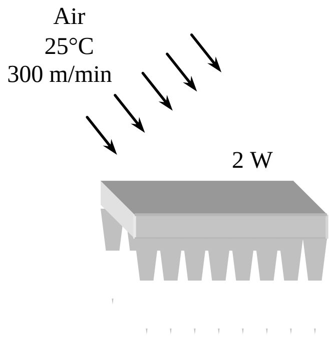
15-55 A plastic DIP with 16 leads is cooled by forced air. Using data supplied by the manufacturer, the junction temperature is to be determined.

Assumptions Steady operating conditions exist.



Analysis The junction-to-ambient thermal resistance of the device with 16 leads corresponding to an air velocity of 300 m/min is determined from Fig.15-23 to be

$$R_{junction-ambient} = 50^\circ\text{C / W}$$

Then the junction temperature becomes

$$\dot{Q} = \frac{T_{junction} - T_{ambient}}{R_{junction-ambient}}$$

$$T_{junction} = T_{ambient} + \dot{Q}R_{junction-ambient} = 25^\circ\text{C} + (2\text{ W})(50^\circ\text{C/W}) = \mathbf{125^\circ C}$$

When the fan fails the total thermal resistance is determined from Fig.15-23 by reading the value for zero air velocity (the intersection point of the curve with the vertical axis) to be

$$R_{junction-ambient} = 70^\circ\text{C / W}$$

which yields

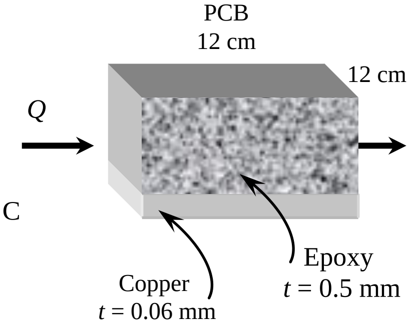
$$\dot{Q} = \frac{T_{junction} - T_{ambient}}{R_{junction-ambient}}$$

$$T_{junction} = T_{ambient} + \dot{Q}R_{junction-ambient} = 25^\circ\text{C} + (2\text{ W})(70^\circ\text{C/W}) = \mathbf{165^\circ C}$$

15-56 A PCB with copper cladding is given. The percentages of heat conduction along the copper and epoxy layers as well as the effective thermal conductivity of the PCB are to be determined.

Assumptions **1** Steady operating conditions exist. **2** Heat conduction along the PCB is one-dimensional since heat transfer from side surfaces is negligible. **3** The thermal properties of epoxy and copper layers are constant.

Analysis Heat conduction along a layer is proportional to the thermal conductivity-thickness product (kt) which is determined for each layer and the entire PCB to be



$$(kt)_{copper} = (386\text{ W / m.}^\circ\text{C})(0.06\times10^{-3}\text{ m}) = 0.02316\text{ W/}^\circ\text{C}$$

$$(kt)_{epoxy} = (0.26\text{ W / m.}^\circ\text{C})(0.5\times10^{-3}\text{ m}) = 0.00013\text{ W/}^\circ\text{C}$$

$$(kt)_{PCB} = (kt)_{copper} + (kt)_{epoxy} = 0.02316 + 0.00013 = 0.02329\text{ W/}^\circ\text{C}$$

Therefore the percentages of heat conduction along the epoxy board are

$$f_{epoxy} = \frac{(kt)_{epoxy}}{(kt)_{PCB}} = \frac{0.00013\text{W/}^\circ\text{C}}{0.02316\text{W/}^\circ\text{C}} = 0.0056 \cong \mathbf{0.6\%}$$

and $f_{copper} = (100 - 0.6)\% = \mathbf{99.4\%}$

Then the effective thermal conductivity becomes

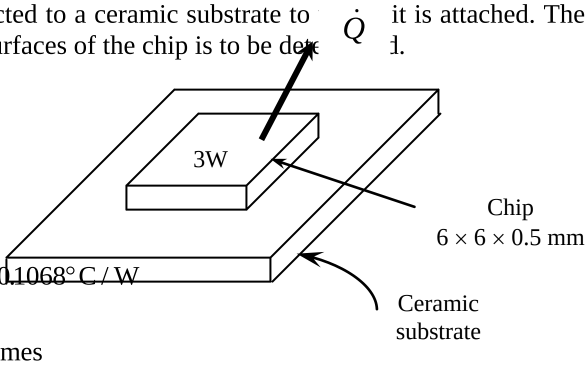
$$k_{eff} = \frac{(kt)_{epoxy} + (kt)_{copper}}{t_{epoxy} + t_{copper}} = \frac{(0.02316 + 0.00013)\text{ W/}^\circ\text{C}}{(0.06 + 0.5)\times10^{-3}\text{ m}} = \mathbf{41.6\ W/m.^\circ C}$$

15-57

```
"!PROBLEM 15-057"

"GIVEN"
length=0.12 "[m]"
width=0.12 "[m]"
"t_copper=0.06 [mm], parameter to be varied"
t_epoxy=0.5 "[mm]"
k_copper=386 "[W/m-C]"
k_epoxy=0.26 "[W/m-C]"

"ANALYSIS"
kt_copper=k_copper*t_copper*Convert(mm, m)
kt_epoxy=k_epoxy*t_epoxy*Convert(mm, m)
kt_PCB=kt_copper+kt_epoxy
f_copper=kt_copper/kt_PCB*Convert(, %)
f_epoxy=100-f_copper
k_eff=(kt_epoxy+kt_copper)/((t_epoxy+t_copper)*Convert(mm, m))
```

T_{copper} [mm]	f_{copper} [%]	k_{eff} [W/m-C]
0.02	98.34	15.1
0.025	98.67	18.63
0.03	98.89	22.09
0.035	99.05	25.5
0.04	99.17	28.83
0.045	99.26	32.11
0.05	99.33	35.33
0.055	99.39	38.49
0.06	99.44	41.59
0.065	99.48	44.64
0.07	99.52	47.63
0.075	99.55	50.57
0.08	99.58	53.47
0.085	99.61	56.31
0.09	99.63	59.1
0.095	99.65	61.85
0.1	99.66	64.55

15-58 The heat generated in a silicon chip is conducted to a ceramic substrate to it is attached. The temperature difference between the front and back surfaces of the chip is to be det d.



Assumptions **1** Steady operating conditions exist. **2** Heat conduction along the chip is one-dimensional.

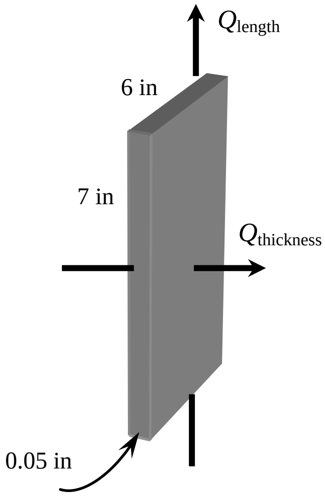
Analysis The thermal resistance of silicon chip is

$$R_{chip} = \frac{L}{kA} = \frac{0.5 \times 10^{-3}\text{ m}}{(130\text{ W/m.°C})(0.006 \times 0.006)\text{m}^2} = 0.1068\text{°C/W}$$

Then the temperature difference across the chip becomes

$$\Delta T = \dot{Q}R_{chip} = (3\text{ W})(0.1068\text{°C/W}) = \mathbf{0.32\text{°C}}$$

15-59E The dimensions of an epoxy glass laminate are given. The thermal resistances for heat flow along the layers and across the thickness are to be determined.



Assumptions **1** Heat conduction in the laminate is one-dimensional in either case. **2** Thermal properties of the laminate are constant.

Analysis The thermal resistances of the PCB along the 7 in long side and across its thickness are

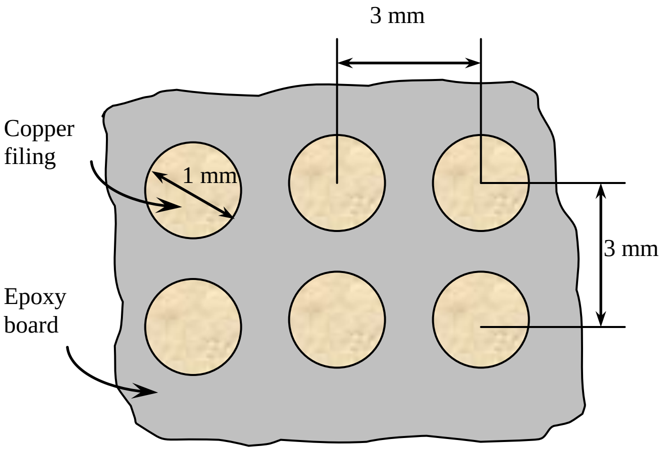
(*a*)

$$\begin{aligned} R_{\substack{along\\length}} &= \frac{L}{kA} \\ &= \frac{(7/12)\text{ft}}{(0.15\text{ Btu/h.ft.°F})(6/12\text{ ft})(0.05/12\text{ ft})} \\ &= \mathbf{1867\text{ h.°F/Btu}} \end{aligned}$$

(*b*)

$$\begin{aligned} R_{\substack{across\\thickness}} &= \frac{L}{kA} \\ &= \frac{(0.05/12)\text{ft}}{(0.15\text{ Btu/h.ft.°F})(7/12\text{ ft})(6/12\text{ft})} = \mathbf{0.095\text{ h.°F/Btu}} \end{aligned}$$

15-60 Cylindrical copper fillings are planted throughout an epoxy glass board. The thermal resistance of the board across its thickness is to be determined.



Assumptions **1** Heat conduction along the board is one-dimensional. **2** Thermal properties of the board are constant.

