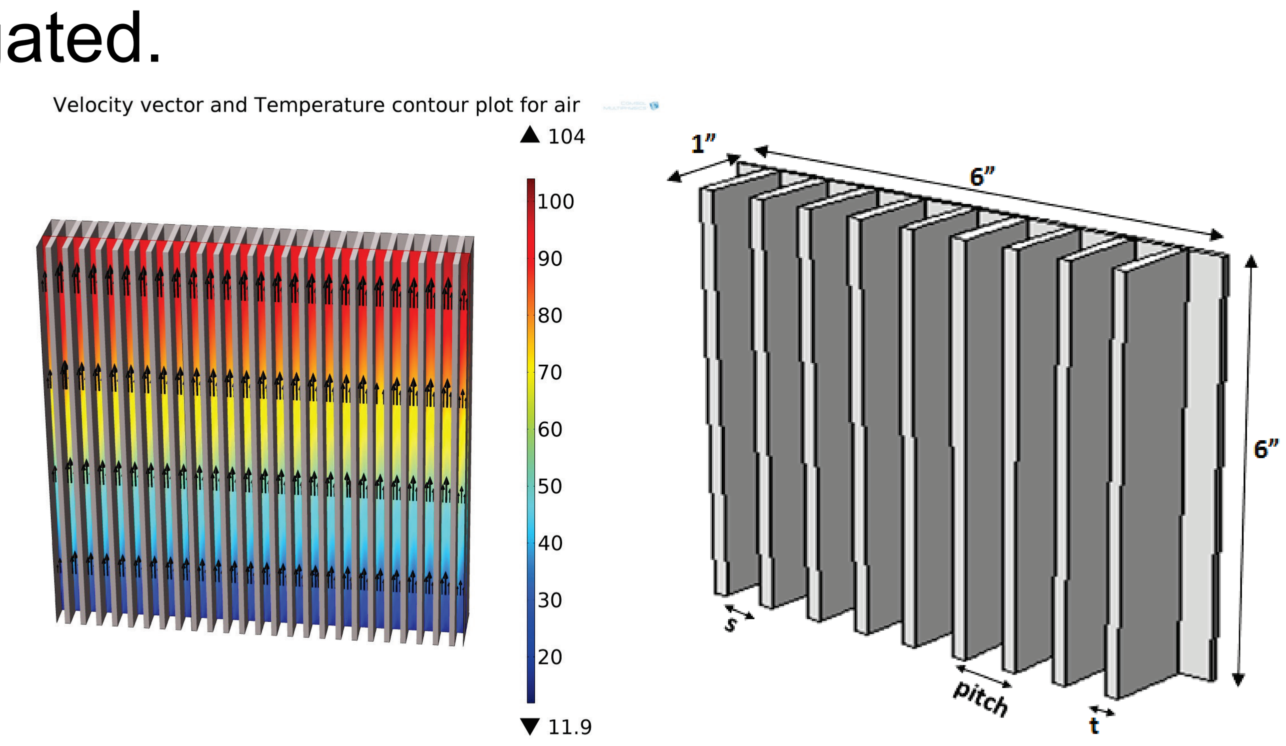

Figure 2. Natural convection through a plate-fin heat sink

Results

The effect of plate-fin pitch (P) to thickness (t) ratio on the temperature of the heat sink is shown for a range of applied heat fluxes in Figure 3. At low values of P/t, the fins obstruct flow and heat loss due to natural convection is limited by the mass flux of fluid over the heat sink. With increasing P/t the total surface area decreases for a fixed heat sink size and therefore less heat is dissipated. Optimum heat sink performance occurs when a balance between increasing the surface area and decreasing the pressure drop caused by flow obstruction over the plate-fins is obtained.

