Lecture 7: Frequency Response Inspection Analysis II

- **Announcements**:
- HW#3 passed out in lecture and posted online
- HW#2 due today at 5 p.m.
- **Lecture Topics**:
  - Frequency Response Examples (cont.)
  - Short Ckt Time Constant (SCTC) Analysis
  - Example Low Freq. Response Determination
  - Start Active Loads
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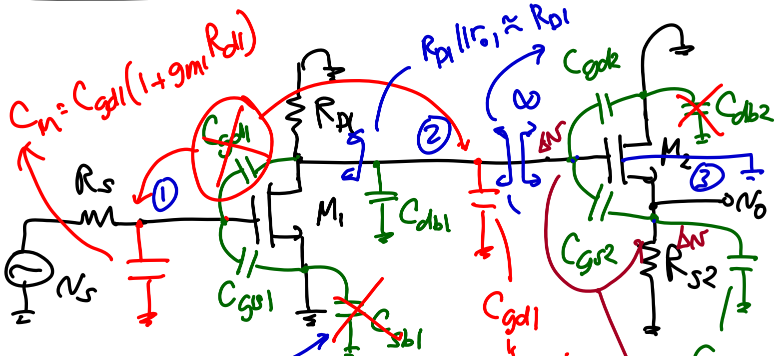
- **Last Time**:

$\boxed{\text{MOS Two-Stage Amplifier}}$



① Eliminate caps.

② Determine time constants:

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

can neglect if $r_{o1} \gg R_{D1}$

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

$$\tau_{③} = C_{sb2}\left[R_{s2} \,\Big\|\, \frac{1}{g_{m2}+g_{mb2}}\right]$$

$$\tau_{gs2} = C_{gs2}\left(\frac{R_{D1}+R_{s2}}{1+(g_{m2}+g_{mb2})R_{s2}}\right)$$

if gain ≈ 1 → can neglect if these are other Xsistors

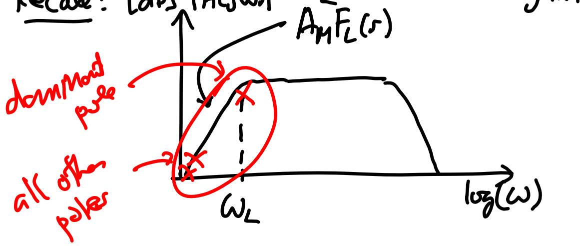
*

and finally:

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

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

Recall: [dB] $|A(j\omega)|$ ← midband gain



In general, for the low freq. response:

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

We can express the coefficient e_1 by:

$$e_1 = \omega_{P1} + \omega_{P2} + \cdots + \omega_{Pn_L}$$

Similar analysis to that used for OCTC...

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

$$F_L(s) \cong \frac{s}{s+\omega_L} = \frac{s}{s+e_1} \rightarrow e_1 \cong \omega_{P1} = \omega_L$$

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

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:

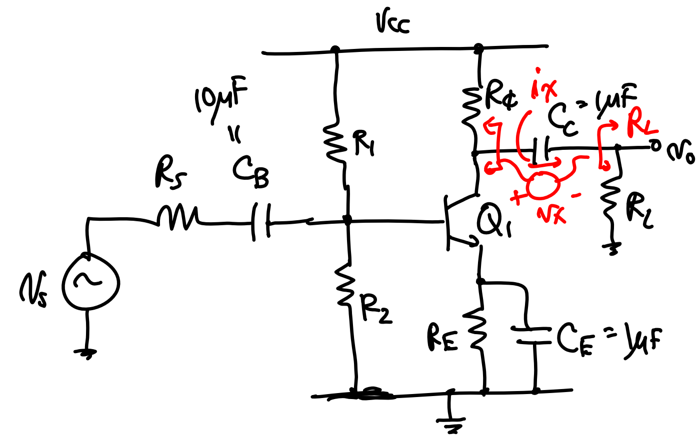
For reading, can go to Sedra & Smith

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)

