Lecture 7: Active Loads I

- Announcements:
- Lab 1 this week – report to your lab section
- Lecture Topics:
  - Short Ckt Time Constant (SCTC) Analysis
  - Example Low Freq. Response Determination
  - Active Loads
    - —Why active loads?
    - —Examples of actively loaded amplifiers
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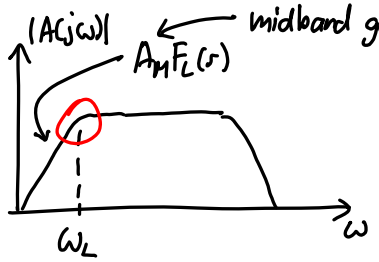
- Last Time:

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

Recall:



In general, for the low freq. response:

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

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

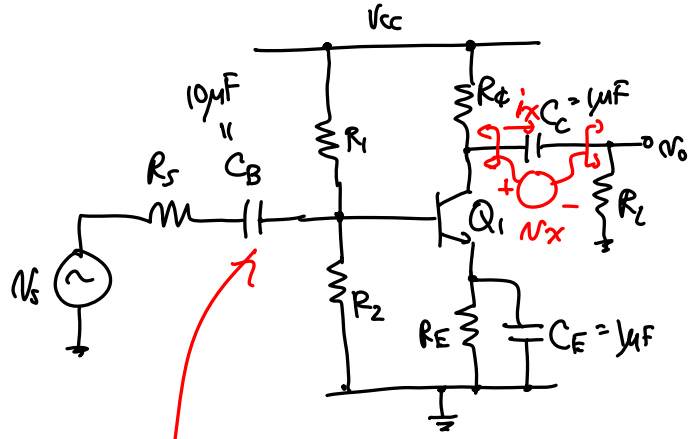
② all independent sources eliminated (i.e., short voltage sources, open current sources)

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

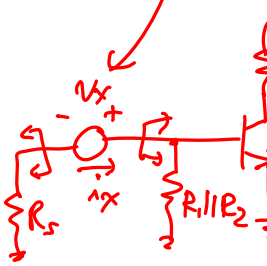
Again, for the case where there are no dominant poles, a reasonable approximation is:

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

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



(a) τ due to C_B: short cbf. C_C & C_E



$R_{BS} = \frac{V_X}{i_X}$: resistance in series w/ V_X

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

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

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

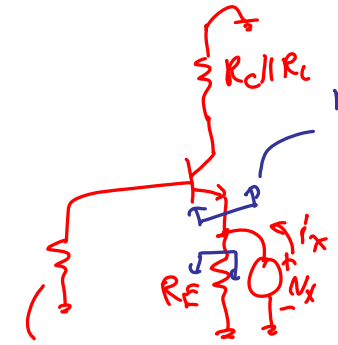
(b) τ due to C_C: short cbf. C_B & C_E

⇒ again R_{CS}: resistance in series seen on both sides

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

(R_C: $R_C \| R_L$)

(c) τ due to C_E: short C_B & C_C



$R_S \| R_1 \| R_2$

$\frac{r_\pi + R_S \| R_1 \| R_2}{\beta + 1}$

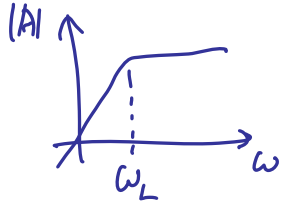
$R_{ES} = R_E \| \frac{r_\pi + R_S \| R_1 \| R_2}{\beta + 1}$

$\tau_E = R_{ES} C_E$

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

and finally:

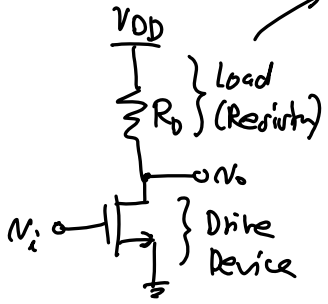
$$\omega_L = \omega_{pB} + \omega_{pC} + \omega_{pE}$$



Active Loads

⇒ Why use them?

