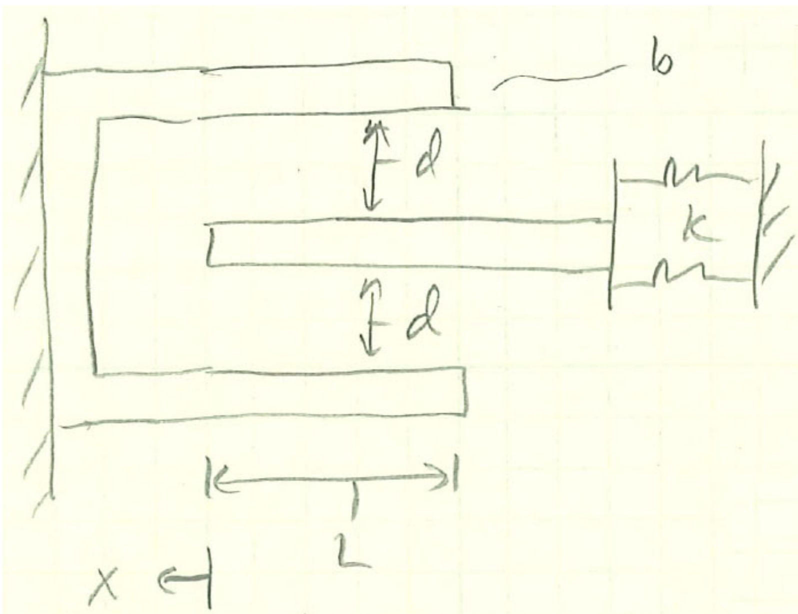
Lecture 10/12/22

<u>Introduction to MEMS Actuators</u>

So far, we have discussed the PPA and the GCA.

1) Electrostatic Comb Drive Actuator (CDA)

Consider this MEMS structure:



"b" is the tooth height into the page.

Motion is constrained by the suspension system to the x-direction, so that the movable tooth on the right moves deeper into or out from between the two fixed teeth on the left.

Applying a voltage, V, between the left and right teeth results in an electrostatic force that attempts to pull the movable tooth deeper between the two fixed teeth, which increases the capacitance between the teeth.
Note: **Electrostatic force always attempts to increase capacitance**.

Here, the motion of the movable tooth is tangential in regard to the two fixed teeth: the movable tooth stays exactly between the two fixed teeth as it moves to the left, but overlap electrode area increases.

Define the resulting net tangential electrostatic force at F_T:

$$F_T = \frac{\varepsilon_o \varepsilon_r b V^2}{d}$$

Observe that F_T is proportional to V^2, but it is NOT a function of displacement! This removes one nonlinearity from the system.

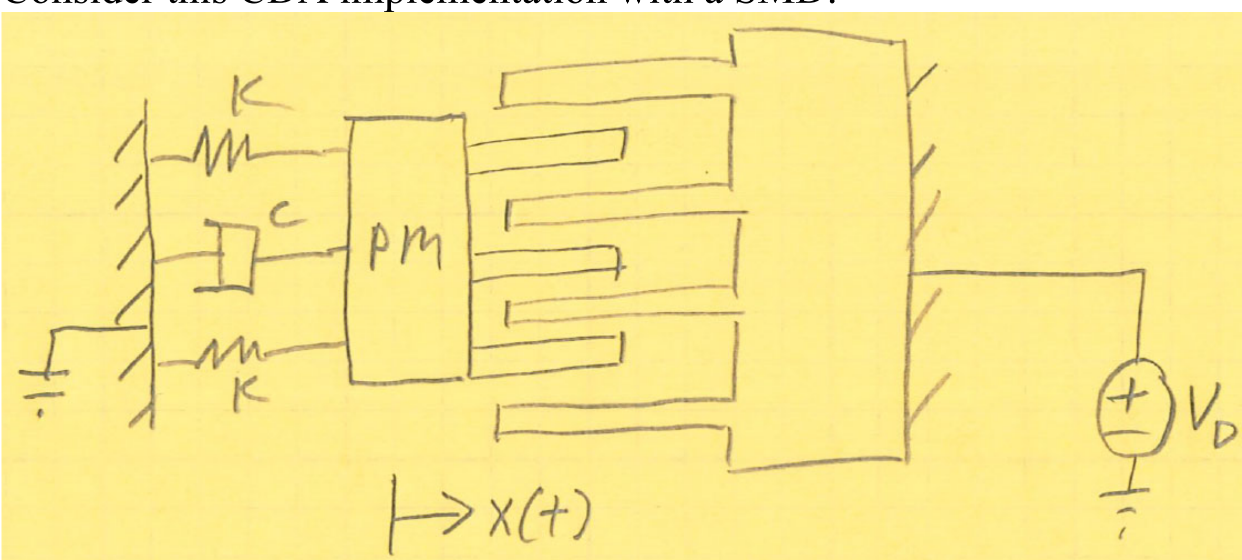
Now, let's connect n of the electrode units above so that all the movable teeth are electrically connected and move together into the fixed teeth, which are also electrically connected. The structure appears as two interdigitated combs. Hence, this actuator is called a Comb Drive Actuator or CDA.

