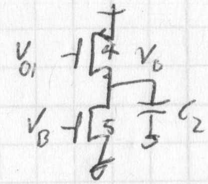
freq response notes

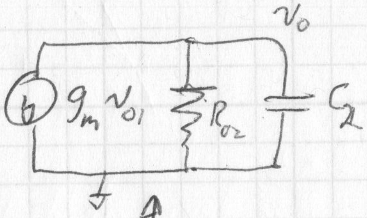
Miller figures

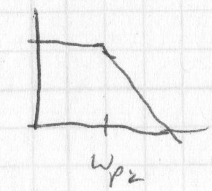
Slew rate

Heaviside, pole & zeros

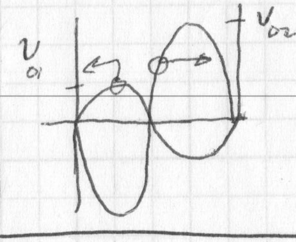
Slew rate - non-linear (current limit) behavior







for linear system (model) response gain is indep of amplitude



$v_{o2} = A_v(\omega)\, v_{o1}$

(at least) 2 important nonlinearities
- voltage supply limit (RoI)
- current limit

$v_o = -G_{m1} R_{o1} v_{o1}$

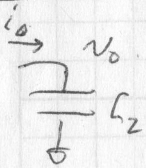
$v_o = v_{o1} + v_c$

$$\frac{dv_o}{dt} = \frac{dv_{o1}}{dt} + \frac{dv_c}{dt}$$

small relative to $\frac{dv_o}{dt}$ $\left(\approx \frac{1}{A}\right)$

v_o can not change any faster than v_c!

$$\frac{dv_c}{dt} = \frac{i_c}{C_c}$$ ← usually limited by I_{tail}

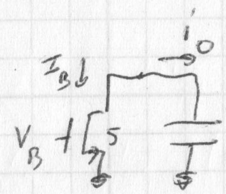


$$\frac{dv_o}{dt} = \frac{i_o}{C_2}$$

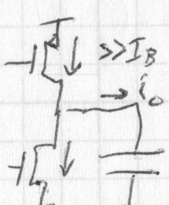
What are limits on i_o?

$v_{o1}\nearrow$, M4 turns off

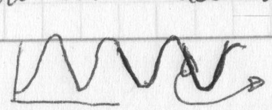
$i_o = -I_B$



$v_{o1}\searrow$ M4 conducts a lot more current

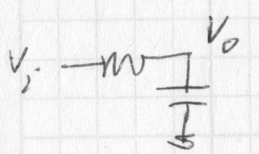


output can increase faster than decrease



$\frac{-I_B}{C_2}$

Heaviside transfer function



$$\frac{dV_o}{dt} = \frac{i_c}{C} \qquad i_c = \frac{V_i - V_o}{R}$$

$$RC\frac{dV_o}{dt} = V_i - V_o$$

$$RC\frac{dV_o}{dt} + V_o = V_i$$

(more generally $\frac{d^n y}{dt} + a_1\frac{d^{n-1}y}{dt^{n-1}} + \ldots + a_n y = b_0\frac{d^m u}{dt^m} + \ldots + b_m u$

Linear ODE)

let $V_i = V_I \sin(\omega t)$

<u>assume</u> $V_o = V_0 \sin(\omega t + \phi) = \cancel{V}_{os} \sin\omega t + V_{oc} \cos(\omega t)$

$$RC\frac{d}{dt}\left[V_0 \sin(\omega t + \phi)\right] + V_0 \sin(\omega t + \phi) = V_I \sin(\omega t)$$

$$RC V_0 \omega \cos(\omega t + \phi) + V_0 \sin(\omega t + \phi) = V_I \sin(\omega t)$$

$$RC V_{os} \omega \cos(\omega t) + RC V_{oc}(-\omega)\sin(\omega t) + V_0 \sin(\omega t) = V_I \sin(\omega t)$$

must be true at all t

$\{\cos\omega t \text{ terms}\} + \{\sin\omega t \text{ terms}\} = V_I \sin\omega t$

