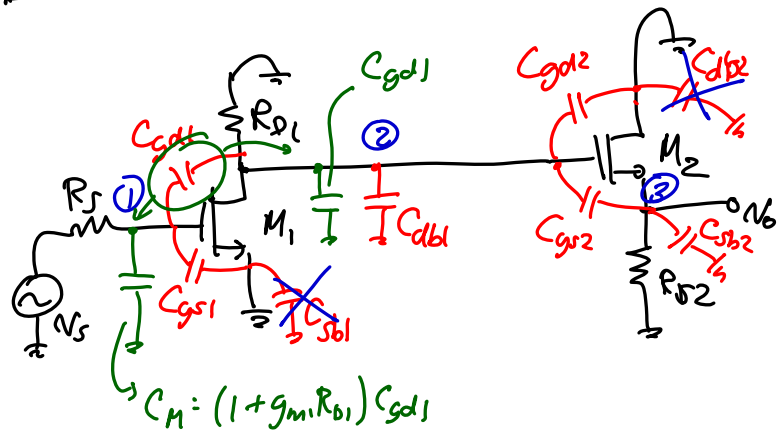
Lecture 7: Active Loads I

- Announcements:
- Lab 1 next week – report to your lab section
- HW#3 has been online
- Lecture Topics:
  - Open Ckt Time Constant (OCTC) Analysis (cont)
  - Short Ckt Time Constant (SCTC) Analysis
  - Example Low Freq. Response Determination
  - Active Loads
    - —Why active loads?
    - —Examples of actively loaded amplifiers
- ----------
- Last Time:

MOS Two-Stage Amplifier



$C_M = (1 + g_{m1}R_{D1})C_{gd1}$

$\tau_{①} = [(1 + g_{m1}R_{D1})C_{gd1} + C_{gs1}]R_S$

$\tau_{②} = [C_{gd1} + C_{db1} + C_{gd2}](r_{o1} \| R_{D1})$

$\tau_{③} = C_{sb2}\left(\frac{1}{g_{m2} + g_{mb2}} \| R_{S2}\right)$

$\tau_{gs2} = C_{gs2}(R_{D2} + R_{S2})$ / $(1 + (g_{m2} + g_{mb2})R_{S2})$ — could neglect since the gain across $C_{gs2} \sim 1$

$\omega_H = \frac{1}{\tau_{①} + \tau_{②} + \tau_{③} + \tau_{gs2}}$ → $f_H = \frac{\omega_H}{2\pi}$

$i = 0$

V_x — C — V_x

$+ \; \Delta V = 0 \; -$

$\equiv$ + C not there

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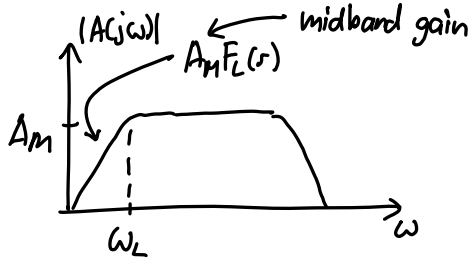
Low Freq. Amplifier Response Using Short Circuit Time Constant Analysis (SCTC)

Recall:



In general, for the low freq. response:

$$F_L(s) = \frac{s^{n_L} + d_1 s^{(n_L-1)} + \cdots}{s^{n_L} + e_1 s^{(n_L-1)} + \cdots}, \quad n_L = \#\text{poles} = \#\text{zeros}$$

We can express the coefficient e_1 by:

$$e_1 = \omega_{p1} + \omega_{p2} + \cdots + \omega_{pn_L}$$

For the case of a dominant pole:
↳ i.e., the highest freq. pole

Similar analysis to that used for OCTC...

$$F_L(s) \cong \frac{s}{s+\omega_L} = \frac{s}{s+e_1} \rightarrow e_1 \cong \omega_{p1} = \omega_L$$

$$\therefore \boxed{\omega_L \cong e_1 = \sum_j \omega_{pj} = \sum_j \frac{1}{C_j R_{js}} = \sum_j \frac{1}{\tau_{js}}}$$

where $C_j \triangleq$ various large (>10nF) capacitors in the ckt. (e.g., the bypass caps.)

