d. Sensors for State Feedback

① Displacement Sensor

→ relatively easy to measure (usually)

→ capacitive

→ piezoelectric

→ piezoresistive

→ optically

→ LVDT {non-MEMS applications}

→ strain gage

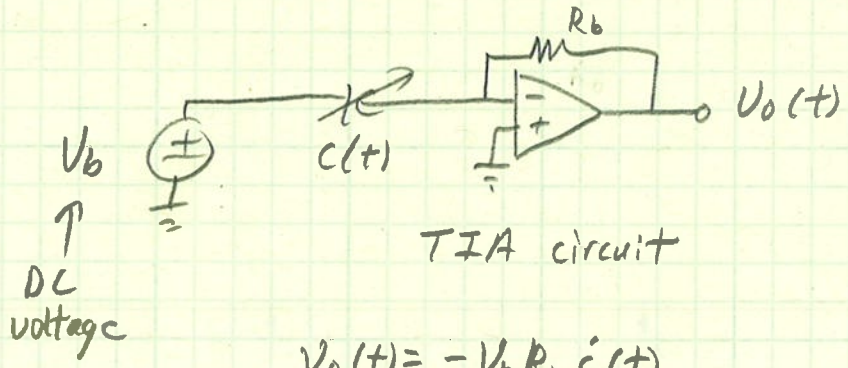
② Velocity Sensor

→ often more difficult to measure

→ Sample the displacement quickly and use the difference between sucessive readings

→ Differentiate the displacement measurement

Capacitive example for measuring the relative velocity between the proofmass and the frame → such as with a MEMS SMD



TIA circuit

$$V_o(t) = -V_b R_b \dot{C}(t)$$

Consider a variable area capacitive sensor:

$$c(t) = \frac{\varepsilon_0 \varepsilon_r w\, x(t)}{d}$$

$$\therefore \dot{c}(t) = \frac{\varepsilon_0 \varepsilon_r w\, \dot{x}(t)}{d}$$

and $$v_0(t) = -\frac{V_b R_b \varepsilon_0 \varepsilon_r w}{d}\dot{x}(t) = H_2 \dot{x}(t)$$

where $$H_2 = -\frac{V_b R_b \varepsilon_0 \varepsilon_r w}{d}$$

Consider a variable electrode distance capacitive sensor:

$$c(t) = \frac{\varepsilon_0 \varepsilon_r A}{d - x(t)}$$

$$\therefore \dot{c}(t) = \frac{\varepsilon_0 \varepsilon_r A \dot{x}(t)}{(d - x(t))^2}$$

consider the typical case where $x(t) = X_0 \sin(\omega t)$

$$\therefore \dot{x}(t) = X_0 \omega \cos(\omega t)$$

and $$\dot{c}(t) = \frac{\varepsilon_0 \varepsilon_r A X_0 \omega \cos(\omega t)}{(d - X_0 \sin(\omega t))^2}$$

if $d \gg X_0$, then $$\dot{c}(t) \approx \frac{\varepsilon_0 \varepsilon_r A X_0 \omega \cos(\omega t)}{d^2}$$

and $$v_0(t) \approx -\frac{V_b R_b \varepsilon_0 \varepsilon_r A X_0 \omega \cos(\omega t)}{d^2} = H_2 X_0 \omega \cos(\omega t)$$

where $$H_2 = -\frac{V_b R_b \varepsilon_0 \varepsilon_r A}{d^2}$$

The approximation is pretty good for $\frac{d}{X_0} \geq 100$

For $\frac{d}{X_0} < 100$, the error increases, but the cross-over points where $\dot{x}$ changes direction remain accurate → useful for some nonlinear feedback techniques

③ <u>Measure displacement and estimate velocity</u>

→ then use the velocity estimate for feedback

→ Requires a State Estimator, also known as an Observer

→ a computer model of the plant that is used to estimate unknown states → velocity here

→ only as <u>good</u> as the model

↓

model accuracy and computational speed

→ How do we develop an Observer:

(1) Use the design equations for the system

(2) Use test data to refine model from (1)

(3) Use BIST (Built In Self Test) methods to apply known inputs to the system and compare system response with the Observer's response, and update the Observer accordingly

(4) System Identification Techniques

→ to build an Observer model

→ could involve a variety of techniques, such as:

i. Least-squares estimation to build a regression model for the system

ii. For a 2nd order mechanical system – apply a random input and measure the transmissibility to obtain estimates for ω_n + Q

④ <u>Actuators</u>

→ Many to choose from

→ MEMS: CDA, PPA most common