$= 0$

$\{\quad\}\cos(\omega t) + \{\quad\}\sin\omega t = V_I \sin(\omega t)$

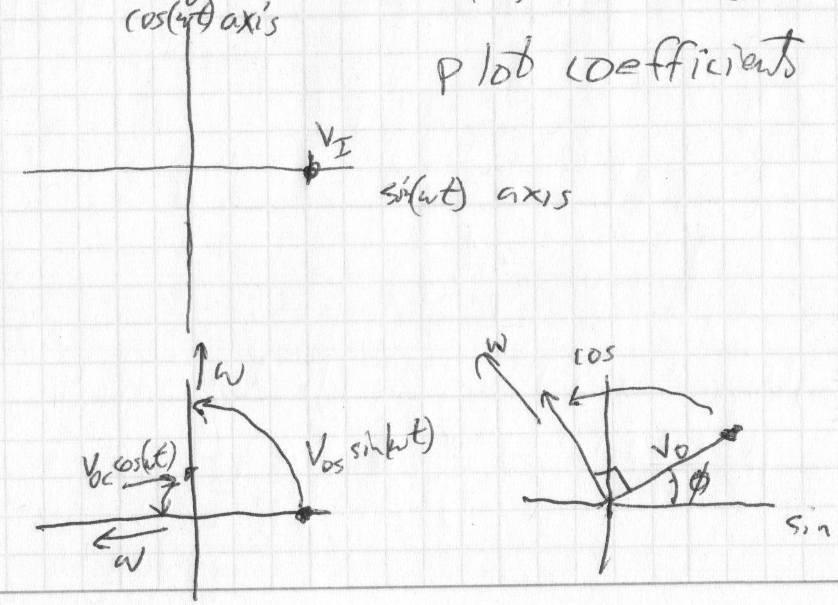
$= 0$

$=$

always works out that way, even in the general case.

got tired of writing $\sin(\omega t)$ and $\cos(\omega t)$

plot coefficients



Heaviside : complex #s to the rescue,

derivative : rotate 90° CCW

scale by ω

don't need sin, cos axes, just use complex #s!

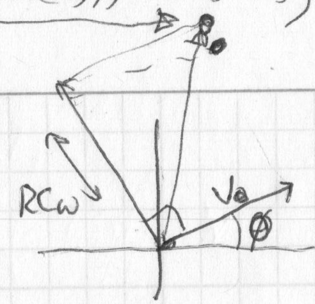
rotate 90° CCW : multiply by j

scale by ω : multiply by ω

derivatives : multiply by $j\omega$

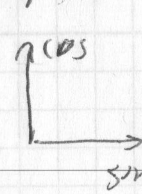
$$\left(RC\frac{d}{dt}+1\right)V_0 = V_0\left(RC\omega\cos(\omega t+\phi)+\sin(\omega t+\phi)\right)$$

$RC\omega\cos(\omega t+\phi)$



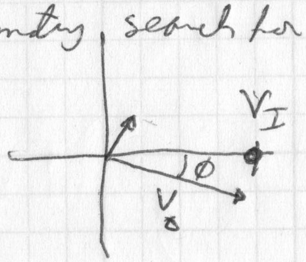
input sine wave
output sine wave
derivative sin wave
scaled deriv sine wave

} are all just ~~complex~~ dots ~~#s~~ where in sin/cos space



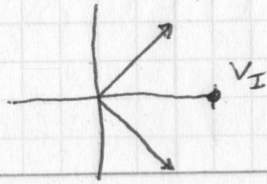
so $\left(RC\frac{d}{dt}+1\right)V_0\sin(\omega t+\phi) = V_I\sin\omega t$

