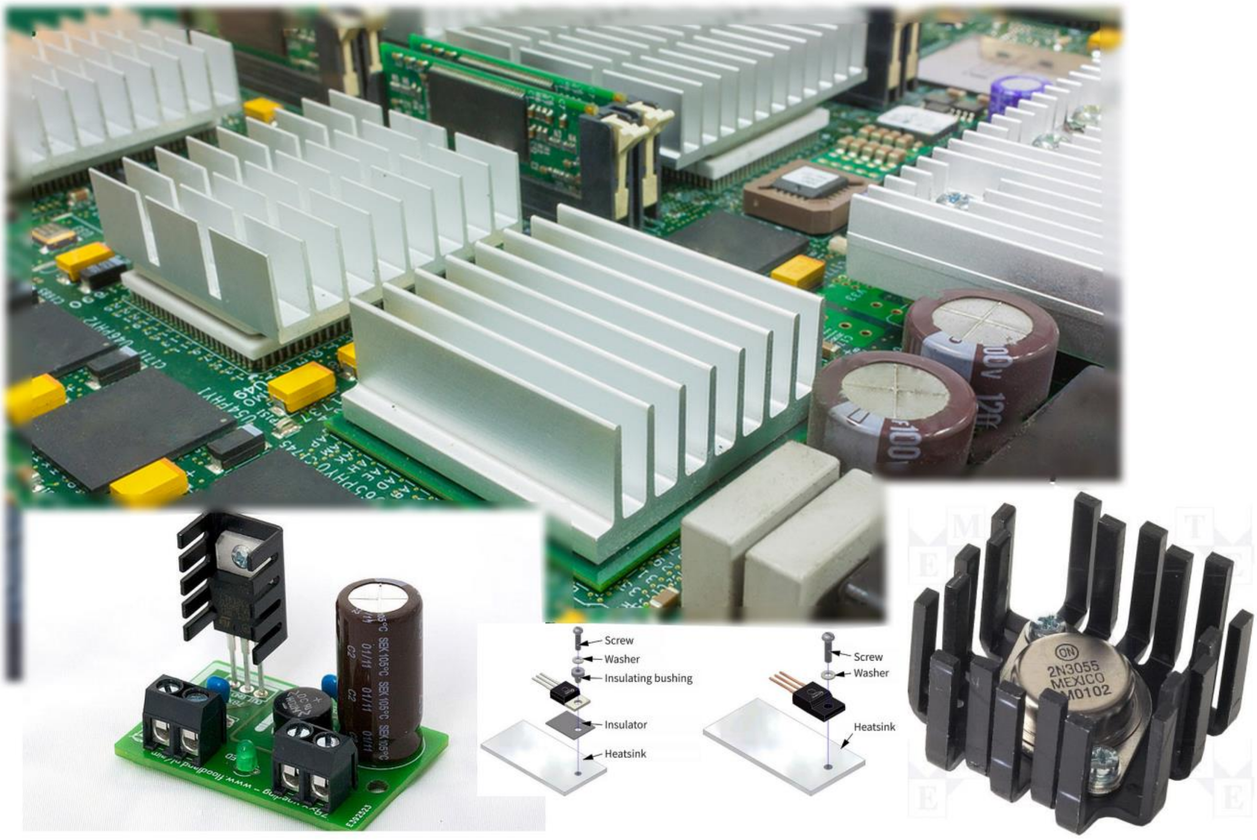


UEE30920 Certificate III in Electronics and Communications

UEEEC0028

FAULT FIND AND REPAIR COMPLEX POWER SUPPLIES

Heatsinks

Heat sinks are common thermal management systems used in electronics to transport heat energy from the circuit to the ambient and away from electronic devices (eg. BJTs, MOSFETs, linear regulators, etc.) using heat transfer methods such as conduction, convection, radiation, or a combination of them.

Heat Transfer

Radiation:

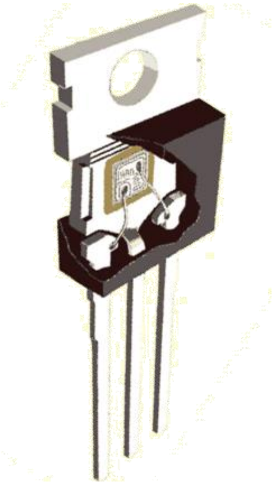
as the name suggests, means that the heat is simply radiated away from the object, through electromagnetic radiation. How well an object can radiate heat depends on the material and the colour (black is best).

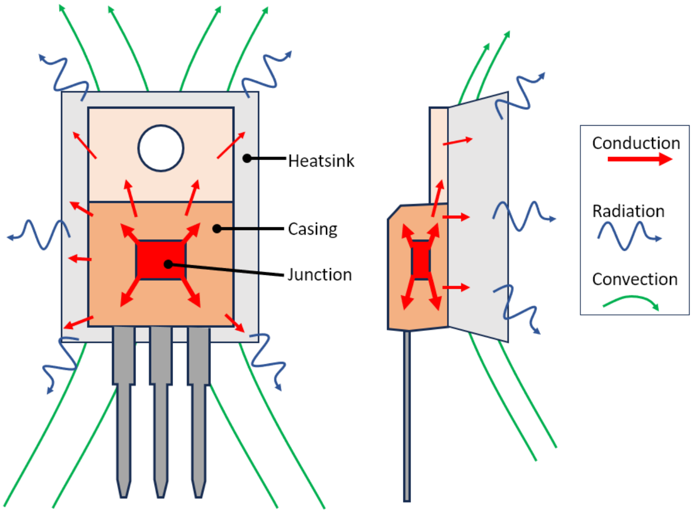
Conduction:

is the exchange of kinetic energy between molecules. Since direct contact is required, a heatsink (surrounded by air) cannot get rid of heat using conduction. However, conduction is the effect that's responsible for the heat transfer from the CPU to the heatsink.

Convection:

is heat transfer by movement of a heated substance. If the gas or liquid around the object is forced into movement (e.g. by a fan blowing air across a heatsink), then we're dealing with forced convection.





The general theory behind a heat sink is to increase the surface area of the heat-producing device, enabling a more efficient transfer of heat into the ambient environment. This improved thermal pathway reduces the temperature rise in the junction of the electronic device.

The maximum allowable junction temperature (T_{JMAX}) is one of the key factors that limit the power dissipation capability of a device. T_{JMAX} is defined by the manufacturer and usually depends on the reliability of the die used in the manufacturing process.
The power dissipated inside the semiconductor junction creates heat which flows from the hottest part of the transistor (the junction) through a lower part (the casing) and then to the lowest part (the ambient air).