Gain = $\frac{v_o}{v_i} = -g_m R_D$



For $\frac{v_o}{v_i} \uparrow$, must:

① Raise g_m → raise I_D

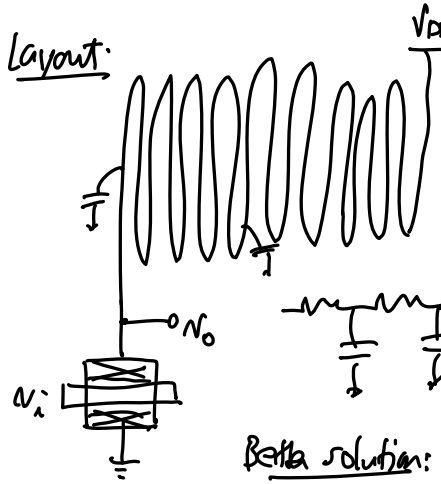
Problem: $V_{R_D} = I_D R_D \uparrow$

Limited by supply V_{DD}

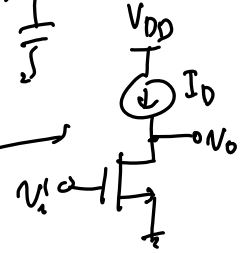
② raise R_D → again, $V_{R_D} \uparrow$

another problem: area consumption by R_D ← high cost!

Layout:

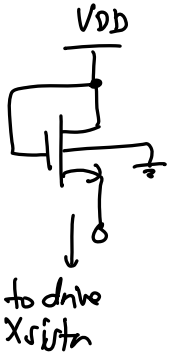


Better solution:

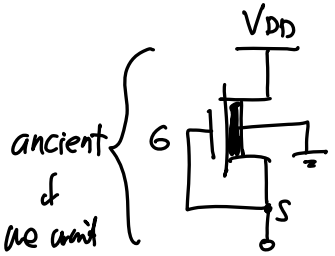


Types of Active Loads → want a current source

Diode-Connected Enhancement Load:

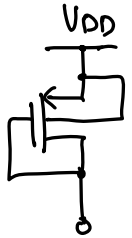


Depletion Load:

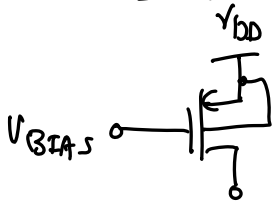


ancient & we won't consider this

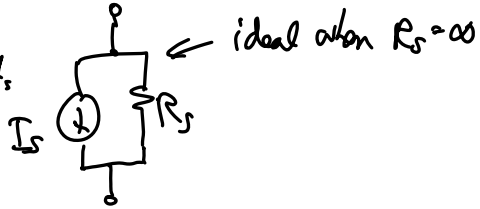
Diode-Connected PMOS Load:



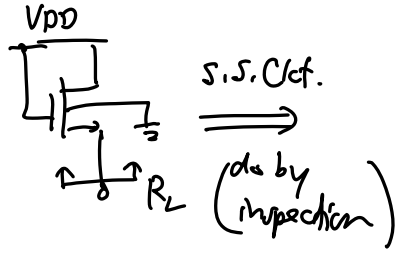
PMOS Current Source Load:

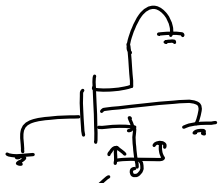


Norton Equivalent:



