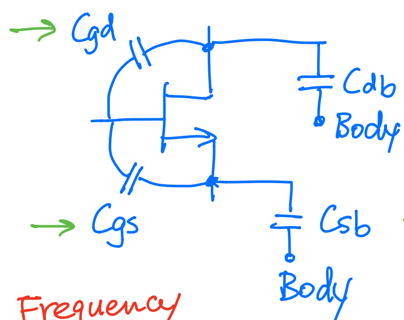
High Frequency Response

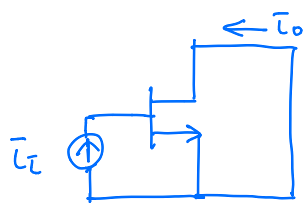


X neglect in EE105

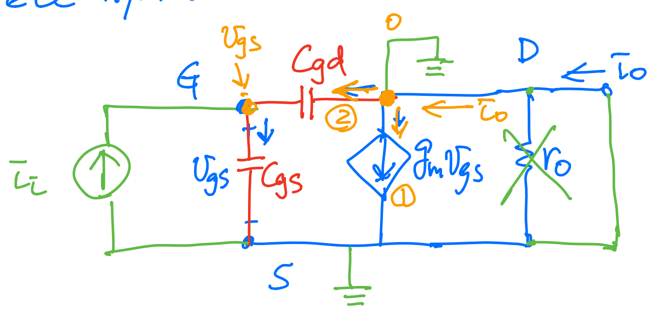
Transit Frequency

f_T of MOSFET : the freq at which current gain = 1 for short circuit load

AC circuit



Complete hybrid-π model.



$S = j\omega$ $\quad$ C_{gd} Impedance $= \dfrac{1}{sC_{gd}} = \dfrac{1}{j\omega C_{gd}}$

C_{gs} $\quad$ " $\quad = \dfrac{1}{sC_{gs}}$

KCL at G : $i_i = \dfrac{V_{gs}}{\frac{1}{SC_{gs}}} + \dfrac{V_{gs}}{\frac{1}{SC_{gd}}} = V_{gs}(sC_{gs} + SC_{gd})$

KCL at D : $i_o = \underset{1}{g_m V_{gs}} + \dfrac{(0 - V_{gs})}{\frac{1}{sC_{gd}}}\,2 = g_m V_{gs} - SC_{gd} \cdot V_{gs}$

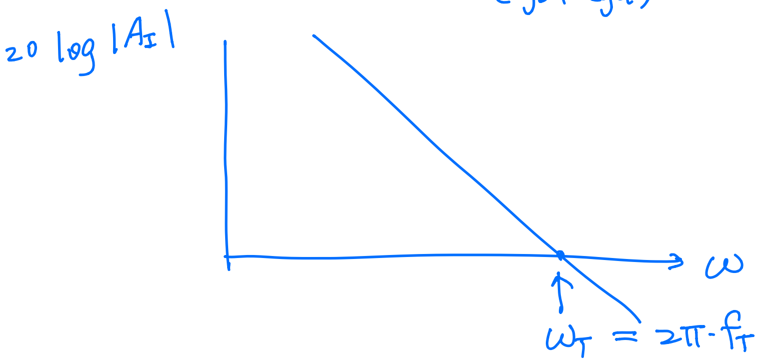
$$i_o = \frac{i_i}{SC_{gs} + SC_{gd}} (g_m - sC_{gd})$$

