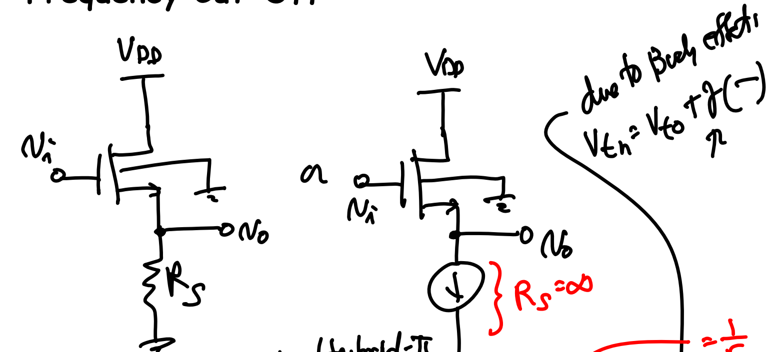
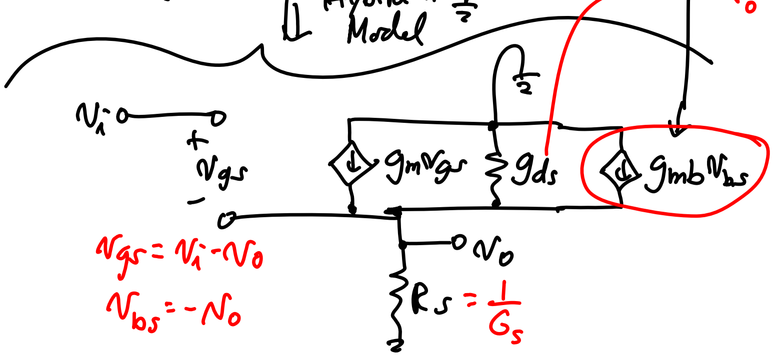
Logistics:

- I will miss Thursday, Feb. 12
- Make up lecture time:
  - Monday, 10-11:30 a.m.? ✗
  - Wednesday, 5-6:30 p.m.? ✗
  - Thursday, 3-4:30 p.m.? ✗
  - Thursday, 5-6:30 p.m.? ✗
    - → Th 7 p.m. ??? possible.
    - → Tu 7 p.m. ⇐ weekend?

Today:

- Open-Circuit Time Constant Analysis for High Frequency Cut-Off
- Short-Circuit Time Constant Analysis for Low Frequency Cut-Off





$v_{gs} = v_i - v_o$

$v_{bs} = -v_o$

$g_m(v_i - v_o) = v_o(g_{mb} + g_{ds} + G_s)$

$$\Rightarrow A_v = \frac{v_o}{v_i} \cong \frac{g_m}{g_m + g_{mb} + g_{ds} + G_s}$$

$R_s = \infty \to G_s = 0$

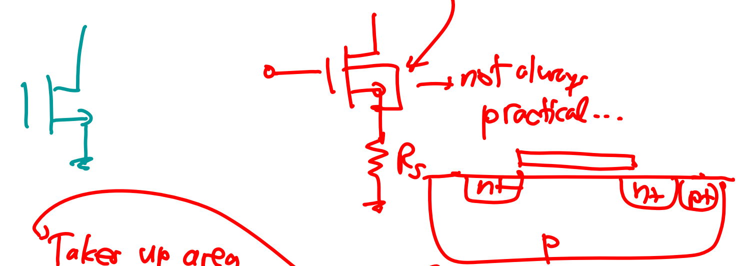
$g_{ds} \ll g_m + g_{mb}$

$$\boxed{A_v \cong \frac{g_m}{g_m + g_{mb}} \cong \frac{1}{1+\eta}}, \quad \eta = \frac{\gamma}{2\sqrt{V_{SB} + 2\phi_F}}$$

Body factor

$\neq 1$

To make it '1', do this:



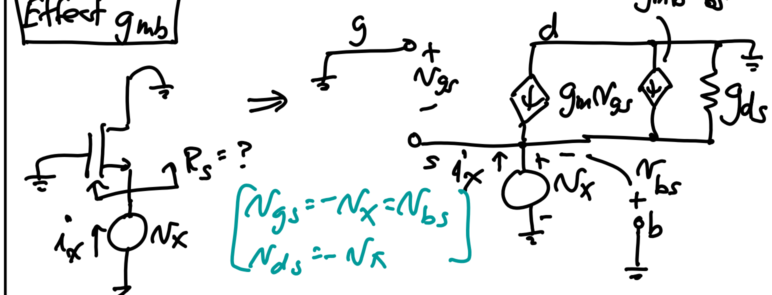
→ not always practical...

Takes up area

not good!

