Ex : 0.8 μm fabrication proces
NMOS transistor

$t_{ox} = 8 nm$

$\mu_n = 450 \frac{cm^2}{V\text{-}s}$

$W = 8 \mu m$

$L = 0.8 \mu m$

$V_t = 0.7 V$

a) $C_{ox} = \frac{\epsilon_r \epsilon_o}{t_{ox}} = \frac{(3.9)(8.85 \times 10^{-12} F/m)}{8 \times 10^{-9} m}$

$C_{ox} = 4.31 \times 10^{-3} \frac{F}{m^2}$

b) $k'_n = \mu_n C_{ox}$

$= \frac{450 cm^2}{V\text{-}s} \left| \frac{4.31 \times 10^{-3} F}{m^2} \right| \frac{1 m^2}{100^2 cm^2}$

$= 194.15 \times 10^{-6} \frac{F}{V\text{-}s}$

$q = CV$ $\quad$ $\underset{[F]}{C} = \frac{q}{V} = \left[\frac{C}{V}\right]$

b) cont

$$k'_n = 194.15 \times 10^{-6} \frac{C/V}{V\text{-}s} = \frac{C}{s} \cdot \frac{1}{V^2}$$

$$k'_n = 194.15 \times 10^{-6} \frac{A}{V^2}$$

$$k'_n = 194.15 \frac{\mu A}{V^2}$$

c) NMOS $\Rightarrow$ $i_D = 100 \mu A$

edge of saturation

$$v_{DS} = v_{GS} - V_t$$

$$i_D = \frac{1}{2} k'_n \frac{W}{L} (v_{GS} - V_t)^2 = 100 \mu A$$

$$i_D = \frac{1}{2}\left(194.15 \frac{\mu A}{V^2}\right)\left(\frac{8 \mu m}{.8 \mu m}\right)(v_{GS} - 0.7)^2$$

$$100 = \frac{1}{2}(194.15)(10)(v_{GS} - V_t)^2$$

$$v_{GS} = 1.02 V$$

$$v_{DS} = v_{GS} - V_t$$

$$= 1.02 - 0.7$$

$$v_{DS} = 0.321 \text{ V}$$

$$\left.\begin{array}{l} v_{OV} \\ V_{OV} \end{array}\right\} \text{overdrive voltage}$$

$$v_{OV} = v_{GS} - V_t$$

$$V_{OV} = V_{GS} - V_t$$

v_{GS} or i_D => ac + dc components

V_{GS} or I_D => dc only

v_{gs} or i_d => ac only (small signal)

Ex 2

$\underbrace{\text{Nmos}}_{}^{\text{from Ex 1}}$ is in triode

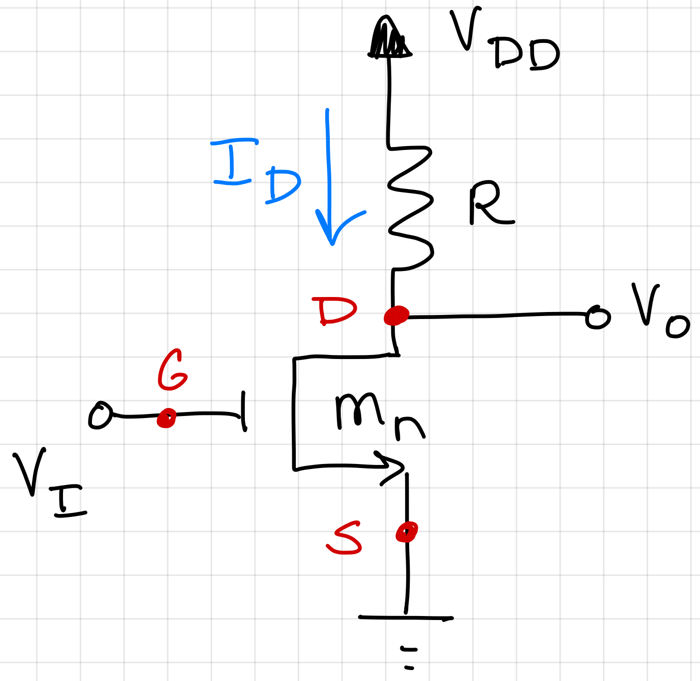
v_{DS} is very small

Nmos device acts like $1000\,\Omega$ resistor. What is v_{GS}?

$$r_{ds} = \frac{v_{DS}}{i_D} = \frac{1}{k'_n\left(\frac{W}{L}\right)(v_{GS} - V_t)}$$

$$r_{ds} = \frac{1}{(194.15\times10^{-6})(10)(v_{GS} - 0.7)} = 1000$$

$$\boxed{v_{GS} = 0.915\ \text{V}}$$



$V_t = 0.4V$

$k'_n = 0.5 \frac{mA}{V^2}$

if $V_{DD} = V_I = 1.3V$

and $V_o = 50mV$

Find $\frac{W}{L}$ and R

$$V_{DS} = V_o - 0 = V_o = 0.05\,V$$

$$V_{GS} = V_I - 0 = V_I = 1.3\,V$$

$$\boxed{V_{DS} < V_{GS} - V_t} \Rightarrow \text{triode region}$$

$$0.05 < 1.3 - 0.4$$

$$0.05 < 0.9$$

we know $r_{ds} = 50\Omega$

$$r_{ds} = \frac{1}{k'_n \frac{W}{L}(V_{GS} - V_t)} = 50$$

$$\frac{1}{(0.5 \times 10^{-3})(\frac{W}{L})(1.3 - 0.4)} = 50$$

$$\boxed{\frac{W}{L} = 44.\overline{4}}$$

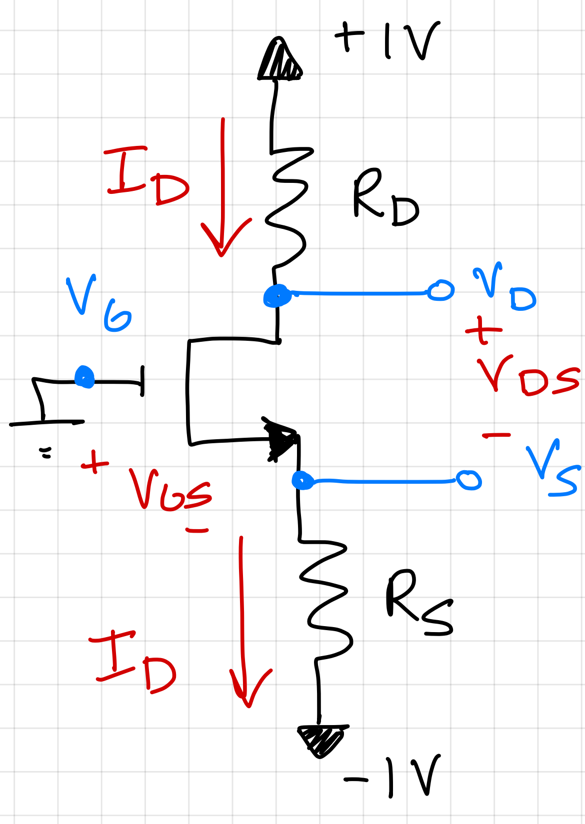
$$R = \frac{V_{DD} - V_O}{I_D}$$

$$I_D = ½k'_n \frac{W}{L}(V_{GS} - V_t)(V_{DS})$$

$$= 0.5\left(44.\overline{4}\right)\left(1.3 - 0.4\right)(.05)$$

$$I_D = 1mA$$

$$R = \frac{1.3 - 0.05}{1m} = 1.25k\Omega$$



Design R_D & R_S

$I_D = 0.1mA$

$V_D = 0.2V$

$V_t = 0.5V$

$\mu_n C_{ox} = 400 \frac{\mu A}{V^2}$

$W = 4\mu m$

$L = 0.5\ \mu m$

$$\frac{W}{L} = \frac{4}{.5} = 8$$

<u>Know</u>

$$V_{GS} = 0 - V_S$$
$$= -V_S$$

$$V_{DS} = 0.2 - V_S$$

$$V_{DS} \bigcirc V_{GS} - V_t$$
$$.2 - V_S \bigcirc -V_S - 0.5$$
$$.2 - V_S \geq -0.5 - V_S$$

assume saturation operation and then check our assumption

$$R_D = \frac{1 - V_D}{I_D} = \frac{1 - 0.2}{0.1m} = 8k\Omega$$

$$I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)^2$$

[mA/V] [mA]

$$\frac{1}{2}(0.4)(8)(V_{GS} - 0.5)^2 = 0.1$$

$$(V_{GS} - 0.5)^2 = 0.0625$$

$$V_{GS} = 0.75V$$

$$V_{GS} = -V_S$$

$$-V_S = 0.75V$$

$$\boxed{V_S = -0.75V}$$

$$\bullet\ 2 - V_S \geq -0.5 - V_S$$

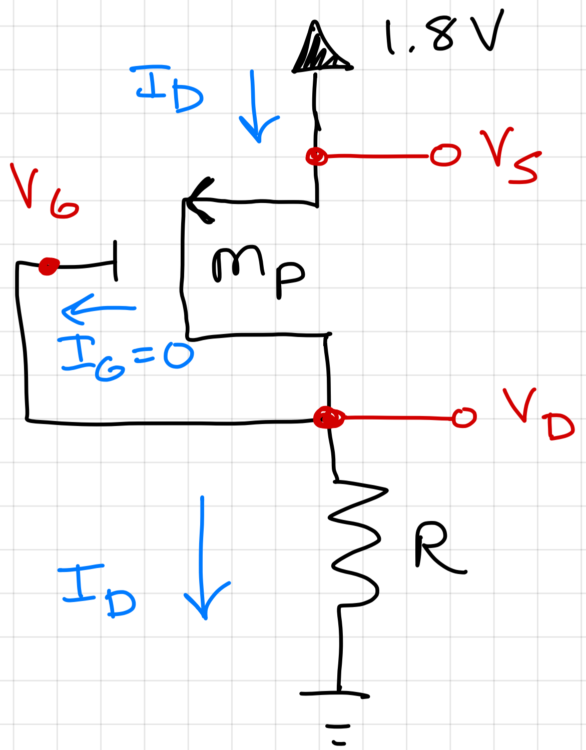
$$0.2 - (-.75) \quad \bigcirc \quad -0.5 - (-.75)$$

