- Tuesday, 4/16, will be a video lecture
- Thursday, 4/18 lecture: we'll see

Reading: Senturia, Chpt. 5, Chpt. 6

Lecture Topics:

- —Electrical Stiffness
- Electrostatic Comb-Drive
  - —1st Order Analysis
  - —2nd Order Analysis

Reading: Senturia, Chpt. 6, Chpt. 14

Lecture Topics:

- Input Modeling
  - —Force-to-Velocity Equiv. Ckt.
  - —Input Equivalent Ckt.
- Current Modeling
  - —Output Current Into Ground
  - —Input Current
  - —Complete Electrical-Port Equiv. Ckt.
- Impedance & Transfer Functions

Last Time:

Electrical stiffness …

Force terms @ ω_o

$$F_{d1}\big|_{\omega_o} = V_{P1}\frac{C_{o1}}{d_1}|v_1|\cos\omega_o t + V_{P1}^2\frac{C_{o1}}{d_1^2}|x|\sin\omega_o t$$

drive force term

k_e → electrical stiffness

proportional to x!

90° phase-shifted f/

∴ in phase w/ displacement!

∴ it's a stiffness!

Electrical Stiffness:

① A negative spring constant!

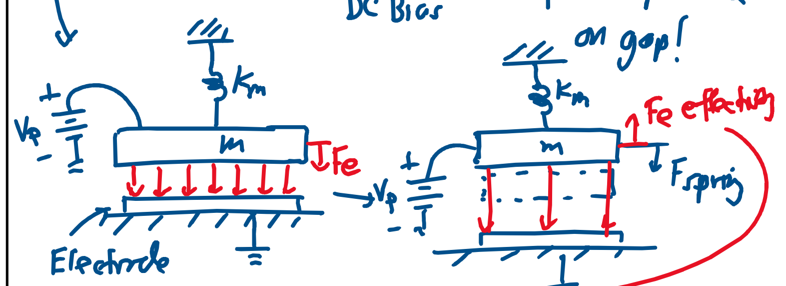
② Derives from V_P:

$$k_e = V_{P1}^2\frac{C_{o1}}{d_1^2} = V_{P1}^2\frac{\epsilon A}{d_1^3}$$

overlap area of the C

DC Bias

3rd power dependence on gap!



∴ negative stiffness!

$k_e \to$ can influence resonance freq. ω_o

$\omega_o \triangleq$ radian resonance freq. w/ no V_P applied (i.e., w/ $V_{P1} = 0V$)

$$\omega_o' = \sqrt{\frac{k_{tot}}{m}} = \sqrt{\frac{k_m - k_e}{m}} \qquad k_m = \text{mech. stiffness}$$

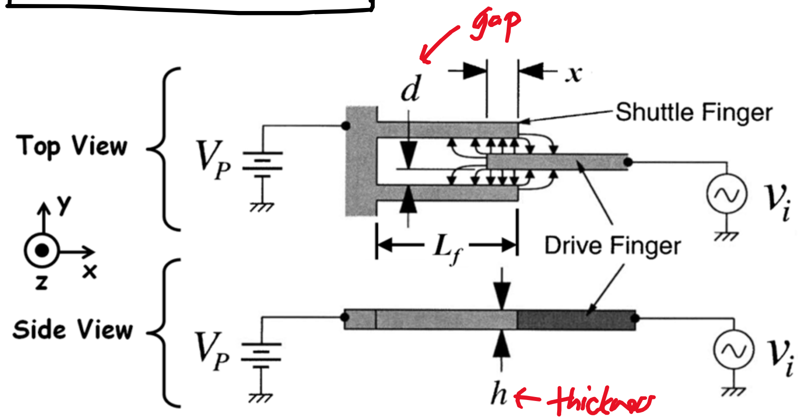
$$= \sqrt{\frac{k}{m}}\left(1 - \frac{k_e}{k_m}\right)^{1/2}$$

$$\boxed{\omega_o' = \omega_o\left[1 - \frac{V_{P1}^2}{k_m}\frac{\epsilon A}{d_1^3}\right]^{1/2}}$$

now a fcn of dc bias V_{P1}! (voltage-controllable!)

