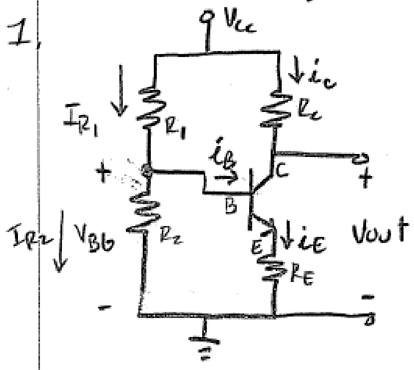
Prelab9 Solutions

1,



$$i_c = \beta_f i_B$$

$$i_E = (1+\beta_f) i_B$$

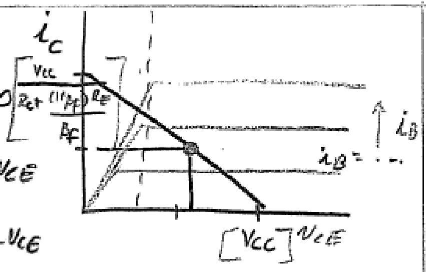
$$-V_{cc} + i_c R_c + V_{CE} + i_E R_E = 0$$

$$i_c R_c + i_E R_E = V_{cc} - V_{CE}$$

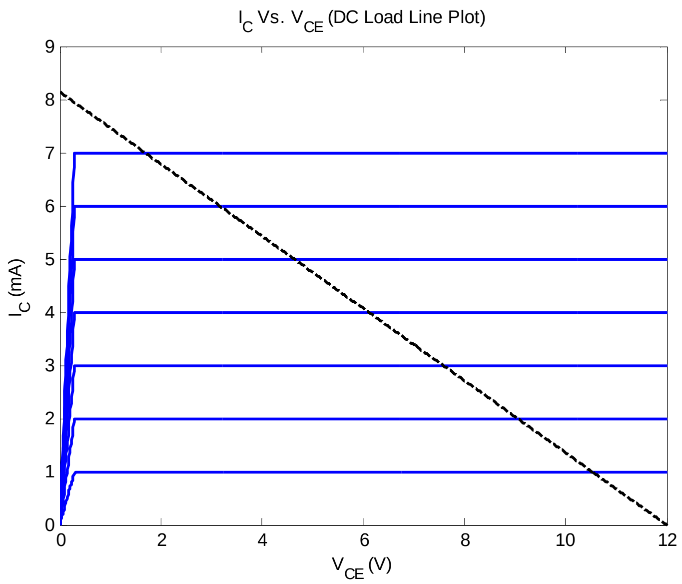
$$i_c R_c + \frac{(1+\beta_f)R_E}{\beta_f} i_c = V_{cc} - V_{CE}$$

$$i_c \left(R_c + \frac{(1+\beta_f)R_E}{\beta_f}\right) = V_{cc} - V_{CE}$$

$$i_c = \frac{V_{cc} - V_{CE}}{\left(R_c + \frac{(1+\beta_f)R_E}{\beta_f}\right)}$$



2)

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% Prelab 8 - Problem 2
% Stephen Maloney

clear all; clc; close all;

% Given parameters
Rc = 1e3;
Re = 470;
Vcc = 12;

% Set up the BJT curves
Bf = 200;
Vce = linspace(0, 12, 1000);
VceSat = .3;
ibrange = linspace(5e-6, 35e-6, 7);

% Generate the load line
ill = (Vcc-Vce)/(Rc+((1+Bf)*Re)/Bf);
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```
% Plot a range of ib values
for ib = ibrange
    ic = bjt(Vce, ib, Bf, VceSat);
    plot(Vce, ic*1e3, 'Linewidth', 2);
    hold on;
end

% Add load line
plot(Vce, ill*1e3, 'k--', 'LineWidth', 2);