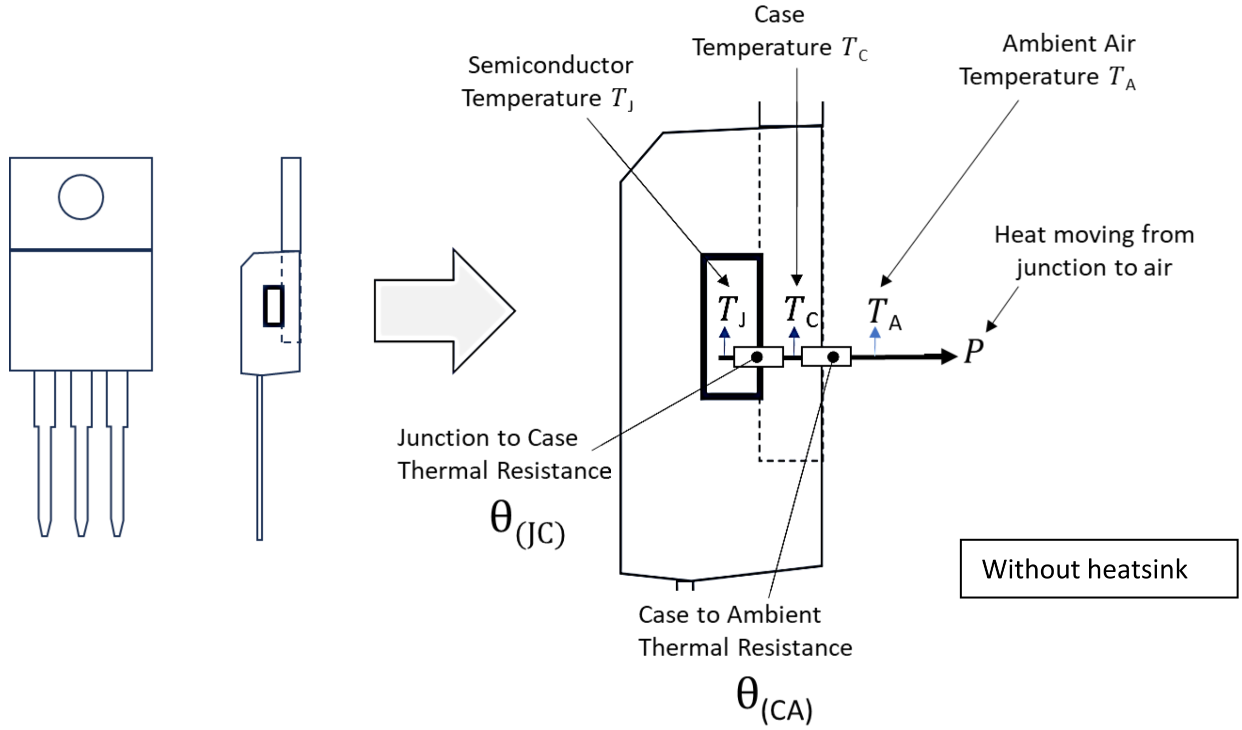
Without a Heatsink

Without a heatsink, this heat energy must pass through a couple of layers.

1. the junction to case
2. the case to air

These layers will restrict the heat flow and so they are called “thermal resistance”.

- The thermal resistance inside the device package, between the junction and its outside case, called $\theta_{(JC)}$.
- The thermal resistance between the case and the ambient is called θ(CA).



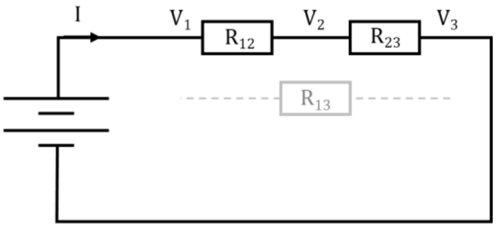
Thermal Analysis

Fortunately, we can analyse these thermal circuits with an equivalent of Ohm’s Law.

- power dissipation is analogous to current
- θ is analogous to electrical resistance
- voltage is analogous to temperature.

Electrical Domain	symbol	unit
Voltage	V	V
Current	I	A
Resistance	R	Ω

Thermal Domain	symbol	unit
Temperature	T	^0C
Heat flow (Watts)	P	W
Thermal Resistance	θ_{xy}	$^0C/W$

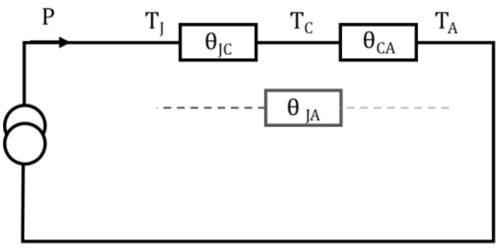


$$R_{Total} = R_{13} = R_{12} + R_{23}$$

$$I = \frac{V_1 - V_3}{R_{13}}$$

$$I = \frac{V_1 - V_2}{R_{12}} \qquad I = \frac{V_2 - V_3}{R_{23}}$$

Electrical analogy



$$\theta_{Total} = \theta_{JA} = \theta_{JC} + \theta_{CA}$$

$$P = \frac{T_J - T_A}{\theta_{JA}}$$

$$P = \frac{T_J - T_C}{\theta_{JC}} \qquad P = \frac{T_C - T_A}{\theta_{CA}}$$

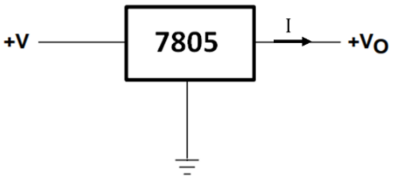
Thermal analogy

- Without heatsink

Where;
T_J = Junction Temperature
T_C = Case Temperature
T_A = Ambient Temperature
θ_{JC} = Junction/Case Thermal Resistance
θ_{CA} = Case/Ambient Thermal Resistance
θ_{JA} = Junction /Ambient Thermal Resistance
P = Power dissipated in semiconductor

Example.

A L7805C voltage regulator has V_{in} = 8V and V_{out} = 5V and supplying 0.6 Amp to a load at an ambient temperature of 25 ^{0}C. Junction to air thermal resistance = θJA = 50 ^{0}C/W & θJC = 5 ^{0}C/W.



Calculate:

1. the junction temperature
2. the case temperature
3. maximum power allowed

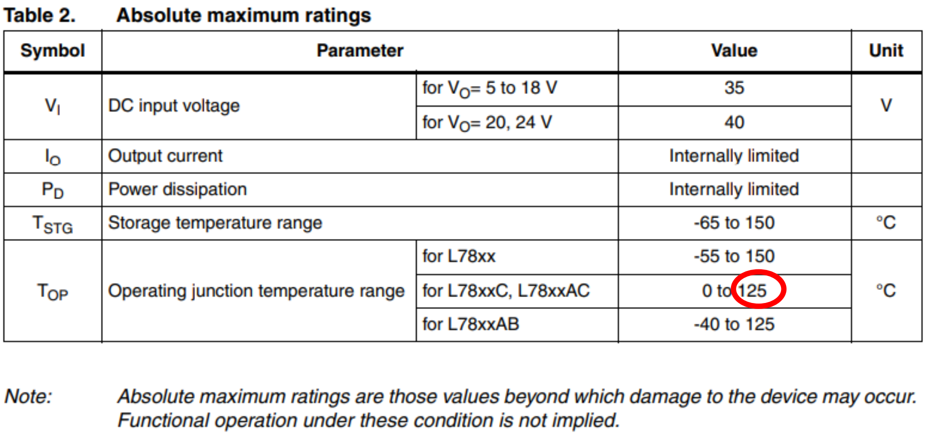


Table 2. Absolute maximum ratings

Symbol	Parameter		Value	Unit
V_I	DC input voltage	for V_O= 5 to 18 V	35	V
		for V_O= 20, 24 V	40	
I_O	Output current		Internally limited	
P_D	Power dissipation		Internally limited	
T_{STG}	Storage temperature range		-65 to 150	°C
T_{OP}	Operating junction temperature range	for L78xx	-55 to 150	°C
		for L78xxC, L78xxAC	0 to 125	
		for L78xxAB	-40 to 125	

Note: *Absolute maximum ratings are those values beyond which damage to the device may occur. Functional operation under these condition is not implied.*

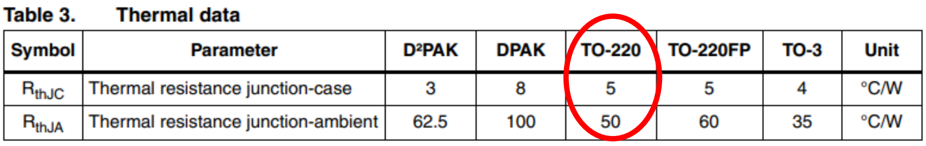


Table 3. Thermal data

Symbol	Parameter	D²PAK	DPAK	TO-220	TO-220FP	TO-3	Unit
R_{thJC}	Thermal resistance junction-case	3	8	5	5	4	°C/W
R_{thJA}	Thermal resistance junction-ambient	62.5	100	50	60	35	°C/W

Answer:

The power dissipated in the regulator = V I = (8-5) x 0.6 = 1.8W.

