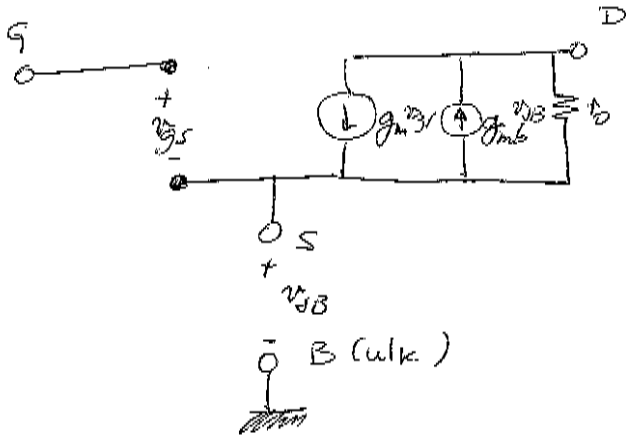


MODELO PARA PEQUENAS SINAIS PARA MOSFETS, MODELOS E PARÂMETROS SPICE

Modelo p/pequenos sinais e baixas frequências (ie., desprezando as capacidades intrínsecas e parasitas do MOSFET)



$$I_D = \frac{\mu C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

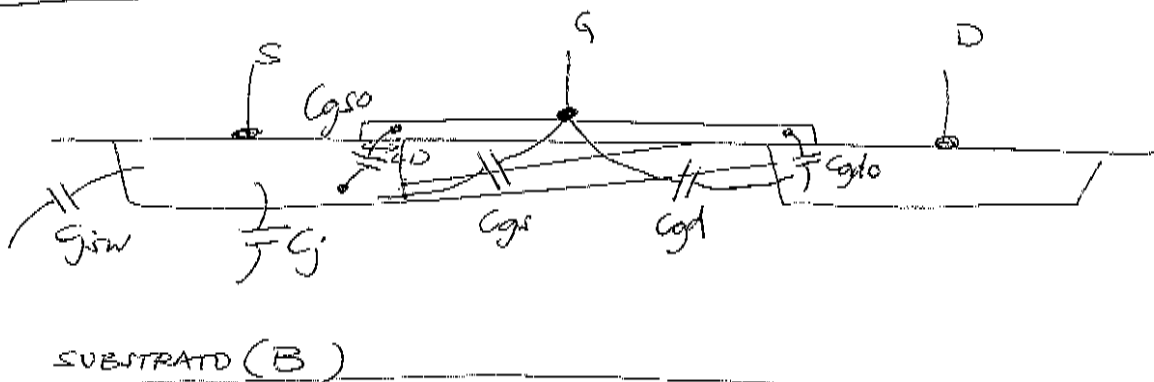
$$V_T = V_{T0} + \gamma (\sqrt{V_{SB} + 2\phi} - \sqrt{2\phi})$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} \Big|_{V_{GS} = V_{GSQ}} = 2 \frac{\mu C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T) = \frac{2 I_D}{(V_{GS} - V_T)} \quad \left[g_m \text{ bipolar} = \frac{I_C}{\phi_T} \approx \frac{I_C}{25 \text{ mV}} \right]$$

$$g_{mb} = \frac{\partial I_D}{\partial V_{BS}} = -2 \frac{\mu C_{ox}}{2} (V_{GS} - V_T) \gamma \frac{1}{\sqrt{V_{SB} + 2\phi}} = -\frac{2 I_D}{(V_{GS} - V_T)} \gamma \frac{1}{\sqrt{V_{SB} + 2\phi}} = -\frac{g_m \gamma}{\sqrt{V_{SB} + 2\phi}}$$

$$\frac{1}{r_o} = \frac{\partial I_D}{\partial V_{DS}} = \lambda I_D$$

MODELO PARA FREQ ELEVADAS



1 - Capacidades de junção CJ (SOURCE, DRAIN)