% Label the graph
xlabel('V_C_E (V)'); ylabel('I_C (mA)');
title('I_C Vs. V_C_E (DC Load Line Plot)');
```

3. $v_{CE} = \frac{V_{CC}}{2} = 6V = V_{CEQ}$

$$i_C = \left(\frac{V_{CC}}{R_C + \frac{(1+\beta_f)R_E}{\beta_f}}\right)\left(\frac{1}{2}\right) = 4.075\,mA = i_{CQ}$$

$I_{R_1} = 100 I_B$, $I_B = \frac{I_{CQ}}{\beta_f} = 20.375\,\mu A$

$\therefore I_{R_1} = 2.0375\,mA$ $\qquad v_{BEf} = .6V$

$\frac{V_{CC} - V_{BG}}{R_1} = I_{R_1}$ $\qquad -V_{BG} + v_{BEf} + i_E R_E = 0$ $\qquad i_E = \frac{(1+\beta_f)\, i_C}{\beta_f}$

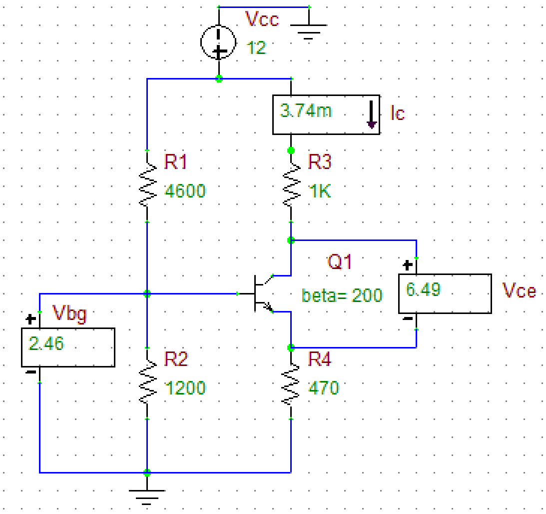
$R_1 = \frac{V_{CC} - V_{BG}}{I_{R_1}}$ $\qquad V_{BG} = v_{BEf} + \frac{R_E(1+\beta_f)\, i_{CQ}}{\beta_f} = 2.5248V$

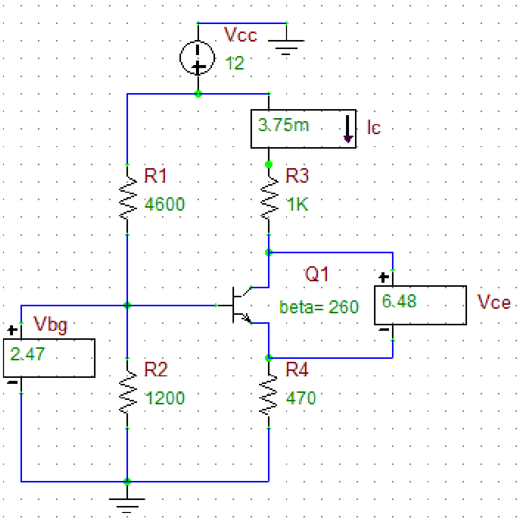
$$R_1 = \frac{V_{CC} - \left[v_{BEf} + \frac{R_E(1+\beta_f)\, i_{CQ}}{\beta_f}\right]}{I_{R_1}} = 4.6504\,k\Omega = R_1$$

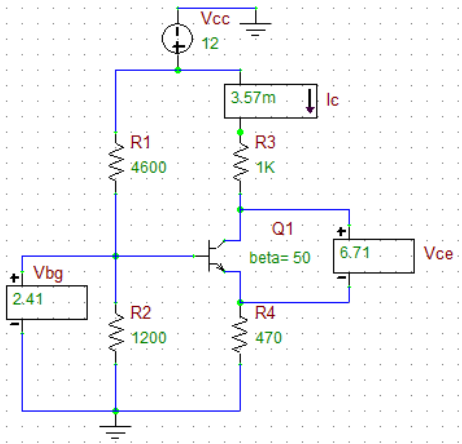
$I_{R_2} = I_{R_1} - i_{BQ}$ $\qquad \frac{V_{BG}}{I_{R_2}} = R_2 = 1.2517\,k\Omega$

$I_{R_2} = 2.0171\,mA$

4) As can be seen from the Spice DC-Operating point simulations below, β_f changing over quite a large range does not produce an extreme swing in operating point due to the feedback resistor, $R_E = R_4$.


Vcc
12
3.74m
Ic
R1
4600
R3
1K
Q1
beta= 200
6.49
Vce
Vbg
2.46
R2
1200
R4
470


Vcc
12
3.75m
Ic
R1
4600
R3
1K
Q1
beta= 260
6.48
Vce
Vbg
2.47
R2
1200
R4
470


Vcc
12
3.57m
Ic
R1
4600
R3
1K
Q1
beta= 50
6.71
Vce
Vbg
2.41
R2
1200
R4
470

5. a) $10 = e^{\frac{q}{kT} v_{BE}}$

$\frac{kT}{q} \ln(10) = v_{BE} = .0576$

b) Taylor Series $= \sum_{n=0}^{\infty} \frac{f^n(a)(x-a)^n}{n!}$

$f(v_{BEQ}) = i_{BQ} = I_s e^{q v_{BEQ}/kT}$

$i_B(v_{BE}) = \underbrace{I_s e^{\frac{q v_{BEQ}}{kT}}}_{i_{BQ}} + \frac{I_s q}{kT} e^{q v_{BEQ}/kT}(v_{BE} - v_{BEQ}) + \cdots$

$i_B(v_{BE}) = i_{BQ}\left(1 + \frac{q}{kT}(v_{BE} - v_{BEQ}) + \cdots\right)$ $\qquad r_\pi = \frac{kT}{q i_{BQ}}$ $\qquad \hat{i}_B = \frac{\hat{v}_{BE}}{r_\pi}$

$i_B(v_{BE}) = i_{BQ} + \frac{v_{BE} - v_{BEQ}}{r_\pi}$

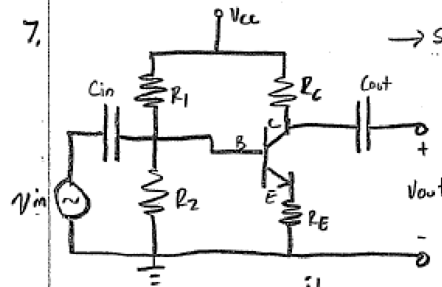
$i_B(v_{BE}) = i_{BQ} + \frac{v_{BE}}{r_\pi} - \frac{v_{BEQ}}{r_\pi} \rightarrow$ $\quad y = mx + b$ $\quad i_b = \frac{1}{r_\pi} v_{BE} - \frac{v_{BEQ}}{r_\pi} + i_{BQ}$

To find $\hat{i}_B$, differentiate with respect to v_{BE}.

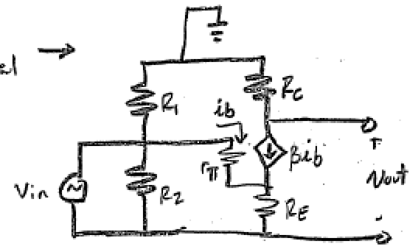
$\frac{d i_B}{d v_{BE}} = \frac{1}{r_\pi}$, $\quad d i_B = \hat{i}_B$, $\quad d v_{BE} = \hat{v}_{BE}$ $\quad \therefore \hat{i}_B = \frac{\hat{v}_{BE}}{r_\pi}$

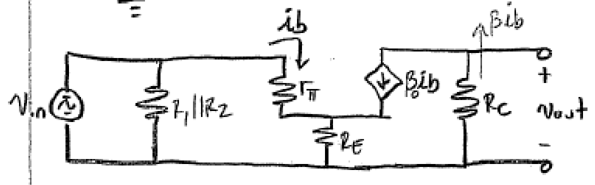
6. $r_\pi = \frac{kT/q}{i_{BQ}} = \frac{(kT/q)\beta_f}{i_{cq}} = 1.227\,k\Omega$

7.



→ Small signal →





$V_{out} = -\beta i_b R_c$

$-v_{in} + i_b r_\pi + (1+\beta_o) i_b R_E = 0$

$v_{in} = i_b(r_\pi + (1+\beta_o)R_E)$

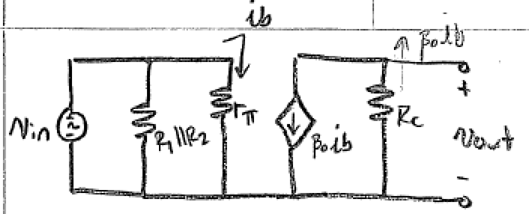
$\frac{v_{in}}{r_\pi + (1+\beta_o)R_E} = i_b$

$$\left[v_{out} = \frac{-\beta_o R_c \; v_{in}}{r_\pi + (1+\beta_o)R_E} \right]$$

If $r_\pi \approx 0$, $\therefore \frac{\hat{v}_{out}}{v_{in}} = \frac{-\beta_o R_c}{(1+\beta_o)R_E} \approx \frac{-R_c}{R_E}$

$\frac{\hat{v}_{out}}{\hat{v}_{in}} \approx -2$

8.



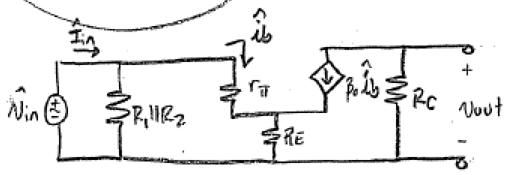
$v_{out} = -\beta_o i_b R_C$ $\qquad$ $-v_{in} + i_b r_\pi = 0$

$i_b = \dfrac{v_{in}}{r_\pi}$

$$v_{out} = \frac{-\beta_o R_C v_{in}}{r_\pi}$$

$$\frac{\hat{v}_{out}}{\hat{v}_{in}} = -163$$

9.



$I_{in} = \dfrac{v_{in}}{R_1 \| R_2} + i_b$ $\qquad$ $v_{in} = i_b r_\pi + (1+\beta_o) i_b R_E$

$\hat{v}_{in} = i_b (r_\pi + (1+\beta_o) R_E)$

$\dfrac{v_{in}}{r_\pi + (1+\beta_o) R_E} = i_b$

$$I_{in} = v_{in}\left(\frac{1}{R_1 \| R_2} + \frac{1}{r_\pi + (1+\beta_o) R_E}\right)$$

with R_E

$$\therefore R_{in}\Big|_{R_E} = \frac{v_{in}}{I_{in}} = \frac{1}{\left(\frac{1}{R_1 \| R_2} + \frac{1}{r_\pi + (1+\beta_o) R_E}\right)} = 976.183\,\Omega$$

$v_{out}\Big|_{oc} = -\beta_o i_b R_C$ $\qquad$ $I_{out}\Big|_{sc} = -\beta_o i_b$ $\qquad$ $\therefore \dfrac{v_{out}}{I_{out}} = R_C = 1k\Omega = R_{out}$

without R_E

$$I_{in} = \frac{v_{in}}{R_1 \| R_2} + \frac{v_{in}}{r_\pi} = v_{in}\left(\frac{1}{R_1 \| R_2} + \frac{1}{r_\pi}\right)$$

$$\frac{v_{in}}{I_{in}} = \frac{1}{\left(\frac{1}{R_1 \| R_2} + \frac{1}{r_\pi}\right)} = 546.763\,\Omega = R_{in}$$

$R_{out} = \text{same} = 1k\Omega$

10.

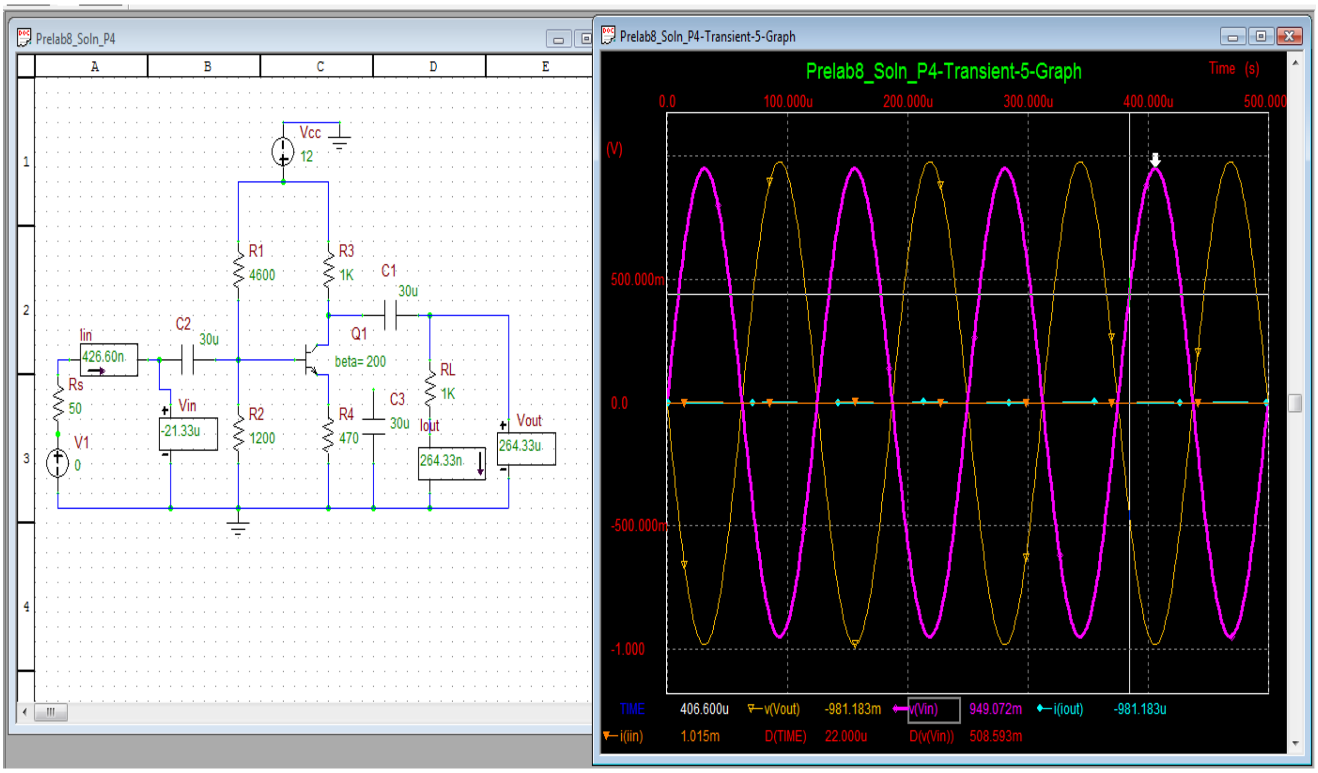
$$\frac{1}{\omega R_{smallest}} \ll C$$

$$\frac{1}{2\pi (8\,kHz)(50\,\Omega)} \ll C$$

$.3\mu F \ll C$

$3\mu F \le C \le 30\mu F$

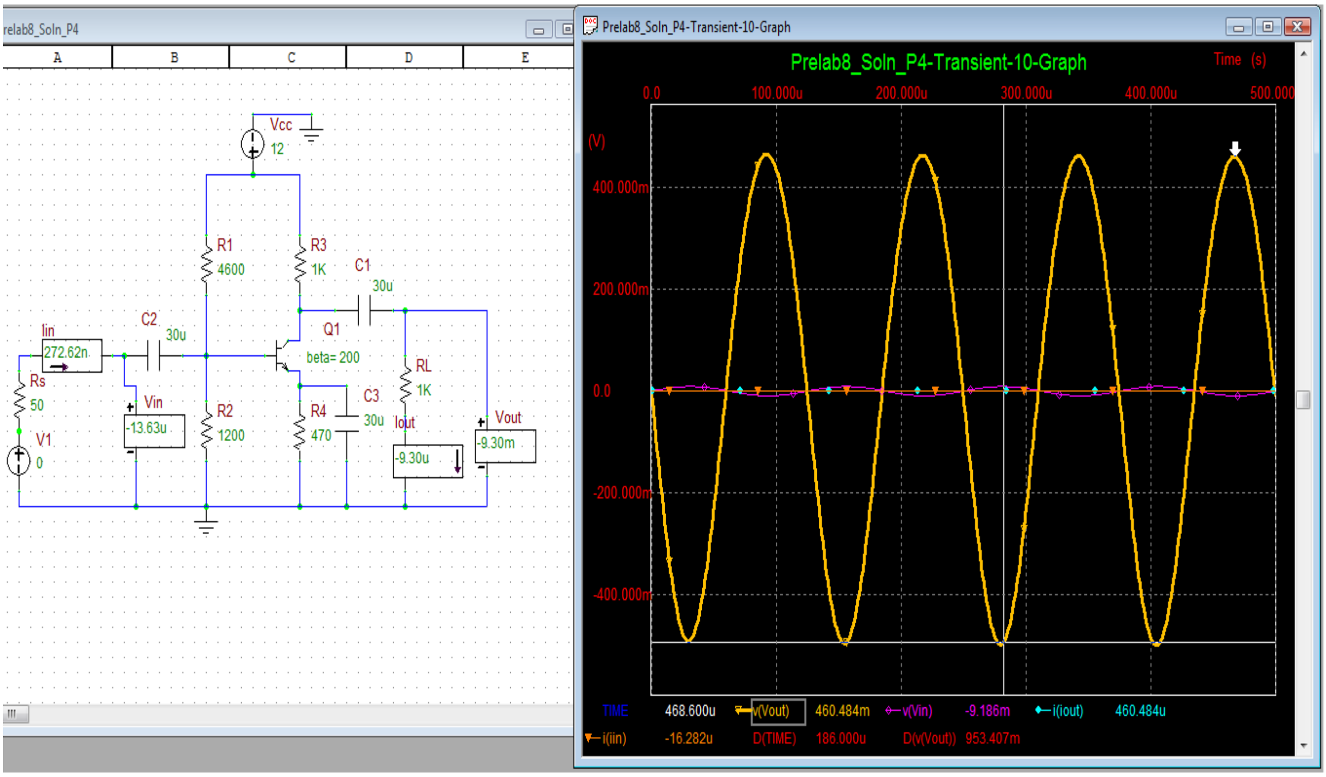
11)



With $R_E = R_4$ in the circuit:

$$\frac{V_{Out}}{V_{In}} \approx -1.033 \quad \frac{I_{Out}}{I_{In}} \approx -.967 \quad \frac{V_{In}}{I_{In}} = R_{In} \approx 935\Omega \quad \frac{V_{Out,Open}}{I_{Out,Short}} = R_{Out} \approx 1075.84\Omega$$

Note - to measure R_{Out} you have to rerun the simulation first removing the load and measuring V_{out} to find the open circuit voltage output, then short the load and measure the short circuit current.



Without $R_E = R_4$ in the circuit:

$$\frac{V_{Out}}{V_{In}} \approx -50.13 \quad \frac{I_{Out}}{I_{In}} \approx -28.28 \quad \frac{V_{In}}{I_{In}} = R_{In} \approx 564.18\Omega \quad \frac{V_{Out,Open}}{I_{Out,Short}} = R_{Out} \approx 1065.69\Omega$$