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Lesson 3 (Part B): Semiconductor Thermal Protection

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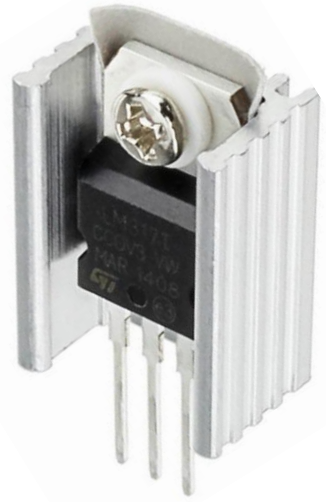
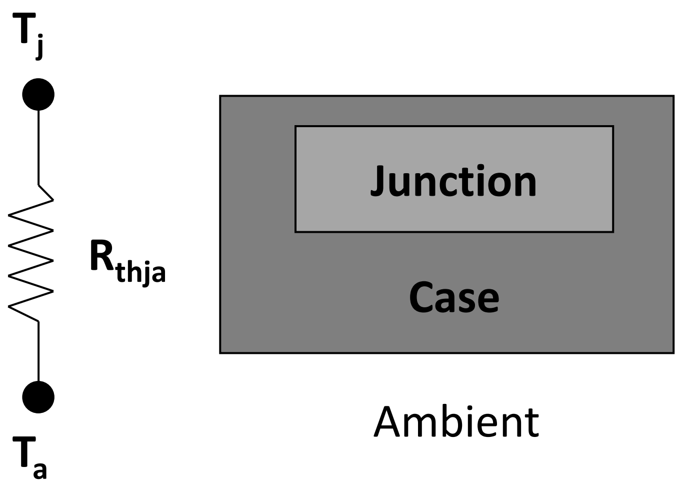


Introduction

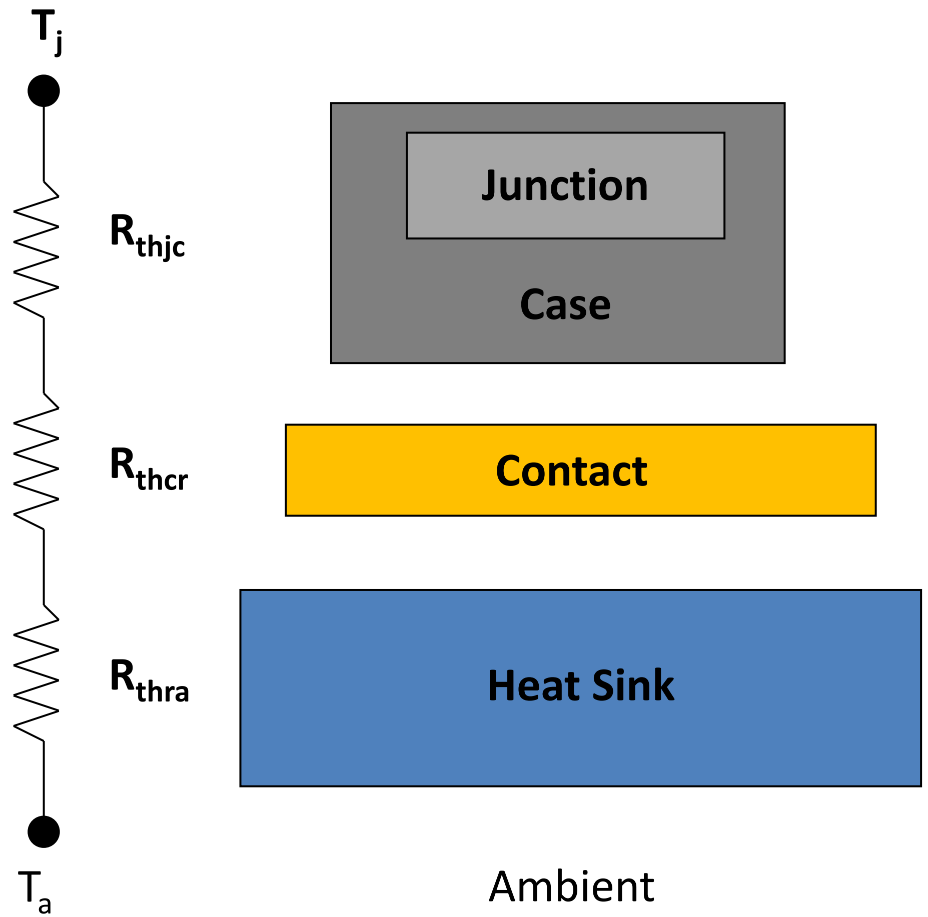
- The techniques covered in this topic are intended to **dissipate** the power generated by semiconductor devices during operation.
- They are based on the use of heat-dissipation components provided or specified by manufacturers.
- The thermal system must be designed to ensure that the semiconductor junction temperature remains within safe operating limits.

