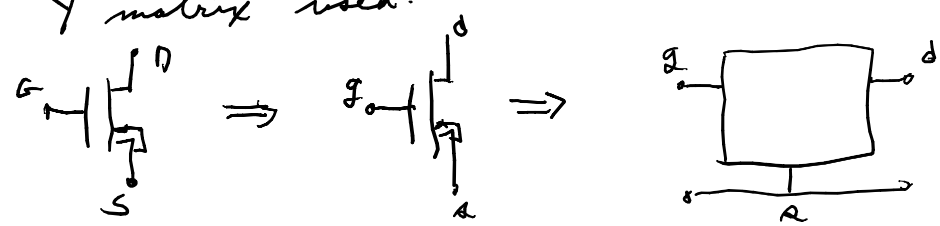
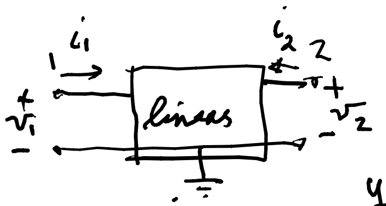
EE 303
02/09/07

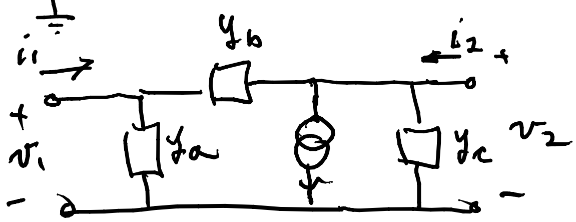
Small signal equivalent circuits

Y matrix used:





$$\Rightarrow \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \Rightarrow i = Yv$$

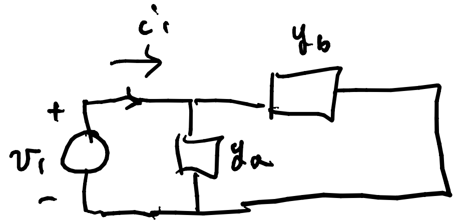


$$y_{11} = \left.\frac{i_1}{v_1}\right|_{v_2=0}$$

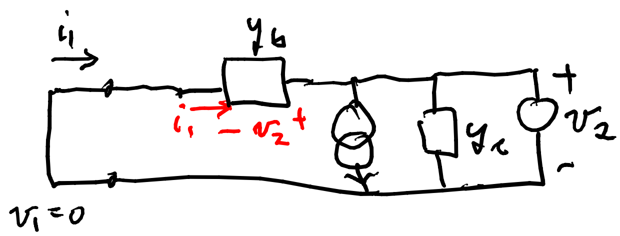
= short on "port" 2

$$y_{12} = \left.\frac{i_1}{v_2}\right|_{v_1=0}$$

short on port 1



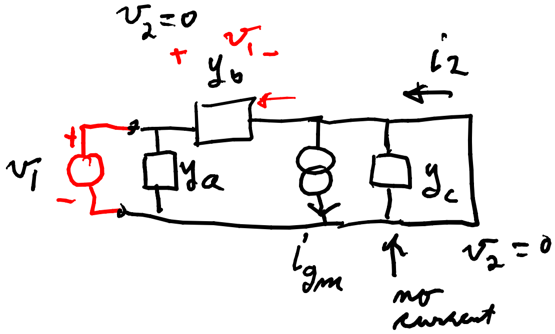
$\Rightarrow y_{11} = y_a + y_b$



here $i_1 = -y_b v_2 \Rightarrow y_{12} = -y_b$

$y_{11} = y_a - y_{12} \Rightarrow y_a = y_{11} + y_{12}$

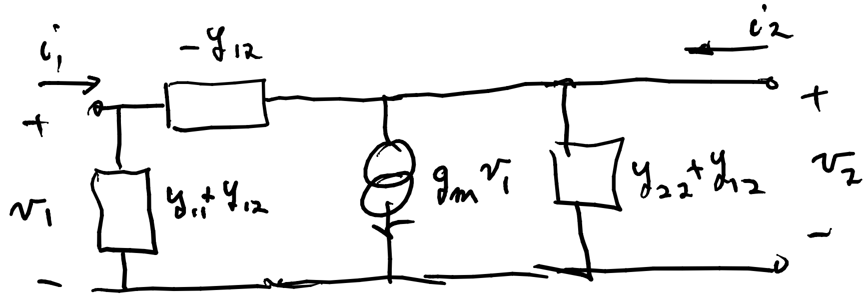
$$y_{21} = \left.\frac{i_2}{v_1}\right|_{v_2=0} \qquad y_{22} = \left.\frac{i_2}{v_2}\right|_{v_1=0}$$



