#1. a) $I_{D_n} = \frac{4\times10^{-4}}{2}\cdot 1\cdot(5-1)^2(1+0.01\times5) = \frac{2\times10^{-4}}{2}\times\left(\frac{W}{L}\right)_p(10-5-1)^2(1+0.01[10-5])$

$\Rightarrow \frac{4}{2} = (W/L)_p \Rightarrow \left(\frac{W}{L}\right)_p = 2$

b) Need $v_O \geq 5-1=4$ for NMOS in saturation; and for PMOS

$V_{DD} - v_O = 10 - v_O = V_{SD_p} \geq V_{SG_p} - (-V_{TO_p}) = V_{DD} - \frac{V_{DD}}{2} - 1 = 4 \Rightarrow 10 - v_O \geq 4$

$\Rightarrow v_O \leq 6$

$\therefore$ $4 \leq v_O \leq 6 \Rightarrow M_n$ & M_p in saturation

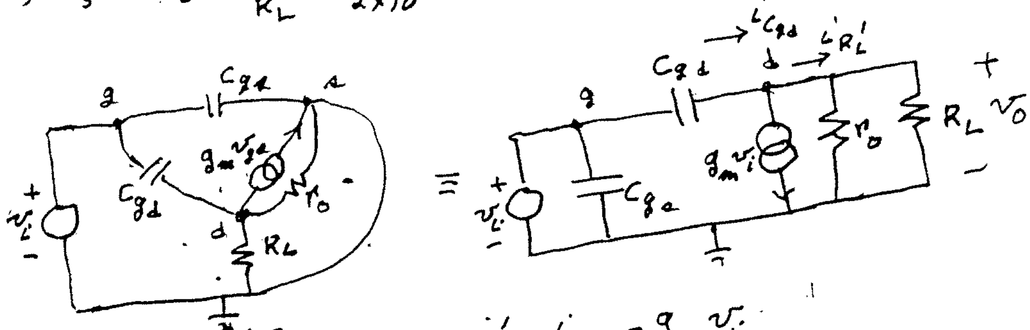
c) @ $v_O = 4 \Rightarrow \frac{4}{2}(1+0.01\times4) = \left(W/L\right)_p(1+0.01[10-4]) \Rightarrow \left(\frac{W}{L}\right)_p = \frac{2.08}{1.06} = 1.962$

@ $v_O = 6 \Rightarrow \frac{4}{2}(1+0.01\times6) = \left(W/L\right)_p(1+0.01[10-6]) \Rightarrow \left(\frac{W}{L}\right)_p = \frac{2.12}{1.04} = 2.038$

$\therefore$ $1.962 \leq \left(\frac{W}{L}\right)_p \leq 2.038$ gives $4 \leq v_O \leq 6 \Rightarrow M_p$ & M_n in saturation

#2. a) as $V_0 = 2$, $I_S = -I_D = \frac{V_0}{R_L} = \frac{2}{2\times10^3} = 1\times10^{-3} = 1\,mA$

b)



Let $R_L' = r_o \| R_L = \frac{r_o R_L}{r_o + R_L} = \frac{1}{G_L'}$ then $i_{R_L}' = i_{C_{gd}} - g_m v_i$

$$G_L' v_o = \frac{1}{R_L'} v_o = sC_{gd}(v_i - v_o) - g_m v_i$$

$$\Rightarrow (G_L' + sC_{gd}) v_o = (sC_{gd} - g_m) v_i$$

$$\Rightarrow \frac{v_o}{v_i}(s) = \frac{sC_{gd} - g_m}{sC_{gd} + G_L'} = \frac{s - g_m/C_{gd}}{s + G_L'/C_{gd}}$$

c) pole @ $s_p = -G_L'/C_{gd}$, zero @ $s_z = g_m/C_{gd}$

Need g_m & g_o: $g_m = \frac{2 I_S}{(V_{SG} - |V_{TO}|_p)}$; $I_S = 1\times10^{-3}$, $V_{SG} = 10 - 8 = 2$

$$= \frac{2\times10^{-3}}{1} = 2m\mho$$

$$g_o = \frac{\lambda I_S}{1 + \lambda V_{SD}} = \frac{10^{-5}}{1 + 0.01\times8} = \frac{10^{-5}}{1.08} = \quad \approx \lambda I_S = 10^{-5}$$

as $G_L = \frac{1}{2}\times10^{-3}$, $G_L' = G_L + g_o \approx 0.5\times10^{-3} + 10^{-5} = 51\times10^{-5}$

and as $C_{gd} = 5\,pFd = 5\times10^{-12}$

$$s_p = -51\times10^{-5}/5\times10^{-12} = -10.2\times10^{7} = -102\times10^{6}$$

$$s_z = 2\times10^{-3}/5\times10^{-12} = \frac{2}{5}\times10^{9} = 4\times10^{8} = 400\times10^{6}$$

