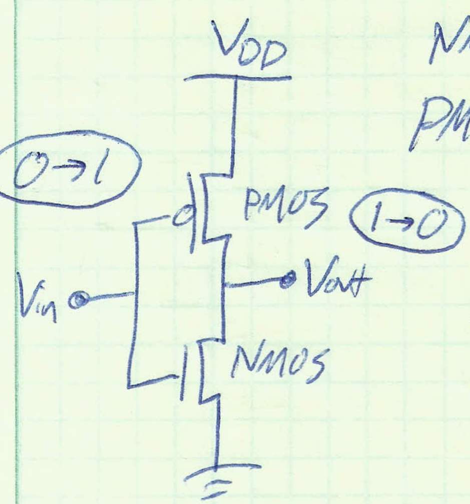
More on lab #7

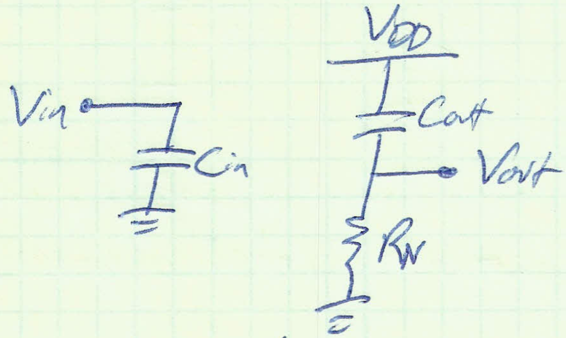
CMOS Inverter:

NMOS is "on" when $V_{in} = V_{DD}$ (and PMOS is "off")

PMOS is "on" when $V_{in} = 0$ (and NMOS is "off")

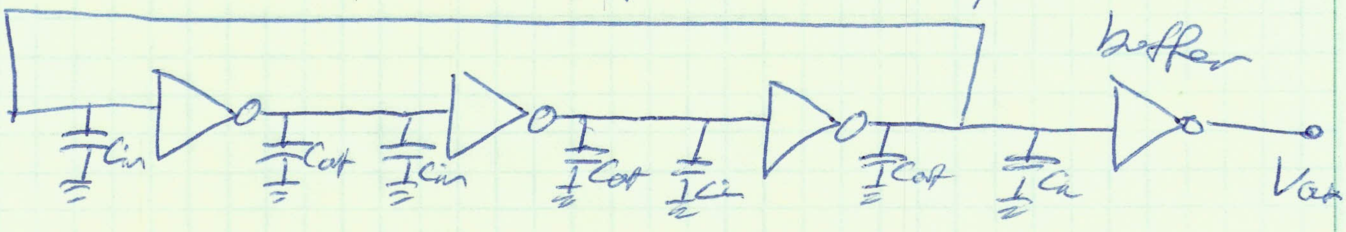


$\Rightarrow$



Cin is gate capacitance and other parasitics

Cout is drain capacitance and other parasitics



$R_0 = \frac{1}{2}(R_P + R_N)$: average of PMOS and NMOS "on" resistance

$C_{load} = C_{in} + C_{out}$: each inverter sees its own output cap, and input of next stage

$T_0 = \frac{1}{2}(T_{DHL} + T_{DLH})$: average of low-high and high-low transitions

$T_{DHL} = 0.69 R_N C_{load}$: $e^{-t/RC} = 0.5 \Rightarrow t = RC \ln 0.5 = 0.69RC$

