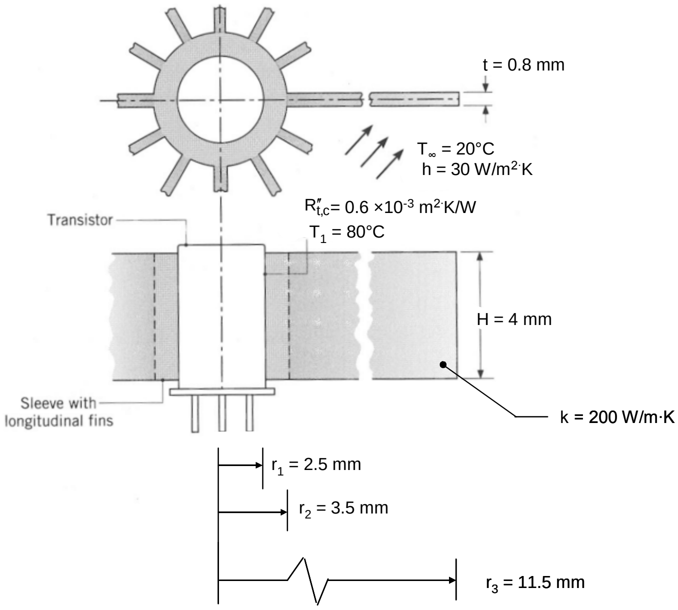
PROBLEM 3.162

KNOWN: Dimensions of finned aluminum sleeve inserted over a transistor. Contact resistance between sleeve and transistor. Surface convection conditions and temperature of transistor case.

FIND: (a) Rate of heat transfer from sleeve and (b) Measures for increasing heat dissipation.

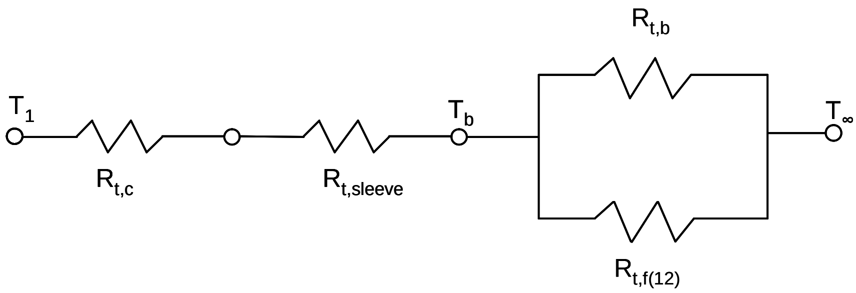
SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Negligible heat transfer from the top and bottom surfaces of the transistor, (3) One-dimensional radial conduction, (4) Constant properties, (5) Negligible radiation.

ANALYSIS:

(a) The circuit must account for the contact resistance, conduction in the sleeve, convection from the exposed base, and conduction/convection from the fins.



Thermal resistances for the contact joint and sleeve are

$$R_{t,c} = \frac{R''_{t,c}}{2\pi r_1 H} = \frac{0.6 \times 10^{-3}\ \text{m}^2 \cdot \text{K/W}}{2\pi(0.0025\ \text{m})(0.004\ \text{m})} = 9.55\ \text{K/W}$$

$$R_{t,sleeve} = \frac{\ln(r_2/r_1)}{2\pi kH} = \frac{\ln(3.5/2.5)}{2\pi(200\ \text{W/m}\cdot\text{K})(0.004\ \text{m})} = 0.0669\ \text{K/W}$$

For a single fin, $R_{t,f} = \theta_b / q_f$, where from Table 3.4, with tip convection,

