EECE 2412 - HW 6 Solutions

Prob. 1

For the circuit in Fig. 4.10 on page 224, the equation for the load line at the input is:

$$V_{BB} + v_{in}(t) = R_B \cdot i_B(t) + v_{BE}(t)$$

Substituting the given values:

$$0.8V + 0.2 \cdot \sin(2000\pi t) = 40 \times 10^3 \cdot i_B(t) + v_{BE}(t)$$

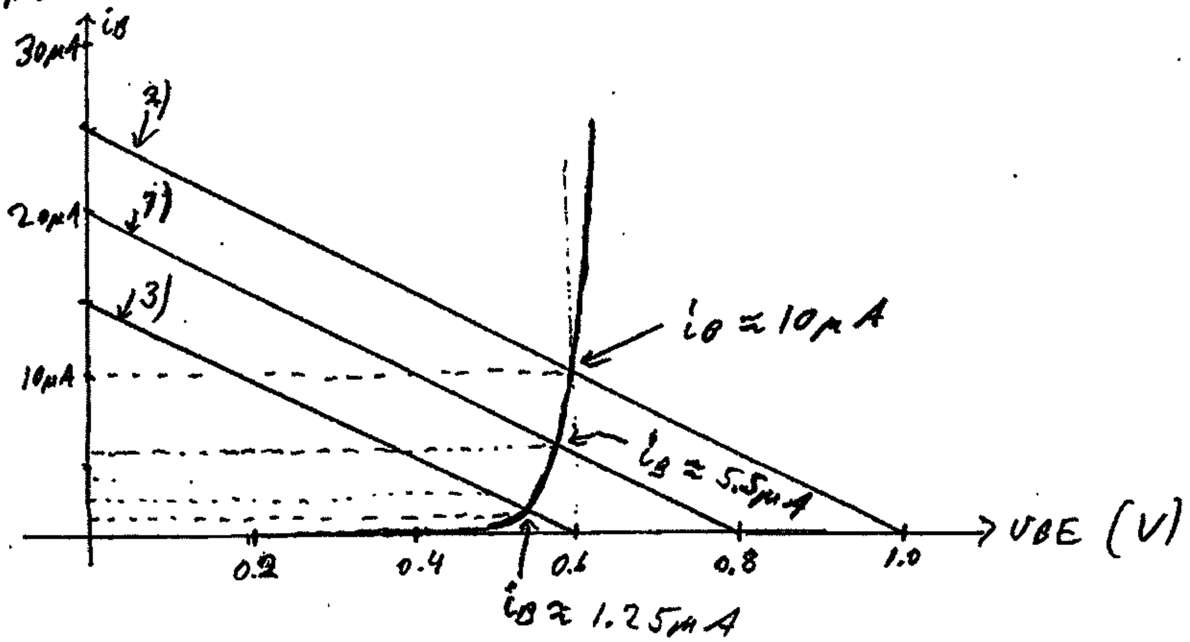
Observing the relevant cases:

1) $V_{in}(t) = 0$: $i_B = 0 \rightarrow v_{BE} = 0.8V$.
   $v_{BE} = 0$ when $i_B = \frac{0.8V}{40000} = 20\mu A$

2) $V_{in}(t) = 0.2V$: $i_B = 0 \rightarrow v_{BE} = 1V$
   $V_{BE} = 0$ when $i_B = \frac{1V}{40000} = 25\mu A$

3) $V_{in}(t) = -0.2V$: $i_B = 0 \rightarrow v_B = 0.6V$
   $v_{BE} = 0$ when $i_B = \frac{0.6V}{40000} = 15\mu A$

Plotting the three load line cases on top of the input characteristic curve:



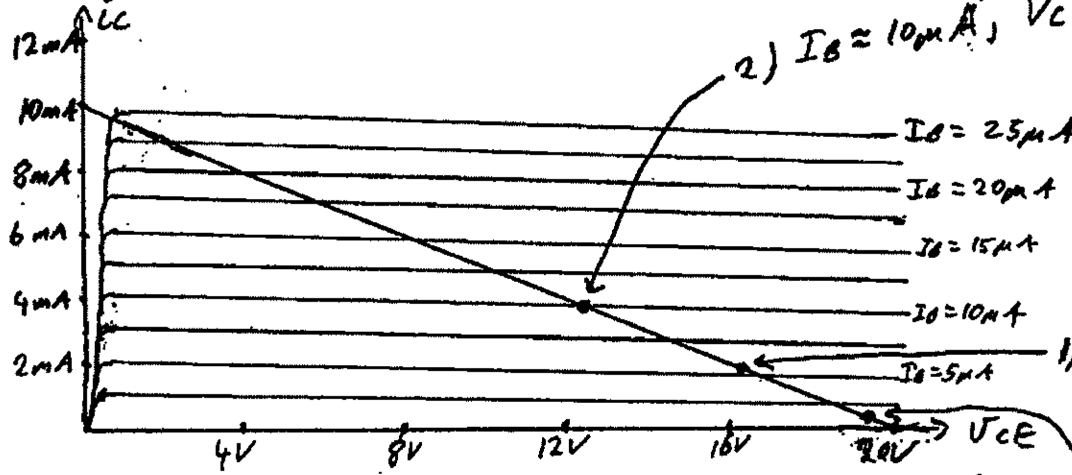
② ... Problem 1 continued:

Output load line equation: $V_{CC} = R_C \cdot i_C + V_{CE}$

Substituting the given values: $20 = 2000 \cdot i_C + V_{CE}$

Plotting this equation on top of the output characteristic curves:

2) $I_B \approx 10\mu A$, $V_{CE} \approx 12V$



1) $I_B \approx 5.5\mu A$, $V_{CE} \approx 16V$

3) $I_B \approx 1.25\mu A$, $V_{CE} \approx 19V$

Identify the points at which the load line intersects with the curves for the i_B values that were found on the previous page:

The min. and max. instantaneous operating points are:

$\boxed{V_{CE} \approx 12\,V,\ I_B \approx 10\mu A}$, $I_C \approx 4mA$

$\boxed{V_{CE} \approx 19V,\ I_B \approx 1.25\mu A}$, $I_C \approx 0.5mA$

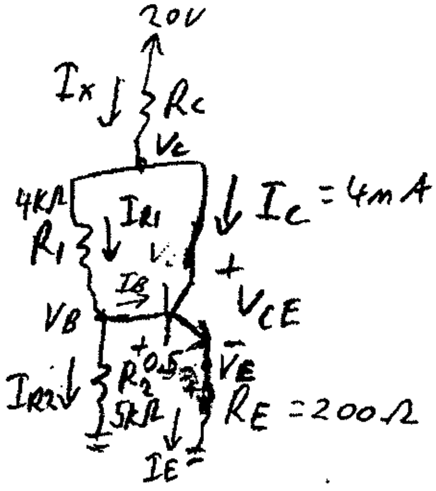
The output signal is $\boxed{\underline{\text{not}}\ \text{clipped.}}$

(Clipping would occur if $V_{CE} < 0.2\,V$ ← BJT would enter the saturation region

or $V_{CE} > 20\,V$ for this case

↳ not possible due to the supply voltage limit

③



$\boxed{\text{Prob.2}}$ $I_c = .4mA$ $\beta = 80$

a)

$$I_E = \frac{1+\beta}{\beta} \cdot I_c = \frac{81}{80} \cdot 4mA = 4.05mA$$

$$V_E = I_E \cdot R_E = (4.05 \times 10^{-3}) \cdot 200 = 0.81V$$

$$V_B = V_E + V_{BE} = 0.81 + 0.5 = 1.31V$$

$$I_{R2} = \frac{V_B}{R_2} = \frac{1.31}{5000} = 262\,\mu A$$

$$I_B = \frac{I_c}{\beta} = \frac{4mA}{80} = 50\,\mu A$$

$$I_{R1} = I_{R2} + I_B = 312\,\mu A$$

$$V_c = V_B + I_{R1} \cdot R_1 = 1.31 + (312 \times 10^{-6}) \cdot 4000 = 2.558V$$

$$I_x = I_c + I_{R1} = 4mA + 312\mu A = 4.312mA$$

$$R_c = \frac{20V - V_c}{I_x} = \frac{20 - 2.558}{4.312 \times 10^{-3}} = \boxed{4.045\,K\Omega = R_c}$$