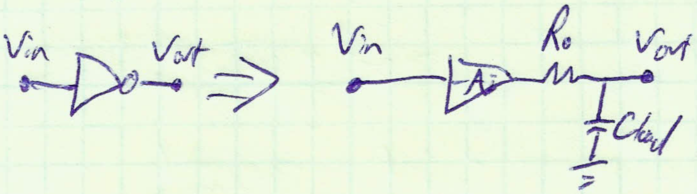
$T_{DLH} = 0.69 R_P C_{load}$

$T_{in} = 0.69 R_0 C_{in}$: last stage sees input of buffer too

total period of oscillator $= 2NT_0 + 2T_{in}$

factor of 2 from $1 \to 0$ and $0 \to 1$ transitions

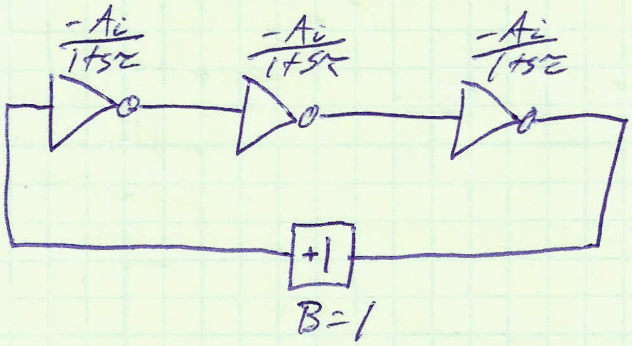
Single Inverter



$$V_{out} = -A_i V_{in} \cdot \frac{1/sC}{R + 1/sC}$$

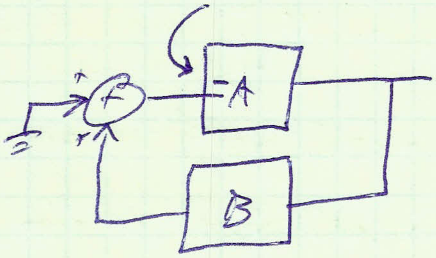
$$\frac{V_{out}}{V_{in}} = \frac{-A_i}{1+s\tau} \rightarrow \tau = R_o C_{load}$$

Cascade of three inverters



$$-A = \frac{-A_i^3}{(1+s\tau)^3}$$

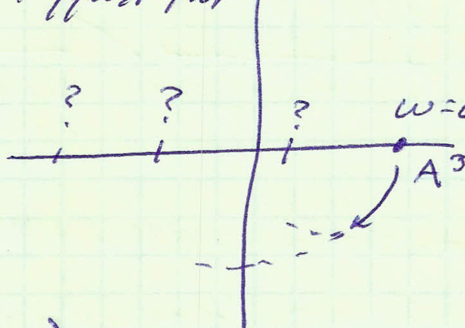
remember we need a ⊖ somewhere



$$AB = \frac{A_i^3}{(1+s\tau)^3}$$

$$AB = \frac{A_i^3}{1 + 3s\tau + 3s^2\tau^2 + s^3\tau^3}$$

Nyquist Plot



where does it cross the real axis

Imaginary part is $3s\tau + s^3\tau^3$

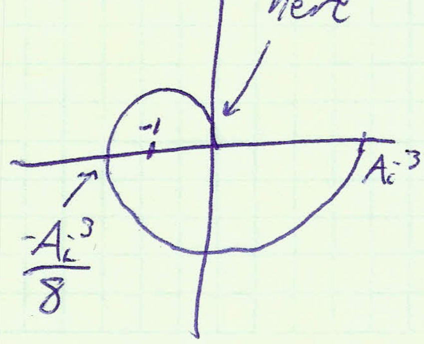
(odd factors of $s = j\omega$)

$$3 + s^2\tau^2 = 0$$

$$3 = \omega^2\tau^2 \rightarrow \omega = \frac{\sqrt{3}}{\tau} \rightarrow \text{plug back into } AB$$

3 poles, so end here

$$AB = \frac{A_i^3}{1 - 3\omega^2\tau^2} = \frac{A_i^3}{1 - 3\left(\frac{3}{\tau^2}\right)\tau^2} = \frac{-A_i^3}{8}$$



