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سایت آموزش مهندسی مکانیک

Chapter 15

COOLING OF ELECTRONIC EQUIPMENT

Introduction and History

15-1C The invention of vacuum diode started the electronic age. The invention of the transistor marked the beginning of a revolution in that age since the transistors performed the functions of the vacuum tubes with greater reliability while occupying negligible space and consuming negligible power compared to the vacuum tubes.

15-2C Integrated circuits are semiconductor devices in which several components such as diodes, transistors, resistors and capacitors are housed together. The initials MSI, LSI, and VLSI stand for medium scale integration, large scale integration, and very large scale integration, respectively.

15-3C The electrical resistance R is a measure of resistance against current flow, and the friction between the electrons and the material causes heating. The amount of the heat generated can be determined from Ohm's law, $W = I^2 R$.

15-4C The electrical energy consumed by the TV is eventually converted to heat, and the blanket wrapped around the TV prevents the heat from escaping. Then the temperature of the TV set will have to start rising as a result of heat build up. The TV set will have to burn up if operated this way for a long time. However, for short time periods, the temperature rise will not reach destructive levels.

15-5C Since the heat generated in the incandescent light bulb which is completely wrapped can not escape, the temperature of the light bulb will increase, and will possibly start a fire by igniting the towel.

15-6C When the air flow to the radiator is blocked, the hot water coming off the engine cannot be cooled, and thus the engine will overheat and fail, and possible catch fire.

15-7C A car is much more likely to break since it has more moving parts than a TV.

15-8C Diffusion in semi-conductor materials, chemical reactions and creep in the bending materials cause electronic components to fail under prolonged use at high temperatures.

15-9 The case temperature of a power transistor and the junction-to-case resistance are given. The junction temperature is to be determined.

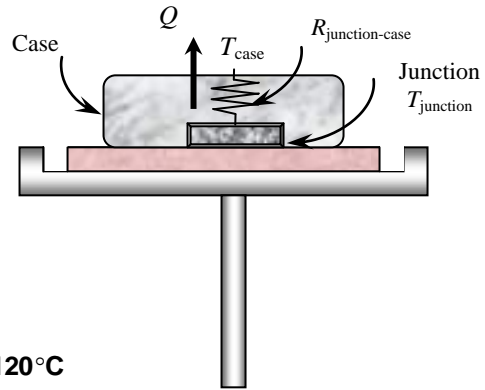
Assumptions Steady operating conditions exist.

Analysis The rate of heat transfer between the junction and the case in steady operation is

$$\dot{Q} = \left(\frac{\Delta T}{R} \right)_{\text{junction-case}} = \frac{T_{\text{junction}} - T_{\text{case}}}{R_{\text{junction-case}}}$$

Then the junction temperature is determined to be

$$T_{\text{junction}} = T_{\text{case}} + \dot{Q}R_{\text{junction-case}} = 60^\circ\text{C} + (12 \text{ W})(5^\circ\text{C/W}) = \mathbf{120^\circ\text{C}}$$



15-10 The power dissipated by an electronic component as well as the junction and case temperatures are measured. The junction-to-case resistance is to be determined.

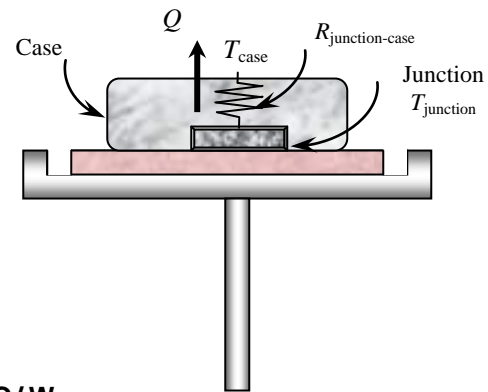
Assumptions Steady operating conditions exist.