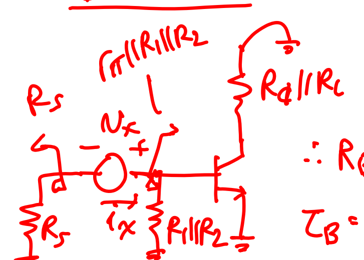
Again, for the case where there are no dominant poles, a reasonable approximation is:

$$\omega_L \cong \sqrt{\omega_{P1}^2 + \omega_{P2}^2 - 2\omega_{Z1}^2 - 2\omega_{Z2}^2}$$

Ex. Determine the L.F. Response of the C.E. amplifier



(a) τ_B due to C_B: short ckt. C_C & C_E

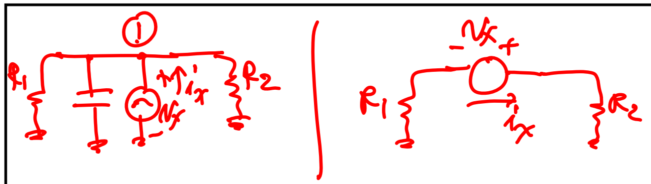


$R_{Bs} = \frac{v_x}{i_x}$ = resistance in series w/ v_x ← driving pt. R associated w/ C_B

$\therefore R_{Bs} = R_s + r_\pi \| R_1 \| R_2$

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

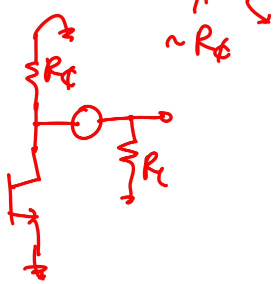
$$\omega_{pB} = \frac{1}{\tau_B} = \frac{1}{(R_s + r_\pi \| R_1 \| R_2) C_B}$$



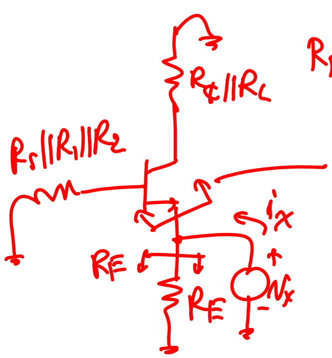
(b) τ_C due to C_C: short ckt. C_B & C_E
↳ again, v_x sees R in series

$\tau_C = (R_L + r_o \| R_C) C_C$
$\sim R_C$

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



(c) τ_E due to C_E: short C_C & C_B



$R_{Es} = \frac{v_x}{i_x} = R_E \| \frac{r_\pi + R_s \| R_1 \| R_2}{(\beta+1)}$

$\frac{1}{g_m} + \frac{R_s \| R_1 \| R_2}{\beta+1} = \frac{r_\pi + R_s \| R_1 \| R_2}{\beta+1}$

$\tau_E = R_{Es} C_E$

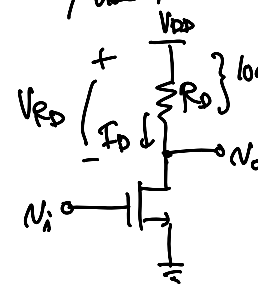
$\omega_{pE} = \frac{1}{\tau_E} = \frac{1}{R_{Es} C_E}$

and finally,

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

Active Loads

→ why use them?



→ Gain $= \frac{v_o}{v_i} = -g_m R_D$

For $\frac{v_o}{v_i}$ ↑, must:

① Raise g_m → raise I_D

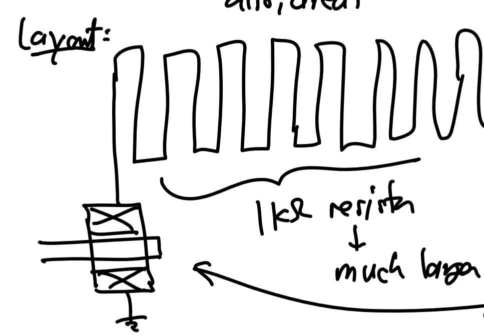
problem: V_{R_D} ↑ → gets too large, limited by V_{DD}!

supply limits the amount of gain you can have

② increase R_D → but same problem

also, area!