Thermal Protection – Basic Thermal Circuit

Without Heat Sink



With Heat Sink



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Thermal Protection – Key Concepts

- **T_j: Maximum Junction Temperature**. Above this temperature, the semiconductor device may be permanently damaged. This value is specified by the manufacturer in the datasheet.
- **R_{thjc}: Junction-to-Case Thermal Resistance**. This value is specified by the manufacturer in the datasheet.
- **R_{thcd}: Case-to-Heat-Sink Thermal Resistance**. Thermal resistance introduced by the interface between the device case and the heat sink. It may be obtained from tabulated data or provided by the manufacturer of the thermal interface material.
- **R_{thda} Heat-Sink-to-Ambient Thermal Resistance**. Thermal resistance of the heat sink, specified by the heat-sink manufacturer.
- **T_a: Ambient Temperature.** Temperature of the environment surrounding the application.

Thermal Protection – Thermal Ohm's Law

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Electrical quantities	**Thermal** quantities
I: Electric Current (A)	P: Power (W)
R: Electrical Resistance (Ω)	R: Thermal Resistance (ºC/W)
V: Voltage (V)	T: temperature (ºC ó K)
Ohm's law: V=IxR	thermal Ohm's law : T=PxR

Relationship: P= I x V (Joule's law)

Power Dissipation Calculation

- Conduction Losses:

$P = V\gamma \cdot \mathrm{Im} + rd \cdot I_{ef}^2$ For diodes, SCRs, GTOs y MCTs

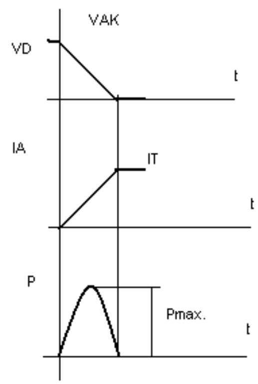
$P = R_{sat} \cdot I_{ef}^2$ For BJTs, MOSs and IGBTs

- Switching Losses:

Turn-On

$$P = f \cdot \frac{V_D \cdot I_T}{3} \cdot t_{on}$$

Total losses can be conservatively estimated as twice the turn-on switching losses.



$$v_{AK} = V_D - \frac{V_D}{t_{on}} \cdot t;\ I_A = \frac{I_T}{t_{on}} \cdot t$$

$$\Rightarrow P(t) = \frac{V_D \cdot I_T}{t_{on}^2}\left(t_{on} \cdot t - t^2\right)$$

$$P = \frac{1}{T}\int_0^{t_{on}} \frac{V_D \cdot I_T}{t_{on}^2}\left(t_{on} \cdot t - t^2\right)dt = \frac{t_{on}}{T} \cdot \frac{V_D \cdot I_T}{6}$$

Example: at line frequency (50 Hz), switching losses can generally be neglected. At higher frequencies, they become increasingly significant.

Thermal Protection – Heat-Sink Calculation (I)

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- Starting from the power dissipated by the semiconductor device, the required thermal resistance of the heat sink is calculated as follows:

$$T_j - T_a = P\left(R_{thjc} + R_{thcr} + R_{thra}\right) \Rightarrow R_{thra} = \frac{T_j - T_a}{P} - R_{thjc} - R_{thcr}$$

- The calculated value is then used to select a heat sink from a manufacturer's catalog whose thermal resistance is lower than the calculated maximum value. Components and extruded profiles are also available for designing and manufacturing custom heat sinks.
- In some cases, a heat sink may not be required:

$$T_j - T_a = P \cdot R_{thja} \Rightarrow R_{thja} = \frac{T_j - T_a}{P} \geq R_{thja}(manufacturer)$$

Thermal Protection – Heat-Sink Calculation (II)

Design a heat sink for a BD137 transistor dissipating 5 W at an ambient temperature of 20 °C, ensuring that its junction temperature does not exceed 120 °C. Use the online tool available at:

https://www.giangrandi.ch/electronics/thcalc/thcalc.shtml

To perform the calculation, obtain the required thermal parameters and package type from the transistor datasheet.

