 Prof. David Perreault

Lecture 16 - Thermal

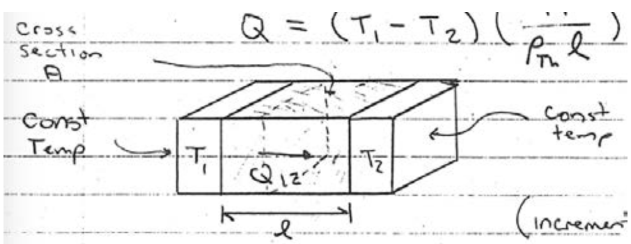
1 Thermal Modeling and Heat Sinking

3 methods of heat removal:

1. Convection: Transfer of heat to a moving fluid which takes it away
2. Conduction: Flow of heat through thermal conductor away from source
3. Radiation: Flow of heat by long-wave electromagnetic radiation

Radiation of heat depends on nonlinearly on temperature difference of source and environment (proportional to $[T_{source}^4 - T_{env}^4]$) and can be neglected in most applications.
Conduction: One dimensional heat conduction through a material can be expressed as

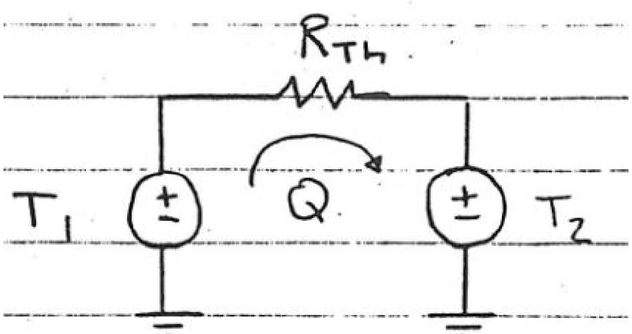
$$Q = (T_1 - T_2)(\frac{A}{\rho_n l})$$



- q is heat flow (w)
- ρ_{Th} is thermal resistivity ($\frac{K-m}{W}$)
- A is cross sectional area (m^2)
- l is length (m)

(Incrementally, q = $\frac{-A}{\rho_{Th}}\frac{\partial T}{\partial x}$)

This relationship suggests an electrical cicrcuit analog:

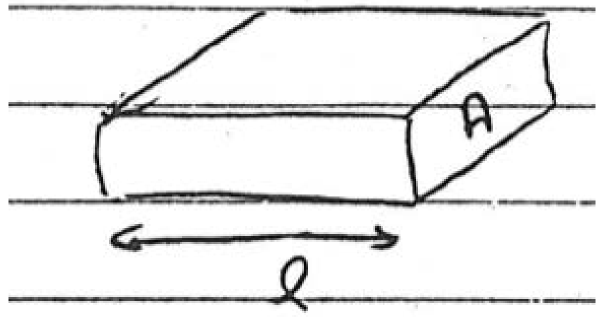


- Q is heat flow in W
- T is temperature in $^\circ C$
- R_{Th} is thermal resistance in $\frac{^\circ C}{W}$

Thermal resistance is very like regular resistance

$$R_{Th} = \frac{\rho_{Th} l}{A}$$

1. l - length of material
2. A - cross sectional area
3. ρ_{Th} - thermal resistance $\frac{^\circ C \cdot m}{W}$



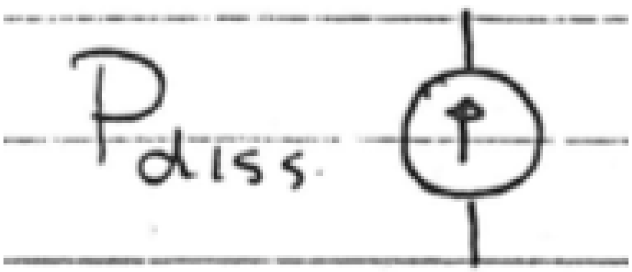
Because of this, we can connect thermal resistance and calculate temperatures + heat flows in various series and parallel paths using circuit model.

Convection: convective heat transfer from a surface to a fluid in motion can be modeled as:

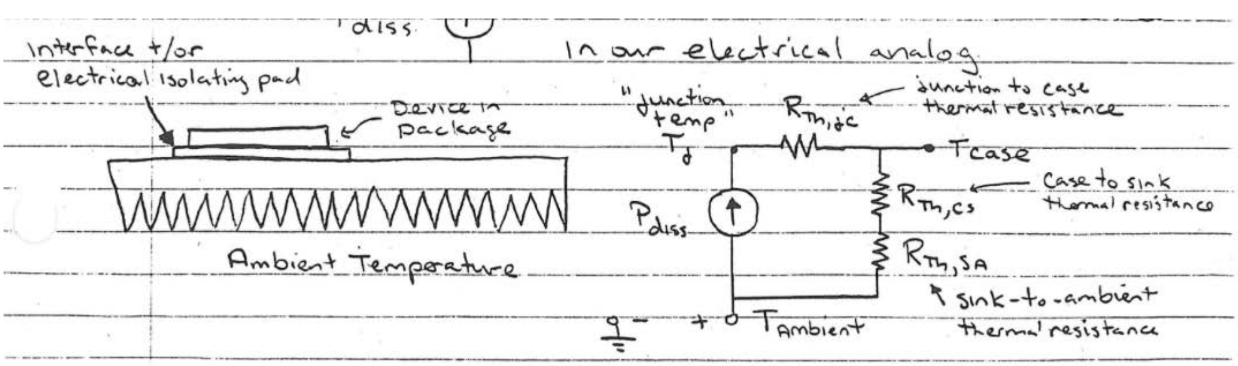
$$q = hA(T_{sw,f} - T_{fluid})$$

where h = heat transfer coefficient
A = "wetted area"