$R_{js} \triangleq$ driving point resistance seen between the terminals of C_j determined with:

For reading, can go to Sedra & Smith

① all large capacitors short-circuited, except C_j, which is replaced by the test voltage source for R determination

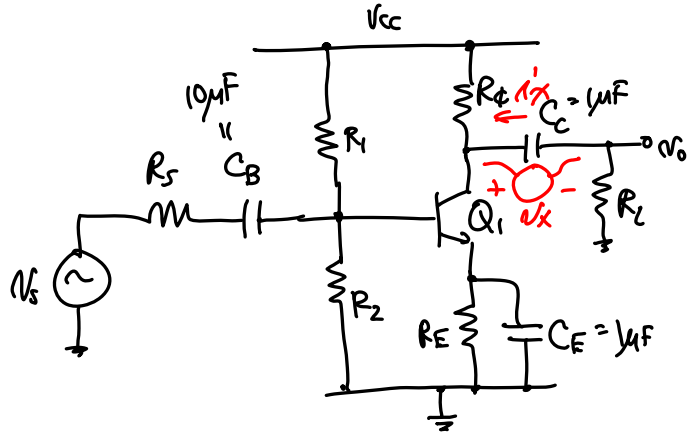
② all independent sources eliminated (i.e., short voltage sources, open current sources)

③ open all H.F. capacitors (i.e., small caps in the pF range, or < 1nF)

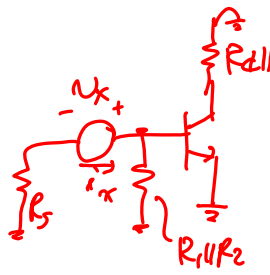
Again, for the case where there are no dominant poles, a reasonable approximation is:

$$\omega_L \cong \sqrt{\omega_{p1}^2 + \omega_{p2}^2 - 2\omega_{z1}^2 - 2\omega_{z2}^2}$$

Ex: Determine the L.F. response of the C.E. Amplifier



(a) ω_{pB} due to C_B: Short ckt. C_C & C_E



$R_{BS} = \frac{V_x}{I_x}$ = resistance in series w/ V_x

$R_{BS} = R_1 \| R_2 \| r_\pi + R_S$

$\tau_B = R_{BS} C_B = (R_1 \| R_2 \| r_\pi + R_S) C_B$

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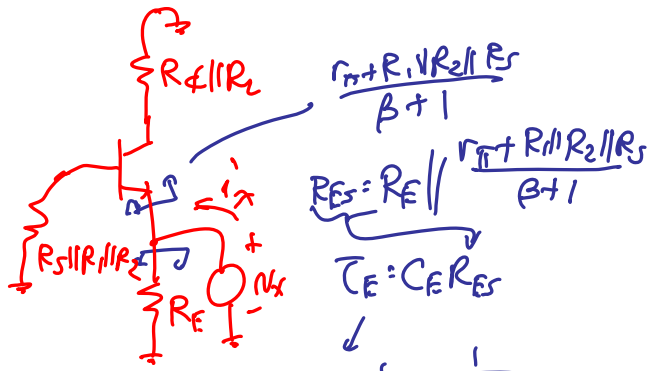
$\therefore \omega_{pB} = \frac{1}{\tau_B} = \frac{1}{(R_1 \| R_2 \| r_\pi + R_S) C_B}$

(b) ω_{pC} due C_C: short cct. C_B & C_E

$\Rightarrow$ again, R_{CS} = resistance in series w/ V_X (seen for both sides)

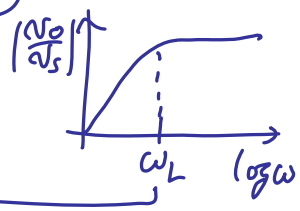
$\tau_C = (R_L + R_C \| R_E) C_C \rightarrow \omega_{pC} = \frac{1}{\tau_C} = \frac{1}{(R_L + R_C) C_C}$

(c) ω_{pE} due to C_E: short C_B & C_C



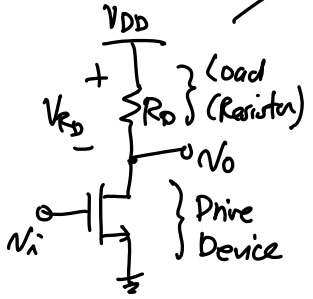
and finally:

$\omega_L = \omega_{pB} + \omega_{pC} + \omega_{pE}$



Active Loads

$\Rightarrow$ Why use them? $\rightarrow$ Gain: $\frac{V_O}{V_i} = -g_m R_D$



For $\frac{V_O}{V_i}\uparrow$, must:

① Raise g_m $\rightarrow$ raise I_D

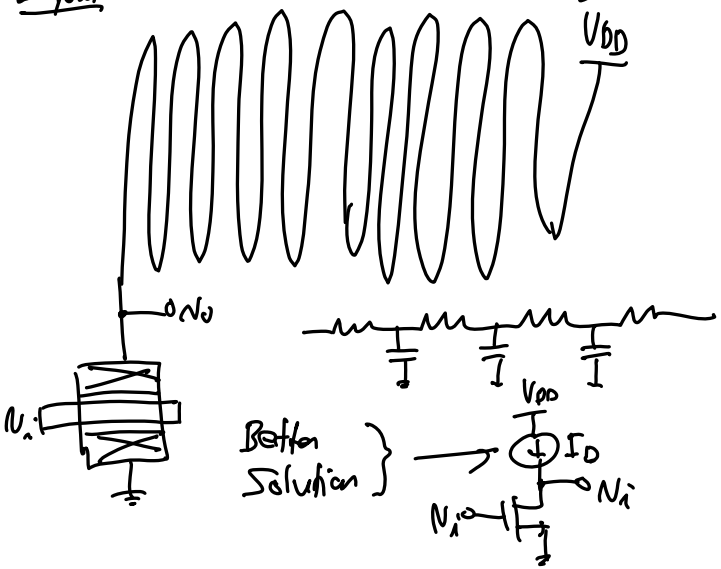
Problem: $V_{RD} = I_D R_D \uparrow$

Limited by the supply V_{DD}!

② Raise R_D $\rightarrow$ gain, $V_{RD}\uparrow$

another problem: area consumption by R_D $\rightarrow$ high cost!

Layout:



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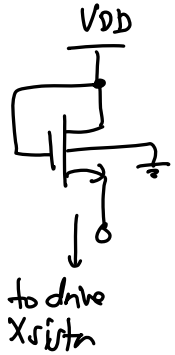
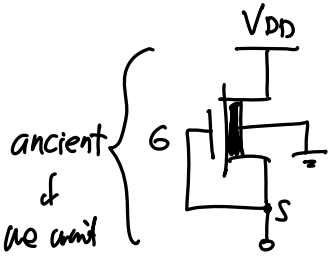
Types of Active Loads → want a current source

Diode-Connected Enhancement Load:

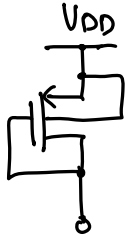


Depletion Load:

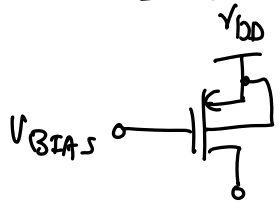


ancient of we won't consider this

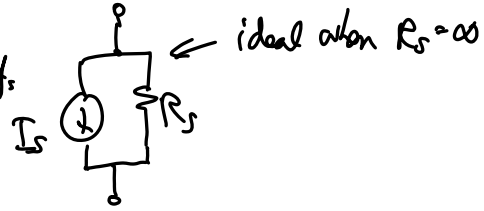
Diode-Connected PMOS Load:



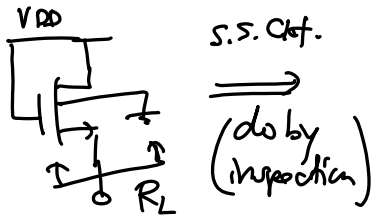
PMOS Current Source Load:

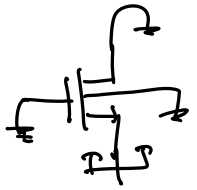


Norton Equivalent:



Diode-Connected Enhancement Load



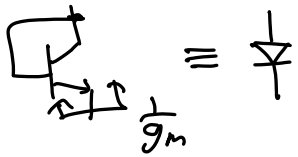


$R_L: \frac{1}{g_m} \| \frac{1}{g_{mb}}$

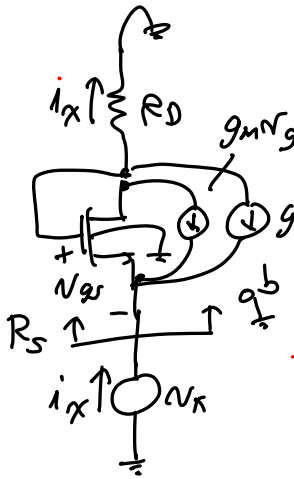
$= \frac{1}{g_m + g_{mb}}$

$\sim 1\text{-}10\,k\Omega$

"Diode-Connected"



How about this?



$i_x = -g_m V_{gs} - g_{mb} V_{bs}$

$= -g_m(i_x R_D - V_x) - g_{mb}(-V_x)$

$= g_m V_x - g_m R_D i_x + g_{mb} V_x$

$i_x(1 + g_m R_D) = (g_m + g_{mb}) V_x$

$\therefore R_S = \frac{V_x}{i_x} = \frac{1 + g_m R_D}{g_m + g_{mb}}$

$= \frac{\frac{1}{g_m} + R_D}{1 + \eta} = R_S$

$[\eta = \frac{g_{mb}}{g_m}]$

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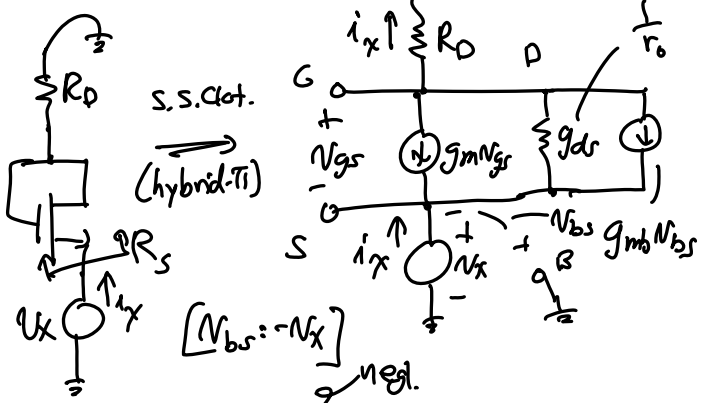
Full hybrid-π analysis:

(in case you want to see it)



$[V_{bs} = -V_x]$

$$i_x = -g_m V_{gs} + g_{ds}(-V_{gs}) - g_{mb} V_{bs}$$

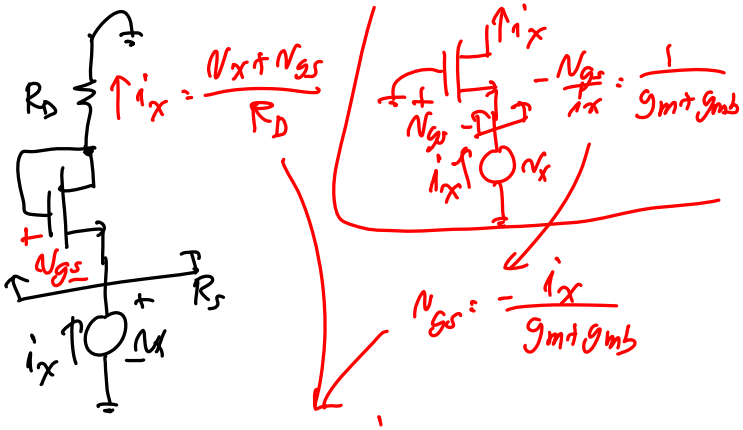
(neglect g_{ds})