$$C_{sb} = C_{j_s}^{\prime} = C_{bottom_s} + C_{sidewall_s} = \frac{CJ \times AD}{\sqrt{1 + \frac{V_{DS}}{\phi_0}}} + \frac{C_{jsw} \times PD}{\sqrt{1 + \frac{V_{DS}}{\phi_0}}}$$

$$C_{db} = C_{j_b}^{\prime} = C_{bottom_b} + C_{sidewall_b} = \frac{CJ \times A_d^{\prime}}{\sqrt{1 + \frac{V_{SB}}{\phi}}} + \frac{C_{jsw} \times PS}{\sqrt{1 + \frac{V_{SB}}{\phi}}}$$

Considere WORT CASE

2 - Capacidades de overlap

$$C_{gs0} = C_{j0} = 6 \times LD \times W = C_{gs0} \times W$$

$$C_{gd0} = C_{j0} \times W$$

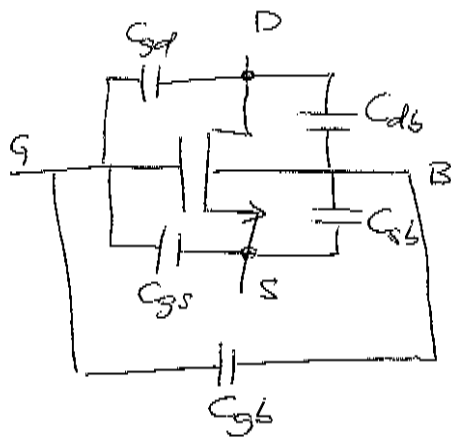
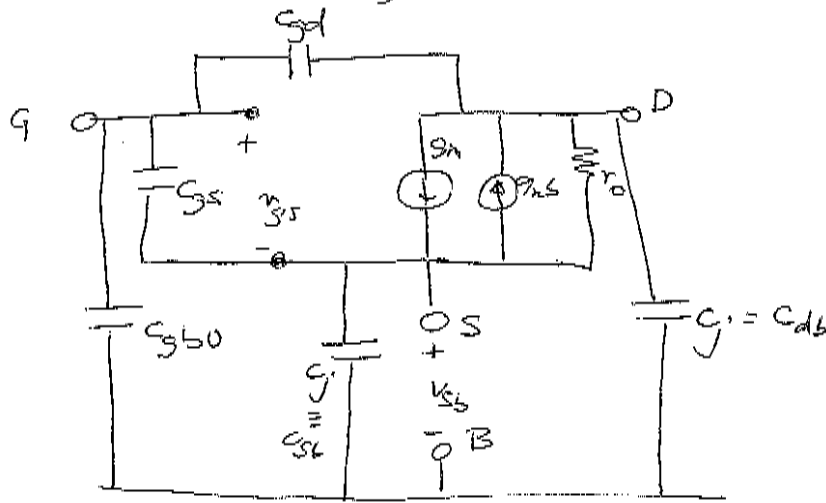
3 - Capacidades do canal c_{gs} , c_{gd}

na zona linear $c_{gs} = \frac{1}{2} C_{ox} W \times L$

$c_{gd} = \frac{1}{2} C_{ox} W \times L$

na zona saturação $c_{gs} = (\frac{2}{3}) C_{ox} W \times L$

$c_{gd} = 0$

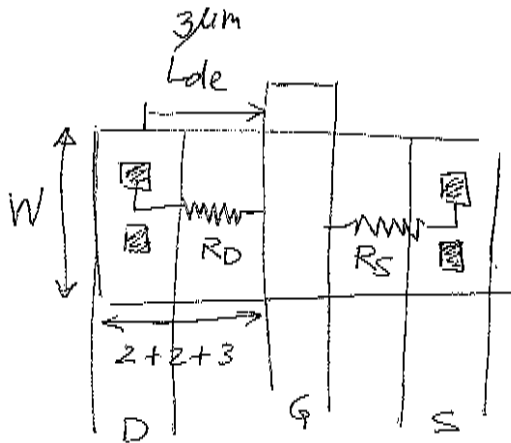


MODELOS SPICE

LEVEL 1

- MODEL C20NMOS NMOS LEVEL1 VT0 GAMMA PHI (NSUB NSS TPG)
- + KP TOX LAMBDA LD U0
- + RSH
- + C9BO C9DO C9SO PB PBSW C0 CJSW MD MJSW

