EE C247B – ME C218 Introduction to MEMS Design Spring 2019

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Lecture Module 12: Capacitive Transducers

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Lecture Outline

- Reading: Senturia, Chpt. 5, Chpt. 6
- Lecture Topics:
  - Energy Conserving Transducers
    - Charge Control
    - Voltage Control
  - Parallel-Plate Capacitive Transducers
    - Linearizing Capacitive Actuators
    - Electrical Stiffness
  - Electrostatic Comb-Drive
    - 1st Order Analysis
    - 2nd Order Analysis

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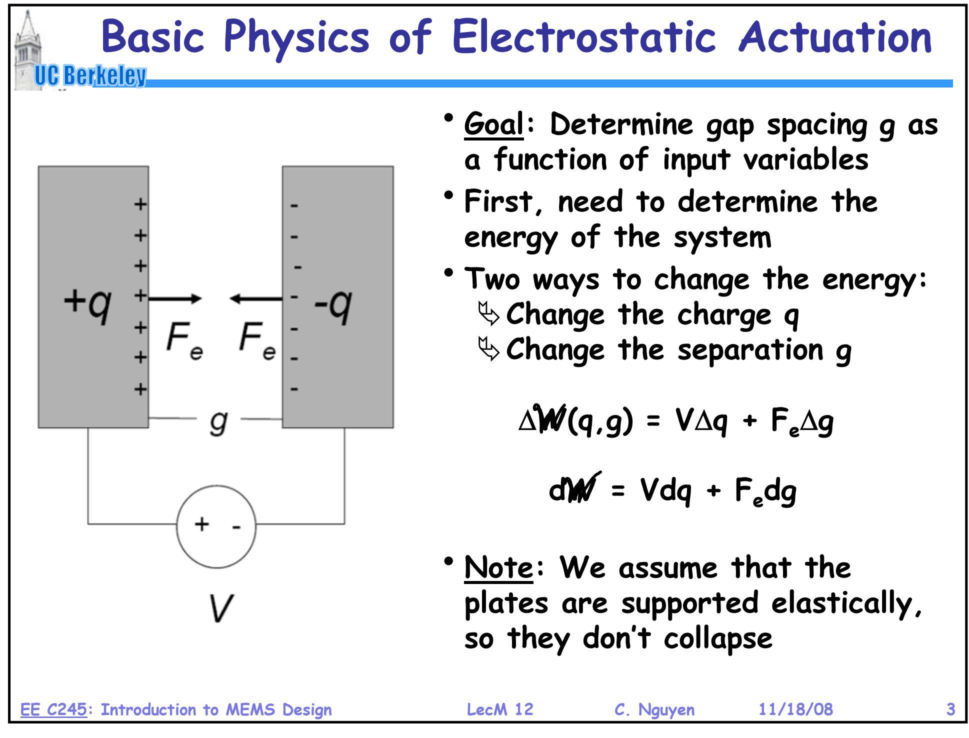

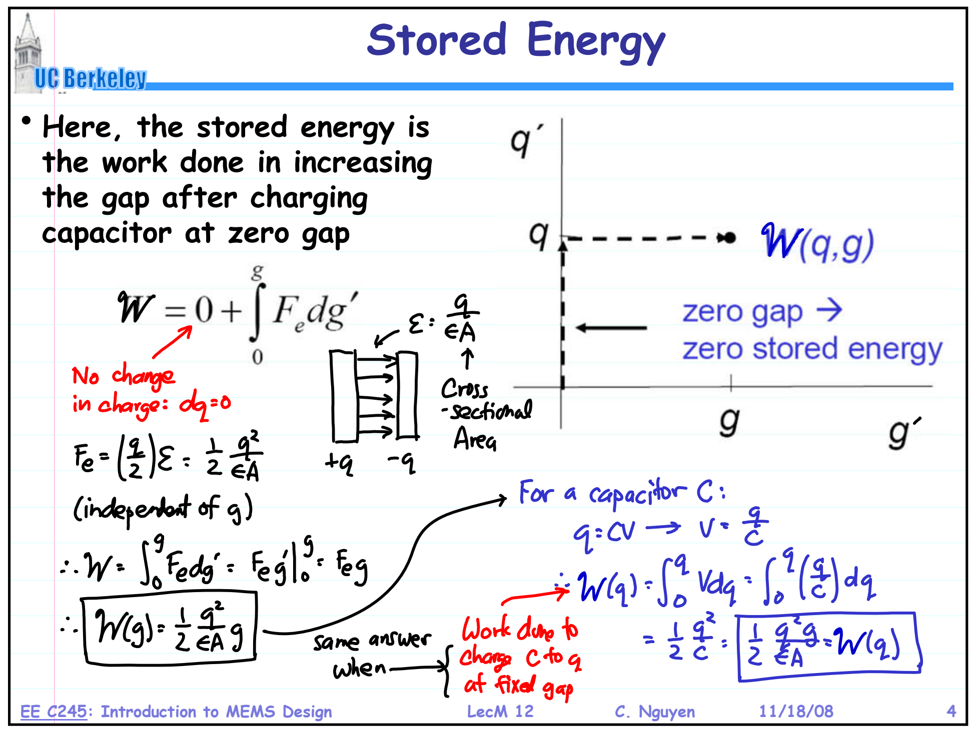

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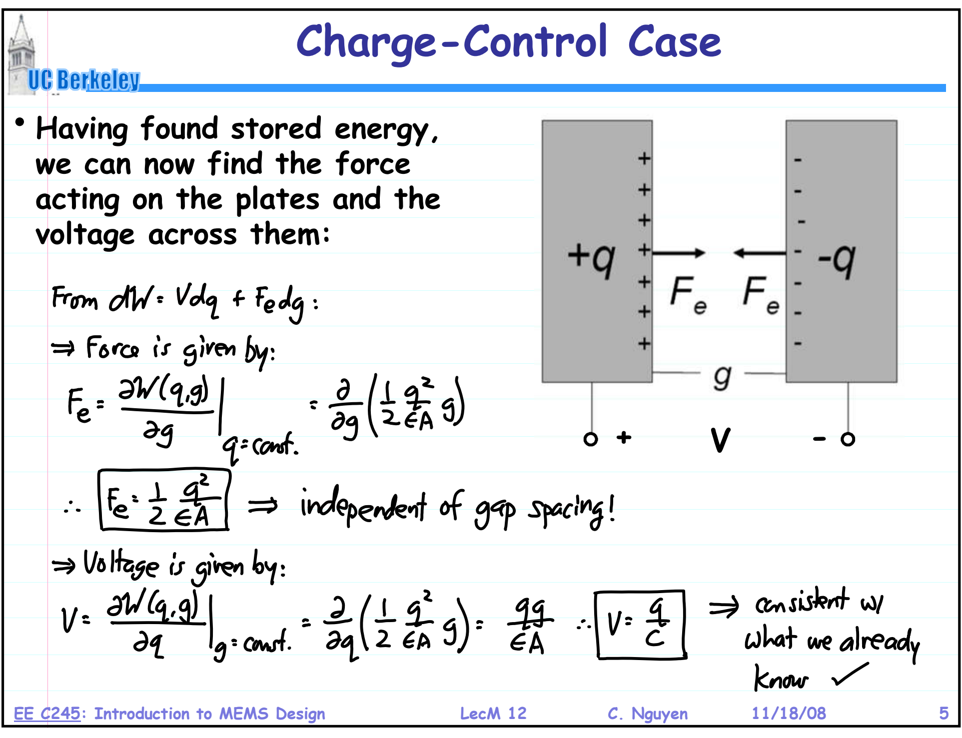

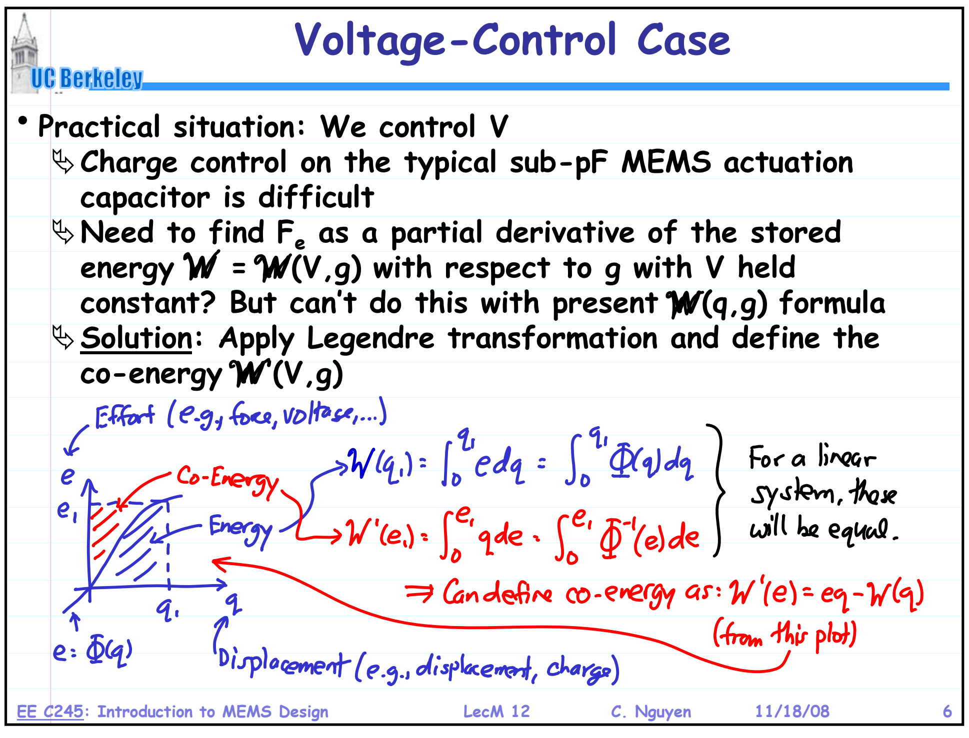

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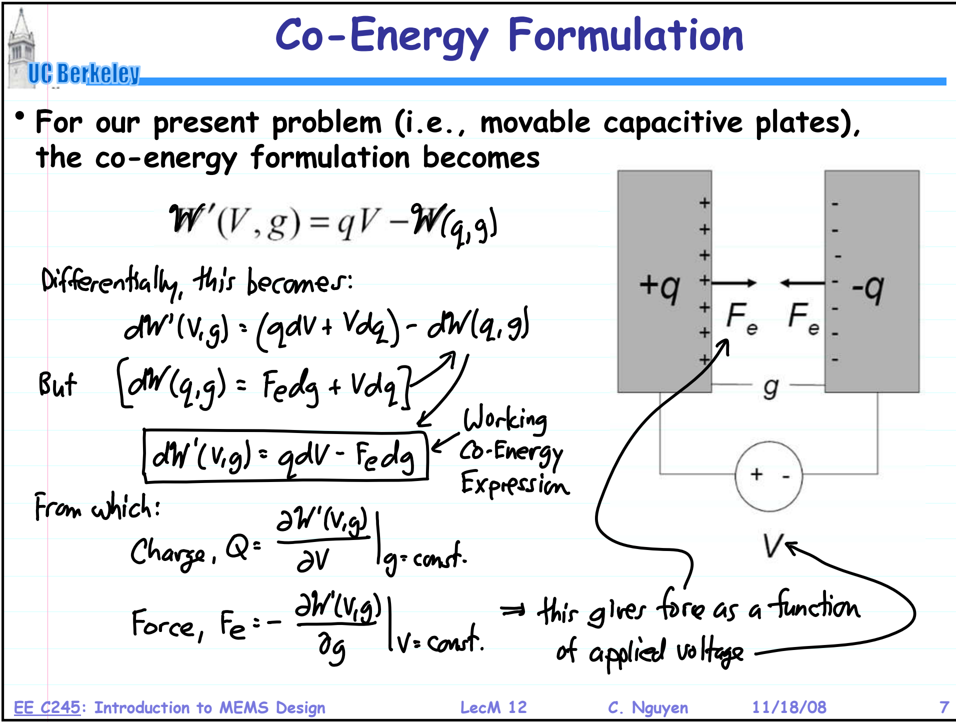

Electrostatic Force (Voltage Control)

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- Find co-energy in terms of voltage *(w/ gap held constant)*

$$\mathcal{W}' = \int_0^V q(g, V')dV' = \int_0^V \left(\varepsilon \frac{A}{g}\right)V'dV' = \frac{1}{2}\left(\frac{\varepsilon A}{g}\right)V^2 = \frac{1}{2}CV^2$$

(as expected)

- Variation of co-energy with respect to gap yields electrostatic force:

$$F_e = -\left.\frac{\partial \mathcal{W}'(V,g)}{\partial g}\right|_V = -\frac{1}{2}\left(-\frac{\varepsilon A}{g^2}\right)V^2 = \frac{1}{2}\frac{C}{g}V^2$$

strong function of gap!