Diode-Connected Enhancement Load



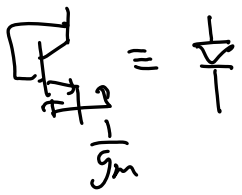


$$R_L = \frac{1}{g_m} \| \frac{1}{g_{mb}}$$

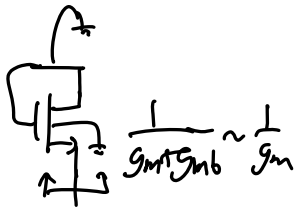
$$= \frac{1}{g_m + g_{mb}}$$

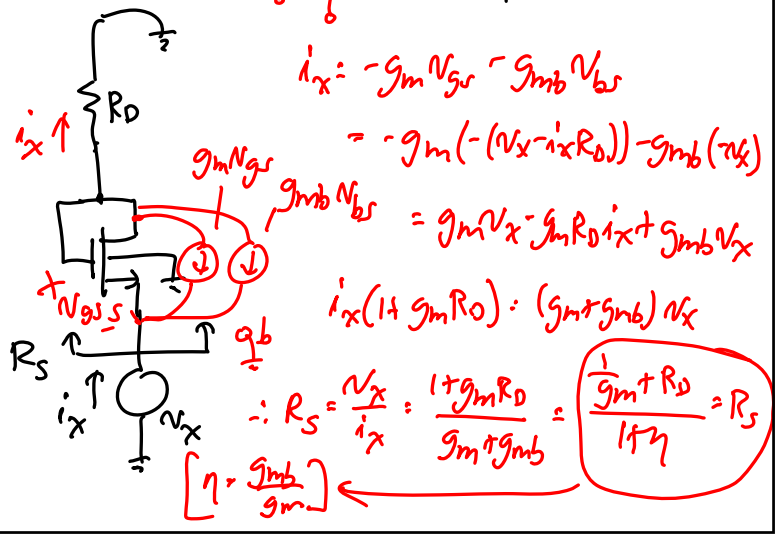
$$\sim \frac{1}{1.1 g_m}$$

"Diode-Connected"



How about this?





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

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

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

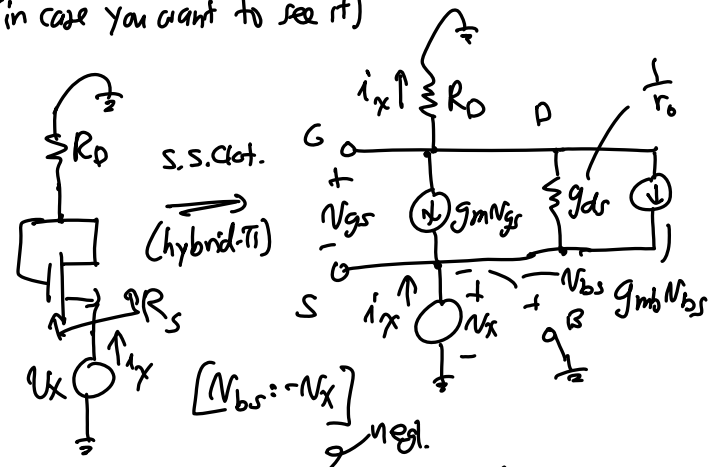
$$i_x(1 + g_m R_D) = (g_m + g_{mb}) V_x$$

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

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

Full hybrid-π analysis:

(in case you want to see it)