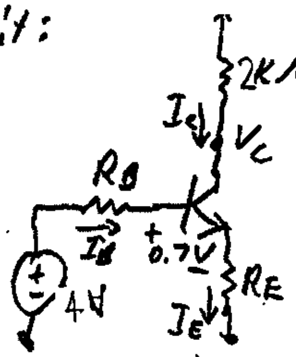
b) $V_{CE} = V_c - V_E = 2.558V - 0.81V$

$$\boxed{V_{CE} = 1.748V}$$

4

Problem 3

a) DC circuit:



Assuming active mode (by design):

$① : I_E = \frac{I_c}{\alpha} = \left(\frac{\beta+1}{\beta}\right) \cdot I_c$

$② : I_B = \frac{I_c}{\beta}$

> FYI:
> for DC analysis:
> Capacitor → open-circuit
> Inductor → short-circuit
> AC volt. source → short-circuit
> AC current source → open circuit

KVL: $0 = -4V + I_B \cdot R_B + 0.7V + I_E \cdot R_E$

Sub. ① and ② → $3.3V = \left(\frac{I_c}{\beta}\right) \cdot R_B + \left(\frac{\beta+1}{\beta}\right) \cdot I_c \cdot R_E$ into the above equ.:

case 1: Sub. $\beta = 100$, $I_c = 4mA$

$3.3V = \left(\frac{4mA}{100}\right) R_B + \left(\frac{100+1}{100}\right) \cdot (4mA) \cdot R_E$

$③ : 3.3V = (40 \times 10^{-6}) \cdot R_B + (4.04 \times 10^{-3}) \cdot R_E$

case 2: Sub. $\beta = 300$, $I_c = 5mA$ into the equ.:

$④ : 3.3V = (16.667 \times 10^{-6}) \cdot R_B + (5.01667 \times 10^{-3}) \cdot R_E$

Solving ③ and ④ simultaneously:

$\boxed{R_B = 24.1728 k\Omega}$ $\boxed{R_E = 577.5 \Omega}$

b) equ. 4.42 in the book:

$g_m = \frac{I_{ca}}{V_T} \longrightarrow g_{m(max)} = \frac{5 mA}{26 mV} = 0.192 \frac{A}{V} = 192 \ mS$ (milli-Siemens)

$V_T \approx 26mV$ at room temp. $\left(V_T = \frac{K \cdot T}{q}\right)$

$g_{m(min)} = \frac{4 mA}{26mV} = 153.8 \ mS$

$\boxed{153.8mS < g_m < 192 mS}$

equ. 4.37 in the book: $r_\pi = \frac{\beta \cdot V_T}{I_{ca}}$

$r_{\pi_1} = \frac{300 \times 26mV}{5mA} = 1.56 \ k\Omega$

$r_{\pi_2} = \frac{100 \times 26mV}{4mA} = 650 \ \Omega$

$\boxed{650\Omega < r_\pi < 1560 \ \Omega}$

Lecture slides: $r_{ce} = \frac{V_A}{I_{ca}}$

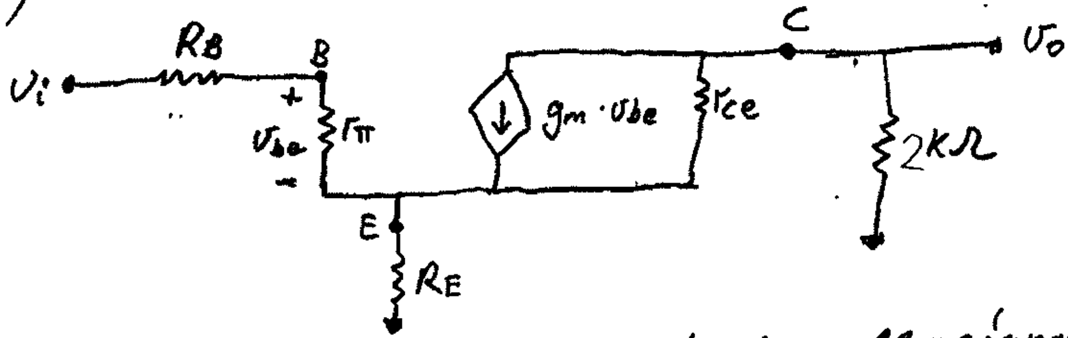
$r_{ce(max)} = \frac{100V}{4mA} = 25K\Omega$