$$0.95 > 0.25$$

assumption was correct
device is operating in saturation

$$R_S = \frac{V_S - (-1)}{I_D} = \frac{-0.75 + 1}{0.1m} = 2.5k\Omega$$

$$\boxed{R_S = 2.5k\Omega}$$



$k'_p = \mu_p C_{ox} = 100 \frac{\mu A}{V^2}$

$V_{tp} = -0.5V$

$L = 0.18\mu m$

$I_D = 160\mu A$

$V_D = 0.8V$

find W and R

$V_S = 1.8V$

$V_G = V_D = 0.8V$

$V_{SG} = 1.8 - 0.8$

$\boxed{V_{SG} = 1V}$

when gate & drain are tied together ($V_G = V_D$), this "diode - connected" configuration.

$$V_{SD} \geq V_{SG} - |V_{tp}|$$

$$V_G = V_D$$

$$V_S - \cancel{V_D} \quad V_S - \cancel{V_G} - |V_{tp}|$$

$$V_S > V_S - |V_{tp}|$$

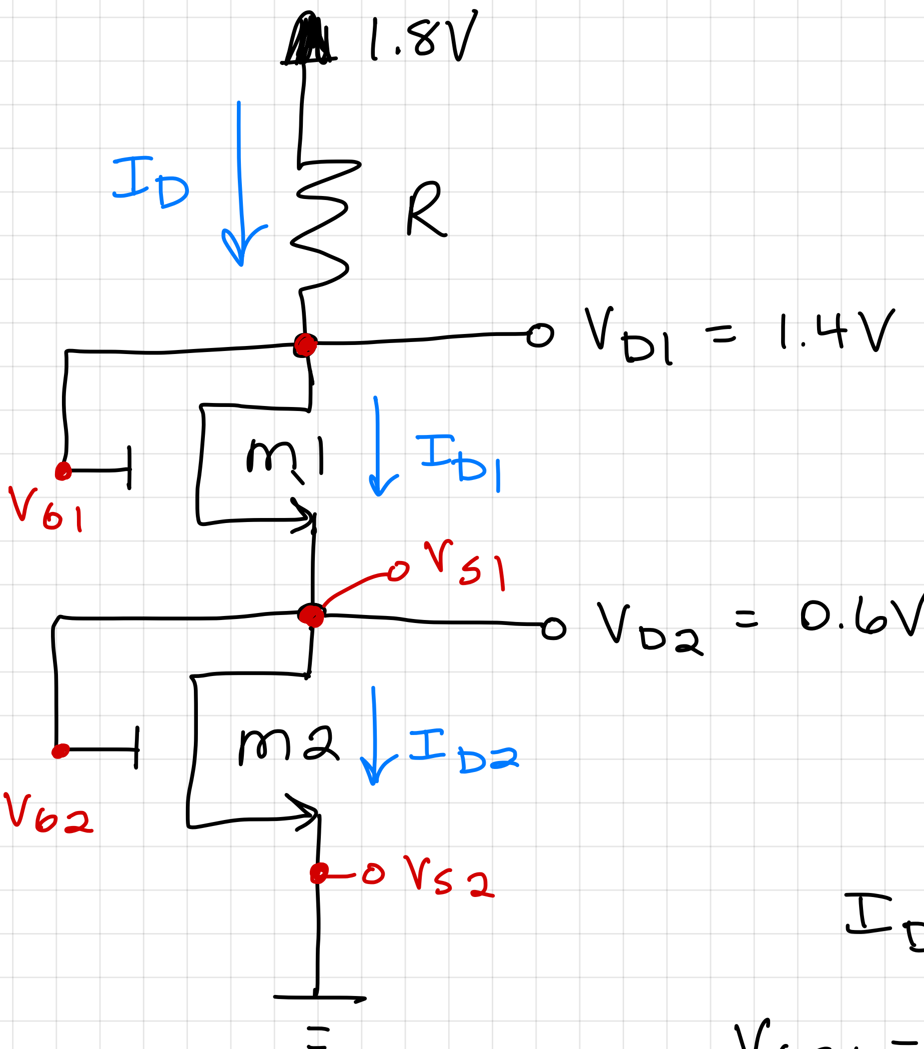
under diode connected conditions the MOSFET operates in saturation.

$$\boxed{R = \frac{V_D}{I_D} = \frac{0.8}{160 \times 10^{-6}} = 11.25\, k\Omega}$$

$$I_D = \frac{1}{2} k'_p \left(\frac{W}{L}\right)\left(V_{SG} - |V_{tp}|\right)^2 = 160\, \mu A$$

$$\frac{1}{2}(100)\left(\frac{W}{.18}\right)\left(1 - |-.5|\right)^2 = 160$$

$$\boxed{W = 2.3\, \mu m}$$



$I_D = 0.1mA$

$V_t = 0.4V$ (both m_1 & m_2)

$\mu_n C_{ox} = k'_n = \frac{0.4mA}{V^2}$

$L_1 = L_2 = 0.18 \mu m$

Find R and W_1, W_2

m_1 & m_2 are diode connected $\Rightarrow$ Saturation

$I_D = I_{D1} = I_{D2} = 0.1mA$

$$V_{GS1} = V_{G1} - V_{S1}$$
$$= V_{D1} - V_{D2}$$
$$= 1.4 - 0.6$$
$$\boxed{V_{GS1} = 0.8V}$$

$$R = \frac{1.8 - V_{D1}}{I_D}$$
$$= \frac{1.8 - 1.4}{.1m}$$
$$\boxed{R = 4k\Omega}$$

$$V_{GS2} = V_{G2} - V_{S2}$$
$$= V_{D2} - 0$$
$$V_{GS2} = 0.6 - 0$$
$$\boxed{V_{GS2} = 0.6V}$$

for M1

$$I_{D1} = \frac{1}{2} k'n \left(\frac{W_1}{L_1}\right)\left(V_{GS1} - V_t\right)^2$$

$$\frac{1}{2}(0.4)\left(\frac{W_1}{.18}\right)(0.8 - 0.4)^2 = 0.1$$

$$\left(\frac{W_1}{.18}\right) = 3.125$$

$$W_1 = 0.56\ \mu m$$

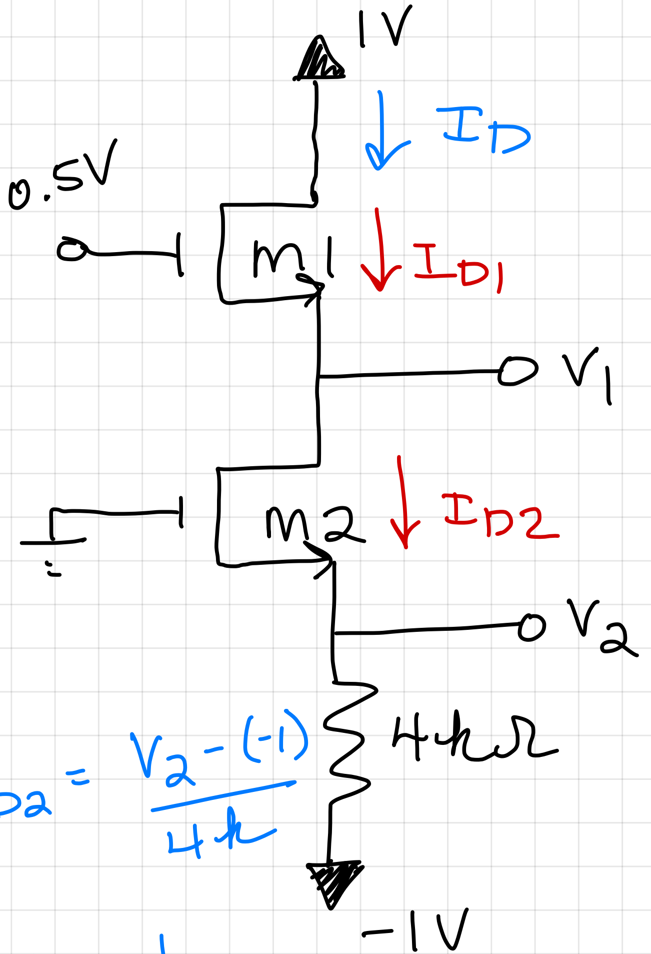
for M2

$$I_{D2} = \frac{1}{2} k'n \left(\frac{W_2}{L_2}\right)\left(V_{GS2} - V_t\right)^2$$