- Variation of co-energy with respect to voltage yields charge:

$$q = \left.\frac{\partial \mathcal{W}'(V,g)}{\partial V}\right|_g = \left(\frac{\varepsilon A}{g}\right)V = CV \quad \text{as expected}$$

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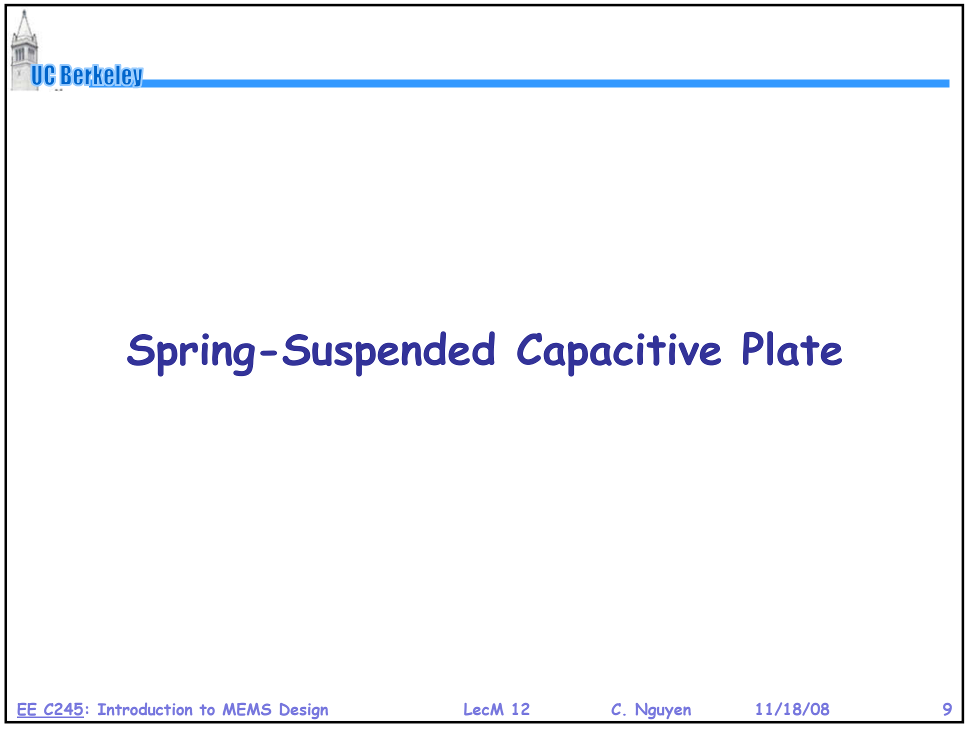

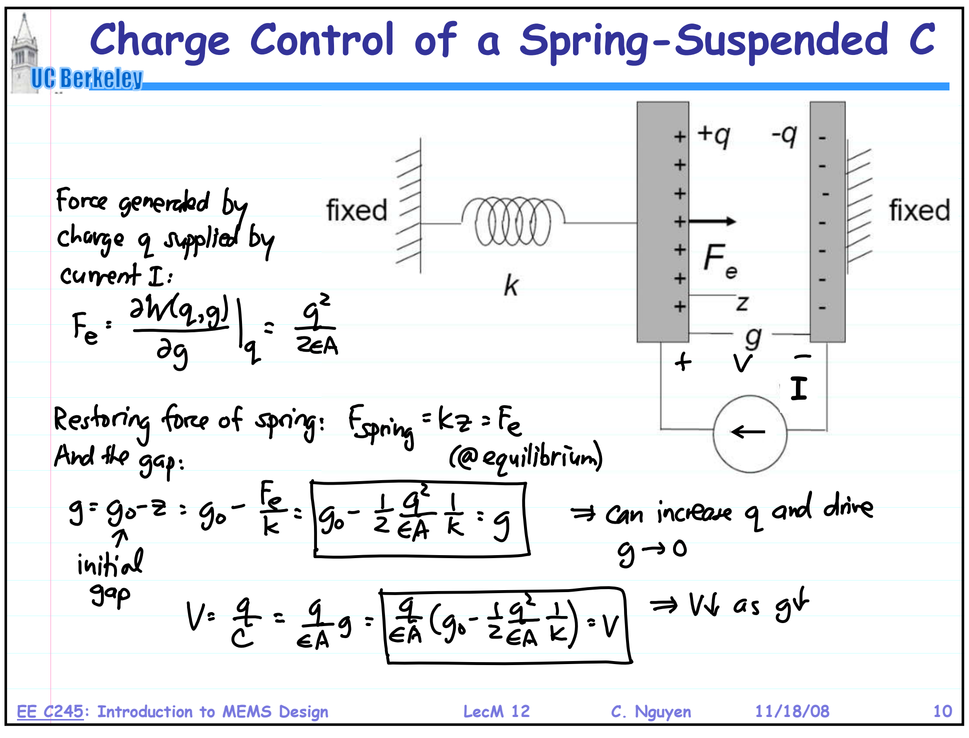

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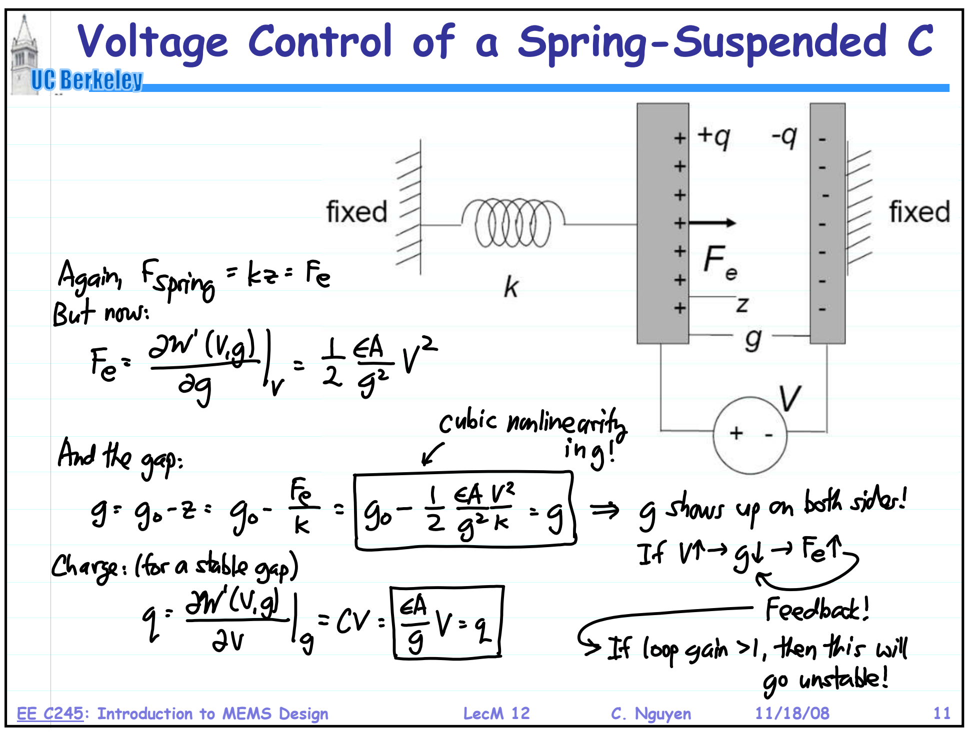

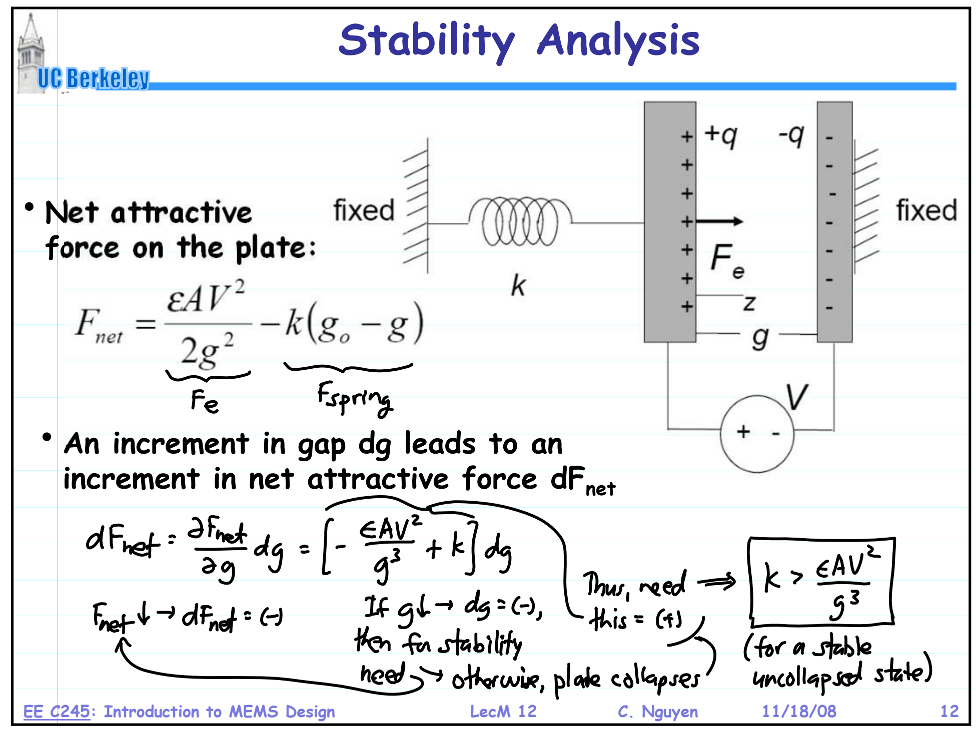

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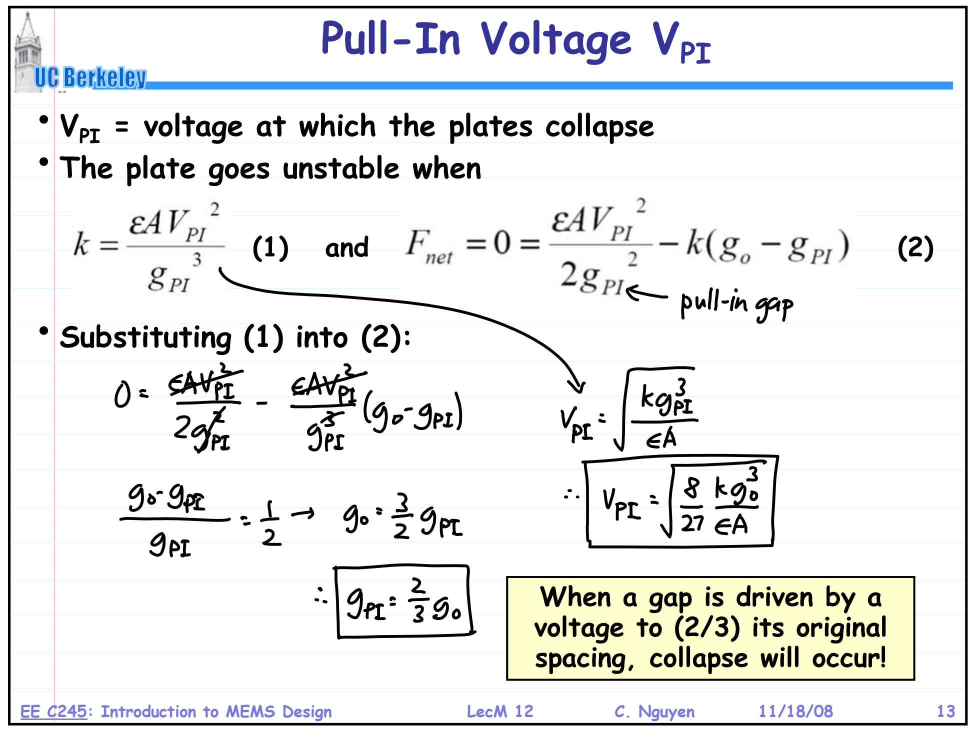