Then we can also model convective heat transfer with a thermal resistance $R_{Th} = (hA)^{-1}$
Usual case: heat power is generated and must be removed.



Heat source looks like a current source in our electrical analog



Example:

IRF620 Mosfet in T0-220 package

$$R_{Th,jc} \approx 2.5 \frac{^\circ C}{W}$$

$$R_{Th,cs} \approx 0.5 \frac{^\circ C}{W}$$

Redpoint Thermalloy KM50-1 Heatsink

$$R_{Th,SA} \approx 4.8 \frac{^\circ C}{W}$$

So if $T_A = 40°C, P_{diss}(device) = 10W$

$$T_j = T_{amb} + P_{diss}(R_{Th,jc} + R_{Th,cs} + R_{Th,SA})$$
$$= 40 + 10(2.5 + 0.5 + 4.8)$$
$$= 118°C$$

Typical limits for T_j $125°C - 175°C$ depending on device.
Note: The data sheet "current rating" or "power rating" of many devices are specified by temperature rise limits. They usually assume the case can be held at $25°C$ (difficult in real life) and compute allowable current + power dissipation. For $T_{j,max}$ to be reached. Hence, the IR620 is theoretically a 50W device, but this is usually impractical to achieve.

The typical design problem is: given $P_{diss}, R_{Th,jc}$ find $R_{Th,SA}$ to limit T_j or T_{case} to acceptable value.
Ex: $P_{diss} = 10W, R_{Th,jc} + R_{Th,cs} = 3.0° \frac{C}{W}$

$$T_A = 100°C$$

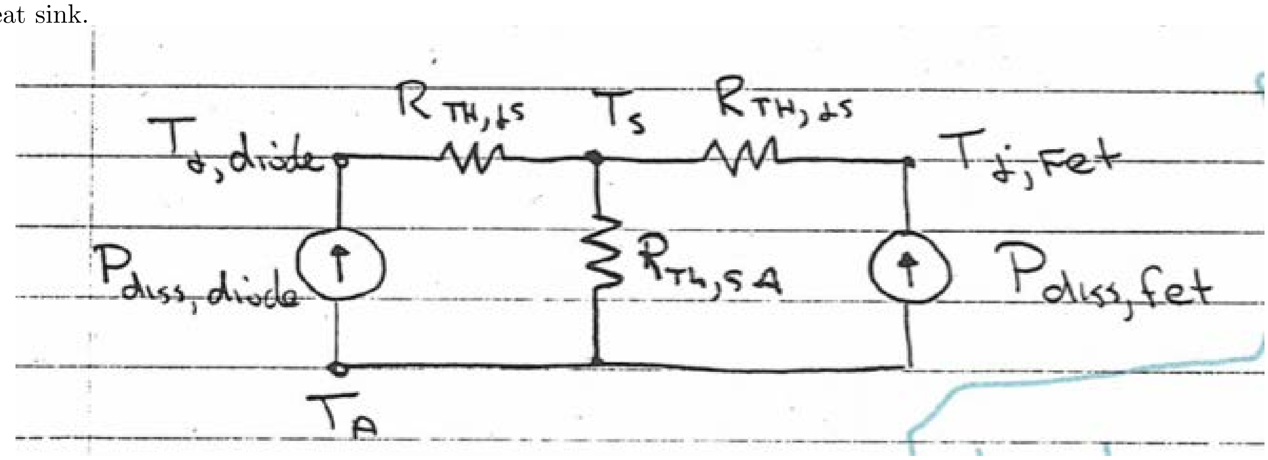
what R_{Th} for $T_j < 150°C$?