$[V_{bs} = -V_x]$

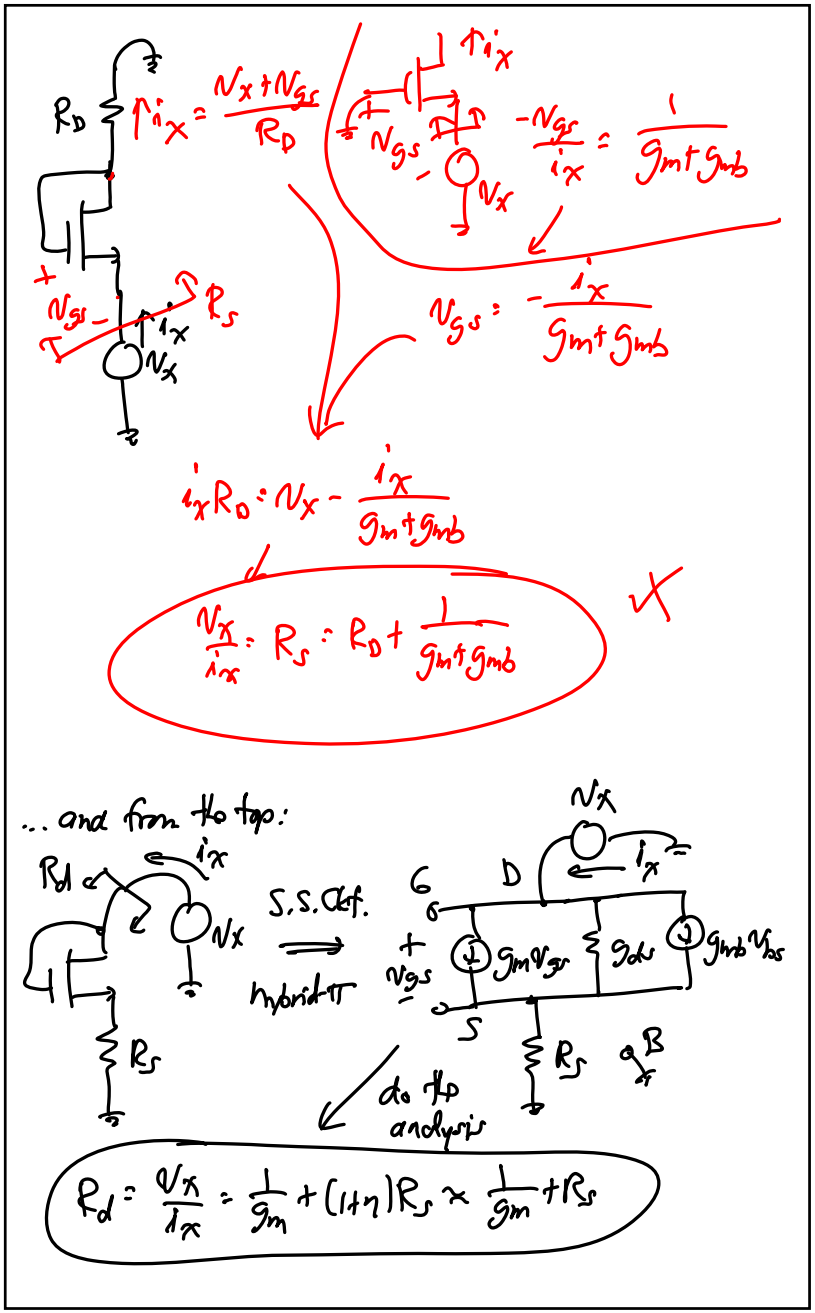
$$i_x = -g_m V_{gs} + g_{ds}(-V_{gs}) - g_{mb} V_{bs}$$ (neglect g_{ds})