• MODEL C20NMOS NMOS LEVEL2



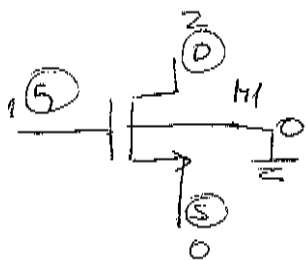
$$R_S = R_D = RSH \times \frac{L_{gate-diffusion\ edge}}{W}$$

LEVEL 2 (NÍVEL 2) - inclui termos de segunda ordem para modelizar efeitos em transistores com $L < 2\mu m$

LEVEL 3 - idem, com alguns parâmetros empíricos

Finalmente

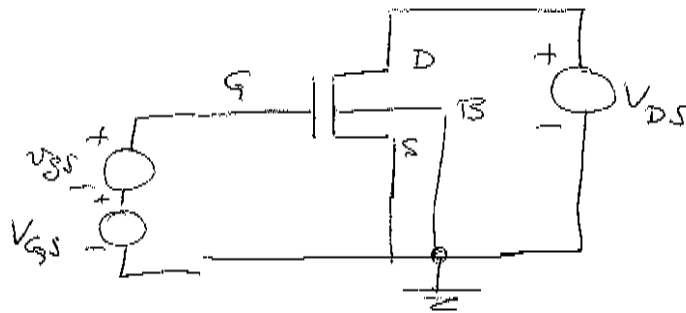
- BSIMV1 (LEVEL 4) modelos muito complexos (+60 parâmetros)
 - BSIMV2
 - BSIMV3 (LEVEL 8) utilizados para modelizar transistores submicron (≈ 120 parâmetros)
- ($L < 1\mu m$) Todos os parâmetros são funções das dimensões (W, L) dos transistores



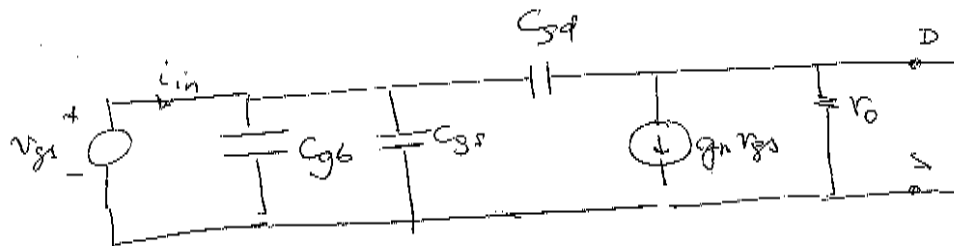
M1 2 1 0 C20NMOS W=4u L=2u

+ AD=28E-12 AS=28E-12 PD=18E-6 PS=18E-6
NRJ(=7/4)=0.7 NRD=1.7

Cálculo da frequência para a qual o ganho em corrente do transistor é igual a 1 - f_T



circuito equivalente



(as capacitades C_{sb} e C_{db} não entram porque a sua tensão é fixa)

$$i_{in} = v_{gs} \cdot j\omega (C_{gb} + C_{gs} + C_{gd})$$

$$i_{out} = g_m v_{gs} \quad (\text{assumindo que } v_{gs} \cdot j\omega C_{gd} \ll g_m r_{gs})$$

$$\left| \frac{i_{out}}{i_{in}} \right| = \frac{g_m}{\omega (C_{gs} + C_{gs} + C_{gd})} \approx \frac{K_P \frac{W}{L} (V_{gs} - V_T)}{2\pi f C_{gs}} = \frac{K_P \frac{W}{L} (V_{gs} - V_T)}{2\pi f \frac{\pi}{3} W L C_{ox}}$$

$$= \frac{3}{4} \frac{K_P}{\pi f L^2 C_{ox}} (V_{gs} - V_T)$$

$$\left| \frac{i_{out}}{i_{in}} \right| = 1 \Rightarrow f_T = \frac{3}{4\pi} \frac{K_P}{L^2 C_{ox}} (V_{gs} - V_T)$$