Layout:

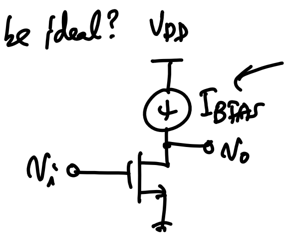


← polysilicon resistor

↓ make long & thin to get large R

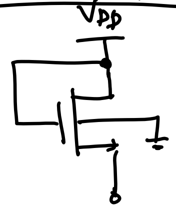
1kΩ resistor ↓ much larger than → too big!

→ What would be ideal?



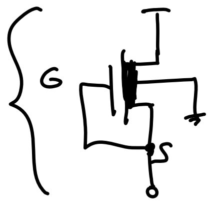
to approximate this, use an active load!

Diode-Connected Enhancement Loads



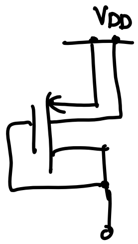
Depletion Load

ancient & we won't consider this

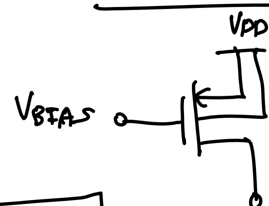


$V_{GS}=0 \rightarrow$ device is on

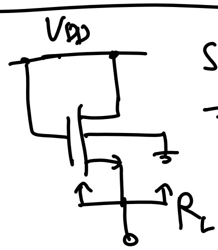
Diode-Connected PMOS Load:



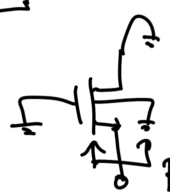
PMOS Current Source Load:



$\boxed{\text{Diode-Connected Enhancement Load}}$



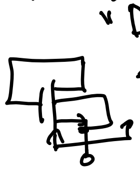
$\xrightarrow{\text{S.S.Ckt.}}$ (do by inspection)



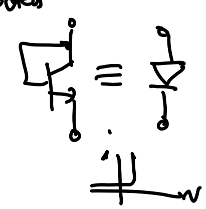
$= \frac{1}{g_m} \| \frac{1}{g_{mb}}$

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

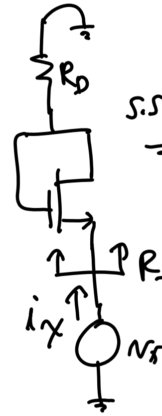
"Diode-connected"



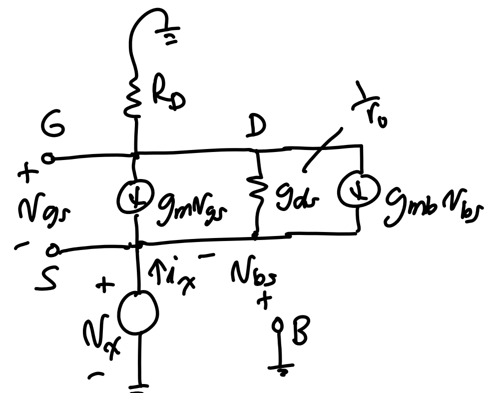
$R = \frac{1}{g_m}$



How about this?



$\xrightarrow{\text{S.S.Ckt.}}$



$[v_{bs} = -v_x]$

$$i_x = -g_m v_{gs} + \underbrace{g_{ds}(-v_{gs})}_{\text{neg!}} - g_{mb} v_{bs} \qquad \eta = \frac{g_{mb}}{g_m}$$

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

$$R_s = \frac{v_x}{i_x} = \frac{1 + g_m R_D}{g_m + g_{mb}} = \frac{1}{g_m + g_{mb}} + \frac{R_D}{(1+\eta)}$$

$$\boxed{R_s \cong \frac{\frac{1}{g_m} + R_D}{1+\eta}}$$