Analysis The rate of heat transfer from the component is

$$\dot{W}_e = \dot{Q} = VI = (12 \text{ V})(0.15 \text{ A}) = 1.8 \text{ W}$$

Then the junction-to-case thermal resistance of this component becomes

$$R_{\text{junction-case}} = \frac{T_{\text{junction}} - T_{\text{case}}}{\dot{Q}} = \frac{(80 - 55)^\circ\text{C}}{1.8 \text{ W}} = \mathbf{13.9^\circ\text{C/W}}$$



15-11 A logic chip dissipates 6 W power. The amount of heat this chip dissipates during a 10-h period and the heat flux on the surface of the chip are to be determined.

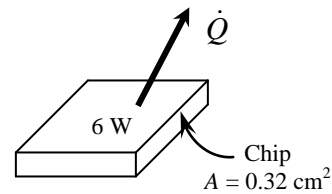
Assumptions 1 Steady operating conditions exist. 2 Heat transfer from the surface is uniform.

Analysis (a) The amount of heat this chip dissipates during an eight-hour workday is

$$Q = \dot{Q}\Delta t = (0.006 \text{ kW})(8 \text{ h}) = \mathbf{0.048 \text{ kWh}}$$

(b) The heat flux on the surface of the chip is

$$\dot{q} = \frac{\dot{Q}}{A} = \frac{6 \text{ W}}{0.32 \text{ cm}^2} = \mathbf{18.8 \text{ W/cm}^2}$$



15-12 A circuit board houses 90 closely spaced logic chips, each dissipating 0.1 W. The amount of heat this chip dissipates in 10 h and the heat flux on the surface of the circuit board are to be determined.

Assumptions 1 Steady operating conditions exist. 2 The heat transfer from the back surface of the board is negligible.

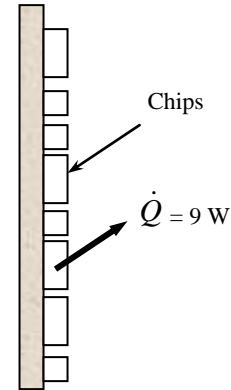
Analysis (a) The rate of heat transfer and the amount of heat this circuit board dissipates during a ten-hour period are

$$\dot{Q}_{total} = (90)(0.1 \text{ W}) = 9 \text{ W}$$

$$Q_{total} = \dot{Q}_{total} \Delta t = (0.009 \text{ kW})(10 \text{ h}) = \mathbf{0.09 \text{ kWh}}$$

(b) The average heat flux on the surface of the circuit board is

$$\dot{q} = \frac{\dot{Q}_{total}}{A_s} = \frac{9 \text{ W}}{(15 \text{ cm})(20 \text{ cm})} = \mathbf{0.03 \text{ W/cm}^2}$$

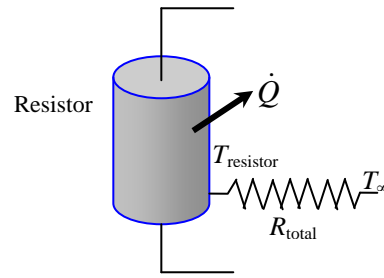


15-13E The total thermal resistance and the temperature of a resistor are given. The power at which it can operate safely in a particular environment is to be determined.

Assumptions Steady operating conditions exist.

Analysis The power at which this resistor can be operate safely is determined from

$$\dot{Q} = \frac{T_{resistor} - T_{ambient}}{R_{total}} = \frac{(360 - 120)^\circ \text{F}}{130^\circ \text{F/W}} = \mathbf{1.85 \text{ W}}$$



15-14 The surface-to-ambient thermal resistance and the surface temperature of a resistor are given. The power at which it can operate safely in a particular environment is to be determined.

Assumptions Steady operating conditions exist.