$$= g_m(V_x - i_x R_D) + g_{mb} V_x$$

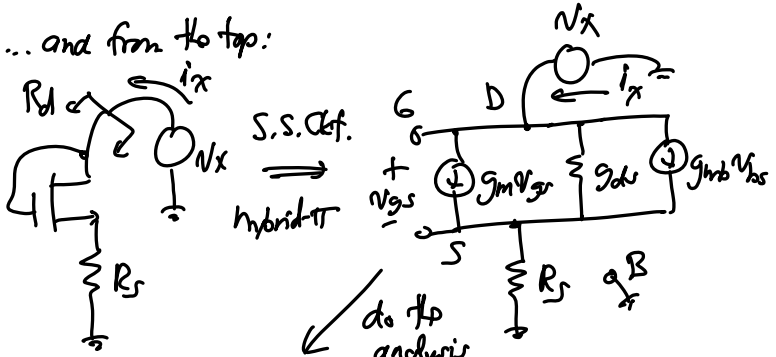
$$R_S = \frac{V_x}{i_x} = \frac{1 + g_m R_D}{g_m + g_{mb}} = \frac{1}{g_m + g_{mb}} + \frac{R_D}{1+\eta}$$

$$\approx \frac{1}{g_m + g_{mb}} + R_D$$

$$R_S \cong \frac{\frac{1}{g_m} + R_D}{1+\eta}$$



... and from the top:



$$R_d = \frac{V_x}{i_x} = \frac{1}{g_m} + (1+\eta) R_S \approx \frac{1}{g_m} + R_S$$

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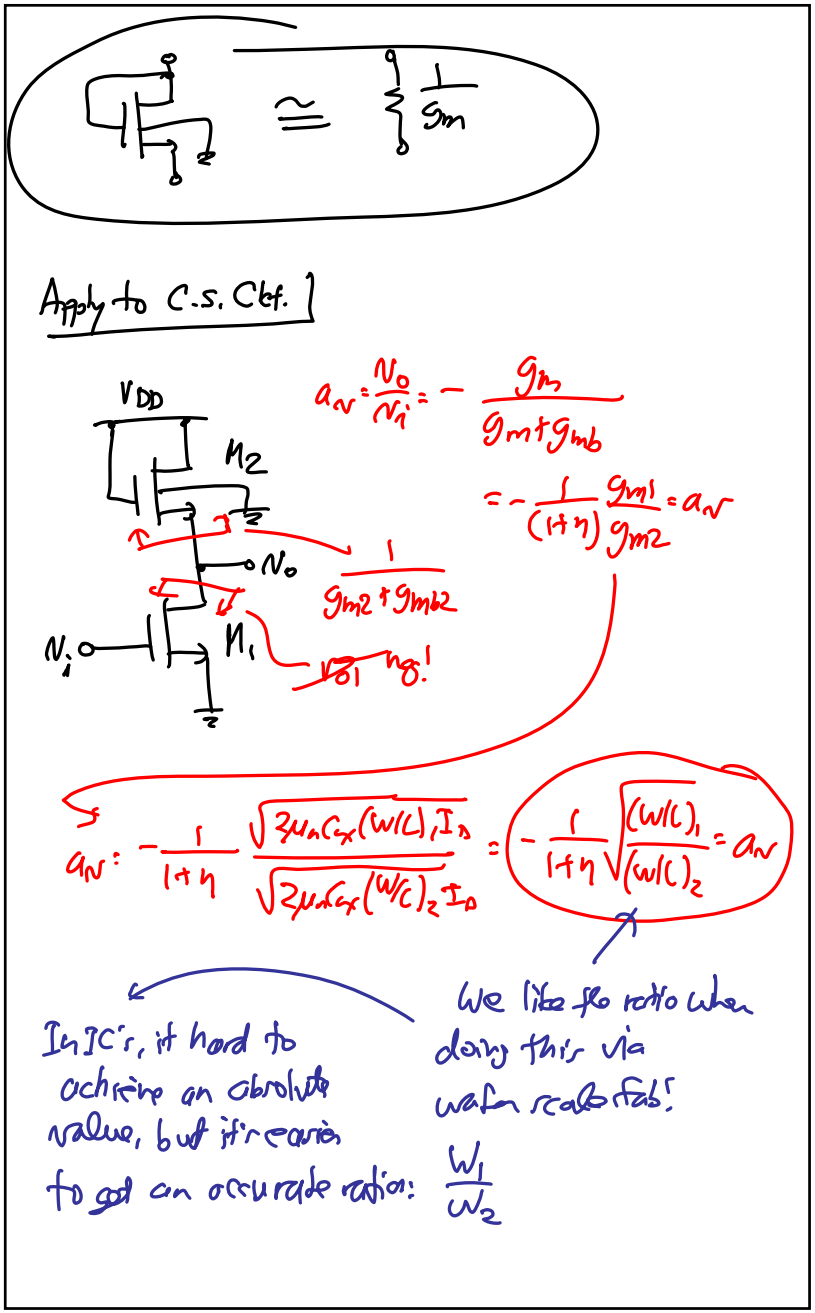