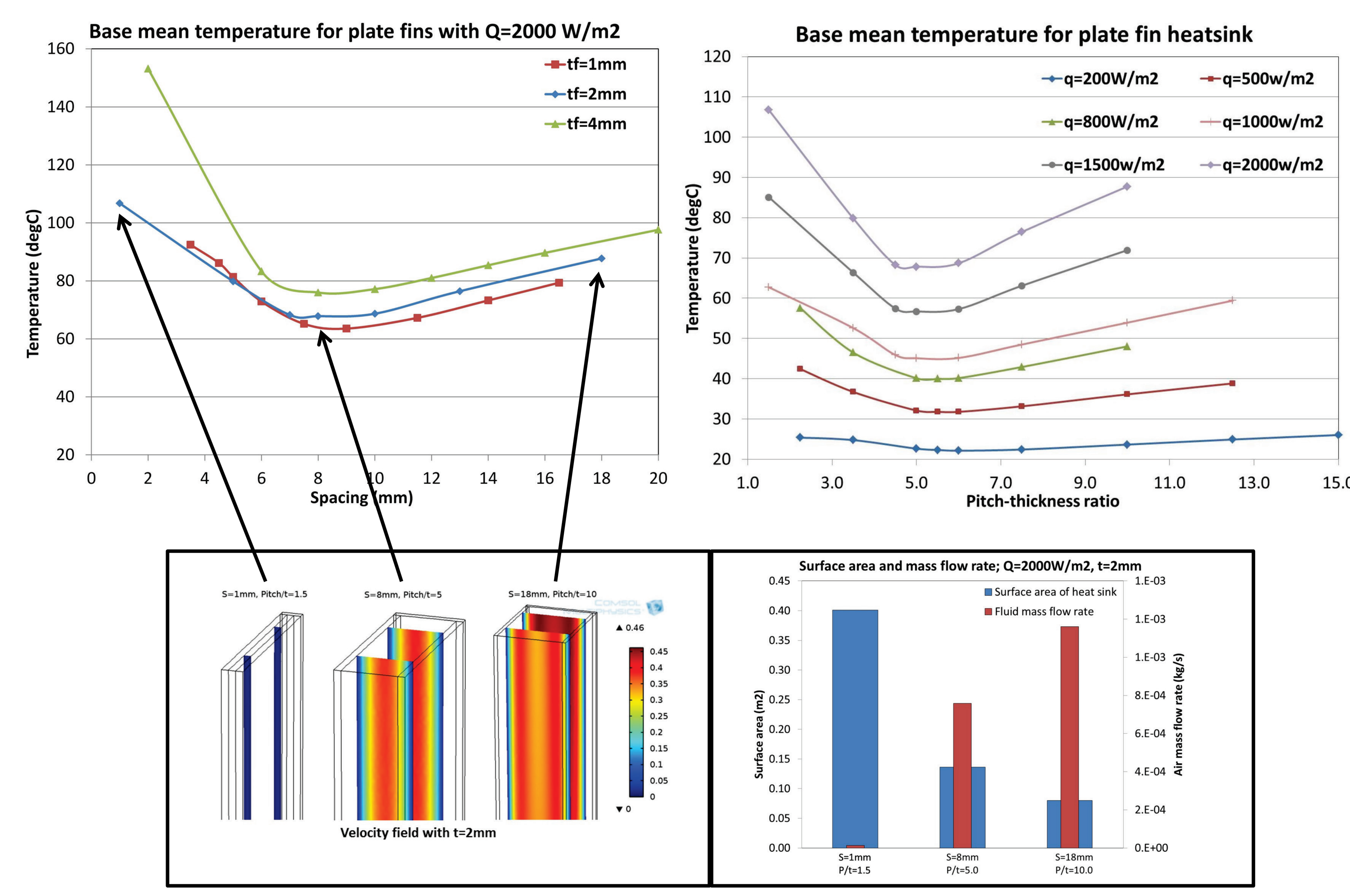

Figure 3. Effect of heat sink design on temperature

In addition to convective heat loss from the walls of the plate-fins, convection from the fin tips and radiation from the plates is important. Figure 4 shows results of analyses in which these effects are included, an additional 10-15% reduction in temperature is predicted.