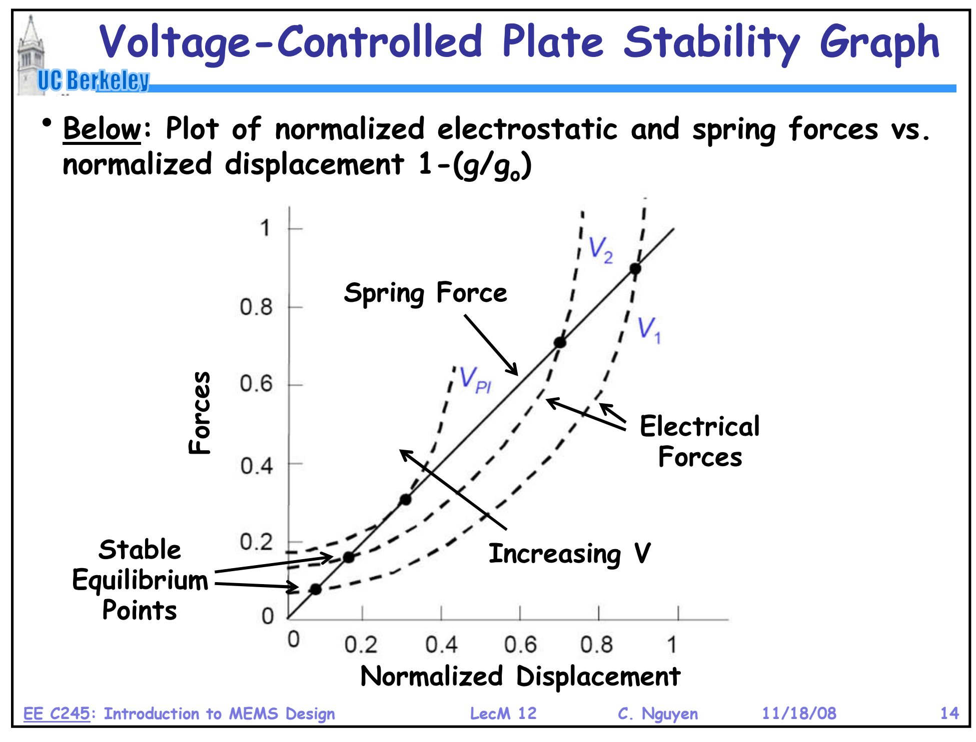

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Advantages of Electrostatic Actuators

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- Easy to manufacture in micromachining processes, since conductors and air gaps are all that's needed → low cost!
- Energy conserving → only parasitic energy loss through I^2R losses in conductors and interconnects
- Variety of geometries available that allow tailoring of the relationships between voltage, force, and displacement
- Electrostatic forces can become very large when dimensions shrink → electrostatics scales well!
- Same capacitive structures can be used for both drive and sense of velocity or displacement
- Simplicity of transducer greatly reduces mechanical energy losses, allowing the highest Q's for resonant structures

Problems With Electrostatic Actuators

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- Nonlinear voltage-to-force transfer function
- Relatively weak compared with other transducers (e.g., piezoelectric), but things get better as dimensions scale

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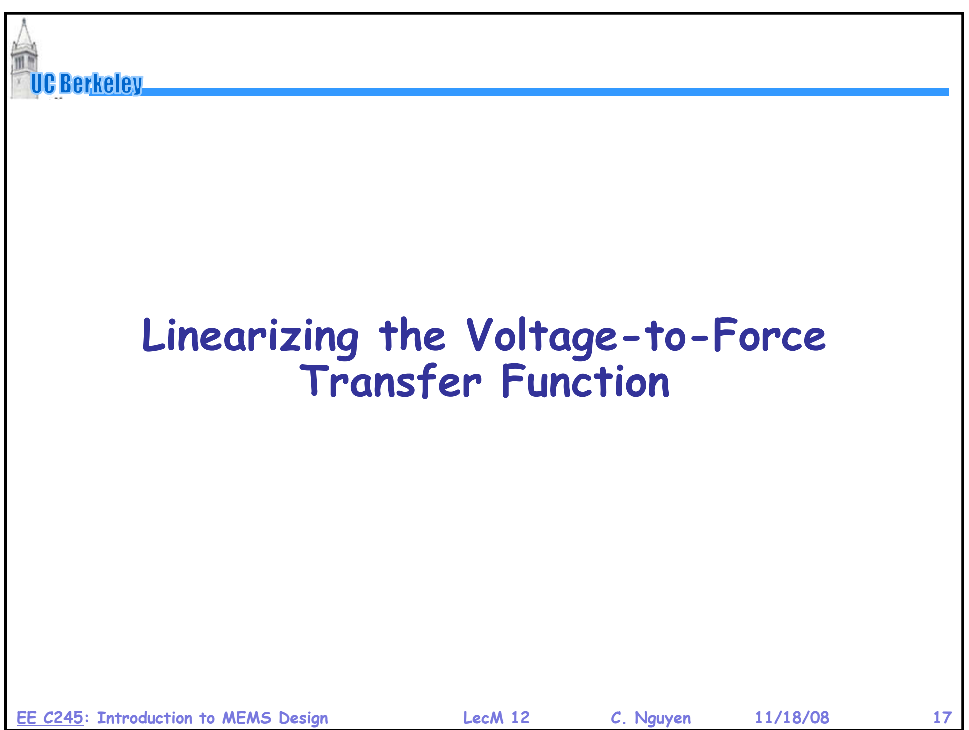

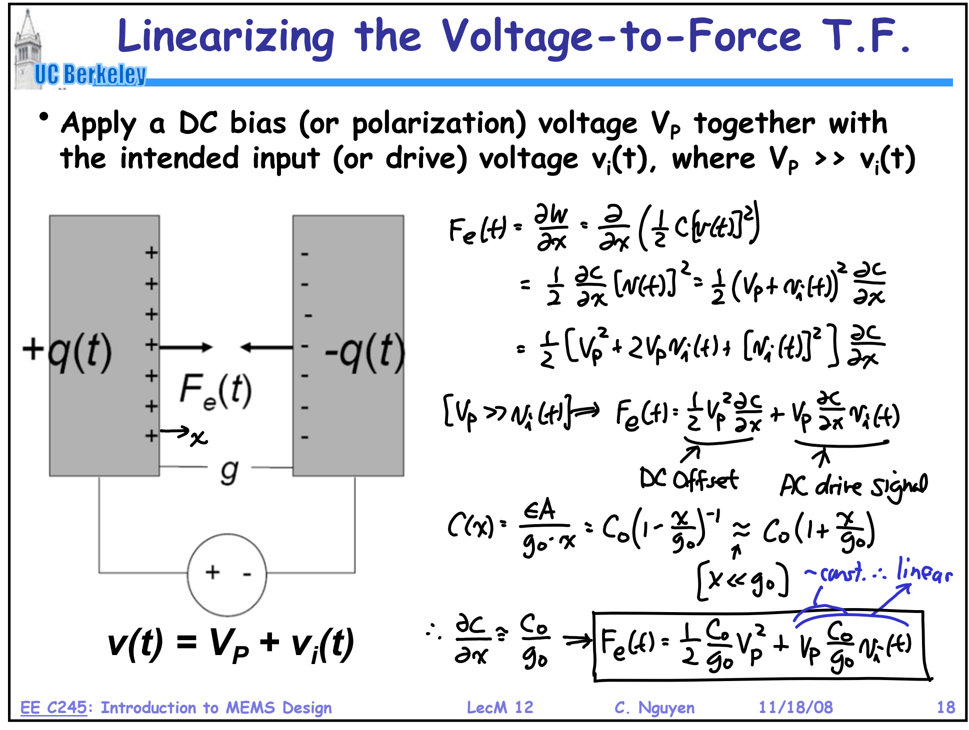

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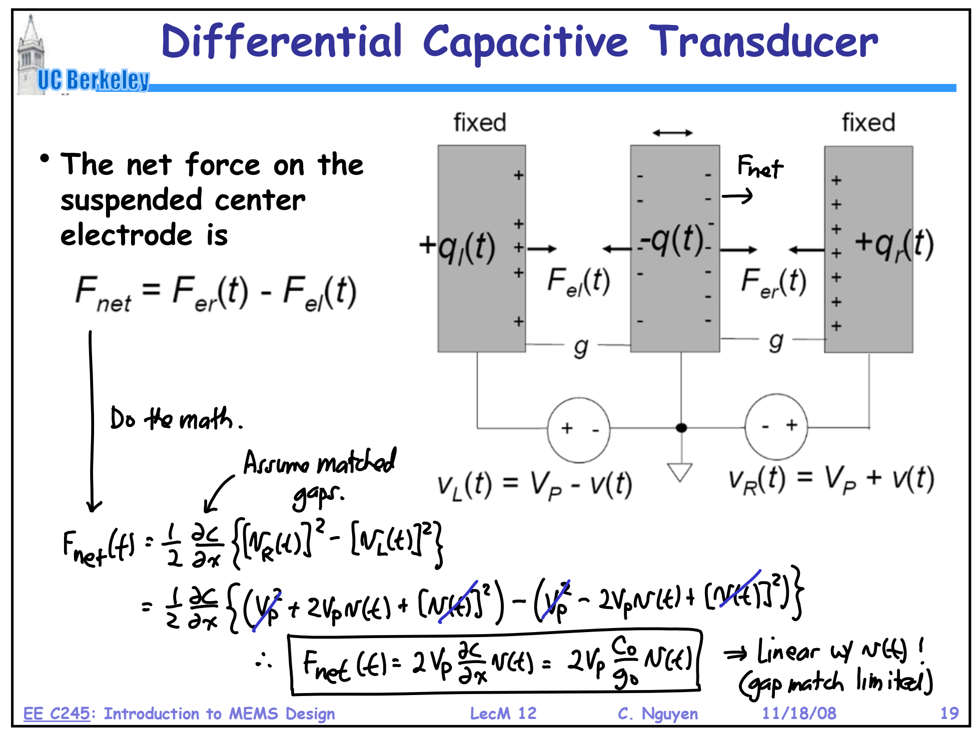

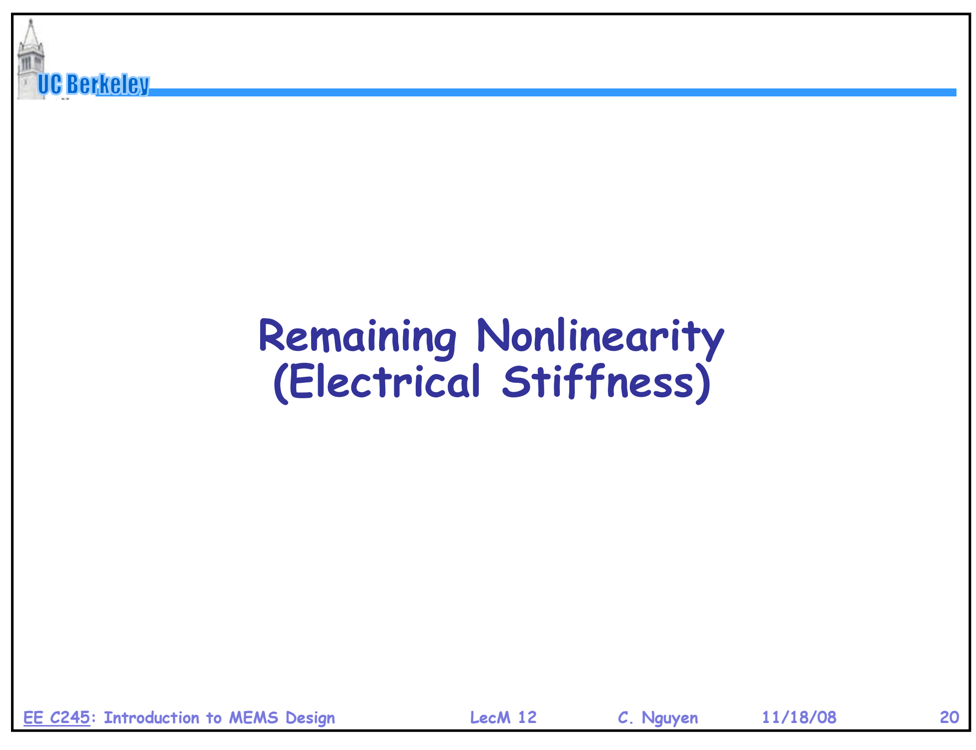

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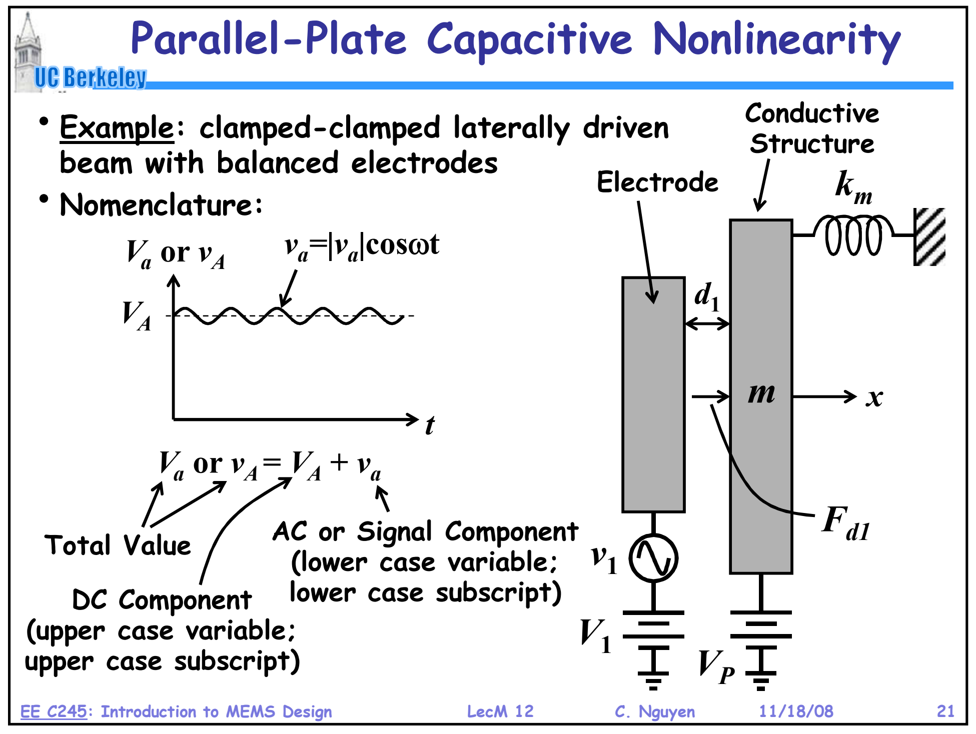