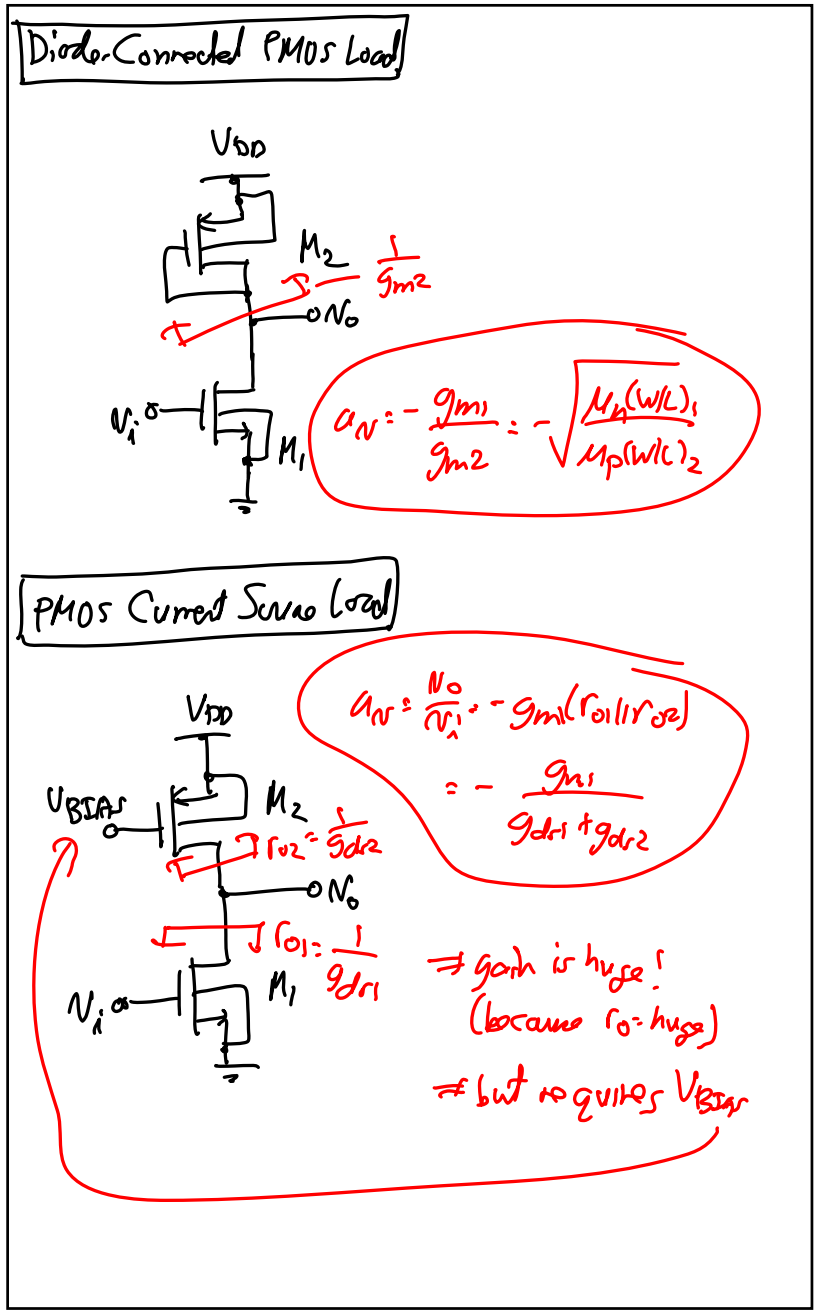

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