1. Junction Temperature:

$$P_D = \frac{(T_J - T_A)}{\theta_{JA}} \text{ » } T_J = P_D\theta_{JA} + T_A = (1.8 \text{ x } 50) + 25 = 115\ ^{O}\text{C which is just less than } T_{(JMAX)} \text{ of } 125\ ^{O}\text{C.}$$

2. ***Case Temperature:*** $(\theta_{CA} = \theta_{JA} - \theta_{JC})$

$$P_D = \frac{(T_J - T_C)}{\theta_{JC}} \text{ » } T_C = T_J - P_D\theta_{JC} = 115 - (1.8 \text{ x } 5) = 106\ ^{O}C \quad \text{OR}$$

$$P_D = \frac{(T_C - T_A)}{\theta_{CA}} \text{ » } T_C = P_D\theta_{JC} + T_A = (1.8 \text{ x } 45) + 25 = 106\ ^{O}C$$

3. ***Maximum power allowed.***

$$P_{D(max)} = \frac{(T_{J(max)} - T_A)}{\theta_{JA}} = \frac{(125-25)}{50} = 2 \text{ W which is higher than 1.8W required here.}$$

If the junction temperature became too hot, there are 4 things that can be done:

1) Use a larger rated regulator.
2) Derate the existing regulator.
3) Add a fan
4) Add a heatsink.

1) Use a larger rated regulator.
The L7805 in a TO-3 package will make the junction temperature cooler.

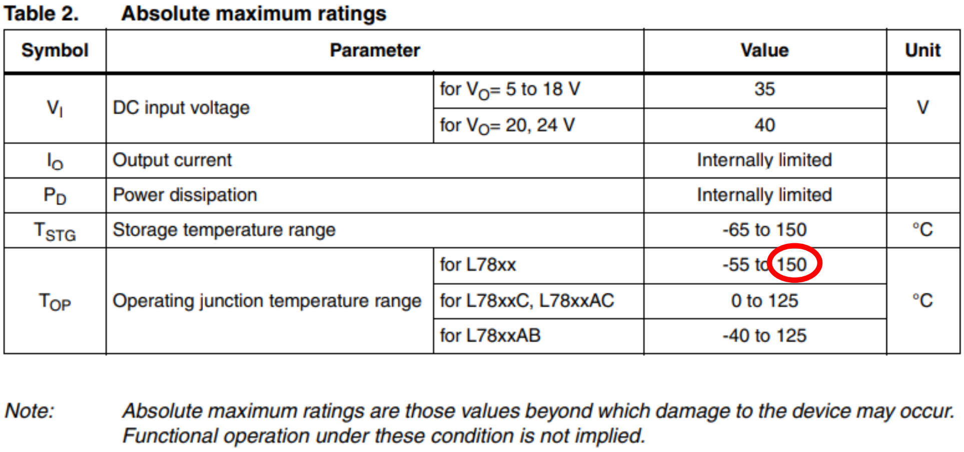


Table 2. Absolute maximum ratings

Symbol	Parameter		Value	Unit
V_I	DC input voltage	for V_O= 5 to 18 V	35	V
		for V_O= 20, 24 V	40	
I_O	Output current		Internally limited	
P_D	Power dissipation		Internally limited	
T_{STG}	Storage temperature range		-65 to 150	°C
T_{OP}	Operating junction temperature range	for L78xx	-55 to 150	°C
		for L78xxC, L78xxAC	0 to 125	
		for L78xxAB	-40 to 125	

Note: *Absolute maximum ratings are those values beyond which damage to the device may occur. Functional operation under these condition is not implied.*

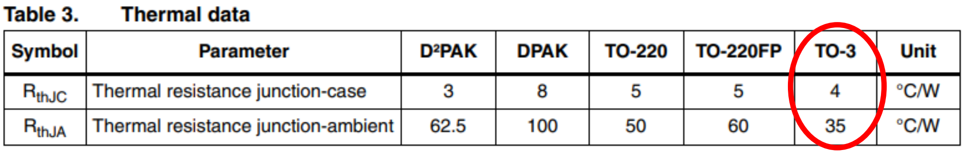
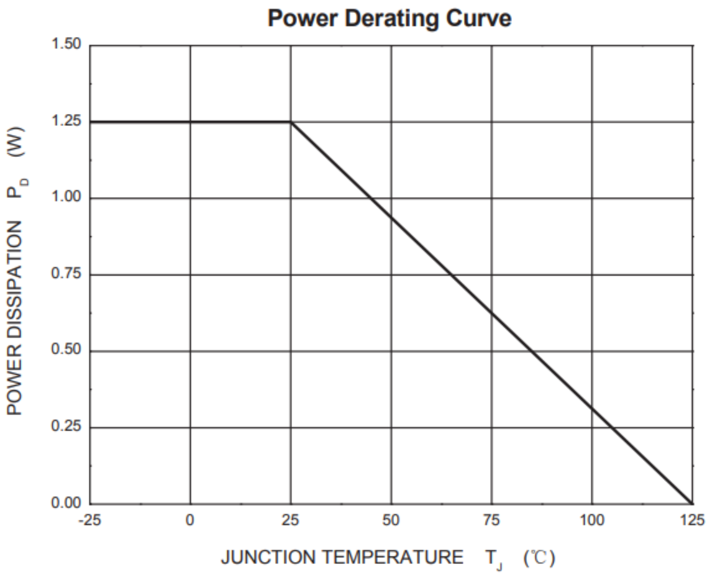


Table 3. Thermal data

Symbol	Parameter	D²PAK	DPAK	TO-220	TO-220FP	TO-3	Unit
R_{thJC}	Thermal resistance junction-case	3	8	5	5	4	°C/W
R_{thJA}	Thermal resistance junction-ambient	62.5	100	50	60	35	°C/W

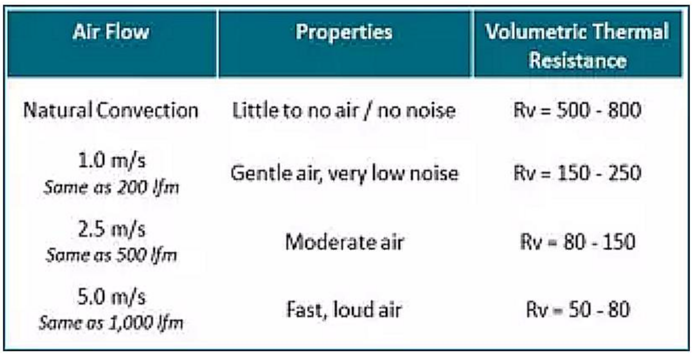
2) Derate the regulator.

If the power output is lowered, then the junction temperature will be cooler.
This will, of course, have repercussions on the circuit design and load.



