Lecture 4: Benefits of Scaling III

- Announcements:
- HW#1A due Wednesday next week
- HW#1B due Wednesday the week after HW#1A
- This is a pre-recorded lecture
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- Today:
- Reading: Senturia, Chapter 1
- Lecture Topics:
  - Benefits of Miniaturization
  - Examples
    - —GHz micromechanical resonators
    - —Chip-scale atomic clock
    - —Thermal Circuits
    - —Micro gas chromatograph
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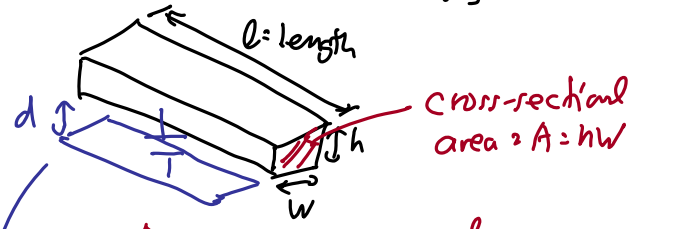
- Last Time: Covering thermal circuit modeling … which we now continue …

Review Electrical Resistance First

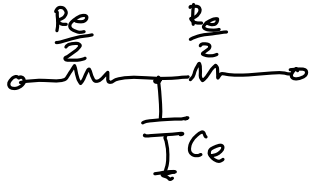
(then attack the thermal R analogy)



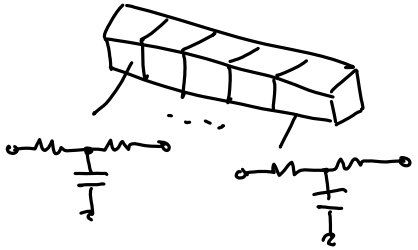
R_e ≜ electrical resistance = $\frac{l}{\sigma A}$ ← electrical conductivity

C_e : capacitance: $\frac{\epsilon_0 WL}{d}$ ← permittivity

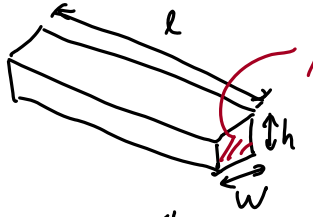
↳ Stored Energy (charge energy) : $\frac{1}{2}CV^2 = E$ ← voltage across the capacitor



⇒ if want to be more exact:



Thermal Ckt.

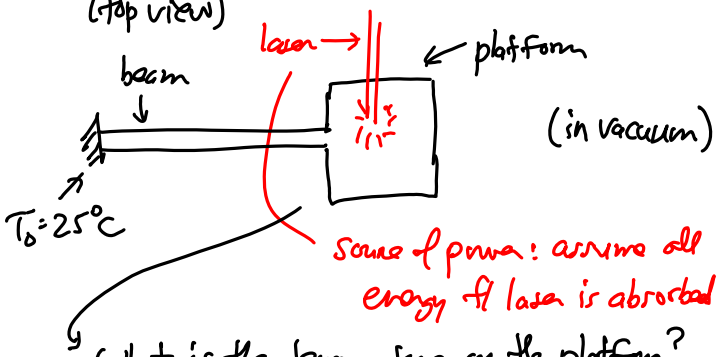


⇒ thermal capacitance: $C_{th} = \rho V C_p$ ← specific heat; volume; density ↘ stores thermal energy

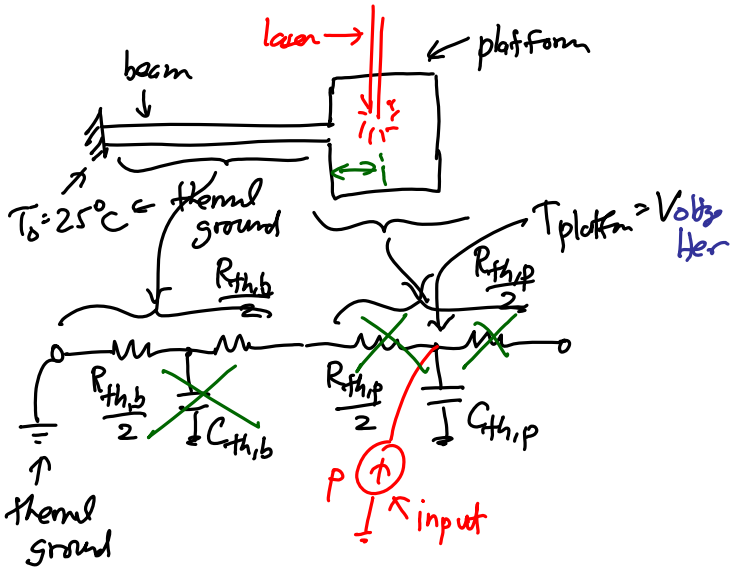
⇒ thermal resistance: $R_{th} = \frac{l}{kA}$ ← length; cross-sectional area; ↑ thermal conductivity

Examples

Ex. MEMS type structure (top view)



What is the temperature on the platform?