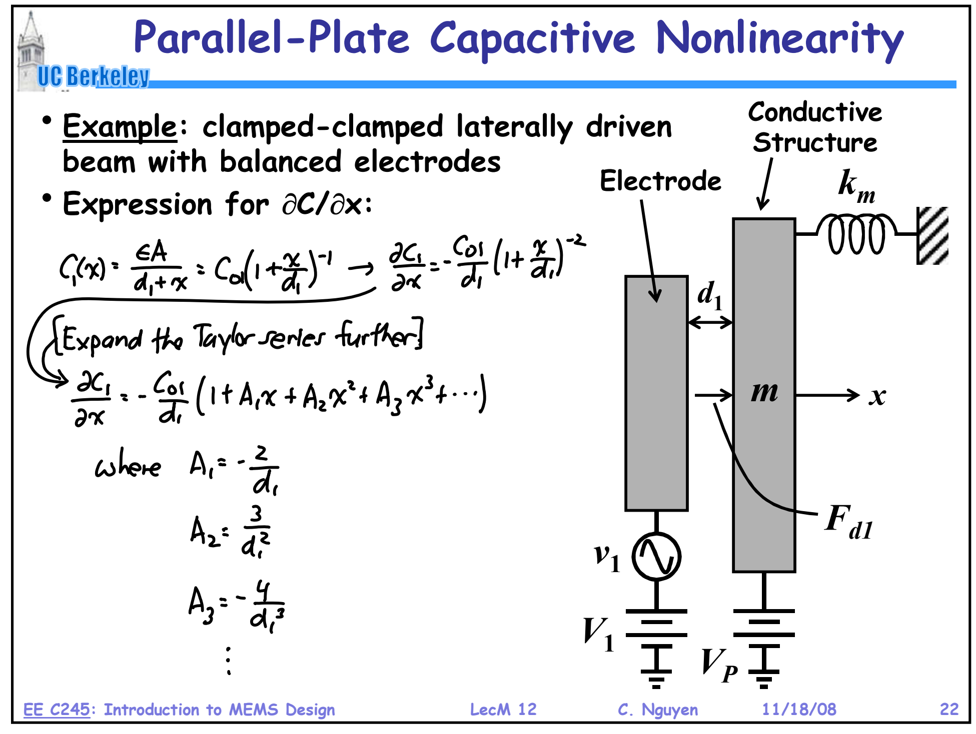

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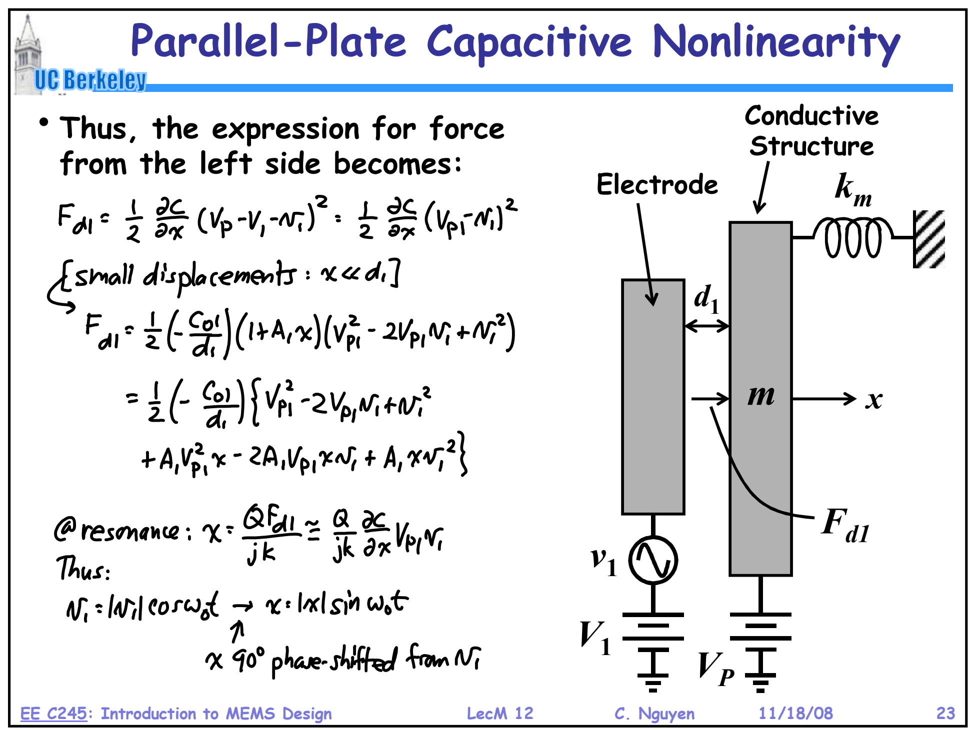

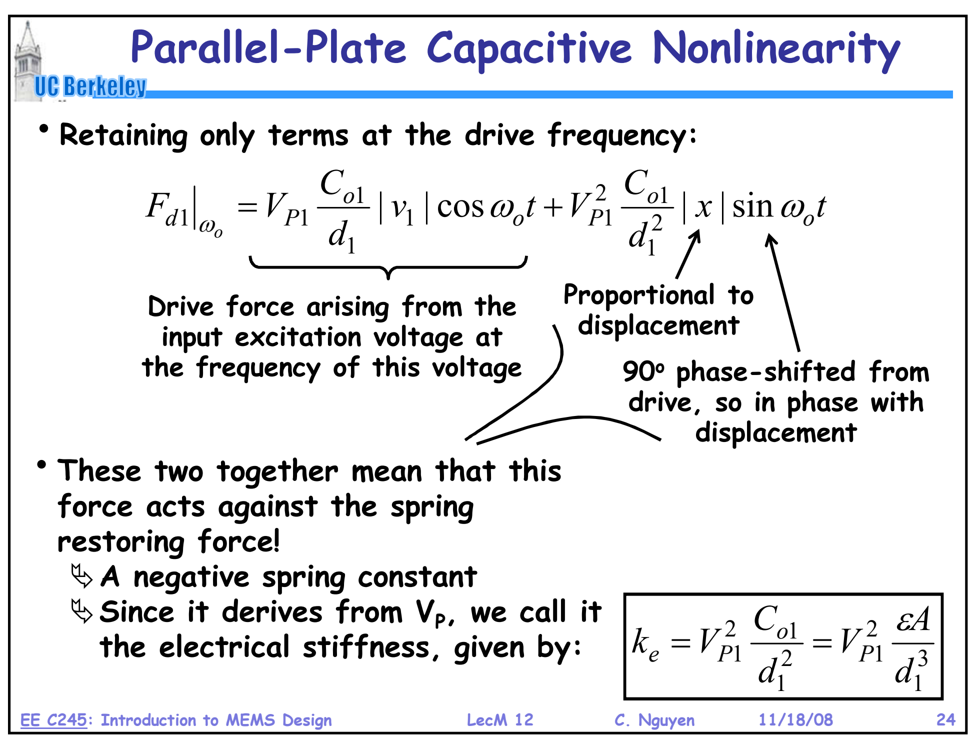

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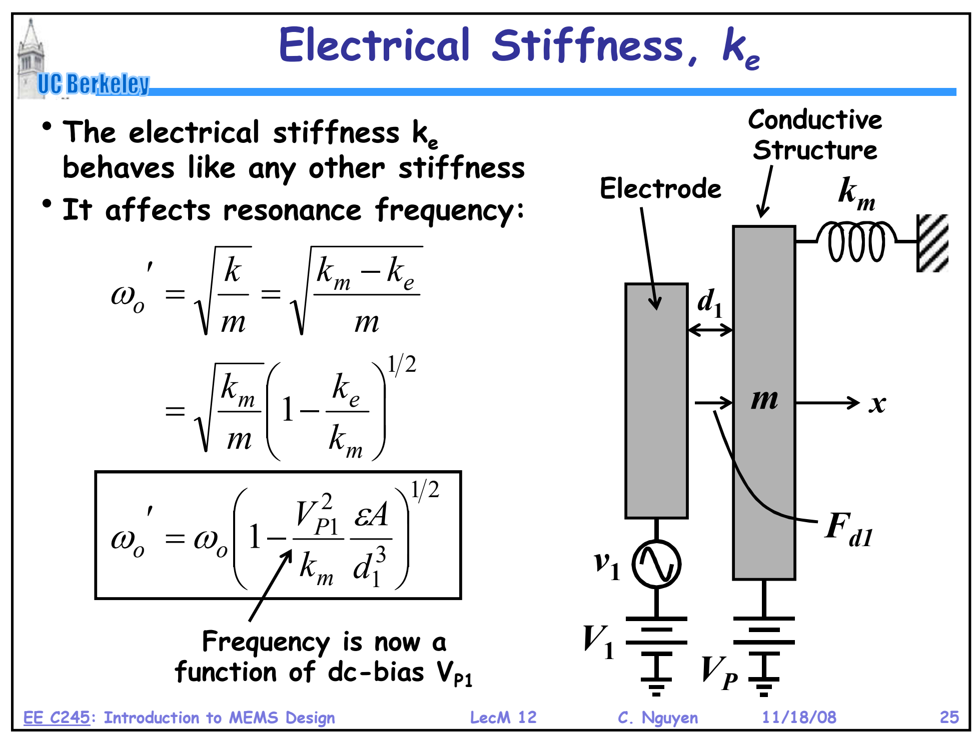