3) Add a fan.
If heat can be taken from the case, then the temperature of the case would go down. This increased convection will cool the device more than natural air flow. This is usually reserved for larger output wattages bolted to heatsinks, but the theory still applies.
Here are some rough guidelines:

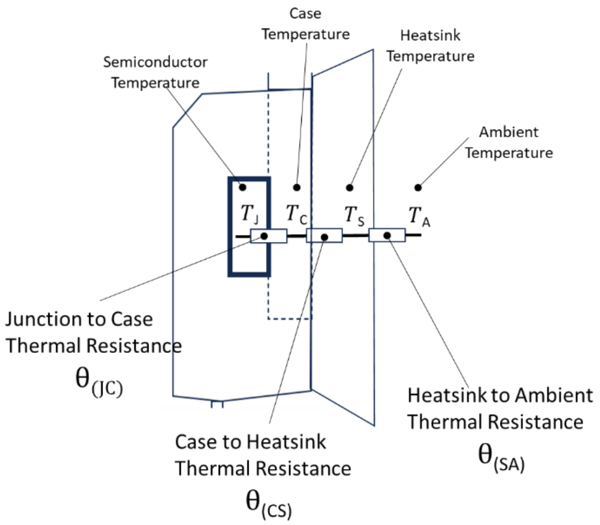
a) Open air natural convection develops about 40 LFM which is about just enough to blow out a match.
b) 1 m/s or 200 LFM you can feel the flow but not hear it.
c) 2.5 m/s or 500 LFM is a good flow that will blow out a whole bunch of candles and you can begin to hear the noise, especially in a quiet environment.
d) 5 m/s or 1000 LFM is going to be noisy. Not to be used in any noise-sensitive environment.

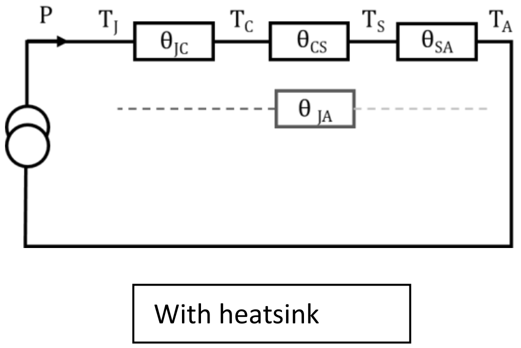


Air Flow	Properties	Volumetric Thermal Resistance
Natural Convection	Little to no air / no noise	Rv = 500 - 800
1.0 m/s *Same as 200 lfm*	Gentle air, very low noise	Rv = 150 - 250
2.5 m/s *Same as 500 lfm*	Moderate air	Rv = 80 - 150
5.0 m/s *Same as 1,000 lfm*	Fast, loud air	Rv = 50 - 80

https://www.macro.sk/katalog/datasheets/Aavidselectionguide.pdf

4) Add a heatsink.





Where;
T_J = Junction Temperature
T_C = Case Temperature
T_A = Ambient Temperature
θ_{JC} = Junction/Case Thermal Resistance
θ_{CS} = Case/Heatsink Thermal Resistance
θ_{SA} = Heatsink /Ambient Thermal Resistance
θ_{JA} = Junction /Ambient Thermal Resistance
P = Power dissipated in semiconductor

$$\theta_{Total} = \theta_{JA} = \theta_{JC} + \theta_{CS}\,\theta_{SA}$$

$$P = \frac{T_J - T_A}{\theta_{JA}}$$

$$P = \frac{T_J - T_C}{\theta_{JC}} \qquad P = \frac{T_C - T_S}{\theta_{CS}} \qquad P = \frac{T_S - T_A}{\theta_{SA}}$$

We have used θ_{JA} up to now as we were depending on the package for a complete thermal system from junction to ambient.

Adding a heatsink achieves a system θ junction to ambient low enough to meet the system thermal requirements. A heatsink accomplishes this by offering a better thermal interface to air versus the package alone. Thus, we require the following to be met:

$$\theta_{JA(max)} \geq \theta_{JC} + \theta_{CS} + \theta_{SA}$$

$$\theta_{SA} \leq \theta_{JA(max)} - \theta_{JC} - \theta_{CS}$$

$$\theta_{SA} \leq [(T_J - T_A)/P_{D(max)}] - \theta_{JC} - \theta_{CS}$$

With the heatsink in place, the heat now must further flow from the

1. case to the heatsink and then
2. from the heatsink to the air.

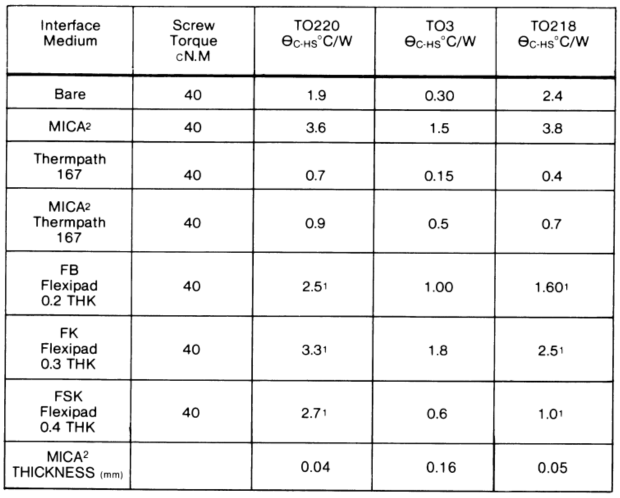
θ_{CS} Case to Heatsink

The thermal impedance required is “case-to-sink” denoted by the symbol θ_{CS}. This is a measure of how easily heat can be transferred from the surface (case) of the device to the surface of the heat sink.

Due to irregularities in the surfaces of the case packages and heat sink base, it is generally recommended to use a Thermal Interface Material (TIM or “thermal compound”) between the two surfaces to ensure that they are fully engaged from a thermal perspective.

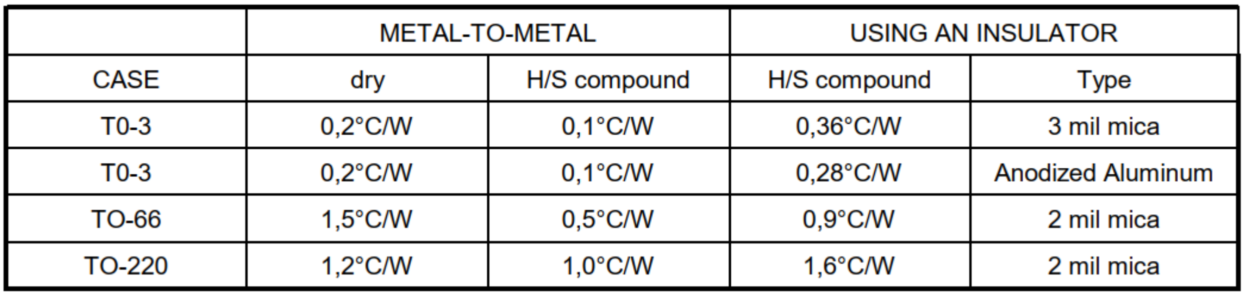
This greatly improves the transfer of heat from the case package to the heat sink but does have a thermal impedance associated with it that must be taken into account.

The value of θ_{CS} depends upon the mounting method between the semiconductor device and the heatsink (ie: the use of thermal grease, mica insulators, flexipads etc).