Thermal Protection Exercise

- SCR conducting for 90°
  - On-State Current: 30 Sin(wt) (amperios)
  - Blocking-State Voltage: 200 Sin(wt) (voltios)
  - Blocking-State Current: 0
  - On-State Voltage: 1.3 V
  - Dynamic Resistance: rd = 0,1Ω
  - Turn-On Time: t_{on}=1µs
  - Frequency = 50 Hz.
  - R_{thjc} = 1 ^{0}C/W
  - R_{thcr} = 0.1 ^{0}C/W
  - T_a = 22 ^{0}C
  - Tj_{max} = 85 ^{0}C

- Calculate the required heat-sink thermal resistance.

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Electrical Calculations

$$Im = \frac{1}{T}\int_{0}^{2\pi} i(t)dt = \frac{1}{T}\int_{T/4}^{T/2} 30Sin\left(\frac{2\pi}{T}t\right)dt = \frac{30}{T}\left(\frac{-Cos\,\frac{2\pi}{T}t}{2\pi/T}\right) = \frac{30}{2\pi}\left(-Cos\pi + Cos\,\pi/2\right) = \frac{30}{2\pi} = 4.774A$$

$$Ief = \sqrt{\frac{1}{T}\int_0^T i^2(t)dt} = \sqrt{\frac{1}{T}\int_{T/4}^{T/2} 900Sin^2\left(\frac{2\pi}{T}t\right)dt} = \sqrt{\frac{900}{T}\int_{T/4}^{T/2}\frac{1-Cos(\frac{4\pi}{T}t)}{2}dt} =$$

$$\sqrt{\frac{900}{2T}\left[\frac{T}{2}-\frac{T}{4}\right] - \frac{900}{2T}\left[\left(\frac{Sen(2\pi)}{4\pi/T}\right) - \left(\frac{Sen(\pi)}{4\pi/T}\right)\right]} = \sqrt{\frac{900}{8} - \frac{900}{8\pi}(0-0)} = \frac{30}{2\sqrt{2}} = 10.606A$$

Conduction Losses: $P = V\gamma * Im + rd * I_{ef}^{\;2} = 1.3 * 4.774 + 0.1 * 10.606^2 = 17.456W$

Switching Losses: $P = f\,\frac{V_D * I_T}{3}\,t_{on} = 50\,\frac{200*30}{3}\,10^{-6} = 0.1W$

Total Losses = 17.556W

Thermal Calculations

Power to Be Dissipated: 17,556W

Heat-Sink Thermal Resistance: $R_{thra} = \frac{T_j - T_a}{P} - R_{thjc} - R_{thcr} = \frac{85-22}{17.556} - 1 - 0.1 \leq 2.488\,{}^{\circ C}/_{W}$

Example Using a Real Thyristor

Tiristor SKT 40/06D.

$R_{th(j-c)}$	cont.	0,6	K/W
$R_{th(j-c)}$	sin. 180	0,66	K/W
$R_{th(j-c)}$	rec. 120	0,7	K/W
$R_{th(c-s)}$	Capsule – heat sink	0,2	K/W
T_{vj}		- 40 ... + 130	°C
T_{stg}		- 55 ... + 150	°C

