MIDTERM II SOLUTIONS FALL 2001 (FOR TEST #1) PARAMETERS

RHowe 11/7/01

① a) $g_m = \frac{\partial i_D}{\partial v_{GS}}\Big|_{Q_1} = \frac{C_{ox} W v_{sat}}{2}\left(\frac{1+\lambda_n V_{DSQ_1}}{1+\lambda_n V_{DSSAT}}\right) = \frac{(4\times10^{-7} F/cm^2)}{2}(5\times10^{-4} cm)(10^7 cm/s)\left(\frac{1+0.075}{1+(0.75)(0.05)}\right)$ (1.5V)

$= 10^{-3} S\left[\frac{1.075}{1.0375}\right] \cong 1.04 mS$

graphical technique: $g_m = \frac{\Delta i_D}{\Delta v_{GS}}\Big|_{Q_1}$ — typo in scale... should be 0.25mA

$\cong \frac{0.5mA}{0.25V} \cong 2mS$

b) $r_o^{-1} = \frac{\partial i_D}{\partial v_{DS}}\Big|_{Q_1} = \frac{C_{ox}Wv_{sat}}{2}(V_{GS}-V_{Tn})\left\{\frac{\lambda_n}{1+\lambda_n V_{DSSAT}}\right\} = \frac{(4\times10^{-7}F/cm^2)}{2}\cdot 5\times10^{-4}cm\cdot 10^7 cm/s \left[\frac{0.05}{1.03}\right]$

$= 4.82\times10^{-5}S \Rightarrow r_{o_1} = 20.75 k\Omega$

c) $g_m = \frac{\partial i_D}{\partial v_{GS}}\Big|_{Q_2} = C_{ox}Wv_{sat}\left(\frac{V_{DS}}{V_{DSSAT}}\right)\left(1-\frac{V_{DS}}{2V_{DSSAT}}\right) = 2\times10^{-3}\left(\frac{0.25}{0.75}\right)\left(1-\frac{0.25}{2(0.75)}\right)S = 0.56 mS$

graphical technique: $g_m = \frac{\Delta i_D}{\Delta v_{GS}}\Big|_{Q_2} = \frac{0.6-0.45mA}{1.75-1.5V} = 0.6 mS$

d) $r_o^{-1} = \frac{\partial i_D}{\partial v_{DS}}\Big|_{Q_2} = C_{ox}Wv_{sat}(V_{GS}-V_{Tn})\left[\frac{1}{V_{DSSAT}} - \frac{V_{DS}}{V_{DSSAT}^2}\right]$; $V_{GS} = 1.5V$, $V_{DS} = 0.25V$.

$= 2\times10^{-3}(0.5)\left[\frac{1}{0.75}-\frac{0.25}{(0.75)^2}\right] = 8.9\times10^{-4}S \Rightarrow r_o = 1.1k\Omega$

$r_o^{-1} \approx \frac{\Delta i_D}{\Delta v_{DS}}\Big|_{Q_2} \cong \frac{0.2mA}{0.25V} \Rightarrow r_o = 1.25k\Omega$

② a) $V_{OUT} = 2.5V \Rightarrow V_B = V_{OUT} + V_{BE} = 3.2V$

b) $V_{OUT} = 2.5V$, $R_E = 5k\Omega \Rightarrow -I_E = \frac{2.5V}{5k\Omega} = 500\mu A$ $\quad I_C = -\alpha_F I_E = 495\mu A$. (or neglect I_B.)

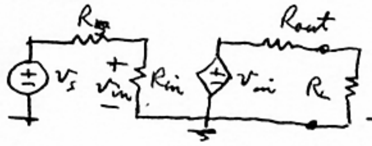
c) common-collector amplifier $\Rightarrow R_{in} = r_\pi + \beta_o(r_o||R_E||R_L)$. $\quad r_\pi = \frac{\beta_o}{g_m} = \frac{100(25mV)}{500\mu A} = 5k\Omega$

$R_{in} = 5k\Omega + 100(100k\Omega||5k\Omega||2.5k\Omega) = 169k\Omega$ $\quad r_o = \frac{V_A}{I_C} = \frac{50V}{0.5mA} = 100k\Omega$.

d) $R_{out} = g_m^{-1} + R_S/\beta_o = \frac{25mV}{0.5mA} + \frac{5k\Omega}{100} = 50\Omega + 50\Omega = 100\Omega$.

e) $A_v = 1$ (exact expression $\frac{1}{1+\frac{r_\pi}{(r_o||R_E)(\beta_o+1)}} = \frac{1}{1+\frac{5k\Omega}{(100||5)(101)}} = 0.99$

f)



$v_{out}/v_s = \left(\frac{R_{in}}{R_S+R_{in}}\right)\left(\frac{R_L}{R_{out}+R_L}\right) = \left(\frac{169}{5+169}\right)\left(\frac{2.5}{.100+2.5}\right) = 0.93$

g) $v_{OUT}|_{max} = 5 - V_{CEsat} = 4.9V$ (hard limit). $v_{OUT}|_{min} = 0V$ [but with $I_C\downarrow$, parameters will change. $\therefore \hat{v}_s|_{max} = (4.9-2.5)/0.93 = 2.55V$

③ a) $I_C = \frac{qD_nA_E}{W_B}\cdot n_{pB}(0)$ $\quad n_{pB}(0) = \frac{I_C W_B}{qD_nA_E} = \frac{2\times10^{-5}A\cdot1\times10^{-5}cm}{(1.6\times10^{-19}C)(20cm^2/s)(25\times10^{-8}cm^2)} = 2.5\times10^{14}cm^{-3}$

b) $n_{pB}(0) = n_{pBo}e^{V_{BE}/V_{th}} \Rightarrow V_{BE} = V_{th}\ln[n_{pB}(0)/n_{pBo}] = 25mV\ln[2.5\times10^{14}/n_{pBo}]$

$n_{pBo} = n_{pB}(0)e^{-V_{BE}/V_{th}} = 2.5\times10^{14}cm^{-3}e^{-692.5/25} = 233$

$= n_i^2/N_A \Rightarrow N_A = \frac{10^{20}}{233} = 4.3\times10^{17}cm^{-3}$

c) $I_B = \frac{qD_pA_E}{W_E}p_{nE}(-x_{BE}) = \frac{1.6\times10^{-19}\cdot5\cdot25\times10^{-8}\cdot(0.05)(2.5\times10^{14})}{7\times10^{-6}} = 357nA$

$\beta_F = I_C/I_B \approx 56$