Interface Medium	Screw Torque cN.M	TO220 $\Theta_{C\text{-}HS}$°C/W	TO3 $\Theta_{C\text{-}HS}$°C/W	TO218 $\Theta_{C\text{-}HS}$°C/W
Bare	40	1.9	0.30	2.4
MICA^2	40	3.6	1.5	3.8
Thermpath 167	40	0.7	0.15	0.4
MICA^2 Thermpath 167	40	0.9	0.5	0.7
FB Flexipad 0.2 THK	40	2.5^1	1.00	1.60^1
FK Flexipad 0.3 THK	40	3.3^1	1.8	2.5^1
FSK Flexipad 0.4 THK	40	2.7^1	0.6	1.0^1
MICA^2 THICKNESS (mm)		0.04	0.16	0.05

Typical insulator thermal resistance (θ_{CS})



	METAL-TO-METAL		USING AN INSULATOR	
CASE	dry	H/S compound	H/S compound	Type
T0-3	0,2°C/W	0,1°C/W	0,36°C/W	3 mil mica
T0-3	0,2°C/W	0,1°C/W	0,28°C/W	Anodized Aluminum
TO-66	1,5°C/W	0,5°C/W	0,9°C/W	2 mil mica
TO-220	1,2°C/W	1,0°C/W	1,6°C/W	2 mil mica

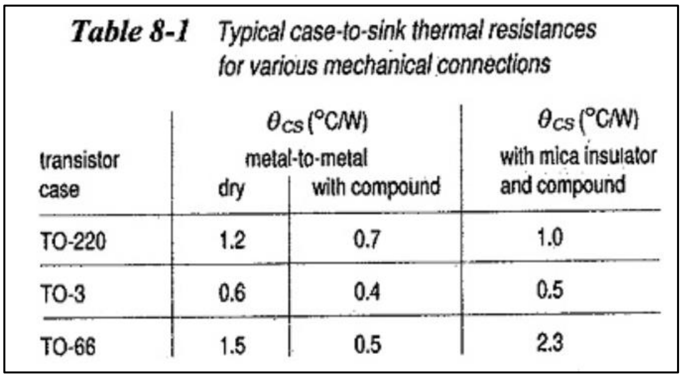


Table 8-1 *Typical case-to-sink thermal resistances for various mechanical connections*

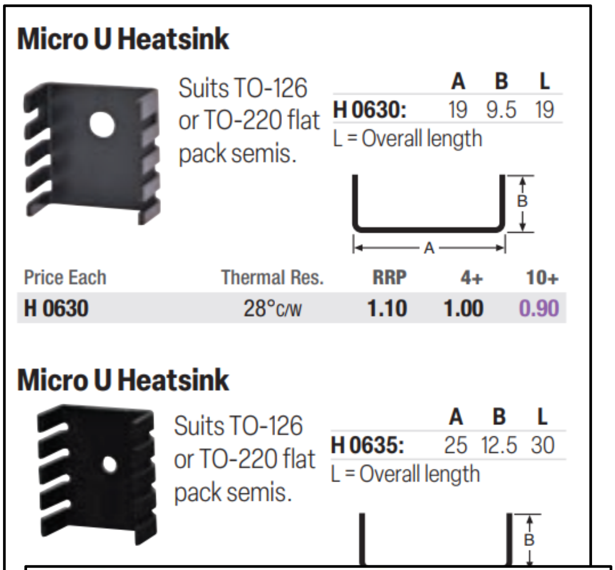
transistor case	θ_{CS} (°C/W) metal-to-metal dry	with compound	θ_{CS} (°C/W) with mica insulator and compound
TO-220	1.2	0.7	1.0
TO-3	0.6	0.4	0.5
TO-66	1.5	0.5	2.3

For a T0-220 package:

If heatsink is mounted directly to the case, then θ_{CS} = 1-1.9C/W
If mounted with heatsink compound, then θ_{CS} = 0.5-0.8 C/W
If mounted with mica insulator and heatsink compound; θ_{CS} = 0.8-1.4 C/W

Θ_{SA} Heatsink to Air

The value of θ_{SA} is the heatsink to ambient thermal resistance and is the aim of the calculation. The more surface area a heatsink has, the faster it can transfer heat to the air and so the lower the thermal resistance θ_{SA}.



Micro U Heatsink

Suits TO-126 or TO-220 flat pack semis.

	A	B	L
H 0630:	19	9.5	19

L = Overall length

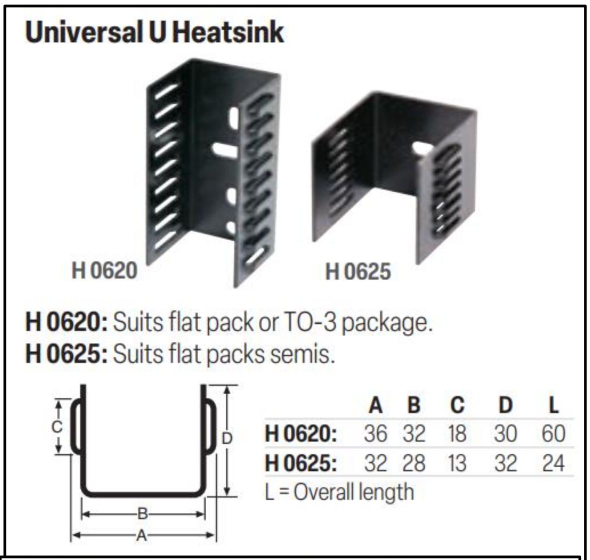
Price Each	Thermal Res.	RRP	4+	10+
H 0630	28°C/W	**1.10**	**1.00**	**0.90**

Micro U Heatsink

Suits TO-126 or TO-220 flat pack semis.

	A	B	L
H 0635:	25	12.5	30

L = Overall length

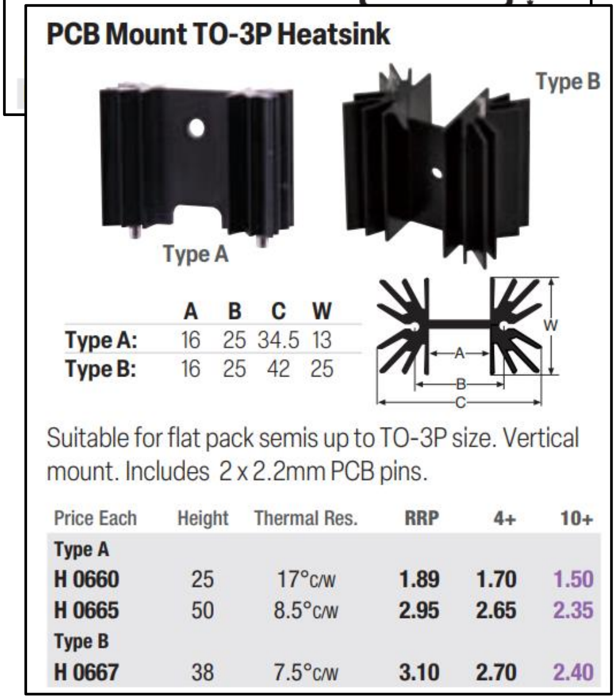


Universal U Heatsink

H 0620: Suits flat pack or TO-3 package.
H 0625: Suits flat packs semis.