Analysis The number of copper fillings on the board is

$$n = \frac{\text{Area of board}}{\text{Area of one square}} = \frac{(150\text{ mm})(180\text{mm})}{(3\text{ mm})(3\text{mm})} = 3000$$

The surface areas of the copper fillings and the remaining part of the epoxy layer are

$$A_{copper} = n\frac{\pi D^2}{4} = (3000)\frac{\pi(0.001\text{ m})^2}{4} = 0.002356\text{ m}^2$$

$$A_{total} = (length)(width) = (0.15\text{ m})(0.18\text{ m}) = 0.027\text{ m}^2$$

$$A_{epoxy} = A_{total} - A_{copper} = 0.027 - 0.002356 = 0.024644\text{ m}^2$$

The thermal resistance of each material is

$$R_{copper} = \frac{L}{kA} = \frac{0.0014\text{ m}}{(386\text{ W/m.°C})(0.002356\text{ m}^2)} = 0.00154\text{°C/W}$$

$$R_{epoxy} = \frac{L}{kA} = \frac{0.0014\text{ m}}{(0.26\text{ W/m.°C})(0.024644\text{ m}^2)} = 0.2185\text{°C/W}$$

Since these two resistances are in parallel, the equivalent thermal resistance of the entire board is

$$\frac{1}{R_{board}} = \frac{1}{R_{epoxy}} + \frac{1}{R_{copper}} = \frac{1}{0.2185\text{°C/W}} + \frac{1}{0.00154\text{°C/W}} \longrightarrow R_{board} = \mathbf{0.00153\text{ °C/W}}$$

15-61

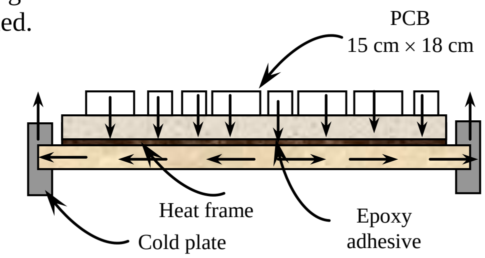
```
"!PROBLEM 15-061"

"GIVEN"
length=0.18 "[m]"
width=0.15 "[m]"
k_epoxy=0.26 "[W/m-C]"
t_board=1.4/1000 "[m]"
k_filling=386 "[W/m-C], parameter to be varied"
"D_filling=1 [mm], parameter to be varied"
s=3/1000 "[m]"

"ANALYSIS"
A_board=length*width
n_filling=A_board/s^2
A_filling=n_filling*pi*(D_filling*Convert(mm, m))^2/4
A_epoxy=A_board-A_filling
R_filling=t_board/(k_filling*A_filling)
R_epoxy=t_board/(k_epoxy*A_epoxy)
1/R_board=1/R_epoxy+1/R_filling
```

$k_{filling}$ [W/m-C]	R_{board} [C/W]
10	0.04671
29.5	0.01844
49	0.01149
68.5	0.008343
88	0.00655
107.5	0.005391
127	0.00458
146.5	0.003982
166	0.003522
185.5	0.003157
205	0.00286
224.5	0.002615
244	0.002408
263.5	0.002232
283	0.00208
302.5	0.001947
322	0.00183
341.5	0.001726
361	0.001634
380.5	0.00155
400	0.001475

$D_{filling}$ [mm]	R_{board} [C/W]
0.5	0.005977
0.6	0.004189
0.7	0.003095
0.8	0.002378
0.9	0.001884
1	0.001529
1.1	0.001265
1.2	0.001064
1.3	0.0009073
1.4	0.0007828
1.5	0.0006823
1.6	0.0005999
1.7	0.0005316

1.8	0.0004743
1.9	0.0004258
2	0.0003843

15-62 A circuit board with uniform heat generation is to be conduction cooled by a copper heat frame. Temperature distribution along the heat frame and the maximum temperature in the PCB are to be determined.



Assumptions **1** Steady operating conditions exist **2** Thermal properties are constant. **3** There is no direct heat dissipation from the surface of the PCB, and thus all the heat generated is conducted by the heat frame to the heat sink.

Analysis The properties and dimensions of various section of the PCB are summarized below as

Section and material	Thermal conductivity	Thickness	Heat transfer surface area
Epoxy board	0.26 W/m.°C	2 mm	10 mm × 120 mm
Epoxy adhesive	1.8 W/m.°C	0.12 mm	10 mm × 120 mm
Copper heat frame (normal to frame)	386 W/m.°C	1.5 mm	10 mm × 120 mm
Copper heat frame (along the frame)	386 W/m.°C	10 mm	15 mm × 120 mm

Using the values in the table, the various thermal resistances are determined to be

$$R_{epoxy}=\frac{L}{kA}=\frac{0.002\text{ m}}{(0.26\text{ W/m.°C})(0.01\text{ m}\times 0.12\text{ m})}=6.41\text{°C/W}$$

$$R_{adhesive}=\frac{L}{kA}=\frac{0.00012\text{ m}}{(1.8\text{ W/m.°C})(0.01\text{ m}\times 0.12\text{ m})}=0.056\text{°C/W}$$

$$R_{copper,\perp}=\frac{L}{kA}=\frac{0.0015\text{ m}}{(386\text{ W/m.°C})(0.01\text{ m}\times 0.12\text{ m})}=0.0032\text{°C/W}$$

$$R_{frame}=R_{copper,parallel}=\frac{L}{kA}=\frac{0.01\text{ m}}{(386\text{ W/m.°C})(0.0015\times 0.12\text{ m})}=0.144\text{°C/W}$$