$$\frac{1}{2}(.4)\left(\frac{W_2}{.18}\right)(0.6 - 0.4)^2 = 0.1$$

$$\frac{W_2}{.18} = 12.5$$

$$\boxed{W_2 = 2.25\ \mu m}$$



$$I_{D2} = \frac{V_2 - (-1)}{4k}$$

$$= \frac{V_2 + 1}{4k}$$

Find I_D, V_1 & V_2 for both m_1 & m_2

$V_t = 0.4V$

$$\left(k_n' \frac{W}{L}\right) = \frac{5mA}{V^2}$$

$$\boxed{V_{GS1} = 0.5 - V_1}$$

$$\boxed{V_{GS2} = 0 - V_2}$$

$$\boxed{V_{DS1} = 1 - V_1}$$

$$\boxed{V_{DS2} = V_1 - V_2}$$

for m1

$V_{DS1} \quad \bigcirc \quad V_{GS1} - V_t$

$1 - V_1 \quad \bigcirc \quad 0.5 - V_1 - 0.4$

$1 - V_1 \geq 0.1 - V_1$

assume m1 is in saturation

for m2

$V_1 - V_2 \quad \bigcirc \quad -V_2 - 0.4$

assume m2 in saturation

$I_D = I_{D1} = I_{D2}$ & devices are matched ($k'_n \frac{W}{L}$, V_t are same)

$$I_{D1} = I_{D2}$$

$$\cancel{\frac{1}{2} k'_n \frac{W}{L}} (V_{GS1} - V_t)^2 = \cancel{\frac{1}{2} k'_n \frac{W}{L}} (V_{GS2} - V_t)^2$$

$$(V_{GS1} - V_t)^2 = (V_{GS2} - V_t)^2$$

$$V_{GS1} = V_{GS2}$$

$$0.5 - V_1 = 0 - V_2$$

$$\boxed{V_1 - V_2 = 0.5V}$$

$$I_{D2} = \frac{V_2 + 1}{4k}$$

$$\frac{1}{2} k'_n \frac{W}{L} (V_{GS2} - V_t)^2 = \frac{V_2 + 1}{4k}$$

$$\frac{1}{2}(5m)(-V_2 - 0.4)^2 = \frac{V_2 + 1}{4k}$$

$$10(-V_2 - 0.4)^2 = V_2 + 1$$

$$10(0.16 + 0.8V_2 + V_2^2) = V_2 + 1$$

$$1.6 + 8V_2 + 10V_2^2 = V_2 + 1$$

$$10V_2^2 + 7V_2 + 0.6 = 0$$

$$V_2 = -0.1V \qquad V_2 = -0.6V$$

$V_1 = 0.4V$

$V_2 = -0.1V$

$V_{GS2} = 0.1V$

$V_{DS2} = 0.5V$

$V_{DS1} = 0.6V$

$V_{GS1} = 0.1V$

$V_{GS1} < V_t$

$.1 < 0.4$

$V_{GS2} < V_t$

$.1 < 0.4$

↑ Both devices are off.

$\boxed{V_{GS1} = 0.5 - V_1}$

$\boxed{V_{GS2} = 0 - V_2}$

$\boxed{V_{DS1} = 1 - V_1}$

$\boxed{V_{DS2} = V_1 - V_2}$

$\boxed{V_1 - V_2 = 0.5V}$

$$\boxed{V_{GS1} = 0.5 - V_1}$$

$$\boxed{V_2 = -0.6V \qquad V_1 = -0.1V}$$

$$\boxed{V_{GS2} = 0 - V_2}$$

$$\boxed{V_{GS1} = 0.6V \qquad V_{GS2} = 0.6V}$$

$$\boxed{V_{DS1} = 1 - V_1}$$

$V_{DS1} = 1.1V$

$$\boxed{V_{DS2} = V_1 - V_2}$$

$V_{DS2} = 0.5V$

$$\boxed{V_1 - V_2 = 0.5V}$$

greater than V_t

$V_{DS1} \quad V_{GS1} - V_t$

$1.1 \geq 0.6 - 0.4$

$V_{DS2} \quad V_{GS2} - V_t$

$0.5 \geq 0.6 - 0.4$

confirmed saturation for both!

$$I_D = \frac{V_2 + 1}{4k} = \frac{-0.6 + 1}{4k}$$

$$\boxed{I_D = 0.1mA}$$

Ex npn transistor $V_T = 25mV$

$v_{BE1}, i_{C1} \Rightarrow 0.7V, 1mA$

$v_{BE2}, i_{C2} \Rightarrow$ ____ $, 0.1mA$

$v_{BE3}, i_{C3} \Rightarrow$ ____ $, 10mA$

a

$$v_{BE2} - v_{BE1} = V_T \ln\left(\frac{i_{C2}}{i_{C1}}\right)$$

$$v_{BE2} - 0.7 = 0.025 \cdot \ln\left(\frac{0.1}{1}\right)$$

$$v_{BE2} = 0.64\ V$$

b

$$v_{BE3} - v_{BE1} = V_T \ln\left(\frac{i_{C3}}{i_{C1}}\right)$$

$$v_{BE3} - 0.7 = 0.025 \ln\left(\frac{10}{1}\right)$$

$$v_{BE3} = 0.76V$$

EX

npn transistor

β range 50 to 150

α range ?

$$\alpha = \frac{\beta}{\beta+1} \qquad \alpha = 0.98 \text{ to } 0.993$$

EX

npn transistor

$i_B = 14.46\,\mu A$

$i_E = 1.46\,mA$

$v_{BE} = 0.7V$

Find i_C, I_S, β, α

$$i_C + i_B = i_E$$

$$i_C = i_E - i_B$$

$$= 1.446\,mA$$

$$= 1.45\,mA$$

$$I_S = \frac{i_C}{\exp(v_{BE}/V_T)}$$

$$= \frac{1.446 \times 10^{-3}}{\exp(.7/.025)}$$

$$i_B = \frac{i_C}{\beta}$$

$$\beta = \frac{i_C}{i_B} = \frac{1.446 \times 10^{-3}}{14.46 \times 10^{-6}}$$

$$\beta = 99.97 \cong 100$$

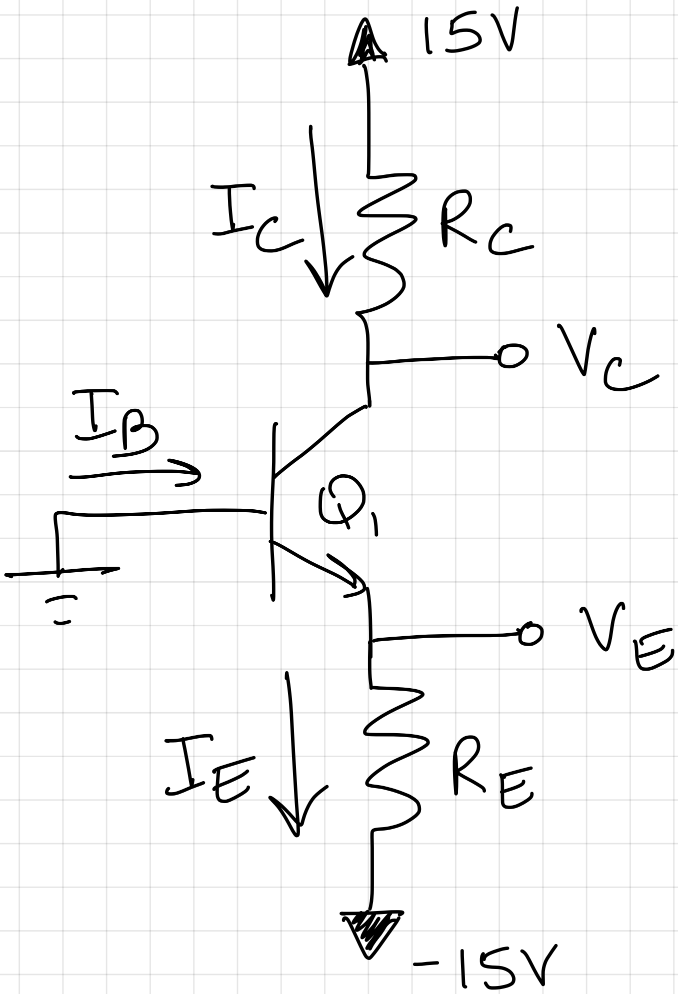
$$\alpha = \frac{\beta}{\beta+1} = 0.99$$