The resulting electrostatic force is:

$$F_{EL} = \frac{n\beta b \varepsilon_o \varepsilon_r V^2}{d}$$

where n is the number of movable teeth, and β is a fringing effect correction factor (β ≥ 1).

Consider this CDA implementation with a SMD:

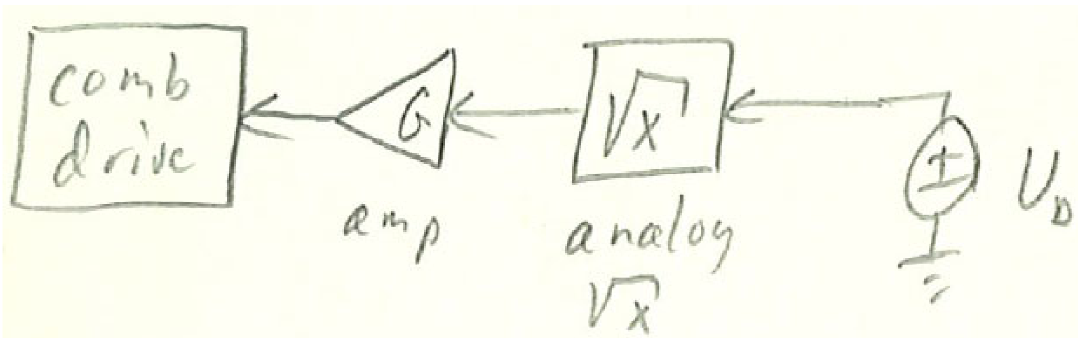


NOTE: k is the system spring constant and V(t) = V_D. Our system differential equation becomes:

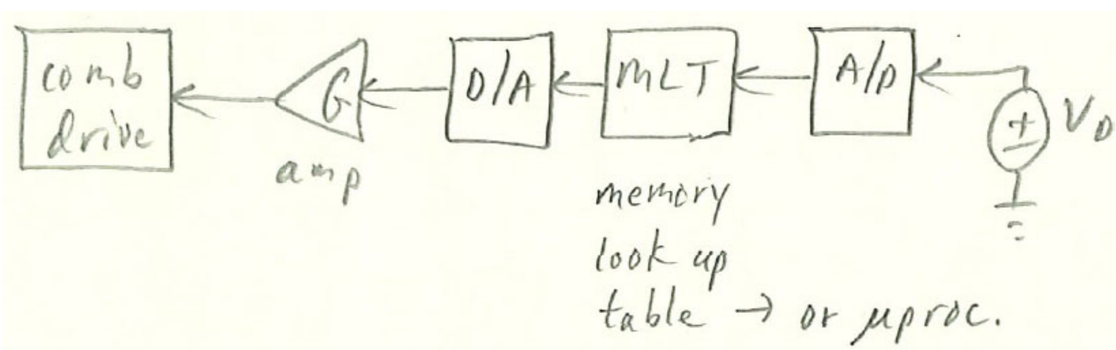
$$m\ddot{x} + c\dot{x} + kx = \frac{n\beta b\varepsilon_o\varepsilon_r V^2}{d}$$

If V is constant, the system is linear. However, it would be nice to remove the nonlinearity of V^2 for any V(t) input. There are some ways to do that:

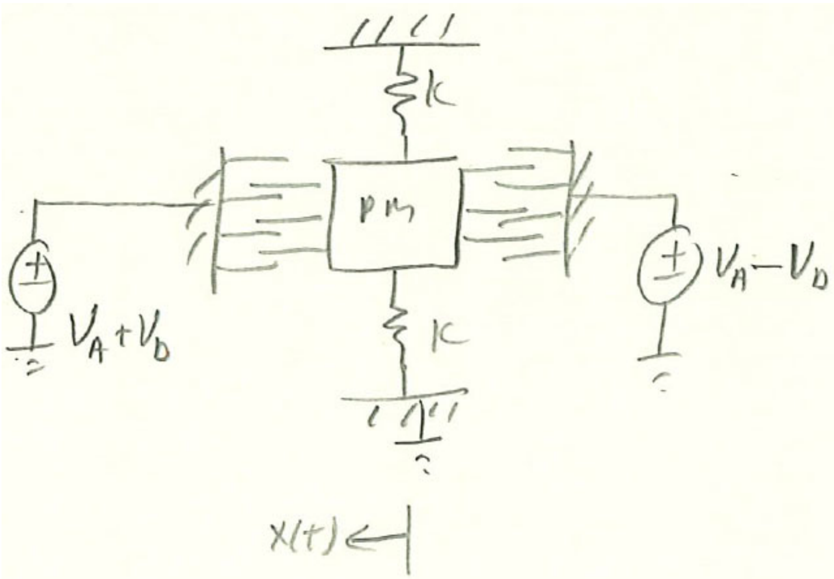
1) Analog square root function



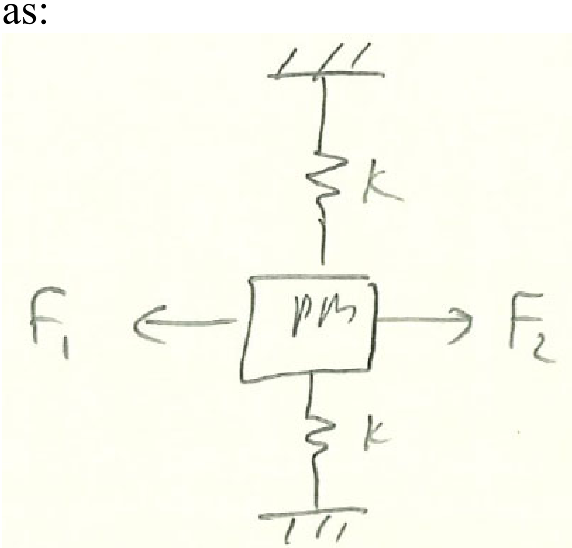
2) Digital square root function



3) Multiple power supplies



The proof mass has two opposing CDA's attached to it. Let's model it as:



Equations for the two opposing forces:

$$F_1 = \frac{n\beta b\varepsilon_o\varepsilon_r}{d}(V_A + V_D)^2 = \frac{n\beta b\varepsilon_o\varepsilon_r}{d}(V_A^2 + 2V_AV_D + V_D^2)$$

$$F_2 = \frac{n\beta b\varepsilon_o\varepsilon_r}{d}(V_A - V_D)^2 = \frac{n\beta b\varepsilon_o\varepsilon_r}{d}(V_A^2 - 2V_AV_D + V_D^2)$$

The net force on the PM is F_N:

$$F_N = F_1 - F_2 = \frac{n\beta b\varepsilon_o\varepsilon_r}{d}(4V_AV_D) = KV$$

where V = V(t) = V_D.

Also, V_A is a constant voltage, and K is a constant: $K = \frac{4n\beta b\varepsilon_o\varepsilon_r V_A}{d}$.