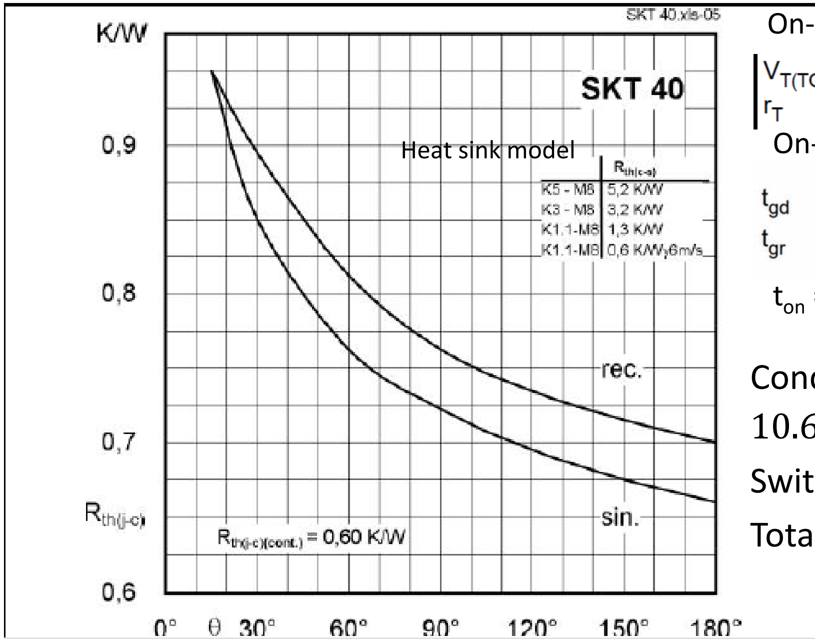

Fig. 5 Thermal resistance vs. conduction angle

On-sate voltage

$V_{T(TO)}$	T_{vj} = 130 °C	max. 1	V
r_T	T_{vj} = 130 °C	max. 9	mΩ

On-state slope resistance

t_{gd}	T_{vj} = 25 °C; I_G = 1 A; di_G/dt = 1 A/µs	1	µs
t_{gr}	$V_D = 0.67 * V_{DRM}$	1.5	µs

$t_{on} = t_{gd} + t_{gr}$

Conduction Losses: $P = V\gamma * Im + rd * I_{ef}^{2} = 1 * 4.774 + 0.009 * 10.606^2 = 5.786W$

Switching Losses: $P = f\frac{V_D*I_T}{3}t_{on} = 50\frac{200*30}{3}2.5 * 10^{-6} = 0.249W$

Total Losses = 6.035W

Case B 3 (IEC 60191-2: A38MA, A14U; JEDEC: TO-208AC (TO-65))

Example Using a Real Thyristor

Total Power Dissipation: 6,035W.

Heat-Sink Thermal Resistance: $R_{thra} = \frac{T_j - T_a}{P} - R_{thjc} - R_{thcr} = \frac{85-22}{6.035} - 0.75 - 0.2 \leq 9.489\,{}^{\circ C}/_{W}$

Graphical Calculation

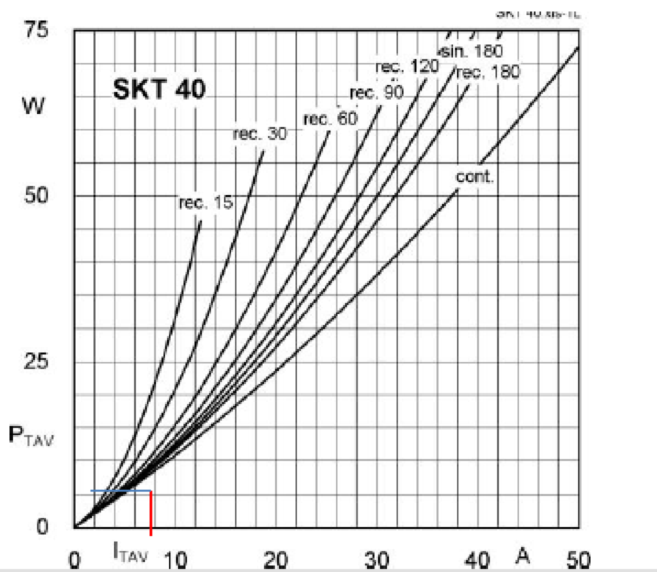

Fig. 1L Power dissipation vs. on-state current

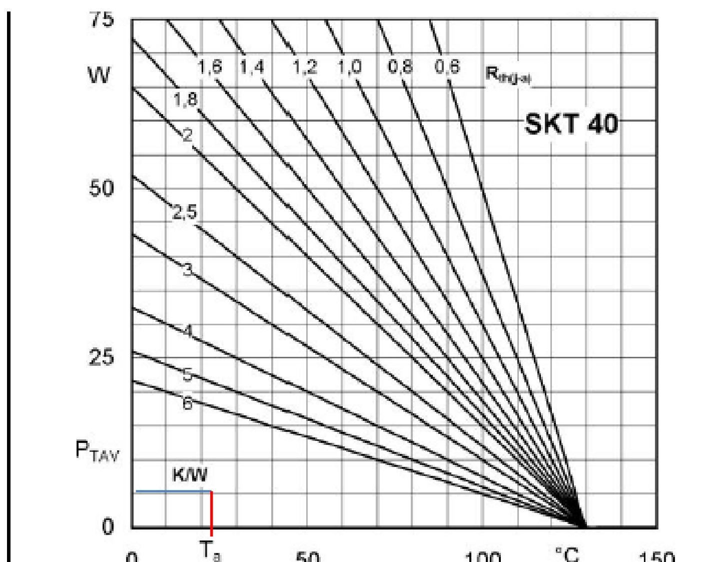

Fig. 1R Power dissipation vs. ambient temperature

K5 $R_{th(ca)}$ = 5.2 K/W, $R_{th(ra)}$ = 5 K/W

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References

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