$$I_S = 9.995 \times 10^{-16} A$$

$$= 10 \times 10^{-16} A$$

$$= 10^{-15} A$$

npn $\Rightarrow$ Q_1 , Q_2 $\qquad$ $v_C = V_C$



$\beta = 100$

$$\boxed{\begin{array}{l} v_{BE} = 0.7V \\ I_C = 1mA \end{array}}$$

what are R_C and R_E for

$I_C = 2mA$
$V_C = 5V$

$V_{CB} > 0 \; \Big\} \; 5 - 0 = 5V$

$$R_C = \frac{15 - V_C}{I_C} = \frac{15 - 5}{2mA} = 5k\Omega$$

$$V_{BE2} - V_{BE1} = V_T \ln\left(\frac{I_{C2}}{I_{C1}}\right)$$

$$V_{BE2} - 0.7 = (.025) \ln\left(\frac{2mA}{1mA}\right)$$

$$\boxed{V_{BE2} = 0.717V}$$

$$V_{BE_2} = \cancel{V_B}^{\,0} - V_E = 0.717\,V$$

$$\boxed{V_E = -0.717\,V}$$

$$R_E = \frac{V_E - (-15)}{I_E}$$

$$I_C = \alpha\, I_E \qquad \alpha = \frac{\beta}{\beta+1} = \frac{100}{101}$$

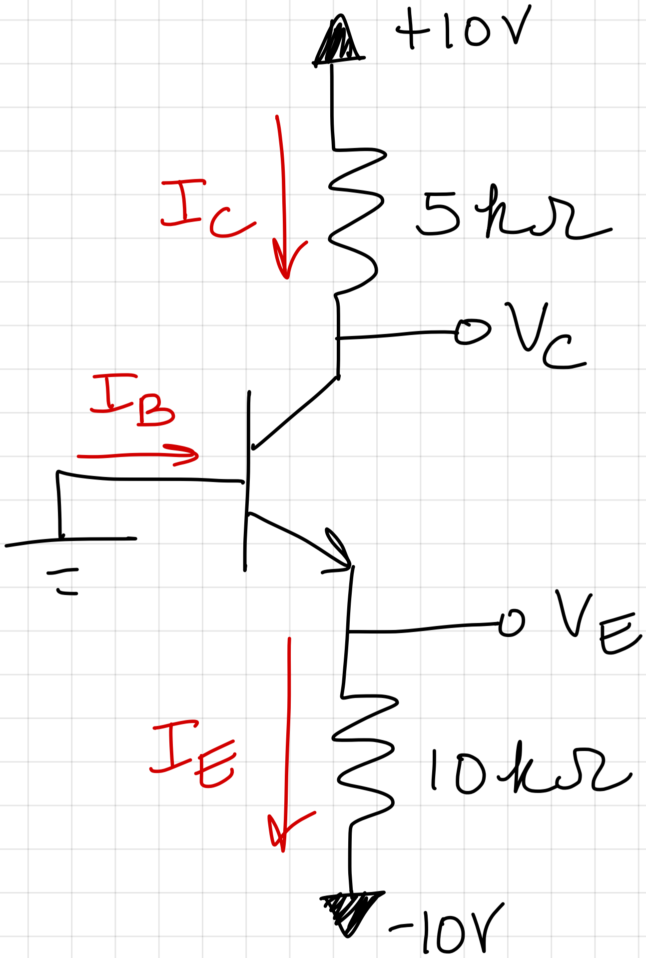
$$\alpha = 0.99$$

$$I_E = \frac{I_C}{\alpha}$$

$$I_E = \frac{2 \times 10^{-3}}{0.99} = 2.02\ mA$$

$$R_E = \frac{-0.717 + 15}{2.02 \times 10^{-3}}$$

$$\boxed{R_E = 7.07\ k\Omega}$$



$\beta = 50$

$V_E = -0.7V$

Find I_C, I_B, I_E & V_C.

$$I_E = \frac{V_E - (-10)}{10 \times 10^3}$$

$$= \frac{-0.7 + 10}{10 \times 10^3}$$

$$\boxed{I_E = 0.93\,mA}$$

$$I_C = \alpha I_E$$

$$= \left(\frac{\beta}{\beta+1}\right) I_E$$

$$= \left(\frac{50}{51}\right)(.93\,mA)$$

$$\boxed{I_C = 0.912\,mA}$$

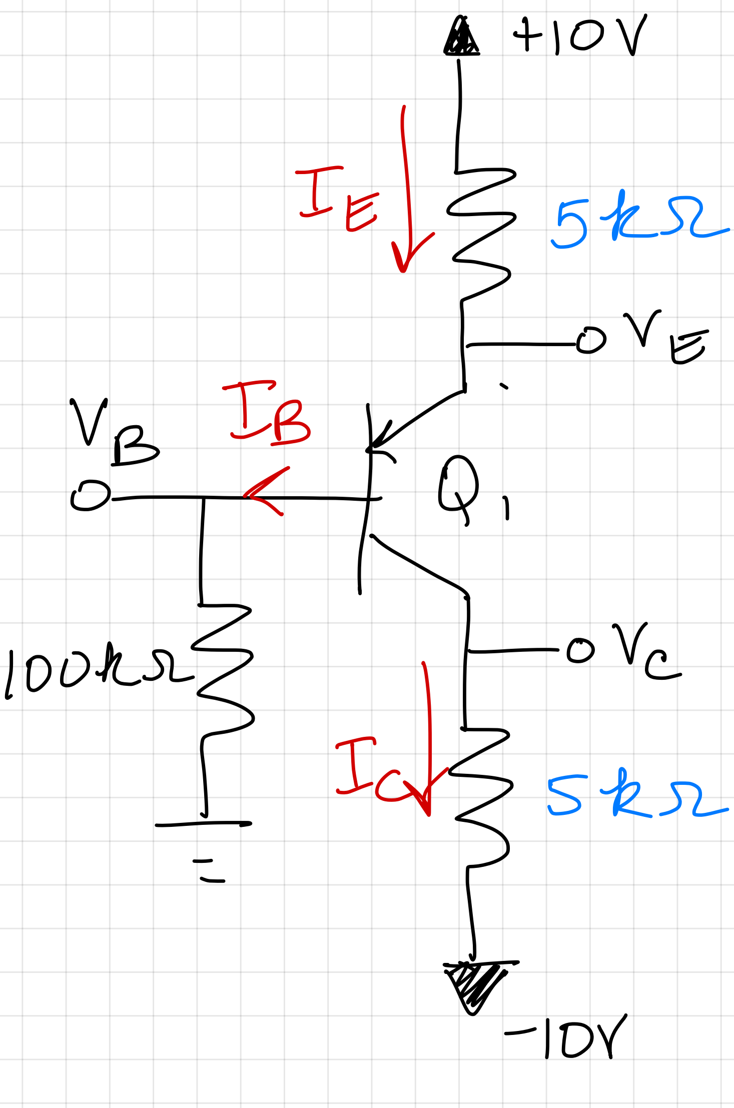
$$I_B = \frac{I_C}{\beta} = \frac{0.912\,mA}{50} = 0.018\,mA$$

$$\boxed{I_B = 0.018\,mA}$$

$$V_C = 10 - \overset{k\Omega}{5}\,\overset{mA}{I_C}$$

$$= 10 - 5(.912)$$

$$\boxed{V_C = 5.44\,V}$$



$V_B = 1V$

$V_E = 1.7V$

β, α, V_C

$V_{EB} = 0.7V$

$$I_B = \frac{V_B}{100\times10^3} = \frac{1}{100\times10^3}$$

$$I_B = 0.01\,mA$$

$$I_E = \frac{10 - V_E}{5\times10^3}$$

$$I_E = \frac{10 - 1.7}{5 \times 10^3} = 1.66\,mA$$

$$I_C = I_E - I_B = 1.65\,mA$$

$$I_C = \alpha I_E$$

$$\boxed{\alpha = \frac{I_C}{I_E} = 0.994}$$

$$\boxed{\beta = \frac{I_C}{I_B} = \frac{1.65}{.01} = 165}$$

$$I_C = \frac{V_C + 10}{5 \times 10^3}$$

$$V_C = 5 I_C - 10$$

$$\boxed{V_C = -1.75\,V}$$

$$V_{BC} = 1 - (-1.75)$$

$$V_{BC} = 2.75V$$

active.

A common source (CS) amplifier w/ NMOS transistor:

$k'_n = 0.2 \frac{mA}{V^2}$ $\frac{W}{L} = 40$ $V_t = 0.5V$

$V_A = 50V$

$R_D = 20k\Omega$

$R_L = 20k\Omega$

$R_{sig} = 100k\Omega$

a) If $I_{DQ} = 0.25mA$

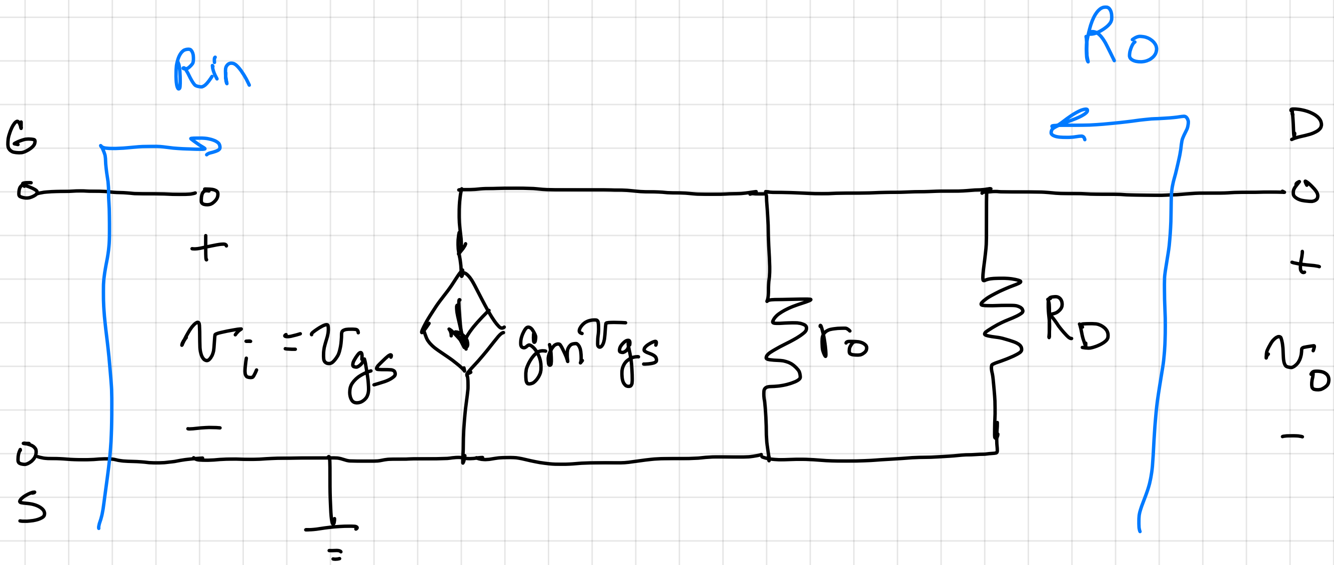
$V_{GSQ} = ?$

$$I_{DQ} = \frac{1}{2} k'_n \frac{W}{L} (V_{GSQ} - V_t)^2$$

$$0.25mA = \frac{1}{2}(.2)(40)(V_{GSQ} - 0.5)^2$$

$$\boxed{V_{GSQ} = 0.75V}$$

b) R_{in}, g_m, R_o, $\underline{A_{vo}}$, r_o



$$R_{in} = \infty$$

$$g_m = k'_n \frac{W}{L}(V_{GS_Q} - V_t) = 2\ mA/V^2$$

$$= 0.2(40)(.25) = 2\ mA/V^2$$

$$r_o = \frac{V_A}{I_{DQ}} = \frac{50}{.25} = 200\ k\Omega$$

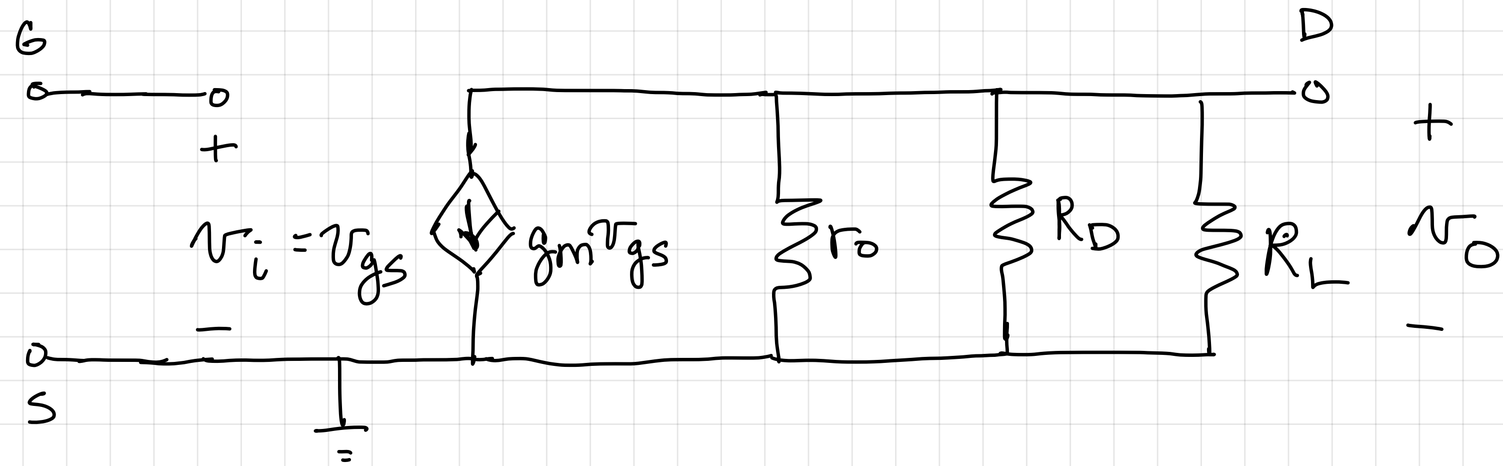
$$R_o = r_o \| R_D = (200 \| 20)\ k\Omega = 18.2\ k\Omega$$

$$A_{vo} = \left.\frac{v_o}{v_i}\right|_{R_L \to \infty} = -g_m (r_o \| R_D)$$

$$= -2(200 \| 20)$$

$$A_{vo} = -36.4\ V/V$$

c) $A_v = \dfrac{v_o}{v_i}$



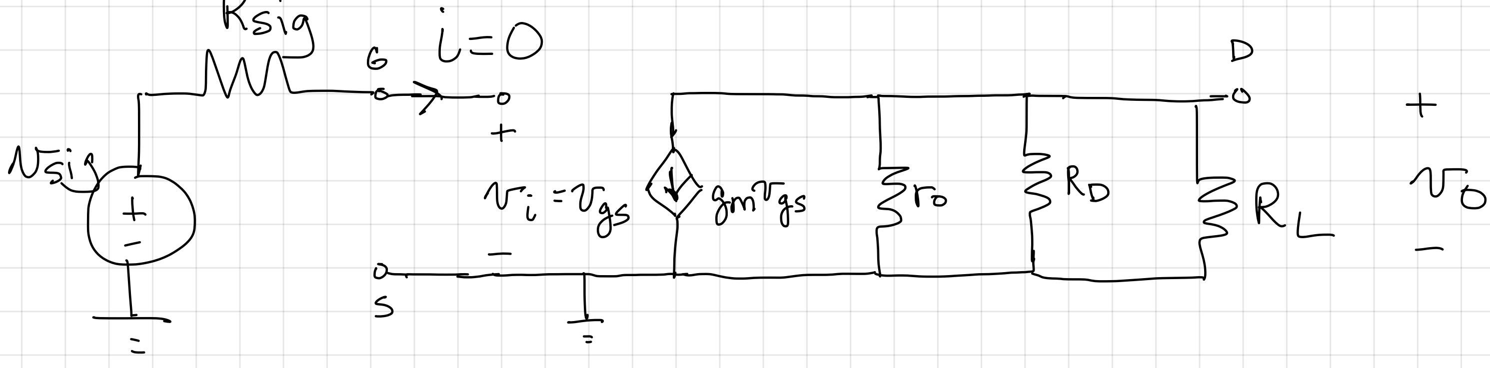
$$A_v = -g_m (r_o || R_D || R_L)$$

$$= -2(200 || 20 || 20)$$

$$= -19.05 \ V/V$$

d) G_v

R_{sig} does not affect G_v



$$G_v \equiv A_v = -g_m(r_o \| R_D \| R_L)$$

$$= -19.05 \ V/V$$

BJT Amp configuration Examples

CE amplifier

$\beta = 100$ $\quad I_{CQ} = 1mA$ $\quad R_L = 5k\Omega$

$V_A = 100$ $\quad R_C = 5k\Omega$ $\quad R_{sig} = 10k\Omega$

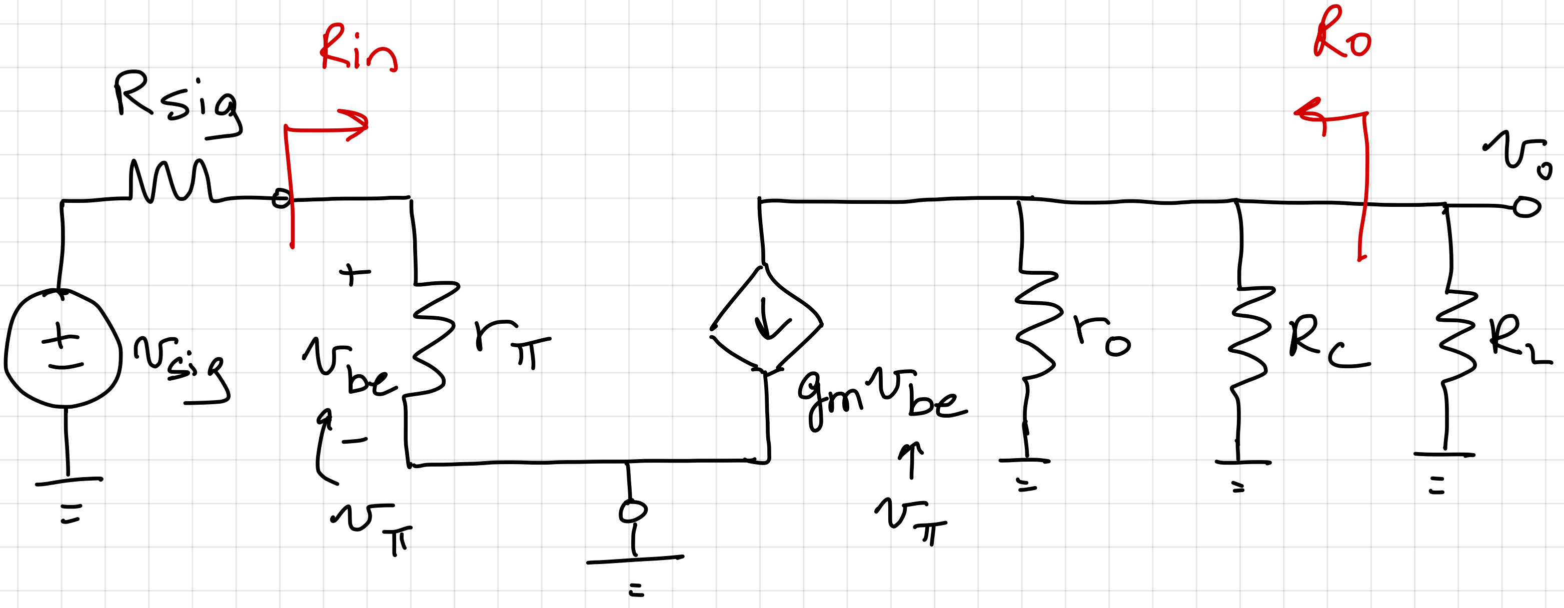
Finding g_m, r_π, r_o

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1mA}{.025V} = 40\frac{mA}{V}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{40\times10^{-3}} = 2.5\times10^3$$

$$2.5\,k\Omega$$

$$r_o = \frac{V_A}{I_{CQ}} = \frac{100}{1} = 100\,k\Omega$$



$R_{in} = r_\pi = 2.5\,k\Omega$

$R_o = r_o \| R_C = 100 \| 5 = 4.76\,k\Omega$

$$G_v = \frac{v_o}{v_{sig}} = -g_m (r_o \| R_C \| R_L)\left(\frac{r_\pi}{r_\pi + R_{sig}}\right)$$

$$= -40\,(100 \| 5 \| 5)\left(\frac{2.5}{12.5}\right)$$

$$G_v = -19.52\ V/V$$

Let's do a redesign:

$I_{CQ} = 0.5\,mA \Rightarrow$ reduction to increase R_{in}

$g_m = \frac{I_{CQ}}{V_T} = 20\,mA$

$r_\pi = 5\,k\Omega$

$r_o = \frac{V_A}{I_{CQ}} = 200\,k\Omega$

$$G_v = -g_m (r_o \| R_C \| R_L)\left(\frac{r_\pi}{r_\pi + R_{sig}}\right)$$

$$= -20(200 \| R_C \| 5)\left(\frac{5}{15}\right)$$

$$= -20(R_C \| 4.88)(1/3)$$

$$= -6.67(R_C \| 4.88)$$

$$-6.67\left(\frac{R_C(4.88)}{R_C+4.88}\right) = -19.52$$

$$\boxed{R_C = 7.33\ k\Omega}$$

$$R_o = 200 \| 7.33 = 7.07\ k\Omega$$

$$R_{in} = 5\ k\Omega$$

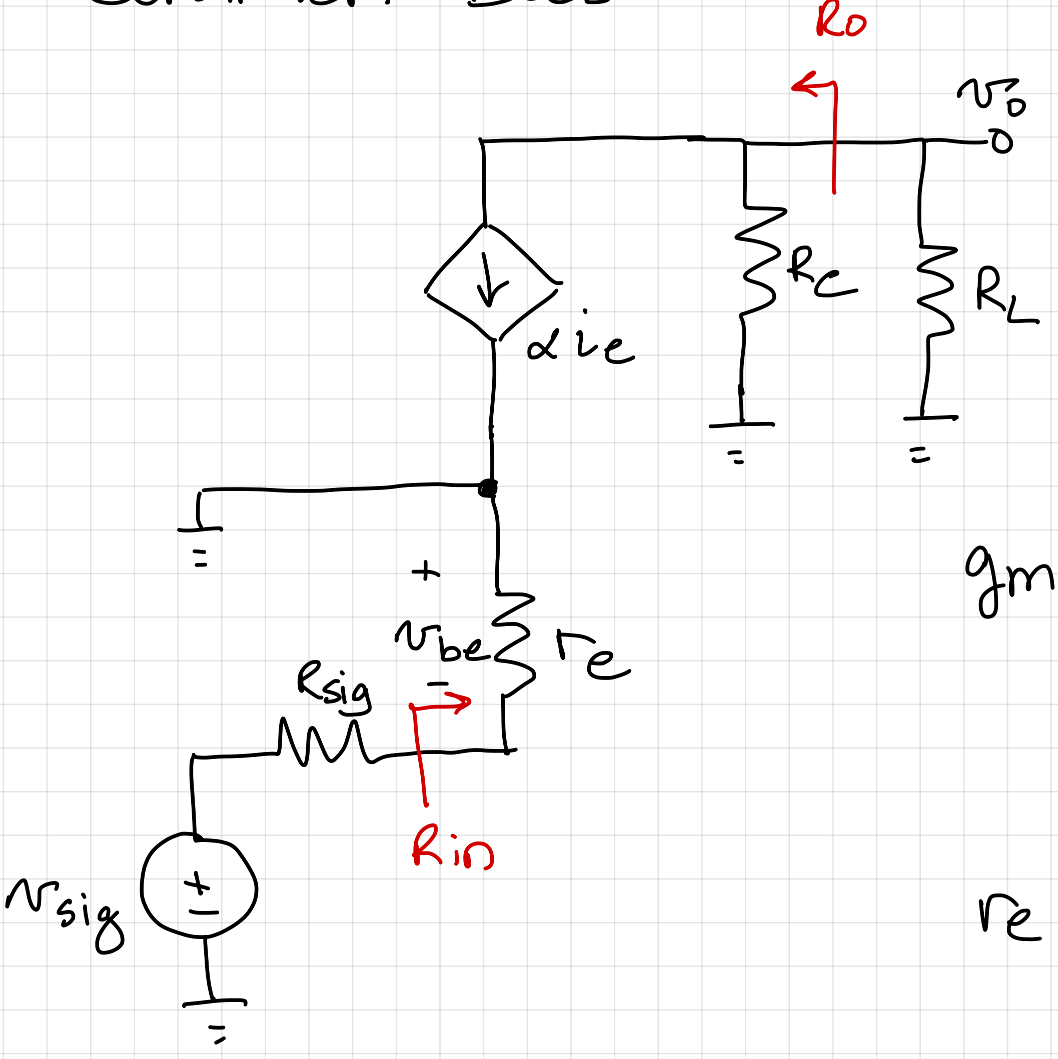
Common Base

$I_{CQ} = 1mA$

$R_C = 5k\Omega$

$R_L = 5k\Omega$

$R_{sig} = 5k\Omega$



$$g_m = \frac{I_{CQ}}{V_T} = \frac{1}{.025} = 40\frac{mA}{V}$$

$$r_e = \frac{\alpha}{g_m} \approx \frac{1}{g_m} = 25\Omega$$

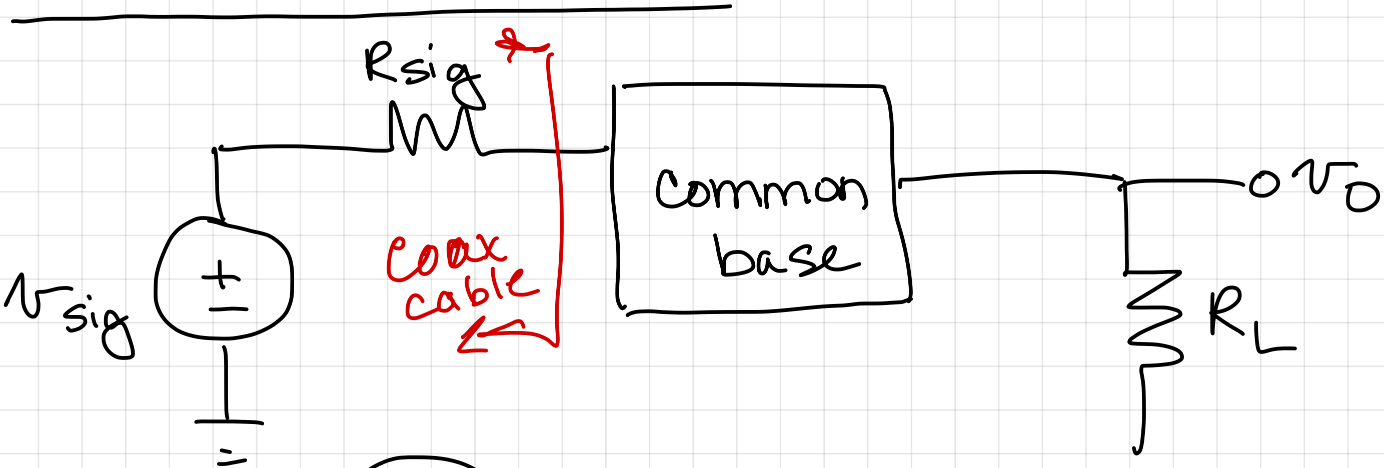
$$R_{in} = r_e = 25\Omega$$

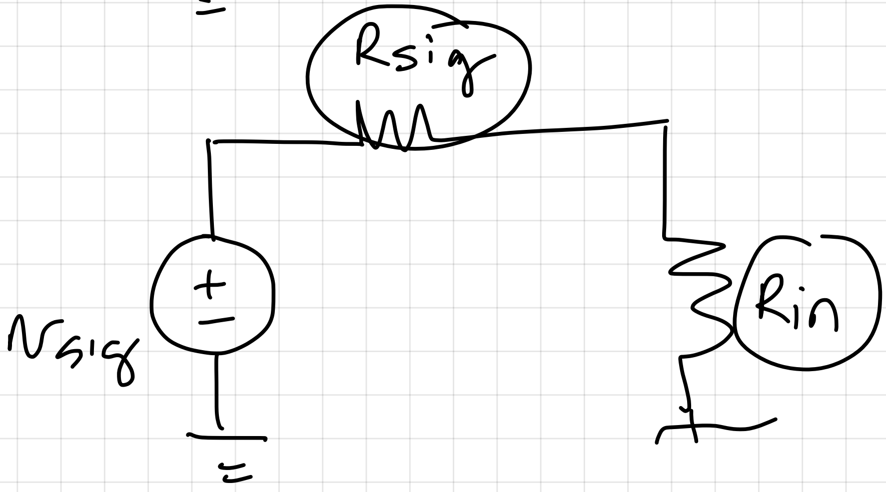
$R_o = R_C = 5k\Omega$

$$\frac{v_o}{v_{sig}} = \left(\frac{r_e}{r_e + R_{sig}}\right)\left(g_m\left(R_C \| R_L\right)\right)$$

$$= \left(\frac{25}{25 + 5000}\right)\left(40\left(5 \| 5\right)\right)$$

$$\frac{v_o}{v_{sig}} = 0.5 \ V/V$$





max power

$R_{TH} = R_L$

Design

$R_{in} = 50\Omega$

$R_{in} = r_e$

$r_e = 50\Omega$

$r_e \approx \frac{1}{g_m} = 50$

$g_m = \frac{20\,mA}{V}$

Design

$G_V = 40\ V/V$

$$40 = \overset{20}{\cancel{g_m}}\,(R_C \| R_L)\left(\cancel{\frac{\overset{r_e}{50}}{\underset{r_e}{50}+\underset{R_L}{50}}}^{\,1/2}\right)$$

$$\frac{40}{20} = (R_C \| R_L)\left(\frac{1}{2}\right)$$

$$\frac{80}{20} = R_C \| R_L$$

$$\boxed{R_C \| R_L = 4}$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$I_{CQ} = g_m V_T$$

$$= 20(.025)$$

$$I_{CQ} = 0.5\,mA$$

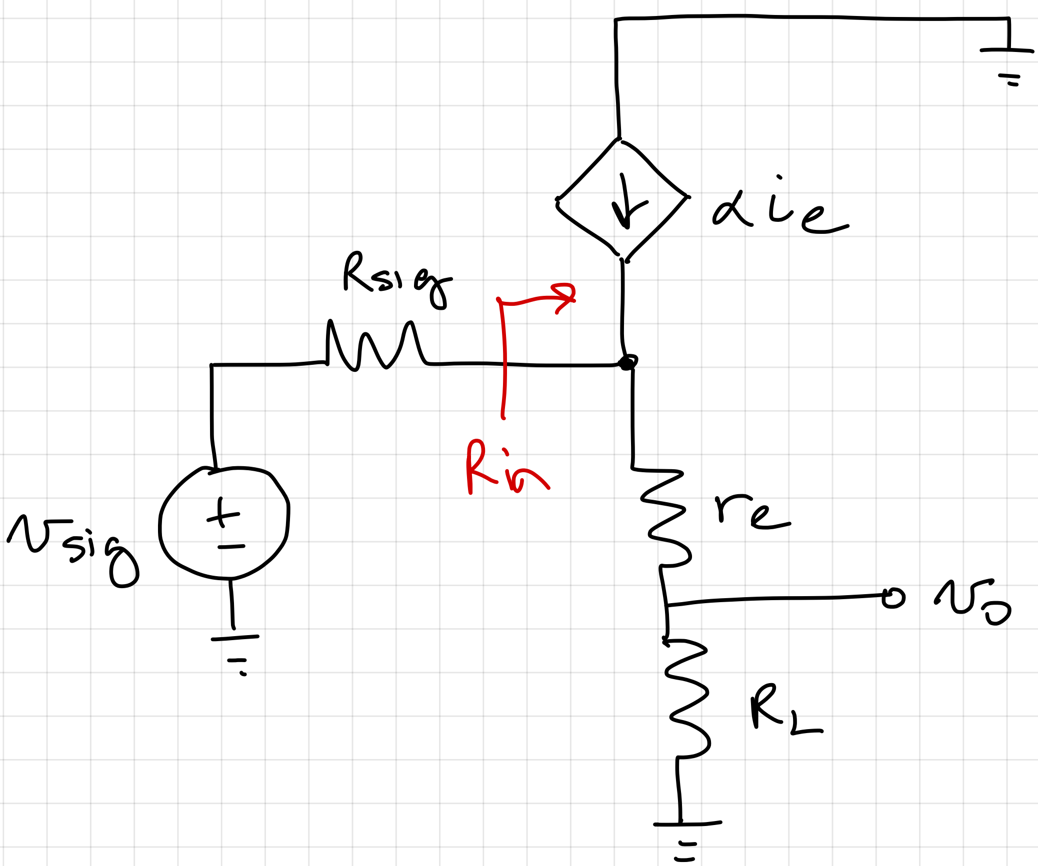
Common Collector

CC amp

$\beta = 100$ $\qquad I_{CQ} = 5mA$

$R_{sig} = 10k\Omega$ $\qquad R_L = 1k\Omega$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{5}{.025} = 200\frac{mA}{V}$$



$$r_e \cong \frac{1}{g_m} = 5\Omega$$

$$R_{in} = (1+\beta)(r_e + R_L)$$

$$= (1 + 100)(5 + 1000)$$

$$= (101)(1005)$$

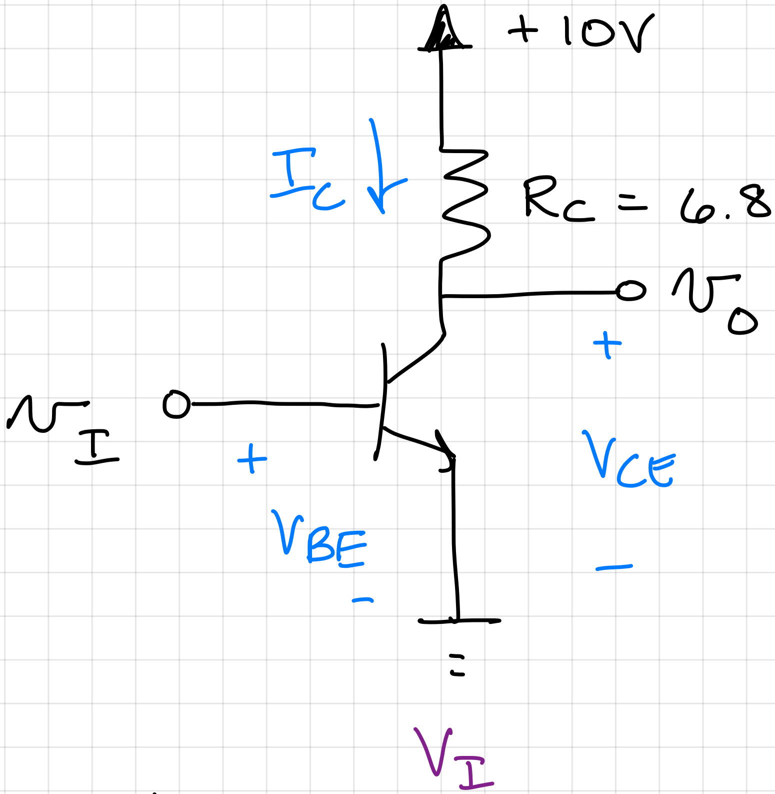
$$R_{in} = 101.5\,k\Omega$$

$$R_o = r_e = 5\Omega$$

$$G_v = \frac{(\beta+1)(R_L)}{(1+\beta)(r_e+R_L)+R_{sig}}$$

$$= \frac{(101)(1000)}{(101)(1005)+10000}$$

$$\boxed{G_v = 0.91\ V/V}$$



$I_S = 1 \times 10^{-15} A$

$V_{CEQ} = 3.2V$

V_O

a) Finding V_{BEQ}, I_{CQ}

$$\boxed{I_{CQ} = \frac{10 - V_{CEQ}}{6.8} = \frac{10-3.2}{6.8} = 1mA}$$

$$I_C = I_S \exp\left(\frac{V_{BEQ}}{V_T}\right)$$

$$1 \times 10^{-3} = 1 \times 10^{-15} \exp(V_{BEQ}/.025)$$

$$\boxed{V_{BEQ} = 0.691 V}$$

b) $$A_v = -\underbrace{\frac{I_{CQ}}{V_T}}_{g_m} R_C$$

$$A_v = -\frac{(1\times10^{-3})(6.8\times10^{3})}{.025}$$

$$= -272 \text{ V/V}$$

c) let small signal of 5mV sine wave be superimposed on V_{BEQ}

$v_{ce} \Rightarrow$ $$A_v = \frac{v_{ce}}{v_{be}}$$

$$v_{ce} = A_v \cdot v_{be}$$

$$= -272(.005)$$

v_{ce} = 1.36V peak sine wave

d) Drive Q pt to edge of saturation

$$v_{CE} = 0.3V$$

what is the change in v_{BE} to do so?

$$i_c = \frac{10 - 0.3}{6.8} = 1.43\,mA$$

$$\underbrace{v_{BE2} - v_{BE1}} = V_T \ln\left(\frac{i_{c2}}{i_{c1}}\right)$$

$$\Delta v_{BE} = (0.025)\ln\left(\frac{1.43}{1}\right)$$

$$\Delta v_{BE} = 8.94\ mV$$

Example 2

NPN transistor

g_m, r_π, r_e at Q point

$\beta = 100$

$I_{CQ} = 1mA$

$V_T = 25mV$

$$\underset{mA/V}{g_m} = \frac{I_{CQ}}{V_T} = \frac{1\,mA}{.025 \times 10^{-3}} = 40\frac{mA}{V}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{40\ mA/V} = 2.5\ k\Omega$$

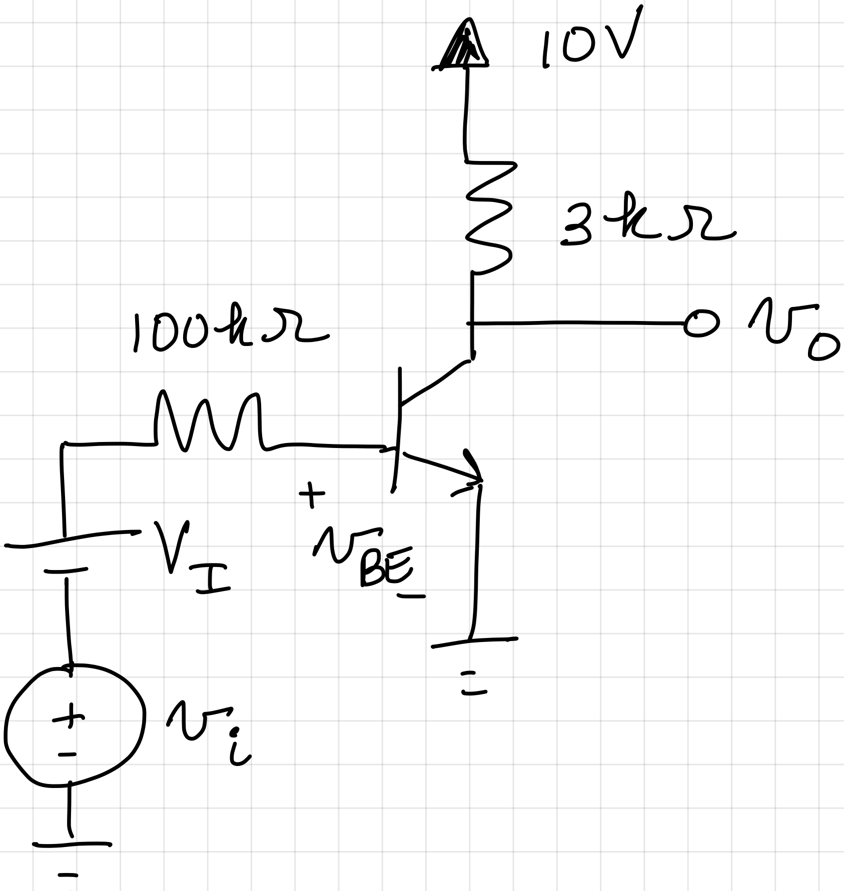
$$r_e \cong \frac{1}{g_m} = \frac{1}{40\ mA/V} = 25\Omega$$

$$r_e = \frac{r_\pi}{(1+\beta)} = 24.75\Omega$$

$\beta \rightarrow$ larger $\quad \beta + 1 \approx \beta$

$\alpha \approx 1$

Example 3

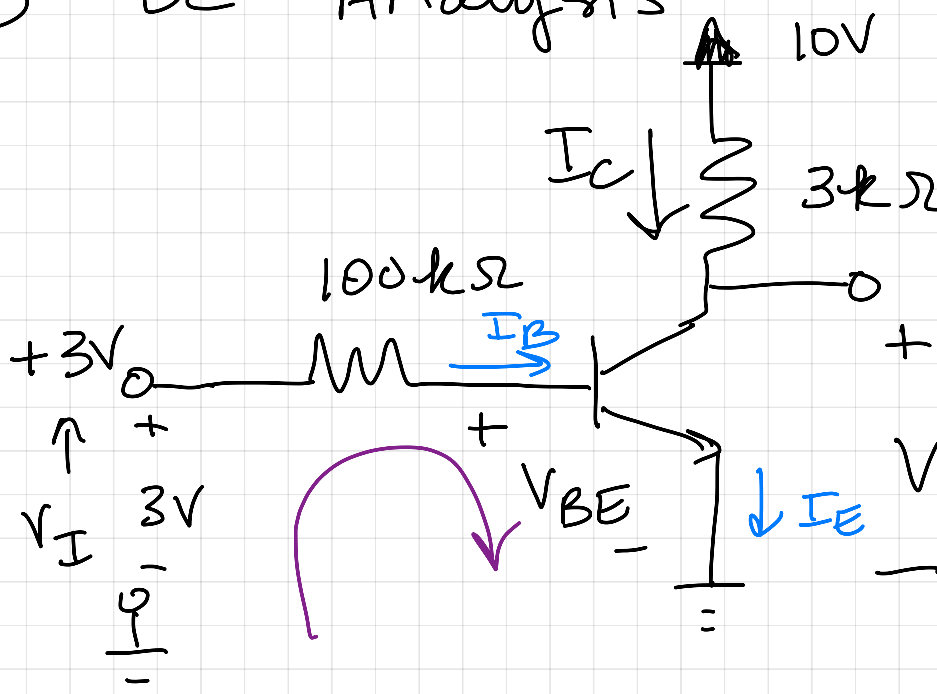


$\beta = 100$

$V_{BE} = 0.7V$

$V_I = 3V$

① DC Analysis



$V_O = V_{CE}$

by KVL: $3 - 100(I_B) - V_{BE} = 0$

$$I_B = \frac{3-0.7}{100} = 0.023\,mA$$

$$I_C = \beta I_B = 100(.023mA)$$

$$\boxed{I_{CQ} = 2.3mA}$$

$$V_{CEQ} = V_{OQ} = 10 - I_{CQ} R_C$$
$$= 10 - (2.3)(3)$$

$V_C > V_B$

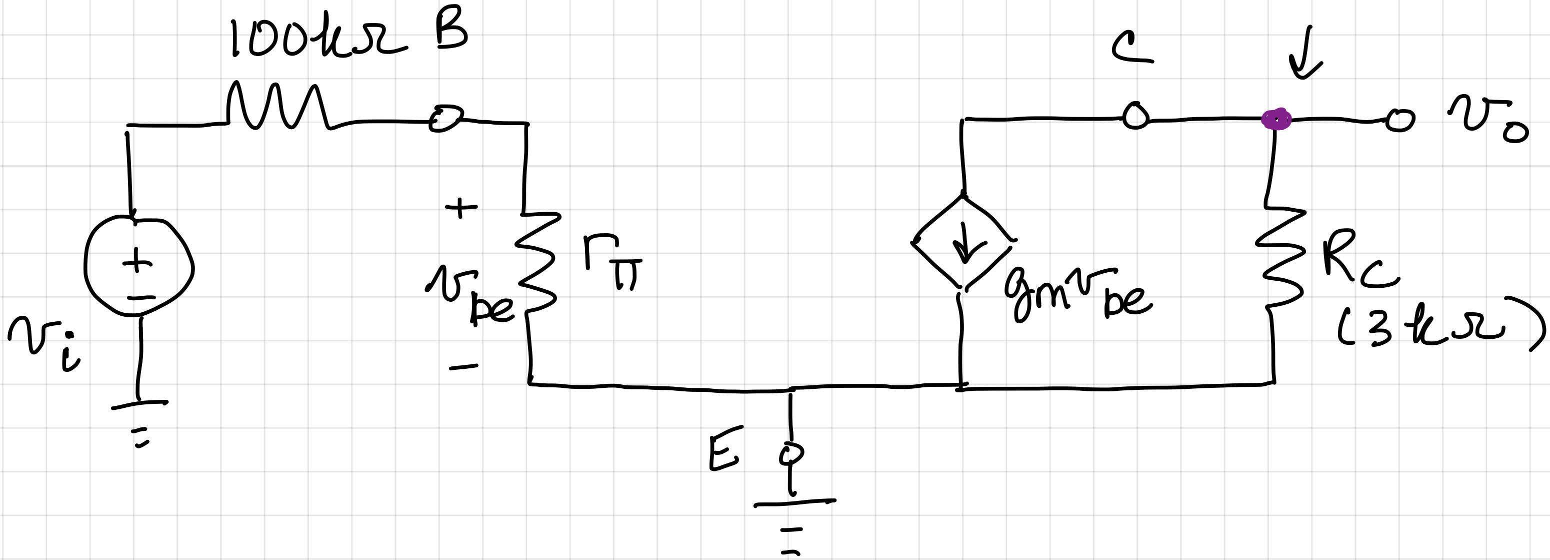
are in active $\Longleftarrow$ V_{CEQ} V_{OQ} $= 3.1V$

---

② small signal

$$g_m = \frac{I_{CQ}}{V_T} = \frac{2.3}{.025} = \frac{92mA}{V}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{92\,mA/V} = 1.09\,k\Omega$$



$$\frac{v_o}{v_i} \Rightarrow \qquad g_m v_{be} + \frac{v_o}{R_C} = 0$$

$$\frac{v_o}{R_C} = -g_m v_{be}$$

$$\frac{v_o}{v_{be}} = -g_m R_C \qquad \left\{ g_m = \frac{I_C}{V_T} \right.$$

$$v_{be} = v_i \left(\frac{r_\pi}{r_\pi + 100k\Omega} \right)$$

$$\frac{v_{be}}{v_i} = \frac{(1.09)}{(1.09 + 100)}$$

$$\frac{v_o}{v_{be}} \cdot \frac{v_{be}}{v_i} = \frac{v_o}{v_i} = -92(3)\left(\frac{1.09}{100+1.09}\right)$$

$$\frac{v_o}{v_i} = -2.98 \text{ V/V}$$