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$$q_f = (hPkA_c)^{1/2}\theta_b \frac{\sinh(mL) + (h/mk)\cosh(mL)}{\cosh(mL) + (h/mk)\sinh(mL)}$$

with P = 2(H + t) = 9.6 mm = 0.0096 m and $A_c = t \times H = 3.2 \times 10^{-6}$ m^2,

$$m = \left(\frac{hP}{kA_c}\right)^{1/2} = \left(\frac{30\ \text{W/m}^2\cdot\text{K} \times 0.0096\ \text{m}}{200\ \text{W/m}\cdot\text{K} \times 3.2 \times 10^{-6}\ \text{m}^2}\right)^{1/2} = 21.2\ \text{m}^{-1}$$

$$mL = 21.2\ \text{m}^{-1} \times 0.008\ \text{m} = 0.170$$

$$\frac{h}{mk} = \frac{30\ \text{W/m}^2\cdot\text{K}}{21.2\ \text{m}^{-1} \times 200\ \text{W/m}\cdot\text{K}} = 0.00707$$

and

$$(hPkA_c)^{1/2} = (30\ \text{W/m}^2\cdot\text{K} \times 0.0096\ \text{m} \times 200\ \text{W/m}\cdot\text{K} \times 3.2 \times 10^{-6}\ \text{m}^2)^{1/2} = 0.0136\ \text{W/K}$$

Use of Table B.1 yields, for a single fin

$$R_{t,f} = \frac{1.014 + 0.00707 \times 0.171}{0.0136\ \text{W/K}\ (0.171 + 0.00707 \times 1.014)} = 421\ \text{K/W}$$

Hence, for 12 fins,

$$R_{t,f(12)} = \frac{R_{t,f}}{12} = 35.1\ \text{K/W}$$

For the exposed base,

$$R_{t,b} = \frac{1}{h(2\pi r_2 - 12t)H} = \frac{1}{30\ \text{W/m}^2\cdot\text{K}\ (2\pi \times 0.0035 - 12 \times 0.0008)\text{m} \times 0.004\ \text{m}} = 673\ \text{K/W}$$

With

$$R_{t,o} = \left[(35.1)^{-1} + (673)^{-1}\right]^{-1} = 33.3\ \text{K/W}$$

it follows that

$$R_{tot} = (9.55 + 0.0669 + 33.3)\ \text{K/W} = 43.0\ \text{K/W}$$

and

$$q_t = \frac{T_1 - T_\infty}{R_{tot}} = \frac{(80 - 20)°\text{C}}{43.0\ \text{K/W}} = 1.40\ \text{W} \qquad <$$

(b) With $2\pi r_2 = 0.022$ m and Nt = 0.0096 m, the existing gap between fins is extremely small (0.96 mm). Hence, by increasing N and/or t, it would become even more difficult to maintain satisfactory airflow between the fins, and this option is not particularly attractive.

Because the fin efficiency for the prescribed conditions is close to unity ($\eta_f = (hA_f R_{t,f})^{-1} = 0.992$), there is little advantage to replacing the aluminum with a material of higher thermal conductivity (e.g. Cu

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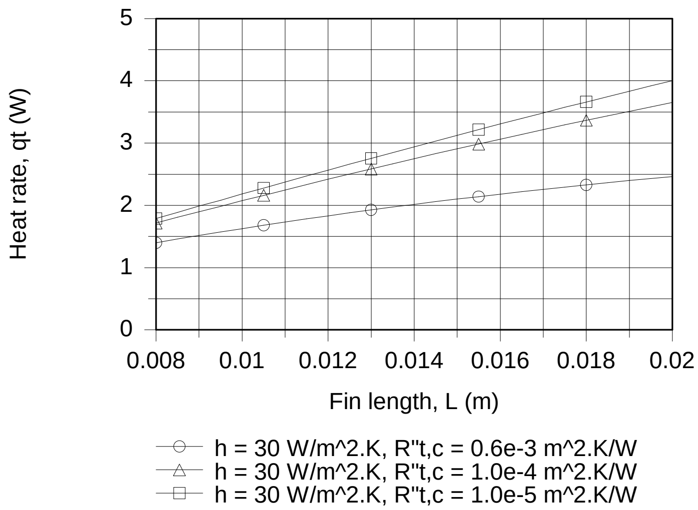
with k ~ 400 W/m·K). However, the large value of η_f suggests that significant benefit could be gained by increasing the fin length, $L = r_3 - r_2$.

It is also evident that the thermal contact resistance is large, and from Table 3.2, it's clear that a significant reduction could be effected by using indium foil or a conducting grease in the contact zone. Specifically, a reduction of $R''_{t,c}$ from 0.6×10^{-3} to 10^{-4} or even 10^{-5} m^2·K/W is certainly feasible.

Table 1.1 suggests that, by increasing the velocity of air flowing over the fins, a larger convection coefficient may be achieved. A value of h = 100 W/m^2·K would not be unreasonable.

As options for enhancing heat transfer, we therefore enter the foregoing equations into IHT to explore the effect of parameter variations over the ranges $8 \le L \le 20$ mm, $10^{-5} \le R''_{t,c} \le 0.6\times10^{-3}$ m^2·K/W and $30 \le h \le 100$ W/m^2·K. As shown below, there is a significant enhancement in heat transfer associated with reducing $R''_{t,c}$ from 0.6×10^{-3} to 10^{-4} m^2·K/W, for which $R_{t,c}$ decreases from 9.55 to 1.59 K/W. At this value of $R''_{t,c}$, the reduction in $R_{t,o}$ from 33.3 to 14.8 K/W which accompanies an increase in L from 8 to 20 mm becomes significant, yielding a heat rate of q_t = 3.65 W for $R''_{t,c} = 10^{-4}$ m^2·K/W and L = 20 mm. However, since $R_{t,o} >> R_{t,c}$, little benefit is gained by further reducing $R''_{t,c}$ to 10^{-5} m^2·K/W.



To derive benefit from a reduction in $R''_{t,c}$ to 10^{-5} m^2·K/W, an additional reduction in $R_{t,o}$ must be made. This can be achieved by increasing h, and for L = 20 mm and h = 100 W/m^2·K, $R_{t,o}$ = 5.0 K/W. With $R''_{t,c} = 10^{-5}$ m^2·K/W, a value of q_t = 11.5 W may be achieved.

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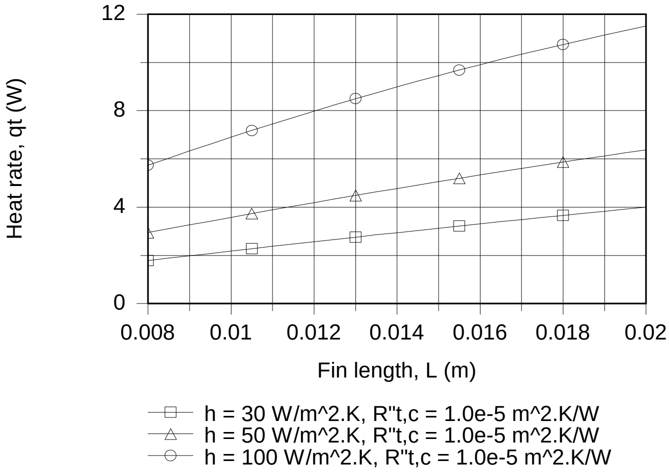
PROBLEM 3.162 (Cont.)



COMMENTS: (1) Without the finned sleeve, the convection resistance of the transistor case is $R_{tran} = (2\pi r_1 Hh)^{-1} = 531$ K/W. Hence there is considerable advantage to using the fins. (2) If an adiabatic fin tip is assumed, tanh(mL) = 0.168 and $R_{t,f} = 437$. Hence the error in the fin resistance is 4% relative to the actual convecting tip. (3) With $\eta_f = 0.992$, Equation 3.102 yields $\eta_o = 0.992$, from which it follows that $R_{t,o} = (\eta_o h A_t)^{-1} = 33.3$ K/W. This result is, of course, identical to that obtained in the foregoing determination of $R_{t,o}$. (4) In assessing options for enhancing heat transfer, the limiting (largest) resistance(s) should be identified and efforts directed at their reduction.