UNIVERSITY MECHANICAL ENGINEERING • EXERCISE SHEET

10.6 Thermal design

Name: _____ Class: _____ Date: _____ **Total: 16 marks**

KEY WORDS fins • fin efficiency • thermal resistance

Objective

Find the heat-sink resistance a component allows, the efficiency of a straight fin, and the junction temperature a fin array gives, natural or fan-cooled.

1 Key knowledge and worked examples

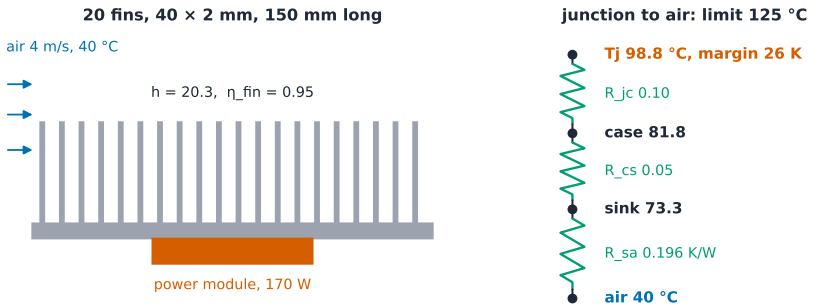
■ **Junction to air in series**

- $T_j = T_a + P(R_{jc} + R_{cs} + R_{sa})$, so $R_{sa,max} = (T_{j,max} - T_a)/P - R_{jc} - R_{cs}$.
- Straight **fins** with tip losses neglected: $m = \sqrt{2h/(kt)}$, **fin efficiency** $\eta_f = \tanh(mH)/(mH)$.
- Sink conductance $hA_{eff} = h(A_b + \eta_f A_f)$ and $R_{sa} = 1/(hA_{eff})$; A_b is the base left between the fins.

■ **Worked example. The allowed resistance and the fins**

$T_j \le 125$ °C, air 40 °C, $P = 170$ W, $R_{jc} = 0.10$, $R_{cs} = 0.05$ K/W.

- $R_{sa,max} = (T_{j,max} - T_a)/P - (R_{jc} + R_{cs}) = (125 - 40)/170 - 0.15 = \mathbf{0.35}$ K/W.
- 20 aluminium fins, 40 mm by 2 mm, $h = 20.3$: $m = \sqrt{2h/(kt)} = 10.1$ m^{-1}, $\eta_f = 0.95$, $R_{sa} = 0.196$ K/W.
- $T_j = T_a + P(R_{jc} + R_{cs} + R_{sa}) = 40 + 170(0.10 + 0.05 + 0.196) = \mathbf{98.8}$ °C, a 26 K margin.



2 Practice

2.1 A 120 W module must keep $T_j \le 110$ °C in air at 35 °C, with $R_{jc} + R_{cs} = 0.23$ K/W. Find the largest allowed R_{sa} (three decimals, K/W). [2]

2.2 An aluminium fin ($k = 200$ W/(m · K)) is 30 mm high and 1.5 mm thick, with $h = 25$ W/(m^2 · K). Find m (two decimals, m^{-1}), mH and η_f (three decimals). [4]

3 Exam-style questions

3.1 The sink of 2.1 has a base 100 mm by 120 mm carrying 25 of the fins of 2.2, each 100 mm long, $h = 25$ W/(m^2 · K). (a) Find the fin area (both faces) and the exposed base area. (b) Find R_{sa} (four decimals) and T_j (one decimal, °C); does it meet the limit? (c) A fan doubles h to 50: find the new η_f, R_{sa} and T_j, and explain why R_{sa} falls by less than half. [10]

Solutions

2.1

- $R_{sa,max} = (T_{j,max} - T_a)/P - (R_{jc} + R_{cs}) = 75/120 - 0.23 = \mathbf{0.395}$ K/W.

2.2

- $m = \sqrt{2h/(kt)} = \sqrt{2 \times 25/(200 \times 0.0015)} = \mathbf{12.91}$ m^{-1}.
- $mH = 12.91 \times 0.030 = 0.387$; $\eta_f = \tanh(0.387)/0.387 = \mathbf{0.953}$.

3.1

- (a) $A_f = 25 \times 2 \times 0.030 \times 0.100 = \mathbf{0.150}$ m^2.
- $A_b = 0.100 \times 0.120 - 25 \times 0.0015 \times 0.100 = \mathbf{0.00825}$ m^2.
- (b) $hA_{eff} = h(A_b + \eta_f A_f) = 25(0.00825 + 0.953 \times 0.150) = 3.779$ W/K, so $R_{sa} = \mathbf{0.2646}$ K/W.
- $T_j = T_a + P(R_{jc} + R_{cs} + R_{sa}) = 35 + 120(0.23 + 0.2646) = \mathbf{94.4}$ °C, inside 110 °C.
- (c) $m = \sqrt{2 \times 50/(200 \times 0.0015)} = 18.26$, $mH = 0.548$, $\eta_f = \mathbf{0.911}$.
- $hA_{eff} = 50(0.00825 + 0.911 \times 0.150) = 7.244$ W/K, $R_{sa} = \mathbf{0.138}$ K/W; $T_j = 35 + 120(0.23 + 0.138) = \mathbf{79.2}$ °C.
- A larger h steepens the temperature fall along the fin, so the tips run cooler and η_f drops: the conductance less than doubles, and $R_{jc} + R_{cs}$ do not change at all.

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