The combined resistance between the electronic components on each strip and the heat frame can be determined by adding the three thermal resistances in series to be

$$R_{vertical}=R_{epoxy}+R_{adhesive}+R_{copper,\perp}=6.41+0.056+0.0032=6.469\text{°C/W}$$

The temperatures along the heat frame can be determined from the relation $\Delta T=T_{high}-T_{low}=\dot{Q}R$. Then,

$$T_1=T_0+\dot{Q}_{1-0}R_{1-0}=30\text{°C}+(22.5\text{ W})(0.144\text{°C/W})=\mathbf{33.24\text{°C}}$$

$$T_2=T_1+\dot{Q}_{2-1}R_{2-1}=33.24\text{°C}+(19.5\text{ W})(0.144\text{°C/W})=\mathbf{36.05\text{°C}}$$

$$T_3=T_2+\dot{Q}_{3-2}R_{3-2}=36.05\text{°C}+(16.5\text{ W})(0.144\text{°C/W})=\mathbf{38.42\text{°C}}$$

$$T_4=T_3+\dot{Q}_{4-3}R_{4-3}=38.42\text{°C}+(13.5\text{ W})(0.144\text{°C/W})=\mathbf{40.36\text{°C}}$$

$$T_5=T_4+\dot{Q}_{5-4}R_{5-4}=40.36\text{°C}+(10.5\text{ W})(0.144\text{°C/W})=\mathbf{41.87\text{°C}}$$

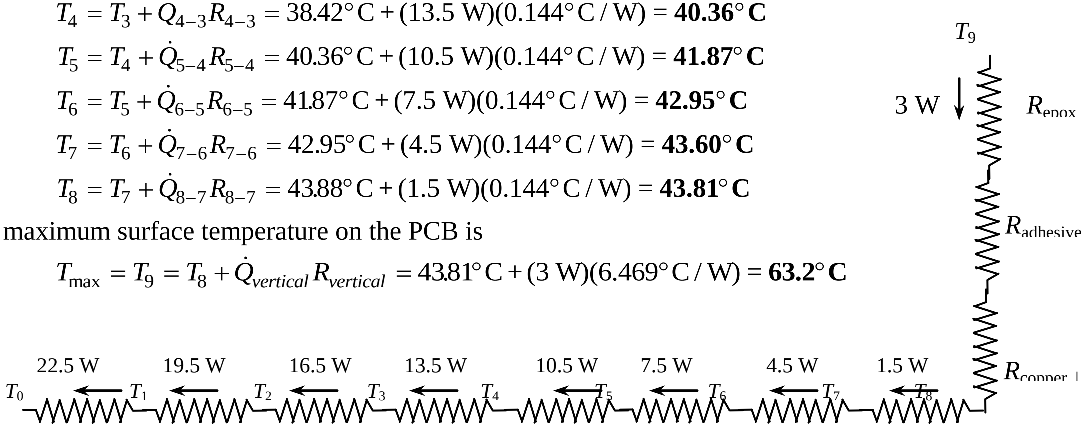
$$T_6=T_5+\dot{Q}_{6-5}R_{6-5}=41.87\text{°C}+(7.5\text{ W})(0.144\text{°C/W})=\mathbf{42.95\text{°C}}$$

$$T_7=T_6+\dot{Q}_{7-6}R_{7-6}=42.95\text{°C}+(4.5\text{ W})(0.144\text{°C/W})=\mathbf{43.60\text{°C}}$$

$$T_8=T_7+\dot{Q}_{8-7}R_{8-7}=43.88\text{°C}+(1.5\text{ W})(0.144\text{°C/W})=\mathbf{43.81\text{°C}}$$

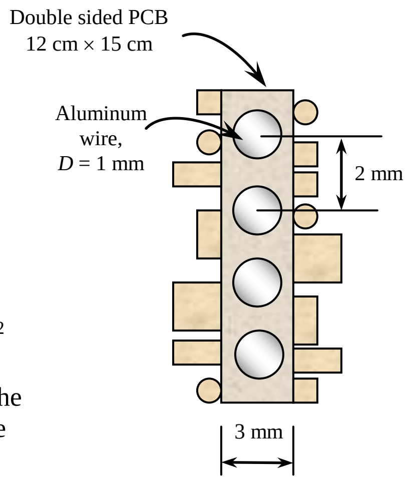
The maximum surface temperature on the PCB is

$$T_{\max}=T_9=T_8+\dot{Q}_{vertical}R_{vertical}=43.81\text{°C}+(3\text{ W})(6.469\text{°C/W})=\mathbf{63.2\text{°C}}$$



15-63 A circuit board with uniform heat generation is to be conduction cooled by aluminum wires inserted into it. The magnitude and location of the maximum temperature in the PCB is to be determined.