$$A_I = \frac{i_o}{i_i} = \frac{g_m - \cancel{sC_{gd}}}{s(C_{gs}+C_{gd})}$$

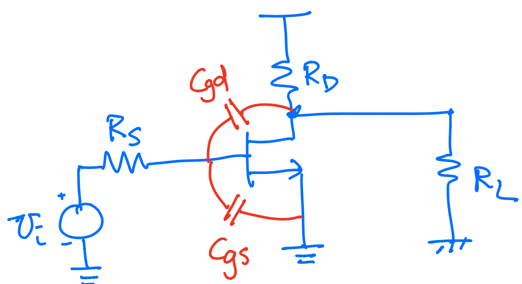
C_{gd} usually small

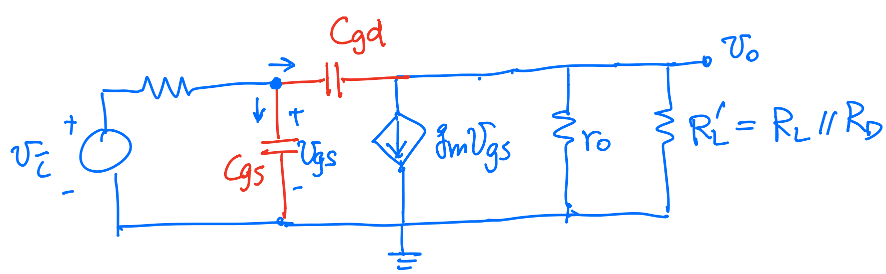
$$|A_I| = 1 = \left| \frac{g_m}{j\omega(C_{gs}+C_{gd})} \right|$$

$$\Rightarrow \omega_T = \frac{g_m}{C_{gs}+C_{gd}}$$



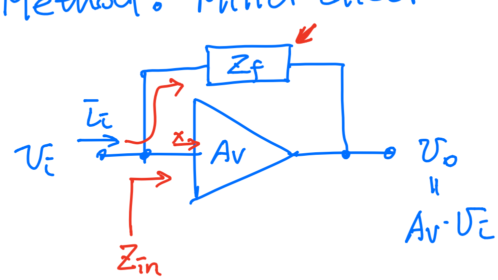
High freq Response of CS amp





Solving using KCL, KVL still works, but tedious,

Simplified Method: Miller Effect



$$Z_{in} = \frac{v_i}{i_i} = \frac{v_i}{\frac{v_i - v_o}{Z_f}}$$

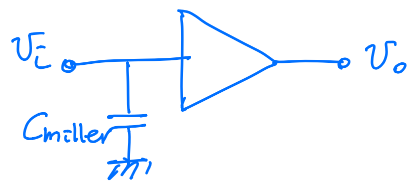
$$Z_{in} = \frac{v_i}{v_i - A_v v_i} Z_f$$

$$Z_{in} = \frac{Z_f}{1 - A_v}$$

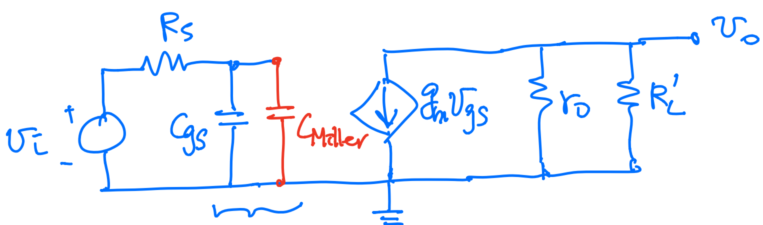
$$Z_f = \frac{1}{j\omega C}$$

$$Z_{in} = \frac{1}{j\omega C(1-A_v)} = \frac{1}{j\omega C_{Miller}}$$

$$C_{Miller} = C(1-A_v)$$



CS Amp with Miller Cap replacing Cgd.



$$C_{in} = C_{gs} + (1-A_v)C_{gd}$$

dc gain. $A_v = -g_m R_L''$

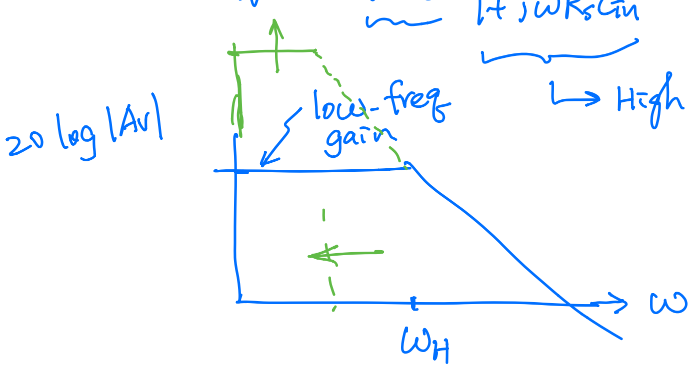
$$r_o // R_L' = R_L''$$

$$v_o = -g_m v_{gs}(r_o // R_L')$$

$$= -g_m \cdot v_i \cdot \frac{\frac{1}{j\omega C_{in}}}{R_s + \frac{1}{j\omega C_{in}}} \cdot R_L''$$