	A	B	C	D	L
H 0620:	36	32	18	30	60
H 0625:	32	28	13	32	24

L = Overall length

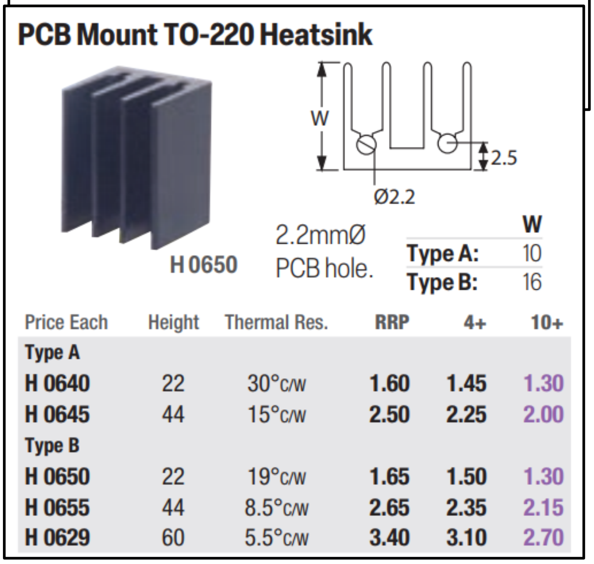


PCB Mount TO-3P Heatsink

	A	B	C	W
Type A:	16	25	34.5	13
Type B:	16	25	42	25

Suitable for flat pack semis up to TO-3P size. Vertical mount. Includes 2 x 2.2mm PCB pins.

Price Each	Height	Thermal Res.	RRP	4+	10+
Type A					
H 0660	25	17°C/W	**1.89**	**1.70**	**1.50**
H 0665	50	8.5°C/W	**2.95**	**2.65**	**2.35**
Type B					
H 0667	38	7.5°C/W	**3.10**	**2.70**	**2.40**

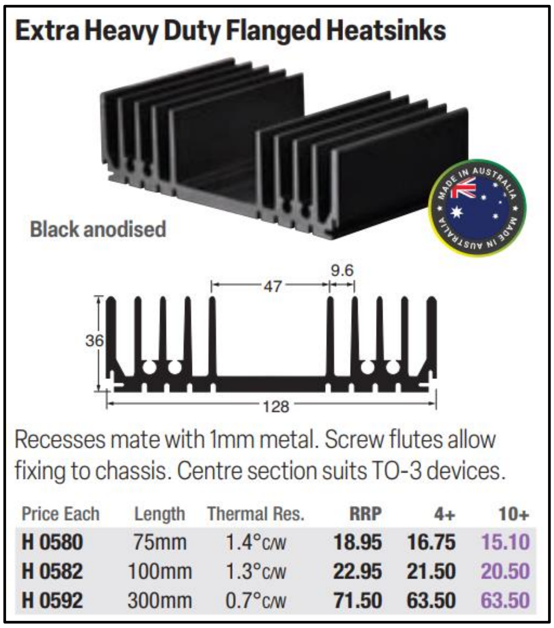


PCB Mount TO-220 Heatsink

2.2mmØ PCB hole.

	W
Type A:	10
Type B:	16

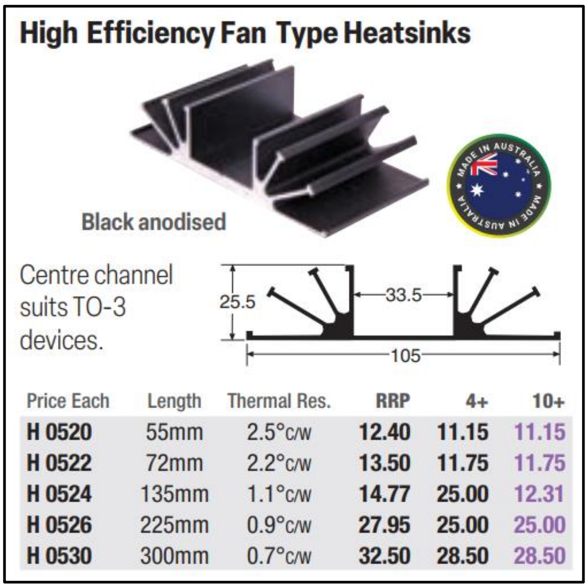
Price Each	Height	Thermal Res.	RRP	4+	10+
Type A					
H 0640	22	30°C/W	**1.60**	**1.45**	**1.30**
H 0645	44	15°C/W	**2.50**	**2.25**	**2.00**
Type B					
H 0650	22	19°C/W	**1.65**	**1.50**	**1.30**
H 0655	44	8.5°C/W	**2.65**	**2.35**	**2.15**
H 0629	60	5.5°C/W	**3.40**	**3.10**	**2.70**



Extra Heavy Duty Flanged Heatsinks

Recesses mate with 1mm metal. Screw flutes allow fixing to chassis. Centre section suits TO-3 devices.

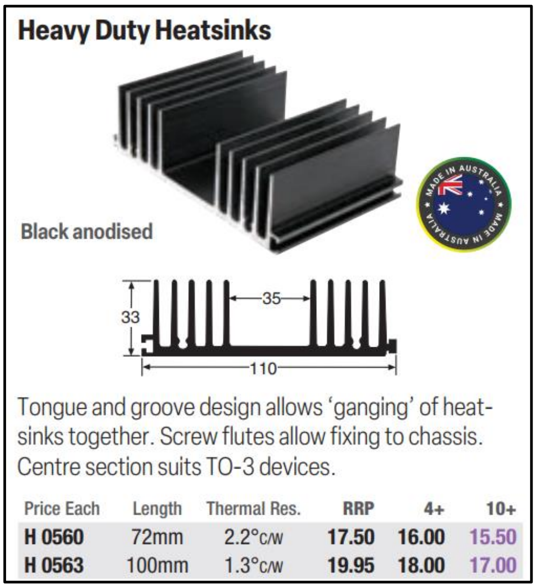
Price Each	Length	Thermal Res.	RRP	4+	10+
H 0580	75mm	1.4°C/W	**18.95**	**16.75**	**15.10**
H 0582	100mm	1.3°C/W	**22.95**	**21.50**	**20.50**
H 0592	300mm	0.7°C/W	**71.50**	**63.50**	**63.50**



High Efficiency Fan Type Heatsinks

Centre channel suits TO-3 devices.

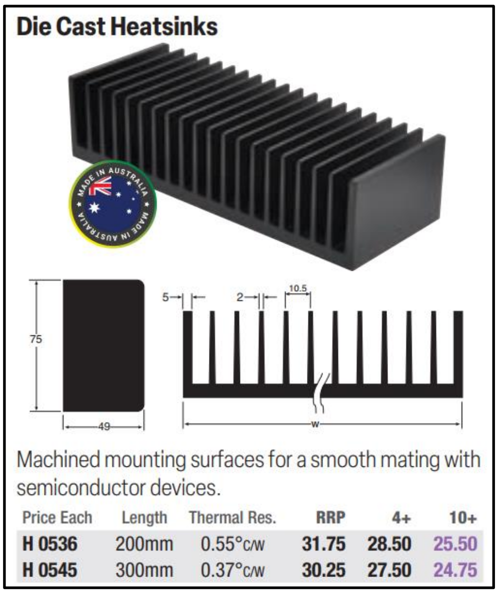
Price Each	Length	Thermal Res.	RRP	4+	10+
H 0520	55mm	2.5°C/W	**12.40**	**11.15**	**11.15**
H 0522	72mm	2.2°C/W	**13.50**	**11.75**	**11.75**
H 0524	135mm	1.1°C/W	**14.77**	**25.00**	**12.31**
H 0526	225mm	0.9°C/W	**27.95**	**25.00**	**25.00**
H 0530	300mm	0.7°C/W	**32.50**	**28.50**	**28.50**



Heavy Duty Heatsinks

Tongue and groove design allows ‘ganging’ of heat-sinks together. Screw flutes allow fixing to chassis. Centre section suits TO-3 devices.