Assumptions **1** Steady operating conditions exist **2** Thermal properties are constant. **3** There is no direct heat dissipation from the surface of the PCB.



Analysis The number of wires in the board is

$$n = \frac{150 \text{ mm}}{2 \text{ mm}} = 75$$

The surface areas of the aluminum wires and the remaining part of the epoxy layer are

$$A_{aluminum} = n\frac{\pi D^2}{4} = (75)\frac{\pi(0.001 \text{ m})^2}{4} = 0.0000589 \text{ m}^2$$

$$A_{total} = (length)(width) = (0.003 \text{ m})(0.15 \text{ m}) = 0.00045 \text{ m}^2$$

$$A_{epoxy} = A_{total} - A_{aluminum} = 0.00045 - 0.0000589 = 0.0003911 \text{ m}^2$$

Considering only half of the circuit board because of symmetry, the thermal resistance of each material per 1-cm length is determined to be

$$R_{aluminum} = \frac{L}{kA} = \frac{0.01 \text{ m}}{(237 \text{ W/m.°C})(0.0000589 \text{ m}^2)} = 0.716\text{°C/W}$$

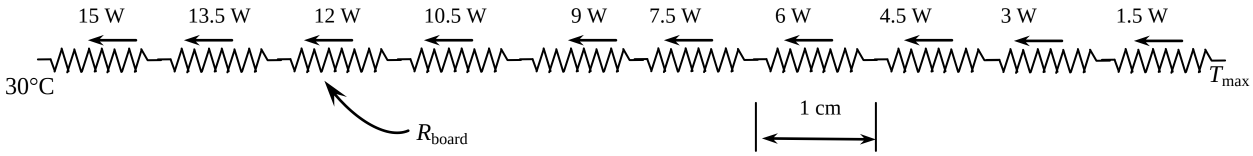
$$R_{epoxy} = \frac{L}{kA} = \frac{0.01 \text{ m}}{(0.26 \text{ W/m.°C})(0.0003911 \text{ m}^2)} = 98.34\text{°C/W}$$

Since these two resistances are in parallel, the equivalent thermal resistance per cm is determined from

$$\frac{1}{R_{board}} = \frac{1}{R_{epoxy}} + \frac{1}{R_{aluminum}} = \frac{1}{0.716\text{°C/W}} + \frac{1}{98.34\text{°C/W}} \longrightarrow R_{board} = 0.711\text{°C/W}$$

Maximum temperature occurs in the middle of the plate along the 20 cm length, which is determined to be

$$T_{\max} = T_{end} + \Delta T_{board,total} = T_{end} + \sum \dot{Q}_i R_{board,1-cm} = T_{end} + R_{board,1-cm}\sum \dot{Q}_i$$
$$= 30\text{°C} + (0.711\text{°C/W})(15 + 13.5 + 12 + 10.5 + 9 + 7.5 + 6 + 4.5 + 3 + 1.5)\text{W} = \mathbf{88.7°C}$$

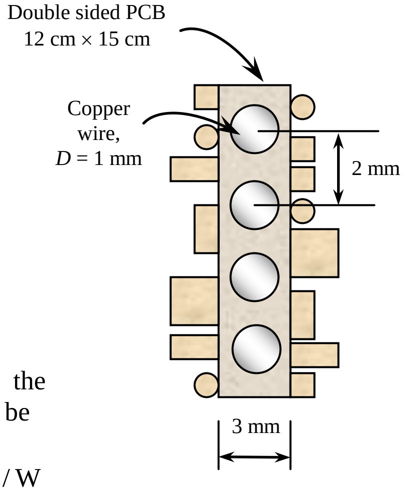


15-64 A circuit board with uniform heat generation is to be conduction cooled by copper wires inserted in it. The magnitude and location of the maximum temperature in the PCB is to be determined.

Assumptions **1** Steady operating conditions exist **2** Thermal properties are constant. **3** There is no direct heat dissipation from the surface of the PCB.

Analysis The number of wires in the circuit board is

$$n = \frac{150\text{ mm}}{2\text{ mm}} = 75$$



The surface areas of the copper wires and the remaining part of the epoxy layer are

$$A_{copper} = n\frac{\pi D^2}{4} = (75)\frac{\pi(0.001\text{ m})^2}{4} = 0.0000589\text{ m}^2$$
$$A_{total} = (length)(width) = (0.003\text{ m})(0.15\text{ m}) = 0.00045\text{ m}^2$$
$$A_{epoxy} = A_{total} - A_{copper} = 0.00045 - 0.0000589 = 0.0003911\text{ m}^2$$

Considering only half of the circuit board because of symmetry, the thermal resistance of each material per 1-cm length is determined to be

