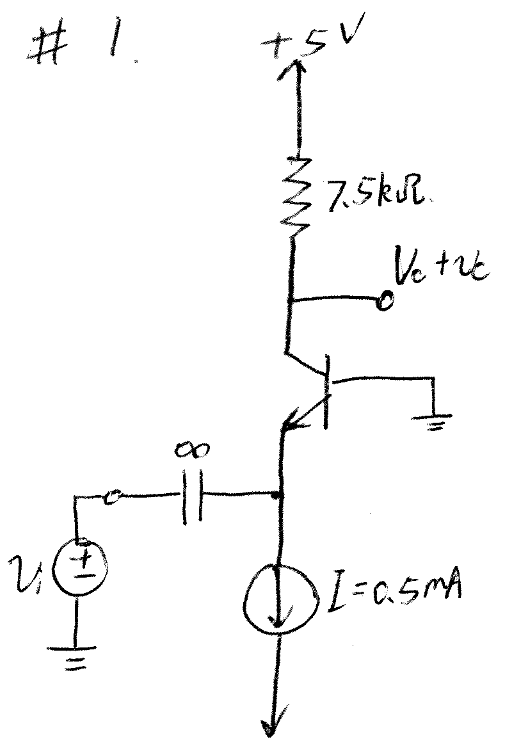
ENEE 302 HW3.

Solutions by Y. Z.

1.



(a) $I_E = 0.5\,mA$

For $\beta = 100$,

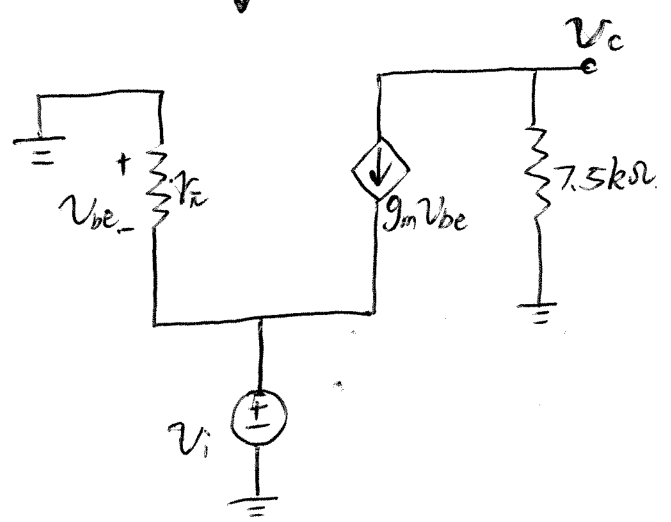
$$I_c = \frac{\beta}{\beta+1} I_E = \frac{100}{101} I_E$$