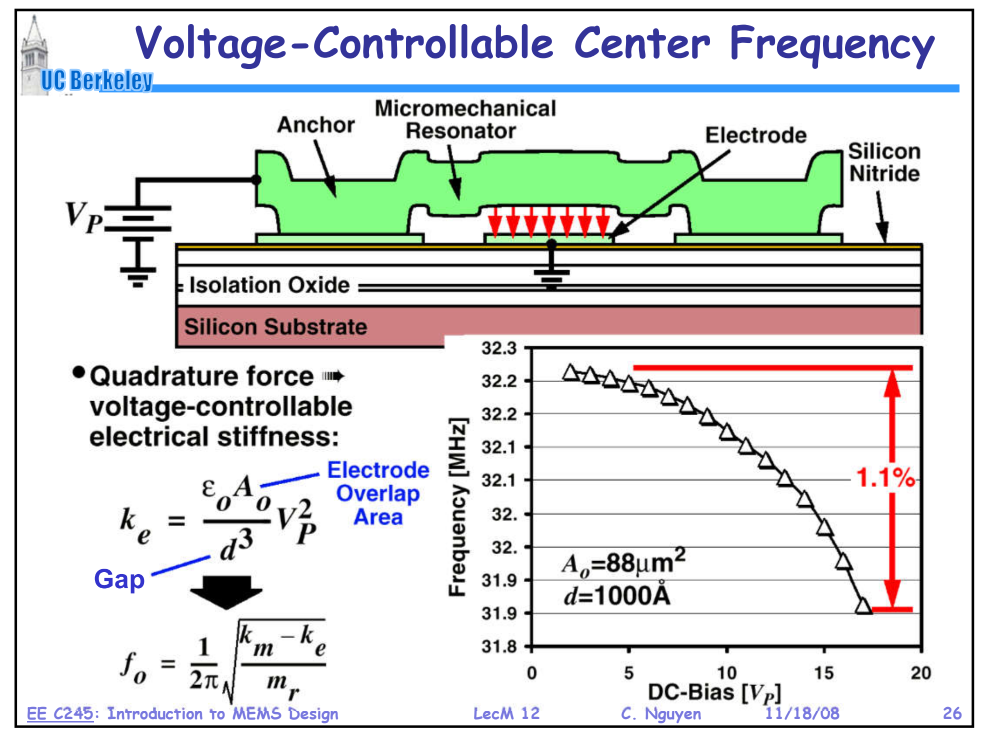

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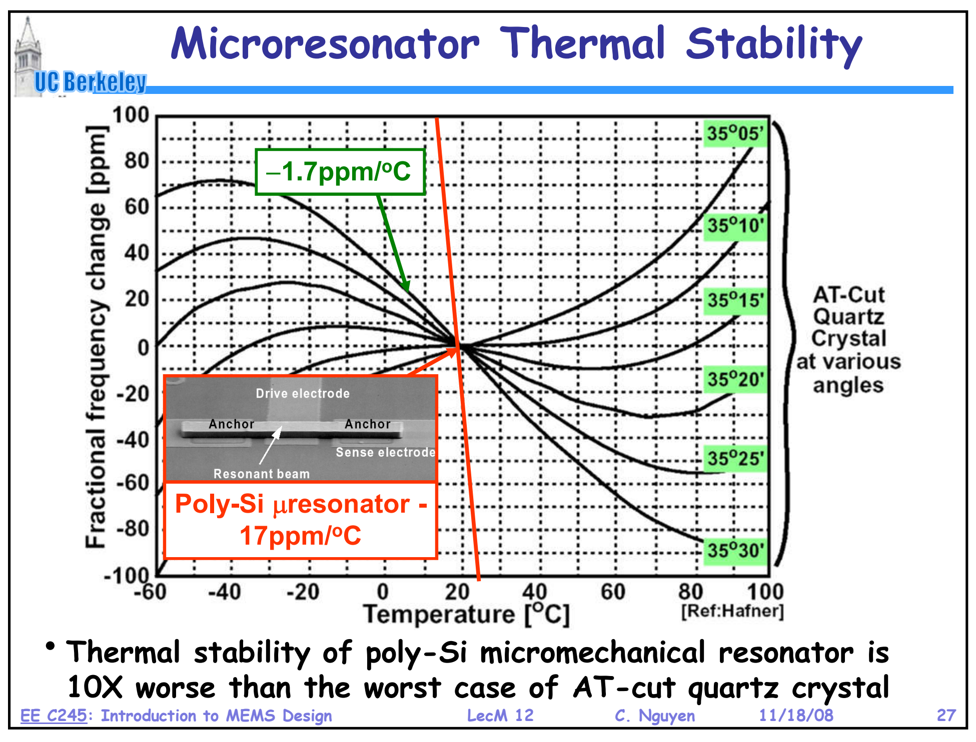

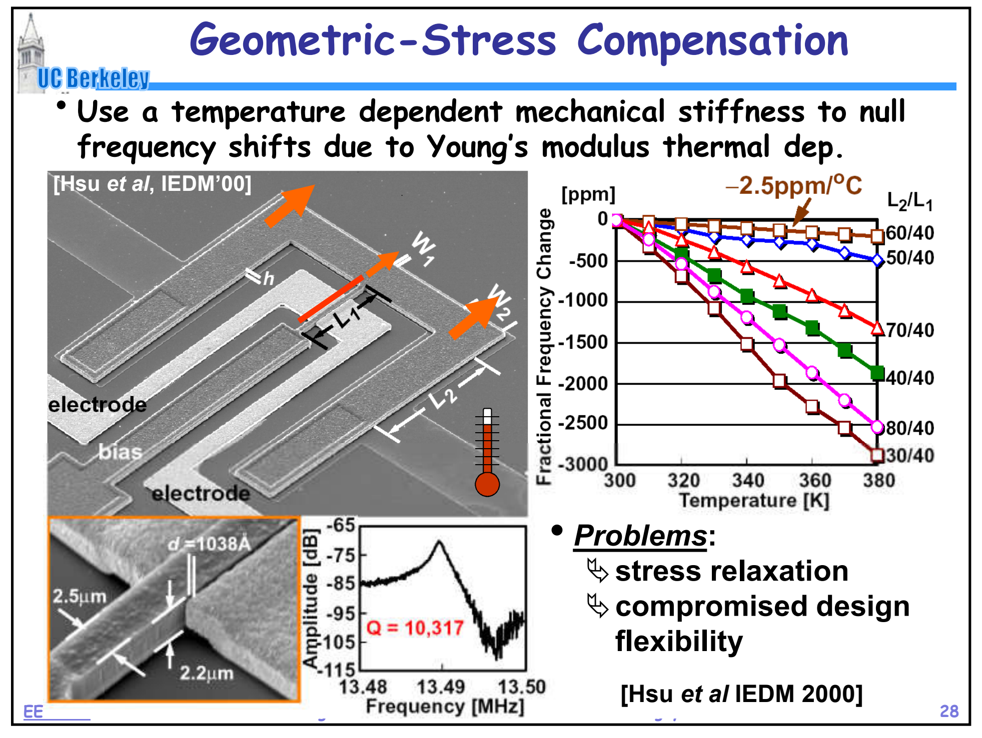

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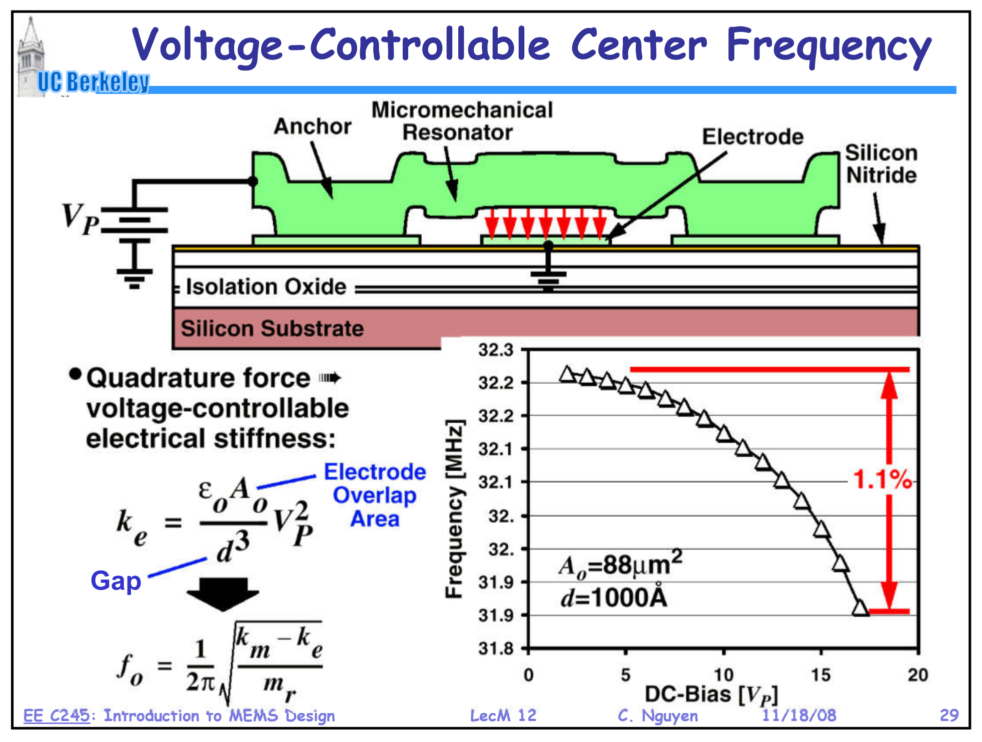

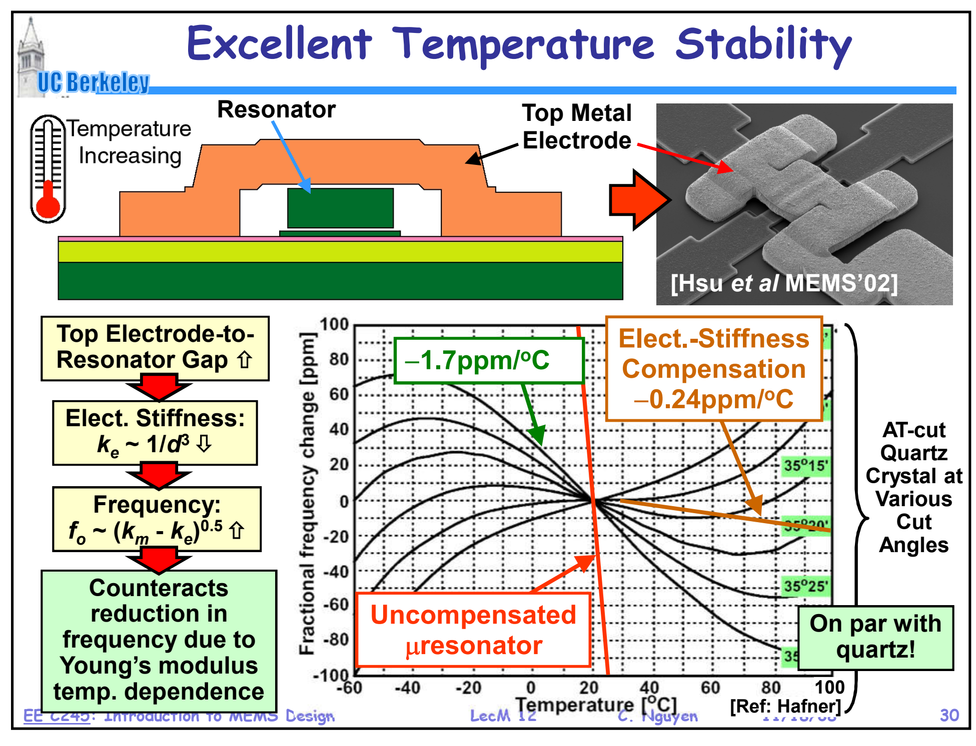

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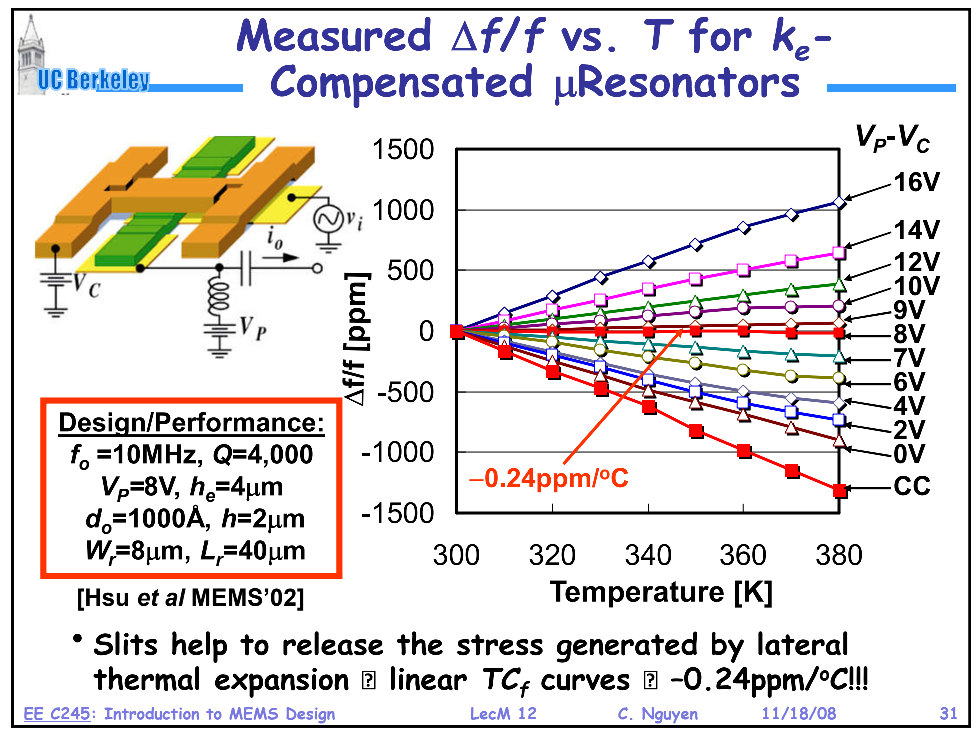