π depende de W
 aumenta para L mínimo
 aumenta com $(V_{gs} - V_T)$

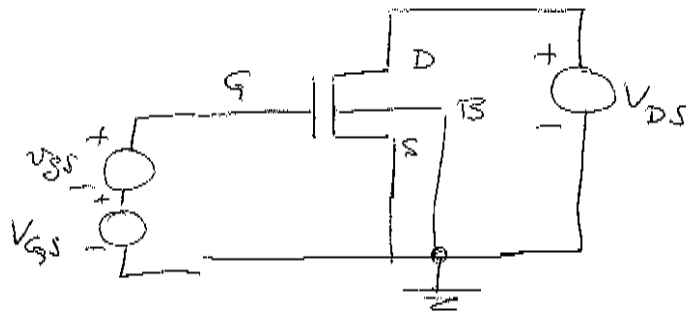
exercício

Calcular o f_T máximo para a tecnologia $C_{ox} = 20$

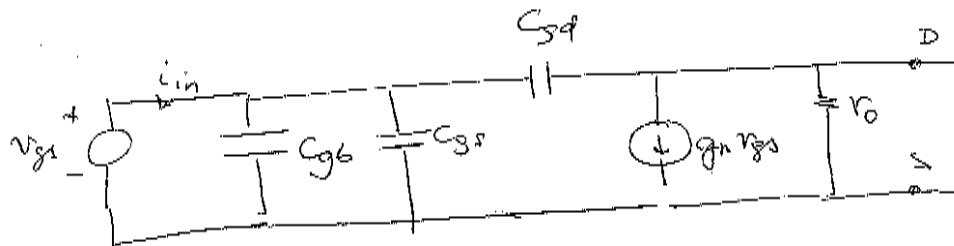
$$f_T \text{ NMOS} =$$

$$f_T \text{ PMOS} =$$

Cálculo da frequência para a qual o ganho em corrente do transistor é igual a 1 - f_T



circuito equivalente



(as capacitades C_{sb} e C_{db} não entram porque a sua tensão é fixa)

$$i_{in} = v_{gs} \cdot j\omega (C_{gb} + C_{gs} + C_{gd})$$

$$i_{out} = g_m v_{gs} \quad (\text{assumindo que } v_{gs} \cdot j\omega C_{gd} \ll g_m v_{gs})$$

$$\left| \frac{i_{out}}{i_{in}} \right| = \frac{g_m}{\omega (C_{gs} + C_{gs} + C_{gd})} \approx \frac{K_P \frac{W}{L} (V_{gs} - V_T)}{2\pi f C_{gs}} = \frac{K_P \frac{W}{L} (V_{gs} - V_T)}{2\pi f \frac{\pi}{3} W L C_{ox}}$$

$$= \frac{3}{4} \frac{K_P}{\pi f L^2 C_{ox}} (V_{gs} - V_T)$$

$$\left| \frac{i_{out}}{i_{in}} \right| = 1 \Rightarrow f_T = \frac{3}{4\pi} \frac{K_P}{L^2 C_{ox}} (V_{gs} - V_T)$$

π depende de W
aumenta para L mínimo
aumenta com $(V_{gs} - V_T)$

exercício

Calcular o f_T máximo para a tecnologia $C_{ox} = 20$

$$f_T \text{ NMOS} =$$

$$f_T \text{ PMOS} =$$