Now, the net electrostatic force on the PM is a linear function of V, and the system in linear:

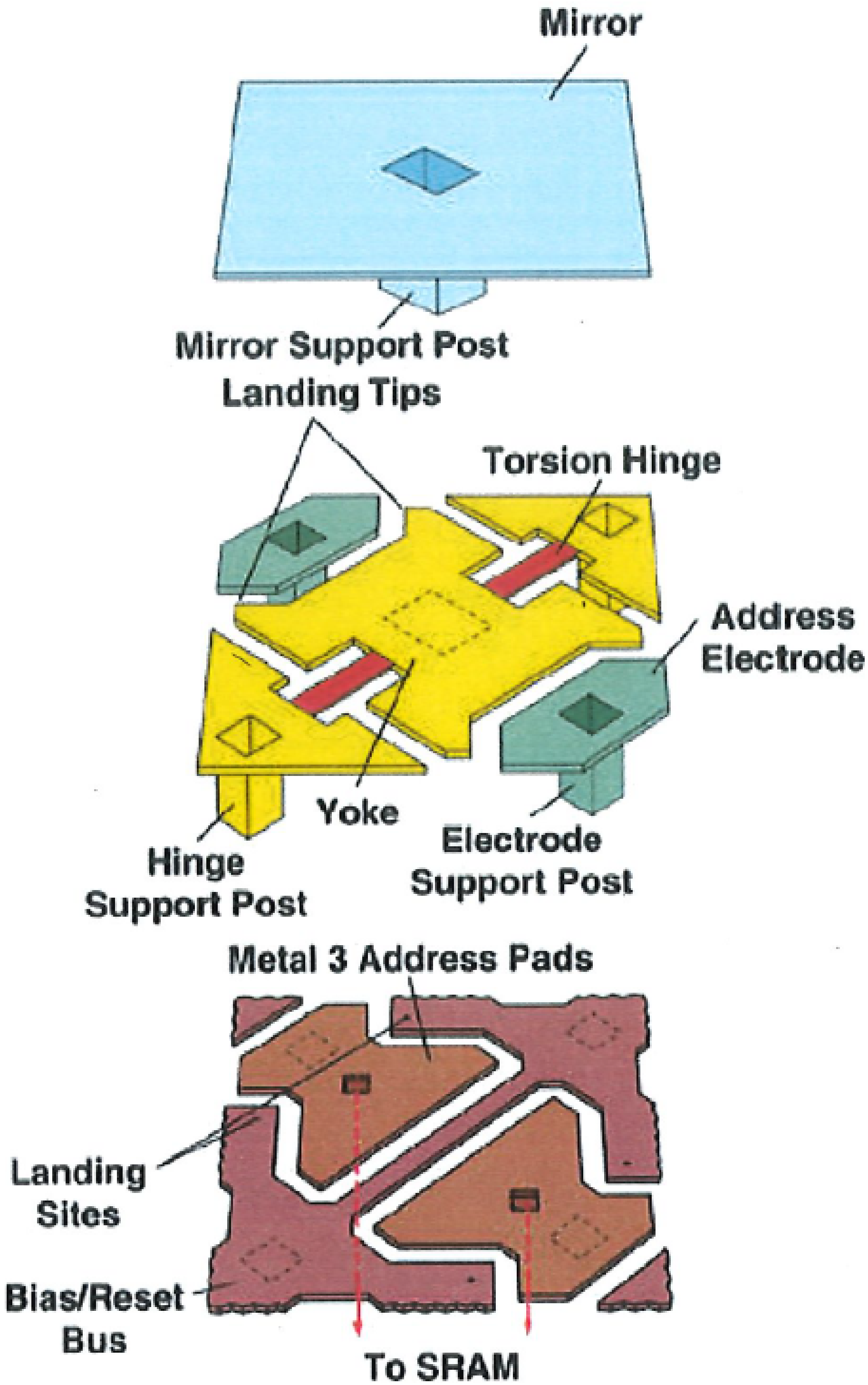
$$m\ddot{x} + c\dot{x} + kx = KV$$

This solution does come with a penalty: a higher voltage is required to achieve the same force on the PM because of the voltage terms that cancel.

We have three electrostatic actuators: PPA, GCA, and CDA.

Some example electrostatic actuators are shown on the next few pages.

Drawing of the TI DLP



Photographs of Comb Drive Actuators (Courtesy Sandia National Labs)