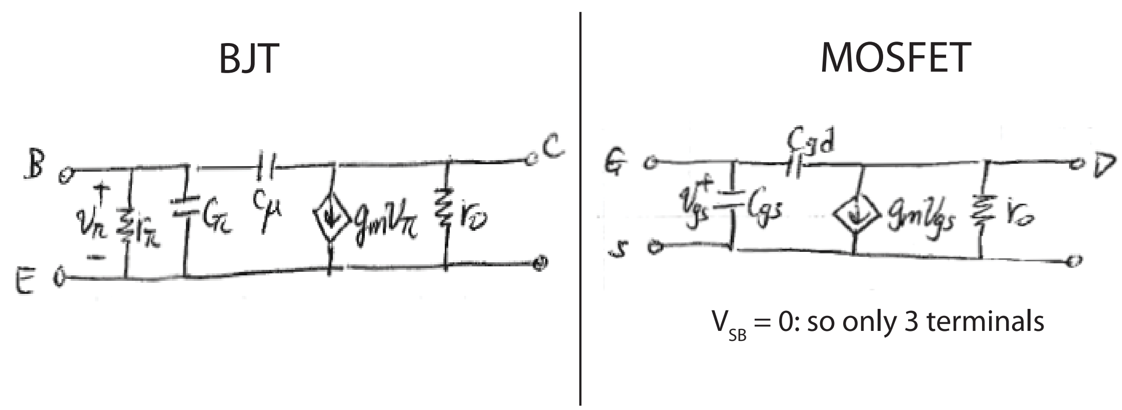
Recitation 21: Intrinsic Frequency Response of CS & CE Amplifier

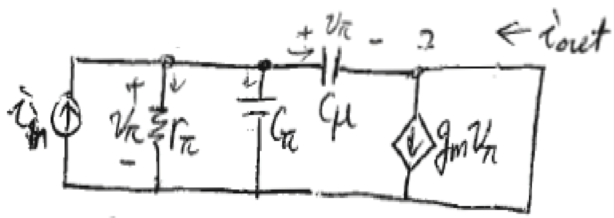
Yesterday, we discussed the intrinsic frequency response of the CE Amplifier. Since there is an analogy between MOSFET & BJT, today we will look at the intrinsic frequency response of a CS Amplifier and compare them.

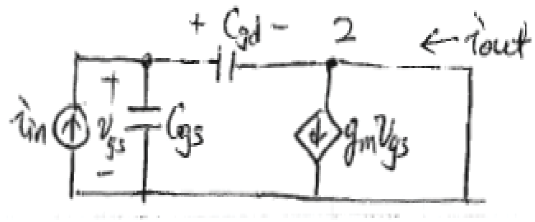
Small Signal Model



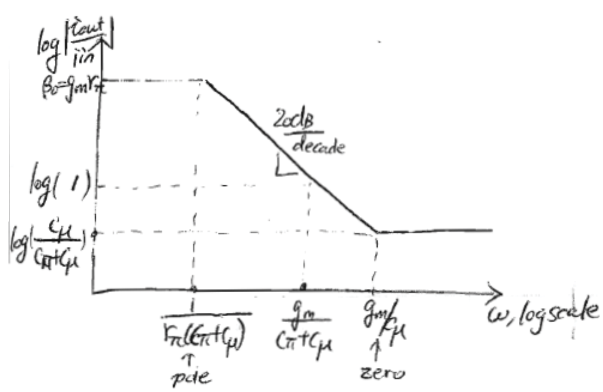
BJT	MOSFET
$C_\pi = C_{je} + C_b = C_{je} + g_m\tau_F = C_{je} + g_m\left(\frac{w_B^2}{2D_n}\right)$	$C_{gs} = \frac{2}{3}wLC_{ox} + wC_{ov}$
C_μ : depletion capacitance only	$C_{gd} = wC_{ov}$

Intrinsic Frequency Response: $R_s \to \infty$ $R_L = 0$



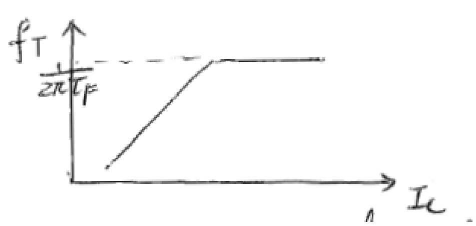


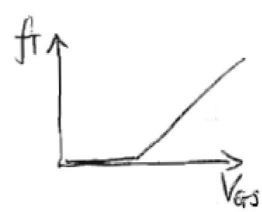
BJT	MOSFET
Node 1: $i_{\text{in}} = \frac{v_\pi}{\gamma_\pi} + jwC_\pi \cdot v_\pi + jwC_\mu v_\pi$	Node 1: $i_{\text{in}} = jwC_{\text{gs}} \cdot V_{\text{gs}} + jwC_{\text{gd}} V_{\text{gs}}$
Node 2: $i_{\text{out}} = g_{\text{m}} v_\pi - jwC_\mu v_\pi$	Node 2: $i_{\text{out}} = g_{\text{m}} v_\pi - jw$
$\frac{i_{\text{out}}}{i_{\text{in}}} = \frac{g_{\text{m}}\gamma_\pi \left(1 - \frac{jwC_\mu}{g_{\text{m}}}\right)}{1 + jw\gamma_\pi (C_\pi + C_\mu)} = \frac{\beta_{\text{o}} \left(1 - \frac{jwC_\mu}{g_{\text{m}}}\right)}{1 + jw\gamma_\pi (C_\pi + C_\mu)}$	$\frac{i_{\text{out}}}{i_{\text{in}}} = \frac{g_{\text{m}} - jwC_{\text{gd}}}{jw(C_{\text{gs}} + C_{\text{gd}})}$

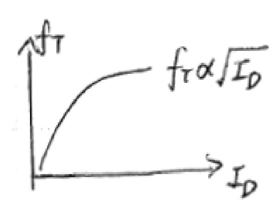


Unit Gain Frequency, f_T

BJT	MOSFET
$f_T = \frac{1}{2\pi} w_T = \frac{1}{2\pi}\frac{g_m}{C_\mu + C_\pi}$ Frequency at which the current gain is reduced to 1(0 dB) This is obtained by: $\left\lvert \frac{i_{out}}{i_{in}} \right\rvert = \left\lvert \frac{\beta_o \left(1 - \frac{jwC_\mu}{g_m}\right)}{1 + jw\gamma_\pi(C_\mu + C_\pi)} \right\rvert = 1$ ignoring the zero on top, $\because \frac{g_m}{C_\mu} \gg w_T$ $\left\lvert \frac{\beta_o}{1 + jw\gamma_\pi(C_\mu + C_\pi)} \right\rvert = 1$ $\because w_T \gg \frac{1}{\gamma_\pi(C_\mu + C_\pi)} \ \therefore w_T \gamma_\pi (C_\mu + C_\pi) \gg 1$ $\left\lvert \frac{\beta_o}{jw\gamma_\pi(C_\mu + C_\pi)} \right\rvert = 1 \implies w_T = \frac{g_m}{C_\mu + C_\pi}$	$f_T = \frac{1}{2\pi}\frac{g_m}{C_{gs} + C_{gd}}$ (this can be derived similar to the BJT case) Physical interpretation: $f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})}$ $\simeq \frac{1}{2\pi}\frac{g_m}{C_{gs}} \simeq \frac{1}{2\pi}\frac{w/L\mu_n C_{ox}(V_{GS} - 1)}{2/3wLC_{ox}}$ $\frac{1}{2\pi}\frac{3}{2}\frac{\mu_n(V_{GS} - V_T)}{L^2} = \frac{3}{2}\frac{\mu_n V_{D,SAT}}{L^2}\frac{1}{2\pi}$ $\frac{\mu_n V_{DSAT}}{L} \sim$ velocity of carrier $\frac{\mu_n V_{DSAT}}{L}/L \sim 1/\tau_T = \tau_T = L/$ velocity τ_T is transit time from source to drain
$f_T = \frac{1}{2\pi}\frac{I_c/V_{th}}{I_c/V_{th} \cdot \tau_F} + C_{je} + C_\mu \quad (\because g_m = \frac{I_c}{V_{th}})$	f_T is independent of V. For high frequency performance, NMOS > PMOS. Scale L as short as possible







At low I_c, f_T is dominated by depletion capacitances at Base-emitter and base collector junctions (C_{je} and C_μ). As $I_c \uparrow$, diffusion capacitance $g_m \tau_F \uparrow$, and becomes dominant.
Fundamental limit for frequency response

$$\tau_F = \frac{w_B^2}{2D_{n,p}}$$

To increase f_T
- high I_c = diffusion cap. limited $\Longrightarrow$ shrink base width.
- low I_c = depletion cap. limited $\Longrightarrow$ shrink device area

Another note for MOSFET: the current gain $\rightarrow \infty$ at $w = 0$. This is because of gate oxide, DC input current = 0. MOSFET not used as current amplifier at low frequency (input resistance too high)