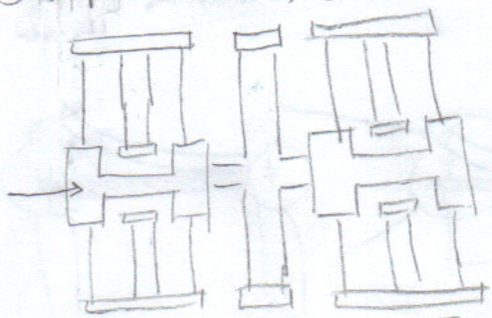
Discussion 11/15

1. Coupled structures, estimated modes.



Consider the coupled folded flexure resonator.

Assume one resonator has a characteristic resonance ω_0.

Are the resonances of the new system higher or lower?

How many are they? What is their mode shape?

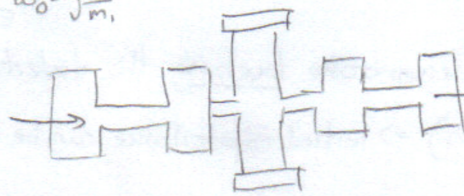
$k_1 \approx k_c$

$m_1 \approx m_{SH}$

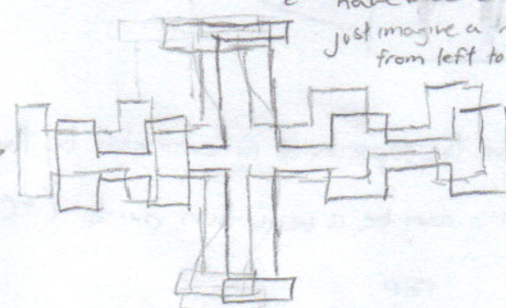
$\omega_0 = \sqrt{\frac{k_1}{m_1}}$ $\quad$ $\omega_0 = \sqrt{\frac{k_1}{m_1}}$

I probably should have used 2 colors... just imagine a translation from left to right

MODE 1: IN-PHASE:



$\sim$



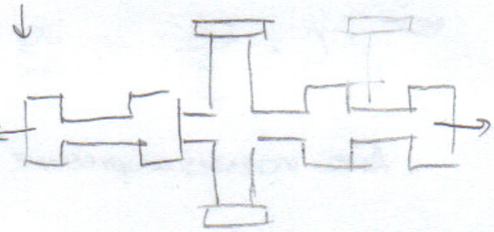
Here the coupling beam moves with the shuttle.

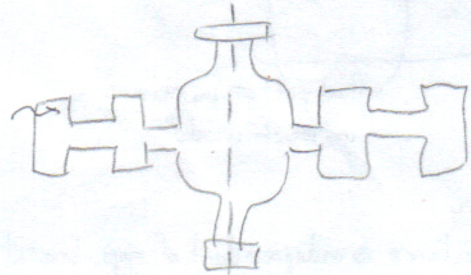
$\Rightarrow$ the effective dynamic mass is increased.

The coupling beams add no stiffness since both shuttles displace the same. (i.e. they do not flex, Like HW5P1 & midterm)

$\Rightarrow \omega_0' = \sqrt{\frac{k}{m+m_x}} \Rightarrow \omega_0 \downarrow$

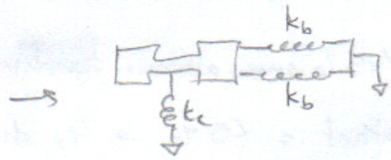
MODE 2: OUT-OF-PHASE:





We now have a half-circuit with virtual ground in the middle.

The effective mass remains roughly the same while the stiffness increases.



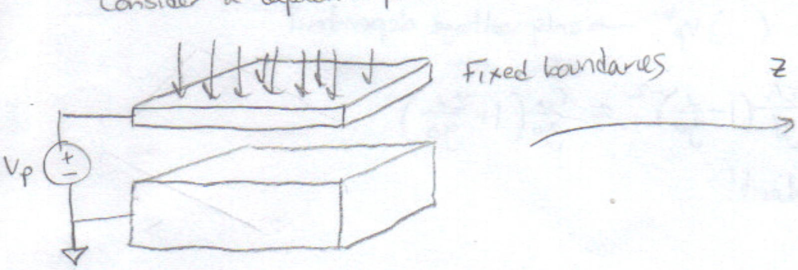
$\Rightarrow \omega_0' = \sqrt{\frac{k+k_x}{m}} \Rightarrow \omega_0 \uparrow$

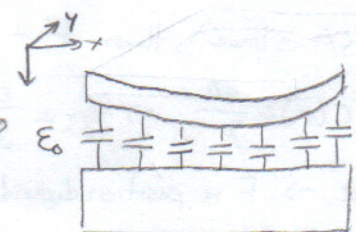
2. Comb drive vs parallel-plate. Linearization of parallel-plate sensors.