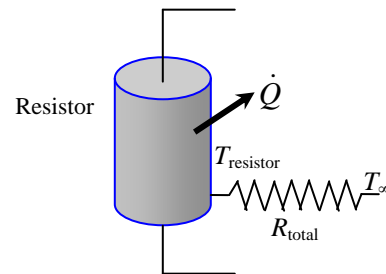
Analysis The power at which this resistor can operate safely is determined from

$$\dot{Q} = \frac{T_{resistor} - T_{ambient}}{R_{total}} = \frac{(150 - 30)^\circ \text{C}}{300^\circ \text{C/W}} = \mathbf{0.4 \text{ W}}$$

At specified conditions, the resistor dissipates

$$\dot{Q} = \frac{V^2}{R} = \frac{(7.5 \text{ V})^2}{(100 \ \Omega)} = 0.5625 \text{ W}$$

of power. Therefore, the current operation is not safe.



15-15 "PROBLEM 15-015"

"GIVEN"

R_electric=100 "[ohm]"

R_thermal=300 "[C/W]"

V=7.5 "[volts]"

T_resistor=150 "[C]"

"T_ambient=30 [C], parameter to be varied"

"ANALYSIS"

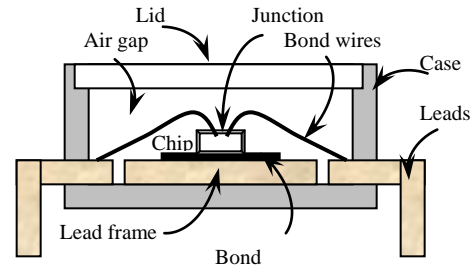
 $Q_{\text{dot_safe}}=(T_{\text{resistor}}-T_{\text{ambient}})/R_{\text{thermal}}$

T _{ambient} [C]	Q _{safe} [W]
20	0.4333
21	0.43
22	0.4267
23	0.4233
24	0.42
25	0.4167
26	0.4133
27	0.41
28	0.4067
29	0.4033
30	0.4
31	0.3967
32	0.3933
33	0.39
34	0.3867
35	0.3833
36	0.38
37	0.3767
38	0.3733
39	0.37
40	0.3667

Manufacturing of Electronic Equipment

15-16C The thermal expansion coefficient of the plastic is about 20 times that of silicon. Therefore, bonding the silicon directly to the plastic case will result in such large thermal stresses that the reliability would be seriously jeopardized. To avoid this problem, a lead frame made of a copper alloy with a thermal expansion coefficient close to that of silicon is used as the bonding surface.

15-17C The schematic of chip carrier is given in the figure. Heat generated at the junction is transferred through the chip to the lead frame, then through the case to the leads. From the leads heat is transferred to the ambient or to the medium the leads are connected to.



15-18C The cavity of the chip carrier is filled with a gas which is a poor conductor of heat. Also, the case is often made of materials which are also poor conductors of heat. This results in a relatively large thermal resistance between the chip and the case, called the junction-to-case thermal resistance. It depends on the geometry and the size of the chip carrier as well as the material properties of the bonding material and the case.

15-19C A hybrid chip carrier houses several chips, individual electronic components, and ordinary circuit elements connected to each other. The result is improved performance due to the shortening of the wiring lengths, and enhanced reliability. Lower cost would be an added benefit of multi-chip packages if they are produced in sufficiently large quantities.

15-20C A printed circuit board (PCB) is a properly wired plane board on which various electronic components such as the ICs, diodes, transistors, resistors, and capacitors are mounted to perform a certain task. The board of a PCB is made of polymers and glass epoxy materials. The thermal resistance between a device on the board and edge of the board is called as device-to-PCB edge thermal resistance. This resistance is usually high (about 20 to 60 °C/W) because of the low thickness of the board and the low thermal conductivity of the board material.

15-21C The three types of circuit boards are the single-sided, double-sided, and multi-layer boards. The single-sided PCBs have circuitry lines on one side of the board only, and are suitable for low density electronic devices (10-20 components). The double-sided PCBs have circuitry on both sides, and are best suited for intermediate density devices. Multi-layer PCBs contain several layers of circuitry, and they are suitable for high density devices. They are equivalent to several PCBs sandwiched together.