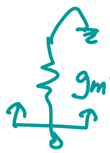
must have your own well to do this

Effect g_{mb}



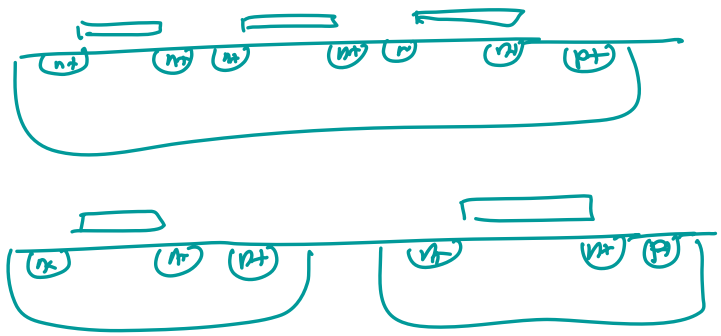
$v_{gs} = -v_x = v_{bs}$

$v_{ds} = -v_x$

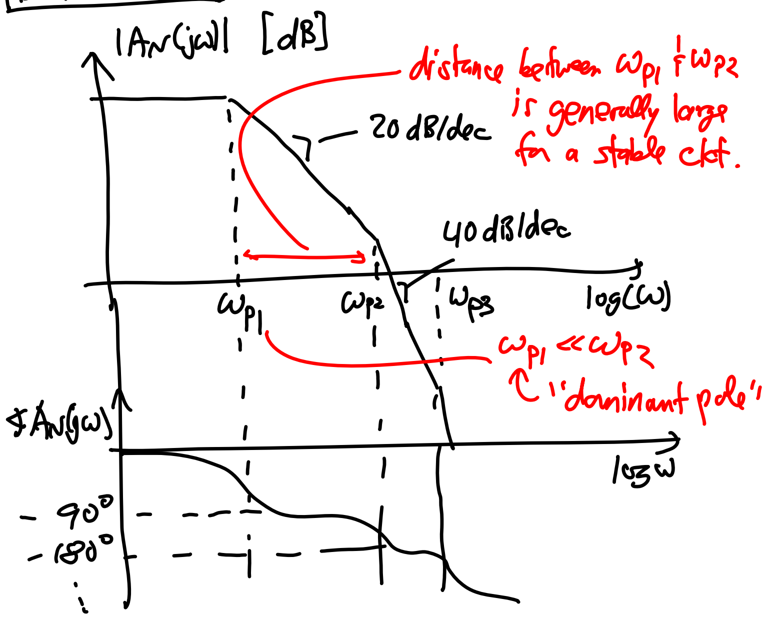


$g_m+g_{mb}+g_{ds} \rightarrow R_s = \dfrac{1}{g_m+g_{mb}+g_{ds}} = \dfrac{1}{g_m} \| \dfrac{1}{g_{mb}} \| r_o$

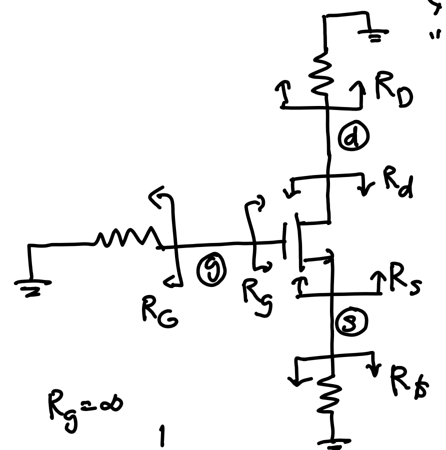
$$\boxed{R_s \approx \frac{1}{g_m+g_{mb}}}$$



Dominant Pole



MOS Inspection Formulas w/ Substrate Grounded



↳ only difference from "substrate tied to source" case is that g_m is replaced by g_m+g_{mb} in some of the formulas ↙ particularly ones where the source is involved!

$R_g = \infty$

$R_s = \dfrac{1}{g_m+g_{mb}}$

$R_d = r_o\left[1+(g_m+g_{mb})R_S\right]$

$\dfrac{v_d}{v_g} = -G_m R_{d}$, $G_m = \dfrac{g_m}{1+(g_m+g_{mb})R_S}$

$\dfrac{v_d}{v_s} = -G_m R_{d}$, $G_m = -(g_m+g_{mb})$

$\dfrac{v_s}{v_g} = \dfrac{g_m R_S}{1+(g_m+g_{mb})R_S}$

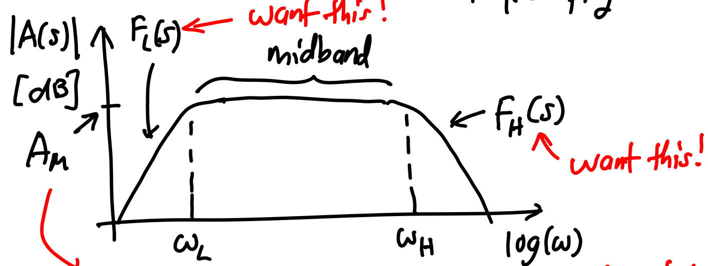
Remark. When the substrate is tied to the source, $g_{mb}=0$.