- Go through Module 12, slides 26-35

Electrostatic Comb-Drive



$$F_d = \frac{\partial W'}{\partial x} = \frac{1}{2}\frac{\partial C}{\partial x}(V_P - v_i)^2$$

$$C(x) = \frac{2\epsilon_o x h}{d} \to \frac{\partial C}{\partial x} = \frac{2\epsilon_o h}{d}$$ — Not a function of x! (ideally)

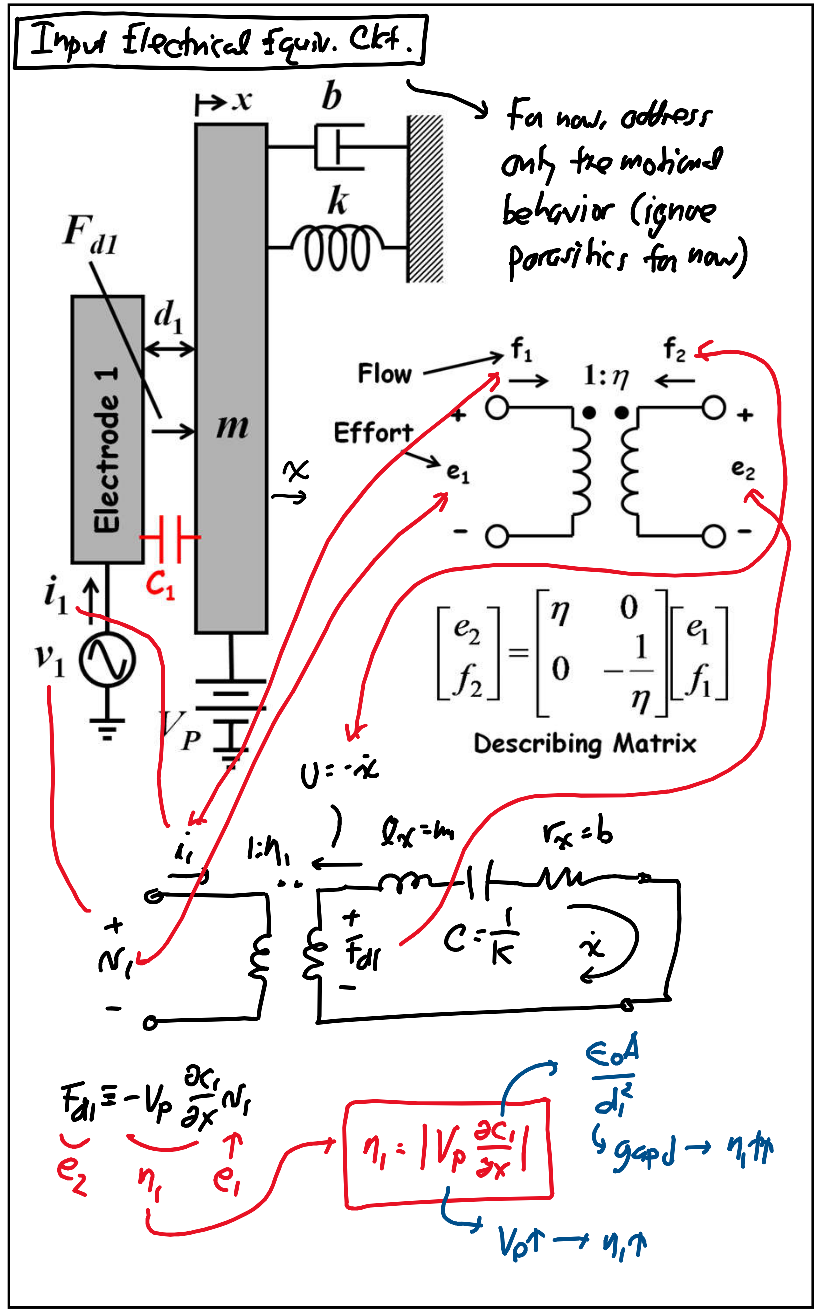
$$F_d = \frac{1}{2}\frac{2\epsilon_o h}{d}(\cancel{V_P^2} - 2V_P v_i + \cancel{v_i^2})$$

can balance out via symmetry (symmetrically placed electrodes)

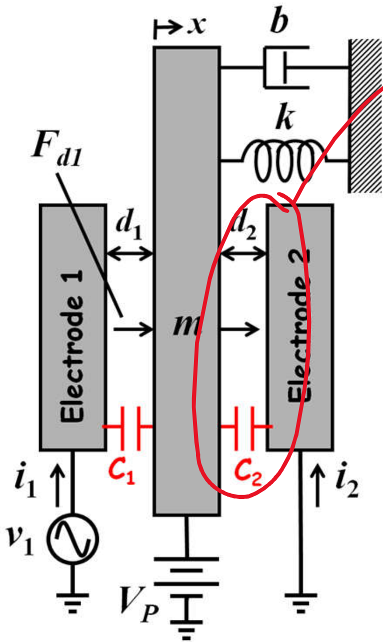
$$\boxed{F_d = -2V_P\frac{\epsilon_o h}{d}v_i}$$ ← linear w/ v_i!

∴ no electrical stiffness! (no k_e!)

- Go through remaining comb-drive slides in Module 12
- Start Module 13: go thru first few slides up to transformer definition
- Then …



Output Current Into Ground



Want this model.

$[q = CV]$

$$i = \frac{dq}{dt} = C\frac{dV}{dt} + V\frac{dC}{dt}$$