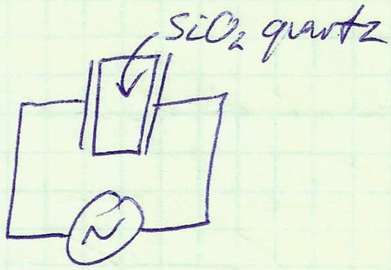
Ring will oscillate if $A_i^3 > 8$

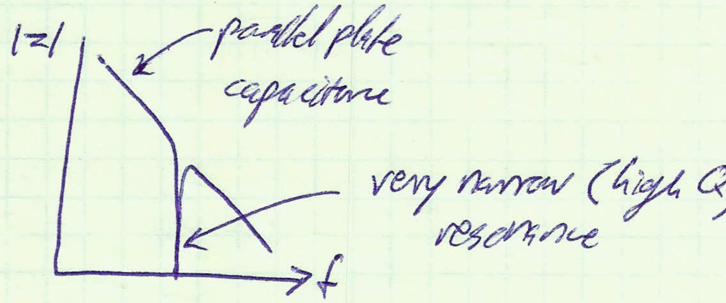
or $A_i > 2$

Quartz Oscillators

used for very accurate clocks → most watches and computers

important for synchronizing data transmission in communications



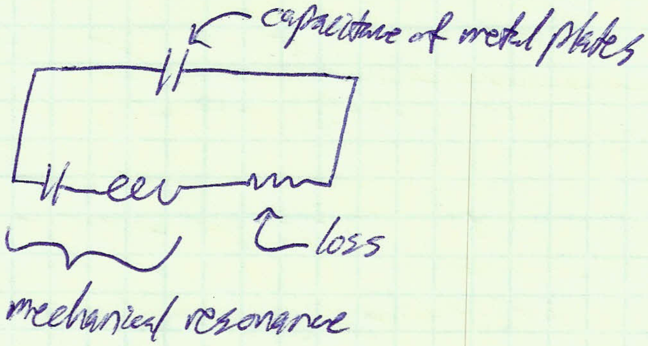


A good quartz watch is accurate to ~1s/month ⇒ $Q \sim 10^6$

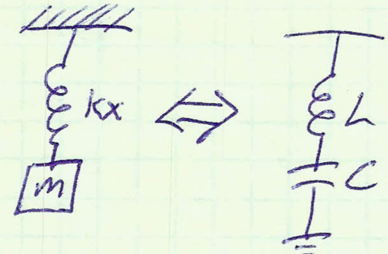
Works based on piezoelectric effect:

- applied electric field squeezes and distorts the crystal

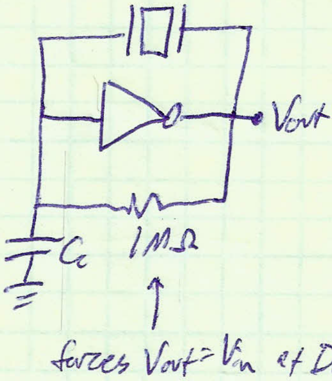
Can be modeled as RLC circuit



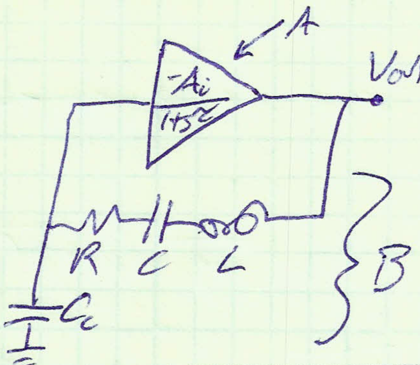
Think of mass/spring analogy:



Example oscillator circuit: (there are lots of other designs)