Freq. Response

Recall that the transfer function of a general amplifier can be expressed as a function of frequency via:

$$A(s) = A_M F_L(s) F_H(s)$$

midband gain (A_M); low freq. shaping ($F_L(s)$); high frequency shaping ($F_H(s)$)



we've already found this using small-signal analysis

High Freq. Response Determination Using Open Ckt. Time Constant (OCTC) Analysis

In general:

$$F_H(s) = \frac{1 + a_1 s + a_2 s^2 + \cdots + a_{n_z} s^{n_z}}{1 + b_1 s + b_2 s^2 + \cdots + b_{n_p} s^{n_p}}, \quad n_p > n_z$$

$$= \frac{\prod_{j=1}^{n_z}\left(1 - \frac{s}{z_j}\right)}{\prod_{i=1}^{n_p}\left(1 - \frac{s}{p_i}\right)} = \frac{\prod_{j=1}^{n_z}\left(1 + \frac{s}{\omega_{zj}}\right)}{\prod_{i=1}^{n_p}\left(1 + \frac{s}{\omega_{pi}}\right)}$$

from which:

$$b_1 = \frac{1}{\omega_{p1}} + \frac{1}{\omega_{p2}} + \cdots + \frac{1}{\omega_{pn_p}} = \sum_{i=1}^{n_p} \frac{1}{\omega_{pi}} = \sum_{k=1}^{n_p} \tau_{pk}$$

(b_1:) coeff. of the 1st order term

Through network theory, one can prove that: (see Gray & Meyer, Chpt. 7)

$$\sum_{i=1}^{n_p} \tau_{pi} = \sum_j C_j R_{jo} = \sum_j \tau_{jo}$$

where C_j are capacitors in the H.F. ckt., i.e., small ones

$R_{jo} \triangleq$ driving pt. resistance seen between the terminals of C_j determined with

1. all small (<1nF) capacitors open-circuited
2. all independent sources eliminated (i.e., short voltage sources, open current sources)
3. short all large (coupling/bypass) capacitors (i.e., >1μF or >1nF)

In calculating the H.F. response, we use the dominant pole approximation:

(i) $\omega_{p1} \ll \omega_{p2}, \ldots, \omega_{pn_p}$

(ii) $F_H(s) \cong \dfrac{1}{1 + \frac{s}{\omega_H}}$

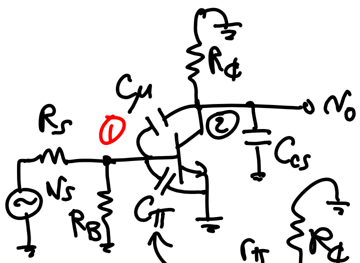
(iii) $b_1 \cong \dfrac{1}{\omega_{p1}} \rightarrow \boxed{\omega_H = \omega_{p1} \cong \frac{1}{b_1} = \frac{1}{\sum_j \tau_{jo}} = \frac{1}{\sum_j C_j R_{jo}}}$

When there is no dominant pole, an approximate expression for ω_H is:

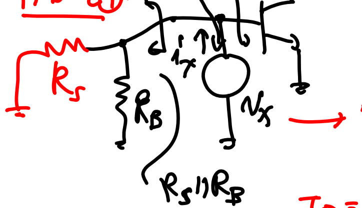
$$\omega_H \approx \frac{1}{\sqrt{\frac{1}{\omega_{p1}^2} + \frac{1}{\omega_{p2}^2} + \cdots - \frac{1}{\omega_{z1}^2} - \frac{1}{\omega_{z2}^2} - \cdots}}$$

(just FYI)

$\boxed{\text{Example H.F. Analysis}}$ C.E. Ckt.



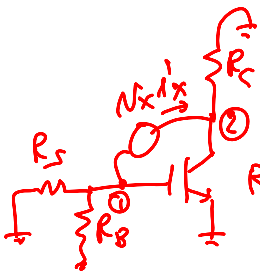
Find $\tau_{①}$:



$\longrightarrow R = \frac{v_x}{i_x} = r_\pi \| R_S \| R_B$

$\tau_{①} = C_\pi (r_\pi \| R_S \| R_B)$

Find $\tau_{\mu o}$: replace C_μ w/ v_x use inspection formula



$R_{\mu o} = \frac{v_x}{i_x} = R_{①} + R_{②} + g_m R_{①} R_{②}$

$R_{\mu o} = R_S \| R_B \| r_\pi + r_o \| R_C$
$\quad + g_m (R_S \| R_B \| r_\pi)(r_o \| R_C)$

$\tau_{\mu o} = R_{\mu o} C_\mu$

Find $\tau_{②}$:

$\tau_{②} = C_{cs} (r_o \| R_C) \approx C_{cs} R_C$

$$\boxed{\omega_H = \frac{1}{\tau_{①} + \tau_{\mu o} + \tau_{②}}}$$