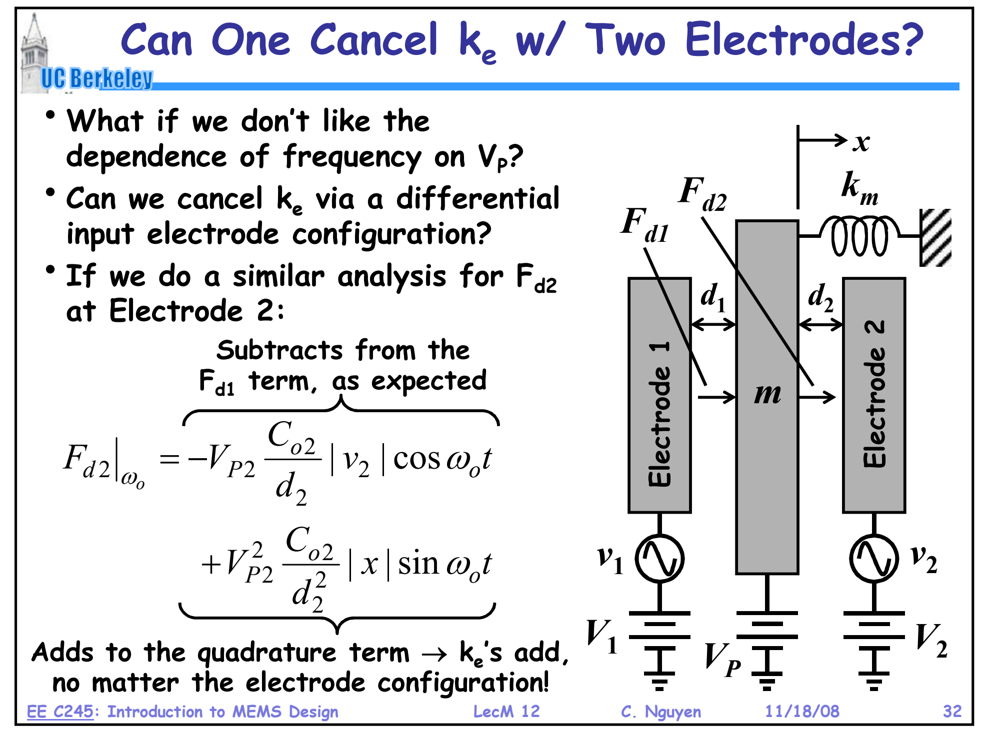

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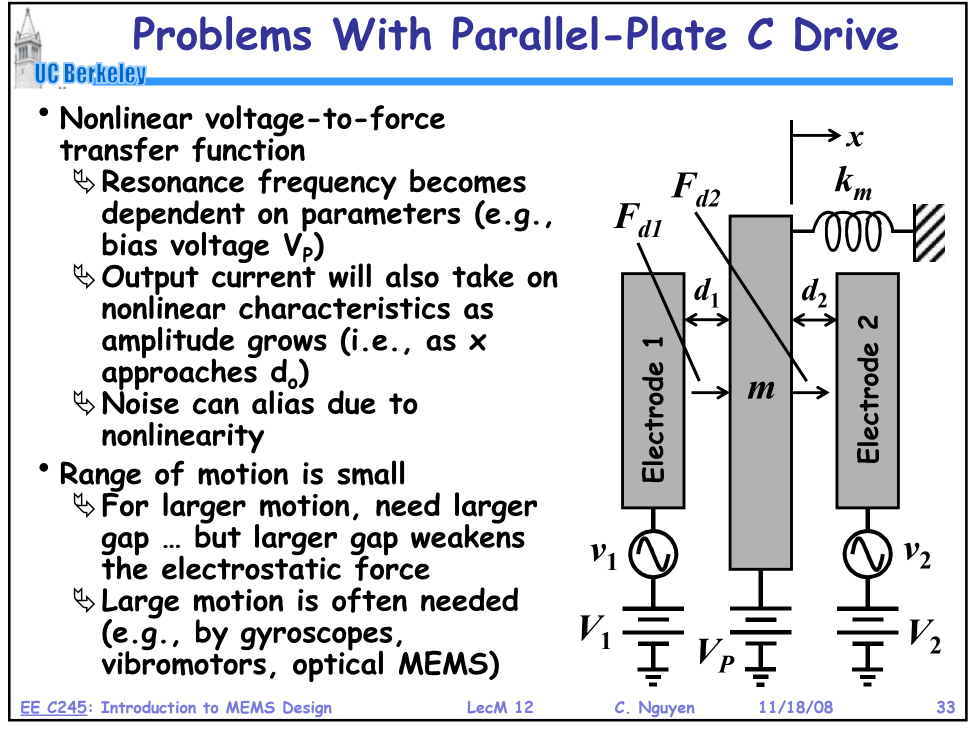

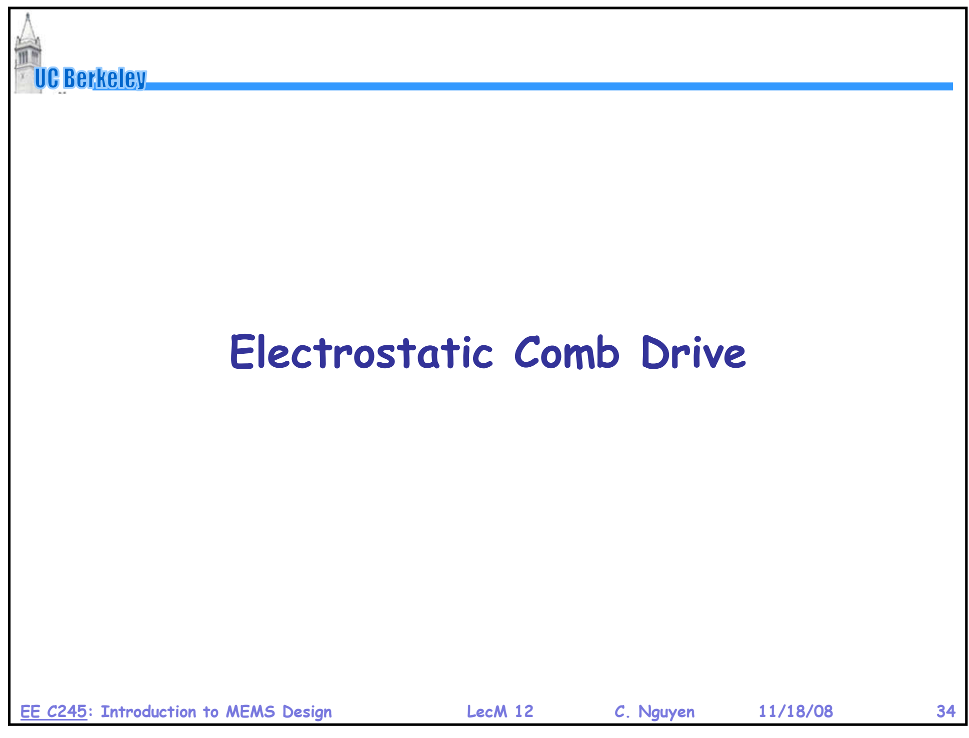

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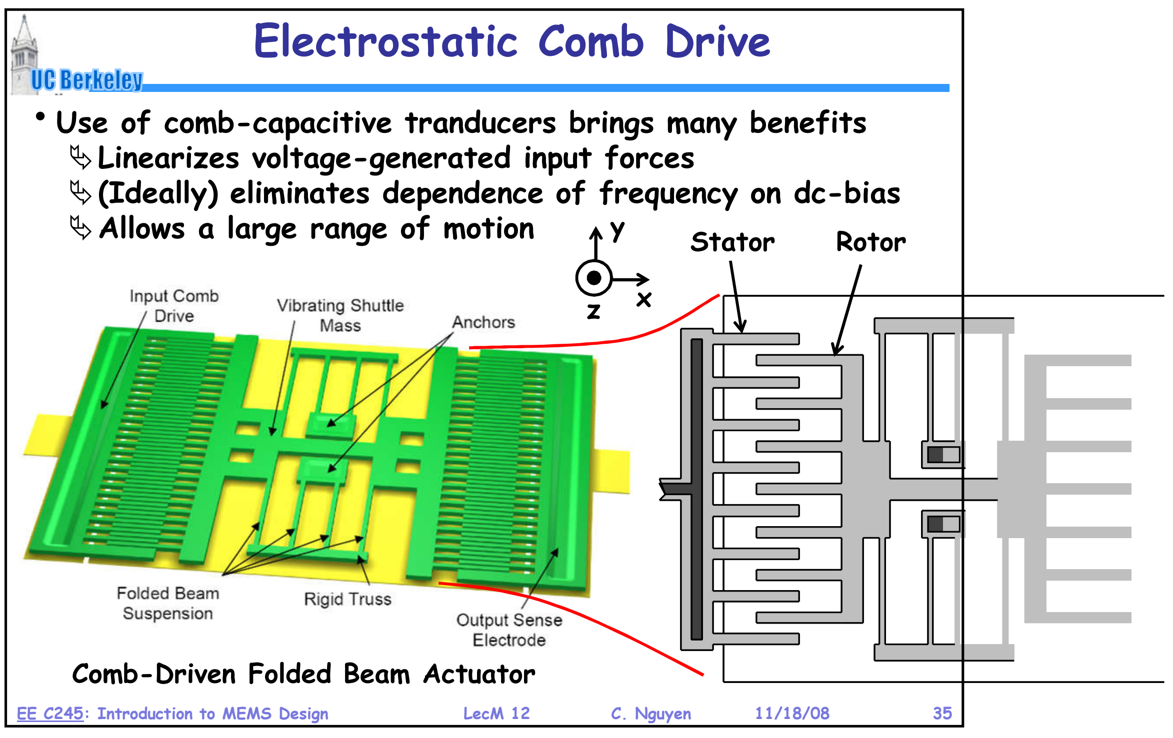

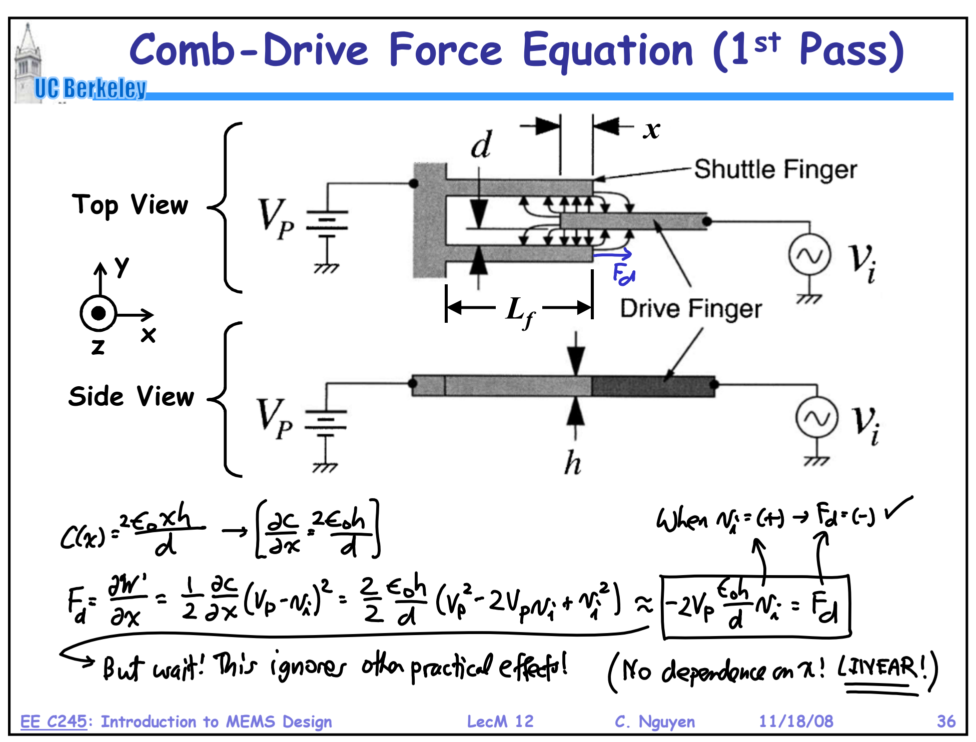

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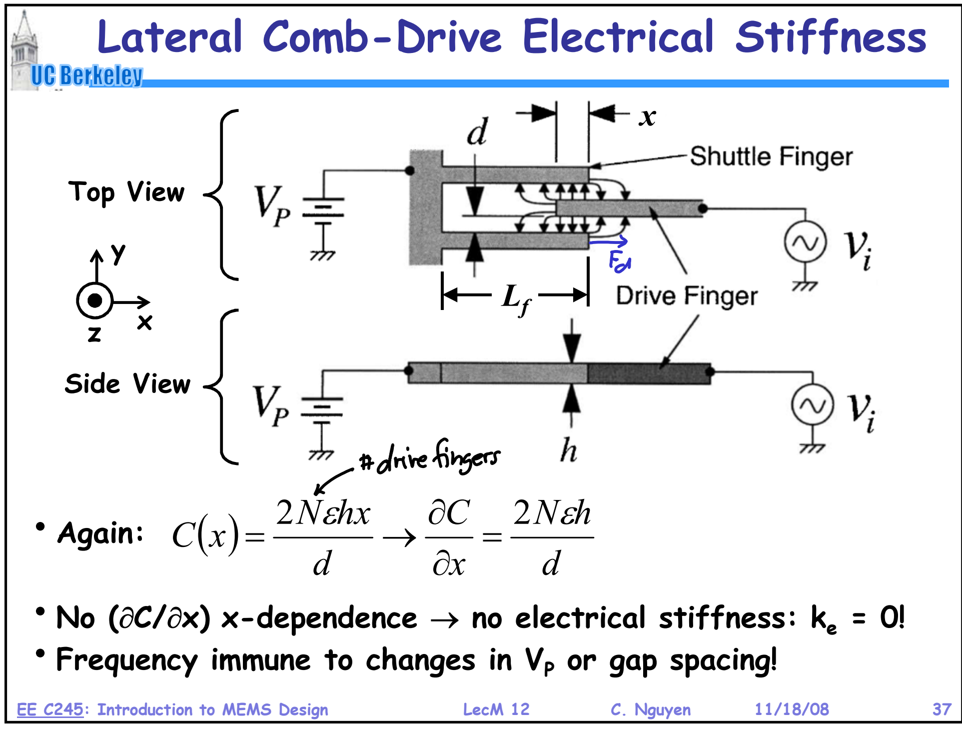

