Detection Scheme

\[ \text{op amp circuit is a TIA -> transimpedance amplifier} \]

\[ V_{01} = V_c + i_1 R_1 \text{ and } V_{02} = V_c + i_2 R_1 \]

\[ C_1 \text{ and } C_2 \rightarrow \text{CDA style variable capacitors with} \]

\[ V_c \text{ applied across each one } \Rightarrow F_{\text{net}} = 0 \]

\[ C_1 = \frac{\varepsilon_0 \varepsilon_r b (x_0 + x)}{d_0} = x_0 \sin(\omega t) \]

\[ C_2 = \frac{\varepsilon_0 \varepsilon r b (x_0 - x)}{d_0} = x_0 \cos(\omega t) \]

\[ i_1 = \frac{dQ_1}{dt} = \frac{V_c dC_1}{dt} = V_c x_0 \omega \cos(\omega t) \Rightarrow Q = C V \Rightarrow \frac{dQ}{dt} = i_1 = (ut) V \]

\[ V_{01} = V_c + V_c R_1 x_0 \omega x_0 \cos(\omega t) \]

\[ i_2 = \frac{dQ_2}{dt} = \frac{V_c dC_2}{dt} = -V_c x_0 \omega x_0 \sin(\omega t) \]

\[ V_{02} = V_c - V_c R_1 x_0 \omega x_0 \cos(\omega t) \]

\[ V_s(t) = V_{01} - V_{02} = 2V_c R_1 x_0 \omega x_0 \cos(\omega t) \Rightarrow x(t) = \sin(\omega t) \]

\[ V_s(t) = \cos(\omega t) \]

leads by \( \theta_0 \)
\( V_{in}(t) \) \( \rightarrow \) \( CDA1 \) \( \rightarrow \) \( V(t) \) \( \rightarrow \) Detection scheme \( \rightarrow \) \( V_{o}(t) \) 

\[ \Theta_{det} = 90° \]

\[ \Theta_{mech} + \Theta_{det} = -90° + 90° = 0° \]

\[ \Theta_{delay} = -180° \]

Use 3 RC phase lag circuits where each one produces -60°

\[ \frac{V_o}{V_{in}}(s) = \left(\frac{1}{s + \frac{1}{RC}}\right)^3 \]

→ select \( R \) and \( C \) to be close to expected \( \omega_n \) for -180°

→ since mechanical system is high \( Q \) and other phase delays exist in the real system, \( V_{osc} \) will "track" changes in \( \omega_n \)

Gain stages

"\( -A \)" → inverts for negative feedback

→ provide \( V_o + V_{o} \cos(\omega_n t) \) to \( CDA1 \) and \( V_o - V_{o} \cos(\omega_n t) \) to \( CDA2 \)

AGC → automatic gain control adjusts loop gain to be 1 at \( \omega_n \) where \( \Delta \omega = -180° \) for a desired mechanical motion amplitude \( \xi \times x_0 \)

→ \( x_0 \) too big → AGC decreases gain

\( x_0 \) too small → AGC increases gain
Another Technique for Measuring Displacement

Mechanical system is low frequency and COAs are high voltage devices.

- Let \( V_{in1} / V_{in2} \) have low freq, high v signal for actuation and high freq (100-200kHz) low voltage signal for displacement measurement.

- Do not need separate actuation and sensing structures → higher force/lower voltage with bigger actuator

→ electronics is more complicated

\( V_{in} \) is actuated and sensed, then HPF and mix with sense

\( V_{sense} \) is then LPF to obtain DC signal proportional to instantaneous displacement

\( X_m \cdot \sin(\omega t) \)