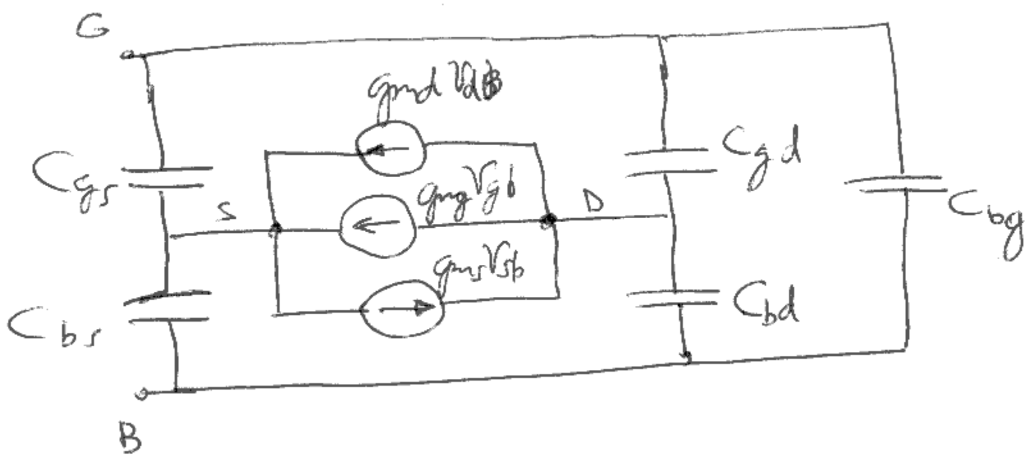
MOSFET CAPACITANCES

QUASI-STATIC MODEL



- MODEL VALID IF $\omega \tau_1 \ll 1$

$$\tau_1 \cong \begin{cases} \frac{4}{15}\frac{\tau}{i_f} & \text{ACTIVE REGION, STRONG INVERSION} \\ \frac{\tau}{6} & \text{WEAK INVERSION (ANY REGION)} \end{cases}$$

$$\tau = \frac{L^2}{\mu V_T} \qquad \alpha = \frac{\sqrt{1+i_r}}{\sqrt{1+i_f}}$$

$$C_{gs} = \frac{2}{3} C'_{ox} \frac{1+2\alpha}{(1+\alpha)^2} \frac{\sqrt{1+i_f}-1}{\sqrt{1+i_f}}$$

C'_{ox} HERE IS $\underline{C_{ox} \times W \times L}$ TOTAL GATE CAPACITANCE

$$C_{gd} = \frac{2}{3} C'_{ox} \frac{\alpha^2+2\alpha}{(1+\alpha)^2} \frac{\sqrt{1+i_r}-1}{\sqrt{1+i_r}}$$

$$C_{bg} = \frac{n-1}{n}\left(C'_{ox} - C_{gs} - C_{gd}\right)$$

$$C_{bs} = (n-1) C_{gs}, \quad C_{bd} = (n-1) C_{gd}$$

1) STRONG INVERSION

TRIODE, ASSUME $i_f = i_r \Rightarrow \alpha = 1$

$C_{gs} \cong \frac{1}{2} C'_{ox}$

$C_{gd} \simeq \frac{1}{2} C'_{ox}$

$C_{gb} \simeq 0$ (MASKED BY CHANNEL)

ACTIVE $\Rightarrow \alpha \simeq 0$

$C_{gs} = \frac{2}{3} C'_{ox}$

$C_{gd} \simeq 0$

$C_{bg} \simeq \left(\frac{n-1}{n}\right) \frac{C_{ox}}{3}$

2) WEAK INVERSION

TRIODE, $i_f = i_r \Rightarrow \alpha = 1$

$C_{gs} \simeq \frac{1}{4} C'_{ox} i_f$

$C_{gd} \simeq \frac{1}{4} C'_{ox} i_r$

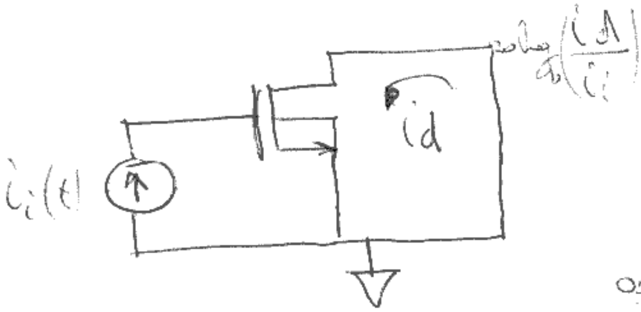
NOTICE i_f, i_r SMALL, SO CAPACITANCES ALSO SMALL