$$A_v = -\underbrace{g_m R_L''}\ \underbrace{\frac{1}{1+j\omega R_s C_{in}}}$$

↳ High freq Response



For CS amp

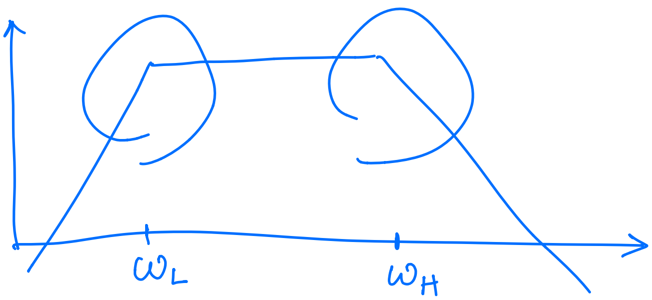
↑ Gain × Bandwidth ↓

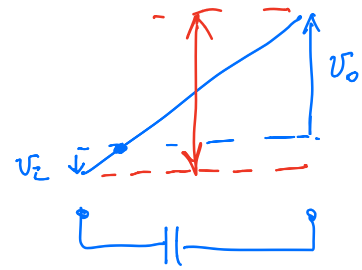
$$GBP \simeq \cancel{g_m} R_L'' \frac{1}{R_s C_{gd} \cdot \cancel{g_m} R_L''}$$

$$= \frac{1}{R_s \cdot C_{gd}}$$

$$\omega_H = \frac{1}{R_s C_{in}} = \frac{1}{R_s(C_{gs} + (1 + \underbrace{g_m R_L''}_{\text{large}})C_{gd})}$$

Typical Amp Freq Response



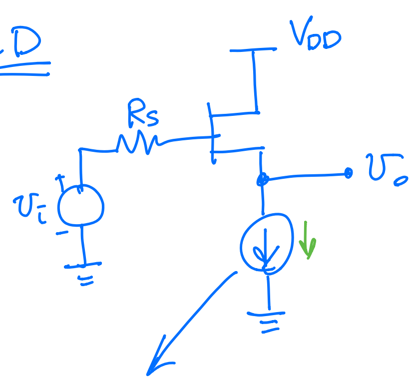


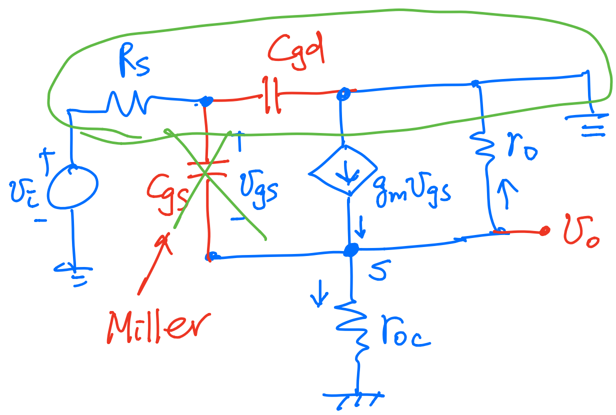
Full KCL, KVL

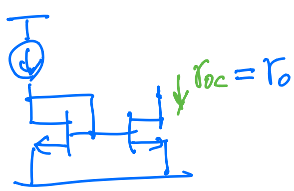
$$\omega_p = \frac{1}{R_s\left(C_{gs} + (1+g_m R_L'')C_{gd}\right) + R_L'' \cdot C_{gd}}$$