15-22C The desirable characteristics of the materials used in the fabrication of circuit boards are: (1) being an effective electrical insulator to prevent electrical breakdown, (2) being a good heat conductor to conduct the heat generated away, (3) having high material strength to withstand the forces and to maintain dimensional stability, (4) having a thermal expansion coefficient which closely matches to that of copper to prevent cracking in the copper cladding during thermal cycling, (5) having a high resistance to moisture absorption since moisture can effect both mechanical and electrical properties and degrade performance, (6) stability in properties at temperature levels encountered in electronic applications, (7) ready availability and manufacturability, and, of course (8) low cost.

15-23C An electronic enclosure (a case or a cabinet) house the circuit boards and the necessary peripheral equipment and connectors. It protects them from the detrimental effects of the environment, and may provide a cooling path. An electronic enclosure can simply be made of sheet metals such as thin gauge aluminum or steel.

Cooling Load of Electronic Equipment and Thermal Environment

15-24C The heating load of an electronic box which consumes 120 W of power is simply 120 W because of the conservation of energy principle.

15-25C Superconductor materials will generate hardly any heat and as a result, more components can be packed into a smaller volume, resulting in enhanced speed and reliability without having to resort to some exotic cooling techniques.

15-26C The actual power dissipated by a device can be considerably less than its rated power, depending on its duty cycle (the fraction of time it is on). A 5 W power transistor, for example, will dissipate an average of 2 W of power if it is active only 40 percent of the time. Then we can treat this transistor as a 2-W device when designing a cooling system. This may allow the selection of a simpler and cheaper cooling mechanism.

15-27C The cyclic variation of temperature of an electronic device during operation is called the temperature cycling. The thermal stresses caused by temperature cycling undermines the reliability of electronic devices. The failure rate of electronic devices subjected to deliberate temperature cycling of more than 20 °C is observed to increase by eight-fold.

15-28C The ultimate heat sink for a TV is the room air with a temperature range of about 10 to 30°C. For an airplane it is the ambient air with a temperature range of about -50°C to 50°C. The ultimate heat sink for a ship is the sea water with a temperature range of 0°C to 30°C.

15-29C The ultimate heat sink for a VCR is the room air with a temperature range of about 10 to 30°C. For a spacecraft it is the ambient air or space with a temperature range of about -273°C to 50°C. The ultimate heat sink for a communication system on top of a mountain is the ambient air with a temperature range of about -20°C to 50°C.

Electronics Cooling in Different Applications

15-30C The electronics of short-range missiles do not need any cooling because of their short cruising times. The missiles reach their destinations before the electronics reach unsafe temperatures. The long-range missiles must be cooled because of their long cruise times (several hours). The electronics in this case are cooled by passing the liquid fuel they carry through the cold plate of the electronics enclosure as it flows towards the combustion chamber.

15-31C Dynamic temperature is the rise in the temperature of a fluid as a result of the ramming effect or the stagnation process. This is due to the conversion of kinetic energy to internal energy which is significant at high velocities. It is determined from $T_{dynamic} = V^2 / (2C_p)$ where V is the velocity and C_p is the specific heat of the fluid. It is significant at velocities above 100 m/s.

15-32C The electronic equipment in ships and submarines are usually housed in rugged cabinets to protect them from vibrations and shock during stormy weather. Because of easy access to water, water cooled heat exchangers are commonly used to cool sea-born electronics. Often air in a closed or open loop is cooled in an air-to-water heat exchanger, and is forced to the electronic cabinet by a fan.

15-33C The electronics of communication systems operate for long periods of time under adverse conditions such as rain, snow, high winds, solar radiation, high altitude, high humidity, and too high or too low temperatures. Large communication systems are housed in specially built shelters. Sometimes it is necessary to air-condition these shelters to safely dissipate the large quantities of heat generated by the electronics of communication systems.