Analogies:

(temperature) T → V (voltage)

(power) P → I (current)

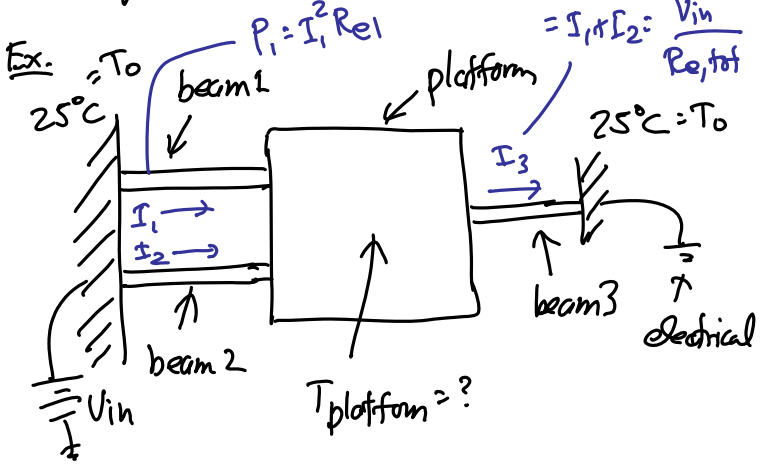
Thermal ← → Electrical

To Analyze:

① Remove small elements to simplify the dof.

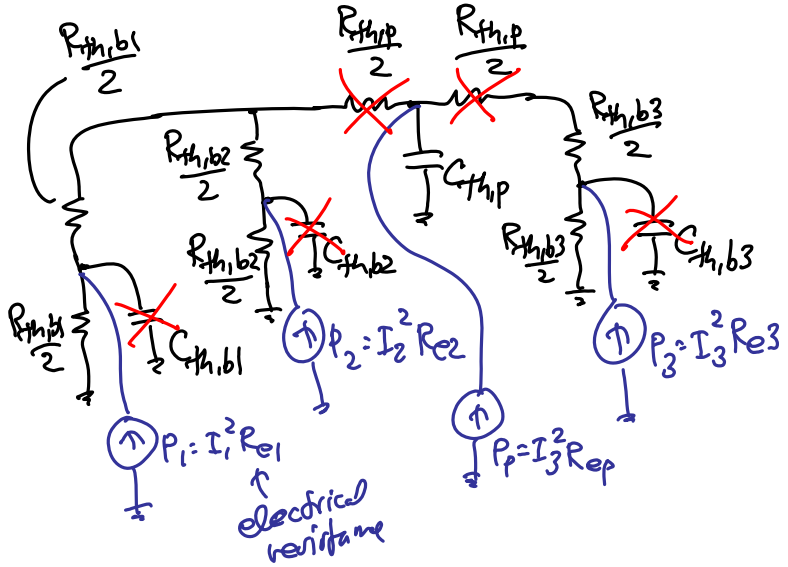
② $T_{platform} = PR_{th,b}$ (in steady-state)

(just like V = IR in an electrical system)



⇒ coupled thermal, electrical system

⇒ Draw the thermal ckt:



To Analyze:

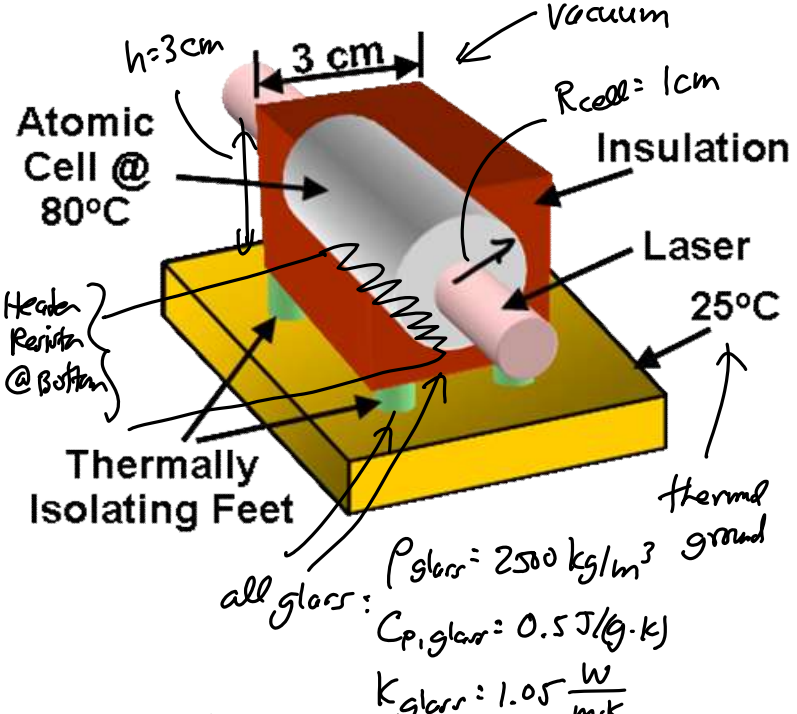
① $I_3 = I_1 + I_2 = \frac{V_{in}}{R_{e,tot}}$ (electrical analysis)

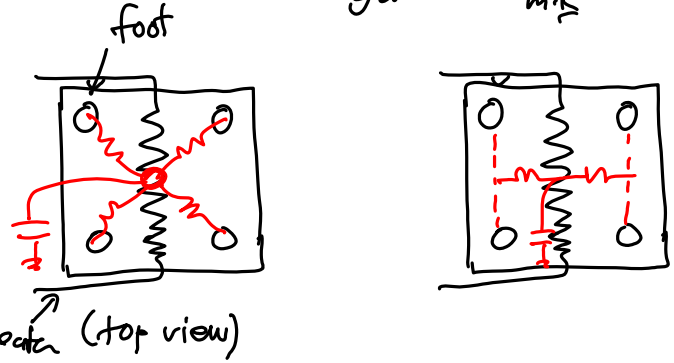
② Get P_i's. (powers)

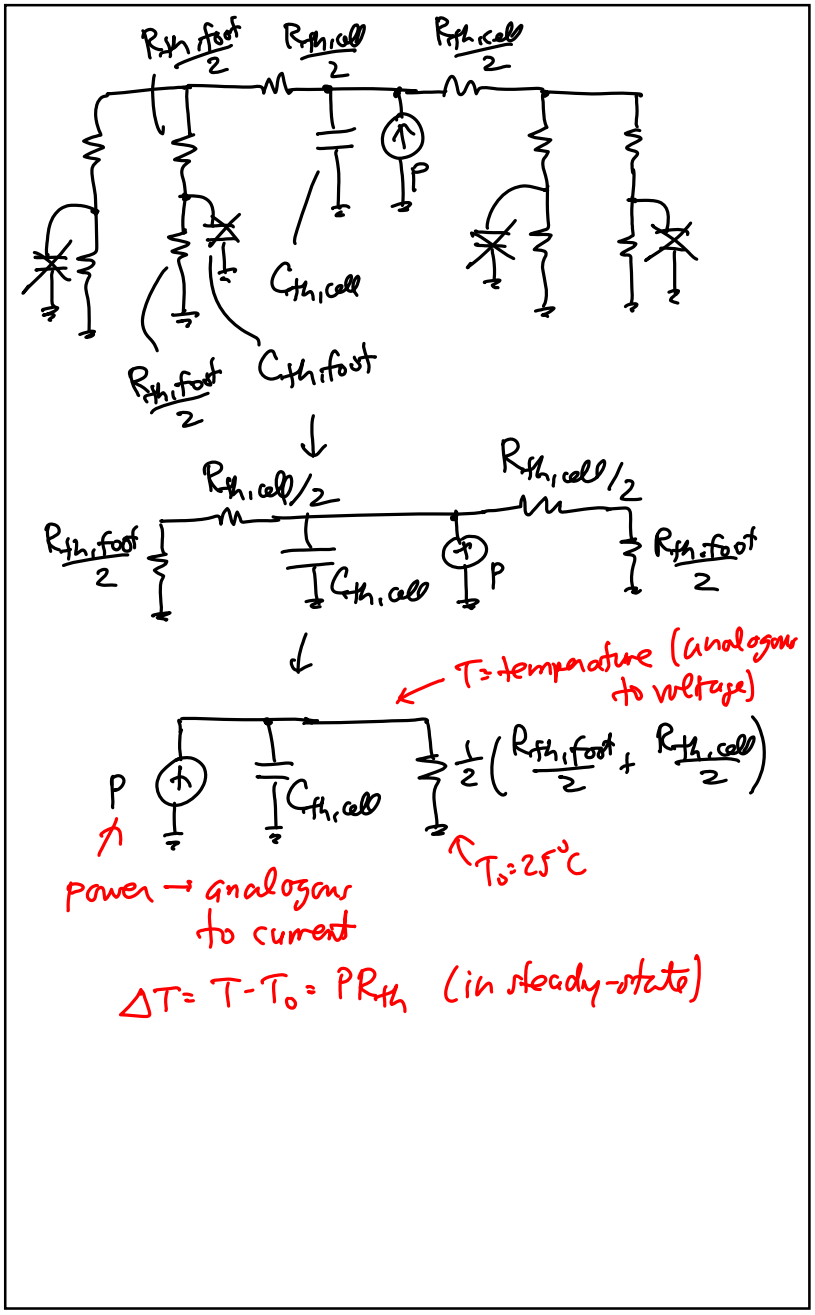
③ Use superposition to solve the thermal ckt.
handle one power source at a time & sum the temperatures (i.e., thermal voltages) to get the total temperature at any node