$r_{ce(min.)} = \frac{100V}{5mA} = 20K\Omega$

$\boxed{20 \ k\Omega < r_{ce} < 25 \ K\Omega}$

... Problem 3 continued:

c) Small-signal equivalent circuit:



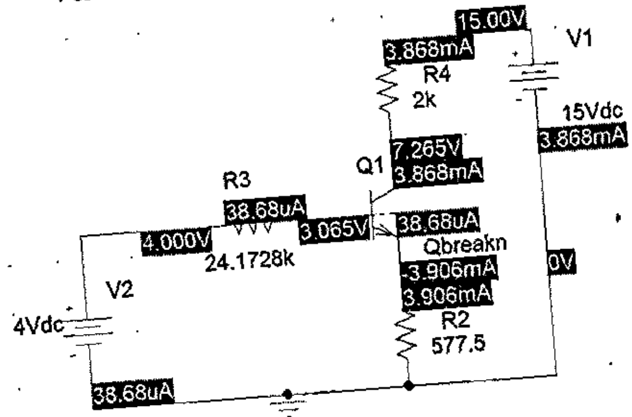
(FYI: In the AC analysis (small-signal equivalent circuit), replace:
DC voltage sources $\xrightarrow{\text{with}}$ short-circuits
DC current sources → open-circuits)

d) PSpice: see next page

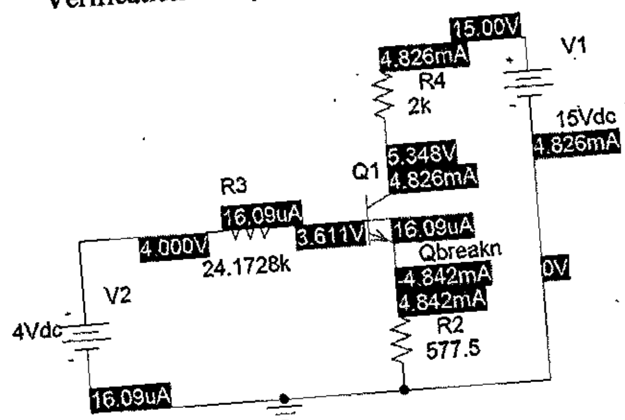
6

d)