$$= 0.495\ mA$$

$$\therefore\ V_c = 5V - 7.5k\Omega \times 0.495mA$$

$$= 1.29\ V$$

$$g_m = \frac{I_c}{V_T} = \frac{0.495mA}{25mV} = 0.0198\ A/V$$



Observe that $v_{be} = -v_i$

The output voltage v_c is found to be

$$v_c = -g_m v_{be} \times 7.5k\Omega$$

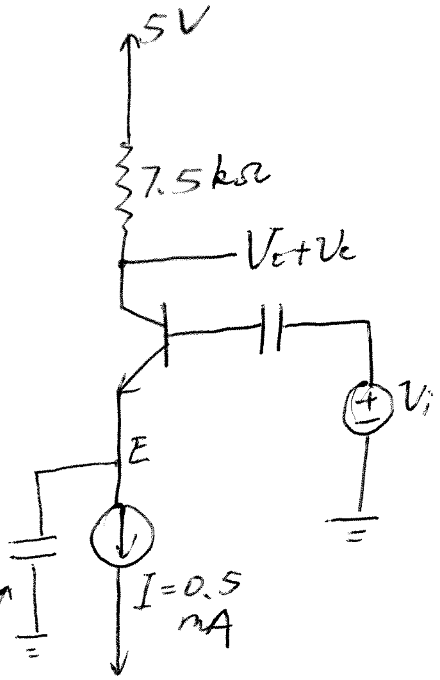
$\Rightarrow$ The voltage gain is

$$\frac{v_c}{v_i} = \frac{-g_m v_{be} \times 7.5k\Omega}{-v_{be}}$$

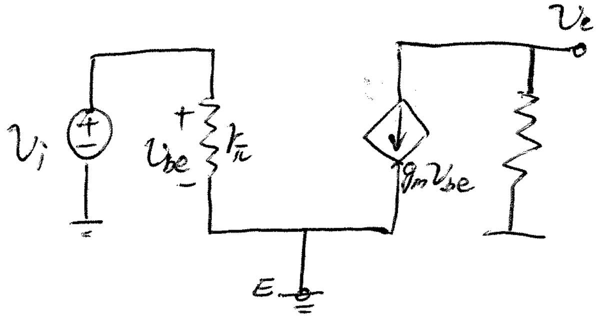
$$= g_m \times 7.5k\Omega$$

$$= 148.5\ V/V$$

(b) Now move the voltage source v_i and its capacitor onto the base



bypass capacitor to provide shortcircuit to ground, see PP. 467, or else use R_E, which we do not know the value here.



$$v_c = -g_m v_{be} \times 7.5\,k\Omega$$

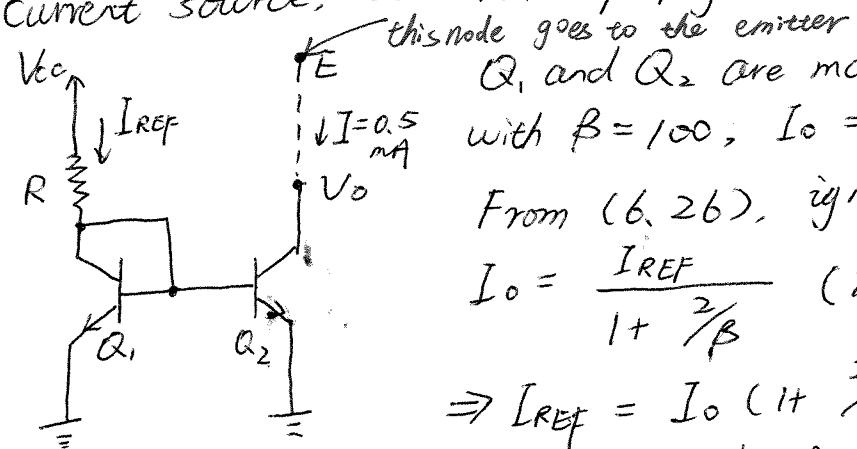
Now $v_i = v_{be}$

$$\Rightarrow \frac{v_c}{v_i} = \frac{-g_m v_{be} \times 7.5\,k\Omega}{v_{be}}$$

$$= -g_m \times 7.5\,k\Omega$$

$$= -148.5 \quad V/V$$

(c) To replace the ideal current source with a simple BJT current source, see PP. 569 Figure 6.10.



Q_1 and Q_2 are matched BJT with $\beta = 100$, $I_O = 0.5\,mA$

From (6.26), ignor V_A term

$$I_O = \frac{I_{REF}}{1 + 2/\beta}$$ ($2/\beta$ is due to two base currents to Q_1 and Q_2)

$$\Rightarrow I_{REF} = I_O (1 + 2/\beta) = 0.5\,mA \times (1 + \frac{2}{100})$$

$$= 0.51\,mA$$

From (6.25)

