Systems Engineering

Thermal Management

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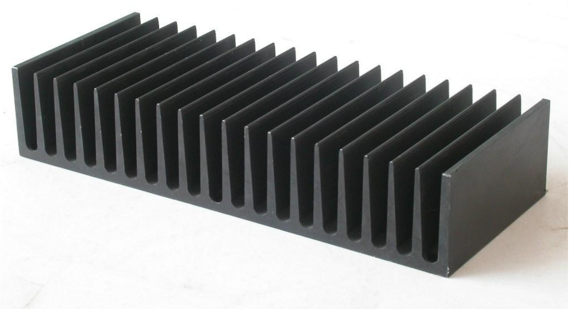
Source: A significant part is from Tim Williams' *The Circuit Designer's Companion*

Temperature rise in electronics

- Non-ideal devices dissipate power (resistance)
- $\rightarrow$ Temperature rise
  - A few degrees if power is small (~ 1 mW)
  - Tens or hundreds of degrees if power is (~ 1 W)
- Excessive temperature kills electronics
- We need thermal management to keep T at reasonable levels



Thermal resistance

- Thermal analysis has an electrical analogue
- Heat source: current source
- Thermal impedances: resistances
- Temperature: voltage

Thermal parameter	Units	Electrical analogue	Units
Temperature difference	°C	Potential difference	V
Thermal resistance	°C/W	Resistance	Ω
Heat flow	J/s (W)	Current	A
Heat capacity	J/°C	Capacitance	F

Heat flow equation

Base equation (Q is (Q)uantity of energy transferred as heat)

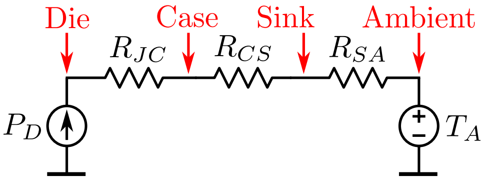
$$\frac{dQ}{dt} = \frac{T_1 - T_2}{R} \tag{1}$$

Dimensional analysis

$$W = \frac{J}{s} = \frac{\circ}{\circ/W} \tag{2}$$

Source: The circuit designer's companion

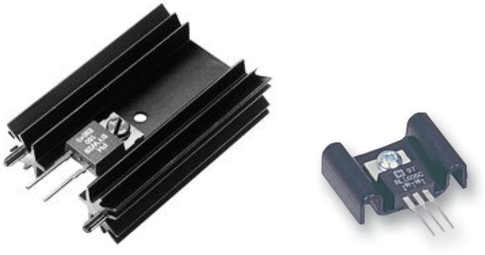
Steady-state equivalent circuit



- Maximum die or junction T: given by manufacturer
- Die to case resistance R_{DC} or θ_{DC} also in datasheet
- R_{CS} insulating washer

Example

- $T_{JMAX} = 125\ ^\circ$(typical for silicon transistors)
- $R_{JC} = 1.5\ ^\circ\mathrm{C/W}$ (typical for TO-220)
- $R_{CS} = 0.8\ ^\circ\mathrm{C/W}$ (typical for TO-220)
  - Heatsink A: $R_{SA} = 11\ ^\circ\mathrm{C/W}$
  - Heatsink B: $R_{SA} = 21\ ^\circ\mathrm{C/W}$



Results

- Heatsink A

$$P_D = \frac{125 - T_{AMB}}{1.5 + 0.8 + 11} \tag{3}$$

If T_{AMB}=70 °, then P_D=4 W

- Heatsink B

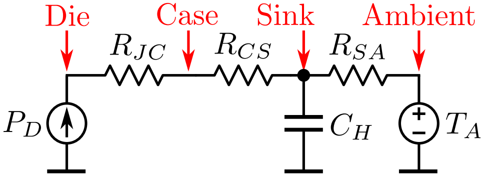
$$P_D = \frac{125 - T_{AMB}}{1.5 + 0.8 + 22} \tag{4}$$

If T_{AMB}=70 °, then P_D=2 W

Discussion

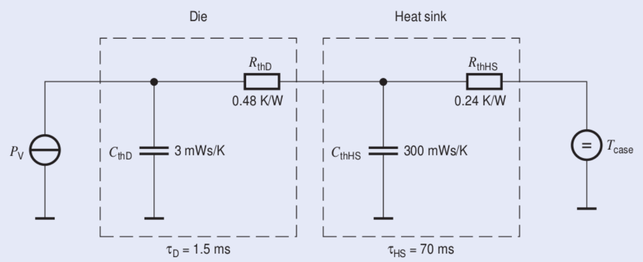
- Datasheet may speak of power rating for 25 $^{\circ}CASE$ temperature
- You will be unable to keep it!
- If the required heatsink is too bulky?
- Use two (or more) devices in parallel