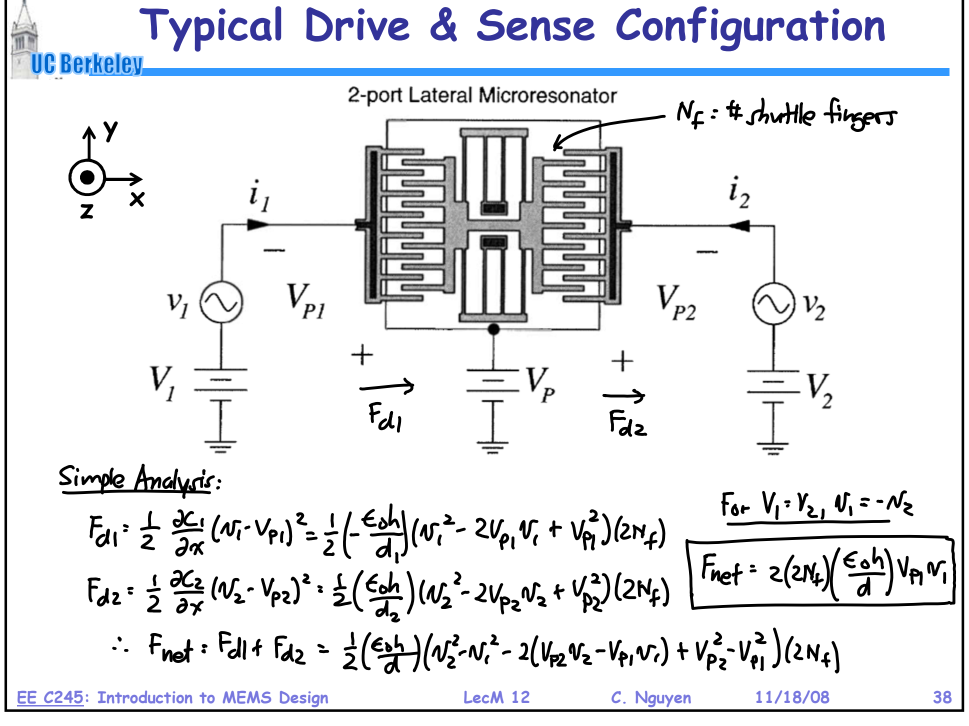

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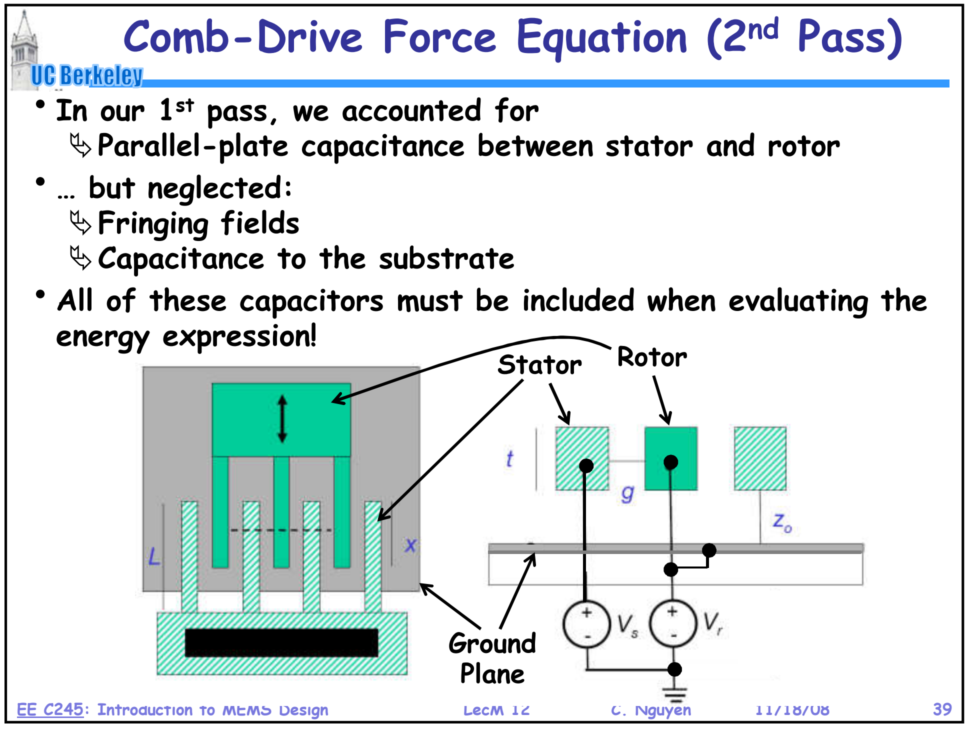

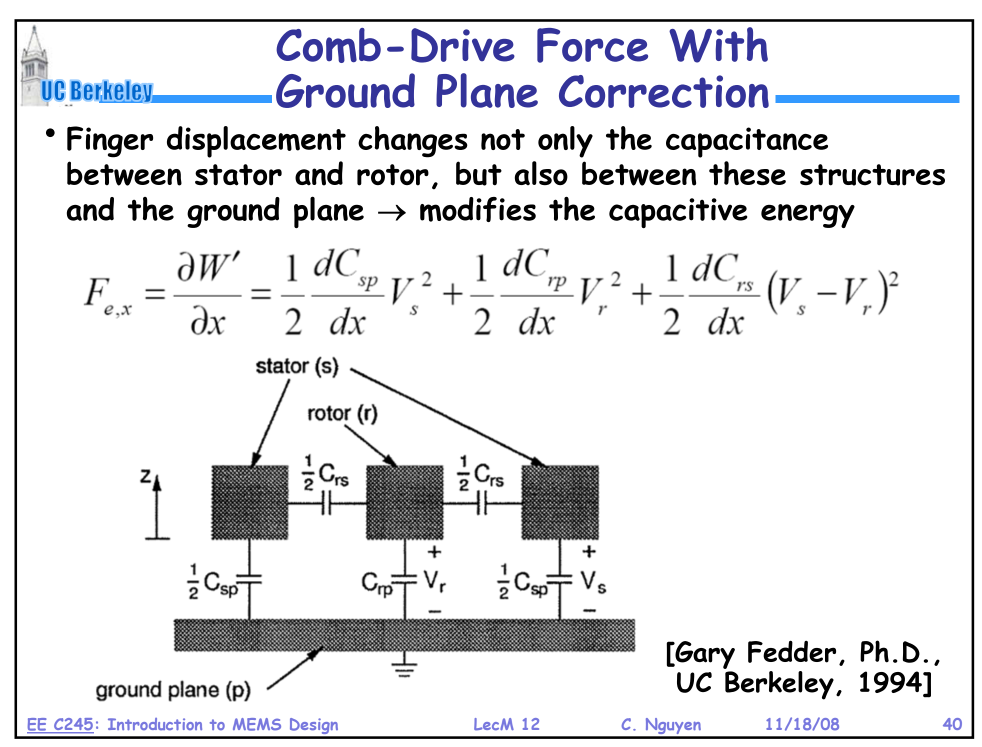

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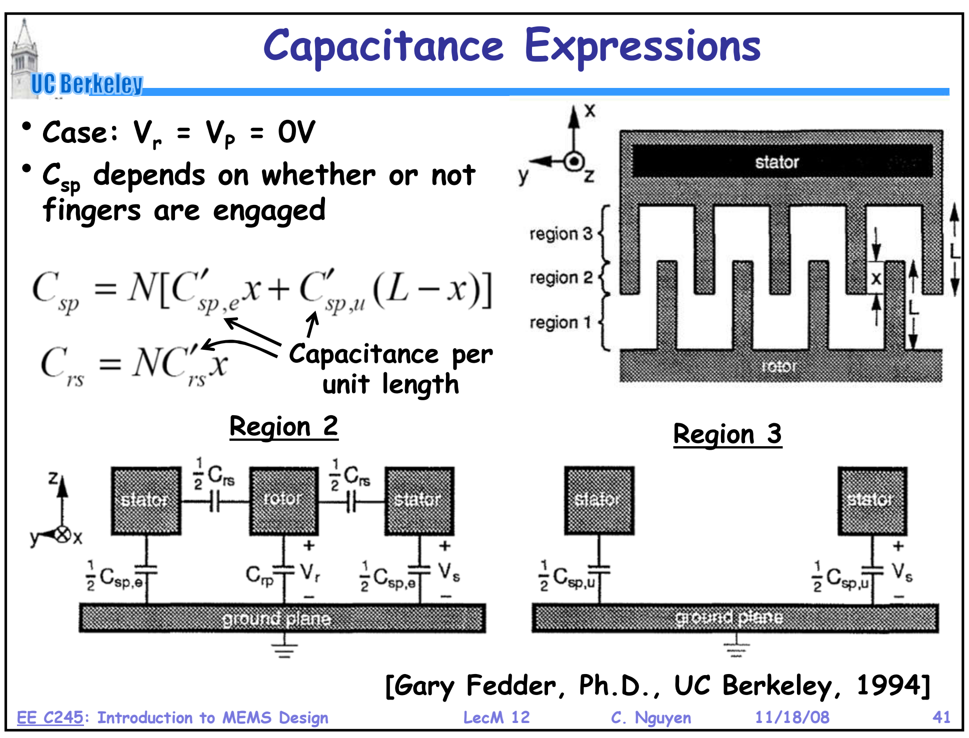

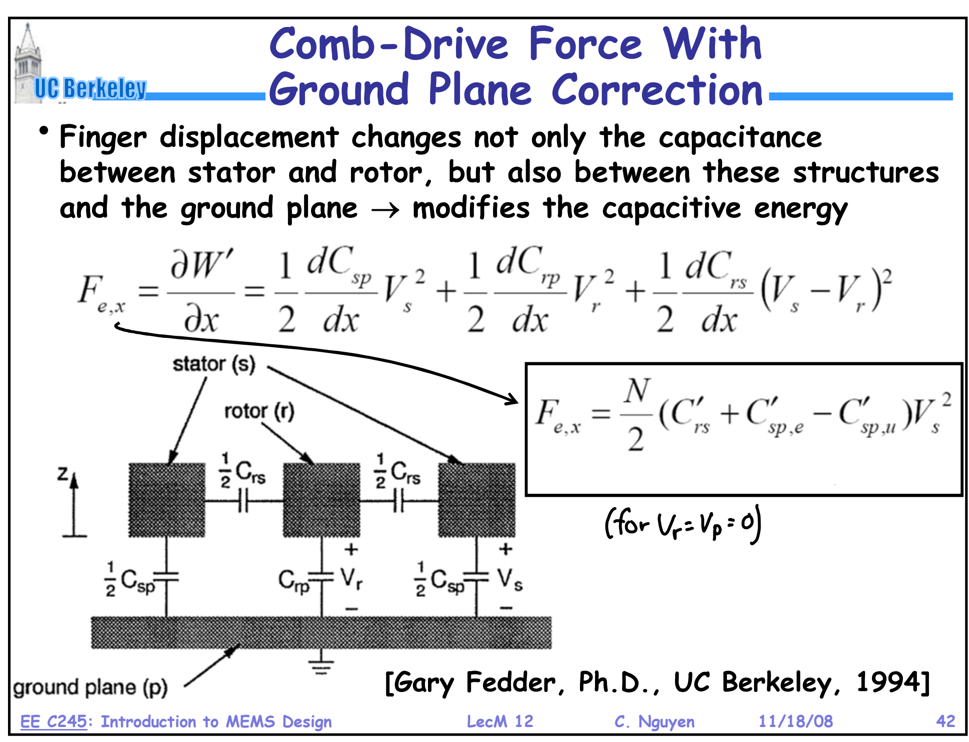

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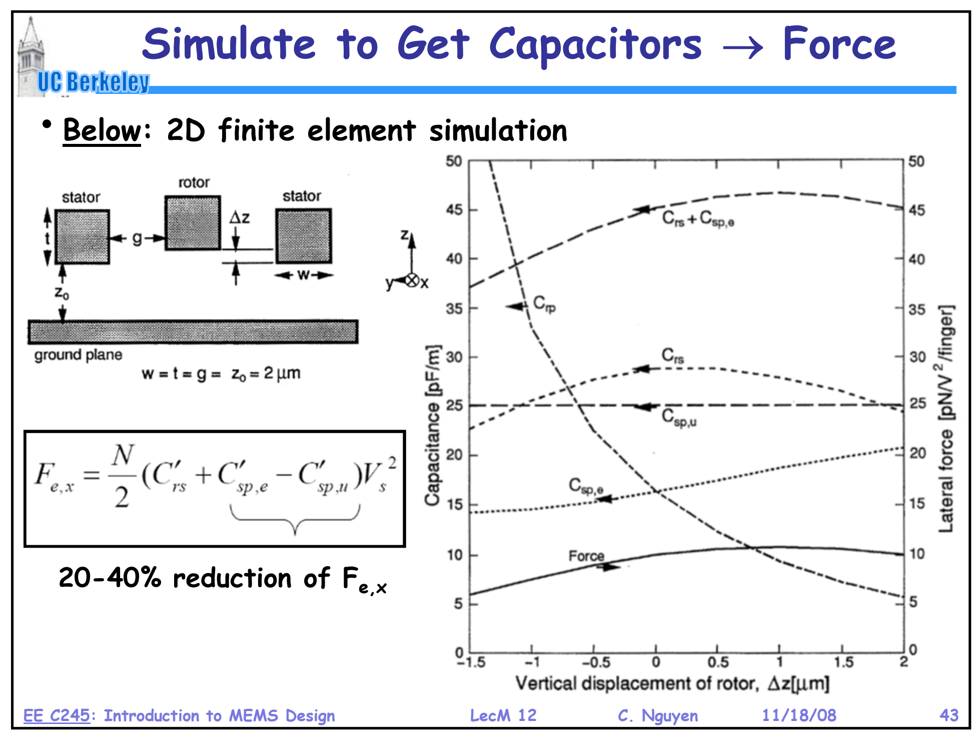

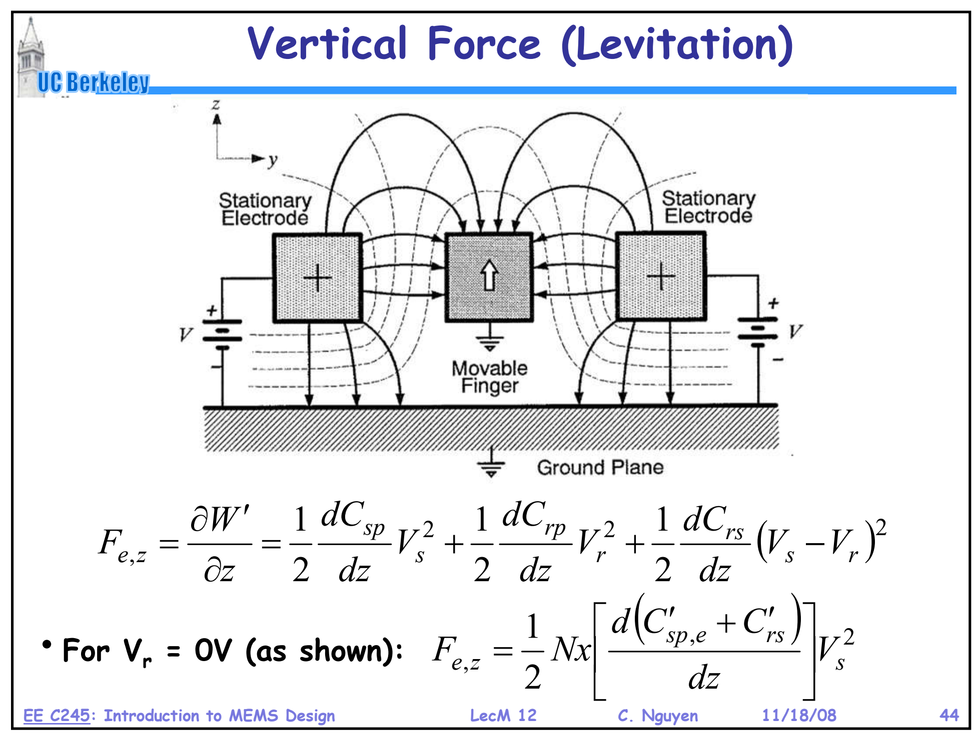

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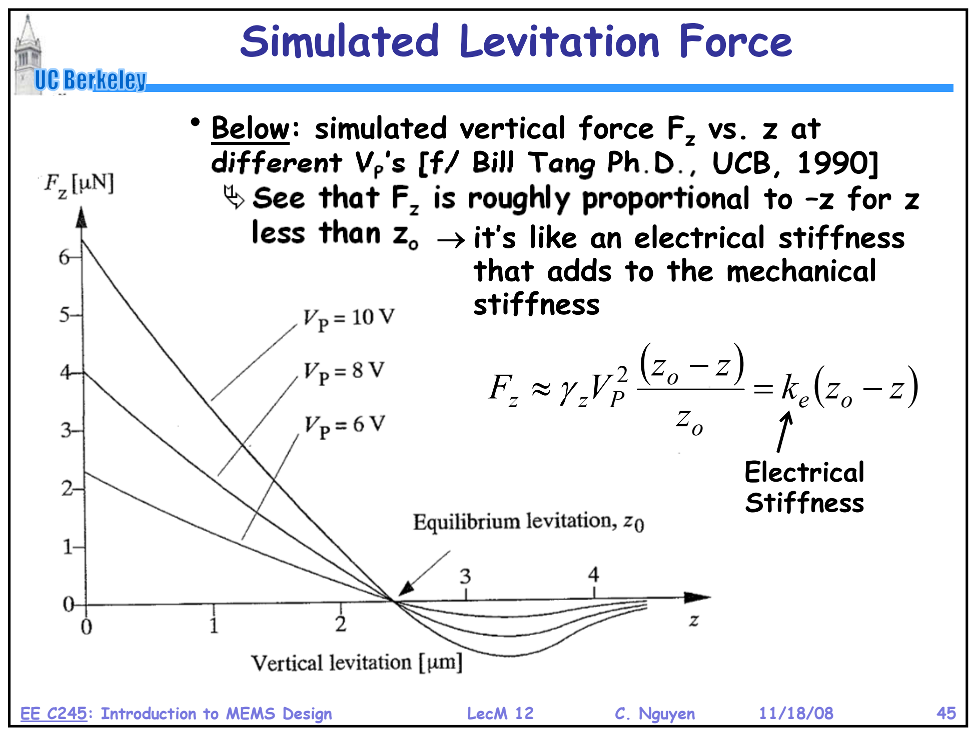

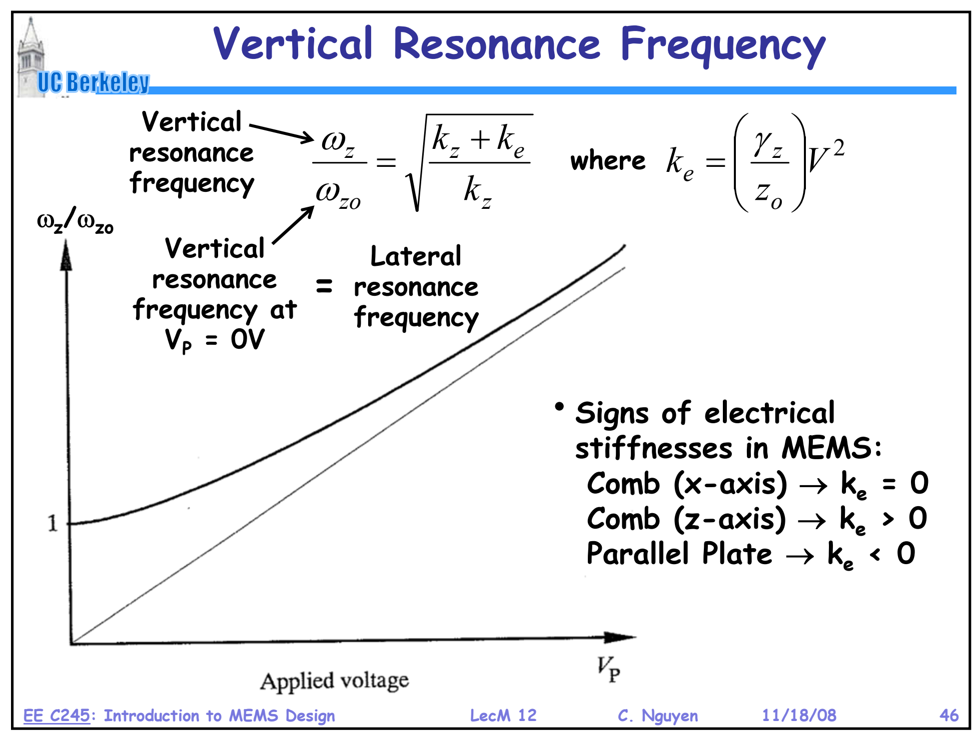

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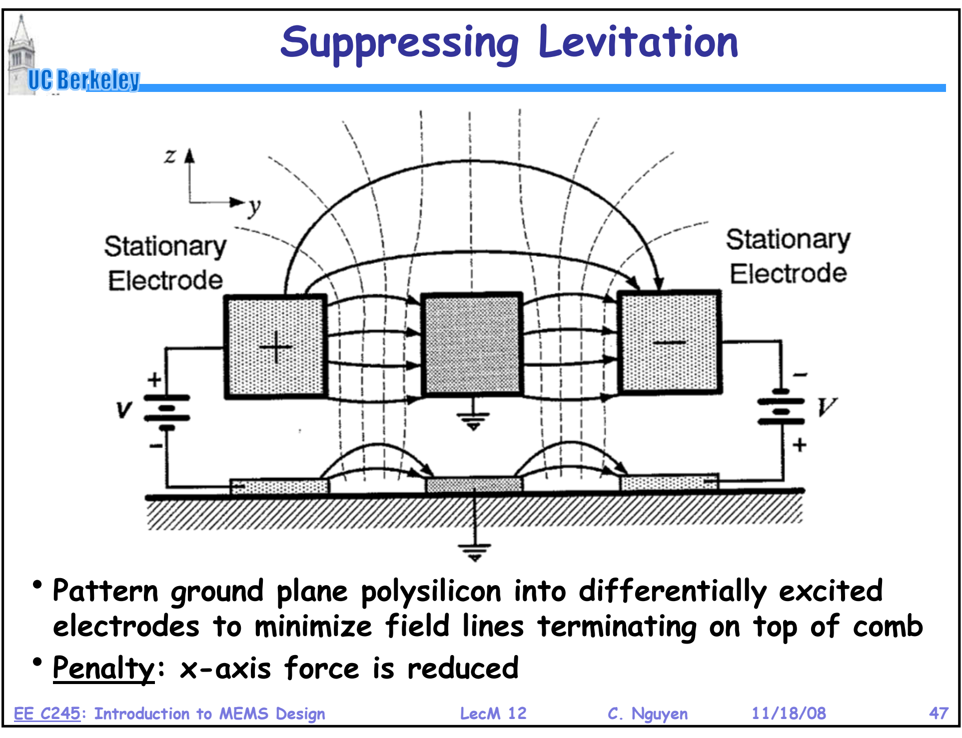

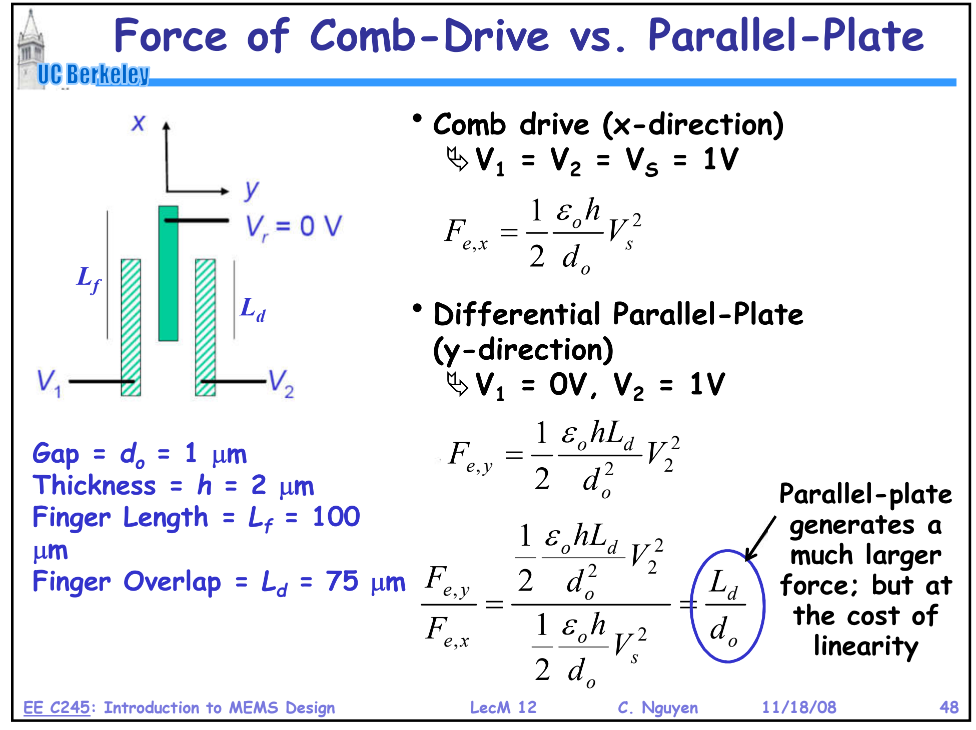

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