$\frac{\partial C}{\partial x} = \text{const}$ $\qquad$ $\frac{\partial C}{\partial x} \propto \frac{1}{x^2} \Rightarrow$ more dynamically sensitive $\Rightarrow$ good for sensing

$\hookrightarrow$ easier to control $\Rightarrow$ good for driving

Consider a capacitive pressure sensor whose membrane deflects due to a static pressure.





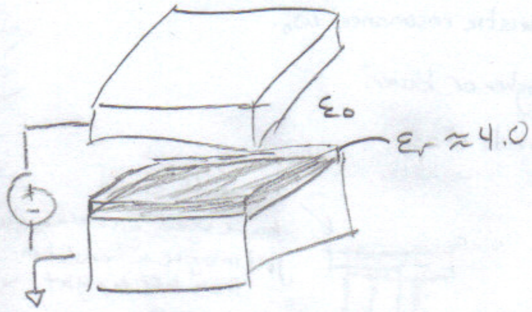
$\frac{\partial C}{\partial z} \propto \frac{1}{z^2}$, and changes over area (which can be integrated from HW1p2)

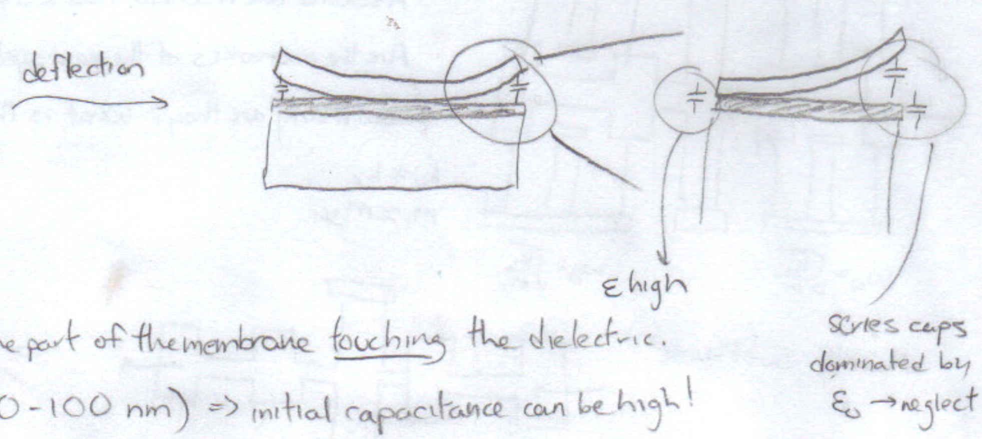
Sensitivity of $\frac{1}{z^2}$ is good, but not always desirable.

How can we linearize $\frac{\partial C}{\partial z}$?

Discussion 11/15

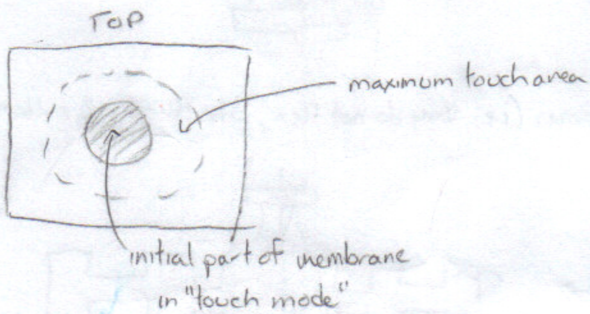
(2) Now consider a "touch-mode" capacitive sensor with a high dielectric in between the membrane and ground.





Here the capacitance is dominated by the part of the membrane touching the dielectric.

This can be a very thin oxide (50 - 100 nm) => initial capacitance can be high!



As the pressure increases, more of the membrane area touches the dielectric. Assuming parts of the membrane not in contact contribute negligible capacitance,

$$C = \frac{\varepsilon A}{g} \Rightarrow \frac{\partial C}{\partial x} = \frac{\varepsilon A'}{g}$$

Area increases as pressure is applied => $\frac{\partial C}{\partial z}$ is predictable, controllable, no pull-in *

Capacitance is independent of gap, based only on area.

Typical touch modes fabricated w/ 15% area already touching.

Max stable area that can make contact is 60% → 4x shift in capacitance.

Issues: Pull-in still exists. After repeated use membrane can stick to dielectric.
High stress at fixed boundaries - can cause interconnect to break!

(3) Basic review / what to expect this week. (Why does this matter?)

Voltage controlled force. $F = \frac{1}{2}\frac{\partial C}{\partial x}V_p^2$

If $\frac{\partial C}{\partial x}$ is constant ($C(x)$ is linear) then $F = (\ \ )V_p^2$ → only voltage dependent

But take parallel plate: $C(x) = \frac{\varepsilon A}{g_0 - x} \Rightarrow \frac{\partial C}{\partial x} = \frac{\varepsilon A}{g_0^2}\left(1 - \frac{x}{g_0}\right)^{-2} \approx \frac{C_0}{g_0}\left(1 + \frac{2x}{g_0}\right)$

$\frac{\partial C}{\partial x}$ is position dependent => F is position dependent!

Instability and positive feedback can result easily.

Clark will discuss compensation schemes this week.