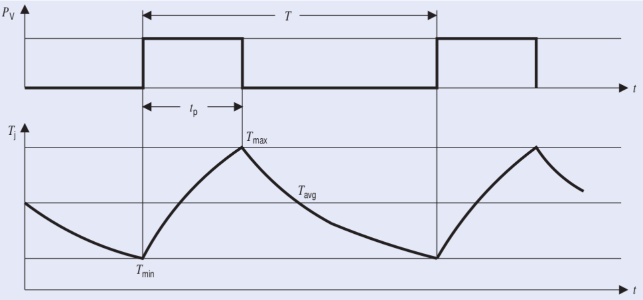
Dynamic properties



- A step in power gives an exponential response in T_j
- Final value is achieved in seconds, minutes or even hours.
- C_H depends on the mass of the heatsink
- C_H has *no* effect on the final value!
- For pulsed applications with low-duty cycle with each cycle faster than time constant, you may use a smaller heatsink

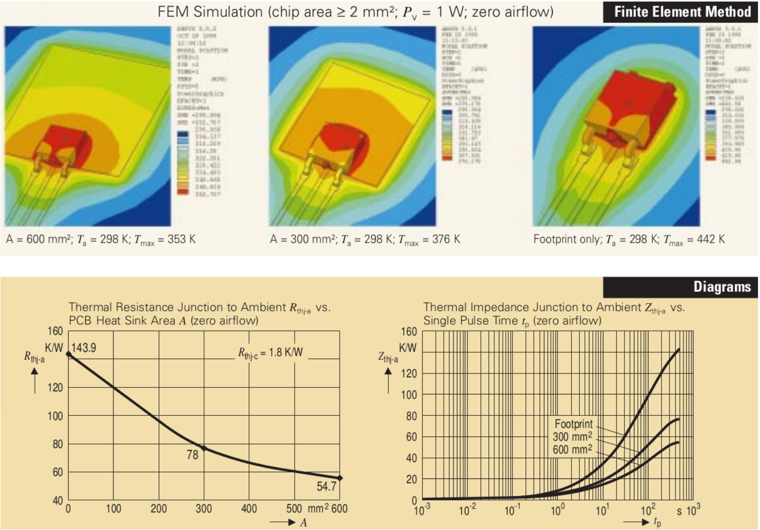
Dynamic properties /2





Source: Infineon. Thermal Resistance Theory and Practice

Finite-element thermal simulations



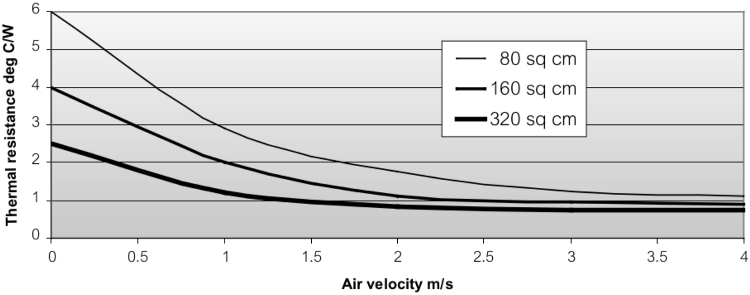
Source: Infineon. Thermal Resistance Theory and Practice

Heatsinks

- Low resistance path between heat source and ambient
- The ambient is the sink, the heatsink is the *exchanger*
- Several kinds of heatsinks available from manufacturers
- Heat transfer mechanism: mainly convection (radiation is secondary)
- Maximize surface area in contact with the convective medium (air) $\rightarrow$ Fins
- Fin orientation: vertical to maximize air flow (heated air rises)
- Convection is dependent on altitude
- Material: black anodised aluminium
  - Good balance: bost, weight and thermal conductivity
  - Black anodised: $\times 15$ better radiation than polished

Forced air cooling

- Thermal resistance of a square flat plate



- Fin placement may be optimised. Staggered fins
- With forced air cooling, radiative cooling is negligible. Unfinished aluminium instead of anodised

Source: The circuit designer's companion

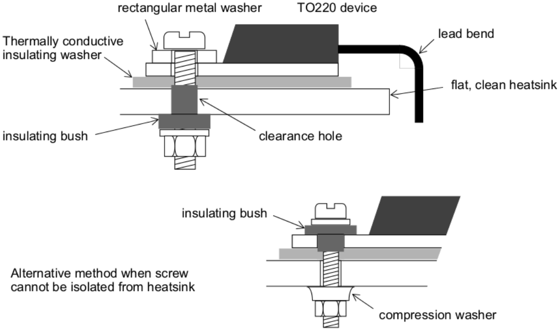
Radiation

- Radiation travels in line of sight
- May rise the temperature of other components (one fin heats the other)
- Thermal radiation loss

$$q = 5.7 \times 10^{-12} \times \Delta T^4 \times \epsilon \tag{5}$$

  q [W/cm^2], ΔT: temperature difference between component and environment, ϵ: relative emissivity compared to black body (Al (polished): 0.04, Al (painted): 0.9)
- Thin surface treatment to minimise effect on convection
- Poor radiators are poor absorbers: shiny aluminium foil to protect heat sensitive components

Power semiconductor mounting



Source: The circuit designer's companion

- (Very) Flat surfaces
- Careful lead bending
- Insulating washer + thermally conductive grease
- Mounting hardware
  - Rectangular washer to distribute pressure
  - Correct torque
- Alternative: Mounting clips