15-34C The electronic components used in the high power microwave equipment such as radars generate enormous amounts of heat because of the low conversion efficiency of electrical energy to microwave energy. The klystron tubes of high power radar systems where radio frequency (RF) energy is generated can yield local heat fluxes as high as 2000 W/cm^2 . The safe and reliable dissipation of such high heat fluxes usually require the immersion of such equipment into a suitable dielectric fluid which can remove large quantities of heat by boiling.

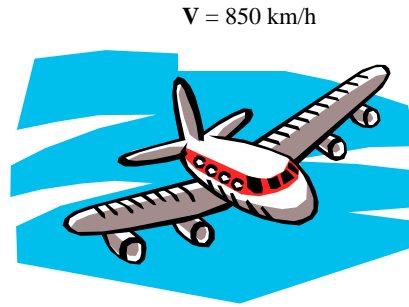
15-35C The electronic equipment in space vehicles are usually cooled by a liquid circulated through the components where heat is picked up, and then through a space radiator where the waste heat is radiated into deep space at 0 K. In such systems it may be necessary to run a fan in the box to circulate the air since there is no natural convection currents in space because of the absence of a gravity field.

15-36 An airplane cruising in the air at a temperature of -25°C at a velocity of 850 km/h is considered. The temperature rise of air is to be determined.

Assumptions Steady operating conditions exist.

Analysis The temperature rise of air (dynamic temperature) at this speed is

$$T_{dynamic} = \frac{V^2}{2C_p} = \frac{(850 \times 1000 / 3600 \text{ m/s})^2}{(2)(1003 \text{ J/kg} \cdot ^{\circ}\text{C})} \left(\frac{1 \text{ J/kg}}{1 \text{ m}^2/\text{s}^2} \right) = \mathbf{27.8^{\circ}\text{C}}$$



15-37 The temperature of air in the wind at a wind velocity of 90 km/h is measured to be 12°C . The true temperature of air is to be determined.

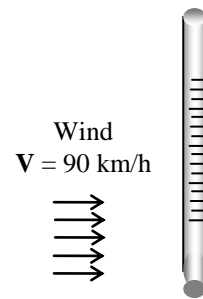
Assumptions Steady operating conditions exist.

Analysis The temperature rise of air (dynamic temperature) at this speed is

$$T_{dynamic} = \frac{V^2}{2C_p} = \frac{(90 \times 1000 / 3600 \text{ m/s})^2}{(2)(1005 \text{ J/kg} \cdot ^{\circ}\text{C})} \left(\frac{1 \text{ J/kg}}{1 \text{ m}^2/\text{s}^2} \right) = \mathbf{0.3^{\circ}\text{C}}$$

Therefore, the true temperature of air is

$$T_{true} = T_{measured} - T_{dynamic} = (12 - 0.3)^{\circ}\text{C} = \mathbf{11.7^{\circ}\text{C}}$$



15-38 "PROBLEM 15-038"

"GIVEN"

T_measured=12 "[C]"

"Vel=90 [km/h], parameter to be varied"

"PROPERTIES"

C_p=CP(air, T=T_measured)*Convert(kJ/kg-C, J/kg-C)

"ANALYSIS"

T_dynamic=(Vel*Convert(km/h, m/s))^2/(2*C_p)*Convert(m^2/s^2, J/kg)

T_true=T_measured-T_dynamic

Vel [km/h]	T _{true} [C]
20	11.98
25	11.98
30	11.97
35	11.95
40	11.94
45	11.92
50	11.9
55	11.88
60	11.86
65	11.84
70	11.81
75	11.78
80	11.75
85	11.72
90	11.69
95	11.65
100	11.62
105	11.58
110	11.54
115	11.49
120	11.45

15-39 Air at 25°C is flowing in a channel. The temperature a stationary probe inserted into the channel will read is to be determined for different air velocities.