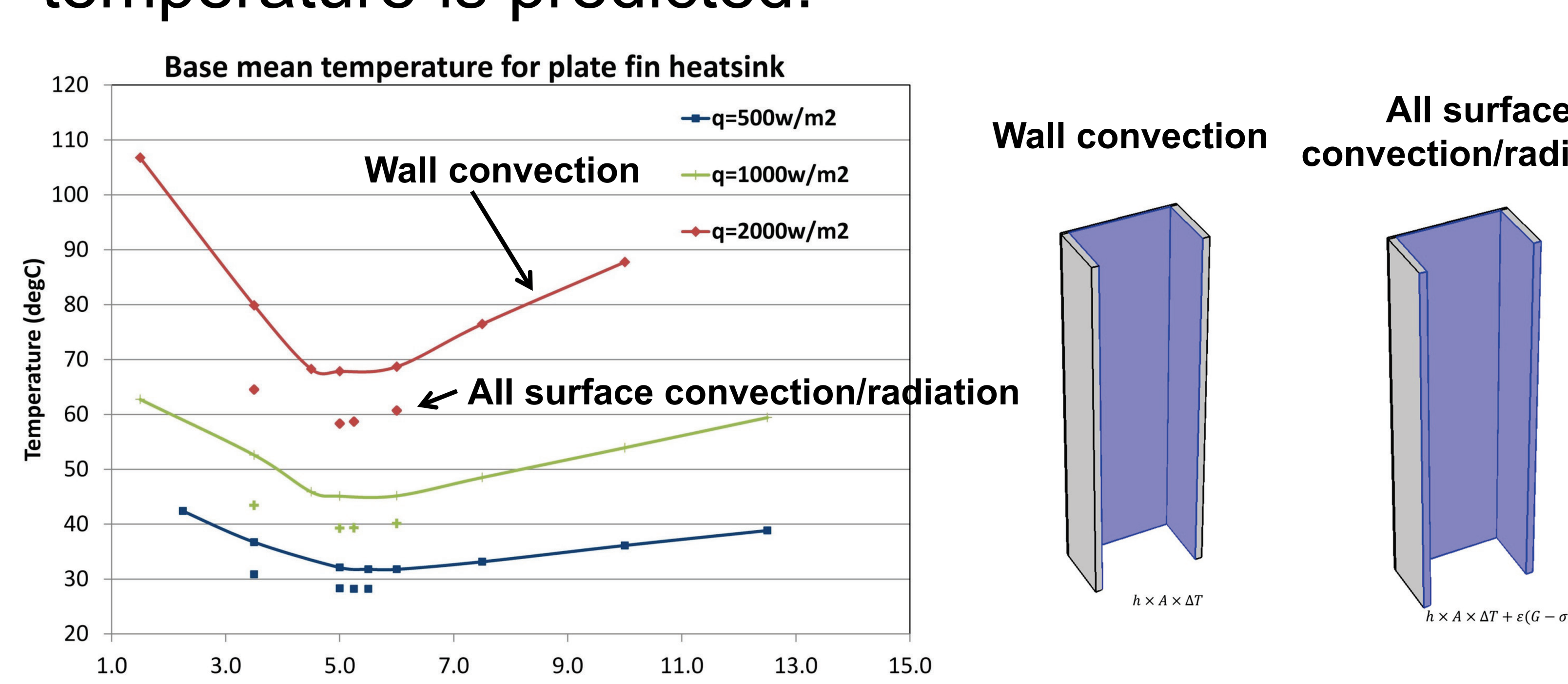

Figure 4. Effect of including plate-fin tip convection and radiation on heat sink temperature

Conclusions

Optimized heat sink designs are provided by a balance between the surface area and the pressure drop over the plate-fins.

Including convection from the plate fin tips and radiation losses predicts a 10-15% reduction in operating temperature.

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