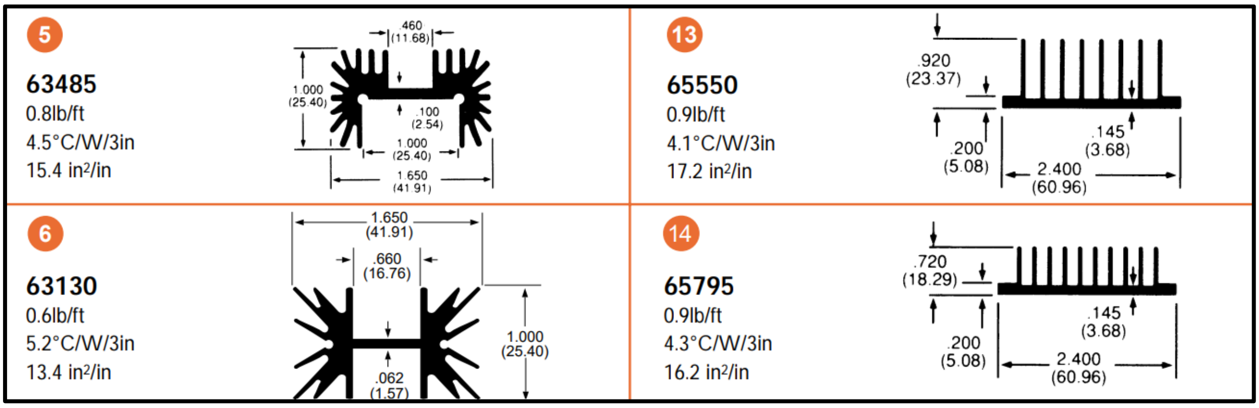
Price Each	Length	Thermal Res.	RRP	4+	10+
H 0560	72mm	2.2°C/W	**17.50**	**16.00**	**15.50**
H 0563	100mm	1.3°C/W	**19.95**	**18.00**	**17.00**



Die Cast Heatsinks

Machined mounting surfaces for a smooth mating with semiconductor devices.

Price Each	Length	Thermal Res.	RRP	4+	10+
H 0536	200mm	0.55°C/W	**31.75**	**28.50**	**25.50**
H 0545	300mm	0.37°C/W	**30.25**	**27.50**	**24.75**



⑤
63485
0.8lb/ft
4.5°C/W/3in
15.4 in²/in

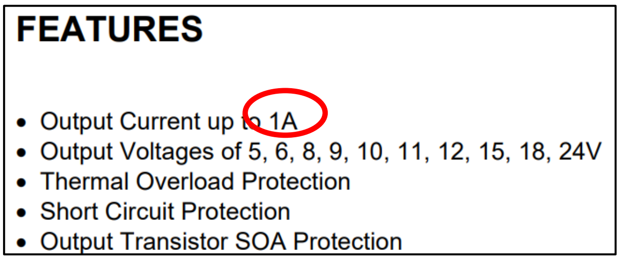
⑬
65550
0.9lb/ft
4.1°C/W/3in
17.2 in²/in

⑥
63130
0.6lb/ft
5.2°C/W/3in
13.4 in²/in

⑭
65795
0.9lb/ft
4.3°C/W/3in
16.2 in²/in

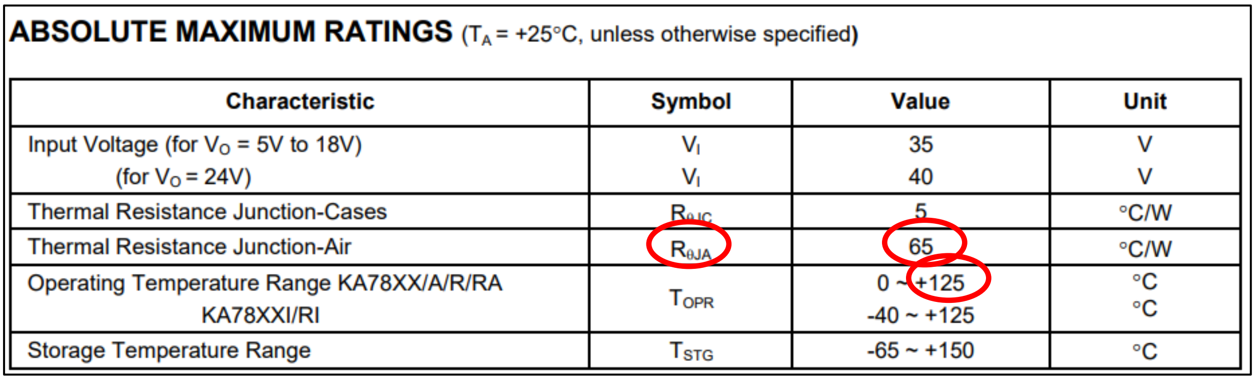
Example#1.

1. LM7809 regulator connected to 12V and supplying 9V to a 9Ω load @30°C.
2. Do we need a heatsink?
    a. Only if the junction temperature is higher than the specified maximum or
    b. The power dissipated is more than the maximum power of the device



FEATURES

- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 11, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor SOA Protection



ABSOLUTE MAXIMUM RATINGS (T_A = +25°C, unless otherwise specified)

Characteristic	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air	$R_{\theta JA}$	65	°C/W
Operating Temperature Range KA78XX/A/R/RA KA78XXI/RI	T_{OPR}	0 ~ +125 -40 ~ +125	°C °C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Solution:

(a) Check Max power output.

I_{out} = V/R = 9 / 9 = 1A

P_{out} = V x I = (12 – 9) x 1 = 3W (so far, so good).

(b) Check operating junction temperature.

$\mathrm{T_J} = \mathrm{P_D}\theta_{\mathrm{JA}} + \mathrm{T_A} = (3\ x\ 65) + 30 = \ 225\ ^o\mathrm{C}$

which is higher than the allowable 125°C so a heatsink is required.

What size heatsink? (assuming worst case of $\theta_{CS} = 1.5\ C/W$)

$$\theta_{SA} = [\frac{(T_J - T_A)}{P_D}] - \theta_{JC} - \theta_{CS}$$

$$\theta_{SA} = [\frac{(125 - 30)}{3} - 5 - 1.5 = 25.2\ °C/W$$

So the heatsink has to have θ_{SA} lower than $25.2\ °C/W$.

Example#2.

A particular transistor has a power rating at 25°C of 200mW, and a maximum junction temperature of 150°C.

(a) What is its thermal resistance?

(b) What is its power rating when operated at an ambient temperature of 70°C?

(c) What is its junction temperature when dissipating 100mW at an ambient temperature of 50°C?

Solution:

$$P_D = \frac{(T_{J(max)} - T_A)}{\theta_{JA}} \quad \text{so}$$

a) Thermal resistance $= \theta_{JA} = \dfrac{(T_{J(max)} - T_A)}{P_D} = \dfrac{(150 - 25)}{0.2} = 0.625\ ^\circ\text{C/mW}$

b) Power rating when ambient = $P_D = \dfrac{(T_{J(max)} - T_A)}{\theta_{JA}} = \dfrac{(150 - 70)}{0.625} = 128\text{mW}$

c) Junction temperature for 100mW @50°C $= T_J = T_A + P_D\theta_{JA} = 50 + 0.1\text{x}0.625 = 112.5\ ^\circ\text{C}$

Example#3.