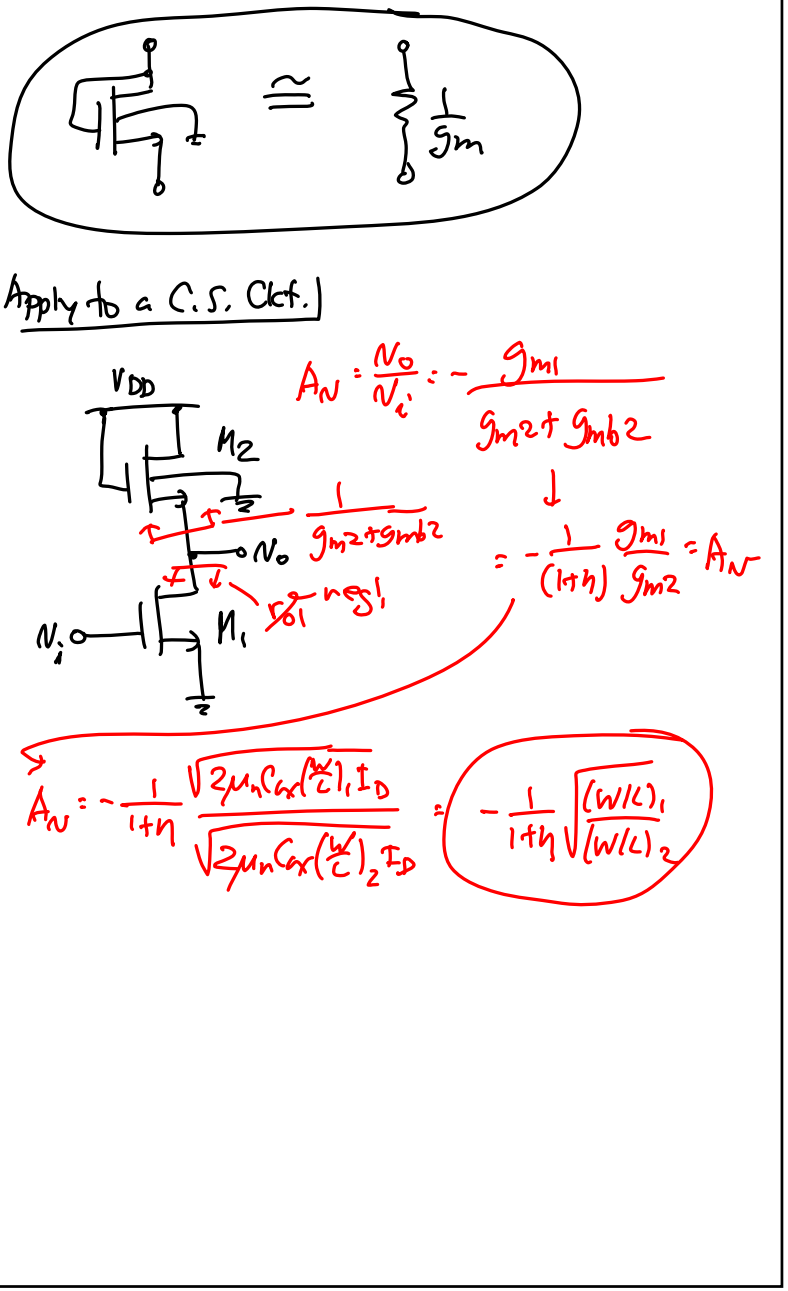
$$= g_m(V_x - i_x R_D) + g_{mb} V_x$$

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

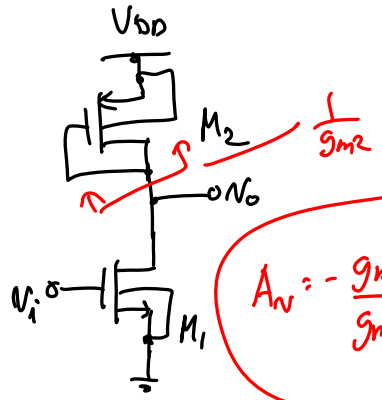
$$\approx \frac{1}{g_m + g_{mb}} + R_D$$