$\Rightarrow$ Remember, Miller Cap is an Approximation

CD



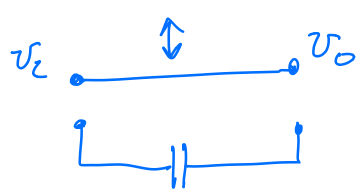




$C_{Miller} = (1 - A_v) \cdot C_{gs}$

$A_v \approx 1$ for CD

$C_{Miller} \rightarrow 0$



KCL at S

$$g_m v_{gs} = \frac{v_o}{r_o // r_{oc}}$$

$$v_g = \frac{\frac{1}{sC_{gd}} v_i}{R_s + \frac{1}{sC_{gd}}} = \frac{1}{1 + sR_sC_{gd}} v_i$$

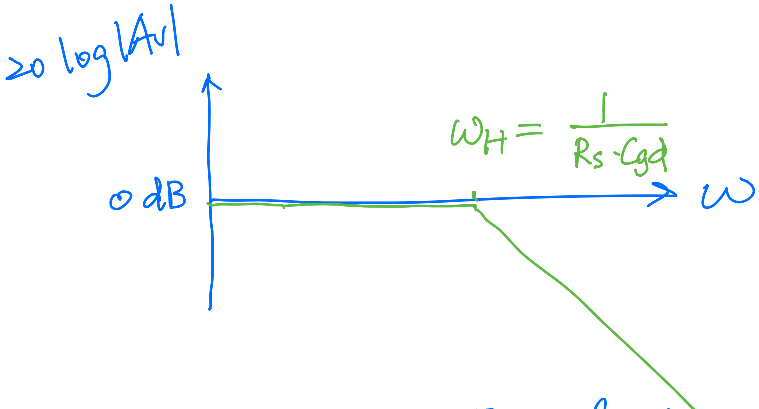
$$v_{gs} = v_g - v_s = v_g - v_o$$

$$g_m(v_g - v_o) = \frac{v_o}{r_o // r_{oc}}$$

$$v_o\left(g_m + \frac{1}{r_o // r_{oc}}\right) = g_m v_g = g_m \frac{1}{1 + sR_sC_{gd}} \cdot v_i$$

$$A_v = \frac{v_o}{v_i} = \underbrace{\frac{g_m}{g_m + \frac{1}{r_o // r_{oc}}}}_{\text{low freq gain} \approx 1} \cdot \underbrace{\frac{1}{1 + j\omega R_s C_{gd}}}_{\text{single pole}}$$

$$g_m \gg \frac{1}{r_o // r_{oc}}$$



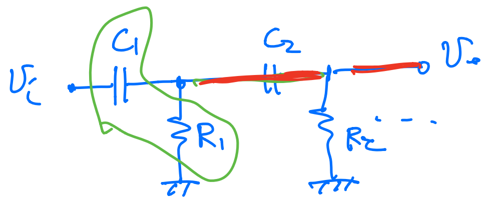
$$\omega_H = \frac{1}{R_s C_{gd}} \quad \text{vs} \quad \underline{\underline{CS}}: \ \frac{1}{R_s(g_m R_L'')C_{gd}}$$

ω_L: Open-Circuit Time Constant (OCTC)

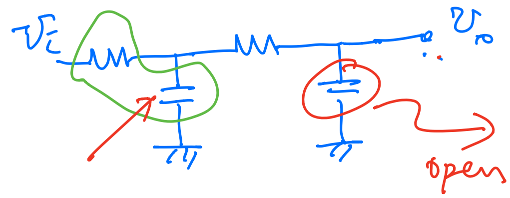
- Same small signal
- Conside one cap at a time, C_i
- Replace all other caps with OPEN circuit
- Find "R_i" seen by C_i

$$\Rightarrow \omega_H = \frac{1}{\sum_i R_i C_i} = \frac{1}{\sum_i \tau_i}$$

Compare SCTC $\downarrow$ ω_L with OCTC $\downarrow$ ω_H



Replace C_2 ... by short circuit



Replace C_2 ... with open circuit