$$T_A + P_{diss}(R_{Th,jc} + R_{Th,cs} + R_{Th,SA}) \leq T_{j,max}$$

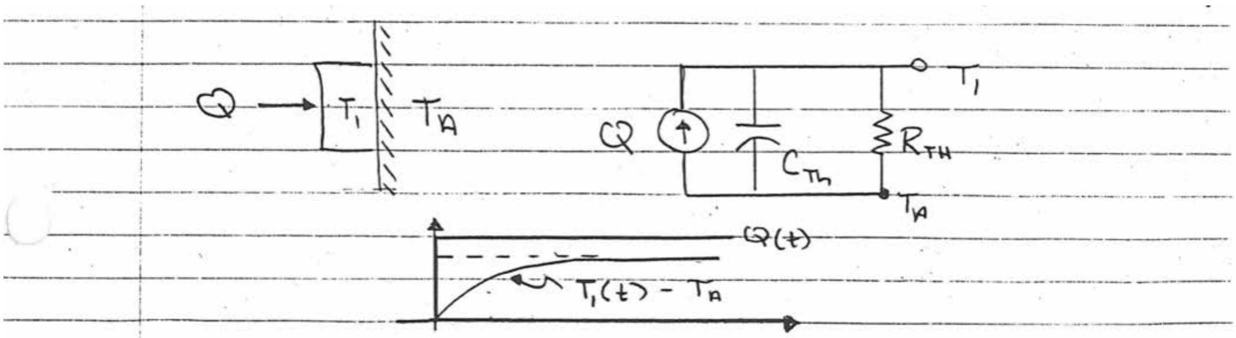
$$\Delta T = T_{j,max} - T_A = 50°C = 10(3 + R_{Th,SA})$$

$$\Rightarrow R_{Th,SA} \leq 2° \frac{C}{W} \rightarrow \text{buy such a heat sink}$$

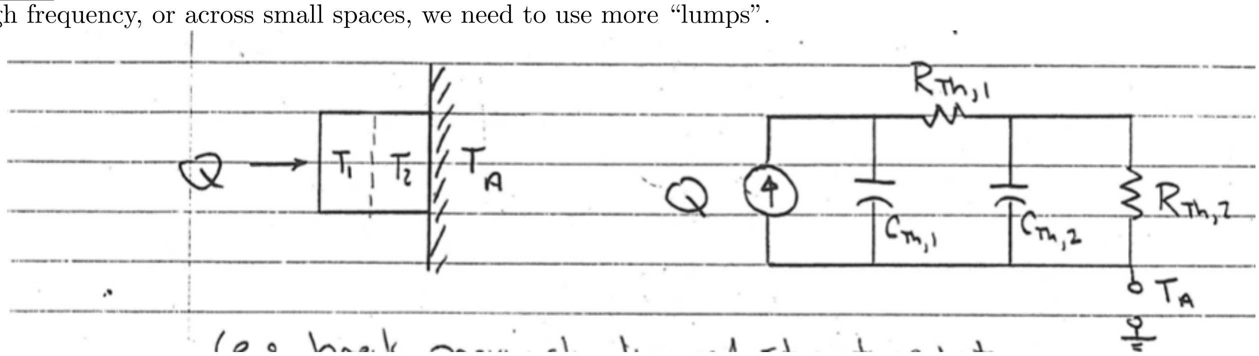
Things get more complicated with multiple heat sources, such as a diode and a MOSFET on the same heat sink.



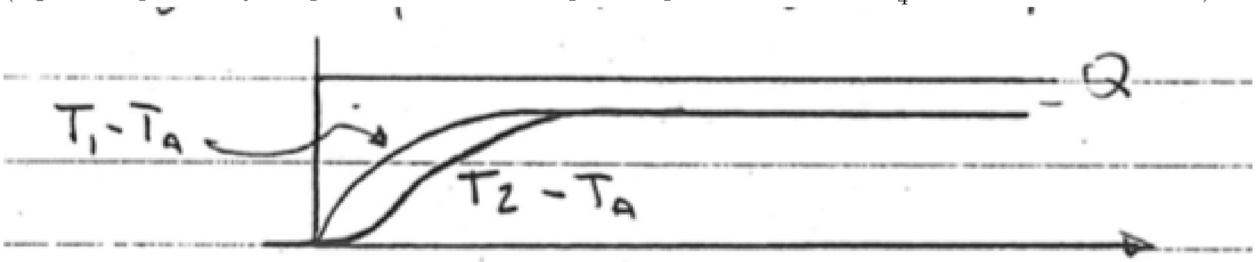
Dynamic case: If we have pulsed power (e.g. a UPS that runs for only a short time or a pulse discharge circuit that operates only once)
The mass of an element can store heat energy
$\therefore$ Thermal capacitance C in $\frac{J}{°C}$ (Heat capacitance is $\frac{J}{°C \cdot Kg} \times$ mass)



Note: This is a lumped parameter model for a distributed system. The temperature calculated is the average temperature across the block. If we want to look over short intervals of time (e.g. ¡¡ $R_{th}C_{th}$), at high frequency, or across small spaces, we need to use more “lumps”.



(e.g. break previously lumped structure into 2 equal lumps $R_1C_1 = R_2C_2 = \frac{1}{4}RC \rightarrow$ shorter timescales)



We can break the system down into as many lumps as needed. In limit, we can go to partical differential equation (distributed) representation.

PDE description ⇒ R. Haberman, “Elementary Applied Partial Differential Equations, 2nd Ed.” Prentice-Hall

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Transient Thermal impedance

To express the temp rise of a subsystem under transient conditions, sometimes a “transient thermal impedance” is used

$$Z_{Th}(t) = \frac{\Delta T(d)}{Q}$$

Where the numerator is temperature rise across element, denominator is magnitude of power step.

So use to get $\Delta T(t)$ for steps or pulses of power. This is a reflection of the “ec” type behavior shown above.

Note: Sometimes temp rise is expressed as a function of duty ratio and pulse repetition rate (of power input). This is based on similar methods.