Assumptions Steady operating conditions exist.

Analysis (a) The temperature rise of air (dynamic temperature) for an air velocity of 1 m/s is

$$T_{dynamic} = \frac{V^2}{2C_p} = \frac{(1 \text{ m/s})^2}{(2)(1005 \text{ J/kg} \cdot \text{°C})} \left(\frac{1 \text{ J/kg}}{1 \text{ m}^2/\text{s}^2} \right) = 0.0005^\circ\text{C}$$

Then the temperature which a stationary probe will read becomes

$$T_{measured} = T_{true} + T_{dynamic} = 25 + 0.0005 = \mathbf{25.0005^\circ\text{C}}$$

(b) For an air velocity of 10 m/s the temperature rise is

$$T_{dynamic} = \frac{V^2}{2C_p} = \frac{(10 \text{ m/s})^2}{(2)(1005 \text{ J/kg} \cdot \text{°C})} \left(\frac{1 \text{ J/kg}}{1 \text{ m}^2/\text{s}^2} \right) = 0.05^\circ\text{C}$$

Then, $T_{measured} = T_{true} + T_{dynamic} = 25 + 0.05 = \mathbf{25.05^\circ\text{C}}$

(c) For an air velocity of 100 m/s the temperature rise is

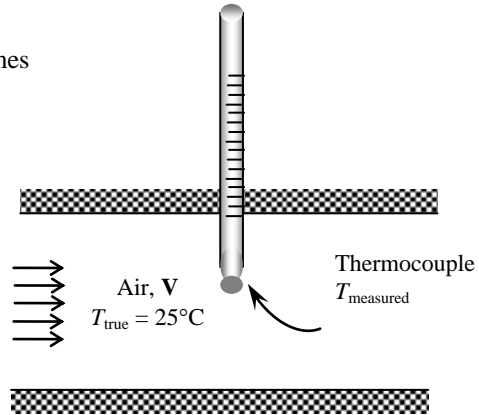
$$T_{dynamic} = \frac{V^2}{2C_p} = \frac{(100 \text{ m/s})^2}{(2)(1005 \text{ J/kg} \cdot \text{°C})} \left(\frac{1 \text{ J/kg}}{1 \text{ m}^2/\text{s}^2} \right) = 4.98^\circ\text{C}$$

Then, $T_{measured} = T_{true} + T_{dynamic} = 25 + 4.98 = \mathbf{29.98^\circ\text{C}}$

(d) For an air velocity of 1000 m/s the temperature rise is

$$T_{dynamic} = \frac{V^2}{2C_p} = \frac{(1000 \text{ m/s})^2}{(2)(1005 \text{ J/kg} \cdot \text{°C})} \left(\frac{1 \text{ J/kg}}{1 \text{ m}^2/\text{s}^2} \right) = 497.5^\circ\text{C}$$

Then, $T_{measured} = T_{true} + T_{dynamic} = 25 + 497.5 = \mathbf{522.5^\circ\text{C}}$

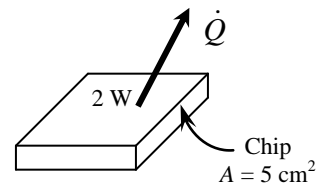


15-40 Power dissipated by an electronic device as well as its surface area and surface temperature are given. A suitable cooling technique for this device is to be determined.

Assumptions Steady operating conditions exist.

Analysis The heat flux on the surface of this electronic device is

$$\dot{q} = \frac{\dot{Q}}{A_s} = \frac{2 \text{ W}}{5 \text{ cm}^2} = \mathbf{0.4 \text{ W/cm}^2}$$



For an allowable temperature rise of 50°C, the suitable cooling technique for this device is determined from Fig. 15-17 to be **forced convection** with direct air.

