Solutions EE303H F2015 final 12/14/15

#1. a) $V_{DS} = V_{DD} - V_0 \geq V_{GS} + V_i - V_0 - V_{T0} \Rightarrow V_{DD} \geq 2V_{GS} - V_{T0} = 6 - 1 = 5 \Rightarrow V_{DD_{min}} \doteq 5V$

b) $V_{GS} = V_{GG} - R\, i_D = 3 - 1\times10^3 \times 1\times10^{-3} = 3 - 1 = 2V$, $i_D = 10^{-3} = k(V_{GS} - V_{T0})^2 = k(2-1)^2 = k$

$\Rightarrow k = 10^{-3}$

c) $i_D = k(v_{GS} - V_{T0})^2 = \frac{1}{R} v_0 + C\frac{d v_0}{dt}$ with $v_{GS} = v_i + V_{GS} - v_0 = 4 - v_0$ for $t > 0$

$\Rightarrow \underset{k}{10^{-3}} \times (3 - v_0)^2 = 10^{-3} v_0 + \underset{C}{10^{-6}} \dot{v}_0 \Rightarrow 10^3(9 - 6v_0 + v_0^2) = 10^3 v_0 + \dot{v}_0 \Rightarrow 9\times10^3 = 7\times10^3 v_0 - 10^3 v_0^2 + \dot{v}_0$ for $t > 0$

for $t < 0$, $v_0 = R i_{D_Q} = 1 V$

#2. a) as the transistors are complementary $g_{m_n} = g_{m_p}$ & $g_{o_n} = g_{o_p}$

@ $v_i = V_{DD}/2$ both transistors are in saturation $\left[V_{GS_n} - V_{T0} = \frac{V_{DD}}{2} - V_{T0} < V_{DS_n} = \frac{V_{DD}}{2}\right]$

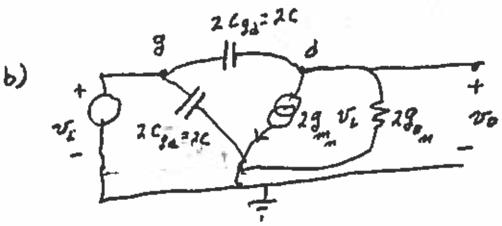
so $i_{D_n} = k(v_{GS_n} - V_{T0_n})^2 (1 + \lambda v_{DS_n}) \Rightarrow g_{m_n} = 2k(v_{GS_n} - V_{T0_n})\cdot(1 + \lambda v_{DS_n})\Big|_Q = 2k\left(\frac{V_{DD}}{2} - V_{T0}\right)\left(1 + \lambda\frac{V_{DD}}{2}\right)$

$= \frac{2 I_{Dn}}{\left(\frac{V_{DD}}{2} - V_{T0_n}\right)}$

$g_{o_n} = \lambda\left[k(v_{GS_n} - V_{T0_n})^2\right]\Big|_Q = \lambda k\left(\frac{V_{DD}}{2} - V_{T0_n}\right)^2$

$= \frac{\lambda I_{Dn}}{(1 + \lambda V_{DD}/2)}$

b)



c) KCL @ d: $2C_{gd}\, s(V_i(s) - V_0(s)) = 2g_{m_n} V_i(s) + 2g_{o_n} V_0(s)$

$\Rightarrow (2C_{gd}s - 2g_{m_n})V_i = (2Cs + 2g_{o_n})V_0 \Rightarrow \frac{V_0(s)}{V_i(s)} = \frac{Cs - g_{m_n}}{Cs + g_{o_n}}$; zero: $s_z = g_{m_n}/C$; pole: $s_p = -g_{o_n}/C$

#3. a) $I_{R_1} = \frac{1}{R_1}\left[V_{CC} - V_{EB_{Q_1}}\right] \Rightarrow R_1 = \frac{V_{CC} - V_{EB_{Q_1}}}{10^{-3}} = \frac{5 - 0.7}{10^{-3}} = 4.3\times10^3\,\Omega = R_1$

b) $I_{out_{Q_2}} = -I_{C_{Q_2}} = \alpha I_{E_{Q_2}} = \alpha I_{EQ_1}$, but $I_{R_1} = -I_{C_{Q_1}} - 2I_{B_{Q_1}} = -(I_{C_{Q_1}})(1 + \frac{2}{\beta}) = \alpha I_{EQ_1}(1 + \frac{2}{\beta})$

$= \frac{\beta}{1+\beta} I_{EQ_1}\cdot\left(\frac{2+\beta}{\beta}\right)$

$= I_{out_{Q_2}} = \frac{\beta}{1+\beta}\cdot I_{EQ_1} = \frac{\beta}{1+\beta}\cdot\frac{1+\beta}{2+\beta}\cdot I_{R_1} = \frac{\beta}{\beta+2}\cdot I_{R_1} = \frac{100}{102}\times10^{-3} = I_{out_{Q_2}}$

≈ 0.98 milli A

c) $v_0(t)\big|_{t<0} = 0$, as v_0 cannot jump $v_0(0+) = 0$ and rises to $v_0(\infty) = R I_{out Q_2}$ with RC time const.

$I_{out\,Q_2} = C\frac{dv_0}{dt} + \frac{1}{R}v_0 \Rightarrow \frac{dv_0}{dt} + \frac{1}{RC}v_0 = \frac{0.98\times10^{-3}}{C}$, $v_C(0+) = 0$

$\Rightarrow v_0 = 0.98\times10^{-3} R(1 - e^{-t/RC})$ for $t > 0$ & $v_0(t) = 0$ for $t < 0$

sketch