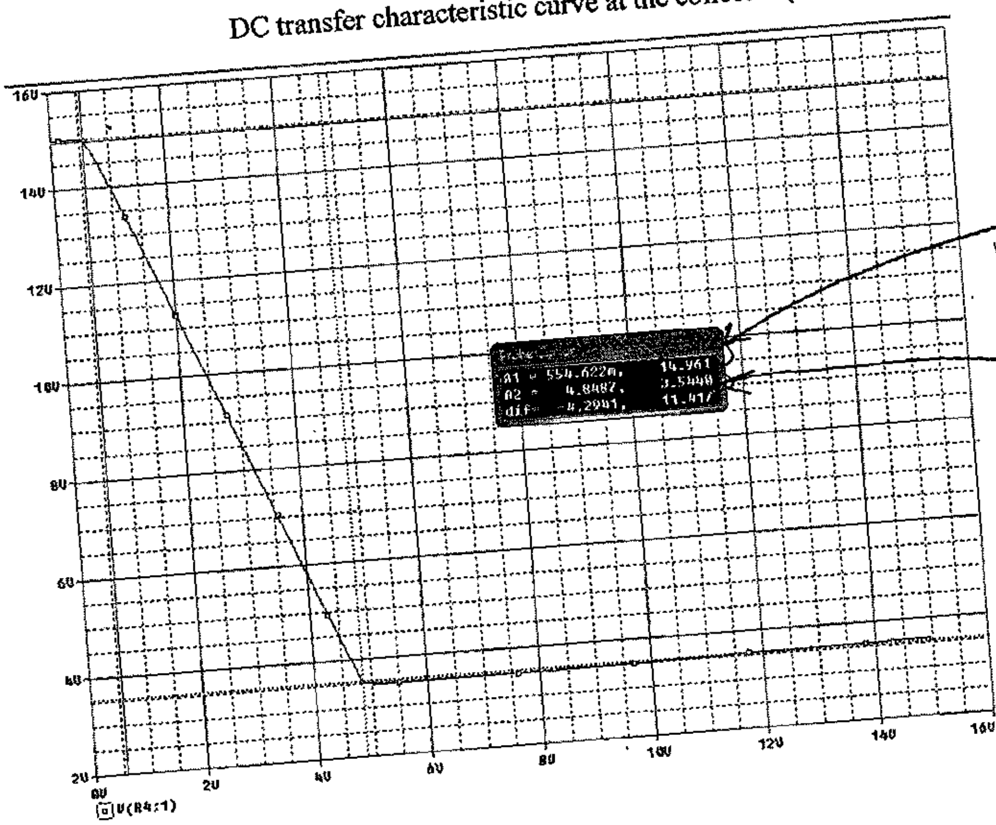
Verification with β=100 (I_C is close to 4mA)



Verification with β=300 (I_C is close to 5mA)



DC transfer characteristic curve at the collector (V_C vs. V_{BB}) ith QN222 BJT model



$V_o\,(max)$

$V_o(max) - V_o(min) = 11.417\,V$

$= V_o(p\text{-}p)$

$V_o\,min$

When;

$V_{BB} = \left(\frac{0.555 + 4.8491}{2}\right)$

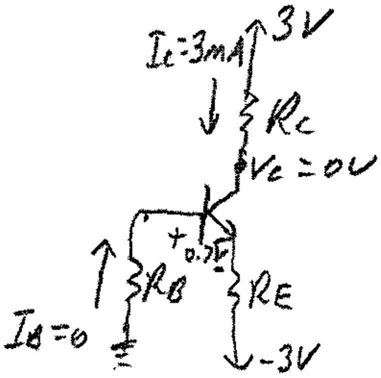
$= 2.70205\,V$

(P.7)

Problem 4

a) with $\beta = \infty \rightarrow I_B = 0$

$\hookrightarrow I_E = I_C = 3mA$



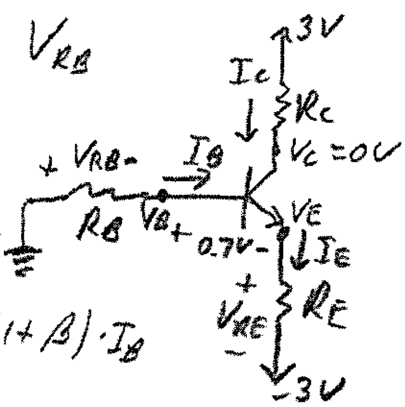
KVL: $0 = -3V + I_C \cdot R_C + V_C$

$V_C = 0V \hookrightarrow R_C = \frac{3V}{I_C} = \frac{3V}{3mA} = \boxed{1k\Omega = R_C}$

KVL: $0 = \cancel{I_B}^{\,0} \cdot R_B + 0.7V + I_E \cdot R_E - 3V$

$\hookrightarrow R_E = \frac{(3V - 0.7V)}{3 \times 10^{-3} A} = \boxed{766.67\,\Omega = R_E}$

b) $\beta = 90$, constraint: $\frac{V_{RE}}{10} = V_{RB}$



$\frac{I_E \cdot R_E}{10} = I_B \cdot R_B \rightarrow \frac{I_E R_E}{10} = \frac{I_E \cdot R_B}{\beta + 1}$

using $I_E = (1+\beta) \cdot I_B$

$\rightarrow$ ①: $R_B = \frac{\beta + 1}{10} \cdot R_E$

KVL: $0 = V_{RB} + 0.7V + V_{RE} - 3V$

$2.3V = \frac{V_{RE}}{10} + V_{RE} \longrightarrow V_{RE} = 2.0909V$

$I_E = \frac{I_C}{\alpha} = \frac{\beta + 1}{\beta} \cdot I_C = \frac{90+1}{90} \cdot 3mA = 3.0333\,mA$