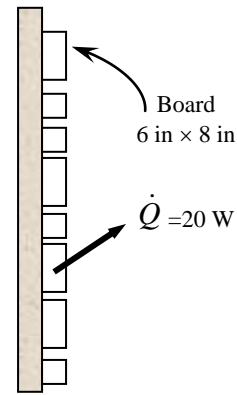
15-41E Power dissipated by a circuit board as well as its surface area and surface temperature are given. A suitable cooling mechanism is to be selected.

Assumptions Steady operating conditions exist.

Analysis The heat flux on the surface of this electronic device is

$$\dot{q} = \frac{\dot{Q}}{A_s} = \frac{20 \text{ W}}{(6 \text{ in} \times 2.54 \text{ cm/in})(8 \text{ in} \times 2.54 \text{ cm/in})} = \mathbf{0.065 \text{ W/cm}^2}$$

For an allowable temperature rise of 80°F, the suitable cooling technique for this device is determined from Fig. 15-17 to be **natural convection** with direct air.



Conduction Cooling

15-42C The major considerations in the selection of a cooling technique are the magnitude of the heat generated, the reliability requirements, the environmental conditions, and the cost.

15-43C Thermal resistance is the resistance of a material or device against heat flow through it. It is analogous to electrical resistance in electrical circuits, and the thermal resistance networks can be analyzed like electrical circuits.

15-44C If the rate of heat conduction through a medium \dot{Q} , and the thermal resistance R of the medium are known, then the temperature difference across the medium can be determined from $\Delta T = \dot{Q}R$.

15-45C The voltage drop across the wire is determined from $\Delta V = IR$. The length of the wire is proportional to the electrical resistance [$R = L/(\rho A)$], which is proportional to the voltage drop. Therefore, doubling the wire length while the current I is held constant will double the voltage drop.

The temperature drop across the wire is determined from $\Delta T = \dot{Q}R$. The length of the wire is proportional to the thermal resistance [$R = L/(kA)$], which is proportional to the temperature drop. Therefore, doubling the wire length while the heat flow \dot{Q} is held constant will double the temperature drop.

15-46C A heat frame is a thick metal plate attached to a circuit board. It enhances heat transfer by providing a low resistance path for the heat flow from the circuit board to the heat sink. The thicker the heat frame, the lower the thermal resistance and thus the smaller the temperature difference between the center and the ends of the heat frame. The electronic components at the middle of a PCB operate at the highest temperature since they are furthest away from the heat sink.

15-47C Heat flow from the junction to the body of a chip is three-dimensional, but can be approximated as being one-dimensional by adding a constriction thermal resistance to the thermal resistance network. For a small heat generation area of diameter a on a considerably larger body, the constriction resistance is given by $R_{constriction} = 1/(2\sqrt{\pi ak})$ where k is the thermal conductivity of the larger body. The constriction resistance is analogous to a partially closed valve in fluid flow, and a sudden drop in the cross-sectional area of an wire in electric flow.

15-48C The junction-to-case thermal resistance of an electronic component is the overall thermal resistance of all parts of the electronic component between the junction and case. In practice, this value is determined experimentally. When the junction-to-case resistance, the power dissipation, and the case temperature are known, the junction temperature of a component is determined from

$$T_{junction} = T_{case} + \dot{Q}R_{junction-case}$$

15-49C The case-to-ambient thermal resistance of an electronic device is the total thermal resistance of all parts of the electronic device between its outer surface and the ambient. In practice, this value is determined experimentally. Usually, manufacturers list the total resistance between the junction and the ambient for devices they manufacture for various configurations and ambient conditions likely to be encountered. When the case-to-ambient resistance, the power dissipation, and the ambient temperature are known, the junction temperature of the device is determined from $T_{junction} = T_{ambient} + \dot{Q}R_{junction-ambient}$

15-50C The junction temperature in this case is determined from

$$T_{junction} = T_{ambient} + \dot{Q}(R_{junction-case} + R_{case-ambient}).$$

When $R_{junction-case} > R_{case-ambient}$, the case temperature will be closer to the ambient temperature.

15-51C The PCBs are made of electrically insulating materials such as glass-epoxy laminates which are poor conductors of heat. Therefore, the rate of heat conduction along a PCB is very low. Heat conduction from the mid parts of a PCB to its outer edges can be improved by attaching heat frames or clamping cold plates to it. Heat conduction across the thickness of the PCB can be improved by planting copper or aluminum pins across the thickness of the PCB to serve as thermal bridges.

15-52C The thermal expansion coefficients of aluminum and copper are about twice as large as that of the epoxy-glass. This large difference in the thermal expansion coefficients can cause warping on the PCBs if the epoxy and the metal are not bonded properly. Warping is a major concern because it decreases reliability. One way of avoiding warping is to use PCBs with components on both sides.

15-53C The thermal conduction module received a lot of attention from thermal designers because the thermal design was incorporated at the initial stages of electrical design. The TCM was different from previous chip designs in that it incorporated both electrical and thermal considerations in early stages of design. The cavity in the TCM is filled with helium (instead of air) because of its very high thermal conductivity (about six times that of air).

15-54 The dimensions and power dissipation of a chip are given. 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. 3 Heat transfer through the air gap and the lid on top of the chip is negligible because of the very large thermal resistance involved along this path.

Analysis The various thermal resistances on the path of primary heat flow are

$$R_{constriction} = \frac{1}{2\sqrt{\pi}ak} = \frac{1}{2\sqrt{\pi}(0.5 \times 10^{-3} \text{ m})(120 \text{ W/m}\cdot\text{C})} = 4.7^\circ\text{C/W}$$

$$R_{chip} = \frac{L}{kA} = \frac{0.5 \times 10^{-3} \text{ m}}{(120 \text{ W/m}\cdot\text{C})(0.004 \times 0.004 \text{ m}^2)} = 0.26^\circ\text{C/W}$$

$$R_{bond} = \frac{L}{kA} = \frac{0.05 \times 10^{-3} \text{ m}}{(296 \text{ W/m}\cdot\text{C})(0.004 \times 0.004 \text{ m}^2)} = 0.011^\circ\text{C/W}$$

$$R_{lead\ frame} = \frac{L}{kA} = \frac{0.25 \times 10^{-3} \text{ m}}{(386 \text{ W/m}\cdot\text{C})(0.004 \times 0.004 \text{ m}^2)} = 0.04^\circ\text{C/W}$$

$$R_{plastic} = \frac{L}{kA} = \frac{0.3 \times 10^{-3} \text{ m}}{(1 \text{ W/m}\cdot\text{C})(18 \times 0.001 \times 0.00025 \text{ m}^2)} = 66.67^\circ\text{C/W}$$

$$R_{leads} = \frac{L}{kA} = \frac{6 \times 10^{-3} \text{ m}}{(386 \text{ W/m}\cdot\text{C})(18 \times 0.001 \times 0.00025 \text{ m}^2)} = 3.45^\circ\text{C/W}$$

Since all resistances are in series, the total thermal resistance between the junction and the leads is determined by simply adding them up

$$\begin{aligned} R_{total} &= R_{junction-lead} \\ &= R_{constriction} + R_{chip} + R_{bond} + R_{lead\ frame} + R_{plastic} + R_{leads} \\ &= 4.7 + 0.26 + 0.011 + 0.04 + 66.67 + 3.45 \\ &= 75.13^\circ\text{C/W} \end{aligned}$$

Knowing the junction-to-leads thermal resistance, the junction temperature is determined from

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

$$T_{junction} = T_{leads} + \dot{Q}R_{junction-case} = 50^\circ\text{C} + (0.8 \text{ W})(75.13^\circ\text{C/W}) = \mathbf{110.1^\circ\text{C}}$$