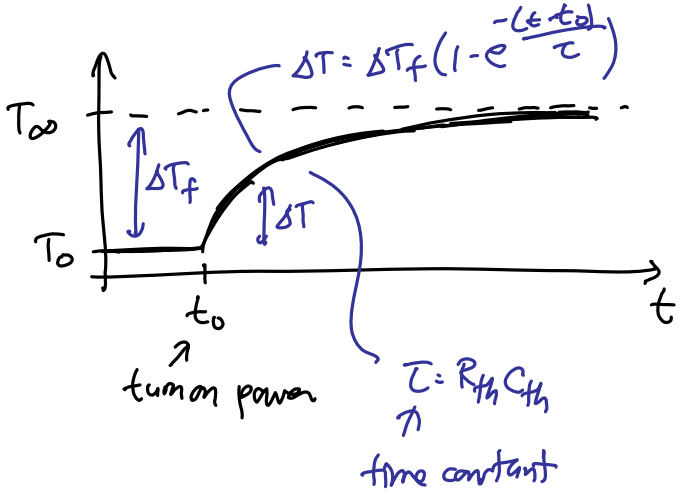
Example: Thermal Ckt.

⇒ determine the power needed to get this atomic cell to 80°C (from RT) & how fast





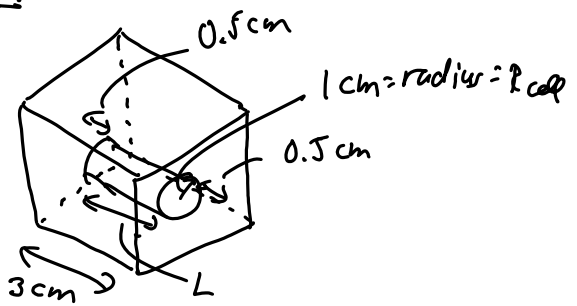




Find $C_{th,cell}$:

↓

First, find the cell volume:



$$V_{cell} = hWL - \pi R_{cell}^2 \cdot L$$
$$= (3\text{cm})(3\text{cm})(3\text{cm}) - \pi(1\text{cm})^2(2\text{cm}) = 20.7\ \text{cm}^3$$

$$C_{th,cell} = \rho_{glass} V_{cell} C_{p,glass}$$
$$= \left(2500\ \frac{\text{kg}}{\text{m}^3}\right)\left(1000\ \frac{\text{g}}{\text{kg}}\right)\left(\frac{1}{100^3}\ \frac{\text{m}^3}{\text{cm}^3}\right) \times (20.7\ \text{cm}^3)\left(0.5\ \frac{\text{J}}{\text{g}\cdot\text{K}}\right)$$

$$\Rightarrow C_{th,cell} = 25.9\ \text{J/K}$$