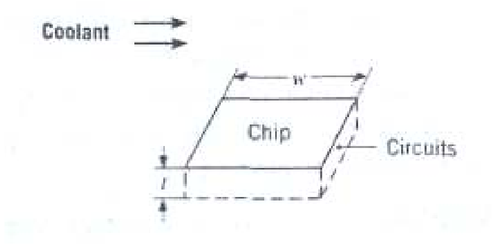
Part G-2: Problem Bank

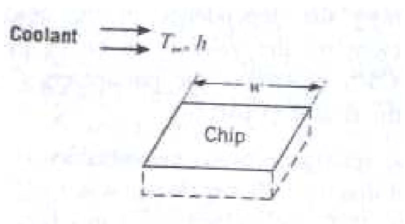
Introduction Problems (Basic Modes of H.T in Electronic Devices)

1. A square silicon chip (k = 150 W/m.K) is of width w = 5 mm on a side and of thickness t = 1 mm. The chip is mounted in a substrate such that its side and back surfaces are insulated, while the front surface is exposed to a coolant. If 4 W are being dissipated in circuits mounted to the back surface of the chip, what is the steady-state temperature difference between back and front surfaces?

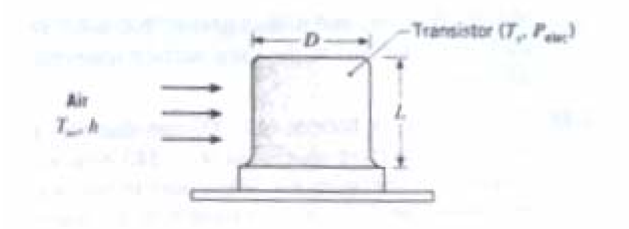


2. A square isothermal chip is of width w = 5 mm on a side and is mounted in a substrate such that its side and back surfaces are well insulated, while the front surface is exposed to the flow of a coolant at T_∞ = 15 °C. From reliability considerations, the chip temperature must not exceed T = 85 °C.

If the coolant is air and the corresponding convection coefficient is h = 200 W/m^2.K. What is the maximum allowable chip power? If the coolant is a dielectric liquid for which h = 3000 W/m^2.K. What is the maximum allowable power?



3. The case of a power transistor, which is of length L = 10mm and diameter D = 12 mm, is cooled by an air stream of temperature T_∞ = 25 °C. Under conditions for which the air maintains an average convection coefficient of h = 100 W/m^2.K on the surface of the case, what is the maximum allowable power dissipation if the surface temperature is not to exceed 85 °C?



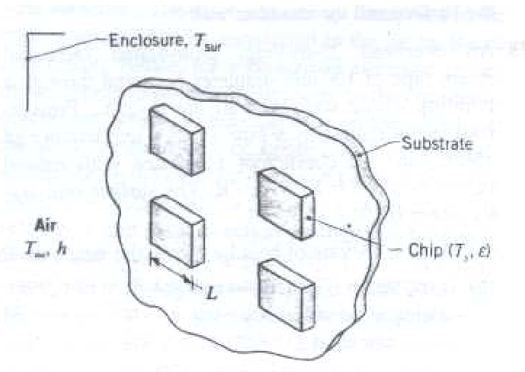
4. The use of impinging air jets is proposed as a means of effectively cooling high-power logic chips in a computer. However, before the technique can be implemented, the convection coefficient associated with jet impingement on a chip surface must be known. Design an experiment that could be used to determine convection coefficients associated with air jet impingement on a chip measuring approximately 10 mm by 10 mm on a side.

5. An instrumentation package has a spherical outer surface of diameter D = 100 mm and emissivity $\varepsilon = 0.25$. The package is placed in a large space simulation chamber whose walls are maintained at 77 K. If operation of the electronic components is restricted to the temperature range $40 \le T \le 85$ °C, what is the range of acceptable power dissipation for the package? Display your results graphically, showing also the effect of variations in the emissivity by considering values of 0.20 and 0.30.

6. Consider the conditions of Problem 2. With heat transfer by convection to air, the maximum allowable chip power is found to be 0.35 W. If consideration is also given to net heat transfer by radiation from the chip surface to large surroundings at 15 °C, what is the percentage increase in the maximum allowable chip power afforded by this consideration?
The chip surface has an emissivity of 0.9.

7. Square chips of width L = 15 mm on a side are mounted to a substrate that is installed in an enclosure whose walls and air are maintained at a temperature of $T_\infty = T_{surr} = 25$ °C. The chips have an emissivity of $\varepsilon = 0.60$ and a maximum allowable temperature of $T_s = 85$ °C.

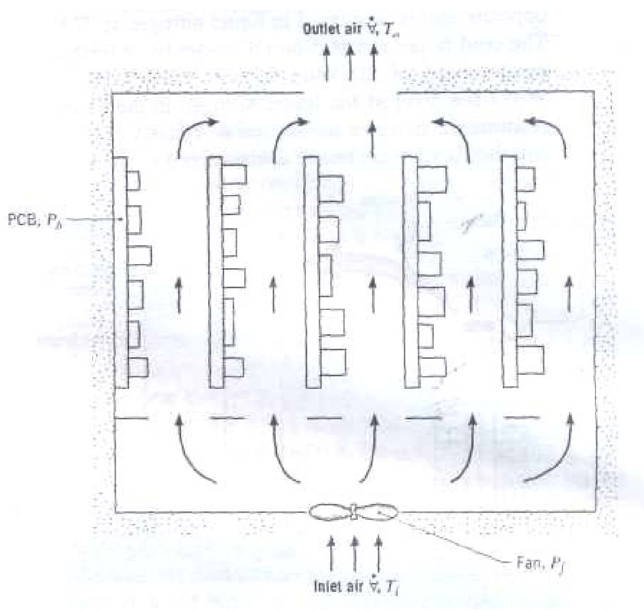
(a) If heat is rejected from the chips by radiation and natural convection, what is the maximum operating power of each chip? The convection coefficient depends on the chip-to-air temperature difference and may be approximated as $h = C\,(T_s - T_\infty)^{0.25}$, Where $C = 4.2\ W/m^2.K^{5/4}$.
(b) If a fan is used to maintain air flow through the enclosure and heat transfer is by forced convection, with $h = 250\ W/m^2.K$, what is the maximum operating power?



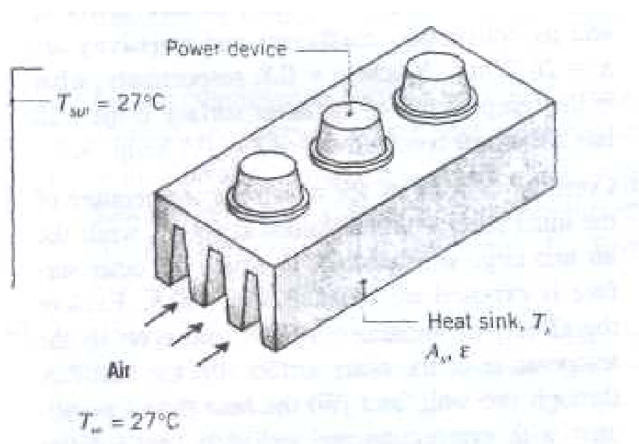
8. A computer consists of an array of five printed circuit boards (PCBs). Each dissipating P_b = 20 W of power. Cooling of the electronic components on a board is provided by the forced flow of air, equally distributed in passages formed by adjoining boards, and the convection coefficient associated with heat transfer from the components to the air is approximately h = 200 $W/m^2.K$. Air enters the computer console at a temperature of T_i = 20 °C, and flow is driven by a fan whose power consumption is P_f = 25 W.

(a) If the temperature rise of the air flow. (T_o - T_i), is not to exceed 15 °C, what is the minimum allowable volumetric flow rate of the air? The density and specific heat of the air may be approximated as $\rho = 1.161$ kg/m^3 and $C_p = 1007$ J/kg.K, respectively.

(b) The component that is most susceptible to thermal failure dissipates 1 W/cm^2 of surface area. To minimize the potential for thermal failure, where should the component be installed on a PCB? What is its surface temperature at this location?



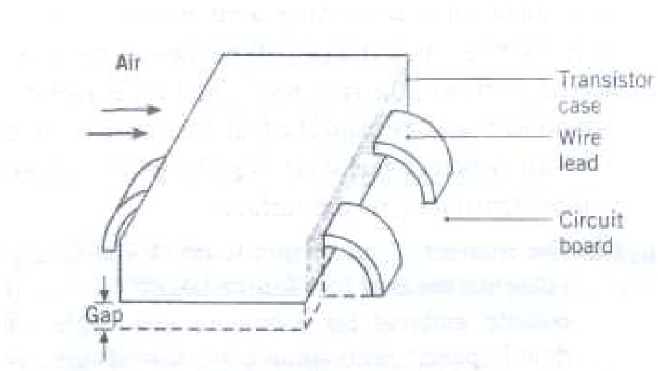
9. Electronic power devices are mounted to a heat sink having an exposed surface area of 0.045 m^2 and an emissivity of 0.80. When the devices dissipate a total power of 20 W and the air and surroundings are at 27 °C, the average sink temperature is 42 ^{o}C. What average temperature will the heat sink reach when the devices dissipate 30 W for the same environmental condition?



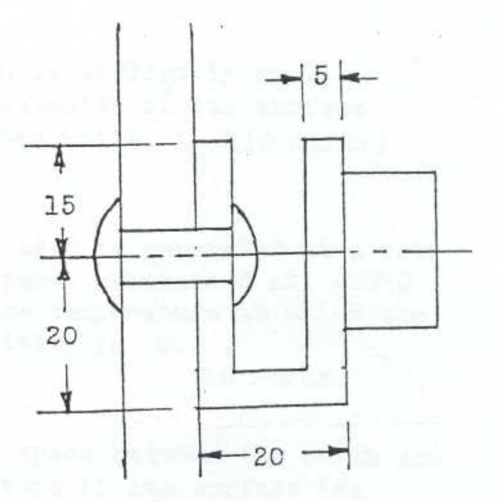
10. Consider a surface-mount type transistor on a circuit board whose temperature is maintained at 35 °C. Air at 20 °C flows over the upper surface of dimensions 4 mm by 8 mm with a convection coefficient of 50 W/m^2.K.Three wire leads, each of cross section 1 mm by 0.25 mm and length 4 mm, conduct heat from the case to the circuit board. The gap between the case and the board is 0.2 mm.

(a) Assuming the case is isothermal and neglecting radiation; estimate the case temperature when 150mW are dissipated by the transistor and (i) stagnant air or (ii) a conductive paste fills the gap. The thermal conductivities of the wire leads, air. And conductive pastes are 25, 0.0263, and 0.12 W/m.K. respectively.

(b) Using the conductive paste to fill the gap, we wish to determine the extent to which increased heat dissipation may be accommodated, subject to the constraint that the case temperature not exceeds 40 °C. Options include increasing the air speed to achieve a larger convection coefficient h and/or changing the lead wire material to one of larger thermal conductivity. Independently considering leads fabricated from materials with thermal conductivities of 200 and 400 W/m.K., compute and plot the maximum allowable heat dissipation for variations in h over the range $50 \leq h \leq 250$ W/m^2.K.



11. A transistor that dissipates10W is mounted on a duralumin heat sink at 50 °C by a duralumin bracket 20 mm wide as shown in the opposite figure. The bracket is attached to the heat sink by a rivet that produces an interface pressure of 12 bar. The surfaces in contact have a roughness of 1.6 μm rms. With convective cooling negligibly small, estimate the surface temperature of the transistor.



12. A cable 10 mm is to be insulated to maximize its current carrying capacity. For certain reasons, the outside diameter of the insulation should be 30 mm. The heat transfer coefficient for the outer surface is estimated to be 10 W /m^2 .K.

What should be the thermal conductivity of the chosen insulation? By what percentage would the insulation increase the energy carrying capacity of the bare cable?

13. The vertical side of an electronics box is 40 x 30 cm with the 40 cm side vertical. What is the maximum radiation energy that could be dissipated by this side if its temperature is not to exceed 60 °C in an environment of 40 °C, and its emissivity is 0.8?

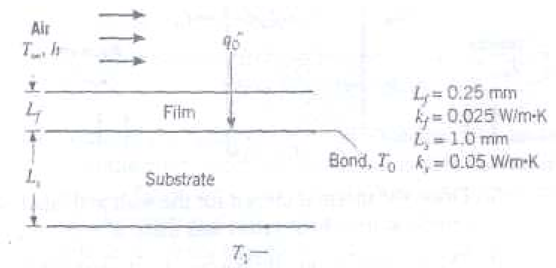
Conduction H.T and Fins Problems

14. In a manufacturing process, a transparent film is being bonded to a substrate as shown in the sketch. To cure the bond at a temperature T_o, a radiant source is used to provide a heat flux q_o'' (W/m^2), All of which is absorbed at the bonded surface. The back of the substrate is maintained at T_1 while the free surface of the film is exposed to air at T_∞ and a convection heat transfer coefficient h.

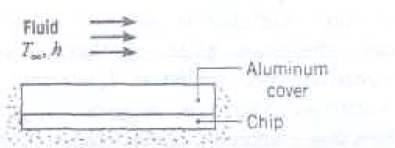
(a) Show the thermal circuit representing the steady-state heat transfer situation. Be sure to label all elements, nodes, and heat rates. Leave in symbolic form.

(b) Assume the following conditions: T_∞ = 20 °C, h = 50 W/m^2.K and T_1 = 30 °C. Calculate the heat flux q_o'' that is required to maintain the boded surface at T_o = 60 °C.

(c) Compute and plot the required heat flux as a function of the film thickness for $0 \leq L_f \leq 1$mm.

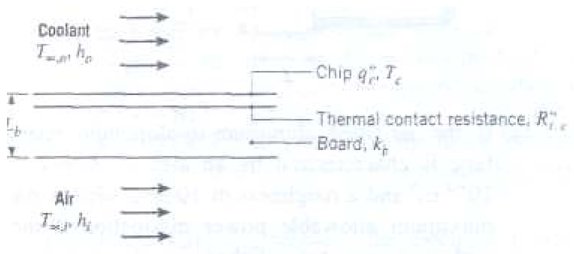


15. A silicon chip is encapsulated such that, under steady-state conditions, all of the power it dissipates is transferred by convection to a fluid stream for which h = 1000 W/m^2.K. and T_∞ = 25 °C. The chip is separated from the fluid by a 2-mm-thick aluminum cover plate, and the contact resistance of the chip/aluminum interface is 0.5 x 10^{-4} m^2.K/W. If the chip surface area is 100 mm^2 and its maximum allowable temperature is 85 °C, what is the maximum allowable power dissipation in the chip?



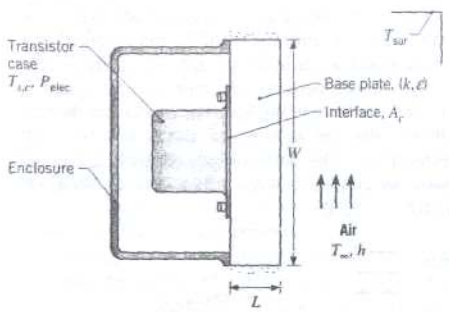
16. Approximately 10^6 discrete electrical components can be placed on a single integrated circuit (chip), with electrical heat dissipation as high as 30,000 W/m^2. The chip, which is very thin, is exposed to a dielectric liquid at its outer surface, with h_o = 1000 W/m^2. K and $T_{\infty,o}$ = 20 °C, and is joined to a circuit board at its inner surface. The thermal contact resistance between the chip and the board is 10^{-4} m^2.K/W. and the board thickness and thermal conductivity are L_b = 5 mm and k_b = 1 W/m.K, respectively. The other surface of the board is exposed to ambient air for which h_i = 40 W/m^2.K and $T_{\infty,i}$ = 20 °C.

(a) Sketch the equivalent thermal circuit corresponding to steady-state conditions. In variable form, label appropriate resistances, temperatures, and heat fluxes.
(b) Under steady-state conditions for which the chip heat dissipation is q_c'' = 30,000 W/m^2. What is the chip temperature?
(c) The maximum allowable heat flux $q_{c,m}''$, is determined by the constraint that the chip temperature must not exceed 85 °C. Determine $q_{c,m}''$ for the foregoing conditions. If air is used in lieu of the dielectric liquid, the convection coefficient is reduced by approximately an order of magnitude. What is the value of $q_{c,m}''$ for h_o = 100 W/m^2.K? With air cooling, can significant improvements be realized by using an aluminum oxide circuit board and/or by using a conductive paste at the chip/board interface for which $R_{t,c}''$ = 10^{-5} m^2.K/W.?

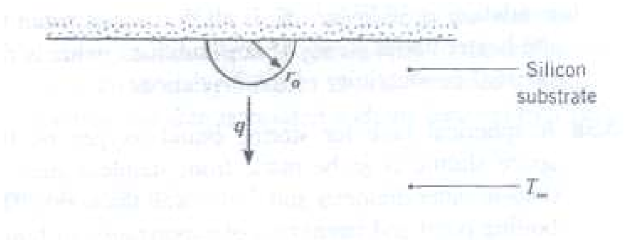


17. Consider a power transistor encapsulated in an aluminum case that is attached at its base to a square aluminum plate of thermal conductivity k = 240 W/m.K., thickness L = 6 mm, and width W = 20 mm. The case is joined to the plate by screws that maintain a contact pressure of 1 bar, and the back surface of the plate transfers heat by natural convection and radiation to ambient air and large surroundings at $T_\infty = T_{sur}$ = 25 °C. The surface has an emissivity of ε = 0.9, and the convection coefficient is h = 4 W/m^2.K. The case is completely enclosed such that heat transfer may be assumed to occur exclusively through the base plate.

(a) If the air-filled aluminum-to-aluminum interface is characterized by an area of A_c = 2 x 10^{-4} m^2 and a roughness of 10 µ.m. what is the maximum allowable power dissipation if the surface temperature of the case, $T_{s,c}$, is not to exceed 85 °C?
(b) The convection coefficient may be increased by subjecting the plate surface to a forced flow of air. Explore the effect of increasing the coefficient over the range 4 ≤ h ≤ 200 W/ m^2.K.

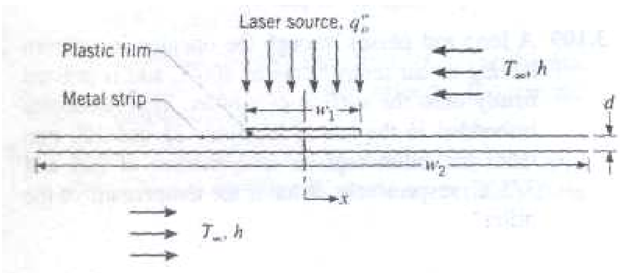


18. A transistor, which may be approximated as a hemispherical heat source of radius r_o = 0.1 mm, is embedded in a large silicon substrate (k = 125 W/m.K) and dissipates heat at a rate q. All boundaries of the silicon are maintained at an ambient temperature of T_∞ = 27°C, except for a plane surface that is well insulated. Obtain a general expression for the substrate temperature distribution and evaluate the surface temperature of the heat source for q = 4 W.



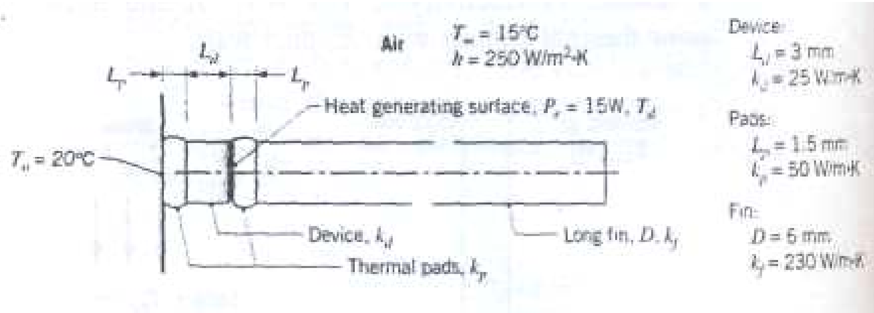
19. A bonding operation utilizes a laser to provide a constant heat flux q''_o, across the top surface of a thin adhesive-backed, plastic film to be affixed to a metal strip as shown in the sketch. The metal strip has a thickness d=1.25 mm and its width is large relative to that of the film. The thermophysical properties of the strip are ρ = 7850 kg/m^3, C_p = 435 J/kg.K, and k = 60 W/m.K. The thermal resistance of the plastic film of width w_1 = 40 mm is negligible. The upper and lower surfaces of the strip (including the plastic film) experience convection with air at 25 ^{o}C and a convection coefficient of 10 W/m^2.K. The strip and film are very long in the direction normal to the page. Assume the edges of the metal strip are at the air temperature (T_∞).

(a) Derive an expression for the temperature distribution in the portion of the steel strip with the plastic film ($-w_1/2 \le x \le +w_1/2$).
(b) If the heat flux provided by the laser is 10,000 W/m^2, determine the temperature of the plastic film at the center (x = 0) and its edges ($x = \pm w_1/2$).
(c) Plot the temperature distribution for the entire strip and point out its special features.



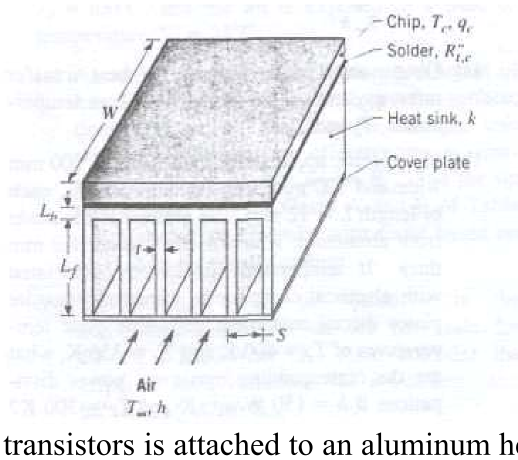
20. A disk-shaped electronic device of thickness L_d, diameter D, and thermal conductivity k_d dissipates electrical power at a steady rate P, along one of its surfaces. The device is bonded to a cooled base at T_o using a thermal pad of thickness L_p and thermal conductivity k_p. A long fin of diameter D and thermal conductivity kf is bonded to the heat-generating surface of the device using an identical thermal pad. The fin is cooled by an air stream, which is at a temperature T_∞ and provides a convection coefficient h.

(a) Construct a thermal circuit of the system.
(b) Derive an expression for the temperature T_d of the heat-generating surface of the device in terms of the circuit thermal resistances, T_o and T_∞. Express the thermal resistances in terms of appropriate parameters.
(c) Calculate T_d for the prescribed conditions.



21. An isothermal silicon chip of width W = 20 mm on a side is soldered to an aluminum heat sink (k = 180W/m.K) of equivalent width. The heat sink has a base thickness of L_b =3 mm and an array of rectangular fins, each of length L_f = 15 mm. Air flow at T_∞ = 20°C is maintained through channels formed by the fins and a cover plate, and for a convection coefficient of h = 100 W/m^2.K., a minimum fin spacing of 1.8 mm is dictated by limitations on the flow pressure drop. The solder joint has a thermal resistance of $R''_{t,c}$ = 2 x 10^{-6} m^2.K.

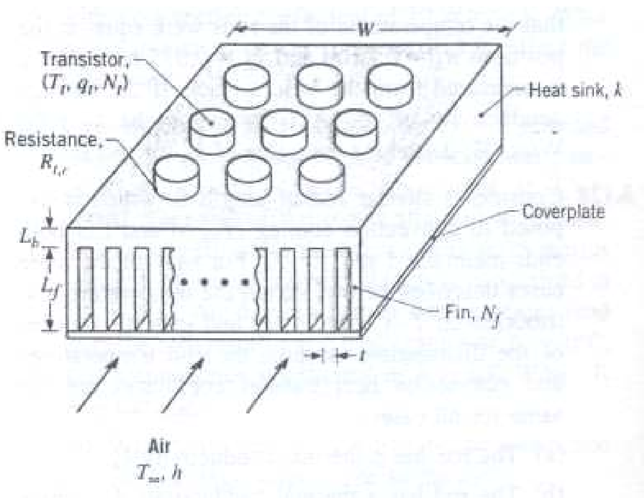
Consider limitations for which the array has N = 11 fins, in which case values of the fin thickness t = 0.182 mm and pitch S = 1.982 mm are obtained from the requirements that W = [(N - 1) S + t] and S - t = 1.8 mm. If the maximum allowable chip temperature is T_c = 85 °C, what is the corresponding value of the chip power q_c? An adiabatic fin tip condition may be assumed, and air flow along the outer surfaces of the heat sink may be assumed to provide a convection coefficient equivalent to that associated with air flow through the channels.



22. A 3 x 3 array of power transistors is attached to an aluminum heat sink (k = 180 W/m.K.) of width W = 150 mm on a side. The thermal contact resistance between each transistor and the heat sink is $R_{t,c}$ = 0.045 K/W. The heat sink has a base thickness of L_b = 6 mm and an array of N_f = 25 rectangular fins, each of thickness t = 3 mm. Cooling is provided by air flow through channels formed by the fins and a cover plate, as well as by air flow along the two sides of the heat sink (the outer surfaces of the outermost fins).

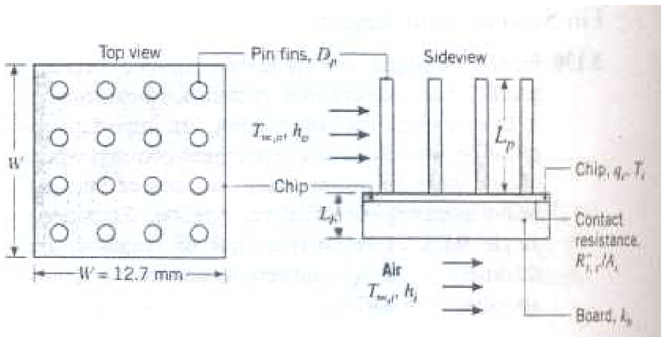
(a) Consider conditions for which the fin length is L_f = 30 mm, the temperature of the air is T_∞ = 27 °C, and the convection coefficient is h = 100 W/m^2.K. If the maximum allowable transistor temperature is T_s = 100 °C, what is the maximum allowable power dissipation, q per transistor? An adiabatic fin tip condition may be assumed.

(b) Explore the effect of variations in the convection coefficient and fin length on the maximum allowable transistor power.



23. As more and more components are placed on a single integrated circuit (chip), the amount of heat that is dissipated continues to increase. However, this increase is limited by the maximum allowable chip operating temperature, which is approximately 75 °C. To maximize heat dissipation, it is proposed that a 4 x 4 array of copper pin fins be metallurgically joined to the outer surface of a square chip that is 12.7 mm on a side.

(a) Sketch the equivalent thermal circuit for the pin-chip-board assembly, assuming one-dimensional, steady-state conditions and negligible contact resistance between the pins and the chip. In variable form, label appropriate resistances, temperatures, and heat rates.
(b) For the conditions prescribed in Problem 16, what is the maximum rate at which heat can be dissipated in the chip when the pins are in place? That is, what is the value of q_c For T_c = 75 °C? The pin diameter and length are D_p= 1.5 mm and L_p = 15 mm.

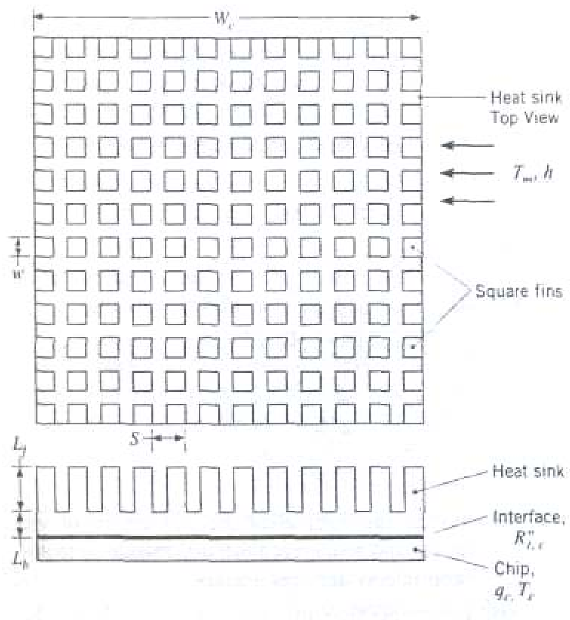


24. As a means of enhancing heat transfer from high-performance logic chips, it is common to attach a heal sink to the chip surface in order to increase the surface area available for convection heat transfer. Because of the ease with which it may be manufactured (by taking orthogonal sawcuts in a block of material), an attractive option is to use a heat sink consisting of an array of square fins of width w on a side. The spacing between adjoining fins would be determined by the width of the sawblade, with the sum of this spacing and the fin width designated as the fin pitch S. The method by which the heat sink is joined to the chip would determine the interfacial contact resistance $R''_{t,c}$.

Consider a chip of width W_c = 16 mm and conditions for which cooling is provided by a dielectric liquid with T_∞ = 25 °C and h = 1500 W/m^2.K. The heat sink is fabricated from copper (k = 400 W/m.K), and its characteristic dimensions are w = 0.25 mm, S = 0.50 mm, L_f = 6 mm, and L_b = 3 mm. The prescribed values of w and S represent minima imposed by manufacturing constraints and the need to maintain adequate flow in the passages between fins.

(a) If a metallurgical joint provides a contact resistance of $R''_{t,c}$ = 5 x 10^{-6} m^2.K/W. and the maximum allowable chip temperature are 85 ^{o}C. What is the maximum allowable chip power dissipation q_c? Assume all of the heat to be transferred through the heat sink.

(b) It may be possible to increase the heat dissipation by increasing w, subject to the constraint that (S - w) ≥ 0.25 mm, and/or increasing L_f (subject to manufacturing constraints that $L_f \leq$ 10 mm). Assess the effect of such change.



25. Because of the large number of devices in today's PC chips, finned heat sinks are often used to maintain the chip at an acceptable operating temperature. Two fin designs are to be evaluated, both of which have base (unfinned) area dimensions of 53 mm x 57 mm. The fins are of square cross section and fabricated from an extruded aluminum alloy with a thermal conductivity of 175 W/m.K. cooling air may be supplied at 25 °C, and the maximum allowable chip temperature is 75 °C. Other features of the design and operating conditions are tabulated.

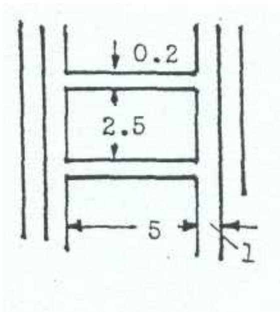
Determine which fin arrangement is superior. In your analysis, calculate the heat rate, efficiency, and effectiveness of a single fin, as well as the total heat rate and overall efficiency of the array. Since real estate inside the computer enclosure is important, compare the total heat rate per unit volume for the two designs.

Design	Fin Dimensions: Cross Section $w \times w$ (mm)	Fin Dimensions: Length L (mm)	Number of Fins in Array	Convection Coefficient ($W/m^2 \cdot K$)
A	3×3	30	6×9	125
B	1×1	7	14×17	375

Transient Conduction Problems

26. A duralumin hollow core PCB is 160 x 200 mm with 58 conduits as shown. It has two laminated PCB's of thermal conductivity 0.4 W /m. K and thickness 1 mm each. The electronic components are cemented to the laminated PCB's by an adhesive of thermal conductivity 0.4 W/m. K. and 0.2 mm thick. These components generate heat evenly at a rate of 1.6 KW /m^2 on the two sides. Air at 50 °C and a rate of 25 kg /h is used for cooling.

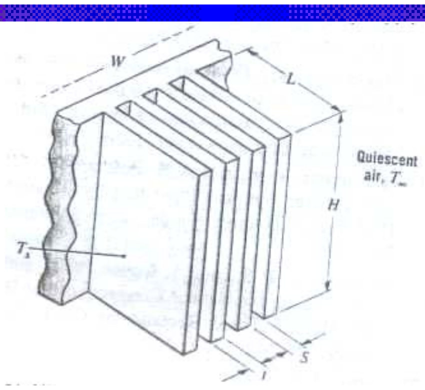
If the hollow core PCB attains at a uniform temperature of 80 °C, when the electronic components mounted on it are turned off while the cooling air continues to flow, estimate the time necessary for the PCB to reach a temperature of 55 °C. You may consider the laminated PCB's to act as perfect insulators.



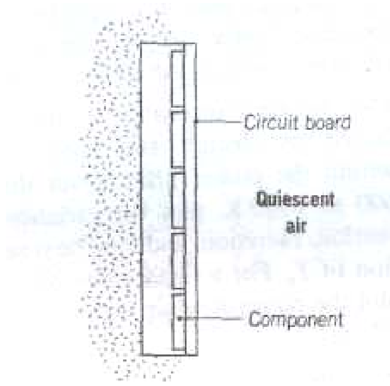
27. A 35 W power transistor is fitted to a duralumin plate 150 x 165 mm and 5 mm thick. The plate is finned on the other side by 15 fins spaced 9 mm apart. The fins are 2 mm thick and protrude 40 mm. In an ambience of 40 °C, how long would it take this transistor, after turning it on, to be within 5 ^{o}C from its final temperature? Neglect effect of radiation.

Free Convection Problems

28. Consider an array of vertical rectangular fins, which is lo be used lo cool an electronic device mounted in quiescent, atmospheric air at T_∞= 27 °C. Each fin has L = 20 mm and H = 150 mm and operates at an approximately uniform temperature of T_s = 77 °C. For the optimum value of fin spacing S and a fin thickness of t = 1.5 mm, estimate the rate of heat transfer from the fins for an array of width W = 355 mm.



29. The components of a vertical circuit board. 150 mm on a side, dissipate 5 W. The back surface is well insulated and the front surface is exposed to quiescent air at 27 °C. Assuming a uniform surface heat flux, what is the maximum temperature of the board? What is the temperature of the board for an isothermal surface condition?

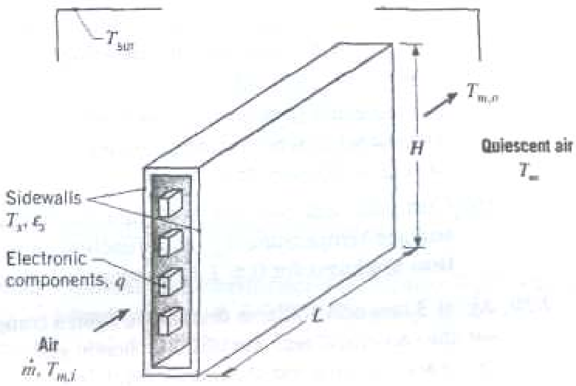


30. Circuit boards are mounted to interior vertical surfaces of a rectangular duct of height H = 400 mm and length L = 800 mm. Although the boards are cooled by forced convection heat transfer to air flowing through the duct, not all of the heat dissipated by the electronic components is transferred to the flow. Some of the heat is instead transferred by conduction to the vertical walls of the duct and then by natural convection and radiation to the ambient (atmospheric) air and surroundings, which are at equivalent temperatures of $T_\infty = T_{sur} = 20$ °C. The walls are metallic and, to a first approximation, may be assumed to be isothermal at a temperature T_s.

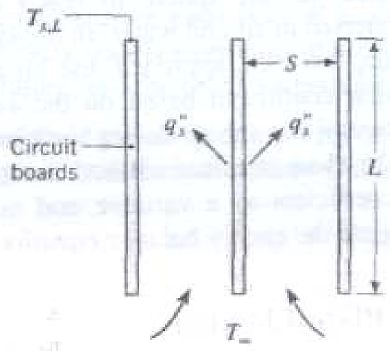
(a) Consider conditions for which the electronic components dissipate 200 W and air enters the duct at a flow rate of m = 0.015 kg/s and a temperature of $T_{m,i} = 20$ °C. If the emissivity of the side walls is $\varepsilon_s = 0.15$ and the outlet temperature of the air is $T_{m,o} = 30$ °C, what is the surface temperature T_s?

(b) To reduce the temperature of the electronic components, it is desirable to enhance heat transfer from the side walls. Assuming no change in the air flow conditions, what is the effect on Ts of applying a high emissivity coating ($\varepsilon_s = 0.90$) to the side walls?

(c) If there is a loss of airflow while power continues to be dissipated, what are the resulting values of T_s for $\varepsilon_s = 0.15$ and $\varepsilon_s = 0.90$?



31. A vertical array of circuit boards is immersed in quiescent ambient air at T_∞ = 17 °C. Although the components protrude from their substrates, it is reasonable, as a first approximation, to assume flat plates with uniform surface heat flux q".
Consider boards of length and width L = W = 0.4 m and spacing S = 25 mm. If the maximum allowable board temperature is 77 °C. What is the maximum allowable power dissipation per board?



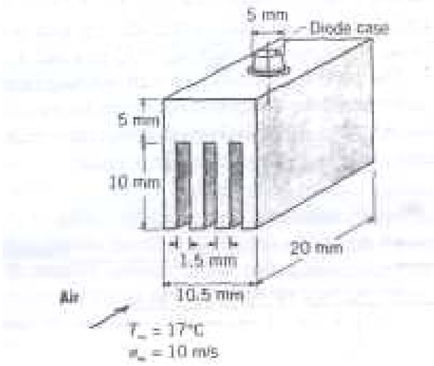
Forced Convection

- **External Flow**

32. A heat sink constructed from 2024 aluminum alloy is used to cool a power diode dissipating 5 W. The internal thermal resistance between the diode junction and the case is 0.8 °C/W, while the thermal contact resistance between the case and the heat sink is 10^{-5} m^2. °C/W. Convection at the fin surface may be approximated as that corresponding to a flat plate in parallel flow.

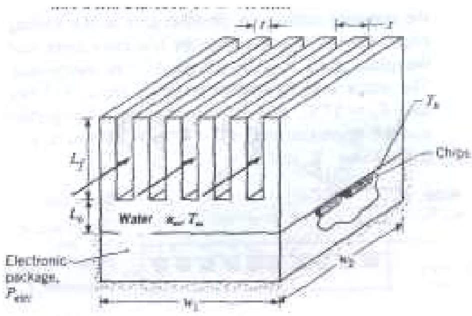
(a) Assuming that all the diode power is transferred to the ambient air through the rectangular fins; estimate the operating temperature of the diode.

(b) Explore options for reducing the diode temperature, subject to the constraints that the air velocity and fin length may not exceed 25 m/s and 20 mm, respectively, while the fin thickness may not be less than 0.5 mm. All other conditions, including the spacing between fins, remain as prescribed.



33. An array of electronic chips is mounted within a sealed rectangular enclosure, and cooling is implemented by attaching an aluminum heat sink (k = 180 W/m.K). The base of the heat sink has dimensions of $w_1 = w_2 = 110$ mm, while the 6 fins are of thickness t = 10 mm and pitch S = 20 mm. The fin length is $L_f = 60$ mm, and the base of the heat sink has a thickness of $L_b = 20$mm.

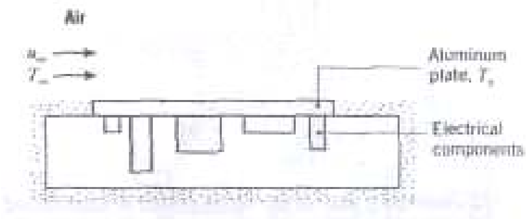
If cooling is implemented by water flow through the heat sink, with $u_\infty = 3$ m/s and $T_\infty = 17$ ^oC, what is the base temperature T_b of the heat sink when power dissipation by the chips is $P_{elec} = 1200$ W? The average convection coefficient for surfaces of the fins and the exposed base may be estimated by assuming parallel flow over a flat plate. Properties of the water may be approximated as k = 0.62 W/m.K, $\nu = 7.73 \times 10^{-7}$ m^2/s, and Pr = 5.2.



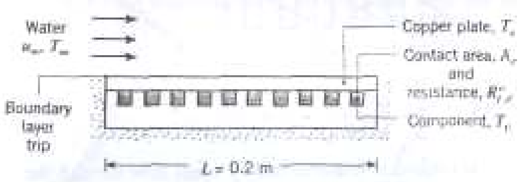
34. An array of heat-dissipating electrical components is mounted on the bottom side of a 1.2 m by 1.2 m horizontal aluminum plate, while the top side is cooled by an air stream for which $u_\infty = 15$ m/s and $T_\infty = 300$ K. The plate is attached to a well-insulated enclosure such that all the dissipated heat must be transferred to the air. Also, the aluminum is sufficiently thick to ensure a nearly uniform plate temperature.

(a) If the temperature of the aluminum is not exceeding 350 K, what is the maximum allowable heat dissipation?

(b) Determine the maximum allowable heal dissipation as a function of air velocity in the range, $5 \leq u_\infty \leq 25$ m/s. With $u_\infty = 25$ m/s, the maximum allowable power may be increased further by using an aluminum plate with longitudinal fins. What is the maximum allowable power if the fin length, thickness, and spacing are 25 mm, 5 mm, and 10 mm, respectively?

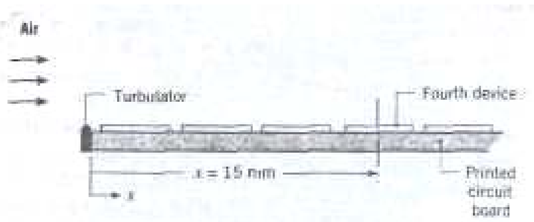


35. One-hundred electrical components, each dissipating 25 W, are attached to one surface of a square (0.2 m x 0.2 m) copper plate, and all the dissipated energy is transferred to water in parallel flow over the opposite surface. A protuberance at the leading edge of the plate acts to trip the boundary layer, and the plate itself may be assumed to be isothermal. The water velocity and temperature are u_∞ = 2 m/s and T_∞ = 17 °C, and its thermophysical properties may be approximated as $\nu = 0.96 \times 10^{-6}$ m/s, k = 0.620 W/m.K, and Pr = 5.2.
(a)What is the temperature of the copper plate?
(b)If each component has a plate contact surface area of 1 cm^2 and the corresponding contact resistance is 2×10^{-4} m^2.K/W, what is the component temperature? Neglect the temperature variation across the thickness of the copper plate.

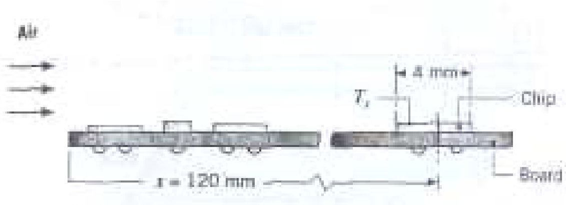


36. Air at 27 °C with a free stream velocity of 10 m/s is used lo cool electronic devices mounted on a printed circuit board. Each device, 4 mm by 4 mm, dissipates 40 mW, which is removed from the top surface. A turbulator is located at the leading edge of the board, causing the boundary layer to be turbulent.

(a) Estimate the surface temperature of the fourth device located 15 mm from the leading edge of the board.
(b) Generate a plot of the surface temperature of the first four devices as a function of the free stream velocity for $5 \leq u_\infty \leq 15$ m/s.
(c) What is the minimum free stream velocity if the surface temperature of the honest device is not to exceed 80 °C?



37. Forced air at 25 °C and 10 m/s is used to cool electronic elements mounted on a circuit board. Consider a chip of length 4 mm and width 4 mm located 120 mm from the leading edge. Because the board surface is irregular, the flow is disturbed and the appropriate convection correlation is of the form $Nu_x = Re_x^{0.85} Pr^{0.33}$. Estimate the surface temperature of the chip, T_s, if its heat dissipation rate is 30 mW.

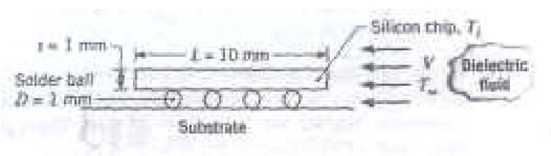


38. To enhance heat transfer from a silicon chip of width W = 4 mm on a side, a copper pin fin is brazed to the surface of the chip. The pin length and diameter are L = 12 mm and D = 2 mm, respectively, and atmospheric air at V = 10 m/s and T_∞ = 300 K is in cross flow over the pin. The surface of the chip, and hence the base of die pin, are maintained at a temperature of T_b = 350 K.

(a) Assuming the chip to have a negligible effect on flow over the pin, what is the average convection coefficient for the surface of the pin?
(b) Neglecting radiation and assuming the convection coefficient at the pin tip to equal that calculated in part (a), determine the pin heat transfer rate.
(c) Neglecting radiation and assuming the convection coefficient at the exposed chip surface to equal that calculated in part (a), determine the total rate of heat transfer from the chip.

39. A silicon chip (k = 150 W/m.K, ρ = 2300 kg/m^3, c_p = 700 J/kg.K), 10 mm on a side and 1 mm thick, is connected to a substrate by solder balls (k = 40 W/m.K, ρ = 10,000 kg/m^3, c_p = 150 J/kg.K) of 1 mm diameter, and during an accelerated thermal stress test, the system is exposed to the flow of a dielectric liquid (k = 0.064 W/m.K, ν= 10^{-6} m^2/s, Pr = 25). As first approximations, treat the top and bottom surfaces of the chip as flat plates in turbulent, parallel flow and assume the substrate and lower chip surfaces to have a negligible effect on flow over the solder balls. Also assume point contact between the chip and the solder, thereby neglecting heat transfer by conduction between the components.

(a) The stress test begins with the components at ambient temperature (T_i = 20 °C) and proceeds with heating by the fluid at T_∞ = 80 °C. If the fluid velocity is V = 0.2 m/s, estimate the ratio of the time constant of the chip to that of a solder ball. Which component responds more rapidly to the heating process?
(b) The thermal stress acting on the solder joint is proportional to the chip-to-solder temperature difference. What is this temperature difference 0.25 s after the start of heating?

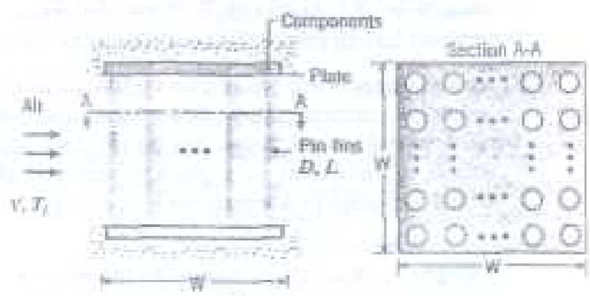


- **<u>Tube Bank</u>**

40. Electrical components mounted to each of two isothermal plates are cooled by passing atmospheric air between the plates, and an in-line array of aluminum pin fins is used to enhance heat transfer to the air. The pins are of diameter D = 2 mm. length L = 100 mm, and thermal conductivity k = 240 W/m.K. The longitudinal and transverse pitches are $S_L = S_T$ = 4 mm. with a square array of 625 pins ($N_T = N_L = 25$) mounted to square plates that are each of width W = 100 mm on a side. Air enters the pin array with a velocity of 10 m/s and a temperature of 300 K.

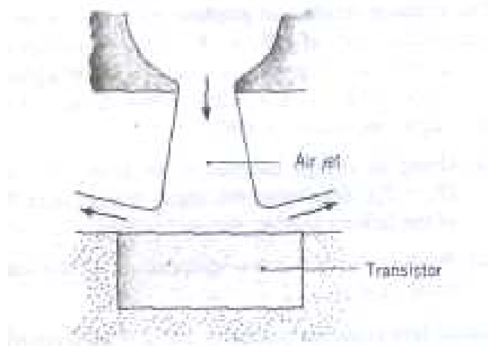
(a)Evaluating air properties at 300 K, estimate the average convection coefficient for the array of pin fins.

(b)Assuming a uniform convection coefficient overall heat transfer surfaces (plates and pins), use the result of part (a) to determine the air outlet temperature and total heat rate when the plates are maintained at 350 K. Hint: The air outlet temperature is governed by an exponential relation of the form $[(T_s - T_o)/(T_s - T_i)] = \exp[[-(\bar{h}A_t\eta_o)/m^{\bullet}C_p]$, where $m^{\bullet}$ = $\rho V L N_T S_T$ is the mass flow rate of air passing through the array, A_t is the total heat transfer surface area (plates and fins), and η_o is the overall surface efficiency defined as $[1-(NA_f / A_t)(1-\eta_f)]$.



- **<u>Impinging Jet</u>**

41. A circular transistor of 10 mm diameter is cooled by impingement of an air jet exiting a 2-mm diameter round nozzle with a velocity of 20 m/s and a temperature of 15 °C. The jet exit and the exposed surface of the transistor are separated by a distance of 10 mm. If the transistor is well insulated at all but its exposed surface and the surface temperature is not to exceed 85 ^{o}C, what is the transistor's maximum allowable operating power?

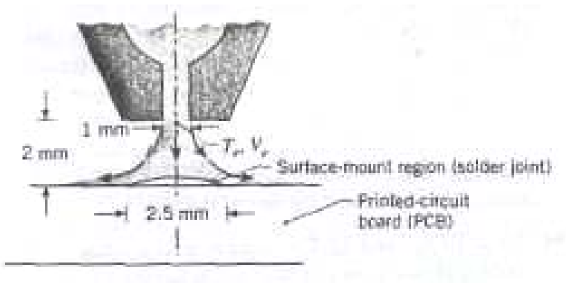


42. You have been asked to determine the feasibility of using an impinging jet in a soldering operation for electronic assemblies. The schematic illustrates the use of a single, round nozzle to direct high velocity, hot air to a location where a surface mount joint is to be formed.

For your study, consider a round nozzle with a diameter of 1 mm located a distance of 2 mm from the region of the surface mount, which has a diameter of 2.5 mm.

(a) For an air jet velocity of 70m/s and a temperature of 400 °C, estimate the average convection coefficient over the area of the surface mount.

(b) For three air jet temperatures of 400, 500, and 600 ^{o}C, calculate and plot the surface temperature as a function of time for $0 \le t \le 40$ s. On this plot, identify important temperature limits for the soldering process: the lower limit corresponding to the solder's eutectic temperature, T_{sol} = 183 °C and the upper limit corresponding to the glass transition temperature, T_{gl} = 250 ^{o}C, at which the PCB becomes plastic. Comment on the outcome of your study, the appropriateness of the assumptions, and the feasibility of using the jet for a soldering application.

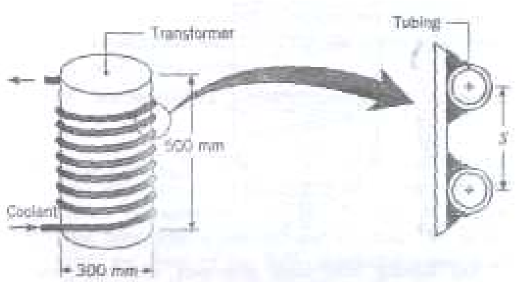


- **Internal Flow**

43. An electrical power transformer of diameter 300 mm and height 500 mm dissipates 1000 W. It is desired to maintain its surface temperature at 47 °C by supplying glycerin at 24 °C through thin-walled tubing of 20 mm diameter welded to the lateral surface of the transformer. All the heat dissipated by the transformer is assumed to be transferred to the glycerin.

(a) Assuming the maximum allowable temperature rise of the coolant to be 6 °C and fully developed flow throughout the tube, determine the required coolant flow rate, the total length of tubing, and the lateral spacing S between turns of the tubing.

(b) For a prescribed tube length of 15 m and a maximum allowable transformer surface temperature of 47 °C, compute and plot the maximum allowable transformer power and the outlet temperature of the glycerin as a function of flow rate for $0.05 \le \dot{m} \le 0.25$ kg/s. Account for the fact that the flow is not fully developed.

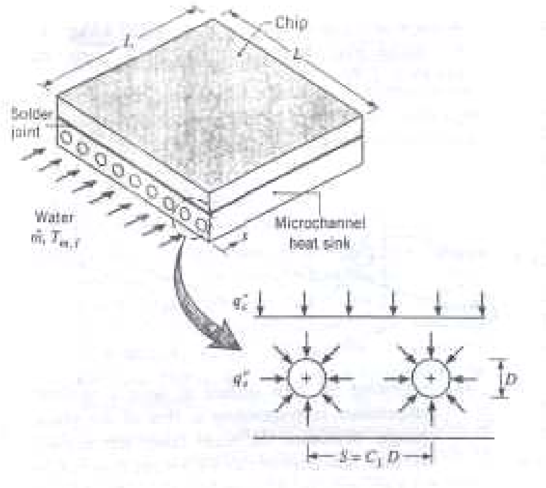


44. A common procedure for cooling a high-performance computer chip involves joining the chip to a heat sink within which circular microchannels are machined. During operation, the chip produces a uniform heal flux q_c'' at its interface with the heat sink, while a liquid coolant (water) is routed through the channels. Consider a square chip and heat sink, each L x L on a side, with microchannels of diameter D and pitch $S = C_1D$, where the constant C_1 is greater than unity.
Water is supplied at an inlet temperature $T_{m,i}$ and a total mass flow rate $m^\bullet$ (for the entire heat sink).

(a) Assuming that q_c'' is dispersed in the heat sink such that a uniform heat flux q_c'' is maintained at the surface of each channel; obtain expressions for the longitudinal distributions of the mean fluid, $T_m(x)$, and surface. $T_s(x)$, temperatures in each channel. Assume laminar, fully developed flow throughout each channel, and express your results in terms of $m^\bullet$. q_c''. C_1, D, and/or L, as well as appropriate thermophysical properties.

(b) For L = 12 mm, D = 1 mm, $C_1 = 2$, q_c'' = 20 W/cm^2, $m^\bullet$ = 0.010 kg/s, and $T_{m,i}$ = 290 K, compute and plot the temperature distributions $T_m(x)$ and T_s (x).

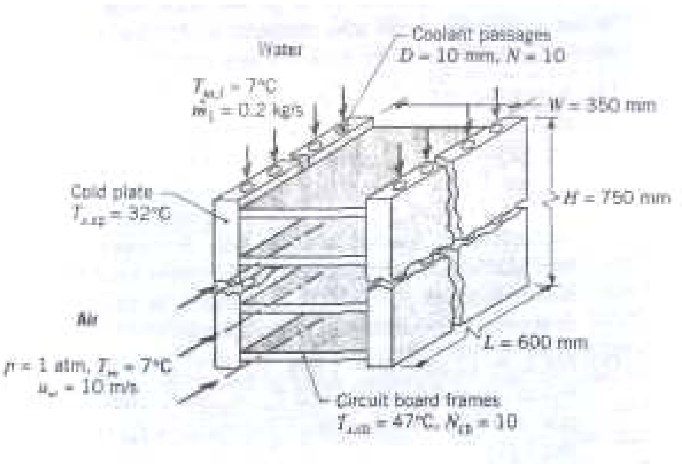
(c) A common objective in designing such heat sinks is to maximize q_c'' while maintaining the heat sink at an acceptable temperature. Subject to prescribed values of L = 12 mm and $T_{m,i}$ = 290 K and the constraint that $T_{s,max} \leq 50°C$, explore the effect on q_c'' of variations in heat sink design and operating conditions.



45. One way to cool chips mounted on the circuit boards of a computer is to encapsulate the boards in metal frames that provide efficient pathways for conduction to supporting cold plates. Heat generated by the chips is then dissipated by transfer to water flowing through passages drilled in the plates. Because the plates are made from a metal of large thermal conductivity (typically aluminum or copper), they may be assumed to be at a uniform temperature, $T_{s,cp}$.

(a)Consider circuit boards attached to cold plates of height H = 750 mm and width L = 600 mm, each with N = 10 holes of diameter D = 10mm. If operating conditions maintain plate temperatures of $T_{s,cp}$ = 32 °C with water flow at $m^{\bullet}{}_{1}$= 0.2 kg/s per passage and $T_{m,i}$ = 7 °C, how much heat may be dissipated by the circuit boards?

(b)To enhance cooling, thereby allowing increased power generation without an attendant increase in system temperatures, a hybrid cooling scheme may be used. The scheme involves forced air flow over the encapsulated circuit boards, as well as water flow through the cold plates. Consider conditions for which N_{cb} = 10 circuit boards of width W = 350 mm are attached to cold plates and their average surface temperature is $T_{s,cb}$ = 47 °C when $T_{s,cp}$ = 32°C. If air is in parallel flow over the plates with u_∞ = 10 m/s and T_∞ = 7 °C, how much of the heat generated by the circuit boards is transferred to the air?



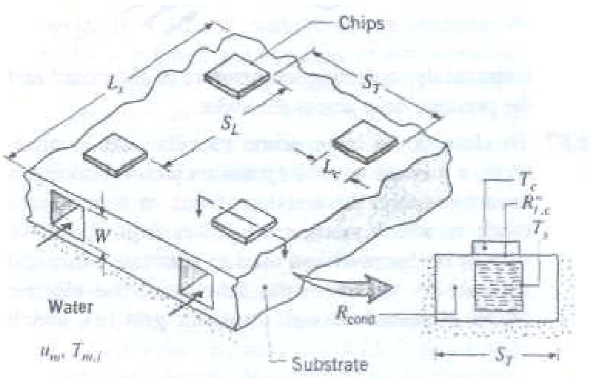
46. Freon is being transported at 0.1 kg/s through a Teflon tube of inside diameter D_i = 25 mm and outside diameter D_o = 28 mm, while atmospheric air at V = 25 m/s and 300 K is in cross flow over the tube. What is the heat transfer per unit length of tube to Freon at 240 K?

47. A novel scheme for dissipating heat from the chips of a multichip array involves machining coolant channels in the ceramic substrate to which the chips are attached. The square chips (L_c = 5 mm) are aligned above each of the channels, with longitudinal and transverse pitches of $S_L = S_T$ = 20 mm. Water flows through the square cross section (W = 5 mm) of each channel with a mean velocity of u_m = 1 m/s, and its properties may be approximated as ρ = 1000 kg/m^3, C_p = 4180 J/kg .K, μ = 855 x 10^{-6} kg/s.m, k = 0.610 W/m.K, and Pr = 5.8. Symmetry in the transverse direction dictates the existence of equivalent conditions for each substrate section of length L_s and width S_T.

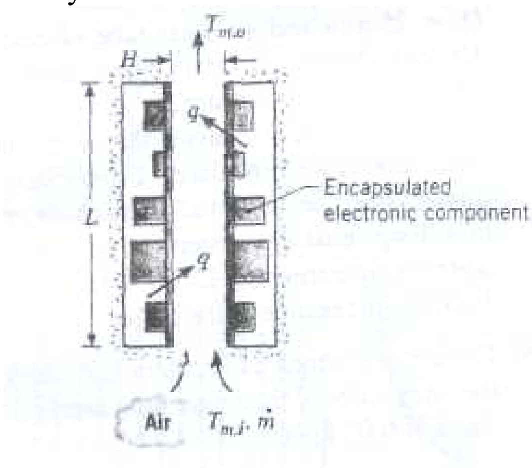
(a) Consider a substrate whose length in the flow direction is L_s = 200 mm, thereby providing a total of N_L = 10 chips attached in-line above each flow channel. To a good approximation, all the heat dissipated by the chips above a channel may be assumed to be transferred to the water flowing through the channel. If each chip dissipates 5 W, what is the temperature rise of the water passing through the channel?

(b) The chip-substrate contact resistance is $R''_{t,c}$ = 0.5 x 10^{-4} m^2.K/W, and the three-dimensional conduction resistance for the L_s x S_T substrate section is R_{cond} =

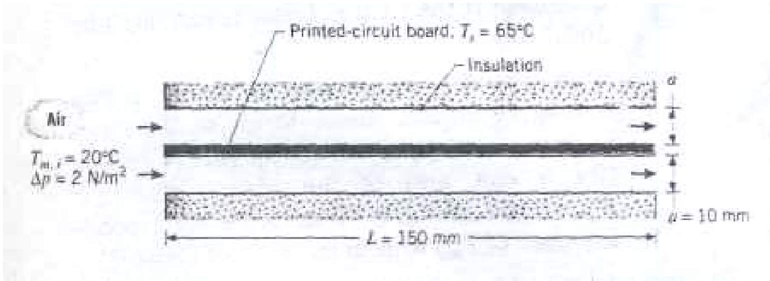
0.120 K/W. If water enters the substrate at 25 °C and is in fully developed flow, estimate the temperature T_c of the chips and the temperature T_s of the substrate channel surface.



48. To cool electronic components that are mounted to a printed circuit board and hermetically sealed from their surroundings, two boards may be joined to form an intermediate channel through which the coolant is passed. Termed a hollow-core PCB, all of the heat generated by the components may be assumed to be transferred to the coolant. Consider a hollow-core PCB of length L = 300 mm and equivalent width W (normal to the page). Under normal operating conditions, 40 W of power are dissipated on each side of the PCB and a uniform distribution of the attendant heat transfer may be assumed for each of the hollow-core surfaces. If air enters a core of height H = 4 mm at a temperature of $T_{m\ i}$ = 20°C and a flow rate of $m^{\bullet}$ = 0.002 kg/s what is its outlet temperature $T_{m\ o}$? What are the surface temperatures at the inlet and outlet of the core? What are the foregoing temperatures if the flow rate is increased by a factor of five?



49. A printed circuit board (PCB) is cooled by laminar, fully developed air flow in adjoining, parallel-plate channels of length L and separation distance a. The channels may be assumed to be of infinite extent in the transverse direction, and the upper and lower surfaces are insulated. The temperature T_s, of the PCB board is uniform, and air flow with an inlet temperature of $T_{m,i}$ is driven by a pressure difference, Δp.
Calculate the average heat removal rate per unit area (W/m^2) from the PCB.



- **Fans Performance**

50. The electronics in a fan cooled box dissipate 450 W. In an environment of 30°C, the cooling air should leave the box at a temperature of no more than 70 °C. Measurements showed that when the air is flowing through the box at a rate of 20 m^3/h, the pressure drop is 40 Pa. *A* fan is available that has the following characteristics

Discharge, m^3/h	0	10	20	30	40	50	60
Pressure drop, Pa	320	225	215	250	200	110	0

Is this fan suitable for the purpose? Under what conditions would it operate?

51. The electronics in a fan cooled box dissipate 600 W in an environment of 30 °C. The cooling air should leave the box at a temperature not exceeding 70 °C. Measurements showed that when the air is flowing through the box at a rate of 30 m^3/h, the pressure drop is 90 Pa. The characteristics of the fan available for the purpose, when operating at 1000 rpm, is given by

$\Delta p = 320 + 0.7\ V^{\bullet} - 0.1\ V^{\bullet 2}$

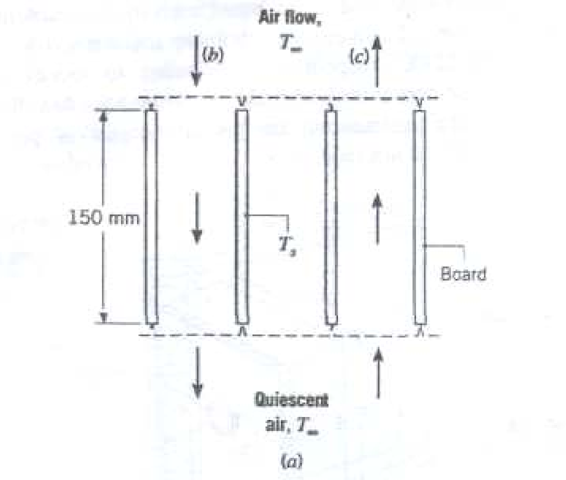
Where $V^{\bullet}$ is the discharge in m^3/h and Δp in Pascal's.
Is this fan suitable for the purpose? If not, suggest a method to make it suitable for the task.

52. The following table gives the performance of a fan that handles air at a speed of 1200 rpm. What would be the performance of this fan when it handles hydrogen at this speed and at a speed of 1800 rpm? (The molecular weight of hydrogen is 2; its apparent value for air is 28.8).

Discharge, m^3/h	0	10	20	30	40	50	60
Pressure drop , Pa	320	225	215	250	200	110	0
Power, W	0.4	1	2	3.5	3.8	2.5	0.4

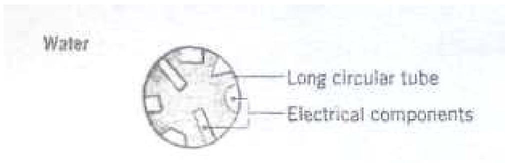
- **Mixed Convection**

53. A vertical array of circuit boards of 150 mm height is to be air cooled such that the board temperature does not exceed 60 °C when the ambient temperature is 25 °C.
Assuming isothermal surface conditions, determine the allowable electrical power dissipation per board for the cooling arrangements:
(a)Free convection only (no forced airflow).
(b)Airflow with a downward velocity of 0.6 m/s.
(c)Airflow with an upward velocity of 0.3 m/s.
(d)Airflow with a velocity (upward or downward) of 5 m/s.



54. Heat-dissipating electrical components are mounted to the inner surface of a long metallic tube. The tube is of 0.10 m diameter and is submerged in a quiescent water bath.

What is the heat dissipation per unit tube length if the tube wall and water temperatures are 350 and 300 K, respectively? What is the heat dissipation per unit length if a forced flow is imposed over the tube, with a cross-flow velocity of 1.0 m/s?



- **<u>Heat Exchangers</u>**

55. In a supercomputer, signal propagation delays are reduced by resorting to high-density circuit arrangements, which are cooled by immersing them in a special dielectric liquid. The fluid is pumped in a closed loop through the computer and an adjoining shell-and-tube heat exchanger having one shell and two tube passes.

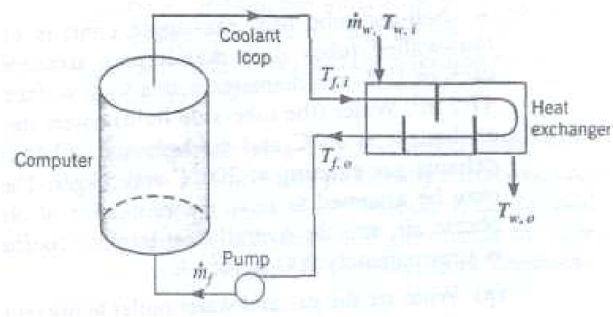
During normal operation, heat generated within the computer is transferred to the dielectric fluid passing through the computer at a flow rate of m_f = 4.81 kg/s. In turn, the fluid passes through the tubes of the heat exchanger and the heat is transferred to water passing over the tubes. The dielectric fluid may be assumed to have constant properties of C_p = 1040 J/kg. K, μ = 7.65 x 10^{-4} kg/s. m, k = 0.058 W/m. K, and Pr = 14. During normal operation, chilled water at a flow rate of $\dot{m}_w$ = 2.5 kg/s and an inlet temperature of $T_{w,i}$ = 5 °C passes over the tubes. The water has a specific heat of 4200 J/kg. K and provides an average convection coefficient of 10,000 W/m^2.K over the outer surface of the tubes.

(a) If the heat exchanger consists of 72 thin-walled tubes, each of 10-mm diameter, and fully developed flow is assumed to exist within the tubes, what is the convection coefficient associated with flow through the tubes?

(b) If the dielectric fluid enters the heat exchanger at $T_{f,i}$ = 25 ^{o}C and is to leave at $T_{f,o}$ = 15 °C, what is the required tube length per pass?

(c) For the exchanger with the tube length per pass determined in part (b), plot the outlet temperature of the dielectric fluid as a function of its flow rate for $4 \leq \dot{m}_w \leq 6$ kg/s.

Account for corresponding changes in the overall heat transfer coefficient, but assume all other conditions to remain the same.



Radiation

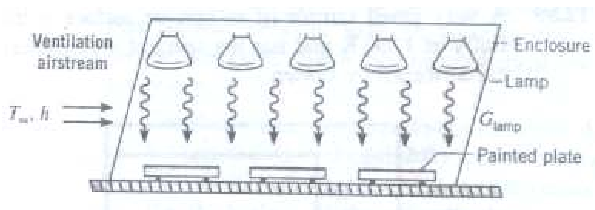
- **Radiation Properties Applications**

56. Square plates freshly sprayed with epoxy paint must be cured at 140 °C for an extended period of time. The plates are located in a large enclosure and heated by a bank of infrared lamps. The top surface of each plate has an emissivity of $\varepsilon = 0.8$ and experiences convection with a ventilation air stream that is at $T_\infty = 27$ °C and provides a convection coefficient of $h = 20$ W/m^2. K. The irradiation from the enclosure walls is estimated to be $G_{wall} = 450$ W/m^2, for which the plate absorptivity is $\alpha_{wall} = 0.7$.

(a) Determine the irradiation that must be provided by the lamps, G_{lamp}. The absorptivity of the plate surface for this irradiation is $\alpha_{lamp} = 0.6$.

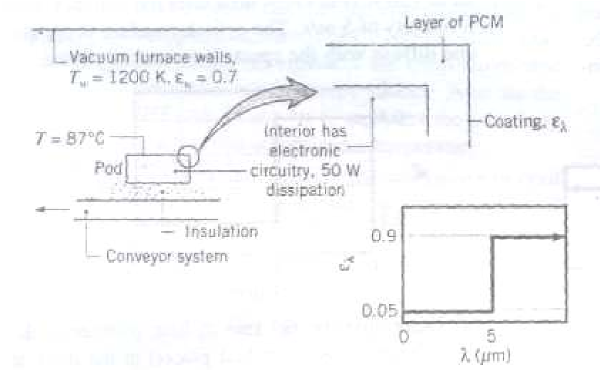
(b) For convection coefficients of h = 15, 20, and 30 W/m^2. K. Plot the lamp irradiation, G_{lamp}, as a function of the plate temperature. Ts, for $100 \leq Ts \leq 300$ °C.

(c) For convection coefficients in the range from 10 to 30 W/m^2. K and a lamp irradiation of $G_{lamp} = 3000$ W/m^2. Plot the air stream temperature T_∞ required to maintain the plate at $T_s = 140$ °C.



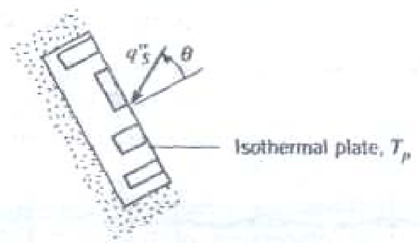
57. An instrumentation transmitter pod is a box containing electronic circuitry and a power supply for sending sensor signals to a base receiver for recording. Such a pod is placed on a conveyor system, which passes through a large vacuum brazing furnace as shown in the sketch. The exposed surfaces of the nod have a special diffuse, opaque coating with spectral emissivity as shown below.

To stabilize the temperature of the pod and prevent overheating of the electronics, the inner surface of the pod is surrounded by a layer of a phase-change material (PCM) having a fusion temperature of 87 °C and a heat of fusion of 25 kJ/kg. The pod has an exposed surface area of 0.040 m^2 and the mass of the PCM is 1.6 kg. Furthermore, it is known that the power dissipated by the electronics is 50 W. Consider the situation when the pod enters the furnace at a uniform temperature of 87 °C and all the PCM are in the solid state. How long will it take before all the PCM changes to the liquid state?



58. Components of an electronic package in an orbiting satellite are mounted in a compartment that is well insulated on all but one of its sides. The uninsulated side consists of an isothermal copper plate whose outer surface is exposed to the vacuum of outer space and whose inner surface is attached to the components. The plate dimensions are 1 m by 1 m on a side.

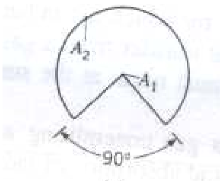
The exposed surface of the plate, which is opaque and diffuse, has a spectral, hemispherical absorptivity of α_λ = 0.2 for $\lambda \leq 2$ μm and α_λ = 0.8 for $\lambda > 2$ μm. Consider steady-state conditions for which the plate is exposed to a solar flux of q''_s = 1350 W/m^2, which is incident at an angle of θ = 30° relative to the surface normal. If the plate temperature is T_p = 500 K, how much power is being dissipated by the components?



- **Radiation Exchange Between Surfaces**

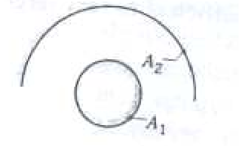
59. Determine F_{12} and F_{21} for the following configurations using the reciprocity theorem and other basic shape factor relations. Do not use tables or charts.

(a) Long duct



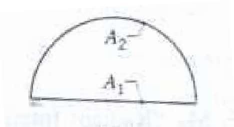
(a)

(b) Small sphere of area A_1 under a concentric hemisphere of area $A_2 = 2A_1$



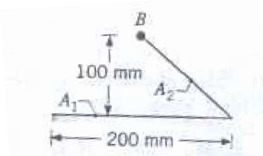
(b)

(c) Long duct. What is F_{22} for this case?



(c)

(d) Long inclined plates (point B is directly above the center of A_1)

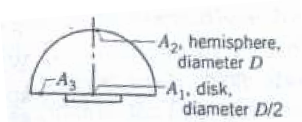


(d)

(e) Sphere lying on infinite plane

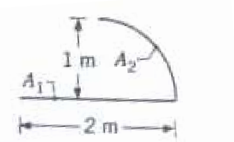
(e)

(f) Hemisphere-disk arrangement



(f)

(g) Long open channel

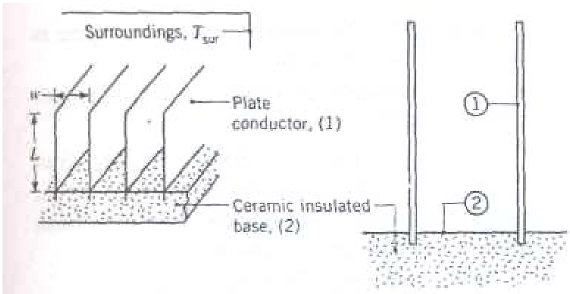


(g)

60. Electrical conductors, in the form of parallel plates of length L = 40 mm, have one edge mounted to a ceramic insulated base and are spaced a distance w = 10 mm apart. The plates are exposed to large isothermal surroundings at T_{sur} = 300 K. The conductor (1) and ceramic (2) surfaces are diffuse and gray with emissivities of ε_1 = 0.8 and ε_2 = 0.6, respectively. For a prescribed operating current in the conductors, their temperature is T_1 = 500 K.

(a) Determine the electrical power dissipated in a conductor plate per unit length q_1' considering only radiation exchange. What is the temperature of the insulated base, T_2?

(b) Determine q_1' and T_2 when the surfaces experience convection with an air stream at 300 K and a convection coefficient of h =25 W/m^2. K

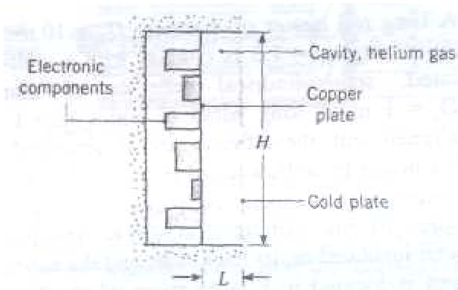


61. A scheme for cooling electronic components involves mounting them to a copper plate that forms one vertical wall of a rectangular cavity containing helium gas at atmospheric pressure.

The cavity width and height are L = 20 mm and H = 160 mm, respectively. The top and bottom surfaces, as well as the back wall of the component compartment, are well insulated. Under steady-state conditions, the copper plate and the adjoining cold plate are maintained at 75 and 15 °C, respectively. The plates each have an emissivity of 0.8.

(a) Determine the rate at which heat is being dissipated by the components per unit distance perpendicular to the cross section (W/m).

(b) Assess the effect of varying the plate spacing L on the heat dissipation rate.



62. In an orbiting space station, an electronic package is housed in a compartment having a surface area, A_S = 1 m^2, which is exposed to space. Under normal operating conditions, the electronics dissipate 1 kW, all of which must be transferred from the exposed surface to space. If the surface emissivity is 1.0 and the surface is not exposed to the sun. What is its steady-state temperature? If the surface is exposed to a solar flux of 750 W/m^2 and its absorptivity to solar radiation is 0.25, what is its steady-state temperature?

63. In the thermal processing of semiconductor materials, annealing is accomplished by heating a silicon wafer according to a temperature-time recipe and then maintaining a fixed elevated temperature for a prescribed period of time. For the process tool arrangement shown as follows, the wafer is in an evacuated chamber whose walls are maintained at 27 °C and within which heating lamps maintain a radiant flux q" at its upper surface. The wafer is 0.78 mm thick, has a thermal conductivity of 30W/m.K. and an emissivity that equals its absorptivity to the radiant flux ($\varepsilon = \alpha = 0.65$). For q"= 3.0 x 10^5 W/m^2, the temperature on its lower surface is measured by a radiation thermometer and found to have a value of $T_{w,l}$ = 997°C. To avoid warping the wafer and inducing slip planes in the crystal structure, the temperature difference across the thickness of the wafer must be less than 2 ^{o}C. Is this condition being met?

64. A satellite in the form of a cube is in deep space between the earth and the sun. Determine its equilibrium temperature if its surface is: (a) polished aluminum (h) painted grey (c) painted white.

65. In a large electronics panel in outer space, heat is generated at a rate of 300 W/m^2. It is cooled by a parallel panel maintained at -23 °C that has a reflectivity of 0.4.Estimate the temperature at which the electronics panel would operate if its emissivity is 0.8.

66. A polished copper panel is 20 x 30 cm and is used as a heat sink for an electronic package at sea level. The panel is finned to dissipate 25 W when at 70 °C in air at 50 °C. The fins are 1.5 mm thick and 40 mm long. How many fins are required for the purpose? How would you set the panel for best operation?

67. A polished copper panel 30 x 20 cm has 15 fins, 1.5 mm, thick protruding 40 mm along the 20 cm length. Estimate the maximum power that could be dissipated by this panel when its temperature is 70 °C in air at 50 °C.

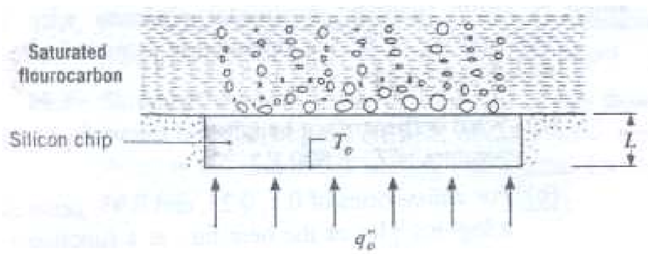
68. The vertical side of an electronics box is 40 x 30 cm with the 40 cm side vertical. What is the maximum energy that could be dissipated by this side if its temperature is not to exceed 60 °C in an environment of 40 °C, and its emissivity is 0.8?

Boiling and Condensation

69. A silicon chip of thickness L = 2.5 mm and thermal conductivity k_s = 135 W/m. K is cooled by boiling a saturated fluorocarbon liquid (T_{sat} = 57 °C) on its surface. The electronic circuits on the bottom of the chip produce a uniform heat flux of $q''_o = 5 \times 10^4$ W/m^2, while the sides of the chip are perfectly insulated. Properties of the saturated fluorocarbon are $C_{p,l}$ = 1100 J/kg. K, h_{fg} = 84,400 J/kg, ρ_l = 1619.2 kg/ m^3, ρ_v = 13.4 kg/ m^3, $\sigma = 8.1 \times 10^{-3}$ kg/s^2, $\mu_l = 440 \times 10^{-6}$ kg/m. s, and Pr_l = 9.01. In addition, the nucleate boiling constants are $C_{s,f}$ = 0.005 and n = 1.7.

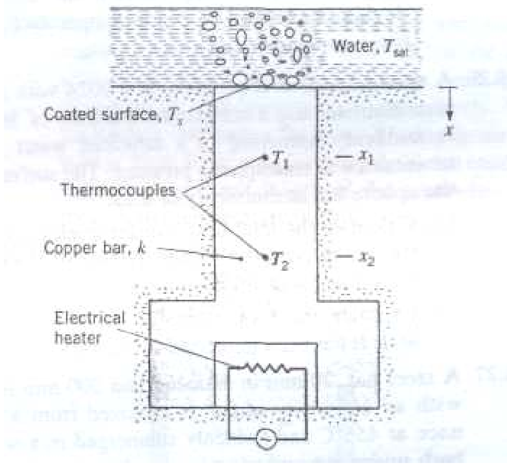
(a) What is the steady-state temperature T_o at the bottom of the chip? If, during testing of the chip, q''_o is increased to 90% of the critical heat flux, what is the new steady-state value of T_o?

(b) Compute and plot the chip surface temperatures (top and bottom) as a function of heat flux for $0.20 \le q''_o / q''_{max} \le 0.90$. If the maximum allowable chip temperature is 80 °C, what is the maximum allowable value of q''_o?



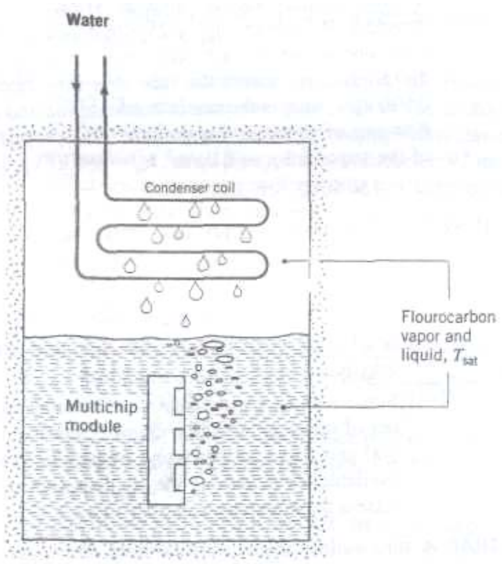
70. A device for performing boiling experiments consists of a copper bar (k = 400 W/m. K), which is exposed to a boiling liquid at one end, encapsulates an electrical heater at the other end, and is well insulated from its surroundings at all but the exposed surface. Thermocouples inserted in the bar are used to measure temperatures at distances of x_1 = 10 mm and x_2 = 25 mm from the surface.

An experiment is performed to determine the boiling characteristics of a special coating applied to the exposed surface. Under steady-state conditions, nucleate boiling is maintained in saturated water at atmospheric pressure and values of T_1 = 133.7 °C and T_2 = 158.6 °C are recorded. If n = 1, what value of the coefficient $C_{s,f}$ is associated with the Rohsenow correlation?



71. A technique for cooling a multichip module involves submerging the module in saturated fluorocarbon liquid. Vapor generated due to boiling at the module surface id condensed on the outer surface of copper tubing suspended in the vapor space above the liquid. the thin-walled tubing is of diameter D = 10 mm and is coiled in a horizontal plane. It is cooled by water that enters at 285 K and leaves at 315 K. All the heat dissipated by the chips within the module is transferred from a 100-mm by 100-mm boiling surface, at which the flux is 10^5 W/m^2, to the fluorocarbon liquid, which is at T_{sat} = 57 °C. Liquid properties are $C_{p,l}$ = 1100 J/kg. K, $h_{fg} = h'_{fg}$ = 84,400 J/kg, ρ_l = 1619.2 kg/m^3, ρ_v = 13.4 kg/m^3, $\sigma = 8.1 \times 10^{-3}$ kg/s^2, $\mu_l = 440 \times 10^{-6}$ kg/m. s, and Pr_l = 9.

(a) For the prescribed heat dissipation, what is the required condensation rate (kg/s) and water flow rate (kg/s)?
(b) Assuming fully developed flow throughout the tube, determine the tube surface temperature at the coil inlet and outlet.
(c) Assuming a uniform tube surface temperature of T_s = 53 °C, determine the required length of the coil.

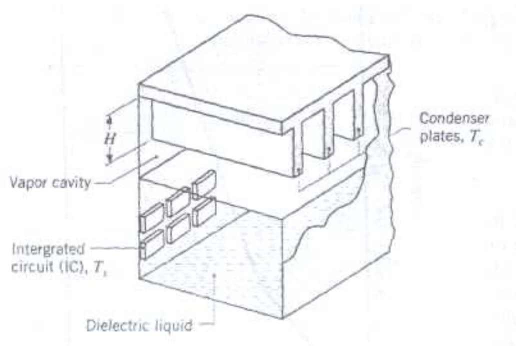


Combined Boiling/Condensation Problems

72. A passive technique for cooling heat-dissipating integrated circuits involves submerging the ICs in a low boiling point dielectric fluid. Vapor generated in cooling the circuits is condensed on vertical plates suspended in the vapor cavity above the liquid. The temperature of the plates is maintained below the saturation temperature, and during steady-state operation a balance is established between the rate of heat transfer to the condenser plates and the rate of heat dissipation by the ICs.

Consider conditions for which the 25-mm^2 surface area of each IC is submerged in a fluorocarbon liquid for which $T_{sat} = 50^oC$, $C_{p,l} = 1005$ J/kg. K, $h_{fg} = 1.05 \times 10^5$ J/kg, $\rho_l = 1700$ kg/m^3, $\sigma = 0.013$ kg/s^2, $\mu_l = 6.80 \times 10^{-4}$ kg/m. s, $k_l = 0.062$ W/m. K and $Pr_l = 11.0$, $C_{s,f} = 0.004$ and $n = 1.7$.

If the integrated circuits are operated at a surface temperature of $T_s = 75\ ^oC$, what is the rate at which heat is dissipated by each circuit? If the condenser plates are of height H = 50 mm and are maintained at a temperature of $T_c = 15$ °C by an internal coolant, and laminar film condensation is assumed, how much condenser surface area must be provided to balance the heat generated by 500 integrated circuits?

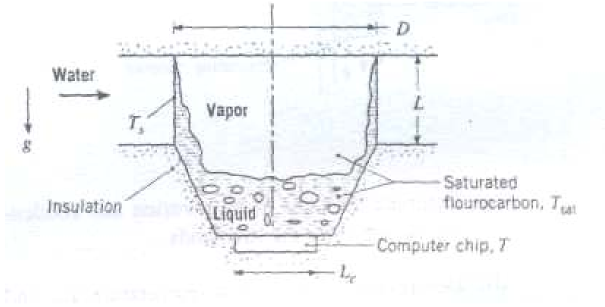


73. A novel scheme for cooling computer chips uses a thermosyphon containing a saturated fluorocarbon. The chip is brazed to the bottom of a cuplike container, within which heat is dissipated by boiling and subsequently transferred to an external coolant (water) via condensation on the inner surface of a thin-walled tube.

The nucleate boiling constants and the properties of the fluorocarbon are provided in Problem 1.0. In addition, $k_l = 0.054$ W/m. K

(a) If the chip operates under steady-state conditions and its surface heat flux is maintained at 90% of the critical heat flux, what is its temperature T? What the total power dissipation if the chip width is $L_c = 20$ mm on a side?

(b) If the tube diameter is D = 30 mm and its surface is maintained at $T_s = 25\ ^oC$ by the water, what tube length L is required to maintain the designated conditions?



TEC

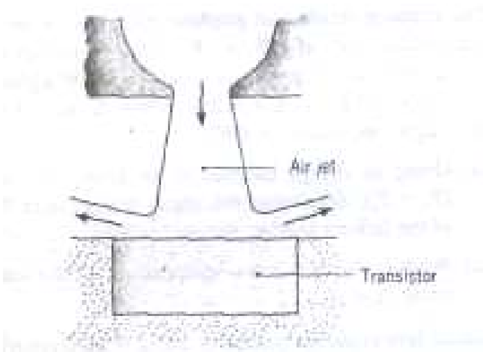
74. The interface temperature of an electronic assembly dissipating 10 W must be limited to 40 ^{o}C in a 50 ^{o}C environment. It is assumed that all of the generated heat will be removed by thermoelectrics and that heat absorbed from the environment is negligible. The interface temperature difference between the assembly and the thermoelectric can be held to 2 ^{o}C. The temperature difference between the thermoelectric and ambient can be held to 8 ^{o}C.
The bismuth telluride element used has a length of 0.3 cm and a cross-area of 0.01 cm^2.

Determine the size and performance characteristics of the thermoelectric temperature control device.
Knowing that

- The equivalent material properties of the thermoelectric couples is
  ρ_e = 0.00267 Ω.cm
  α_e = 425 x 10^{-6} V/K
  k_e= 0.00785 W/cm.K
- Design for maximum refrigeration capacity.

Impinging Jets Problems

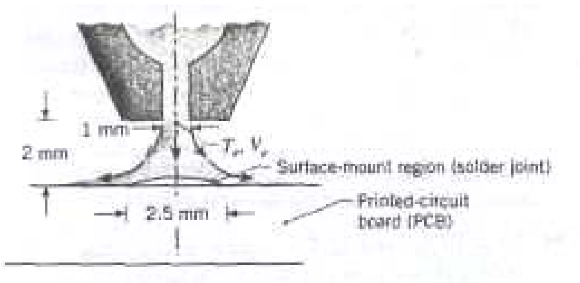
75. A circular transistor of 10 mm diameter is cooled by impingement of an air jet exiting a 2- mm diameter round nozzle with a velocity of 20 m/s and a temperature of 15 °C. The jet exit and the exposed surface of the transistor are separated by a distance of 10 mm. If the transistor is well insulated at all but its exposed surface and the surface temperature is not to exceed 85 ^{o}C, what is the transistor's maximum allowable operating power?



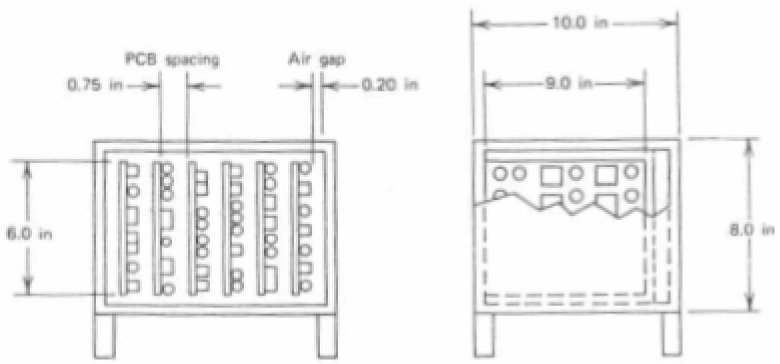
76. You have been asked to determine the feasibility of using an impinging jet in a soldering operation for electronic assemblies. The schematic illustrates the use of a single, round nozzle to direct high velocity, hot air to a location where a surface mount joint is to be

formed.
For your study, consider a round nozzle with a diameter of 1 mm located a distance of 2 mm from the region of the surface mount, which has a diameter of 2.5 mm.

(c) For an air jet velocity of 70m/s and a temperature of 400 °C, estimate the average convection coefficient over the area of the surface mount.
(d) For three air jet temperatures of 400, 500, and 600 ^oC, calculate and plot the surface temperature as a function of time for $0 \leq t \leq 40$ s. On this plot, identify important temperature limits for the soldering process: the lower limit corresponding to the solder's eutectic temperature, T_{sol} = 183 °C and the upper limit corresponding to the glass transition temperature, T_{gl} = 250 ^oC, at which the PCB becomes plastic. Comment on the outcome of your study, the appropriateness of the assumptions, and the feasibility of using the jet for a soldering application.

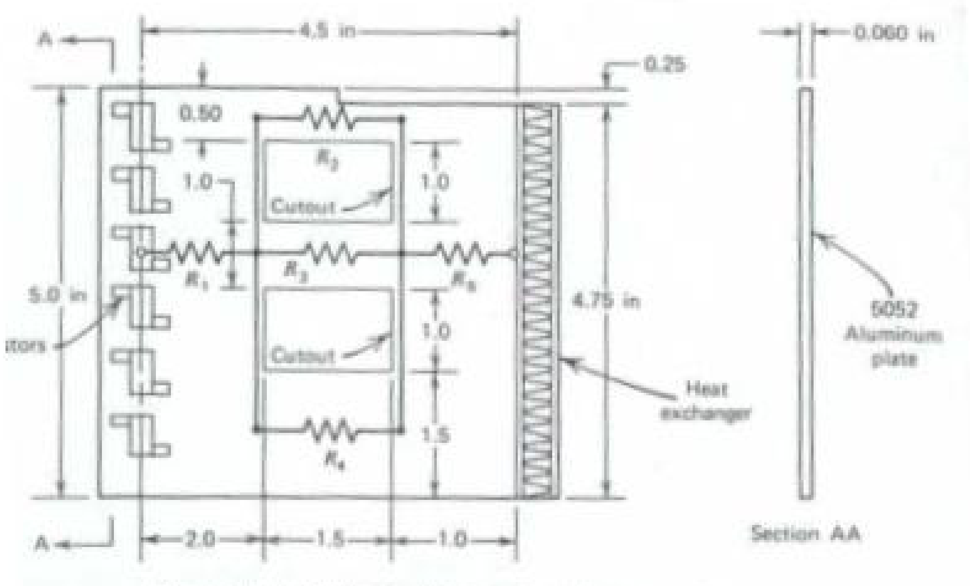


Packaging of Electronic Equipments
Surface Mount Problems
77. An electronic chassis was designed for natural convection cooling, so that a clearance of 0.75 in (1.905 cm) was provided between the PCBs and components. However, a design change required the addition of another PCB, which might reduce the clearance too much unless the new PCB is placed very close to the side wall of the chassis, with a clearance of only 0.20 in (0.51 cm). The PCB measures 6 x 9 in and dissipates 5.5 watts. The electronic chassis must operate at sea level conditions in a maximum ambient temperature of 110 °F (43.3 °C). The maximum allowable component surface temperature is 212 °F (100 °C) with the chassis shown in Figure below. The aluminum chassis has a polished finish that has a low emissivity, so that the heat lost by radiation is small. The PCB construction only allows heat to be removed from the component mounting face. Determine if the design is adequate.



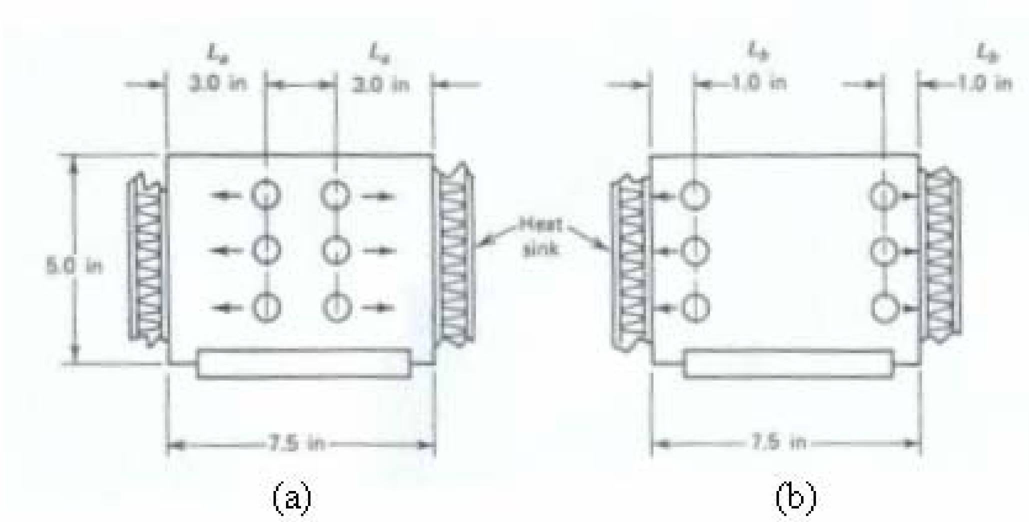
PCB spaced close to an end bulkhead

78. An aluminum (5052) plate is used to support a row of six power resistors. Each resistor dissipates 3 watts, for a total power dissipation of 18 watts. The bulkhead conducts the heat to the opposite wall of the chassis, which is cooled by a multiple fin heat exchanger. The bulkhead has two cutouts for connectors to pass through, as shown in figure below. Determine the temperature rise across the length of the bulkhead.



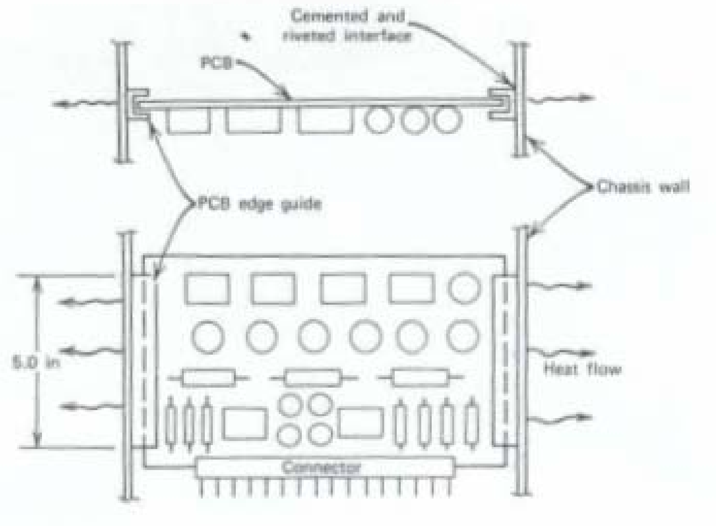
Bulkheads with two cutouts for connectors

79. Several power transistors, which dissipate 7 watts each, are mounted on a power supply circuit board that has a 0.093 in thick 5052 aluminum heat sink plate, as shown in Figure below. Determine how much lower the case temperatures will be when these components are mounted close to the edge of the PCB (new design), instead of the center of the PCB (old design).



Power transistors mounted on an aluminum heat sink plate. (a) Old design (b) new design

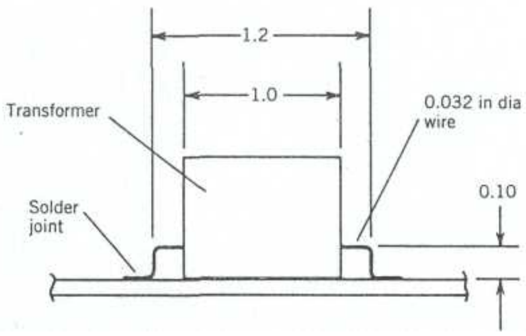
80. Determine the temperature rise across the PCB edge guide (from the edge of the PCB to the chassis wall) for the assembly shown in figure below. The edge guide is 5.0 in long, type d. The total power dissipation of the PCB is 8 watts, uniformly distributed, and the equipment must operate at 100,000 ft.



Plug-in PCB assembly with board edge guides

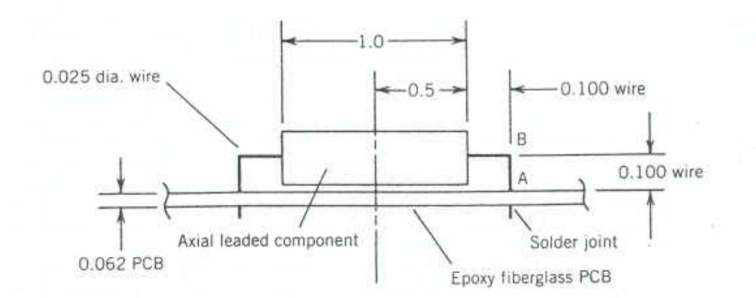
Electronics Cooling Problems

81. Determine the deflections and thermal stresses expected in the lead wires and solder joints of the surface mounted transformer shown in the following figure, when it is mounted on an aluminum composite PCB which experiences in plane (X and Y) thermal expansion during rapid temperature cycling tests over a temperature range from -30 to +80 °C, with no electrical operation. (Note: All dimensions in inches)
Assuming that:
$a_T = 35 \times 10^{-6}$ in/in/°C (average TCE of transformer)
$a_P = 20 \times 10^{-6}$ in/in/°C (average TCE of composite PCB)
$E_W = 16 \times 10^{6}$ psi (modulus of elasticity, copper wire)

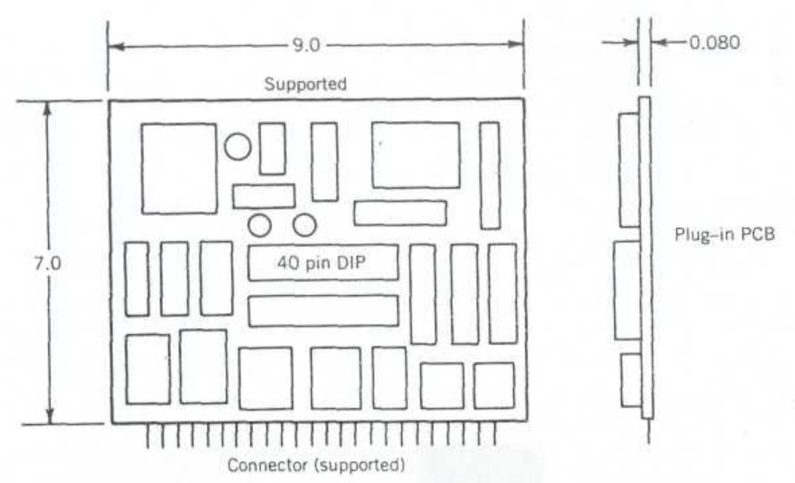


82. Determine the axial force in the lead wire for the resistor shown in figure below, when bending of the PCB is included in the analysis over a temperature cycling range from -50 to +90 °C, which produce total horizontal displacement expected at the top of the wire will be 0.0003 in. (Note: All dimensions in inches)

Assuming that:
$E_W = 16 \times 10^6$ Ib/in^2 (copper wire modulus elasticity)
$E_P = 1.95 \times 10^6$ Ib/in^2 (PCB modulus of elasticity)



83. Determine the resonant frequency of a rectangular plug-in epoxy fiberglass PCB simply supported (or hinged) on all four sides, 0.080 in thick, with a total weight of 1.0 pounds, as shown in figure. (Note: All dimensions in inches)
Assuming that:
$E = 2 \times 10^6$ Ib/in^2 (PCB modulus of elasticity)
$\mu = 0.12$ (Poisson's ratio, dimensionless)



84. A 40 pin DIP (Dual inline package, electronic equipment) with standard lead wires, 2.5 in length will be installed at the center of a 8.0 x 6.0 x 0.080 in plug-in PCB. The DIP will be mounted parallel to the 9 in edge. The assembly must be capable of passing a 4.0G peak sine vibration qualification test with resonant dwell conditions. Determine the minimum desired PCB resonant frequency for a 10 million cycle fatigue life, and the approximate fatigue life.