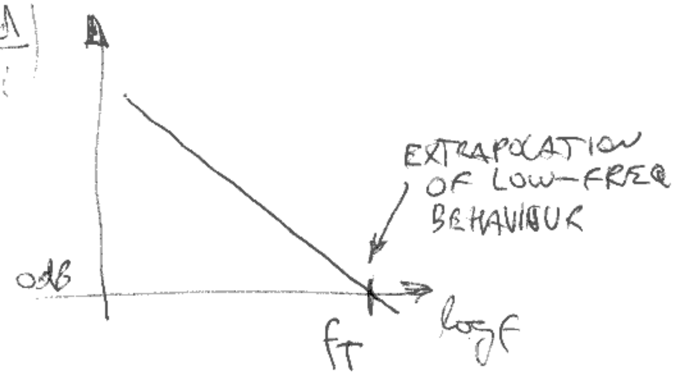
$C_{bg} \simeq \frac{n-1}{n} C'_{ox}$ ← MOST OF GATE CAPACITANCE GOES TO BULK

ACTIVE, $\alpha \simeq 1 \Rightarrow$ SAME AS TRIODE

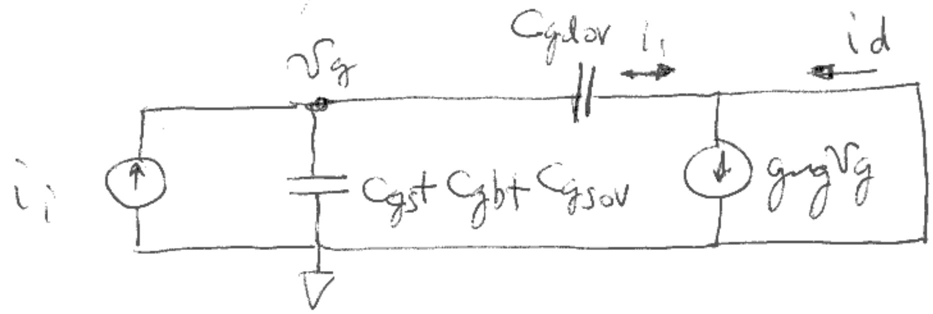
NOTE: THIS CAPACITANCES ONLY VALID FOR SMALL-SIGNAL MODEL. FOR LARGE-SIGNAL, NONLINEAR CHARGES MUST BE USED.

TRANSITION FREQUENCY (f_T)





(SMALL SIGNAL)



<u>NOTE</u>: FOR ACTIVE MODE C_{gd} NEGLIGIBLE COMPARED TO C_{gdov}

<u>ASSUMPTION</u>: @ LOW FREQUENCIES $i_1 << i_d$

$\therefore i_d \simeq g_m v_g$

$v_g = i_i \times X_{C_T}$, $C_T = C_{gs} + C_{gb} + C_{gsov} + C_{gdov}$

$$v_g = \frac{i_i}{j\omega C_T}$$

$$\left|\frac{i_d}{i_i}\right| = \frac{g_m}{\omega C_T} = 1 \quad @\,\omega = \omega_T$$

$$\boxed{f_T = \frac{g_m}{2\pi C_T}}$$

$$f_T = \frac{2 I_S}{n V_T \times 2\pi C_T} \left(\sqrt{1+i_f} - 1\right) = \frac{\mu C_{ox} \left(\frac{W}{L}\right) V_T}{2\pi C_T} \left(\sqrt{1+i_f} - 1\right)$$

$$I_S = \frac{n \mu C_{ox} V_T^2}{2} \left(\frac{W}{L}\right)$$

OBSERVATION: ASSUMING C_T DOES NOT CHANGE MUCH, STRONGER INVERSION ACHIEVES HIGHER f_T

- CONSIDER NOW ONLY THE INTRINSIC CAPACITANCES, AND APPROXIMATE $C_{gs} + C_{gb} \approx \frac{1}{2} C_{ox} WL$ (AVERAGE FOR WEAK-STRONG INVERSION)

(*)

$$f_T \cong \frac{\mu C_{ox} \frac{W}{L} V_T}{2\pi \times \frac{1}{2} C_{ox} WL} \left(\sqrt{1+i_f} - 1\right) = \frac{\mu C_{ox} V_T}{\pi C_{ox} L^2} \left(\sqrt{1+i_f} - 1\right)$$

OBSERVATION: SHORTER CHANNEL $\Rightarrow f_T \uparrow$

RULE OF THUMB: TRANSISTOR USEFUL FOR AMPLIFICATION UP TO $\left(\frac{f_T}{10}\right)$.

(*) CONSIDERING OVERLAP CAPACITANCES:

$$\boxed{f_T \simeq \frac{\mu V_T}{2\pi \left[\frac{L^2}{2} + 2 L_D L\right]} \left(\sqrt{1+i_f} - 1\right)}$$