1. Energy Scavenging or Salvaging or Harvesting

→ capturing energy present in the enviroment and converting it to electrical energy for current or future use (storage)

a. Energy sources possibly present in an operating environment:

① light (IR, visible, UV)
② heat
③ mechanical vibrations
④ mechanical impact
⑤ acoustic
⑥ fluid flow (wind, flowing liquid)
⑦ RF
⑧ radiation (x-ray, Beta, etc.)
⑨ chemical
⑩ static discharge
⑪ repetitive motion (arm motion, walking, etc.)

b. motivation

→ MEMS Technology ⇒ excellent for realizing micro-sensors
- → small, lightweight, inexpensive, disposable
- → can transmit data wirelessly
- → power ?

→ Power Option:

① wires from remote power supply → limits use
② batteries → limits lifetime unless batteries can be changed
③ energy scavenging → could solve these issues

2. Non-MEMS Energy Scavenging Techniques that are MEMS Compatible

a. Photovoltaics → i.e. solar cells

→ PN junction

→ for locations with ambient light

b. Peltier Effect Devices

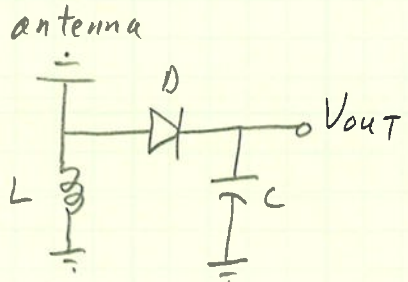
TEC → "Thermoelectic Cooler" → a PN junction → apply a voltage across it and one side heats while the other side cools → a semiconductor heat pump

However → if you heat one side with respect to the other side → it will generate electricity

→ low energy conversion efficiency

c. Retenna

→ converts received ambient RF energy to DC



L → DC path to ground

D → rectifier circuit

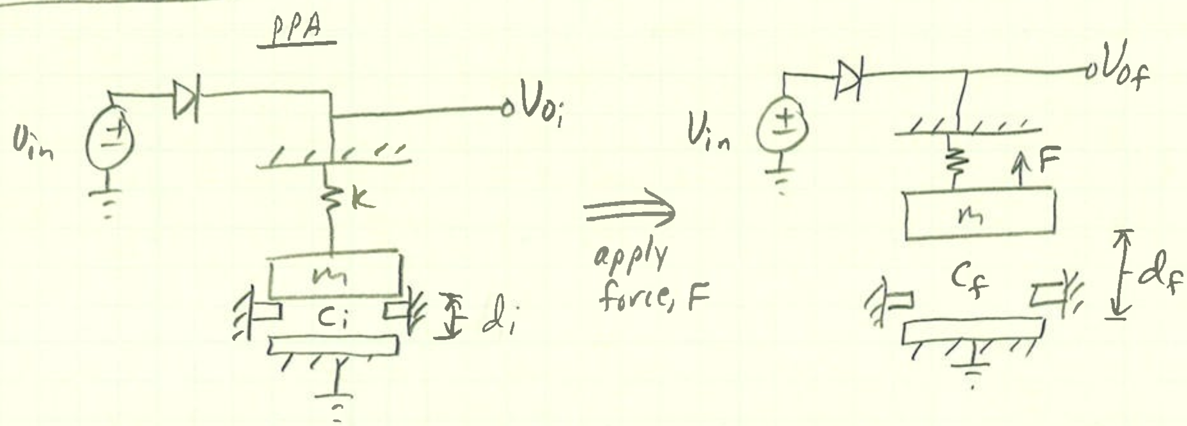
C → energy storage

→ antenna can be designed for a particular frequency band

3. MEMS Energy Scavenging

a. Electrostatic Vibration Energy Scavenging

Consider this



$V_{in} > V_p$: mech. stops prevent electrode shorting

For discussion: let F be such that $d_f = 2d_i$

For $F = 0$: $V_{oi} = V_{in}$

$$C_i = \frac{\varepsilon_0 \varepsilon_r A}{d_i}$$

$$E_i = \frac{1}{2} C_i V_{oi}^2$$

$$Q = C_i V_{oi}$$

For F applied : $d_f = 2d_i$

$$C_f = \frac{\varepsilon_0 \varepsilon_r A}{d_f} = \frac{\varepsilon_0 \varepsilon_r A}{2d_i} = \frac{C_i}{2}$$

$$Q = C_i V_{oi} = C_f \cdot V_{of}$$

$$\therefore C_i V_{oi} = \tfrac{1}{2} C_i V_{of}$$

or $V_{of} = 2V_{oi} = 2V_{in}$: Q = constant : $C\downarrow : V\uparrow$

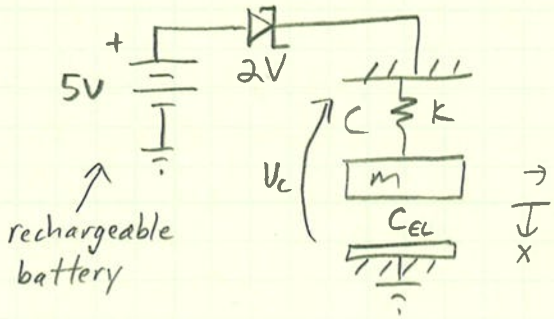
$$E_f = \frac{1}{2} C_f V_{of}^2 = \frac{1}{2}\left(\frac{1}{2}C_i\right)(2V_{oi})^2 = C_i V_{oi}^2$$

$$\therefore E_f = 2E_i$$

→ mechanical motion has been converted to electrical energy stored in the capacitor

Vibrational Electrostatic Energy Scavenging

Consider this:



→ $\omega_n = \sqrt{\frac{k}{m}}$, $5V < V_p$ + motion never reaches unstable equilibrium point B

resonate the SMD device at f_n

for $\dot{x} > 0$: C ↑, V_c ↓ until forward biased diode turns on

→ C_{EL} at ~5V an $C_{EL_{max}}$

for $\dot{x} < 0$: C ↓, V_c ↑ until $V_c \approx 7V$ and zener diode turns on in reverse

→ charge is pumped into battery at ~7V, recharging the battery

→ this happens at frequency, f_n

<u>Notice</u>: Scavenged Power $\propto f_n$, * battery must be partially charged to work

a. <u>Other Configurations</u>

① use an electret instead of a battery → more difficult to fabricate

② Magnetic equivalent: permanent magnet and a coil in relative motion

③ Piezoelectric energy scavenger

→ timevarying strain ⇒ time varying voltage

→ more efficient than electrostatic device: $\varepsilon_{r_p} \gg \varepsilon_{r_{air}}$

→ more difficult to fabricate than electrostatic energy scavenging devices