A power transistor is specified to have a maximum junction temperature of 130oC.

When the device is operated at this junction temperature with a heat sink, the case temperature is found to be 90oC.

The case is attached to the heat sink with a bond having a thermal resistance θCS=0.5oC/W and the thermal resistance of the heat sink θSA=0.1oC/W.

If the ambient temperature is 30oC ;

a) What is the power being dissipated in the device?

$$T_C - T_A = P_D\theta_{CA} \quad so \quad T_C - T_A = P_D(\theta_{CS} + \theta_{SA})$$

$$P_D = \frac{(T_S - T_C)}{(\theta_{CS} + \theta_{SA})} = \frac{(90 - 30)}{(0.5 + 0.1)} = 100\text{W}$$

b) What is the thermal resistance of the device, θ_{JC}, from junction to case?

$$\theta_{JC} = \frac{(T_{J(max)} - T_C)}{P_D} = \frac{(130 - 90)}{100} = 0.4\ ^0\text{C/W}$$

Example#4.

Determine the appropriate heat sink rating for a power device rated as follows:

TJ (max) = 150 ^{0}C, TO-220 case style, θ_{JC} = 3.0 ^{0}C/W. The device will be dissipating a maximum of 6W in an ambient temperature of 40 ^{0}C. Assume that the heat sink will be mounted with heat sink grease and a 0.002 mica insulator.

First, find θ_{CS} from the TO-220 graph. Curve 3 is used.

The approximate (conservative) value is θ_{CS} = 1.6 ^{0}C.

Solution:

$$P_D = \frac{(T_J - T_A)}{(\theta_{JC} - \theta_{CS} - \theta_{SA})}$$

$$\theta_{SA} = \frac{(T_J - T_A)}{P_D} - \theta_{JC} - \theta_{CS} =$$

$\theta_{SA} = 150 - 406 - 3 - 1.6 = 13.73°C/W$ So the heatsink must have a thermal value lower than this.

Example#5.

A power transistor is specified to have a maximum junction temperature of 150°C.

When the device is operated at this junction temperature with a heat sink, the case temperature is found to be 97°C.

The case is attached to the heat sink with a bond having a thermal resistance θ_{CS} = 0.5°C/W and the thermal resistance of the heat sink θ_{SA} = 0.1°C/W.

(a) If the ambient temperature is 25°C, what is the power being dissipated in the device?

(b) What is the thermal resistance of the device, θ_{JC}, from junction to case?

Solution:

a. $\mathrm{P} = \frac{\mathrm{T_C} - \mathrm{T_A}}{\theta_{\mathrm{CS}} + \theta_{\mathrm{SA}}} = \frac{97-25}{0.5+0.1} = 120\ W$

b. $\theta_{JC} = \frac{(T_J - T_C)}{P_D} = \frac{(150-97)}{120} = 0.44°\mathrm{C/W}$

Example#6.

A transistor and its thermal management is shown below. Its thermal resistance $\theta_{JC} = 4\ {}^{o}C/W$.

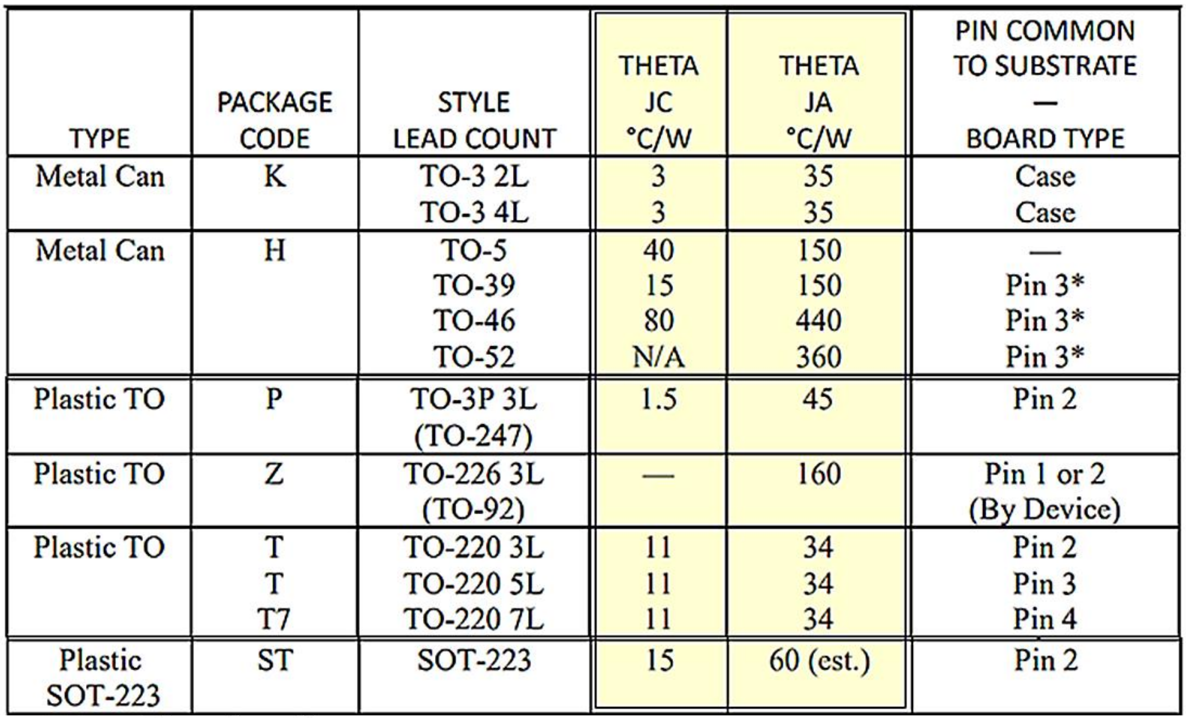
The loss of the transistor is based on the product of V_{CE} and I_E. V_{CE} is always set at the mid-point of the single ended DC supply voltage of $V_{CE} = 10V$.

(a) With $I_E = 0.5A$, the ambient temperature is 25 ${}^{o}C$. Calculate the junction temperature. (If no heatsink is used.) Given that $\theta_{CA} = 26{}^{o}C/W$.

(b) Following from (a), if the junction temperature is wanted to reduce to 75°C calculate the maximum θ_{SA}, of the heatsink needed? Given that $\theta_{CS} = 1{}^{o}C/W$.

(c) Following from (a), what is the temperature of the case T_C and heatsink T_A?

https://www.analog.com/media/en/package-pcb-resources/package/thermal-table.pdf



TYPE	PACKAGE CODE	STYLE LEAD COUNT	THETA JC °C/W	THETA JA °C/W	PIN COMMON TO SUBSTRATE — BOARD TYPE
Metal Can	K	TO-3 2L	3	35	Case
		TO-3 4L	3	35	Case
Metal Can	H	TO-5	40	150	—
		TO-39	15	150	Pin 3*
		TO-46	80	440	Pin 3*
		TO-52	N/A	360	Pin 3*
Plastic TO	P	TO-3P 3L (TO-247)	1.5	45	Pin 2
Plastic TO	Z	TO-226 3L (TO-92)	—	160	Pin 1 or 2 (By Device)
Plastic TO	T	TO-220 3L	11	34	Pin 2
	T	TO-220 5L	11	34	Pin 3
	T7	TO-220 7L	11	34	Pin 4
Plastic SOT-223	ST	SOT-223	15	60 (est.)	Pin 2

TO-3

TO-220

TO-52

TO-92

SOT-233