Practice Problems on Heat Sink Design

Q1 – A TO-220 package outline device dissipates 4W; the maximum permissible junction temperature is 150°C, and the ambient temperature (T_a) is 50°C. The device datasheet lists the junction-to-case resistance (R_{jc}) as 3°C/W. Select a commercially available heat sink for the given package under natural convection conditions.

Sol. – Given data P_{diss} = 4W

Maximum junction temperature (T_{j_max}) = 150°C

Ambient Temperature (T_a) = 50°C

Junction-to-casing Resistance (R_{jc}) = 3°C/W

We know that

$$(R_{th})_{total} = \frac{\Delta T}{P_{diss}}$$

$$R_{jc} + R_{TIM} + R_{hs} = \frac{T_j - T_a}{P_{diss}}$$

Let us assume that the TIM material used in this case is Silicon grease, and its properties are mentioned in Table 1.

Table 1- Properties of Silicon grease

Material	t (in)	Contact area (in^2)	k (W/m°C)
Silicon grease	0.002	0.36	0.193

Therefore, R_{hs} can be calculated for the given package

$$R_{hs} = \frac{T_j - T_a}{P_{diss}} - R_{jc} - R_{TIM}$$

$$R_{hs} = \frac{150 - 50}{4} - 3 - 1.13$$

$$R_{hs} = 20.87\ °C/W$$

Therefore, a heat sink will be required with a thermal resistance equal to 20.87 °C/W or (T_{hs} - T_a) < 83.48°C.

Using Aavid Thermalloy Product Selection Guide, **Extrusion Heat Sink Profile 60270** is selected for the given package.



Terms and Definitions

60270	The extrusion's 5 digit base part number
in2/in	The perimeter of the cross-sectional profile of the extrusion is also the outside surface area per inch of length. This is used to predict the thermal resistance (θsa) using the performance factor table.
lb/ft	Weight of extrusion per foot.
°C/W/3in	The theoretical thermal resistance (°C/W) for a 3 inch long piece in Natural Convection. This is a calculated number based on the following assumptions: - sink-to-ambient ΔT = 75°C - black anodized finish - single point heat source at the center of the 3 inch section

Source: (https://www.mouser.com/catalog/supplier/library/AavidProductSelectionGuide.pdf)

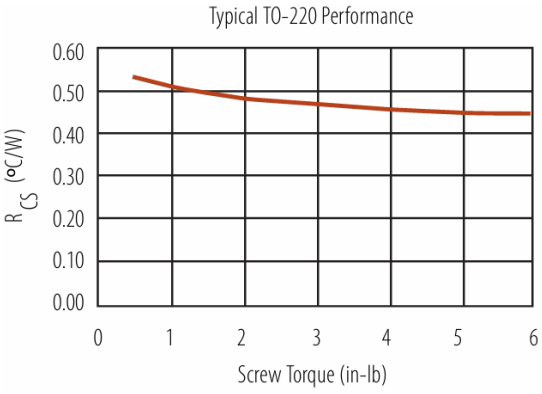
Q2 - Find a space-saving heat sink to keep a TO-220 device below the maximum junction temperature in natural convection. The device will be screw-mounted with an electrically conductive interface. Given that P_{diss} = 6 W, R_{jc} = 3°C/W (from semiconductor manufacturer) T_{jmax} = 150°C (from semiconductor manufacturer) T_a = 65°C.

Sol. – Given that P_{diss} = 6 W

R_{jc} = 3°C/W

T_{jmax} = 150°C

T_a = 65°C.



A Kondux™ pad is a good choice for electrically conductive applications. The thermal resistance of Kondux™ can be determined from the given graph.

At 2 in-lb of torque, the thermal resistance is approximately R_{TIM} = 0.5°C/W

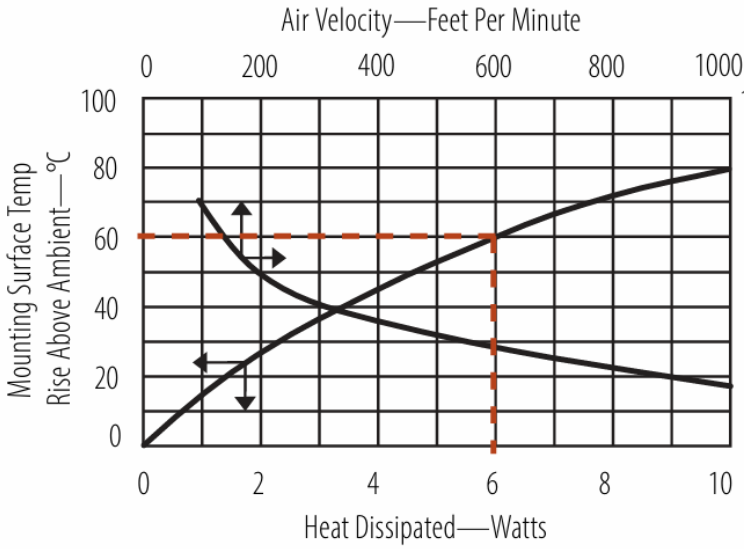
Solving the following equation, we will get the value of R_{hs} -

$$R_{hs} = \frac{T_j - T_a}{P_{diss}} - R_{jc} - R_{TIM}$$

$$R_{hs} = \frac{150 - 65}{6} - 3 - 0.5$$

$$R_{hs} = 10.7\ ^{\circ}C/W$$





Part number **593202B03500G** from the BOYD-Board-Level-Heat-Sink Catalogue shows a 60 °C temperature rise at 6 watts.

$$R_{hs} = \frac{60}{6} = 10^{\circ}C/W$$

which meets the above requirement in natural convection.

Source: (https://info.boydcorp.com/hubfs/Thermal/Air-Cooling/Boyd-Board-Level-Heatsinks Catalog.pdf)

Q3 - Find a heat sink to keep a TO-220 device below the maximum 150°C junction temperature in forced convection at 400 ft/min. The device must be electrically insulated and mounted with a labour-saving clip. Given: P_{diss} = 12 W, R_{jc} = 2.5°C/W (from semiconductor manufacturer), $T_{j,max}$ = 140°C (from semiconductor manufacturer) T_a = 50°C.

Sol. - Given that P_{diss} = 12 W

R_{jc} = 2.5°C/W

T_{jmax} = 140°C

T_a = 50°C.

A Hi-Flow® pad works great with clip mounting and provides the necessary electrical insulation. Thermal resistance for Hi-Flow® at low pressure is 1.15°C/W.

Solving the following equation for R_{hs}, we get

$$R_{hs} = \frac{T_j - T_a}{P_{diss}} - R_{jc} - R_{TIM}$$

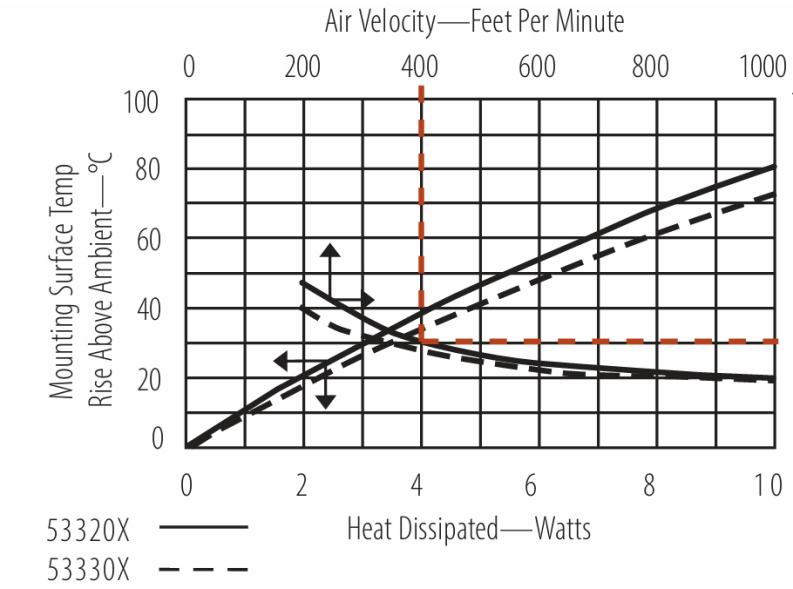
$$R_{hs} = \frac{140 - 50}{12} - 2.5 - 1.15$$

$$R_{hs} = 10.7\ ^{\circ}C/W$$

Out of all the commercially available heat sinks, 533202B02551G meets the requirements.



Extruded Heat sink with radial fins (533202B02551G)



According to the above graph, an airflow of 400 ft/min results in a thermal resistance of 3°C/W. This is less than the required thermal resistance of 3.85°C/W and is therefore acceptable under these airflow conditions.

Source: (https://info.boydcorp.com/hubfs/Thermal/Air-Cooling/Boyd-Board-Level-Heatsinks Catalog.pdf)

Q4 – A rectifier assembly carries a forward current of 10A, with a duty cycle of 1. The maximum permissible junction temperature and ambient temperature are given as 125°C and 20°C, respectively. In the present setup, a TIM with a thermal conductivity of 1.6 W/m k is attached to the rectifier with a clamping force of 34 N/cm^2. Also, the junction-to-casing resistance is mentioned as 0.5 °C/W in the rectifier's datasheet. Select a suitable heat sink to maintain the operating temperature of the rectifier below 80% of the maximum junction temperature under forced convection conditions.

Sol. – Given that forward current (I) = 10A, duty cycle = 1

Step 1: Estimation of power dissipated by the rectifier circuit.

The power dissipation can be estimated by the available graph of Power dissipation Vs forward current and ambient temperature per diode, as shown below –

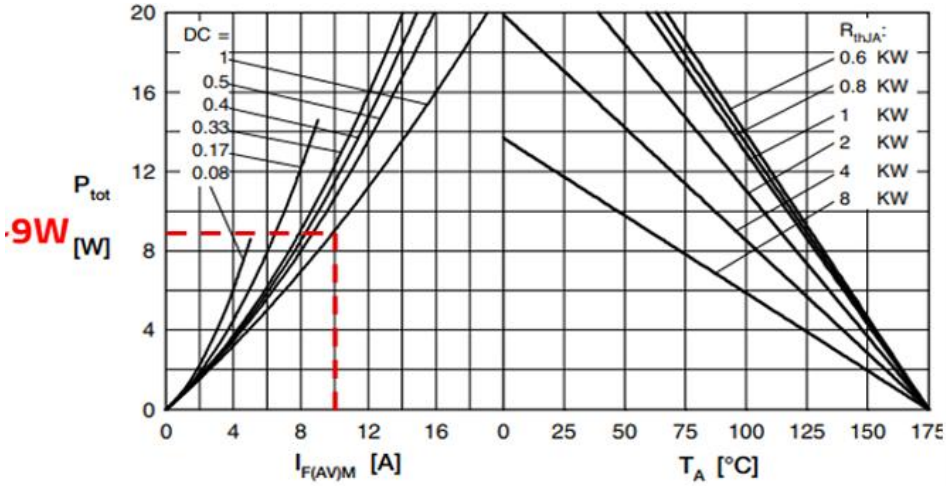
Therefore,

$P_{diss} = 9W$

Operating temperature of rectifier

$T_{op.} = 0.8T_{j,\,max}$

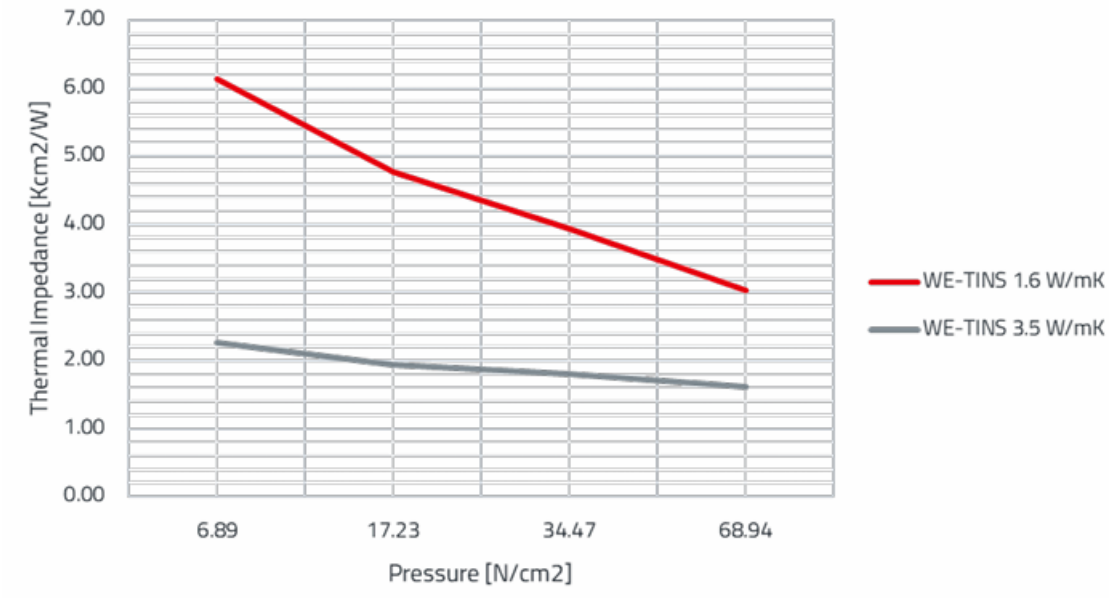
$T_{op.} = 100°C$



Power dissipation vs. forward current and ambient temperature per diode

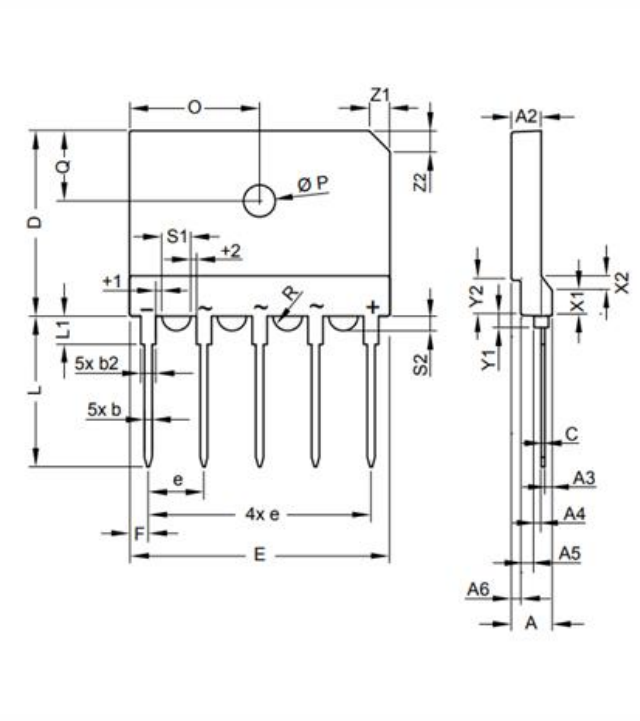
Step 2: Estimation of Thermal resistance of TIM

The thermal resistance of the TIM can be determined using the thermal impedance versus clamping pressure graph. The graph provides the thermal impedance at the desired clamping pressure. The thermal resistance can then be calculated by dividing the thermal impedance by the contact surface area of the TIM.



For the given condition, TIM (k = 1.6W/m k) is used with a clamping pressure of 34 N/cm^2. From the graph, the thermal impedance comes out to be 3.94 k cm^2/W

The dimensions of the rectifier are shown in the picture below, and the surface area of the TIM can be calculated using the given details.



Dim.	Millimeter			Inches		
	min	typ.	max	min	typ.	max
A	5.40	5.50	5.60	0.213	0.217	0.221
A2	3.90	4.00	4.10	0.154	0.158	0.162
A3	0.95	1.00	1.10	0.037	0.039	0.043
A4	0.95	1.00	1.05	0.037	0.039	0.041
A5	1.60	1.70	1.80	0.063	0.067	0.071
A6	1.25	1.30	1.35	0.049	0.051	0.053
b	0.95	1.00	1.05	0.037	0.039	0.041
b2	1.95	2.00	2.05	0.077	0.079	0.081
C	0.45	0.50	0.55	0.018	0.020	0.022
D	24.80	25.00	25.20	0.977	0.985	0.993
E	34.70	35.00	35.30	1.367	1.379	1.391
e	BSC 7.50			BSC 0.296		
F	2.40	2.50	2.60	0.095	0.099	0.102
L	20.30	20.40	20.50	0.800	0.804	0.808
L1	3.70	3.75	3.80	0.146	0.148	0.150
O	17.40	17.50	17.60	0.686	0.690	0.693
ØP	4.10	4.20	4.30	0.162	0.165	0.169
Q	9.20	9.30	9.40	0.362	0.366	0.370
⌀/₂R		1.77			0.070	
s1	3.45	3.50	3.55	0.136	0.138	0.140
s2	1.45	1.50	1.55	0.057	0.059	0.061
t1	0.95	1.00	1.05	0.037	0.039	0.041
t2	0.95	1.00	1.05	0.037	0.039	0.041
x1	3.20	3.30	3.40	0.126	0.130	0.134
x2	1.90	2.00	2.10	0.075	0.079	0.083
y1	1.60	1.65	1.70	0.063	0.065	0.067
y2	4.65	4.70	4.75	0.183	0.185	0.187
z1	2.80	2.90	3.00	0.110	0.114	0.118

Surface area of TIM = 6.97 cm^2

$$R_{TIM} = \frac{3.94}{6.97}$$

R_{TIM} = 0.57 °C/W

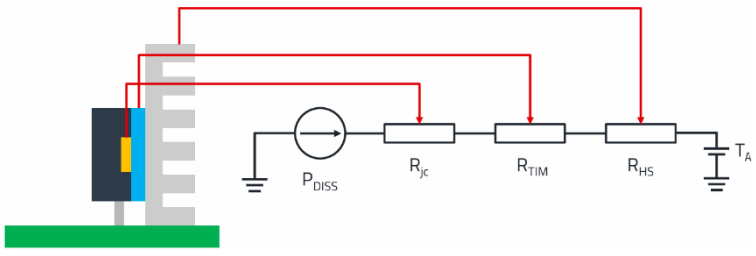
Step3: Calculation of the required thermal resistance of the heat sink

Using the equation given below, the heat sink thermal resistance can be estimated for the rectifier circuit.

$$R_{hs} = \frac{T_{op.} - T_a}{P_{diss}} - R_{jc} - R_{TIM}$$

$$R_{hs} = \frac{100 - 20}{9} - 0.5 - 0.57$$

$$R_{hs} = 7.81\ °C/W$$

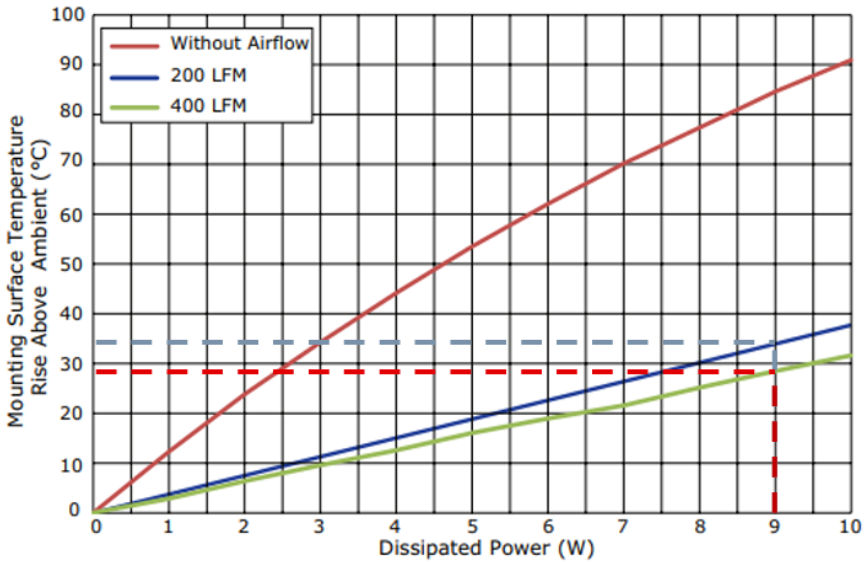


Step4: Selection of Heat Sink

The required heat sink thermal resistance is 7.81°C/W. Corresponding to this, the mounting surface temperature above ambient should be less than 70.23°C.

So, from the available graph for the heat sink, we can find the suitable flow rate conditions for heat sink.

For 200 LFM 34°C
For 400 LFM 29°C



Both 200 and 400 LFM result in temperature rises below the allowable limit at 9 W; therefore, 200 LFM was selected.

Heat sink manufacturers measure performance by forcing air through the fins, so it is a good habit to add a 20- 30% safety margin.

$$R_{hs} = \frac{Rise\ above\ T_a}{P_{diss}} \times 1.25$$

$$R_{hs} = \frac{34}{9} \times 1.25$$

$$R_{hs} = 4.7\ ℃/W$$

Hence, this heat sink will keep the operating temperature of the rectifier below 100°C.

Q5 - A TO-220 package outline device dissipates 7W; the maximum permissible junction temperature is 110°C, and the ambient temperature (T_a) is 40°C. The device datasheet lists the junction-to-case resistance (R_{jc}) as 5°C/W. Select a commercially available heat sink (**from Aavid Product Selection guide**) for the given package under natural convection conditions, using Silicon grease as the interface material.

Q6 - Consider a 40 mm × 40 mm × 2 mm electronic package that dissipates 5 W. The manufacturer's data sheet shows that the junction-to-case thermal resistance is R_{jc} = 5°C/W, but no information is given for the case-to-air thermal resistance, R_{ca}. Air at a velocity of 2 m/s and a temperature of 25°C is blowing over the package.

a) Calculate the case-to-air thermal resistance of the package.

b) What is the junction temperature of the package if all the power is dissipated through the case of the package?
c) If the junction temperature is not to exceed 105°C, determine the maximum thermal resistance of a heat sink that has to be placed on this package.

Use the air properties at 25°C in all your calculations.

Q7 – A power transistor dissipates 12 W in an industrial power supply. Its maximum junction temperature is 130°C, and the local ambient temperature is 50°C with an air velocity of 250 ft/min. It is given that the junction-to-case resistance is 4.5°C /W. Select a compatible heat sink from the **Wakefield-Vette catalogue** along with a suitable interface material. Also, calculate the actual junction temperature of the transistor corresponding to the selected heat sink.

Q8 - A straight fin heat sink has to be designed with thermal resistance of $R_{hs} = 3°C/W$ at 1.5 m/s air velocity. The heat sink is made of aluminium with thermal conductivity of 230 W/m °C; its base is 50 mm × 50 mm, and fins are 20 mm long and 2 mm thick. How many fins are required for this heat sink? Assume total heat sink efficiency is equal to the fin efficiency and check this assumption at the end. Use air properties at 25°C in all the calculations.

Q9 – A MOSFET in a TO-247 package has power dissipation of 20W during continuous operation. The maximum junction temperature is 120°C, and the local ambient temperature is 25°C. From the manufacturer's datasheet, the junction-to-case resistance is 0.9°C/W, with interface resistance equivalent to 0.3°C/W. The maximum available space for the heat sink is 50 x 40 x 30 mm under natural convection conditions. Identify a suitable commercially available heat sink to maintain the junction temperature 15°C below the maximum junction temperature. Determine whether any catalogue heat sink satisfies all thermal and dimensional requirements.

Q10 – A power transistor has a 10W rating during normal operation and 16 W during peak operating conditions. The maximum allowable junction temperature is 150°C, with a 2°C/W junction-to-casing resistance. The local ambient temperature is maintained at 55°C, and the transistor operates under forced convection, with a maximum available airflow of 300 ft/min. Select a commercial heat sink and determine the junction temperature under both operating conditions. Check the manufacturer's thermal performance data at the available airflow and explain whether the design meets the temperature limit in both cases.

Q11 - Find a space-saving heat sink to keep a TO-220 device below the maximum junction temperature in natural convection. The device will be screw-mounted with an electrically conductive interface, with a tightening torque of 3.5 in-lb. Given that $P_{diss} = 20W$, $R_{jc} = 3°C/W$ (from the semiconductor manufacturer), $T_{jmax} = 130$ °C (from the semiconductor manufacturer), and $T_a = 40°C$.