Lecture 22: Equivalent Circuits II

Announcements:
- HW#8 due Wednesday, 4/14, at 12 noon
- Project Slide Set #2 due Friday, April 16
- Module 13 on “Equivalent Circuits II” online

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

Reading: Senturia, Chpt. 6, Chpt. 14
- Lecture Topics:
  - Input Modeling
    - Input Equivalent Ckt.
  - Current Modeling
    - Output Current Into Ground
    - Input Current
    - Complete Electrical-Port Equiv. Ckt.
  - Impedance & Transfer Functions

Last Time:
- 1st order electrostatic comb-drive analysis
- Now, get deeper …
• Go through remaining comb-drive slides in Module 12
• Start Module 13: go thru first few slides up to transformer definition
• Then ...

\[
\begin{bmatrix}
  e_2 \\
  f_2
\end{bmatrix} =
\begin{bmatrix}
  \eta & 0 \\
  0 & -\frac{1}{\eta}
\end{bmatrix}
\begin{bmatrix}
  e_1 \\
  f_1
\end{bmatrix}
\]

Describing Matrix

\[
F_{di} = -V_P \frac{\partial^2 \phi}{\partial x^2} N_c^2
\]

\[
\eta_1 = \left| \frac{V_P}{\partial x} \right|
\]

\[
\varepsilon = \frac{\lambda}{d_1} \rightarrow \eta_1 \uparrow
\]

\[
v_P \uparrow \rightarrow \eta_1 \uparrow
\]
Output Current Into Ground

\[ q = C V \]

\[ i = \frac{dq}{dt} = C \frac{dV}{dt} + V \frac{dc}{dt} \]

\[ C_{x} = f(t) \]  
\( \text{important for MEMS} \)

\[ \mathbf{I}_2(j\omega) = \begin{pmatrix} V_p \frac{dC_2}{dx} \end{pmatrix} \]

\[ \mathbf{I}_2(j\omega) = -jwV_p \frac{dC_2}{dx} x \]

\[ \mathbf{I}_2(j\omega) = -jwV_p \frac{dC_2}{dx} \]

\[ \text{Output motional current} \]
Get \( I_i(\omega) \):
\[
I_i(\omega) = j\omega C_i V_i + j\omega V_p \frac{\partial C}{\partial x} x - j\omega V_p \frac{\partial C}{\partial x} x
\]
Feed-through current

Motional current (due to mass motion)

\( V_i \ll V_p \) small \( X = \) small P not @ drive frequency

\[ V_i = V_p \]

@ Resonance, this is a "motional resistance"