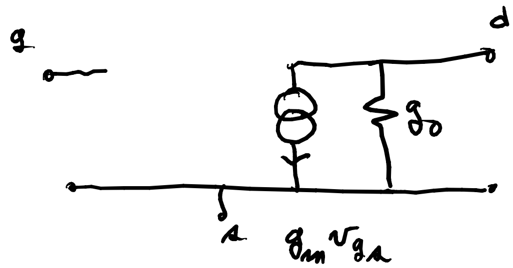
here $i_2 = i_{gm} + (-y_b v_1) \Rightarrow y_{21} = \left.\frac{i_2}{v_1}\right|_{v_2=0} = \frac{i_{gm}}{v_1} - y_b$

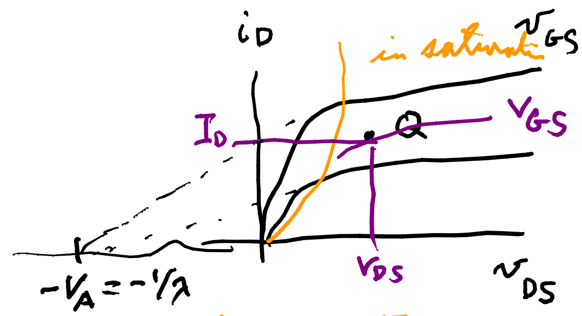
$= \frac{i_{gm}}{v_1} + y_{12}$

$\Rightarrow \frac{i_{gm}}{v_1} = y_{21} - y_{12} \triangleq g_m$ (= def. of g_m)



this is the Π equivalent circuit for a linear 2-port





sat: $v_{GS} - VTO \le v_{DS}$

$$g_m = 2\frac{I_D}{(V_{GS}-VTO)}$$

$$g_o = \frac{I_D}{V_A} \times \frac{1}{1+v_{DS}/V_A}$$

$$Y = \begin{bmatrix} 0 & 0 \\ g_m & g_o \end{bmatrix}$$

$$i_D = \frac{KP}{2}\frac{W}{L}(v_{GS}-VTO)^2(1+\lambda v_{DS})$$

Ex: $KP = 2\times10^{-4}\ \frac{\text{amps}}{\text{volt}^2}$; $W = 10\mu$, $L = 10\mu$; $VTO = 1.1$ volt, $V_A = 200$ volt

B-S transistor properties

circuit choice: Q $\quad V_{GS} = 3.1v$, $V_{DS} = 3v$

check on transistor status: $V_{GS} - VTO = 2v < V_{DS} = 3$

$$I_D = \frac{2\times10^{-4}}{2}\cdot\frac{10\times10^{-6}}{10\times10^{-6}}(2)^2\left(1+\frac{3}{200}\right) \approx 4\times10^{-4}\ \text{amps} = 0.4\text{mA}$$

thus at Q: $g_m = \frac{2I_D}{(V_{GS}-VTO)} = \frac{2\times4\times10^{-4}}{2} = 0.4\,m\mho$

$$r_o = \frac{1}{g_o} = \frac{V_A}{I_D} = \frac{200}{4\times10^{-4}} = 50\times10^4 = 500K\Omega$$

For higher frequencies we need to add the capacitances

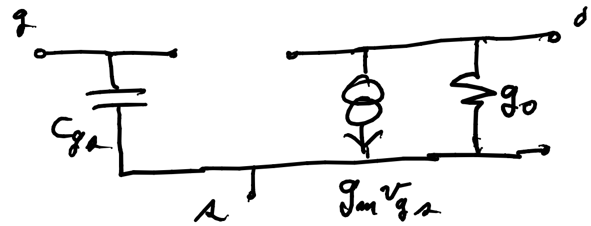
total gate capacitance is $W \times L \times \underbrace{\frac{\epsilon_{ox}}{t_{ox}}}_{C_{ox}}$; r. 243 $\epsilon_{ox} = 3.45\times10^{-11}\ \frac{\text{Farads}}{\text{meter}}$

"Useful" capacitance: in saturation: $C_{gs} = \frac{2}{3} \cdot W \times L \times C_{ox}$

p. 321

$C_{gd} = 0$

in ohmic: $C_{gs} = C_{gd} = \frac{1}{2} W \times L \times C_{ox}$



$$Y(s) = \begin{bmatrix} C_{gs} \cdot s & 0 \\ g_m & g_o \end{bmatrix}$$

small signal