turns into geometry, search for V_0, ϕ

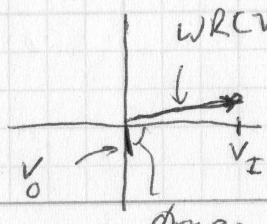


$\omega RC < 1$

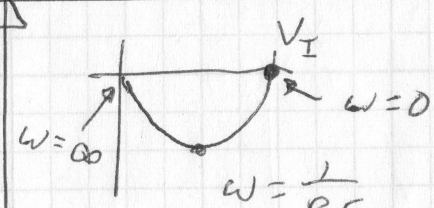
solutions parameterize by ω



$\omega RC \approx 1$



$\phi \approx 90$



$|V_0|$ goes from V_I to 0

ϕ goes from 0 to -90

-45 when $V_0 = \frac{1}{\sqrt{2}}V_I$

so $\left(RC\frac{d}{dt}+1\right)v_o = v_i$

turns into $(RC(j\omega)+1)\,v_o = v_i$

$$\frac{v_o}{v_i} = \frac{1}{1+RCj\omega} = H(j\omega)$$

Heaviside!

conventional to ~~take~~ look at this function in the complex plane $H(s)$ but don't forget why we evaluate at $j\omega$

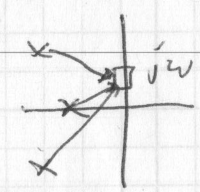
$$H(s) = \frac{\sum_{i=0}^{m} b_i s^{m-i}}{\sum_{i=0}^{n} a_i s^{n-i}} = \frac{b(s)}{a(s)} = \frac{\prod (s-z_i)}{\prod (s-p_i)}$$

poles are places where $a(s)=0$, $H(s)=\infty$

zeros are places where $b(s)=0$, $H(s)=0$

zeros come from having 2 paths to the output

$$H(j\omega) = \frac{\prod_{i=0}^{m} (j\omega - z_i)}{\prod_{i=0}^{n} (j\omega - p_i)}$$



pole locations correspond to unforced solutions to the original ODE

$y_i(t) = e^{p_i t}$ Real poles, LHP $p_i < 0$

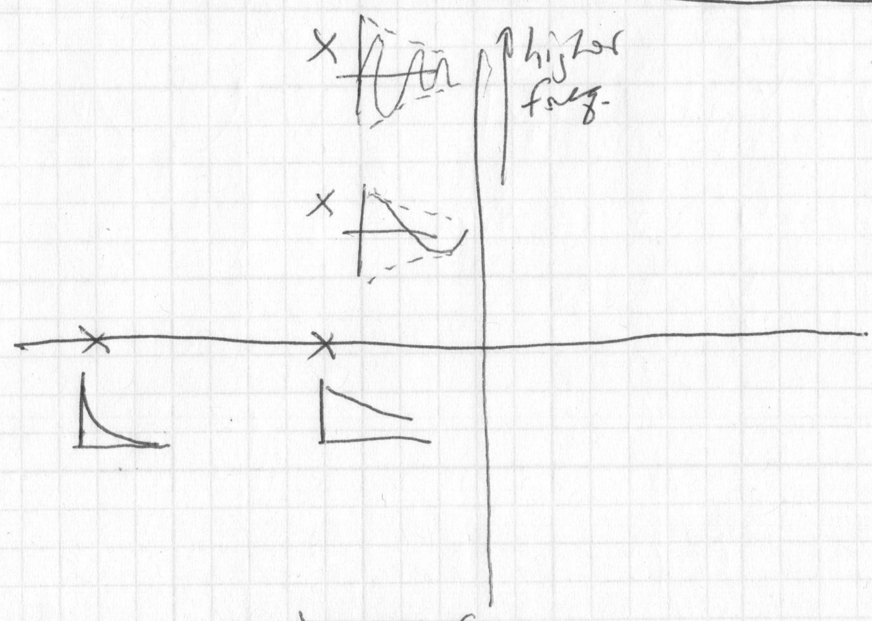
RHP $p_i > 0$

complex poles $p = \sigma \pm j\omega$

LHP $\sigma < 0$

RHP $\sigma > 0$

$$e^{\sigma \pm j\omega} \Rightarrow e^{\sigma t}\sin(\omega t + \phi)$$



all have same exponential