Cmos op-amp

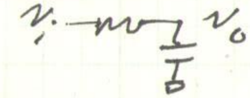
2 stage output swing

2 stage sizing

poles & freq response
poles & time response

poles move in feedback

ODEs $RC\frac{dv_o}{dt} + v_o = v_i$



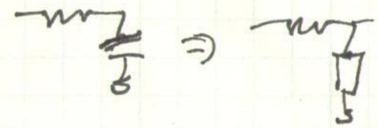
$C\frac{dv_o}{dt} = \frac{1}{R}(v_i - v_o)$

Heaviside $(\cancel{s}RC + 1)v_o = v_i$

$H(s) = \frac{1}{1+sRC} = \frac{1}{1+s/\omega_p}$

when is $H(s) = \infty$? when $s = -\omega_p$ pole

Shortcut to ODEs: $\frac{\perp}{\top} \Rightarrow Z = \frac{1}{sC}$



$\frac{v_o}{v_i} = \frac{Z_C}{R + Z_C}$

$= \frac{1}{1+s/\omega_p}$

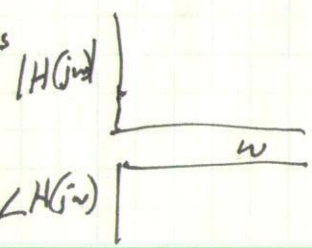
Linear Time Invariant $\sum_{i=0}^{n} a_i \frac{d^i v_o}{dt^i} = \sum_{j=0}^{m} b_j \frac{d^j v_i}{dt^j}$

$\sin(\omega t) \rightarrow \boxed{H(s)} \rightarrow |H(j\omega)|\sin(\omega t + \angle H(j\omega))$

$\Sigma A_i \sin(\omega_i t + \phi_i) \rightarrow \boxed{H(s)} \rightarrow \Sigma |H(j\omega_i)| A_i \sin(\omega_i t + \angle H(j\omega_i))$

changes magnitude and phase

hence, Bode plots



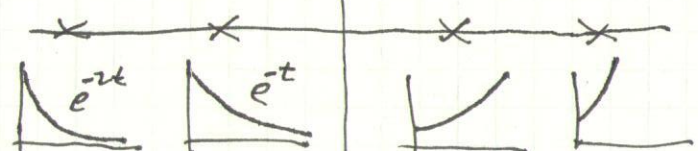
time response $\left(\sum_{i=0}^{n} a_i s^i\right) v_o = \left(\sum_{j=0}^{m} b_j s^j\right) v_i$

$H(s) = \frac{\Sigma b_j s^j}{\Sigma a_i s^i}$ ← characteristic polynomial

$= \frac{b(s)}{a(s)}$

roots of $a(s) = 0$ are poles
p_i or $\sigma_i \pm j\omega_i$

impulse response: $e^{p_i t}$

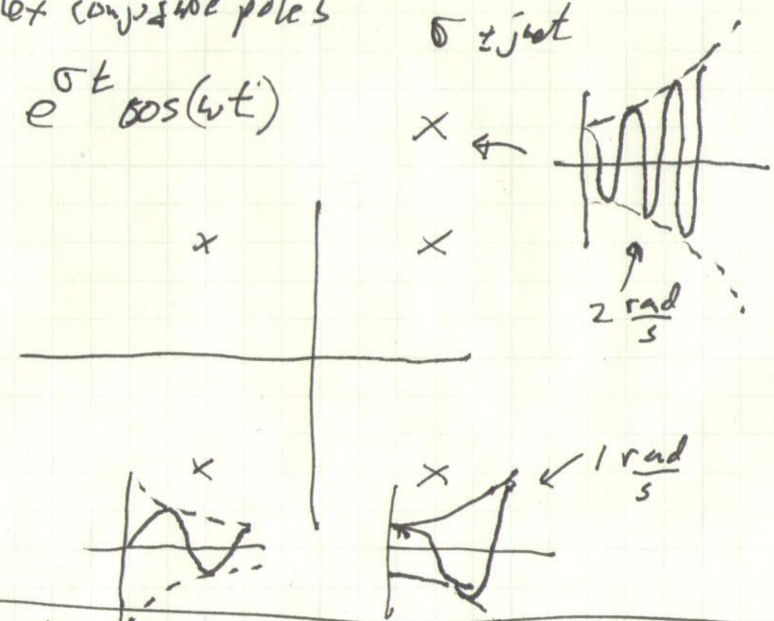


faster slower e^{t} e^{2t}

complex conjugate poles

$\Rightarrow e^{\sigma t} \cos(\omega t)$

$\sigma \pm j\omega t$



poles move in feedback

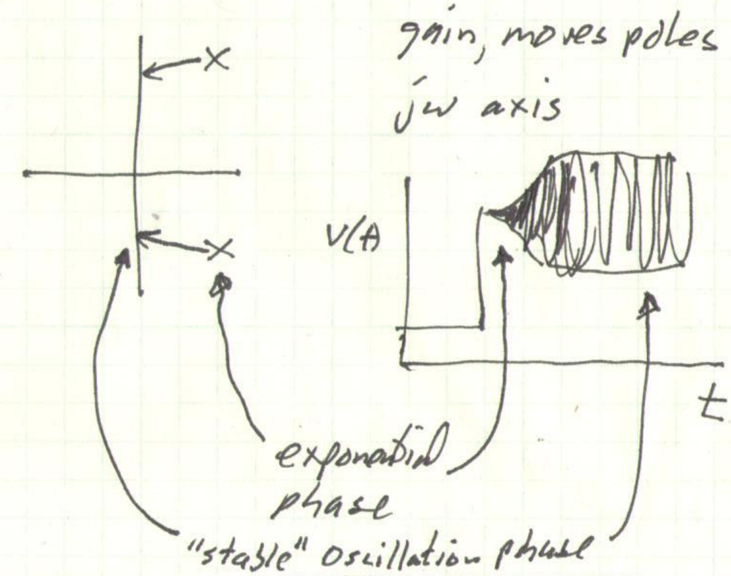
$A(s) = \dfrac{A_0}{1 + s/\omega_p}$ where $A_0 = 10^5$