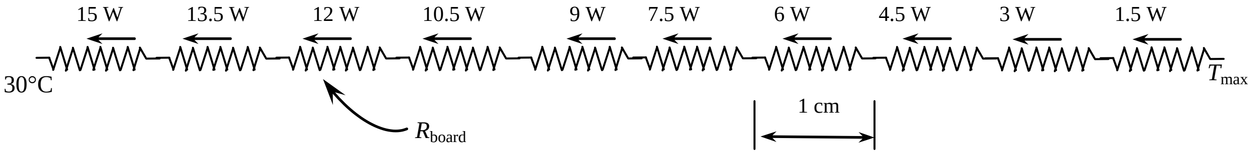
$$R_{copper} = \frac{L}{kA} = \frac{0.01\text{ m}}{(386\text{ W/m.°C})(0.0000589\text{ m}^2)} = 0.440\text{°C/W}$$
$$R_{epoxy} = \frac{L}{kA} = \frac{0.01\text{ m}}{(0.26\text{ W/m.°C})(0.0003911\text{ m}^2)} = 98.34\text{°C/W}$$

Since these two resistances are in parallel, the equivalent thermal resistance is determined from

$$\frac{1}{R_{board}} = \frac{1}{R_{epoxy}} + \frac{1}{R_{copper}} = \frac{1}{0.440\text{°C/W}} + \frac{1}{98.34\text{°C/W}} \longrightarrow R_{board} = 0.438\text{°C/W}$$

Maximum temperature occurs in the middle of the plate along the 20 cm length which is determined to be

$$T_{\max} = T_{end} + \Delta T_{board,total} = T_{end} + \sum \dot{Q}_i R_{board,1-cm} = T_{end} + R_{board,1-cm}\sum \dot{Q}_i$$
$$= 30\text{°C} + (0.438\text{°C/W})(15 + 13.5 + 12 + 10.5 + 9 + 7.5 + 6 + 4.5 + 3 + 1.5)\text{W} = \mathbf{66.1\text{°C}}$$

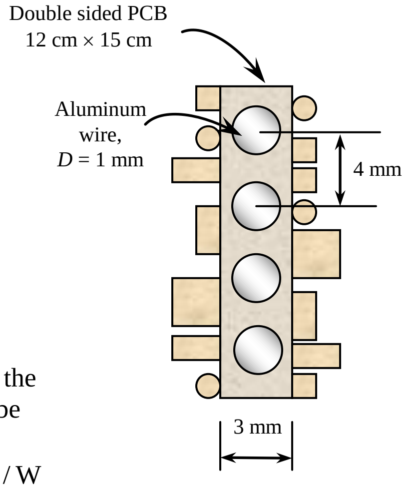


15-65 A circuit board with uniform heat generation is to be conduction cooled by aluminum wires inserted into it. The magnitude and location of the maximum temperature in the PCB is to be determined.

Assumptions **1** Steady operating conditions exist **2** Thermal properties are constant. **3** There is no direct heat dissipation from the surface of the PCB.

Analysis The number of wires in the board is

$$n = \frac{150 \text{ mm}}{4 \text{ mm}} = 37$$



The surface areas of the aluminum wires and the remaining part of the epoxy layer are

$$A_{aluminum} = n\frac{\pi D^2}{4} = (37)\frac{\pi(0.001 \text{ m})^2}{4} = 0.000029 \text{ m}^2$$

$$A_{total} = (length)(width) = (0.003 \text{ m})(0.15 \text{ m}) = 0.00045 \text{ m}^2$$

$$A_{epoxy} = A_{total} - A_{aluminum} = 0.00045 - 0.000029 = 0.000421 \text{ m}^2$$

Considering only half of the circuit board because of symmetry, the thermal resistance of each material per 1-cm length is determined to be

$$R_{aluminum} = \frac{L}{kA} = \frac{0.01 \text{ m}}{(237 \text{ W/m.°C})(0.000029 \text{ m}^2)} = 1.455\text{°C/W}$$

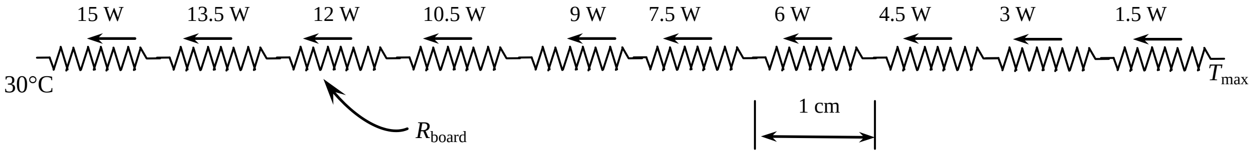
$$R_{epoxy} = \frac{L}{kA} = \frac{0.01 \text{ m}}{(0.26 \text{ W/m.°C})(0.000421 \text{ m}^2)} = 91.36\text{°C/W}$$

Since these two resistances are in parallel, the equivalent thermal resistance is determined from

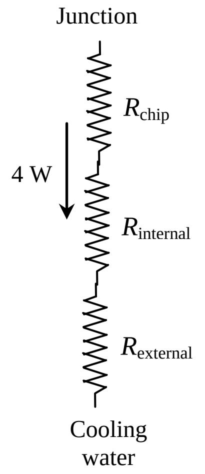
$$\frac{1}{R_{board}} = \frac{1}{R_{epoxy}} + \frac{1}{R_{aluminum}} = \frac{1}{1.455\text{°C/W}} + \frac{1}{91.36\text{°C/W}} \longrightarrow R_{board} = 1.432\text{°C/W}$$

Maximum temperature occurs in the middle of the plate along the 20 cm length which is determined to be

$$T_{\max} = T_{end} + \Delta T_{board,total} = T_{end} + \sum \dot{Q}_i R_{board,1-cm} = T_{end} + R_{board,1-cm}\sum \dot{Q}_i$$
$$= 30\text{°C} + (1.432\text{°C/W})(15 + 13.5 + 12 + 10.5 + 9 + 7.5 + 6 + 4.5 + 3 + 1.5)\text{W} = \mathbf{148.1°C}$$



15-66 A thermal conduction module with 80 chips is cooled by water. The junction temperature of the chip is to be determined.



Assumptions **1** Steady operating conditions exist **2** Heat transfer through various components is one-dimensional.

Analysis The total thermal resistance between the junction and cooling water is

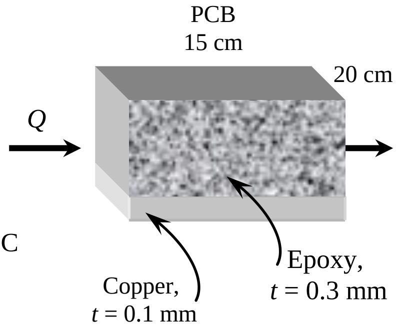
$$R_{total} = R_{junction-water} = R_{chip} + R_{\text{int}ernal} + R_{external} = 1.2 + 9 + 7 = 17.2°\text{C}$$

Then the junction temperature becomes

$$T_{junction} = T_{water} + \dot{Q}R_{junction-water} = 18°\text{C} + (4\text{ W})(17.2°\text{C/W}) = \mathbf{86.8°C}$$

15-67 A layer of copper is attached to the back surface of an epoxy board. The effective thermal conductivity of the board and the fraction of heat conducted through copper are to be determined.

Assumptions **1** Steady operating conditions exist **2** Heat transfer is one-dimensional.



Analysis Heat conduction along a layer is proportional to the thermal conductivity-thickness product (*kt*) which is determined for each layer and the entire PCB to be

$$(kt)_{copper} = (386\text{ W/m.°C})(0.0001\text{m}) = 0.0386\text{ W/°C}$$

$$(kt)_{epoxy} = (0.26\text{ W/m.°C})(0.0003\text{m}) = 0.000078\text{W/°C}$$

$$(kt)_{PCB} = (kt)_{copper} + (kt)_{epoxy} = 0.0386 + 0.000078 = 0.038678\text{W/°C}$$

The effective thermal conductivity can be determined from

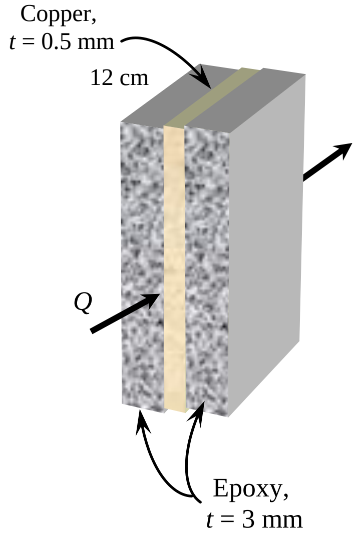
$$k_{eff} = \frac{(kt)_{epoxy} + (kt)_{copper}}{t_{epoxy} + t_{copper}} = \frac{(0.0386 + 0.000078)\text{ W/°C}}{(0.0003\text{m} + 0.0001\text{m})} = \mathbf{96.7\ W/m.°C}$$

Then the fraction of the heat conducted along the copper becomes

$$f = \frac{(kt)_{copper}}{(kt)_{PCB}} = \frac{0.0386\text{ W/°C}}{0.038678\text{W/°C}} = 0.998 = \mathbf{99.8\%}$$

Discussion Note that heat is transferred almost entirely through the copper layer.

15-68 A copper plate is sandwiched between two epoxy boards. The effective thermal conductivity of the board and the fraction of heat conducted through copper are to be determined.



Assumptions **1** Steady operating conditions exist **2** Heat transfer is one-dimensional.

Analysis Heat conduction along a layer is proportional to the thermal conductivity-thickness product (*kt*) which is determined for each layer and the entire PCB to be

$$(kt)_{copper} = (386\ \text{W/m.°C})(0.0005\ \text{m}) = 0.193\ \text{W/°C}$$

$$(kt)_{epoxy} = (2)(0.26\ \text{W/m.°C})(0.003\ \text{m}) = 0.00156\ \text{W/°C}$$

$$(kt)_{PCB} = (kt)_{copper} + (kt)_{epoxy} = 0.193 + 0.00156 = 0.19456\ \text{W/°C}$$

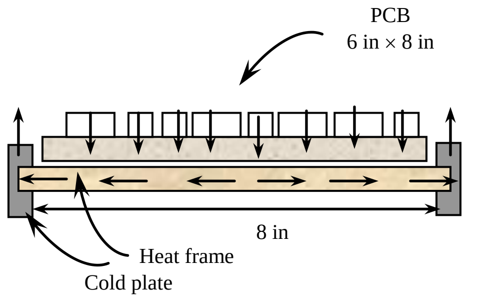
The effective thermal conductivity can be determined from

$$k_{eff} = \frac{(kt)_{epoxy} + (kt)_{copper}}{t_{epoxy} + t_{copper}} = \frac{(0.00156 + 0.193)\ \text{W/°C}}{[(2\times 0.003\text{m}) + 0.0005\text{m}]} = \mathbf{29.9\ W/m.°C}$$

Then the fraction of the heat conducted along the copper becomes

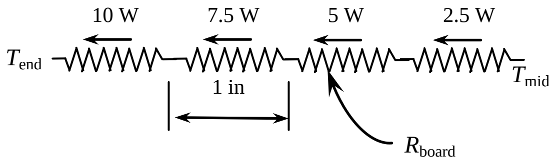
$$f = \frac{(kt)_{copper}}{(kt)_{PCB}} = \frac{0.193\ \text{W/°C}}{0.19456\ \text{W/°C}} = 0.992 = \mathbf{99.2\%}$$

15-69E A copper heat frame is used to conduct heat generated in a PCB. The temperature difference between the mid section and either end of the heat frame is to be determined.



Assumptions **1** Steady operating conditions exist **2** Heat transfer is one-dimensional.

Analysis We assume heat is generated uniformly on the 6 in × 8 in board, and all the heat generated is conducted by the heat frame along the 8-in side. Noting that the rate of heat transfer along the heat frame is variable, we consider 1 in × 8 in strips of the board. The rate of heat generation in each strip is (20 W)/8 = 2.5 W, and the thermal resistance along each strip of the heat frame is



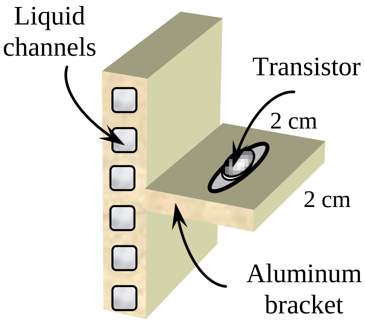
$$\begin{aligned} R_{frame} &= \frac{L}{kA} \\ &= \frac{(1/12)\,\text{ft}}{(223\,\text{Btu/h.ft.°F})(6/12\,\text{ft})(0.06/12\,\text{ft})} \\ &= 0.149\,\text{h.°F/Btu} \end{aligned}$$

Maximum temperature occurs in the middle of the plate along the 20 cm length. Then the temperature difference between the mid section and either end of the heat frame becomes

$$\begin{aligned} \Delta T_{\max} = \Delta T_{\text{midsection-edge of frame}} &= \sum \dot{Q}_i R_{frame,1-in} = R_{frame,1-in} \sum \dot{Q}_i \\ &= (0.149\text{°F.h/Btu})(10 + 7.5 + 5 + 2.5\ \text{W})(3.412\,\text{Btu/h.W}) = \mathbf{12.8°F} \end{aligned}$$

15-70 A power transistor is cooled by mounting it on an aluminum bracket that is attached to a liquid-cooled plate. The temperature of the transistor case is to be determined.

Assumptions **1** Steady operating conditions exist
2 Conduction heat transfer is one-dimensional.



Analysis The rate of heat transfer by conduction is

$$\dot{Q}_{conduction} = (0.80)(12 \text{ W}) = 9.6 \text{ W}$$

The thermal resistance of aluminum bracket and epoxy adhesive are

$$R_{aluminum} = \frac{L}{kA} = \frac{0.01 \text{ m}}{(237 \text{ W/m.°C})(0.003 \text{ m})(0.02 \text{ m})} = 0.703\text{°C/W}$$

$$R_{epoxy} = \frac{L}{kA} = \frac{0.0002 \text{ m}}{(1.8 \text{ W/m.°C})(0.003 \text{ m})(0.02 \text{ m})} = 1.852\text{°C/W}$$

The total thermal resistance between the transistor and the cold plate is

$$R_{total} = R_{case-cold\ plate} = R_{plastic} + R_{epoxy} + R_{aluminum} = 2.5 + 1.852 + 0.703 = 5.055\text{°C/W}$$

Then the temperature of the transistor case is determined from

$$T_{case} = T_{\substack{cold\\plate}} + \dot{Q}R_{case-cold\ plate} = 50\text{°C} + (9.6\text{ W})(5.055\text{°C/W}) = \mathbf{98.5\text{°C}}$$