#3. a) @ DC no current in C_{pb} $\Rightarrow$

MOS: $I_D = 2ma \Rightarrow V_O = V_{DD} - R_L I_D = 10 - 2\times10^{-3} \times 2\times10^{3} = 6V$

BJT: need $\alpha = \frac{\beta}{1+\beta} = \frac{99}{100} = 0.99 \Rightarrow I_C = \alpha \times 2\times10^{-3} = 1.88\times10^{-3}$

$\Rightarrow V_O = 10 - 2\times10^{-3} \times 2\times\frac{99}{100}\times10^{3} = 10 - 3.76 = 6.24$

$\therefore V_{O_{MOS}} = 6V < 6.24 = V_{O_{BJT}}$ due to $I_C < I_D = I_{bias}$

b) MOS: need V_{GS}: $I_D = 2\times10^{-3} = \frac{4\times10^{-4}}{2} \cdot 1 \, (V_{GS}-1)^2 (1 + 0.01[6-3])$ ($V_{DS} = V_O - V_{C_{bp}}$)

$\Rightarrow \frac{10}{1.03} = (V_{GS}-1)^2 \Rightarrow V_{GS} = 1 + \sqrt{10/1.03} = 1 + 3.116$

$\Rightarrow V_G = V_{C_{bp}} + V_{GS} = 3 + 1 + \sqrt{10/1.03} = 7.116$

$= \frac{R_b}{R_a + R_b} V_{DD} = \frac{1}{1 + \frac{100\times10^3}{R_b}} \times 10 \Rightarrow 1 + \frac{100\times10^3}{R_b} = \frac{10}{7.116} \approx 1.405$

$\Rightarrow \frac{100\times10^3}{R_b} = 0.405 \Rightarrow R_b = \frac{100}{0.405}\times10^3 = 247K\Omega$

BJT: $V_B = V_{BE} + V_{C_{pb}} = 3.7 = R_b I_{R_b} \Rightarrow R_b = V_B / I_{R_b} \Rightarrow$ need I_{R_b}

$I_{R_b} = I_{R_a} - I_B = I_{R_a} - \frac{I_C}{\beta} = I_{R_a} - \frac{\alpha}{\beta} I_{bias} = I_{R_a} - \frac{1}{\beta+1} I_C$

$= I_{R_a} - 2\times10^{-5}$

and

$V_{CC} = I_{R_a} R_a + V_B \Rightarrow I_{R_a} = \frac{V_{CC} - V_G}{R_a} = \frac{10-3.7}{R_a} = \frac{6.3}{R_a} = \frac{6.3}{10^5}$

$\Rightarrow I_{R_b} = (6.3-2)\times10^{-5} = 4.3\times10^{-5}$

$\Rightarrow R_b = \frac{3.7}{4.3}\times10^5 = 0.837\times10^5 = 83.7K\Omega$

c) MOS: $g_m = \frac{2 I_D}{(V_{GS} - VTO)} = \frac{4\times10^{-3}}{\sqrt{10/1.03}} \approx \frac{4}{3.116}\times10^{-3} = 1.28\times10^{-3}$

$g_o = \frac{\lambda I_D}{1 + \lambda V_{DS}} = \frac{10^{-2}\times2\times10^{-3}}{1.03} = \frac{2}{1.03}\times10^{-5} = 1.94\times10^{-5} \approx \lambda I_D = 2\times10^{-5}$

BJT: $g_m = \frac{I_C}{V_T} = \frac{\alpha\times2\times10^{-3}}{26\times10^{-3}} = \frac{\alpha}{13} = 0.0762$

$g_o = \frac{I_C}{V_A} = \frac{\alpha\times2\times10^{-3}}{100} = 1.88\times10^{-5}$

$g_{m_{MOS}} = 1.2\times10^{-3} < 76.2\times10^{-3} = g_{m_{BJT}} \Rightarrow$ BJT is stronger

$g_{o_{BJT}} = 1.88\times10^{-5} < 1.94\times10^{-5} = g_{o_{MOS}} \Rightarrow$ MOS has less loss