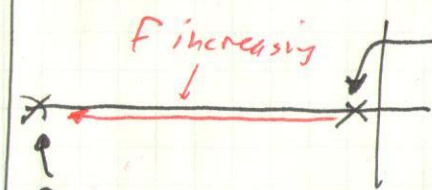
$\omega_p = 10$ rad/sec

$$A_{CL} = \frac{A_0}{1 + Af} = \frac{\frac{A_0}{1+s/\omega_p}}{1 + \frac{A_0 f}{1+s/\omega_p}} = \frac{A_0}{1 + A_0 f + s/\omega_p}$$

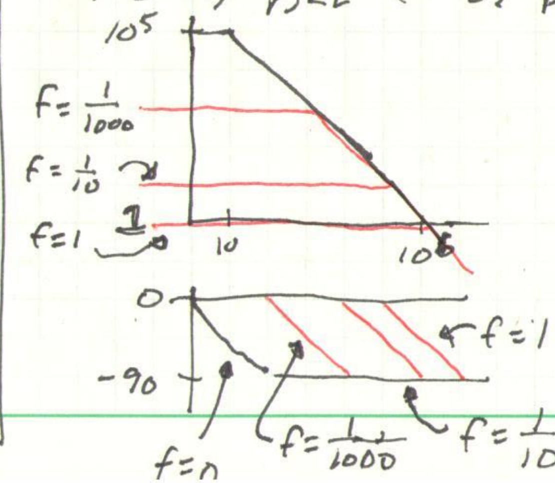
$$= \underbrace{\frac{A_0}{1 + A_0 f}}_{DC} \; \frac{1}{1 + \frac{s}{\omega_{pCL}}} \qquad \omega_{pCL} = \omega_p (1 + A_0 f)$$

nonlinear effects: growth of oscillation reduces gain, moves poles toward $j\omega$ axis





unity gain; $\omega_{p,CL} = (1 + A_0)\omega_p$ = unity gain BW



feedback is great for lots of reasons, <u>but</u>

risk of instability

Negative feedback good
positive feedback (usually) dangerous/bad

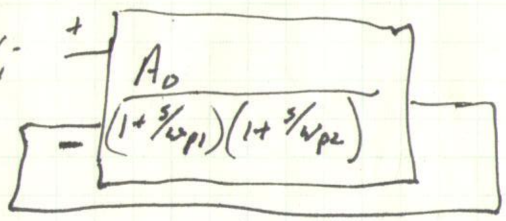
e.g.

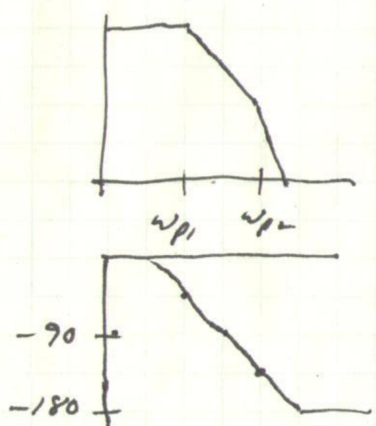
unity gain buffer

latch

each pole gives -90 phase shift above $\approx 10\,\omega_p$

so 2 poles gives -180



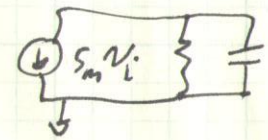


at high frequency, -180 phase shift +/- swap!

~~poles move in~~

consider the effect of phase

single pole v_i

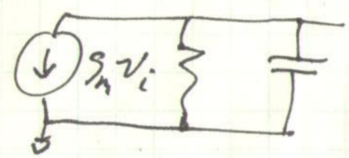


$$\frac{v_o}{v_i} = \frac{-g_m r_o}{1 + s/\omega_p} \qquad \omega_p = \frac{1}{r_o C}$$

$$|H(j\omega)| = \begin{cases} g_m r_o & \omega \ll \omega_p \\ g_m r_o/\sqrt{2} & \omega = \omega_p \\ \dfrac{g_m}{\omega C} & \omega \gg \omega_p \end{cases} \qquad \angle H(j\omega) = \begin{cases} -180 \\ -225 \\ -270 \end{cases}$$

$1\,\mu V \sin(\omega t)$

v_i



$g_m = 1\,mS$

$r_o = 1\,M\Omega$

$C_o = 1\,pF$

$$\omega_p = \frac{1}{10^6\, 10^{-12}} = 10^6$$

$g_m v_i = 10^{-6} A \sin(\omega t)$

at low freq, $v_o = -1V \sin(\omega t)$

$1V \sin(\omega t - \pi)$

$1V \sin(\omega t - 180°)$

above ω_p $\quad Z_o \approx \frac{1}{j\omega C}$

$i_c = C\frac{dv_o}{dt} = -1\mu A \sin(\omega t) = i_{g_m}$

$\frac{dV_o}{dt} = -10^6 \frac{V}{s} \sin(\omega t)$

$$V_o = \frac{10^6 \frac{V}{s}}{\omega} \cos(\omega t) = \frac{10^6 \frac{V}{s}/\omega_p}{\omega/\omega_p} \sin(\omega t - 270°)$$

$$= 1V\left(\frac{\omega_p}{\omega}\right) \sin\left(\omega t - \frac{3\pi}{2}\right)$$