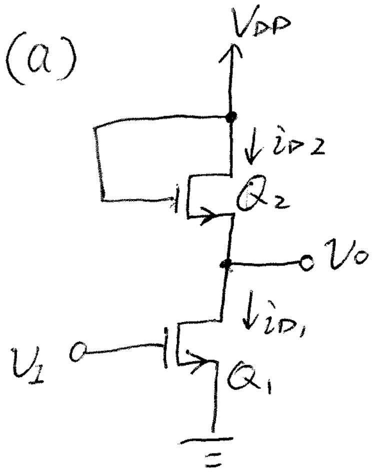
$$I_{REF} = \frac{V_{CC} - V_{BE}}{R} = 0.51\,mA$$

∴ For a given V_{CC}, we can calculate R

For example. For $V_{CC} = 5V$,

$$R = \frac{V_{CC} - V_{BE}}{0.51\,mA} = \frac{(5 - 0.7)V}{0.51\,mA} = 8.43\,k\Omega$$

2. (a)



Q_2 is always in saturation

For $V_{t1} \le V_I \le V_O + V_{t1}$, Q_1 is also in saturation.

for Q_1, $V_{GS1} = V_I$

$$I_{D1} = \frac{1}{2} k_n' \frac{W_1}{L_1} (V_I - V_t)^2$$

For Q_2, $V_{GS2} = V_{DD} - V_O$, $I_{D2} = \frac{1}{2} k_n' \cdot \frac{W_2}{L_2} (V_{DD} - V_O - V_t)^2$

$$I_{D1} = I_{D2} \Rightarrow \frac{1}{2} k_n' \frac{W_1}{L_1} (V_I - V_t)^2 = \frac{1}{2} k_n' \frac{W_2}{L_2} (V_{DD} - V_O - V_t)^2$$

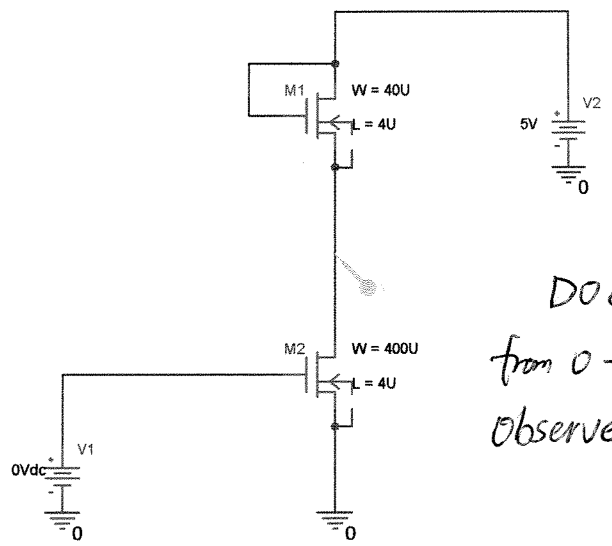
$$\Rightarrow \sqrt{\frac{W_1}{L_1}} (V_I - V_t) = \sqrt{\frac{W_2}{L_2}} (V_{DD} - V_O - V_t)$$

$$\Rightarrow V_O = V_{DD} - V_t + \sqrt{\frac{(W/L)_1}{(W/L)_2}}\, V_t - \sqrt{\frac{(W/L)_1}{(W/L)_2}}\, V_I$$

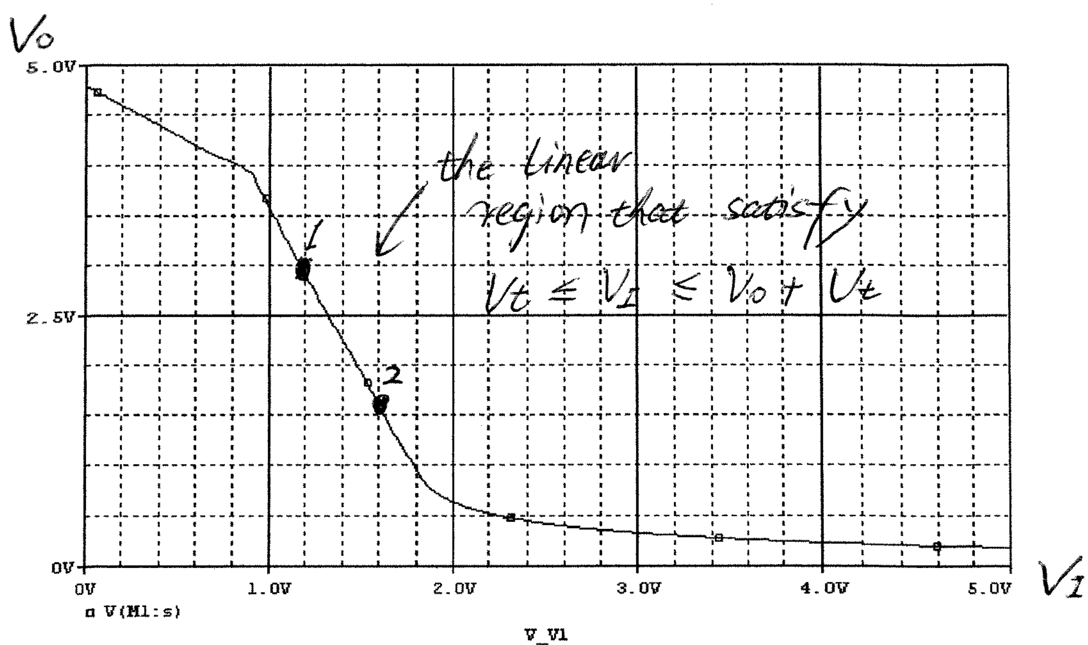
For $(W/L)_1 = \frac{50um}{0.5um}$, $(W/L)_2 = \frac{5um}{0.5um}$. The voltage gain is

$$\frac{V_O}{V_I} = -\sqrt{\frac{(W/L)_1}{(W/L)_2}} = -\sqrt{10} = -3.16$$

(b)



Do a DC sweep from 0 ~ 5V on V_I. Observe V_o.



Chose two points from the region $V_t \le V_I \le V_o + V_t$

$V_{I_1} = 1.2V \quad V_{o_1} = 2.92\,V$

$V_{I_2} = 1.6\,V, \quad V_{o_2} = 1.62\,V \quad \Rightarrow \quad \frac{\Delta V_o}{\Delta V_I} = -3.25$

Agrees well with predicted value -3.16

3. The small-signal model for NMOS (PP. 297)

$$g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D} = \sqrt{2 \times 90 \times 10^{-6} \times \frac{20}{2} \times 100 \times 10^{-6}}$$

$$= 4.24 \times 10^{-4} \quad A/V$$

$$V_A = 16V$$

$$r_o = \frac{V_A}{I_D} = \frac{16V}{100 \times 10^{-6} A} = 160 k\Omega$$

$$\chi = \frac{\gamma}{2\sqrt{2\phi_f + V_{SB}}} = \frac{0.5}{2\sqrt{2 \times 0.34 + 1}} = 0.193$$

$$g_{mb} = \chi g_m = 0.193 \times 4.24 \times 10^{-4} = 8.2 \times 10^{-5} \quad A/V$$

$$g_m = \frac{2 I_D}{V_{OV}} \Rightarrow V_{OV} = \frac{2 \times 10^{-4}}{4.24 \times 10^{-4}} = 0.48 V$$

The small-signal model for PMOS

$$g_m = \sqrt{2 \mu_p C_{ox} \frac{W}{L} I_D} = \sqrt{2 \times 30 \times 10^{-6} \times \frac{20}{2} \times 100 \times 10^{-6}}$$

$$= 2.45 \times 10^{-4} \quad A/V$$

$$V_A = 24 V$$

$$r_o = \frac{V_A}{I_D} = \frac{24 V}{100 \times 10^{-6} A} = 240 k\Omega$$

$$\chi = 0.193$$

$$g_{mb} = 0.193 \times 2.45 \times 10^{-4} = 4.7 \times 10^{-5} \quad A/V$$

$$V_{OV} = \frac{2 \times 0.1}{0.24} = 0.83 V$$