

obtained by Martin [13]. In reducing the original correlation, the applicable parametric ranges were narrowed into those of practical interest in electronics cooling.

3.2.7 Forced convective heat transfer from modules on board

Once mounted on the printed circuit board, heat transfer from the module is affected by the geometric parameters depicted in Fig. 3.10. In addition to the size of the module [b (height) \times l (length) \times w (width)], there are such parameters as the separation distance between the neighboring modules (row spacing s , column spacing s'), the location of the module [in row number n ($1 \leq n \leq N$) counted from the entrance of the coolant channel], and the channel height (H). The real situation is far more complex than that portrayed in Fig. 3.10; particularly in small systems, the geometric regularity in placement of modules and other components exists only to a certain extent. Most of the pertinent data reported in the literature are useful for the design of big systems, where a number of equal-sized modules are mounted on the board with a regular placement pitch. A brief account of such knowledge base is given below, with an intention to provide some conceptual guides for designers of small systems as well.

Figure 3.11 presents a collection of the curves of heat transfer coefficient (h) versus the air velocity (U). The data "single module" was reported by Chang, Shyu, and Fang [2], with a single heated block measuring $6 \times 6 \times 2$ cm ($b/l = 1/3$) in a channel having a relative height $H/b = 3$. The curve "sparse flat packs" correlates the data obtained by Wirtz and Dykshoorn [20]. Their model of flat pack (block) had a

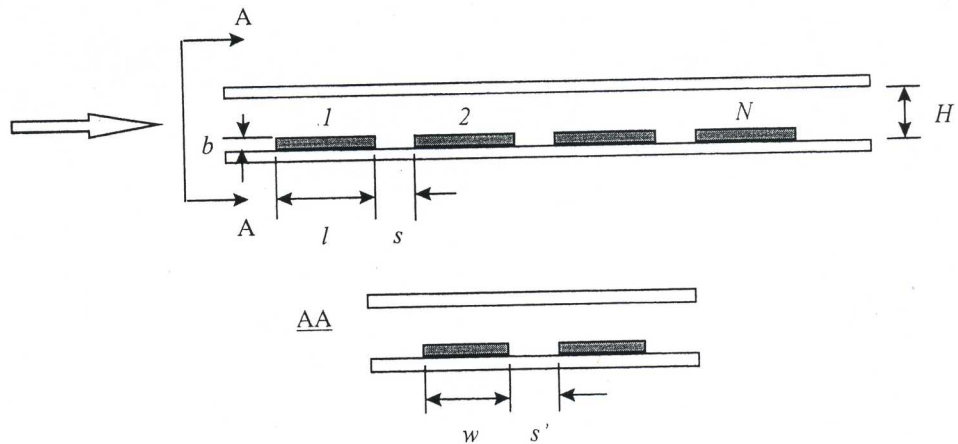


Figure 3.10 Module array on board.

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TABLE 3

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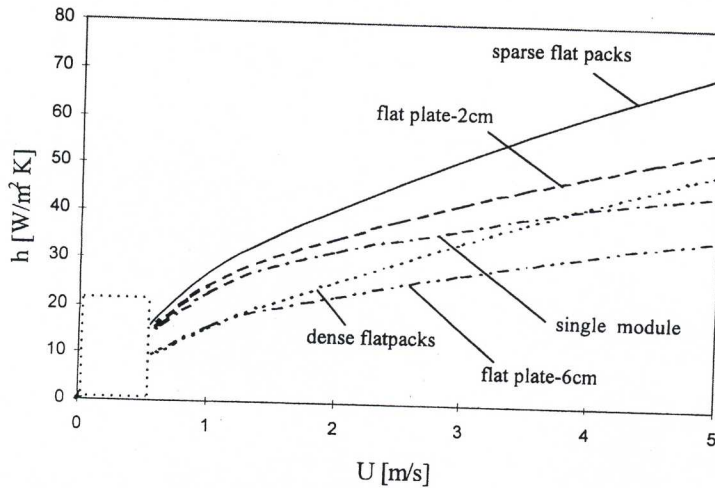


Figure 3.11 Typical heat transfer coefficients for forced convection air cooling of modules and flat plates.

dimension $2.54 \times 2.54 \times 0.64\text{cm}$, hence, the ratio $b/l = 0.23$. Other parameters were $H/b = 3.6$ and $s/l = 1$. The curve “densely flatpacks” correlates the data obtained by Sparrow, Neithammer, and Chaboki [19]. The block was $2.667 \times 2.667 \times 1\text{cm}$, and placed in a channel having $H/b = 2.67$. The spacing between the blocks was $s/l = 0.25$. Those data and correlations were discussed by Moffat and Ortega [15]. Also shown in Fig. 3.11 are the curves for heat transfer from a 2.54-cm-long flat plate (“flat plate-2cm”) and a 6-cm-long flat plate (“flat plate-6cm”), drawn using the first formula of Table 3.3 and the physical properties of air listed in Table 3.4. What we see in Fig. 3.11 are interpreted as follows.

1. The smaller the size of the module, the higher the heat transfer coefficient. See the sparse flatpacks and the flat plate-2cm versus the single module and the flat plate-6cm.
2. The coolant stream in the channel is accelerated where the module partially blocks the channel. Acceleration of coolant flow has an

TABLE 3.4 Thermophysical Properties of Single-Phase Coolant at 300K

Coolant	Density, ρ [kg/m ³]	Specific heat, c_p [kJ/kg K]	Kinematic viscosity, ν [10 ⁻⁶ m ² /s]	Thermal conductivity, λ [W/m K]	Thermal diffusivity, κ [10 ⁻⁶ m ² /s]	Prandtl number, Pr	Coeff. thermal expansion, β [K ⁻¹]
Air	1.16	1.00	15.9	0.0263	22.5	0.7	0.0033 (300K)
PC77	1590	1.17	0.28	0.057	0.03	9.25	0.0014
Water	1000	4.18	0.86	0.613	0.15	5.7	0.00028

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