⇒

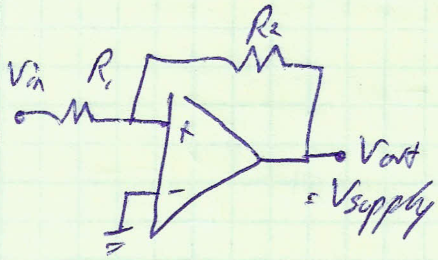


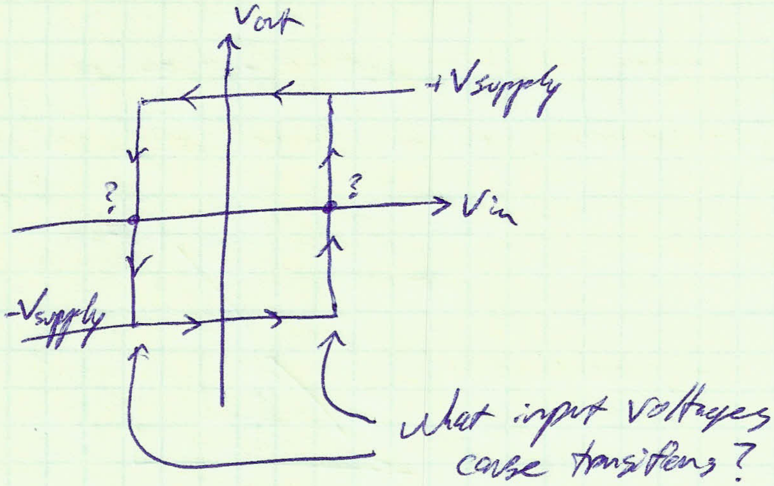
Inverter works like amplifier

Use same procedure as last example to find where Nyquist plot crosses real axis

Relaxation Oscillator:

Schmitt trigger:



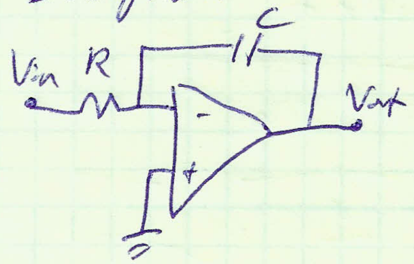


$$\frac{V_+ - V_{in}}{R_1} + \frac{V_+ - V_{supply}}{R_2} = 0$$

$$V_+ = 0$$

$$V_{in} = \frac{-R_1}{R_2} V_{supply} \Rightarrow \text{transition voltages are at } \pm \frac{R_1}{R_2} V_{supply}$$

Integrator:



Laplace transform: $\frac{1}{s} F(s) \longleftrightarrow \int_0^t f(\tau)\,d\tau$

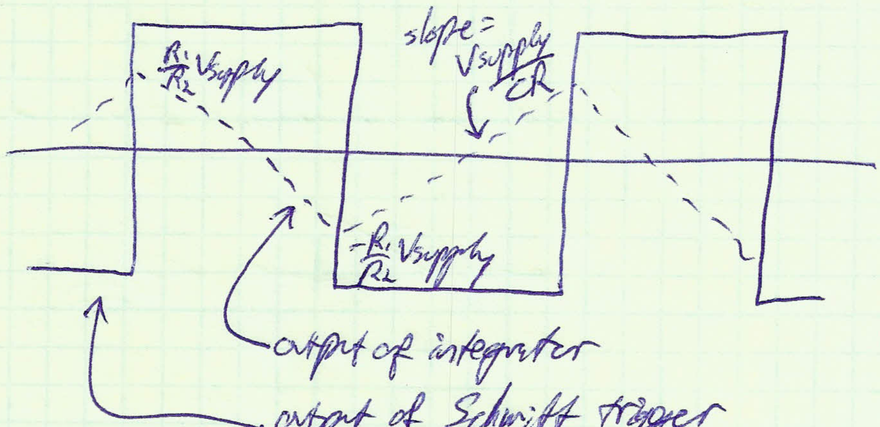
when $V_{in} = -V_{supply}$,

$$V_{out}(t) = \frac{-1}{CR} \int_0^t -V_{supply}\,d\tau = \frac{V_{supply}}{CR} t$$

$$\frac{V_- - V_{out}}{1/sC} + \frac{V_- - V_{in}}{R} = 0$$

$$V_- = 0$$

$$\frac{V_{out}}{V_{in}} = \frac{-1}{sCR}$$



Transitions at $\frac{V_{supply}}{CR} t = \frac{R_1}{R_2} V_{supply}$

$$t = CR \frac{R_1}{R_2} = \frac{1}{4} \text{ period}$$