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



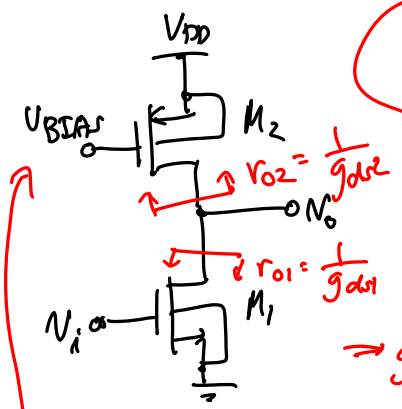


Diode-Connected PMOS Load



$$A_V = -\frac{g_{m1}}{g_{m2}} = -\sqrt{\frac{\mu_n (W/L)_1}{\mu_p (W/L)_2}}$$

PMOS Current Source Load

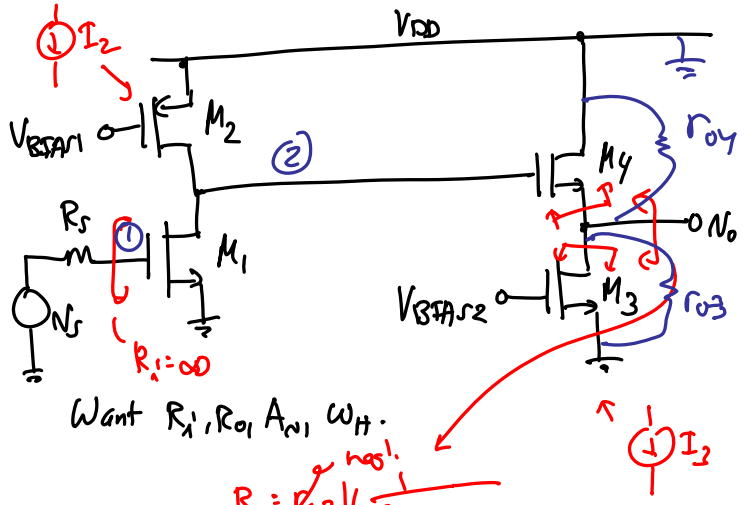


$$A_V = \frac{V_o}{V_i} = -g_{m1}(r_{o1} \| r_{o2}) = -\frac{g_{m1}}{g_{ds1} + g_{ds2}}$$

⇒ gain is huge! (r_o = huge)

⇒ but requires V_{BIAS}

Ex. Multi-Stage Actively-load MOS Clef.



Want R_i, R_o, A_{v1}, ω_H.

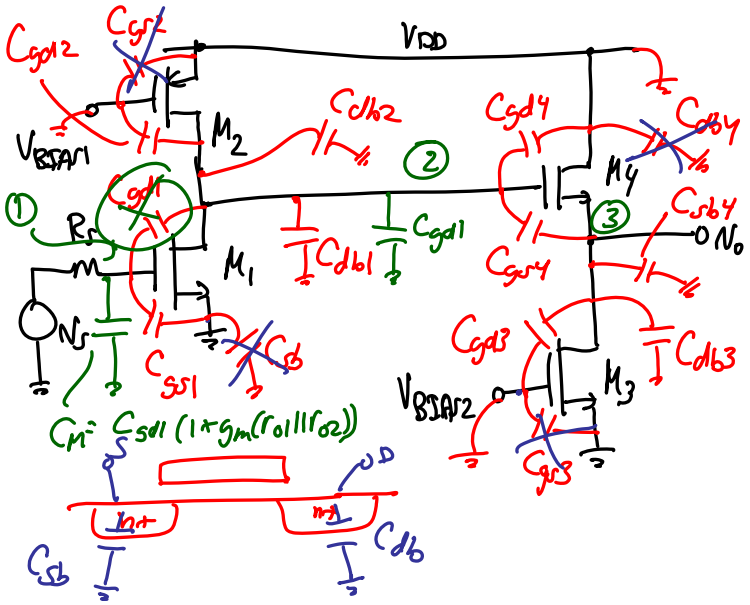
$$R_o = r_{o3} \| \frac{1}{g_{m4} + g_{mb4}}$$

$$a_V = \frac{V_o}{V_s} \cdot \frac{V_{(2)}}{V_{(1)}} \cdot \frac{V_o}{V_{(2)}} \rightarrow$$

$$= (1)(-g_{m1}(r_{o1} \| r_{o2})) \cdot \frac{g_{m4}(r_{o3} \| r_{o4})}{(g_{m4} + g_{mb4})(r_{o3} \| r_{o4})}$$

$$a_V = -g_{m1}(r_{o1} \| r_{o2}) \left(\frac{g_{m4}}{g_{m4} + g_{mb4}} \right)$$

Now, taddo freq. response:



$\tau_{①} = [C_{gs1} + C_{gd1}(1+g_{m1}(r_{o1}\|r_{o2}))]R_S$

$\tau_{②} =$