$R_E = \frac{V_{RE}}{I_E} = \frac{2.0909V}{3.0333mA} = \boxed{689.3\,\Omega = R_E}$

Substituting the value of RE into equation ①:

$R_B = \frac{90+1}{10} \cdot 689.3\,\Omega = \boxed{6272\,\Omega = R_B}$

$R_C = \frac{3V - V_C}{I_C} = \frac{3V - 0V}{3mA} = \boxed{1k\Omega = R_C}$

(p.8) ... Problem 4 cont.:

c) Standard 5%-resistor values for the results in part b):

$\boxed{R_C = 1k\Omega}$ $\boxed{R_E = 680\,\Omega}$ $\boxed{R_B = 6.2\,k\Omega}$

d) With $\beta = \infty$: $I_B = 0$, $I_C = I_E$

KVL: $0 = \cancel{I_B}^{\to 0} \cdot R_B + V_B \rightarrow \boxed{V_B = 0}$

KVL: $0 = \cancel{I_B}^{\to 0} \cdot R_B + 0.7V + V_E \rightarrow \boxed{V_E = -0.7V}$

KVL: $0 = \cancel{I_B}^{\to 0} \cdot R_B + 0.7V + I_E \cdot R_E - 3V$

$\hookrightarrow I_E = \frac{3V - 0.7V}{R_E} = \frac{2.3V}{680\Omega} = 3.382\,mA$

$\boxed{I_C = I_E = 3.382\,mA}$

With $\beta = 90$:

KVL: $0 = I_B \cdot R_B + 0.7V + I_E \cdot R_E - 3V$

$0 = \frac{I_E}{\beta+1} \cdot R_B + I_E \cdot R_E - 2.3V$

$2.3V = \frac{I_E}{91} \cdot 6200 + I_E \cdot 680 \longrightarrow I_E = 3.074\,mA$

$I_C = \alpha \cdot I_E = \frac{\beta}{\beta+1} \cdot I_E = \frac{90}{91} \cdot I_E = \boxed{3.041\,mA = I_C}$

KVL: $0 = I_B \cdot R_B + V_B \rightarrow V_B = -I_B \cdot R_B = -\frac{I_C}{\beta} \cdot R_B = -\frac{3.041mA}{90} \cdot 6200\Omega$

$\boxed{V_B = -0.209V}$

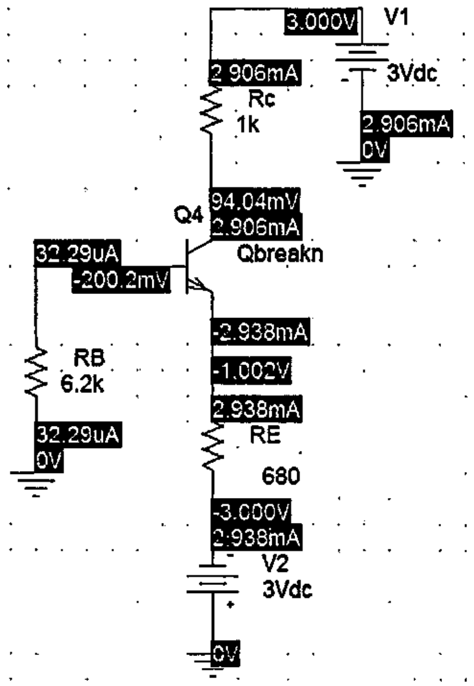
$V_E = V_B - 0.7V = \boxed{-0.909V = V_E}$

$V_C = 3V - I_C \cdot R_C = 3V - 3.041mA \cdot 1k\Omega = \boxed{-0.0405V = V_C}$

(p.9)

Problem 4, Part e)

with β=90:



with β=400: