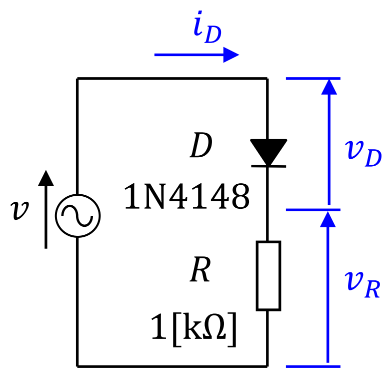
NAGOYA UNIVERSITY

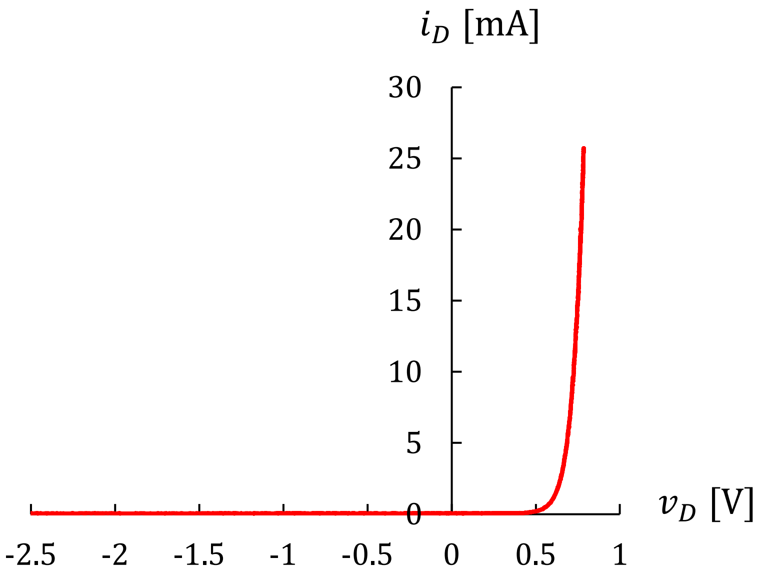
Electronic Circuits
Solutions for Homework

Exercise 1.2 (Homework)

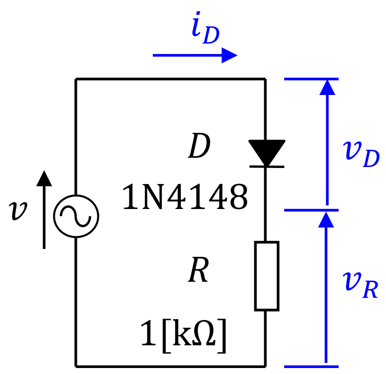
Exercise 1.2 (Homework)

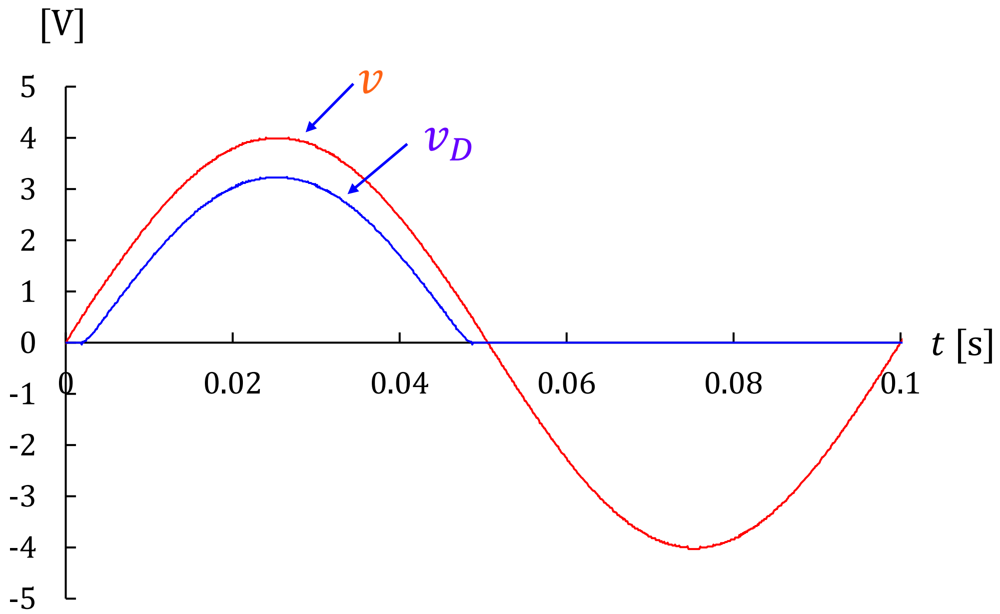
Draw the waveforms of v and v_R if $v = V_m \sin \omega t$, where $V_m = 4$ [V], $f = 10$ [Hz]. The diode characteristic of 1N4148 is given by the graph below.





Exercise 1.2 (Answer)





Exercise 1.3 (Homework)

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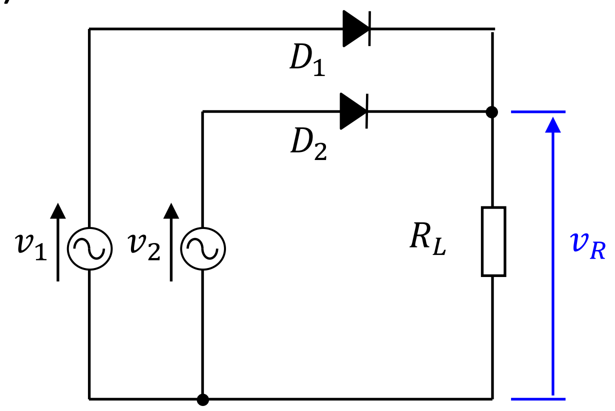
(1)



Assume that

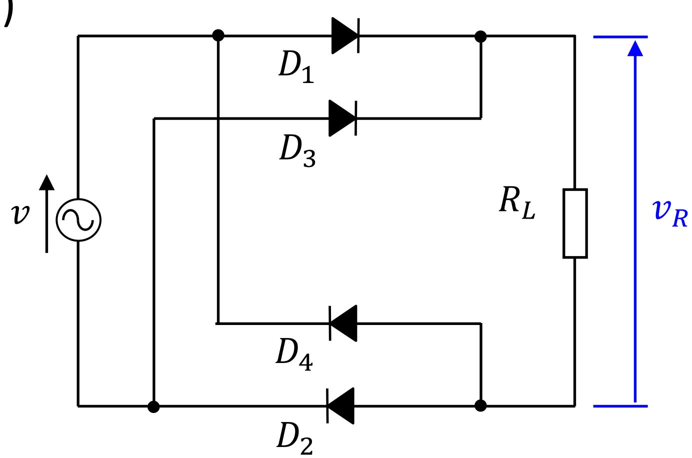
$$v_1 = V_m \sin \omega t$$
$$v_2 = V_m \sin\left(\omega t - \frac{\pi}{2}\right),$$

and the diodes D_1 and D_2 are ideal diodes.

Draw the waveforms of v_1, v_2 and v_R.

Hint: A positive and higher source voltage appears across R_L

(2)



Assume that

$$v_1 = V_m \sin \omega t\,,$$

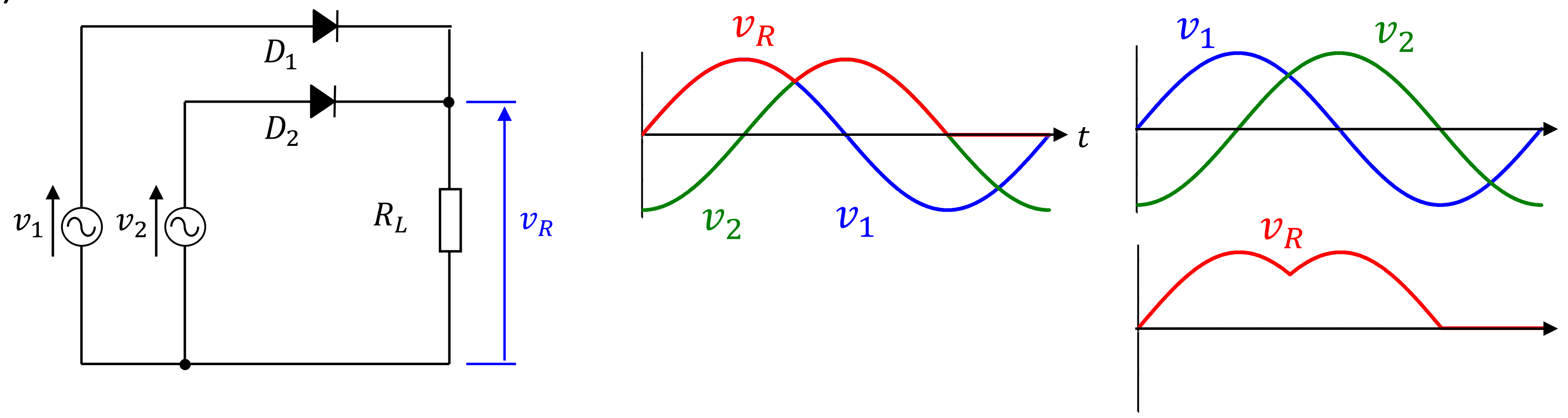
and the diodes $D_1 \sim D_4$ are ideal diodes.

Draw the waveforms of v and v_R.

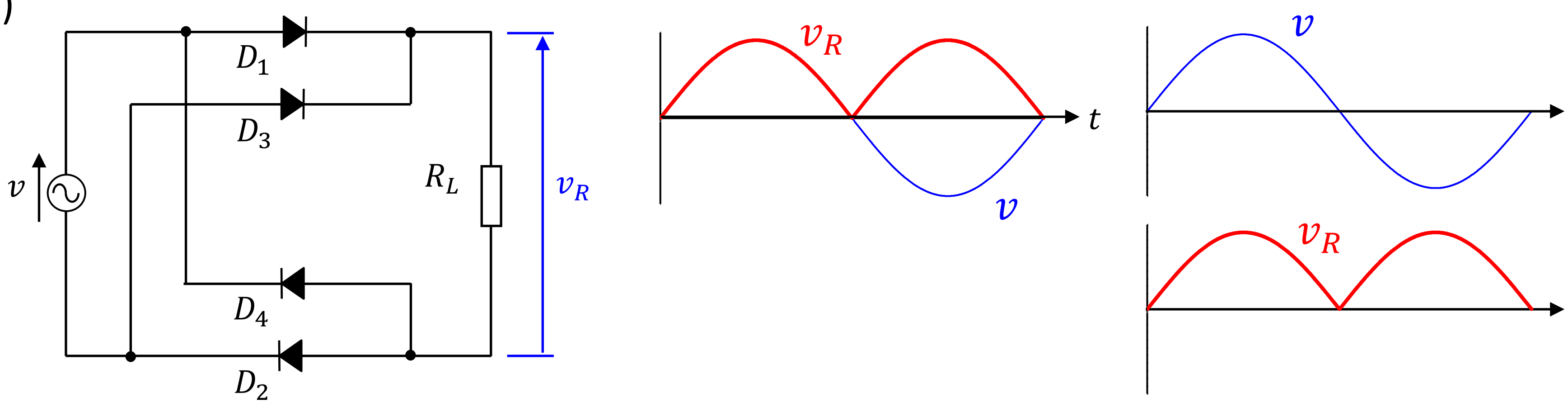
Hint: If $v > 0$, then D_1 and D_2 conduct.
If $v < 0$, then D_3 and D_4 conduct.

Exercise 1.3 (Answer)

(1)



(2)

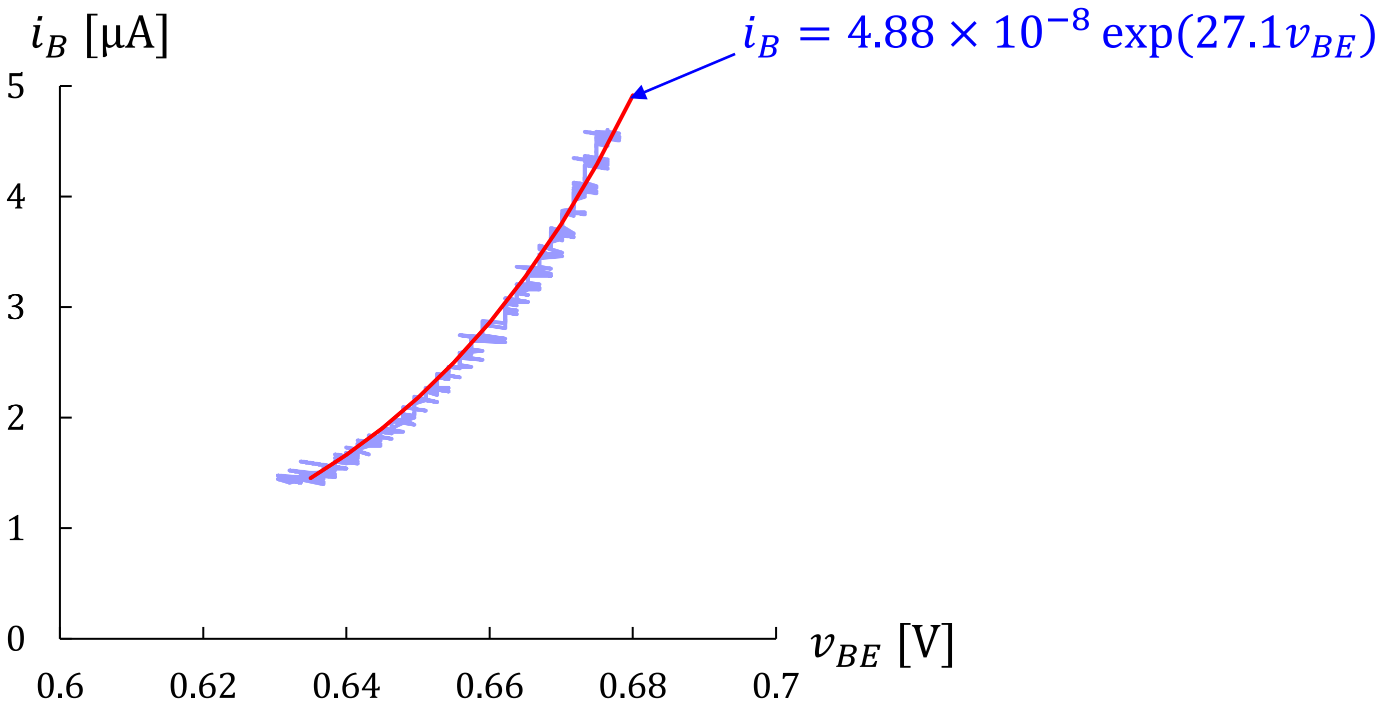


Exercise 2.3 (Homework)

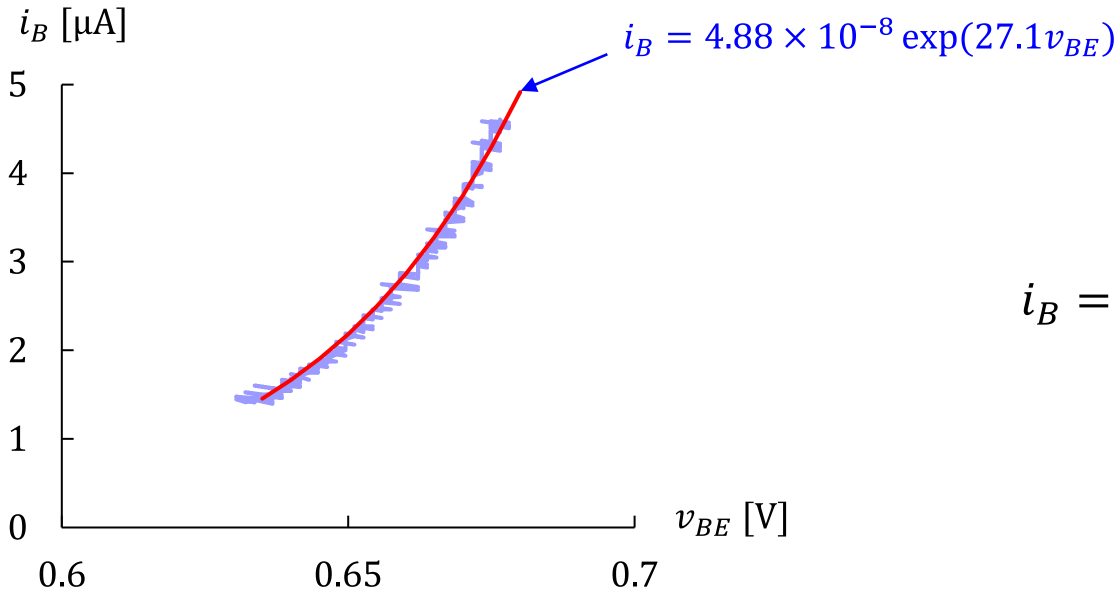
Exercise 2.3

Exercise 2.3 (Homework)

Find the empirical constant m of this transistor. The temperature $T = 25$ [°C].



Exercise 2.3 (Answer)



$$i_B = I_0 \exp\left(\frac{q}{mkT} v_{BE}\right)$$

$$T = 298\ [°\text{K}]$$
$$k = 1.38 \times 10^{-23}$$
$$q = 1.6 \times 10^{-19}$$

$$\frac{q}{mkT} = 27.1$$

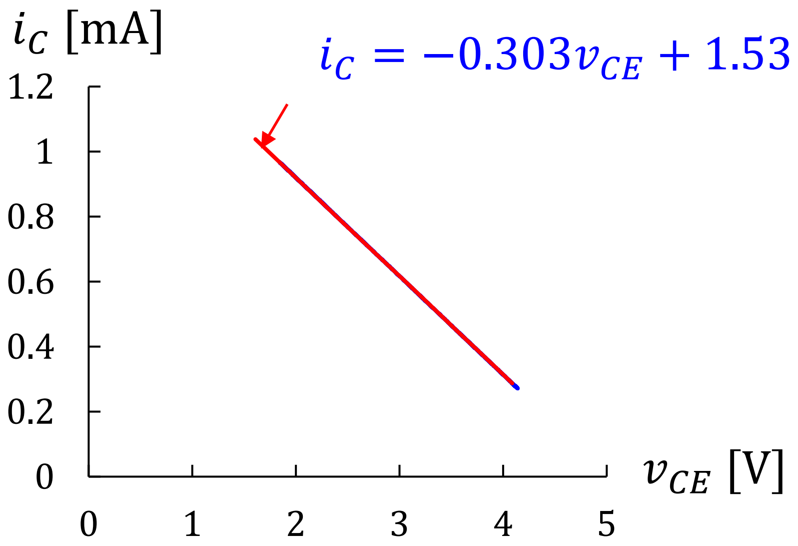
$$m = \frac{q}{27.1kT} = 1.44$$

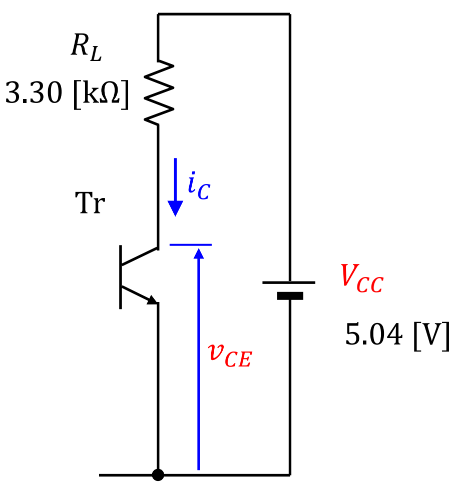
Exercise 2.5 (Homework)

Exercise 2.5

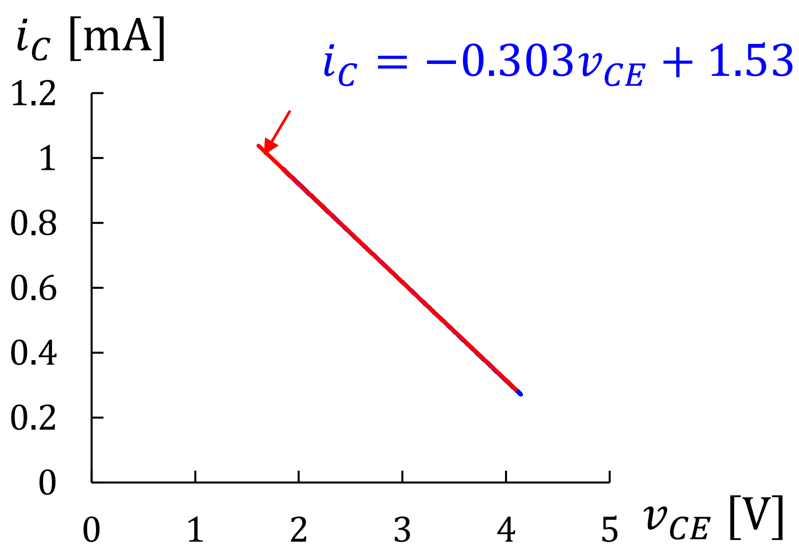
Exercise 2.5 (Homework)

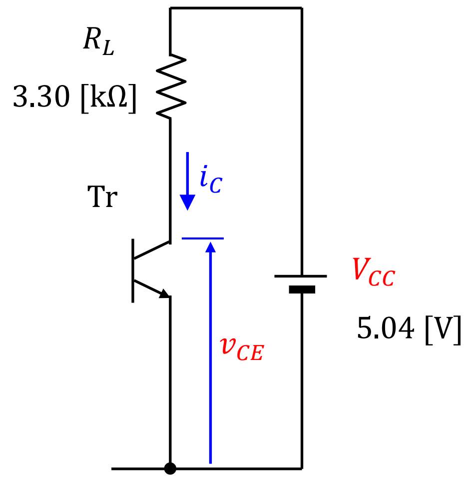
Confirm that the approximate equation $i_C = -0.303 v_{CE} + 1.53$ meets the load line of the circuit below. In the experiment, $V_{CC} = 5.04$ [V] and $R_L = 3.30$ [kΩ].





Exercise 2.5 (Answer)





$$v_{CE} = V_{CC} - R_L i_C$$

$$i_C = \frac{-v_{CE} + V_{CC}}{R_L} = \frac{-v_{CE} + 5.04}{3.30} = -3.03v_{CE} + 1.53$$

Exercise 2.6 (Homework)

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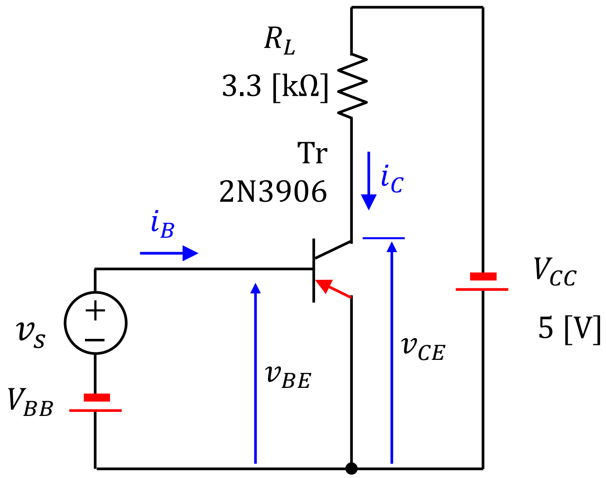
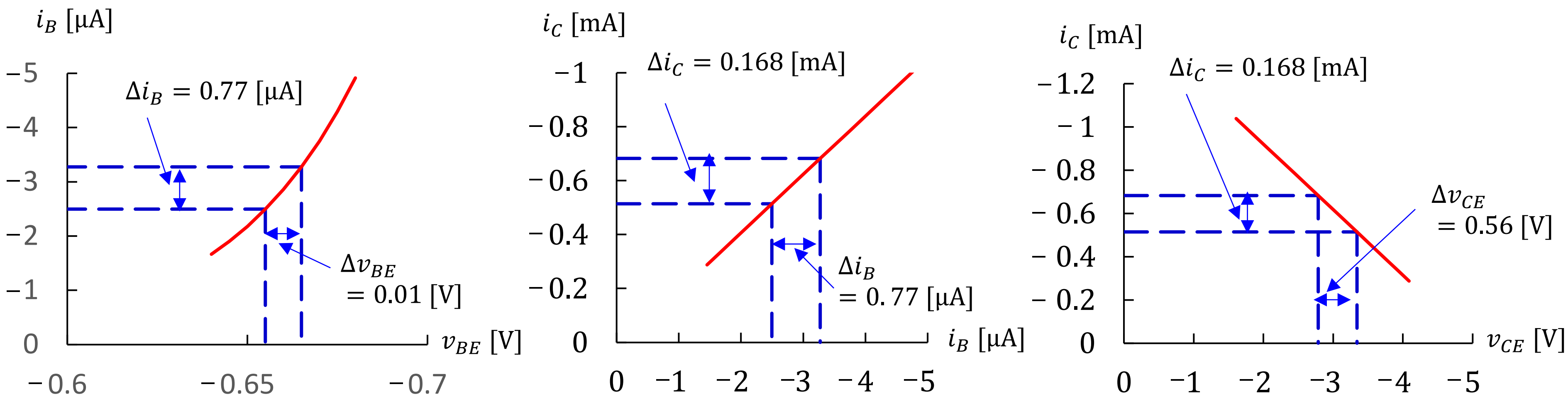
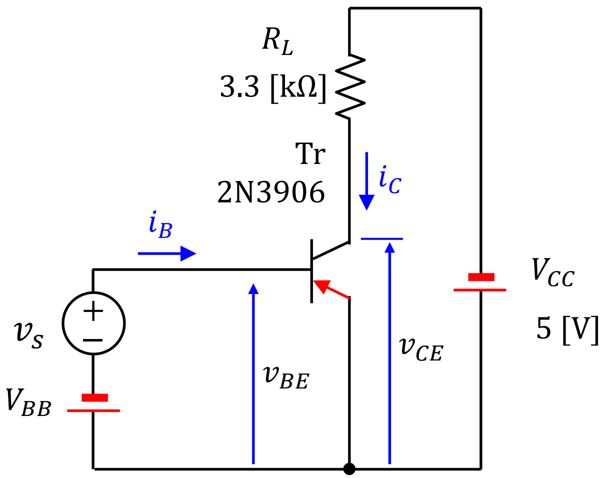
Exercise 2.6

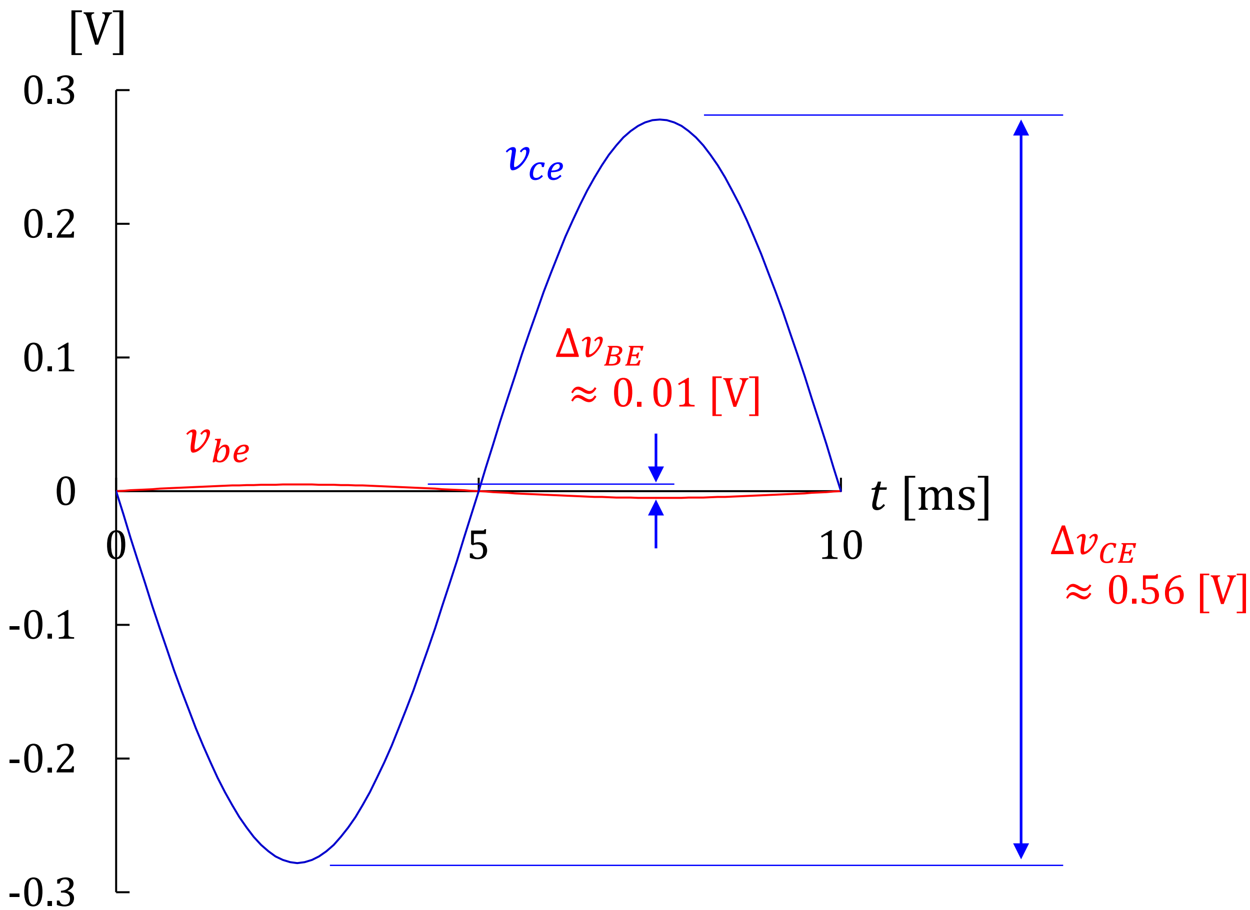


This is a transistor circuit for a $p-n-p$ transistor. For the operation of this circuit, the polarities of V_{BB} and V_{CC} are opposite to those for an $n-p-n$ transistor. Assume that $v_s + V_{BB} = 0.005 \sin \omega t - 0.66$ [V], $f = 100$ [Hz] and $\bar{v}_{CE} = -3$ [V]. Draw the waveforms of v_s and v_{ce}. Note that v_s and v_{ce} are AC components.



Exercise 2.6 (Answer)



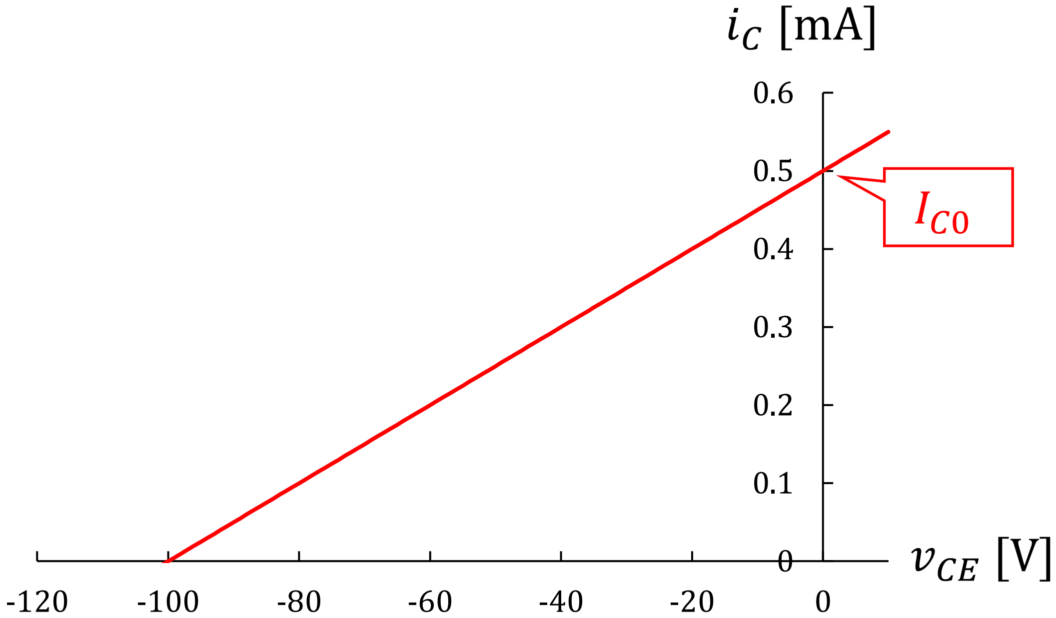


Exercise 3.1

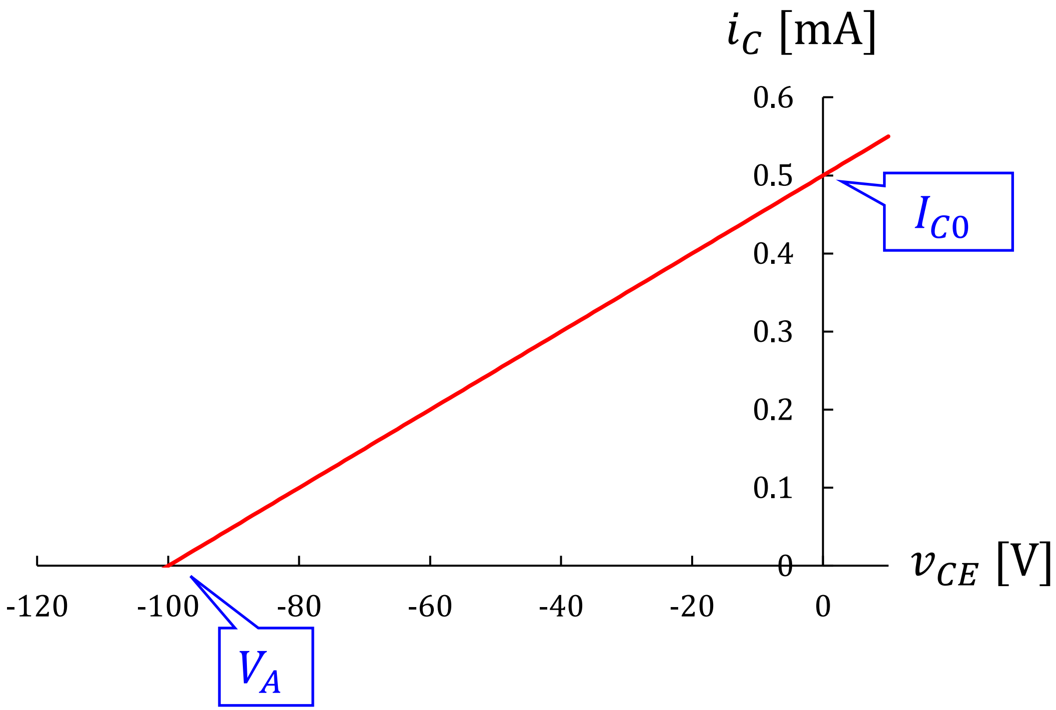
Exercise 3.1

Exercise 3 .1

This is an output characteristic of an $n-p-n$ transistor. The intercept of i_C line is denoted by I_{C0}. Derive an equation of i_C as a function of v_{CE}, I_{C0} and V_A.



Exercise 3 .1(Answer)



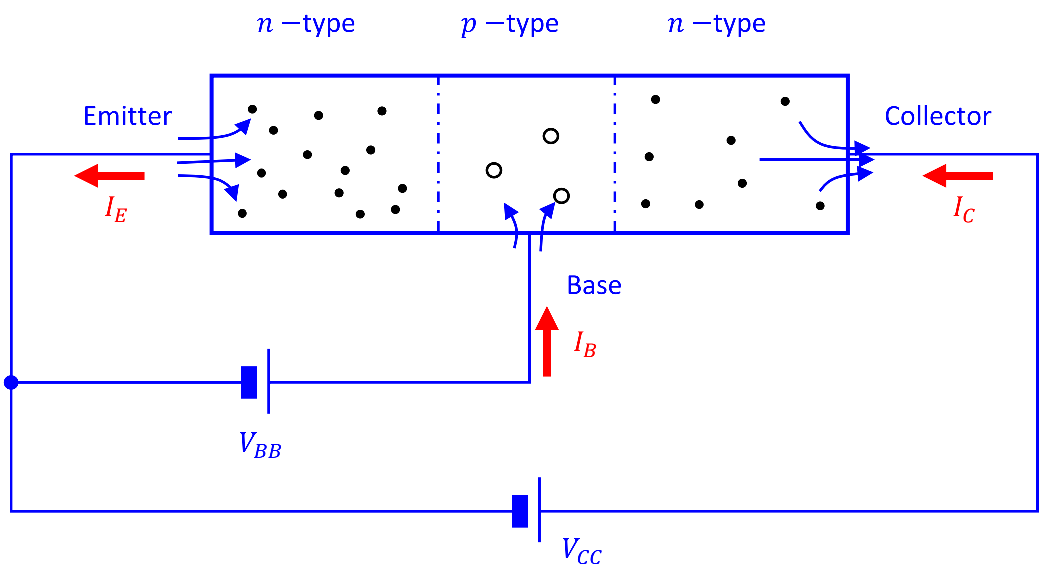
$$i_C = I_{C0}\left(1 + \frac{v_{CE}}{V_A}\right)$$
$$= 0.5\left(1 + \frac{v_{CE}}{100}\right) \text{ [mA]}$$

Exercise 3.2 (Homework)

Exercise 3.2 (Homework)

Exercise 3.2 (Homework)

Assume that I_B is 0.5% of I_E. Find α and h_{FE}.



Exercise 3.2 (Answer)

$$\alpha = \frac{I_C}{I_E} = \frac{0.995}{1} = 0.995$$

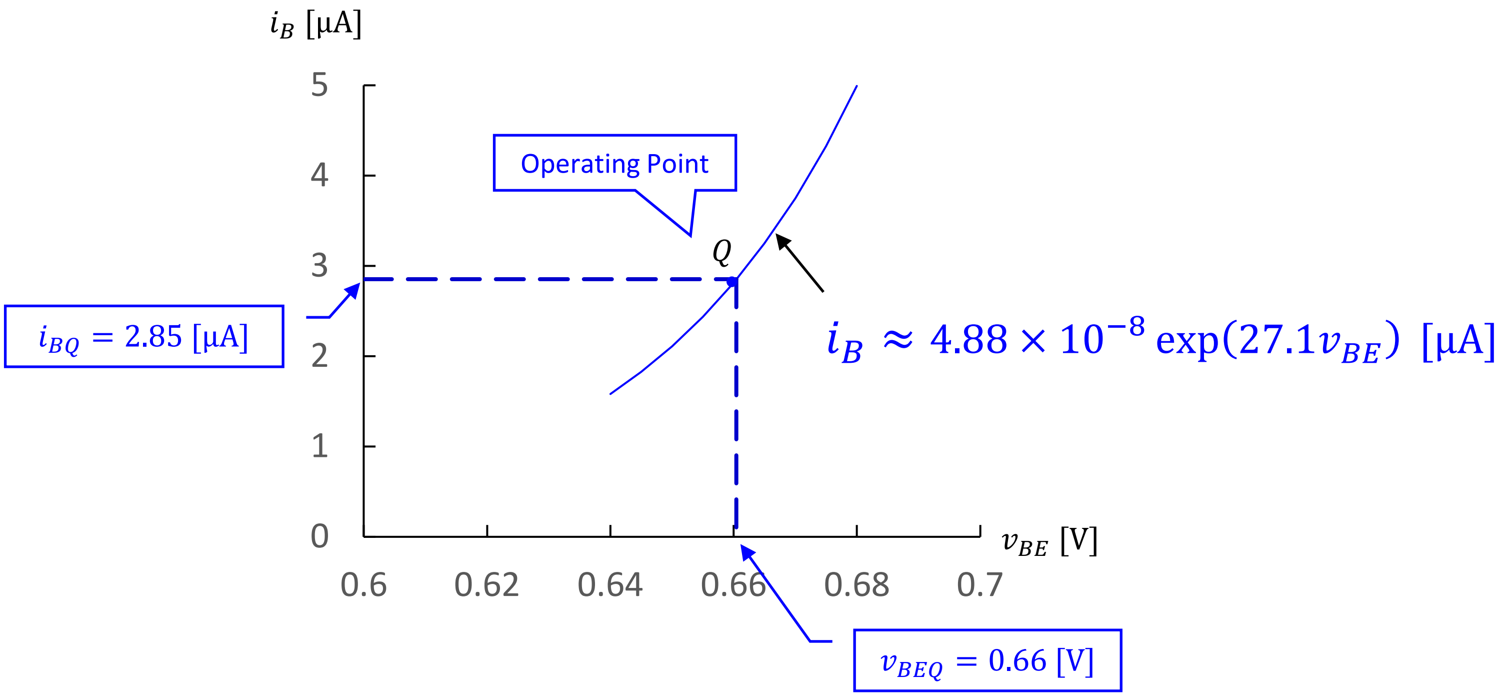
$$h_{FE} = \frac{I_C}{I_B} = \frac{0.995}{0.005} = 199$$

Exercise 3.3 (Homework)

Exercise 3.3 (Homework)

Exercise 3.3 (Homework)

The graph below is an input characteristic of a transistor. The approximate equation of this characteristic is also given below. Q is the operating point. Show that the input resistance $h_{ie} = 12.9\ [\mathrm{k\Omega}]$ at Q.



Exercise 3.3 (Answer)

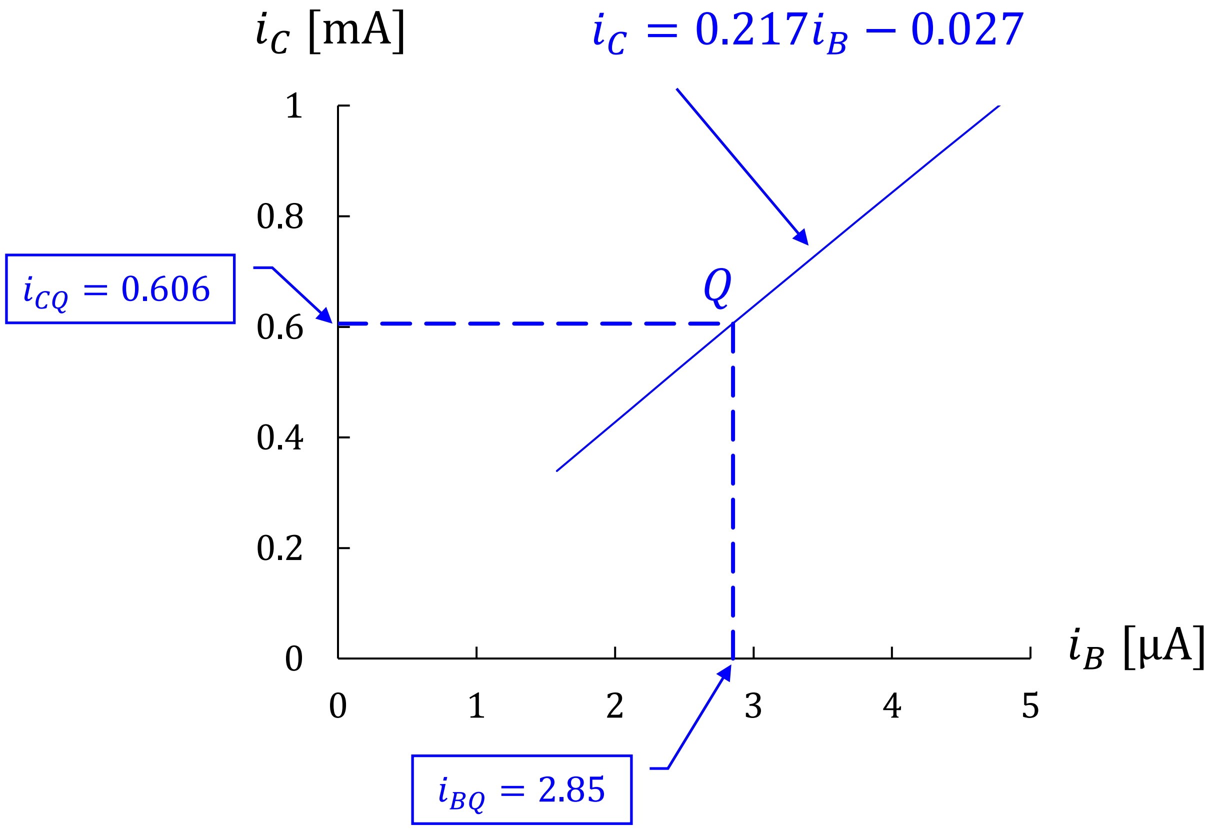
$$h_{ie} = \frac{V_T}{i_{BQ}}$$
$$= \frac{1}{2.85 \times 10^{-6} \times 27.1}$$
$$= 1.29 \times 10^{4}\ [\Omega]$$
$$= 12.9\ [\mathrm{k}\Omega]$$

Exercise 3.4.1 (Homework)

Exercise 3.4.1 (Homework)

Exercise 3.4.1 (Homework)

Find the DC current gain h_{FE} at the operating point Q.



Exercise 3.4.1 (Answer)

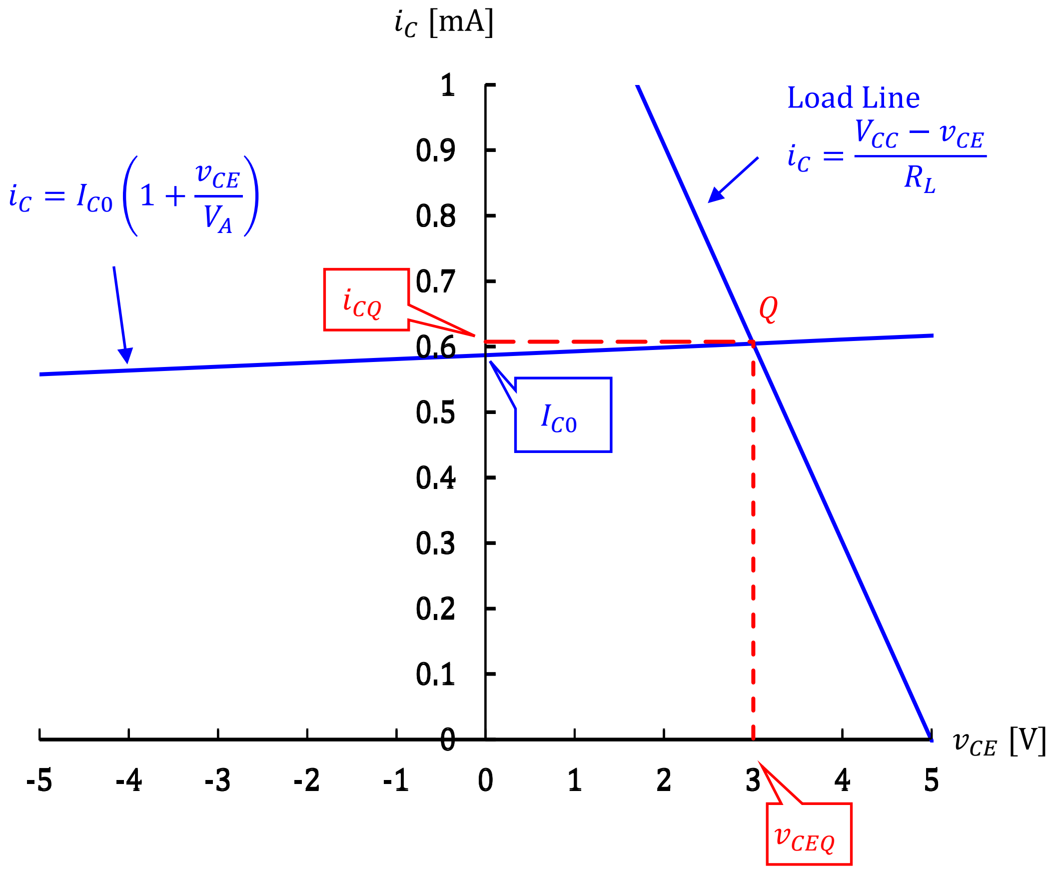
$$h_{FEQ} = \frac{i_{CQ}}{i_{BQ}} = \frac{0.606 \times 10^{-3}}{2.85 \times 10^{-6}} = 213$$

Exercise 3.4.2 (Homework)

Exercise 3.4.2 (Homework)

Exercise 3.4.2 (Homework)

Assume that, $R_L = 3.3$ [kΩ], $V_A = 100$ [V], $V_{CC} = 5$ [V], and $i_{CQ} = 0.606$ [mA]. Find I_{C0}, and show that $h_{oe} = 5.88$ [μS] and its approximated value is 6.06 [μS].



Exercise 3.4.2 (Answer)

$$i_C = I_{C0}\left(1 + \frac{v_{CE}}{V_A}\right) \quad (1)$$

$$i_C = \frac{V_{CC} - v_{CE}}{R_L} \quad (2)$$

i_C is given as

$$i_C = i_{CQ}.$$

Then, from eq. (2)

$$v_{CEQ} = V_{CC} - R_L i_{CQ}. \quad (3)$$

Thus, from eq. (1) and (3)

$$I_{C0} = \frac{i_{CQ}}{1 + \frac{v_{CEQ}}{V_A}} = \frac{i_{CQ}}{1 + \frac{V_{CC} - R_L i_{CQ}}{V_A}} = \frac{0.606 \times 10^{-3}}{1 + \frac{5 - 3.3 \times 0.606}{100}} = 0.588 \times 10^{-3}\ [\mathrm{A}]$$

$$= 0.588\ [\mathrm{mA}].$$

$$h_{oe} = \frac{I_{C0}}{V_A} = \frac{0.588 \times 10^{-3}}{100} = 5.88 \times 10^{-6}\ [\mathrm{S}]$$

$$= 5.88\ [\mu\mathrm{S}]$$

Approximated value $\quad h_{oe} \approx \frac{I_{CQ}}{V_A} = \frac{0.606 \times 10^{-3}}{100} = 6.06\ [\mu\mathrm{S}]$

Exercise 3.5 (Homework)

Exercise 3.5 (Homework)

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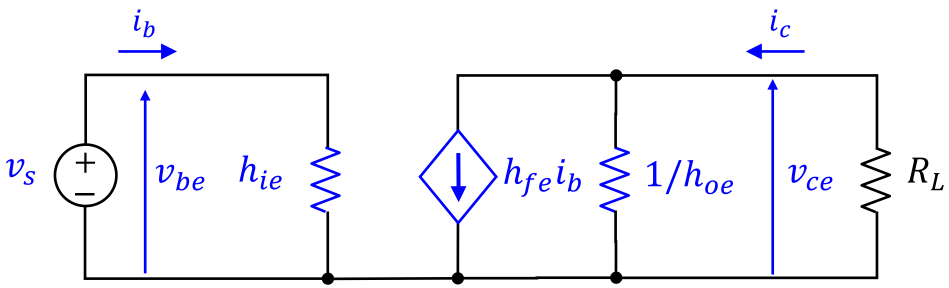
Derive the equation of v_{ce}/v_{be} from the three equations (1)~(3)



$$i_b = \frac{v_{be}}{h_{ie}} \qquad (1)$$

$$i_c = h_{fe}i_b + h_{oe}v_{ce} \qquad (2)$$

$$v_{ce} = -R_L i_c \qquad (3)$$

$$\frac{v_{ce}}{v_{be}} = -\frac{h_{fe}R_L}{h_{ie}(1 + h_{oe}R_L)}$$

Exercise 3.5 (Answer)

From (3)

$$v_{ce} = -R_L i_c$$

Replacing i_c with (2)

$$v_{ce} = -R_L\left(h_{fe} i_b + h_{oe} v_{ce}\right)$$

v_{ce} term on the right hand side is moved to the left, and

$$(1 + R_L h_{oe}) v_{ce} = -R_L h_{fe} i_b$$

Then

$$v_{ce} = -\frac{h_{fe} R_L}{1 + h_{oe} R_L} i_b$$

i_b is replaced with (1), and

$$v_{ce} = -\frac{h_{fe} R_L}{1 + h_{oe} R_L} \times \frac{v_s}{h_{ie}}$$

Thus

$$\frac{v_{ce}}{v_s} = -\frac{h_{fe} R_L}{h_{ie}(1 + h_{oe} R_L)}$$

Exercise 4.2 (Homework)

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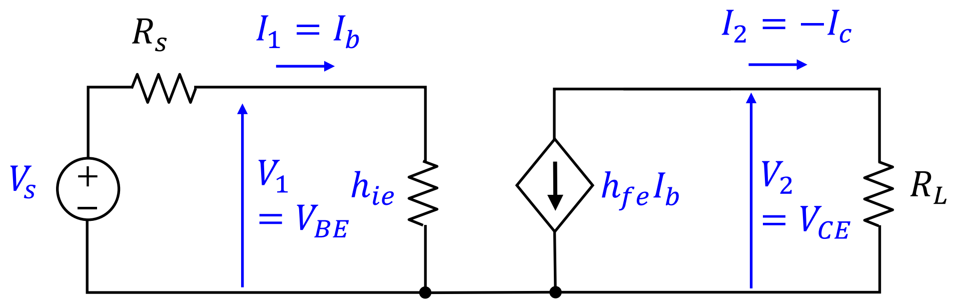
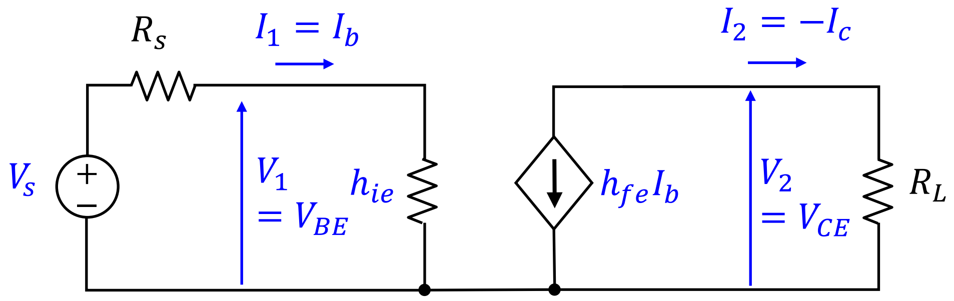
Find the input resistance R_i, voltage gain A_v, and the current gain A_i, output resistance R_o.



$$h_{ie} = 12.9\ [\mathrm{k\Omega}],\ h_{fe} = 217,\ R_s = R_L = 3.3\ [\mathrm{k\Omega}]$$

Exercise 4.2 (Answer)



$$h_{ie} = 12.9\ [\text{k}\Omega],\ h_{fe} = 217,\ R_s = R_L = 3.3\ [\text{k}\Omega]$$

$$R_i = h_{ie} = 12.9\ [\text{k}\Omega]$$

$$A_v = -\frac{h_{fe}R_L}{h_{ie}} = -55.5$$

$$A_i = -h_{fe} = -217$$

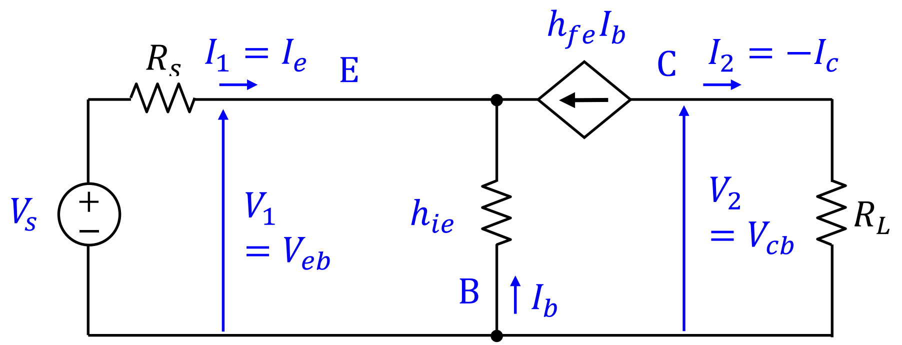
$$R_o = \infty$$

Exercise 4.3 (Homework)

Exercise 4.3 (Homework)

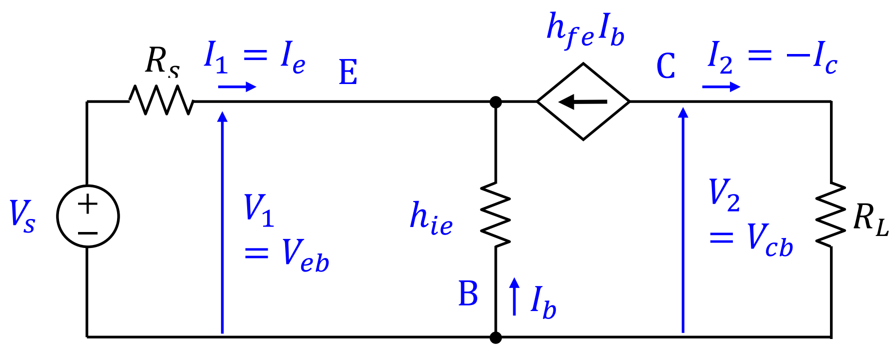
Exercise 4.3 (Homework)

Find the input resistance R_i, output resistance R_o, voltage gain A_v, and the current gain A_i.



$$h_{ie} = 12.9\ [\mathrm{k\Omega}],\ h_{fe} = 217,\ R_s = R_L = 3.3\ [\mathrm{k\Omega}]$$

Exercise 4.3 (Answer)



$$h_{ie} = 12.9\ [\text{k}\Omega],\ h_{fe} = 217,\ R_s = R_L = 3.3\ [\text{k}\Omega]$$

$$R_i = \frac{h_{ie}}{1 + h_{fe}} = 59.2\ [\Omega]$$ ← small input resistance

$$A_v = \frac{h_{fe}R_L}{h_{ie}} = 55.5$$

$$A_i = \frac{h_{fe}}{1 + h_{fe}} = 0.995$$ ← Current is not amplified.

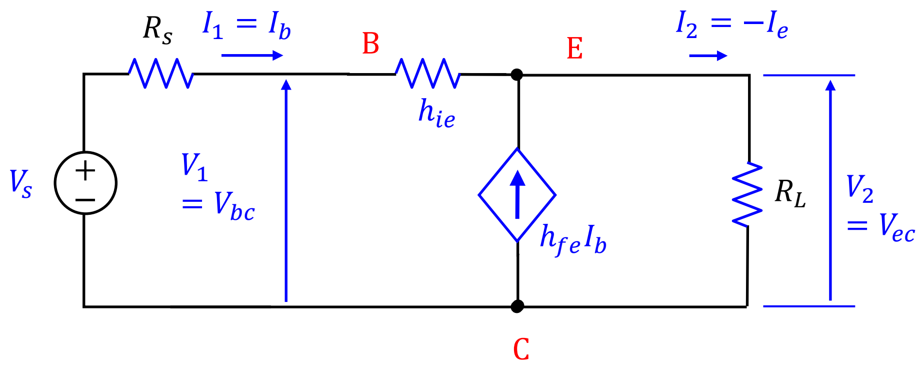
$$R_o = \infty$$

Exercise 4.4.1 (Homework)

Exercise 4.4.1 (Homework)

Exercise 4.4.1 (Homework)

Show that the performance measures for this common collector amplifier are given by these equations.



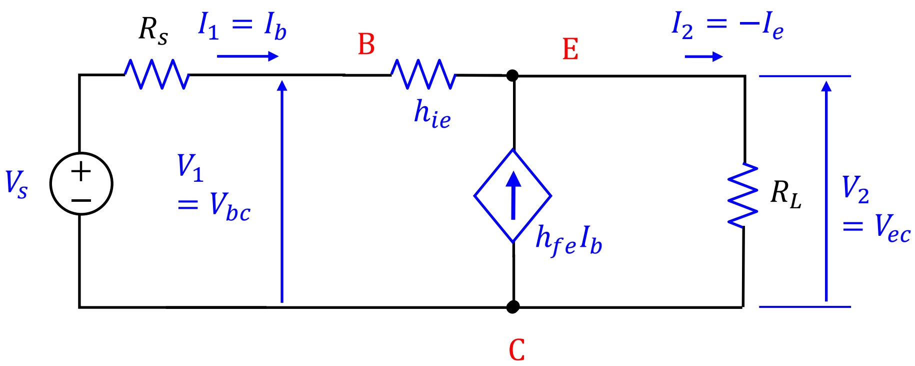
$$R_i = \frac{V_1}{I_1} = h_{ie} + (1 + h_{fe})R_L$$

$$A_v = \frac{V_2}{V_1} = \frac{(1 + h_{fe})R_L}{h_{ie} + (1 + h_{fe})R_L}$$

$$A_i = \frac{I_2}{I_1} = 1 + h_{fe}$$

$$R_o = \left.\frac{V_2}{-I_2}\right|_{R_L=\infty,\ V_s=0} = \frac{R_s + h_{ie}}{1 + h_{fe}}$$

Exercise 4.4.1 (Answer)



$$V_1 = h_{ie}I_1 + V_2$$

$$= h_{ie}I_1 + R_L I_2$$

$$= h_{ie}I_1 + R_L(1 + h_{fe})I_1$$

$$V_2 = R_L I_2$$

$$I_2 = I_1 + h_{fe}I_1$$

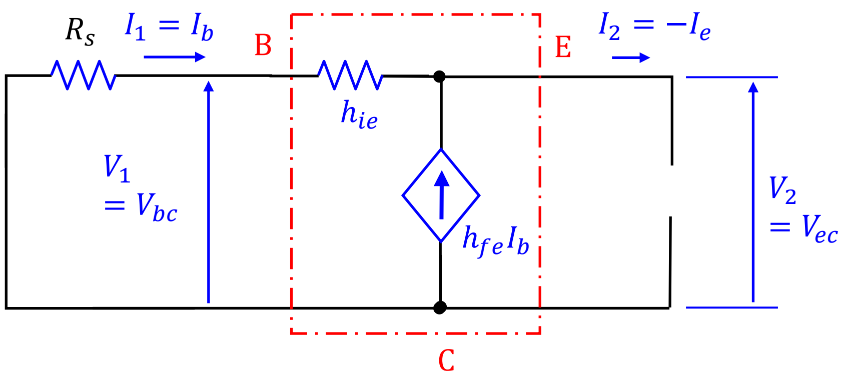
$$A_i = \frac{I_2}{I_1} = 1 + h_{fe}$$

$$V_2 = (1 + h_{fe})R_L I_1$$

$$R_i = \frac{V_1}{I_1} = h_{ie} + (1 + h_{fe})R_L$$

$$A_v = \frac{V_2}{V_1} = \frac{(1 + h_{fe})R_L}{h_{ie} + (1 + h_{fe})R_L}$$

Exercise 4.4.1 (Answer)



$$I_1 = -\frac{V_2}{R_s + h_{ie}}$$

$$I_2 = (1 + h_{fe})I_1$$

$$= -(1 + h_{fe})\frac{V_2}{R_s + h_{ie}}$$

$$R_o = \left.\frac{V_2}{-I_2}\right|_{R_L=\infty,\ V_s=0} = \frac{R_s + h_{ie}}{1 + h_{fe}}$$

Exercise 4.4.2 (Homework)

Exercise 4.4.2 (Homework)

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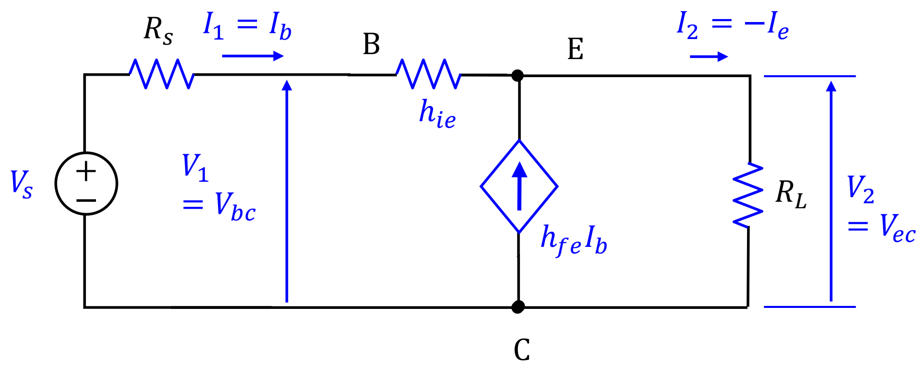
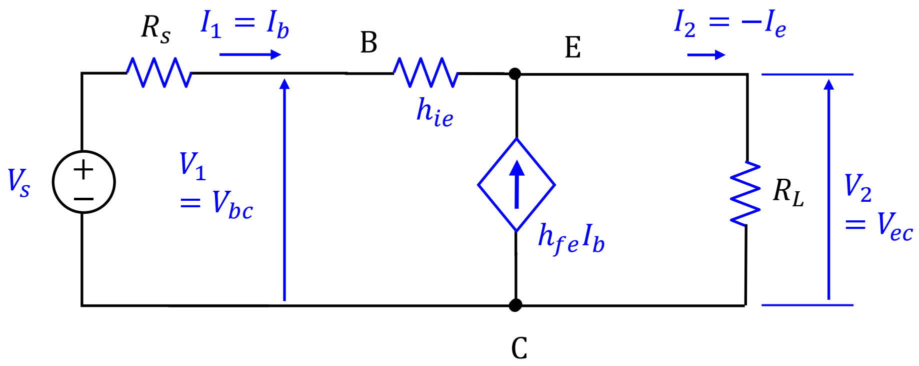
Find the input resistance R_i, output resistance R_o, voltage gain A_v, and the current gain A_i.



$$h_{ie} = 12.9\ [\mathrm{k}\Omega],\ h_{fe} = 217,\ R_s = R_L = 3.3\ [\mathrm{k}\Omega]$$

Exercise 4.4.2 (Answer)



$$h_{ie} = 12.9\ [\mathrm{k\Omega}],\ h_{fe} = 217,\ R_s = R_L = 3.3\ [\mathrm{k\Omega}]$$

$$R_i = h_{ie} + \left(1 + h_{fe}\right) R_L = 732\ [\mathrm{k\Omega}]$$ ⬅ Large input resistance

$$A_v = \frac{(1 + h_{fe}) R_L}{h_{ie} + (1 + h_{fe}) R_L} = 0.982$$ ⬅ Voltage is not amplified.

$$A_i = 1 + h_{fe} = 218$$

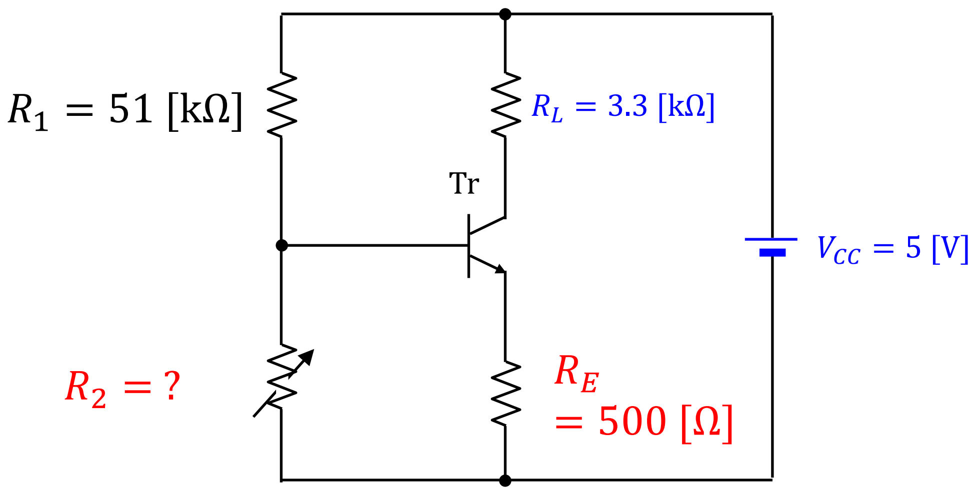
$$R_o = \frac{R_s + h_{ie}}{1 + h_{fe}} = 9.22\ [\Omega]$$ ⬅ Small output resistance

Exercise 5.1 (Homework)

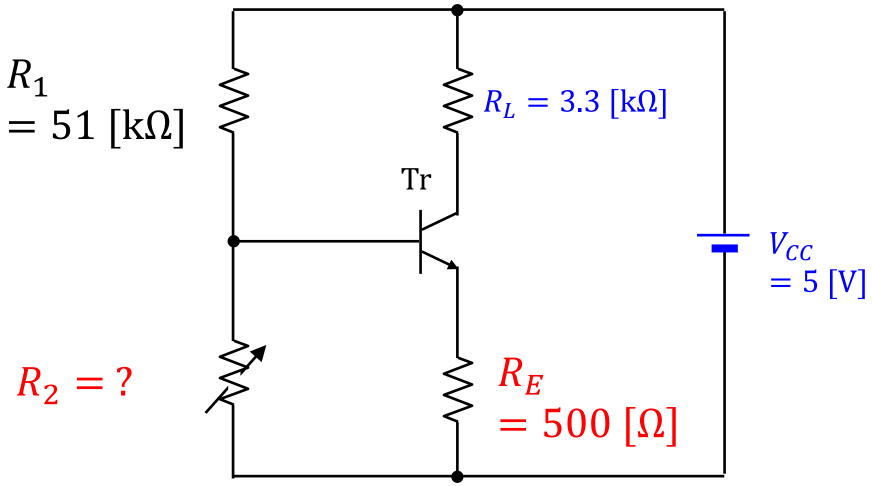
Exercise 5.1 (Homework)

Exercise 5.1 (Homework)

Assume that R_E is mistakenly set at $500\ [\Omega]$. Find R_2.



Exercise 5.1 (Answer)



$R_E = 500$ [Ω]

$V_{CC} = 5$ [V]
$V_{BEQ} = 0.66$ [V]
$I_{CQ} = 0.606$ [mA]
$I_{BQ} = 2.85$ [μA]

$$V_{BGQ} = V_{BEQ} + R_E(I_{BQ} + I_{CQ})$$
$$= 0.66 + 500 \times 0.609 \times 10^{-3}$$
$$= 0.965 \text{ [V]}$$

$R_1(I_1 + I_{BQ}) = V_{CC} - V_{BGQ}$ ➡ $I_1 = 76.3$ [μA]

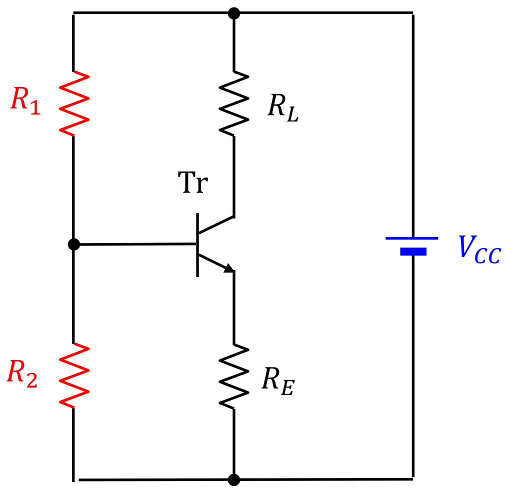
$$R_2 = \frac{V_{BGQ}}{I_1} = 12.6 \text{ [k}\Omega\text{]}$$

Exercise 5.2.1 (Homework)

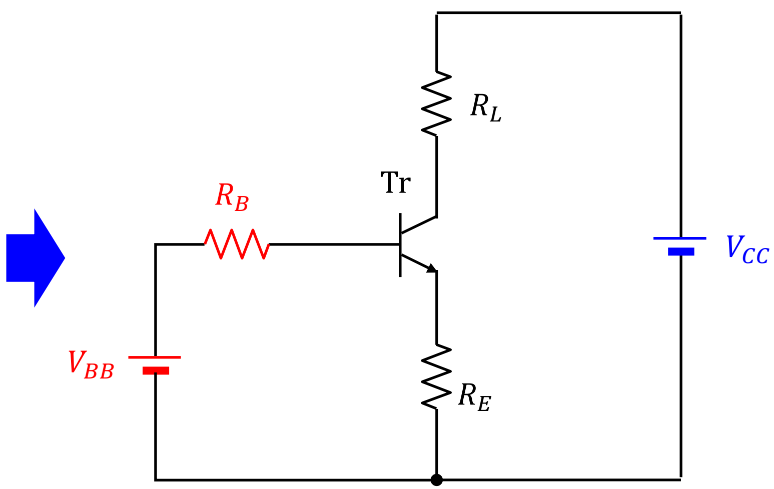
Exercise 5.2.1 (Homework)

Exercise 5.2.1 (Homework)

Show that V_{BB} and R_B in the equivalent circuit are given by the following equations.



Single battery bias circuit

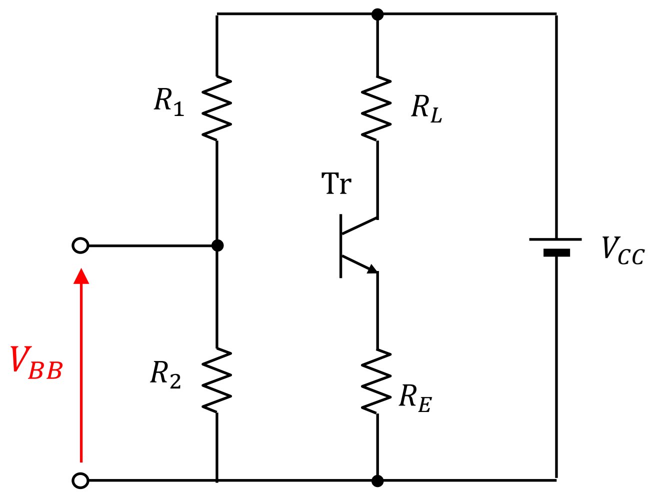


Equivalent bias circuit

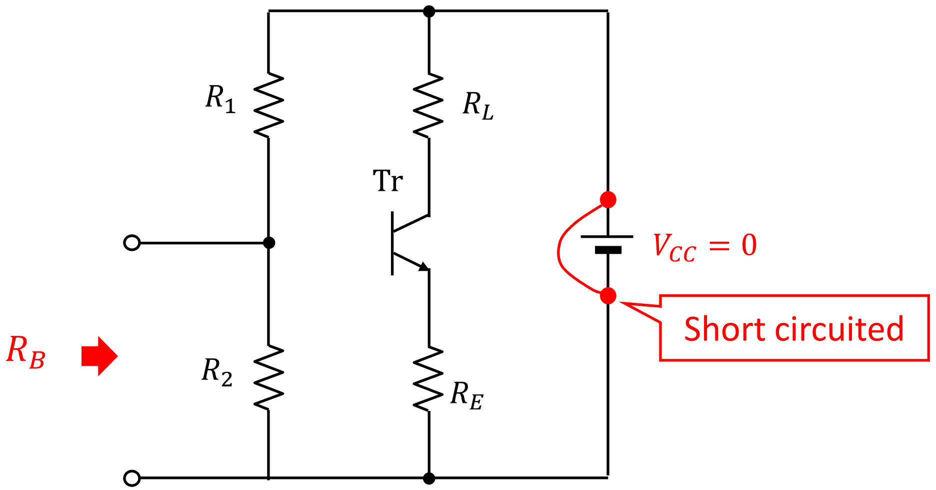
$$V_{BB} = \frac{R_2}{R_1 + R_2} V_{CC}$$

$$R_B = \frac{R_1 R_2}{R_1 + R_2}$$

Exercise 5.2.1 (Answer)



$$V_{BB} = \frac{R_2}{R_1 + R_2} V_{CC}$$



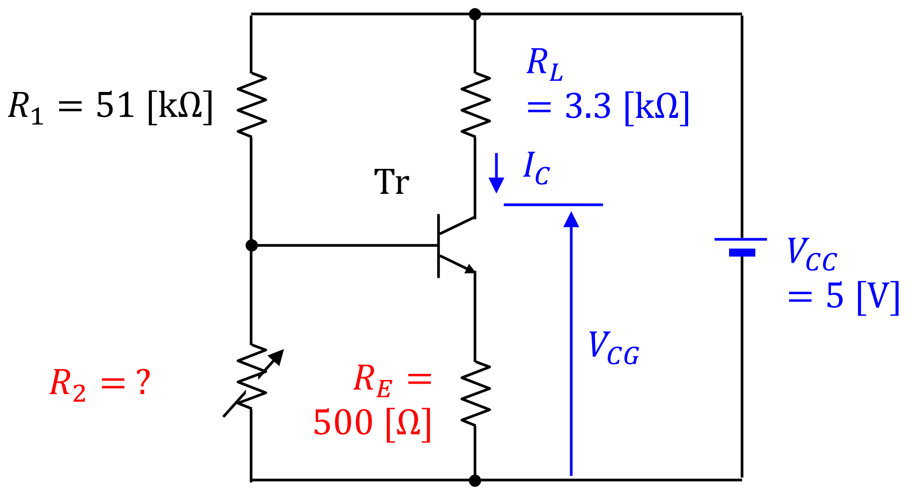
$$R_B = \frac{R_1 R_2}{R_1 + R_2}$$

Exercise 5.2.2 (Homework)

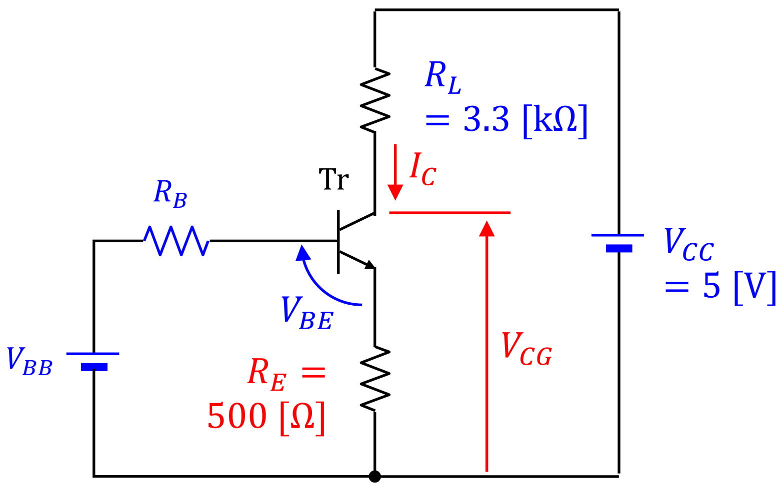
Exercise 5.2.2 (Homework)

Exercise 5.2.2 (Homework)

Assume that R_E is mistakenly set at $500\ [\Omega]$. Find $S_h, S_V, \Delta I_{CQ}$ and ΔV_{CG}.



Exercise 5.2.2 (Answer)



$$R_1 = 51\ [\mathrm{k\Omega}], R_2 = 12.6\ [\mathrm{k\Omega}]$$

$$V_{BB} = \frac{R_2}{R_1 + R_2} V_{CC} = 0.991\ [\mathrm{V}]$$

$$R_B = \frac{R_1 R_2}{R_1 + R_2} = 10.1\ [\mathrm{k\Omega}]$$

$$h_{FEQ} = 213, V_{BEQ} = 0.66\ [\mathrm{V}]$$

$$S_h = \frac{(V_{BB} - V_{BEQ})(R_B + R_E)}{\{R_B + R_E(1 + h_{FEQ})\}^2} = 2.56 \times 10^{-7}$$

$$S_V = \frac{-h_{FEQ}}{R_B + R_E(1 + h_{FEQ})} = -1.82 \times 10^{-3}$$

$$C_{hQ} \approx 0.5\ [\%/^\circ\mathrm{C}],\ C_{VQ} \approx -2.0\ [\mathrm{mV}/^\circ\mathrm{C}], \Delta T = 40\ [^\circ\mathrm{C}]$$

$$\Delta I_{CQ} \approx S_h C_{hQ} h_{FEQ} \Delta T + S_V C_{VQ} \Delta T = 160\ [\mu\mathrm{A}]$$

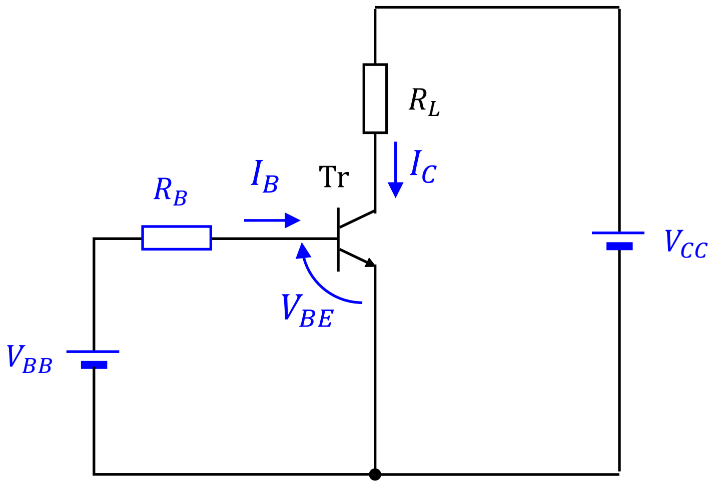
$$\Delta V_{CG} = -R_L \Delta I_{CQ} \approx -0.53\ [\mathrm{V}]$$

Exercise 5.2.3 (Homework)

Exercise 5.2.3 (Homework)

Exercise 5.2.3 (Homework)

Show that the stability factor S_h and S_V are given by the following equations:

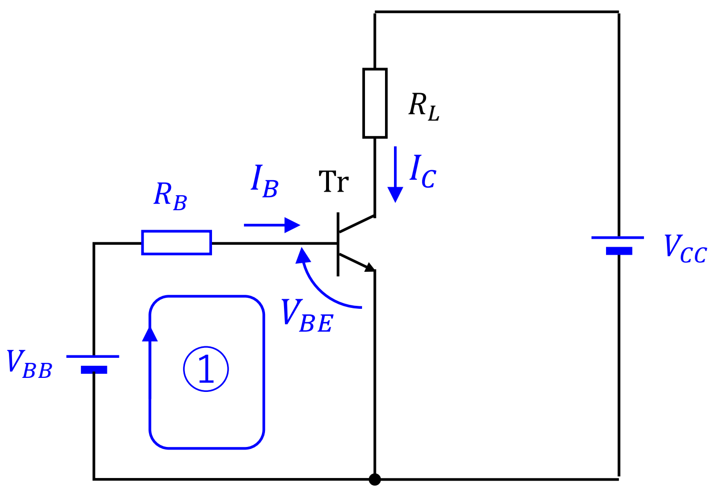


$$S_h = \left.\frac{\partial I_C}{\partial h_{FE}}\right|_Q = \frac{V_{BB} - V_{BEQ}}{R_B}$$

$$S_V = \left.\frac{\partial I_C}{\partial V_{BE}}\right|_Q = \frac{-h_{FEQ}}{R_B}$$

Equivalent bias circuit

Exercise 5.2.3 (Answer)



Equivalent bias circuit

Along the loop 1, KVL gives

$$V_{BB} = R_B I_B + V_{BE}.$$

From Eq.(3.3)

$$I_C = h_{FE} I_B.$$

Then

$$I_C = \frac{h_{FE}(V_{BB} - V_{BE})}{R_B}.$$

Thus

$$S_h = \left.\frac{\partial I_C}{\partial h_{FE}}\right|_Q = \frac{V_{BB} - V_{BEQ}}{R_B}$$

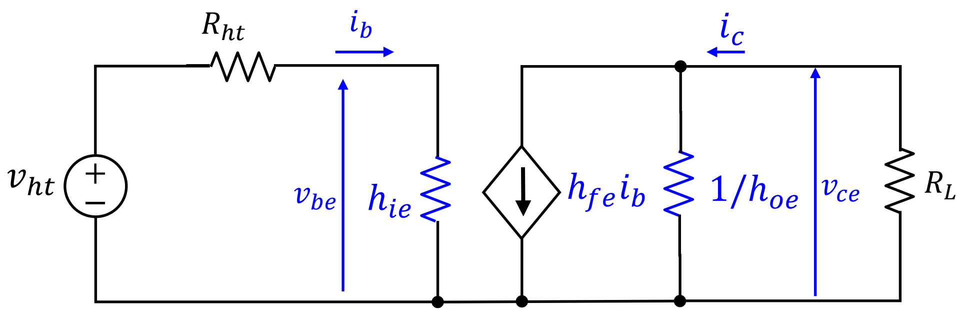
$$S_V = \left.\frac{\partial I_C}{\partial V_{BE}}\right|_Q = \frac{-h_{FEQ}}{R_B}$$

Exercise 5.3 (Homework)

Exercise 5.3 (Homework)

Exercise 5.3 (Homework)

Show that the voltage gain of this bias circuit A_{vs} is given by the equation below.



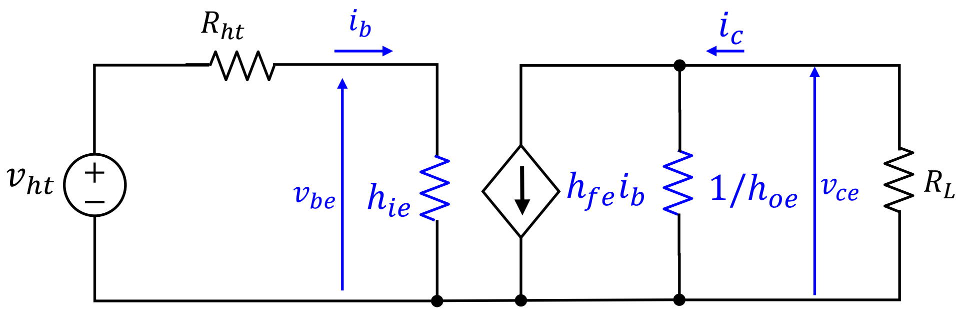
$$v_{ht} = \frac{R_{12}}{R_s + R_{12}} v_s$$

$$R_{ht} = \frac{R_s R_{12}}{R_s + R_{12}}$$

$$A_{vs} = \frac{v_{ce}}{v_s}$$

$$= -\frac{R_L h_{fe}}{1 + R_L h_{oe}} \times \frac{1}{R_{ht} + h_{ie}} \times \frac{R_{12}}{R_s + R_{12}}$$

Exercise 5.3 (Answer)



$$v_{ht} = \frac{R_{12}}{R_s + R_{12}} v_s$$

$$R_{ht} = \frac{R_s R_{12}}{R_s + R_{12}}$$

$$i_b = \frac{v_{ht}}{R_{ht} + h_{ie}}$$

$$v_{ht} = \frac{R_{12}}{R_s + R_{12}} v_s$$

$$v_{ce} = -\frac{h_{fe}}{h_{oe} + \frac{1}{R_L}} i_b = -\frac{R_L h_{fe}}{1 + R_L h_{oe}} \times \frac{1}{R_{ht} + h_{ie}} v_{ht}$$

$$= -\frac{R_L h_{fe}}{1 + R_L h_{oe}} \times \frac{1}{R_{ht} + h_{ie}} \times \frac{R_{12}}{R_s + R_{12}} v_s$$

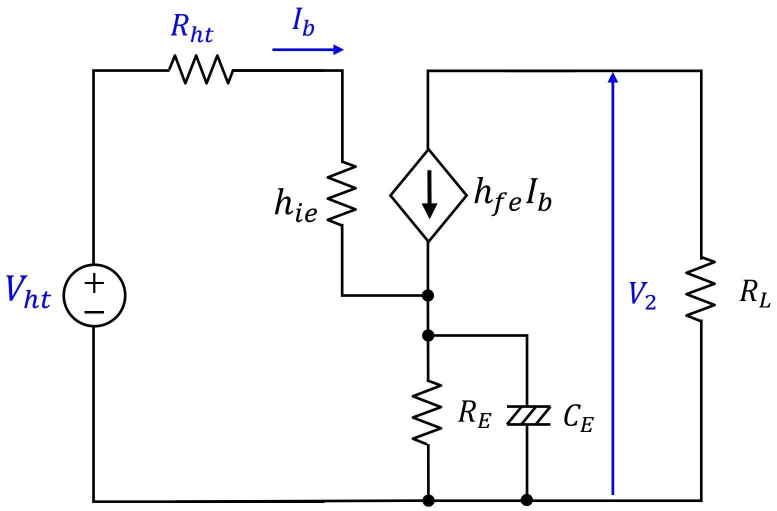
$$A_{vs} = \frac{v_{ce}}{v_s} = -\frac{R_L h_{fe}}{1 + R_L h_{oe}} \times \frac{1}{R_{ht} + h_{ie}} \times \frac{R_{12}}{R_s + R_{12}}$$

Exercise 6.1 (Homework)

Exercise 6.1 (Homework)

Exercise 6.1 (Homework)

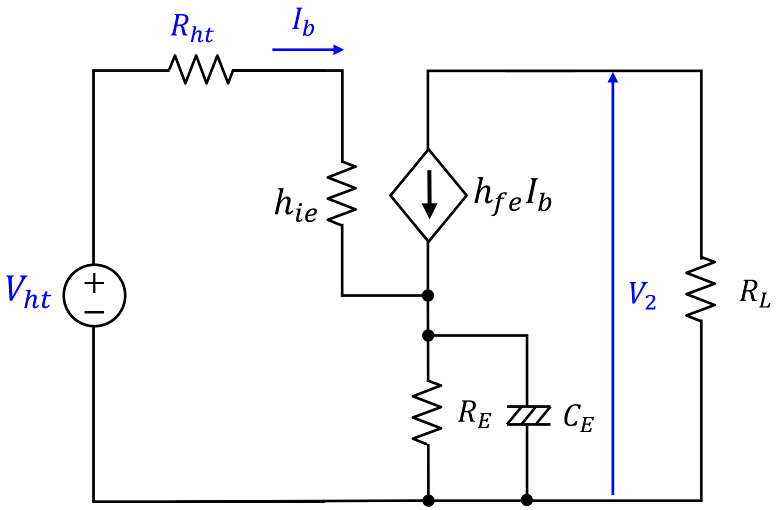
Show that the ratio $\frac{V_2}{V_{ht}}$ is given by this equation.



$$\frac{V_2}{V_{ht}} = -\frac{h_{fe}R_L}{R_X} \times \frac{1 + j\omega C_E R_E}{1 + \frac{j\omega C_E R_E (R_{ht} + h_{ie})}{R_X}}$$

$$R_X = R_{ht} + h_{ie} + (1 + h_{fe})R_E$$

Exercise 6.1 (Answer)



$$\frac{V_2}{V_{ht}} = \frac{-h_{fe}R_L}{R_{ht} + h_{ie} + \frac{1 + h_{fe}}{1 + j\omega C_E R_E} R_E}$$

$$= \frac{-h_{fe}R_L(1 + j\omega C_E R_E)}{(R_{ht} + h_{ie})(1 + j\omega C_E R_E) + (1 + h_{fe})R_E}$$

$$= \frac{-h_{fe}R_L(1 + j\omega C_E R_E)}{R_{ht} + h_{ie} + (1 + h_{fe})R_E + j\omega C_E R_E(R_{ht} + h_{ie})}$$

$$= \frac{-h_{fe}R_L}{R_X} \times \frac{1 + j\omega C_E R_E}{1 + \frac{j\omega C_E R_E(R_{ht} + h_{ie})}{R_X}}$$

$$R_X = R_{ht} + h_{ie} + (1 + h_{fe})R_E$$

Exercise 6.2 (Homework)

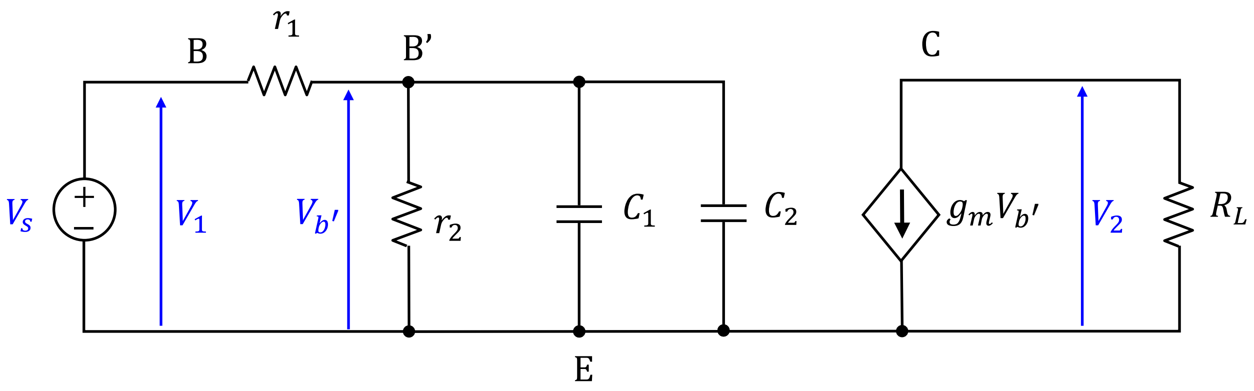
Exercise 6.2 (Homework)

Exercise 6.2 This is your homework.

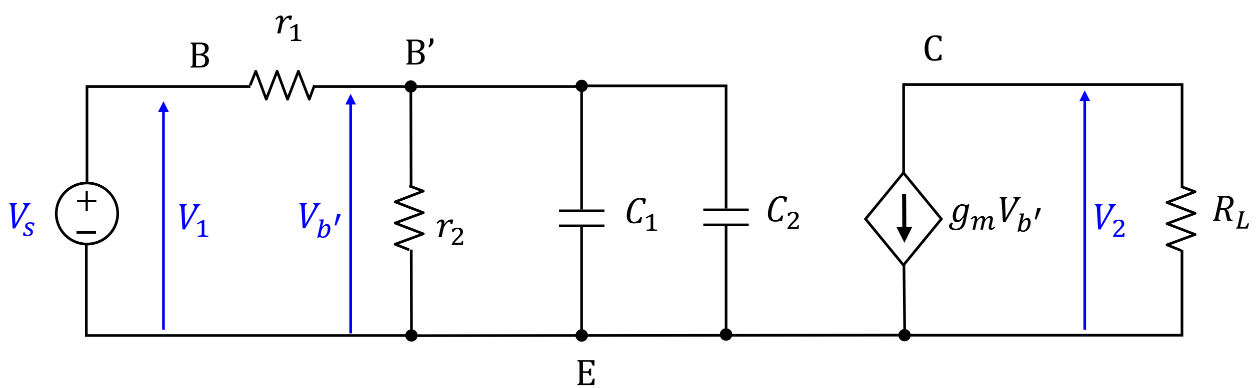
Exercise 6.2

Show that the following equation is obtained from the circuit below:

$$V_2 = \frac{-g_m R_L}{1 + \frac{r_1}{r_2} + j\omega r_1 (C_1 + C_2)} V_1$$



Exercise 6.2 (Answer)



$$V_{b'} = \frac{\dfrac{1}{\dfrac{1}{r_2} + j\omega(C_1 + C_2)}}{r_1 + \dfrac{1}{\dfrac{1}{r_2} + j\omega(C_1 + C_2)}} V_1$$

$$= \frac{1}{1 + \dfrac{r_1}{r_2} + j\omega r_1 (C_1 + C_2)} V_1$$

$$V_2 = -g_m R_L V_{b'}$$

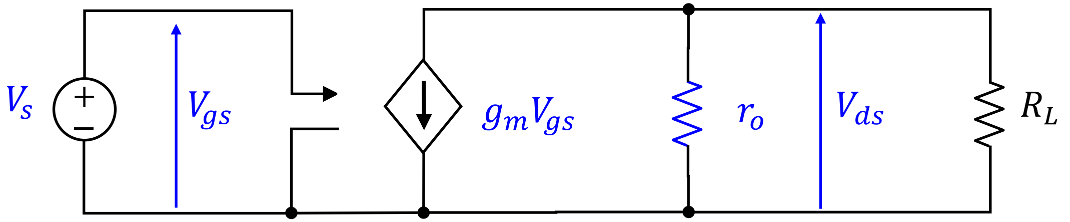
$$V_2 = \frac{-g_m R_L}{1 + \dfrac{r_1}{r_2} + j\omega r_1 (C_1 + C_2)} V_1$$

Exercise 7.5 (Homework)

Exercise 7.5 (Homework)

Exercise 7.5 (Homework)

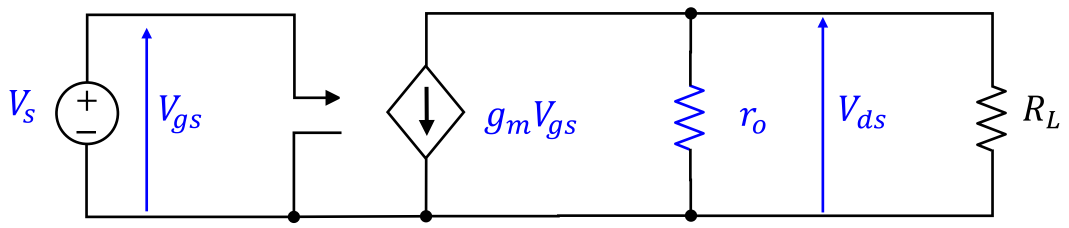
Find the voltage gain $A_v = \frac{V_{ds}}{V_{gs}}$ of this circuit.



$g_m = 3.30 \times 10^{-3}$ $r_o = 34.6\ [k\Omega]$ $R_L = 3.3\ [\mathrm{k}\Omega]$

Pause the video, and answer the problem.

Exercise 7.5 (Answer)



$g_m = 3.30 \times 10^{-3}$ $\quad r_o = 34.6\ [k\Omega]$ $\quad R_L = 3.3\ [\mathrm{k}\Omega]$

$$A_v = \frac{V_{ds}}{V_{gs}}$$

$$= -g_m \frac{1}{\frac{1}{r_o} + \frac{1}{R_L}}$$

$$= -3.30 \times 10^{-3} \times \frac{1}{\frac{1}{34.6 \times 10^3} + \frac{1}{3.3 \times 10^3}}$$

$$= -9.9$$

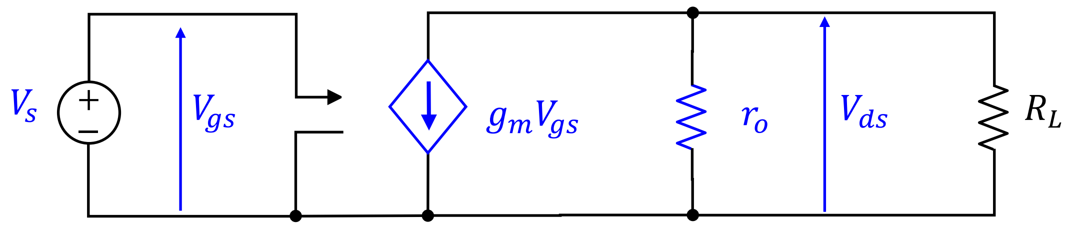
This is the answer to Exercise 7.5. The absolute value of A_v is 10 % smaller than that in Experiment 7.2, which was 10.9. This is mainly due to the inaccurate settings of Experiment 7.3.1 for i_D vs. v_{GS} curve in which v_{DS} should have been kept constant.

Exercise 8.5 (Homework)

Exercise 8.5 (Homework)

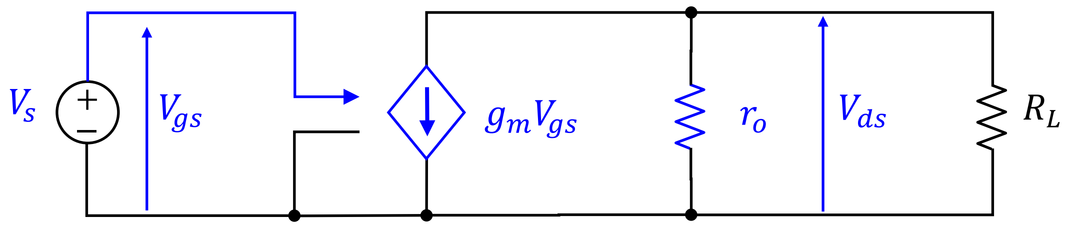
Exercise 8.5 (Homework)

Find the voltage gain $A_v = \frac{V_{ds}}{V_{gs}}$ of this circuit.



$g_m = 5.34 \times 10^{-3}$ $r_o = 50.8$ [kΩ] $R_L = 3.3$ [kΩ]

Exercise 8.5 (Answer)



$g_m = 5.34 \times 10^{-3}$ $r_o = 50.8\ [\mathrm{k}\Omega]$ $R_L = 3.3\ [\mathrm{k}\Omega]$

$$A_v = \frac{V_{ds}}{V_{gs}}$$

$$= -g_m \frac{1}{\frac{1}{r_o} + \frac{1}{R_L}}$$

$$= -5.34 \times 10^{-3} \times \frac{1}{\frac{1}{50.8 \times 10^3} + \frac{1}{3.3 \times 10^3}}$$

$$\approx 16.5$$

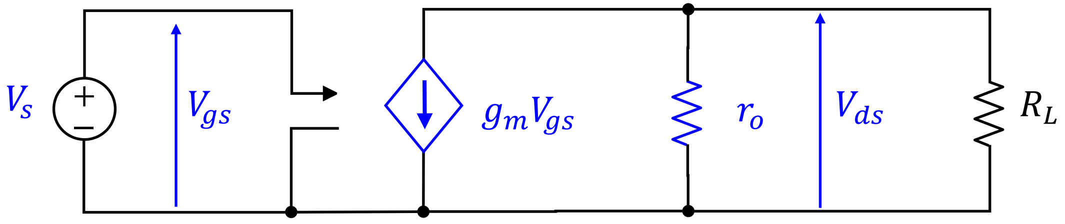
This is the answer to Exercise 8.5. The absolute value of A_v is 6 % smaller than that in Experiment 8.2, which was 17.6. This is mainly due to the inaccurate settings of Experiment 8.3.1 for i_D vs. v_{GS} curve in which v_{DS} should have been kept constant.

Exercise 9.1 (Homework)

Exercise 9.1 (Homework)

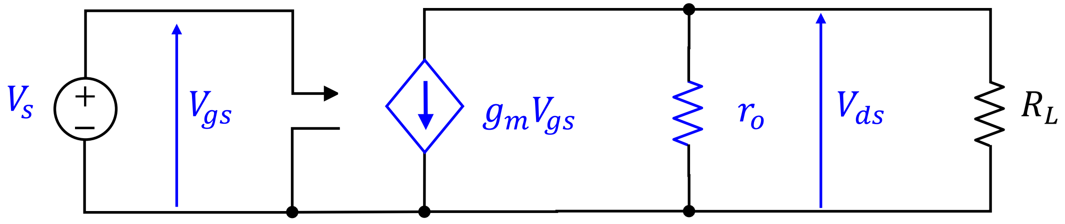
Exercise 9.1 (Homework)

Find the input resistance R_i, voltage gain A_v, and the current gain A_i, output resistance R_o.



$g_m = 5.34 \times 10^{-3}$ $\quad r_o = 50.8\ [\mathrm{k\Omega}]$ $\quad R_L = 3.3\ [\mathrm{k\Omega}]$

Exercise 9.1 (Answer)



$g_m = 5.34 \times 10^{-3}$ $r_o = 50.8\ [\mathrm{k\Omega}]$ $R_L = 3.3\ [\mathrm{k\Omega}]$

$$R_i = \infty$$

$$A_v = -g_m \frac{r_o R_L}{r_o + R_L} = -16.5$$

$$A_i = -\infty$$

$$R_o = r_o = 50.8\ [\mathrm{k\Omega}]$$

In Exp. 8.2

$$|A_v| = 17.6$$

In Section 8.3

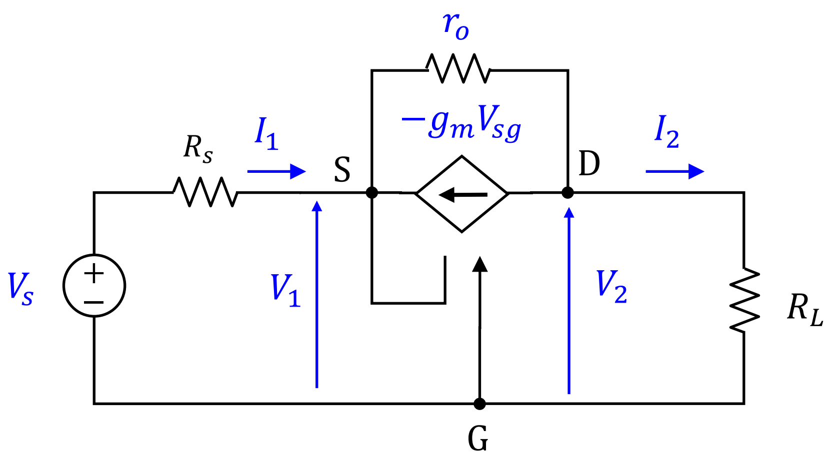
$$A_v = -18$$

Exercise 9.2 (Homework)

Exercise 9.2 (Homework)

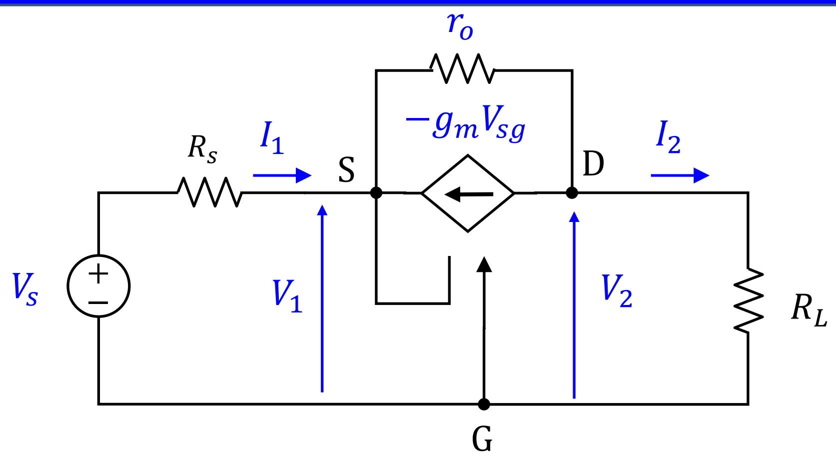
Exercise 9.2 (Homework)

Find the input resistance R_i, output resistance R_o, voltage gain A_v, and the current gain A_i.



$g_m = 5.34 \times 10^{-3}$ $r_o = 50.8$ [kΩ] $R_s = R_L = 3.3$ [kΩ]

Exercise 9.2 (Answer)



$g_m = 5.34 \times 10^{-3}$ $r_o = 50.8$ [kΩ] $R_L = 3.3$ [kΩ]

$$R_i = \frac{r_0 + R_L}{1 + r_0 g_m} = 200\ [\Omega]$$

$$A_v = \frac{1 + r_o g_m}{1 + \frac{r_o}{R_L}} = 16.6$$

In Exp. 9.2

$|A_v| = 18.1$

$$A_i = 1$$

$$R_o = r_o(1 + g_m R_s) + R_s = 13.8\ [\text{M}\Omega]$$

CSA

$R_i = \infty$

$A_v = -16.5$

$A_i = -\infty$

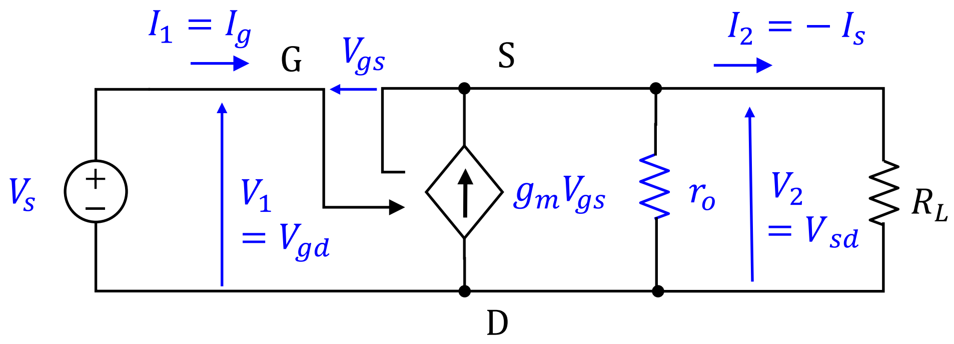
$R_o = 50.8$ [kΩ]

Exercise 9.3.1 (Homework)

Exercise 9.3.1 (Homework)

Exercise 9.3.1 (Homework)

Show that the input resistance R_i, voltage gain A_v, and the current gain A_i, output resistance R_o are given by the following equations:



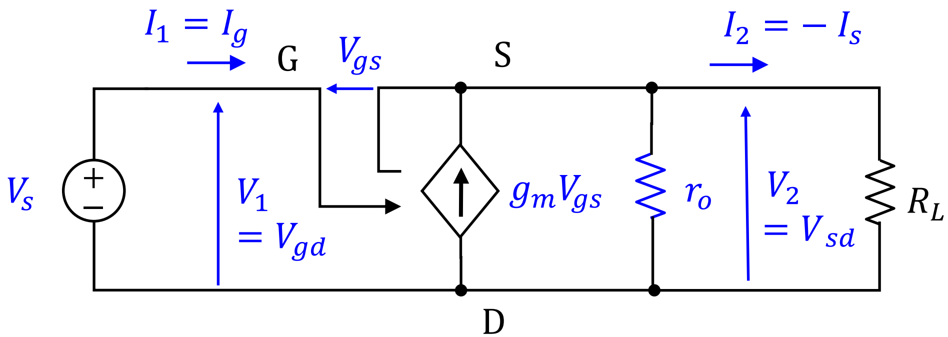
$$R_i = \frac{V_1}{I_1} = \infty$$

$$A_v = \frac{V_2}{V_1} = \frac{g_m r_o R_L}{r_o + R_L + g_m r_o R_L}$$

$$A_i = \frac{I_2}{I_1} = \infty$$

$$R_o = \left.\frac{V_2}{-I_2}\right|_{R_L=\infty,\ V_s=0} = \frac{r_o}{1 + g_m r_o}$$

Exercise 9.3.1 (Answer)



$$I_1 = 0$$

$$R_i = \frac{V_1}{I_1} = \infty$$

CSA: $R_i = \infty$

$$A_i = \frac{I_2}{I_1} = \infty$$

CSA: $A_i = -\infty$

$V_{gs} = V_1 - V_2$

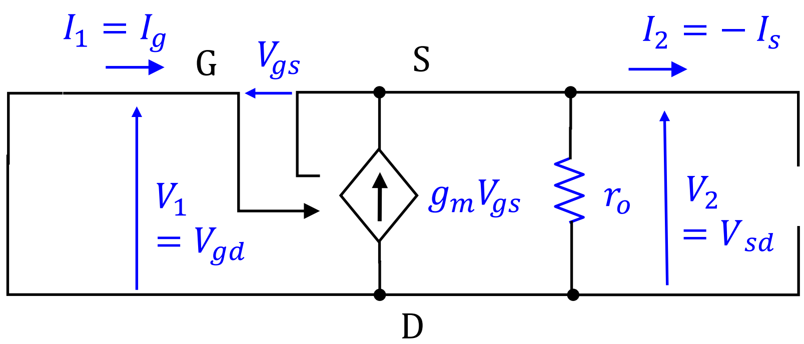
$$V_2 = g_m V_{gs} \frac{1}{\frac{1}{r_o} + \frac{1}{R_L}}$$

$$\left(1 + g_m \frac{1}{\frac{1}{r_o} + \frac{1}{R_L}}\right) V_2 = g_m V_1 \frac{1}{\frac{1}{r_o} + \frac{1}{R_L}}$$

$$A_v = \frac{V_2}{V_1} = \frac{g_m r_o R_L}{r_o + R_L + g_m r_o R_L} < 1$$

CSA: $A_v = -g_m \frac{r_o R_L}{r_o + R_L}$

Exercise 9.3.1 (Answer)



$V_{gs} = -V_2$

$$I_2 = -\frac{V_2}{r_o} + g_m V_{gs}$$

$$= -\frac{V_2}{r_o} - g_m V_2$$

$$R_o = \left.\frac{V_2}{-I_2}\right|_{R_L=\infty,\ V_s=0} = \frac{r_o}{1 + g_m r_o}$$

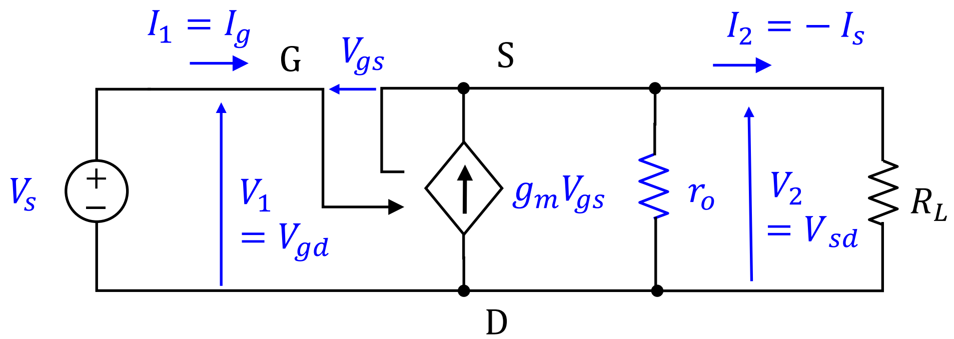
CSA: $R_o = r_o$

Exercise 9.3.2 (Homework)

Exercise 9.3.2 (Homework)

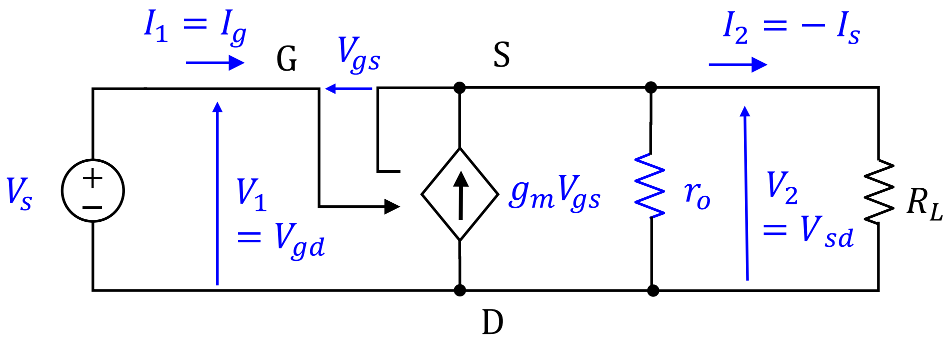
Exercise 9.3.2 (Homework)

Find the input resistance R_i, voltage gain A_v, and the current gain A_i, output resistance R_o.



$g_m = 5.34 \times 10^{-3}$ $\quad r_o = 50.8$ [kΩ] $\quad R_L = 3.3$ [kΩ]

Exercise 9.3.2 (Answer)



$g_m = 5.34 \times 10^{-3}$ $r_o = 50.8$ [kΩ] $R_L = 3.3$ [kΩ]

$$R_i = \infty$$

$$A_v = \frac{g_m r_o R_L}{r_o + R_L + g_m r_o R_L} = 0.943$$

$$A_i = \infty$$

$$R_o = \frac{r_o}{1 + g_m r_o} = 187\ [\Omega]$$

CSA

$R_i = \infty$

$A_v = -16.5$

$A_i = -\infty$

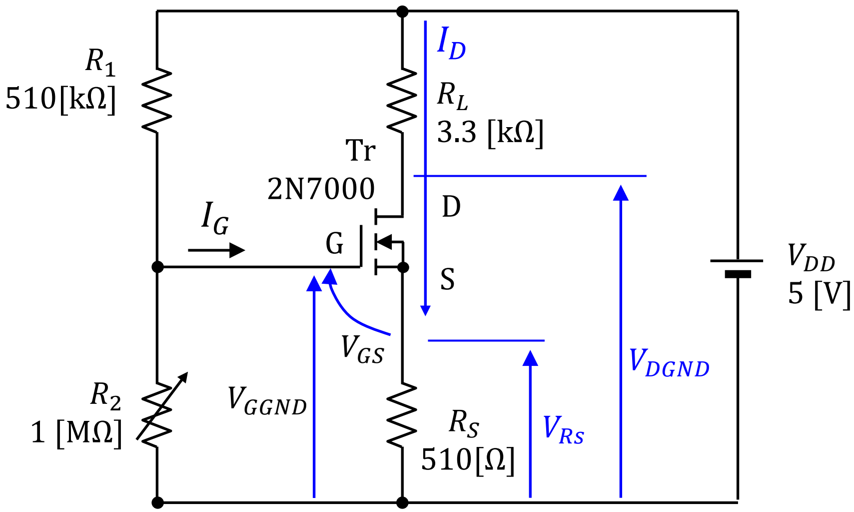
$R_o = 50.8$ [kΩ]

Exercise 9.4 (Homework)

Exercise 9.4 (Homework)

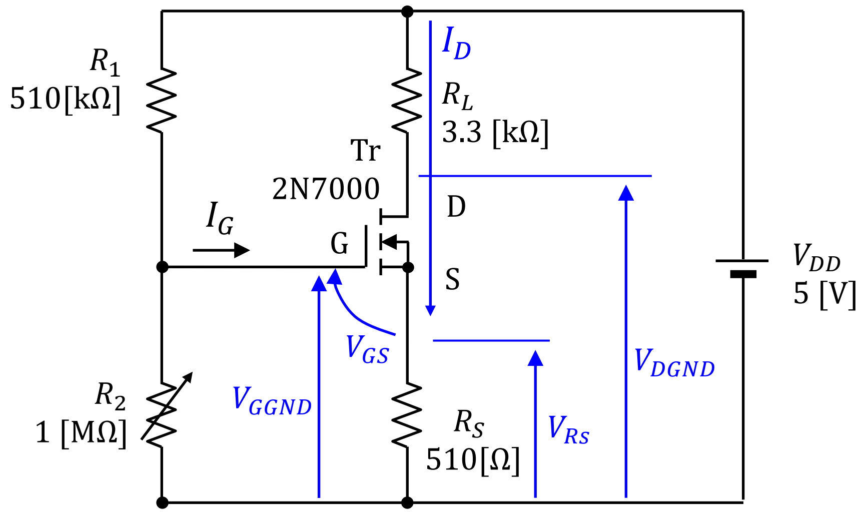
Exercise 9.4 (Homework)

Find R_2 which sets $V_{GGND} = 3$ [V]. Note that at $I_{DQ} = 0.606$ [mA], $V_{GSQ} = 2.20$ [V] .



Hint: $I_G = 0$

Exercise 9.4 (Answer)



$$V_{GGND} = V_{GS} + V_{Rs}$$

$$V_{Rs} = R_S I_{DQ}$$

$$\begin{aligned} V_{GGNDQ} &= V_{GSQ} + R_S I_{DQ} \\ &= 2.2 + 510 \times 0.606 \times 10^{-3} \\ &= 2.51\ [\mathrm{V}] \end{aligned}$$

Because $I_G = 0$,

$$V_{GGNDQ} = \frac{R_2}{R_1 + R_2} V_{DD}$$

$$\begin{aligned} R_2 &= \frac{V_{GNDQ} R_1}{V_{DD} - V_{GNDQ}} \\ &= \frac{2.51 \times 510 \times 10^3}{5 - 2.51} \\ &= 514\ [\mathrm{k\Omega}] \end{aligned}$$

Exercise 10.5 (Homework)

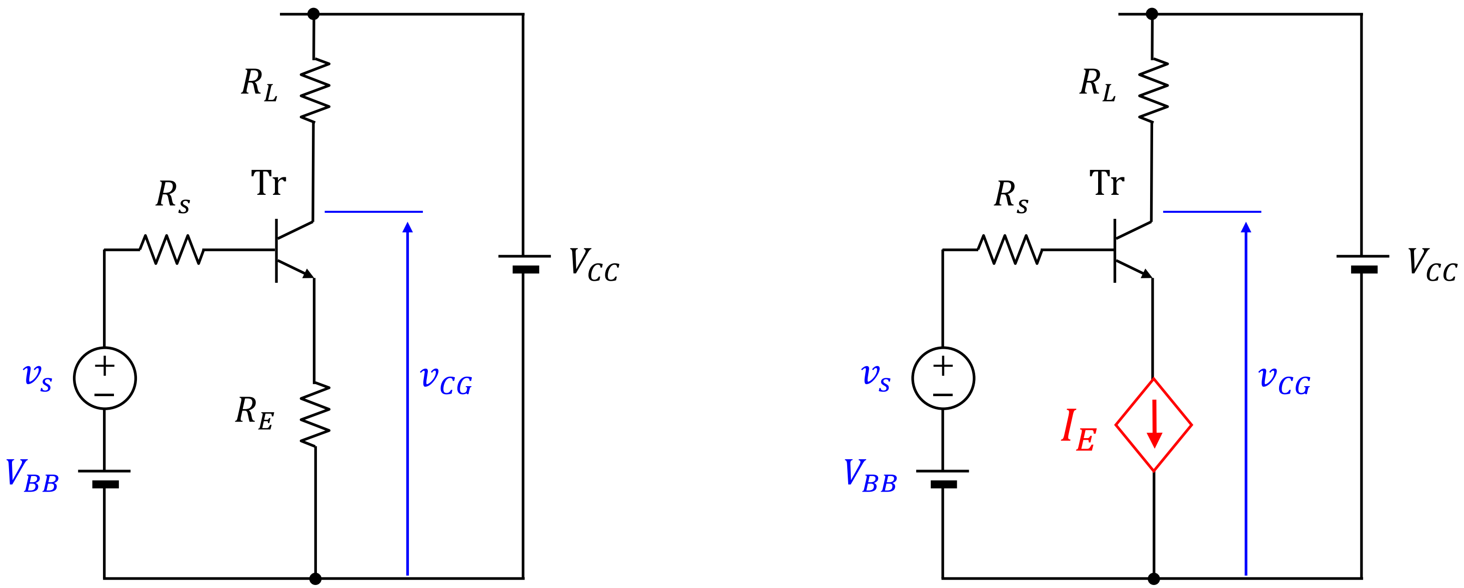
Exercise 10.5 (Homework)

Exercise 10.5 This is your homework.

Exercise 10.5 (Homework)

Find the voltage gains $A_v = \dfrac{V_{cg}}{V_s}$ in the circuits below.

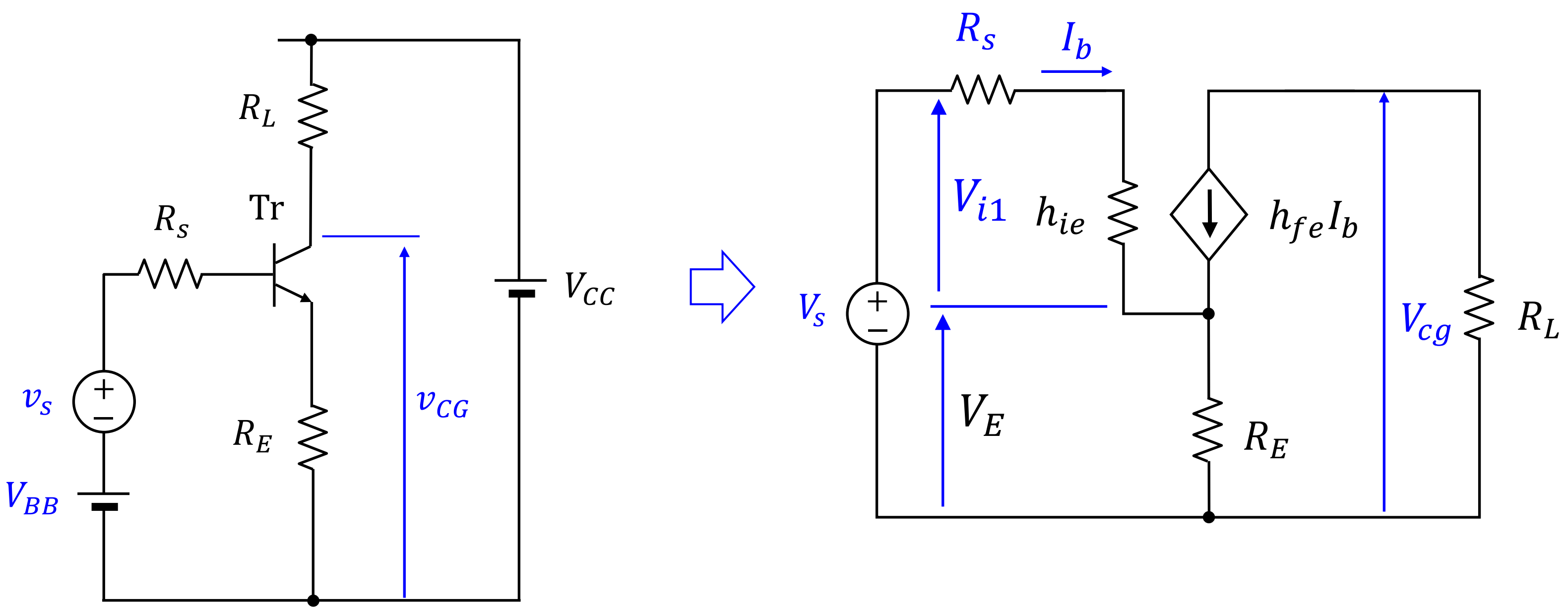
V_s and V_{cg} are effective values of AC components of v_s and v_{CG}, respectively.



(a) (b)

Pause the video, and answer the problem.

Exercise 10.5 (Answer)



$$V_{i1} = (R_s + h_{ie})I_b$$

$$V_E = R_E(1 + h_{fe})I_b$$

$$V_s = V_{i1} + V_E$$
$$= (R_s + h_{ie})I_b + R_e(1 + h_{fe})I_b$$

$$V_{cg} = -h_{fe}R_L I_b$$

$$A_v = \frac{V_{cg}}{V_s} = -\frac{h_{fe}R_L}{R_S + h_{ie} + (1 + h_{fe})R_E}$$

In the circuit in (b), $R_E = \infty$.

$$A_v = 0$$

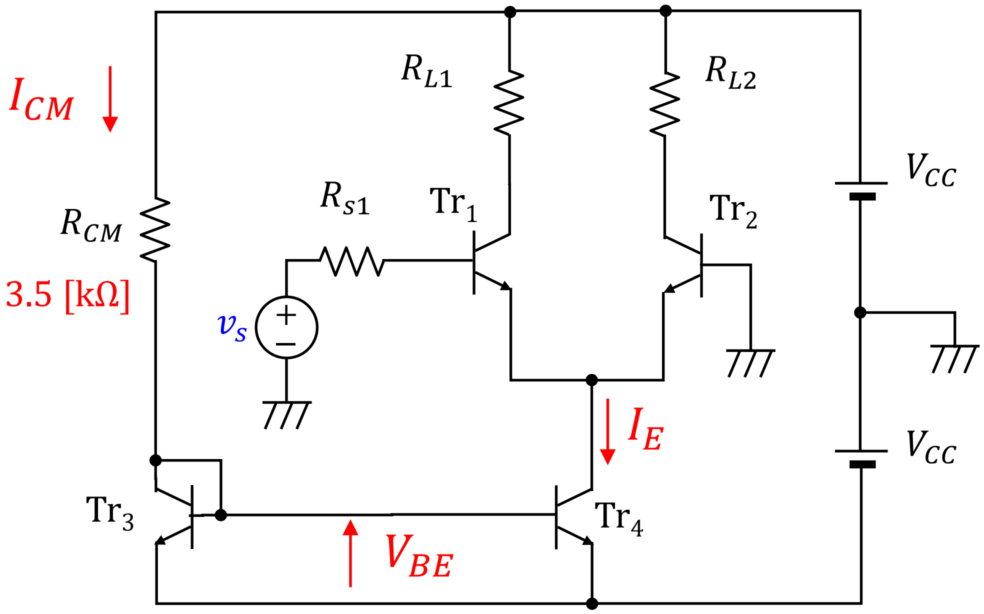
Exercise 10.6 (Homework)

Exercise 10.6 (Homework)

Exercise 10.6 This is your homework.

Exercise 10.6 (Homework)

The temperature stability of operating point Q of the circuit below depends on the stability of I_E. The stability factor S_V is defined as



$$S_V = \left.\frac{\partial I_E}{\partial V_{BE}}\right|_Q$$

Find S_V and compare the value with those in Section 5.2, which were

Robust bias circuit:

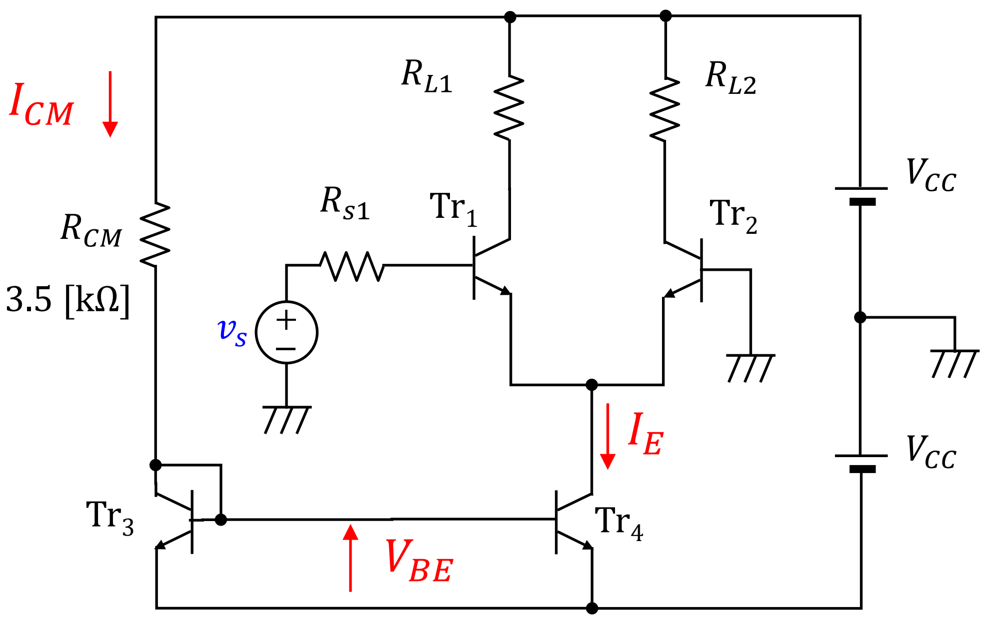
$$S_V = -9.37 \times 10^{-4}$$

Non Robust bias circuit:

$$S_V = -0.0307$$

Pause the video, and answer the problem. Find the temperature stability of this circuit.

Exercise 10.6 (Answer)



$$I_E = I_{CM} = \frac{2V_{CC} - V_{BE}}{R_{CM}}$$

$$S_V = \left.\frac{\partial I_E}{\partial V_{BE}}\right|_Q$$

$$= -\frac{1}{R_{CM}}$$

$$= -2.86 \times 10^{-4}$$

In Section 5.2

Robust bias circuit:

$$S_V = -9.37 \times 10^{-4}$$

Non Robust bias circuit:

$$S_V = -0.0307$$

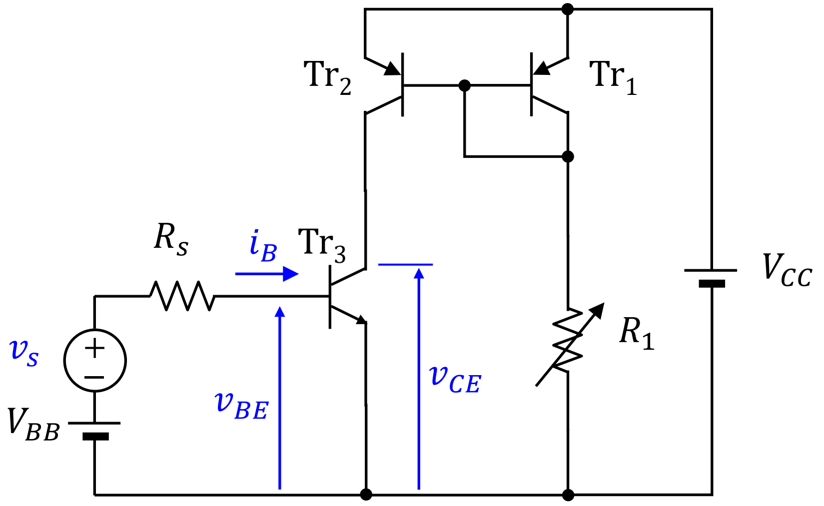
Exercise 10.10 (Homework)

Exercise 10.10 (Homework)

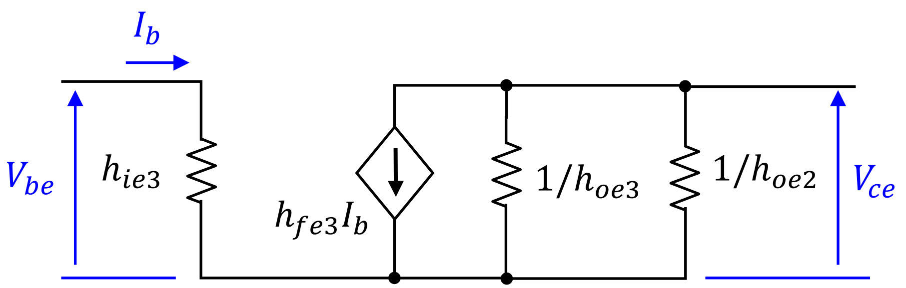
Exercise 10.10 This is your homework.

Exercise 10.10 (Homework)

Find the voltage gain $A_v = V_{ce}/V_{be}$ of high gain amplifier below by assuming that $h_{ie3} = 13\ [\mathrm{k\Omega}], h_{fe3} = 210$, and $h_{oe2} = h_{oe3} = 6\ [\mu\mathrm{S}]$.



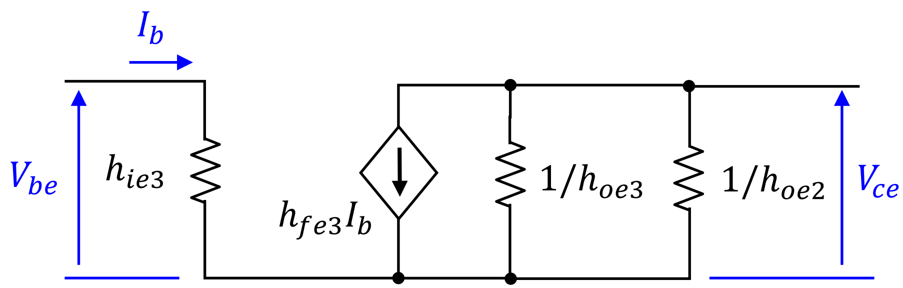
High gain amplifier



Equivalent circuit

Pause the video, and answer the problem.

Exercise 10.10 (Answer)



Equivalent circuit

$$A_v = \frac{V_{ce}}{V_{be}}$$

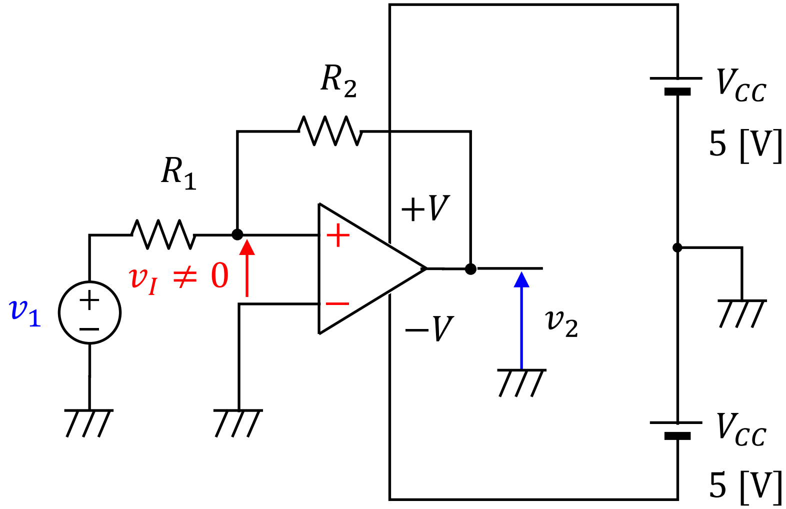
$$= -\frac{h_{fe3}}{h_{ie3}} \frac{1}{h_{oe2} + h_{oe3}}$$

$$\approx 1350$$

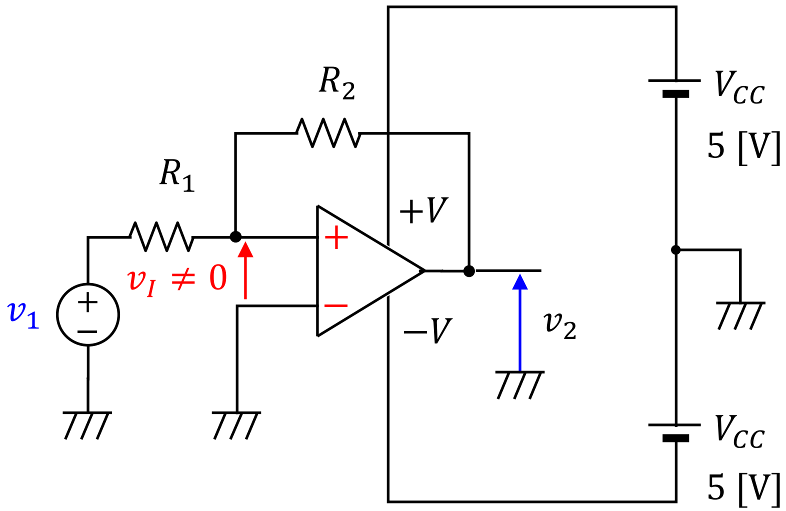
Exercise 11.1 (Homework)

Exercise 11.1 (Homework)

The connection of this circuit is wrong. The input terminals are reversed. The virtual short is not valid in this circuit, i.e. $V_I \neq 0$. Find v_2, if $v_1 > 0$.

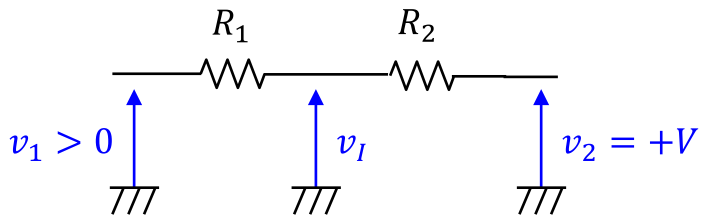


Exercise 11.1 (Answer)



v_2 goes up to the limit. The limit is at most $+V$, depending on Op-Amp hardware.

If the limit is $+V$, then



$$v_I = \frac{R_2 v_1 + R_1 v_2}{R_1 + R_2}$$
$$= \frac{R_2 v_1 + R_1 V}{R_1 + R_2} > 0$$

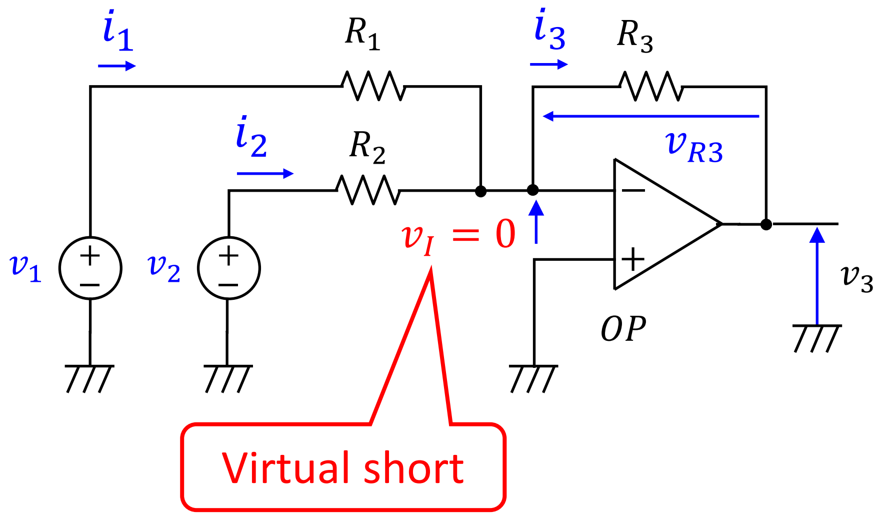
Exercise 11.3 (Homework)

Exercise 11.3 (Homework)

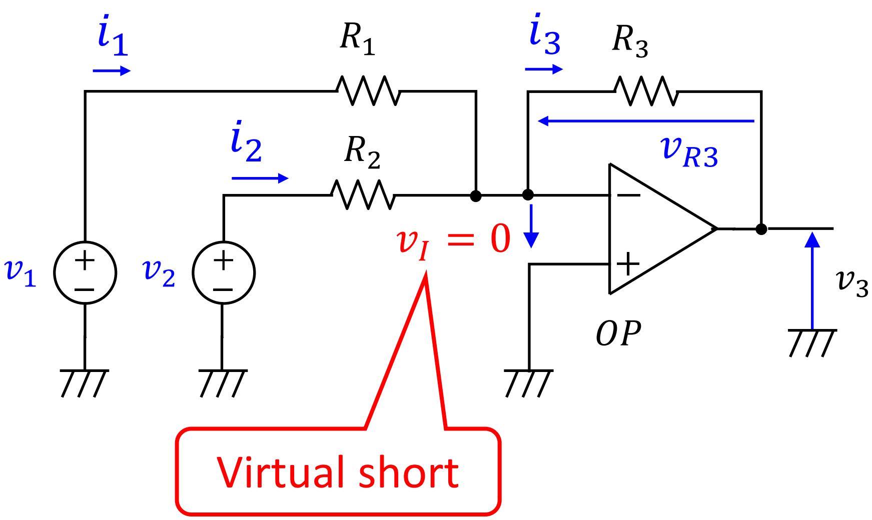
Exercise 11.3 (Homework)

Show that, if $R_1 = R_2$, then v_3 is given as follows:

$$v_3 = -\frac{R_3}{R_1}(v_1 + v_2).$$



Exercise 11.3 (Answer)



According to Ohm's law,

$$i_1 = \frac{v_1}{R_1}$$

$$i_2 = \frac{v_2}{R_2}$$

Because $R_i = \infty$,

$$i_3 = i_1 + i_2$$

Then,

$$v_{R3} = R_3\, i_3$$

$$= \frac{R_3}{R_1} v_1 + \frac{R_3}{R_2} v_2$$

$R_1 = R_2$

$$= \frac{R_3}{R_1}(v_1 + v_2)$$

Thus,

$$v_3 = -v_{R3} - v_{in}$$

$$= -\frac{R_3}{R_1}(v_1 + v_2)$$

$$= A_v(v_1 + v_2)$$

$$A_v = -\frac{R_3}{R_1}$$

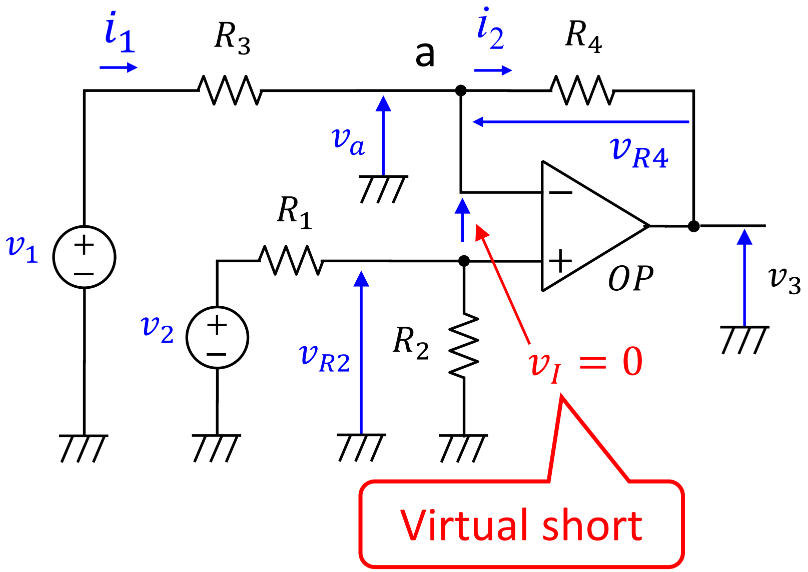
Exercise 11.4 (Homework)

Exercise 11.4 (Homework)

Exercise 11.4 (Homework)

Show that, if $\frac{R_2}{R_1} = \frac{R_4}{R_3} = k$, then v_3 is given as follows:

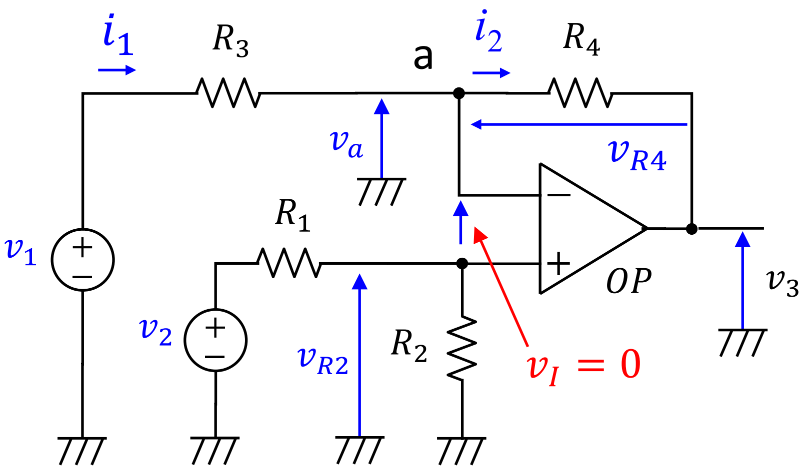
$$v_3 = -k(v_1 - v_2).$$



Hints:

1. Since $R_i = \infty$, we can find the relationship between v_{R2} and v_2.
2. Using the virtual short, we can find the voltage v_a at node “a”.
3. We can express i_1 with v_1, v_2.
4. Since $R_i = \infty$, we can express i_2 using v_1, v_2.
5. Now we can find v_{R4} as a function of v_1, v_2.
6. Note that $v_3 = v_a - v_{R4}$. Find v_3 as a function of v_1, v_2.
7. Substitute the condition $\frac{R_2}{R_1} = \frac{R_4}{R_3} = k$ in to the above equation, and show that $v_3 = -k(v_1 - v_2)$.

Exercise 11.4 (Homework)



1. $R_{in} = \infty$

$$v_{R2} = \frac{R_2}{R_1 + R_2} v_2$$

2. $v_I = 0$

$$v_a = v_{R2}$$

3. $$i_1 = \frac{v_1 - v_a}{R_3}$$

4. $R_{in} = \infty$

$$i_2 = i_1$$

5. $$v_{R4} = R_4\, i_2 = \frac{R_4}{R_3}(v_1 - v_a) = \frac{R_4}{R_3}\left(v_1 - \frac{R_2}{R_1 + R_2} v_2\right)$$

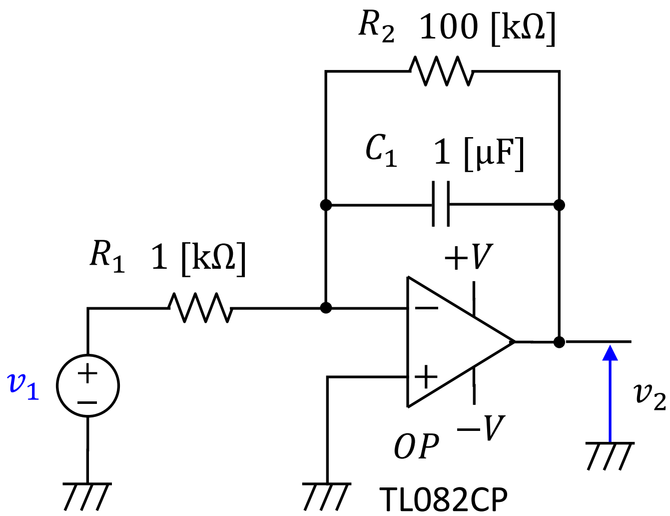
6. $$v_3 = v_a - v_{R4} = \frac{R_2}{R_1 + R_2} v_2 - \frac{R_4}{R_3}\left(v_1 - \frac{R_2}{R_1 + R_2} v_2\right)$$

7. $$\frac{R_2}{R_1} = \frac{R_4}{R_3} = k$$

$$v_3 = \frac{k}{1+k} v_2 - k\left(v_1 - \frac{k}{1+k} v_2\right) = -k(v_1 - v_2)$$

Exercise 11.5 (Homework)

Exercise 11.5 (Homework)



These were the results of Experiment 11.5,

$$V_{1rms} = 0.675\ [\mathrm{V}], \qquad V_{2rms} = 1.08$$

where $v_1 = V_m \sin \omega t$, $f = 100\ [\mathrm{Hz}]$.

1. Show that the ratio V_{2rms}/V_{1rms} is given by,

$$\frac{V_{2rms}}{V_{1rm}} = \frac{1}{\omega C_1 R_1}.$$

2. Confirm that the experimental and theoretical values of the above ratio coincide with each other.

You can neglect R_2 for its large resistance.

Exercise 11.5 (Answer)

1.

If $v_1 = V_m \sin \omega t$, then

$$v_2 = -\frac{1}{C_1 R_1} \int V_m \sin \omega t \, dt$$
$$= \frac{V_m}{\omega C_1 R_1} \cos \omega t \, .$$

Then, by the definition of rms value,

$$V_{1rms} = \frac{V_m}{\sqrt{2}}, V_{2rms} = \frac{V_m}{\sqrt{2}\omega C_1 R_1}$$

Thus

$$\frac{V_{2rms}}{V_{1rm}} = \frac{1}{\omega C_1 R_1}.$$

2.

$f = 100$ [Hz], $C_1 = 1$ [μF], $R_1 = 1$ [kΩ]

$$\frac{1}{\omega C_1 R_1} = \frac{1}{2\pi \times 100 \times 10^{-6} \times 1000}$$
$$= 1.59$$

$V_{1rms} = 0.675$
$V_{2rms} = 1.08$

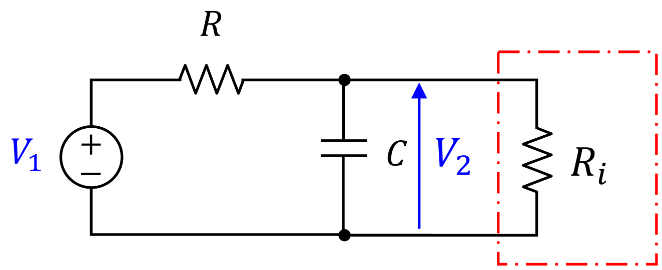
$$\frac{V_{2rms}}{V_{1rm}} = \frac{1.08}{0.675} = 1.60$$

Exercise 12.2 (Homework)

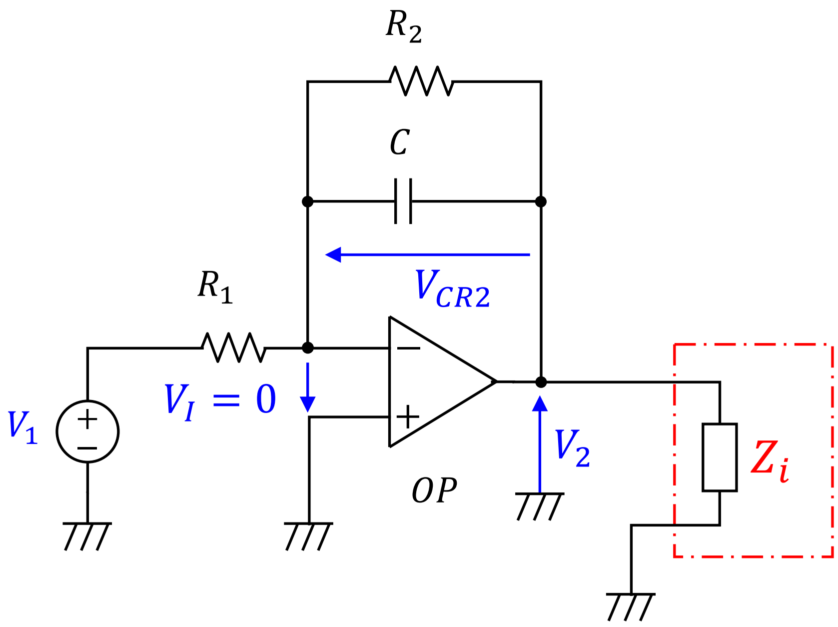
Exercise 12.2 (Homework)

Exercise 12.2 (Homework)

1. Find the cutoff frequency of the $R - C$ filter in (a) where $Z_i = R_i$.
2. Explain why the cutoff frequency in (b) is not influenced by Z_i.

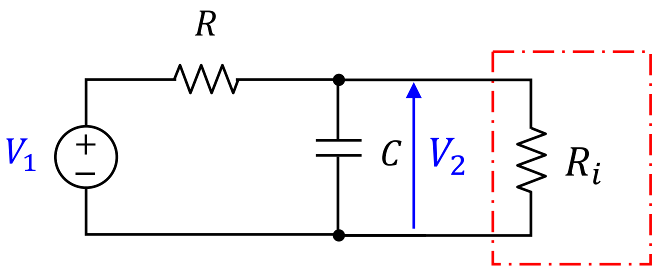


(a) $R - C$ low pass filter



(b) Op-Amp low pass filter

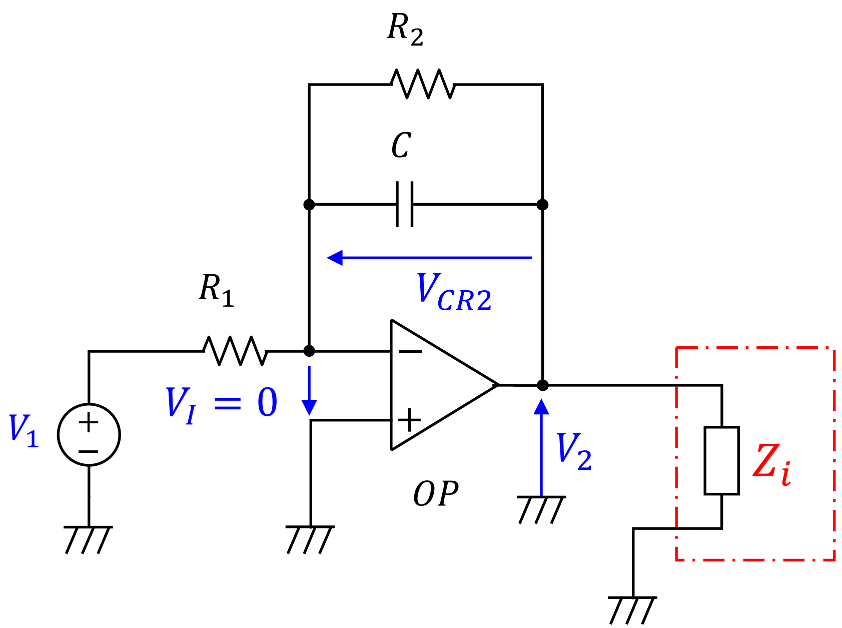
Exercise 12.2 (Homework)



$$V_2 = \frac{\dfrac{1}{\dfrac{1}{R_i} + j\omega C}}{R + \dfrac{1}{\dfrac{1}{R_i} + j\omega C}} V_1 = \frac{\dfrac{R_i}{1 + j\omega C R_i}}{R + \dfrac{R_i}{1 + j\omega C R_i}} V_1$$

$$= \frac{R_i}{R + R_i + j\omega C R R_i} V_1 = \frac{R_i}{R + R_i} \times \frac{1}{1 + j\omega C \dfrac{R R_i}{R + R_i}} V_1$$

$$f_c = \frac{1}{2\pi C \dfrac{R R_i}{R + R_i}}$$



Assume that the virtual short is working in this circuit. Then, V_2 is determined by V_{CR2}, and V_{CR2} is determined by V_1.

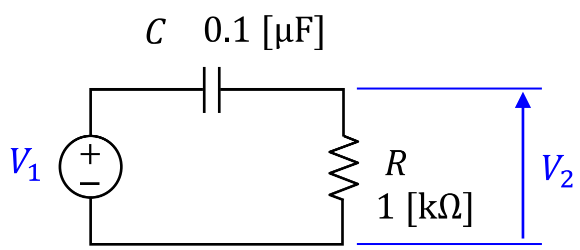
V_2 is not influenced by Z_i

Exercise 12.3 (Homework)

Exercise 12.3 (Homework)

Exercise 12.3 (Homework)

1. Show that the voltage gain G_V and the phase difference $\psi_{V_2-V_1}$ of the circuit below are given by the following equations:



$$G_V = 20\log\frac{V_2}{V_1} = 20\log\frac{\omega CR}{\sqrt{1+(\omega CR)^2}}$$

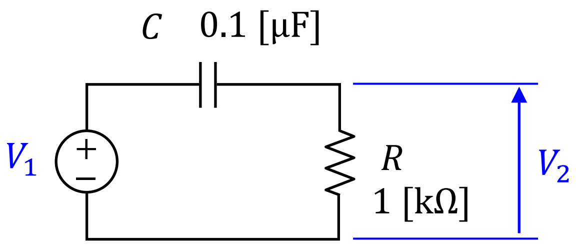
$$\psi_{V_2-V_1} = 90° - \tan^{-1}\omega CR$$

2. Show that the cutoff frequency is expressed as follows:

$$f_c = \frac{1}{2\pi CR}$$

3. Find the value of cutoff frequency.

Exercise 12.3 (Answer)



1.

$$V_2 = \frac{R}{R + \frac{1}{j\omega C}} V_1$$

$$= \frac{j\omega CR}{1 + j\omega CR} V_1$$

$$G_V = 20 \log \frac{V_2}{V_1} = 20 \log \frac{\omega CR}{\sqrt{1 + (\omega CR)^2}}$$

$$\psi_{V_2 - V_1} = 90° - \tan^{-1} \omega CR$$

2.

At $\omega CR = 1$

$$G_V = 20 \log \frac{1}{\sqrt{2}} = -3 \text{ [dB]}$$

$$\psi_{V_2 - V_1} = 90° - \tan^{-1} 1 = 45 \text{ [°]}$$

$$f_c = \frac{1}{2\pi CR}$$: Cutoff Frequency

3.

$$= \frac{1}{2\pi \times 0.1 \times 10^{-6} \times 10^3}$$

$$= 1.59 \text{ [kHz]}$$

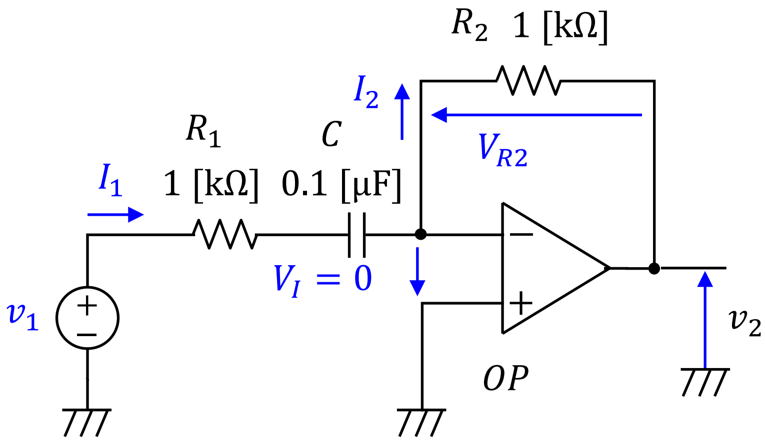
Exercise 12.4 (Homework)

Exercise 12.4 (Homework)

Exercise 12.4 (Homework)

1. Show that the voltage gain G_V and the phase difference $\psi_{V_2-V_1}$ of the circuit below are given by the following equations:

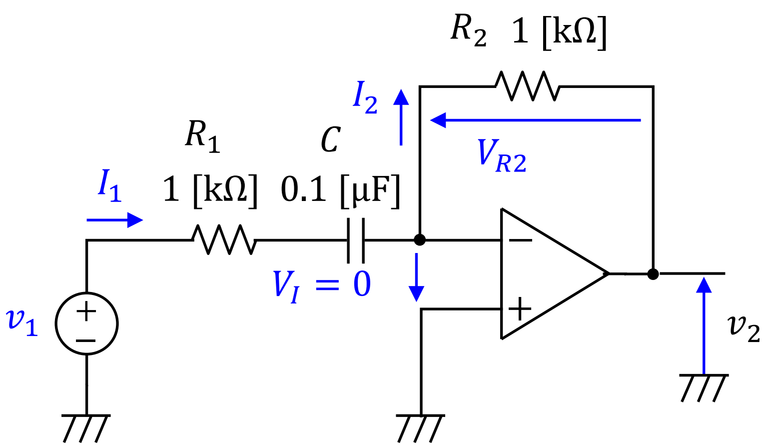
2. Find the value of cutoff frequency.



$$G_V = 20\log\frac{V_2}{V_1} = 20\log\frac{R_2}{R_1}\frac{\omega C R_1}{\sqrt{1+(\omega C R_1)^2}}$$

$$\psi_{V_2-V_1} = -90° - \tan^{-1}\omega C R_1$$

Exercise 12.4 (Answer)



1.

$V_I = 0$ ⇨ $I_1 = \dfrac{V_1}{R_1 + \dfrac{1}{j\omega C}}$

$Z_i = \infty$ ⇨ $I_2 = I_1$

$$V_{R2} = R_2 I_2 = \frac{R_2}{R_1}\frac{1}{1 + \dfrac{1}{j\omega C R_1}}V_1 = \frac{R_2}{R_1}\frac{j\omega C R_1}{1 + j\omega C R_1}V_1$$

$$V_2 = -V_{R2} - V_I = -\frac{R_2}{R_1}\frac{j\omega C R_1}{1 + j\omega C R_1}V_1$$

$$G_V = 20\log\frac{V_2}{V_1} = 20\log\frac{R_2}{R_1}\frac{\omega C R_1}{\sqrt{1 + (\omega C R_1)^2}}$$

$$\psi_{V_2 - V_1} = -90° - \tan^{-1}\omega C R_1$$

2.

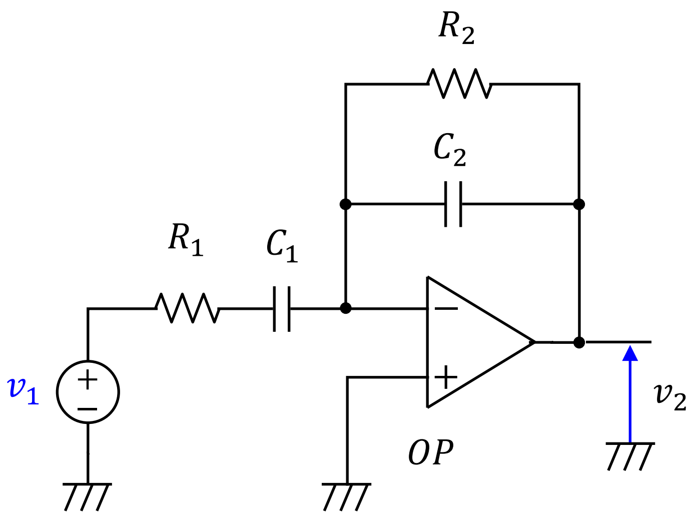
$\omega C R_1 = 1$ ⇨ $f_c = \dfrac{1}{2\pi C R_1} = 1.59$ [kHz]

Exercise 12.5 (Homework)

Exercise 12.5 (Homework)

Exercise 12.5 (Homework)

$$f_{c1} = \frac{1}{2\pi C_1 R_1}, f_{c2} = \frac{1}{2\pi C_2 R_2}$$



Show that

If $f \ll f_{c1}, f_{c2}$

$$G_V = 20 \log \omega C_1 R_2$$
$$\psi_{V_2 - V_1} = -90°$$

If $f_{c1} \ll f \ll f_{c2}$

$$G_V = 20 \log \frac{R_2}{R_1}$$
$$\psi_{V_2 - V_1} = -180°$$

If $f_{c1}, f_{c2} \ll f$

$$G_V = 20 \log \frac{1}{\omega C_2 R_1}$$
$$\psi_{V_2 - V_1} = -270°$$

Exercise 12.5 (Answer)

$$G_V = 20\log\frac{R_2}{R_1}\frac{\omega C_1 R_1}{\sqrt{1+(\omega C_1 R_1)^2}\sqrt{1+(\omega C_2 R_2)^2}}$$

$$\psi_{V_2-V_1} = -90° - \tan^{-1}\omega C_1 R_1 - \tan^{-1}\omega C_2 R_2$$

$$f_{c1} = \frac{1}{2\pi C_1 R_1},\ f_{c2} = \frac{1}{2\pi C_2 R_2}$$

If $f \ll f_{c1}, f_{c2}$

$$G_V = 20\log\frac{R_2}{R_1}\frac{\omega C_1 R_1}{\sqrt{1+(\cancel{\omega C_1 R_1})^2}\sqrt{1+(\cancel{\omega C_2 R_2})^2}} \approx 20\log\omega C_1 R_2$$

$$\psi_{V_2-V_1} \approx -90° - \tan^{-1}0 - \tan^{-1}0 = -90°$$

If $f_{c1} \ll f \ll f_{c2}$

$$G_V = 20\log\frac{R_2}{R_1}\frac{\omega C_1 R_1}{\sqrt{\cancel{1}+(\omega C_1 R_1)^2}\sqrt{1+(\cancel{\omega C_2 R_2})^2}} \approx 20\log\frac{R_2}{R_1}$$

$$\psi_{V_2-V_1} \approx -90° - \tan^{-1}\infty - \tan^{-1}0 = -180°$$

If $f_{c1}, f_{c2} \ll f$

$$G_V = 20\log\frac{R_2}{R_1}\frac{\omega C_1 R_1}{\sqrt{\cancel{1}+(\omega C_1 R_1)^2}\sqrt{\cancel{1}+(\omega C_2 R_2)^2}} \approx 20\log\frac{1}{\omega C_2 R_1}$$

$$\psi_{V_2-V_1} \approx -90° - \tan^{-1}\infty - \tan^{-1}\infty = -270°$$

Exercise 13.4 (Homework)

Exercise 13.4 (Homework)

Exercise 13.4 (Homework)

Prove the following equations:

$$X_2(X_1 + X_0) = X_2X_1 + X_2X_0$$

$$X_2 + X_1X_0 = (X_2 + X_1)(X_2 + X_0)$$

$$\overline{X_1 + X_0} = \bar{X}_1\bar{X}_0$$

$$\bar{X}_1\bar{X}_0 + X_1\bar{X}_0 + X_1X_0 = X_1 + \bar{X}_0$$

Exercise 13.4 (Answer)

$$X_2(X_1 + X_0) = X_2X_1 + X_2X_0$$

X_2	X_1	X_0	X_1+X_0	$X_2(X_1+X_0)$	X_2X_1	X_2X_0	$X_2X_0+X_1X_0$
0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0
0	1	0	1	0	0	0	0
0	1	1	1	0	0	0	0
1	0	0	0	0	0	0	0
1	0	1	1	1	0	1	1
1	1	0	1	1	1	0	1
1	1	1	1	1	1	1	1

$$X_2 + X_1X_0 = (X_2 + X_1)(X_2 + X_0)$$

X_2	X_1	X_0	X_1X_0	$X_2+X_1X_0$	X_2+X_1	X_2+X_0	$(X_2+X_0)(X_1+X_0)$
0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	0
0	1	0	0	0	1	0	0
0	1	1	1	1	1	1	1
1	0	0	0	1	1	1	1
1	0	1	0	1	1	1	1
1	1	0	0	1	1	1	1
1	1	1	1	1	1	1	1

Exercise 13.4 (Answer)

$\overline{X_1 + X_0} = \bar{X}_1\bar{X}_0$

X_1	X_0	$X_1 + X_0$	$\overline{X_1 + X_0}$	$\bar{X}_1$	$\bar{X}_0$	$\bar{X}_1\bar{X}_0$
0	0	0	1	1	1	1
0	1	1	0	1	0	0
1	0	1	0	0	1	0
1	1	1	0	0	0	0

$\bar{X}_1\bar{X}_0 + X_1\bar{X}_0 + X_1X_0 = X_1 + \bar{X}_0$

X_1	X_0	$\bar{X}_1$	$\bar{X}_0$	$\bar{X}_1\bar{X}_0$	$X_1\bar{X}_0$	X_1X_0	$\bar{X}_1\bar{X}_0 + X_1\bar{X}_0 + X_1X_0$	$X_1 + \bar{X}_0$
0	0	1	1	1	0	0	1	1
0	1	1	0	0	0	0	0	0
1	0	0	1	0	1	0	1	1
1	1	0	0	0	0	1	1	1

Exercise 13.5 (Homework)

Exercise 13.5 (Homework)

Exercise 13.5 (Homework)

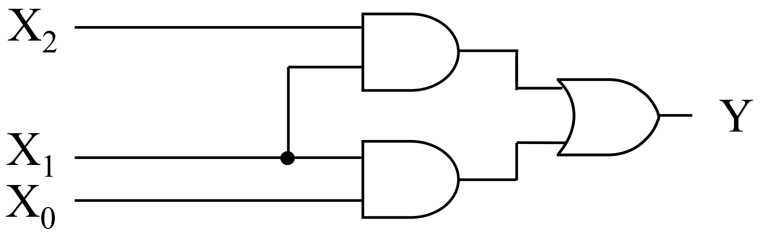
Design a logic circuit with three inputs X_2, X_1 and X_0 and one output Y which meets the truth table below.

X_2	X_1	X_0	Y
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	1

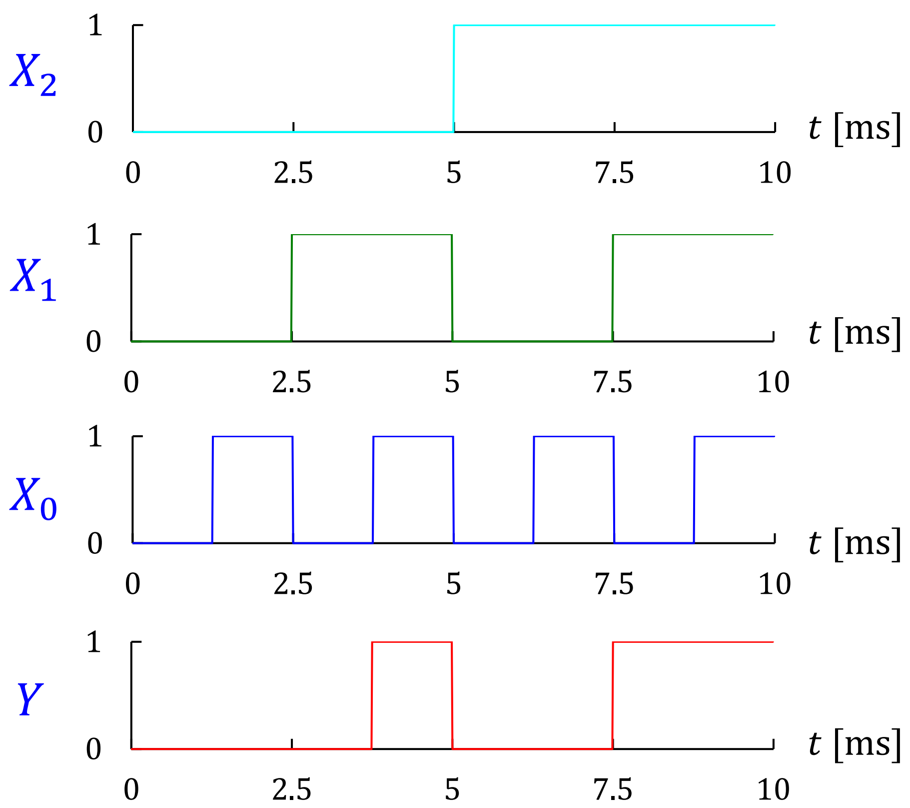
Exercise 13.5 (Answer)

X_2	X_1	X_0	Y
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	1

$$Y = \bar{X}_2 X_1 X_0 + X_2 X_1 \bar{X}_0 + X_2 X_1 X_0$$
$$= X_1 X_0 + X_2 X_1$$



Exercise 13.5 (Answer)



Exercise 14.4.1

Exercise 14.4.1

Exercise 14.4.1

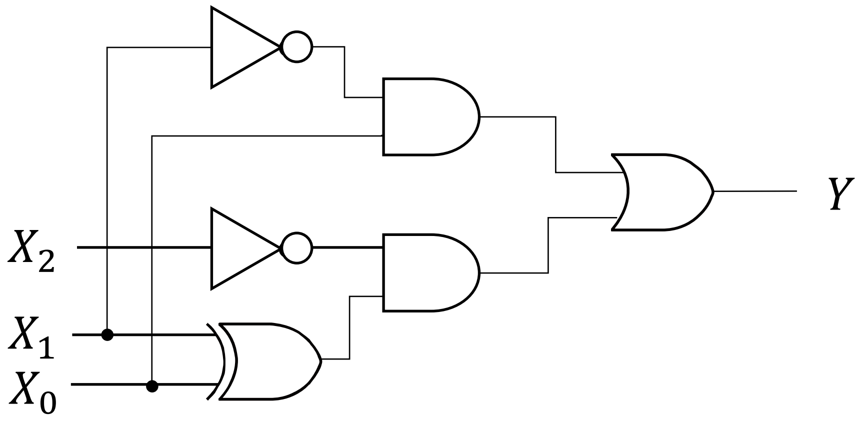
Design logic circuits that satisfy the truth table below. You can use any of AND, OR, NOT, NAND, NOR, XOR gates. You can easily find a circuit that has 6 logic gates by using an XOR gate. You are encouraged to find a circuit that has 5 gates.

X_2	X_1	X_0	Y
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	0

Exercise 14.4.1 (Answer)

X_2	X_1	X_0	Y
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	0

$$Y = \bar{X}_2\bar{X}_1X_0 + \bar{X}_2X_1\bar{X}_0 + X_2\bar{X}_1X_0$$
$$= \bar{X}_2(\bar{X}_1X_0 + X_1\bar{X}_0) + \bar{X}_1X_0$$



6 gates

Exercise 14.4.1 (Answer)

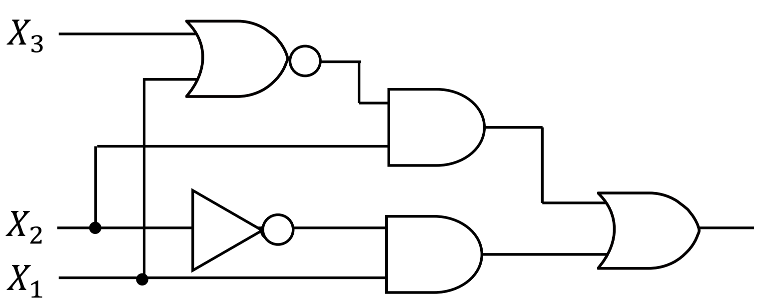
X_3	X_2	X_1	Y
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	0

$$Y = \bar{X}_3\bar{X}_2X_1 + \bar{X}_3X_2\bar{X}_1 + X_3\bar{X}_2X_1$$

$$= \bar{X}_3X_2\bar{X}_1 + \bar{X}_2X_1$$

$$= X_2\overline{\overline{\bar{X}_3\bar{X}_1}} + \bar{X}_2X_1$$

$$= X_2\overline{X_3 + X_1} + \bar{X}_2X_1$$



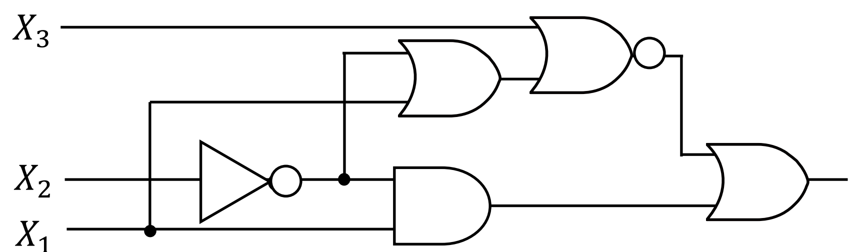
5 gates

$$Y = \bar{X}_3\bar{X}_2X_1 + \bar{X}_3X_2\bar{X}_1 + X_3\bar{X}_2X_1$$

$$= \bar{X}_3X_2\bar{X}_1 + \bar{X}_2X_1$$

$$= \overline{\overline{\bar{X}_3X_2\bar{X}_1}} + \bar{X}_2X_1$$

$$= \overline{X_3 + \bar{X}_2 + X_1} + \bar{X}_2X_1$$



5 gates

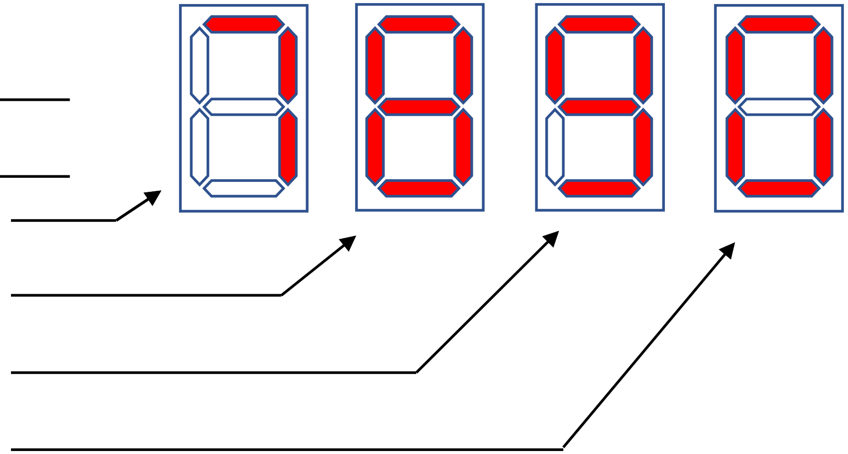
Exercise 14.4.2

Exercise 14.4.2

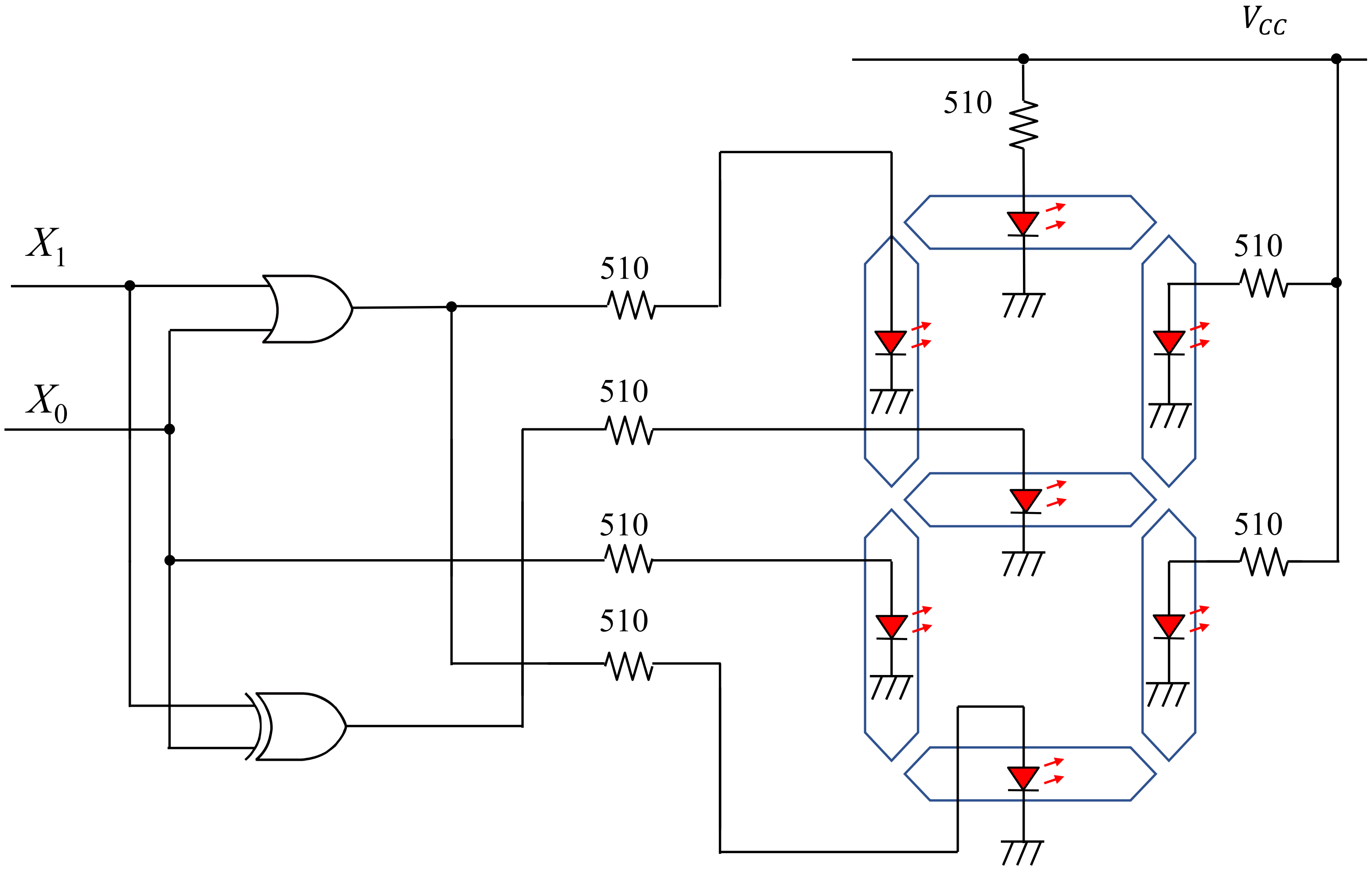
Exercise 14.4.2

Design a logic circuit that has the input-output relationship below.

X_1	X_0
0	0
0	1
1	0
1	1



Exercise 14.4.2 (Answer)



Exercise 14.5

Exercise 14.5

Exercise 14.5 (Homework)

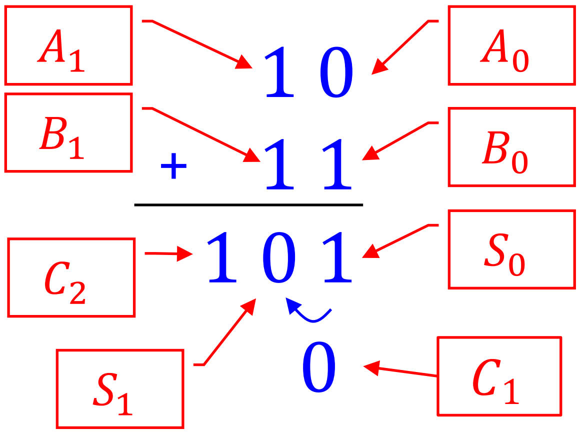
Design a logic circuit that performs the additions below.

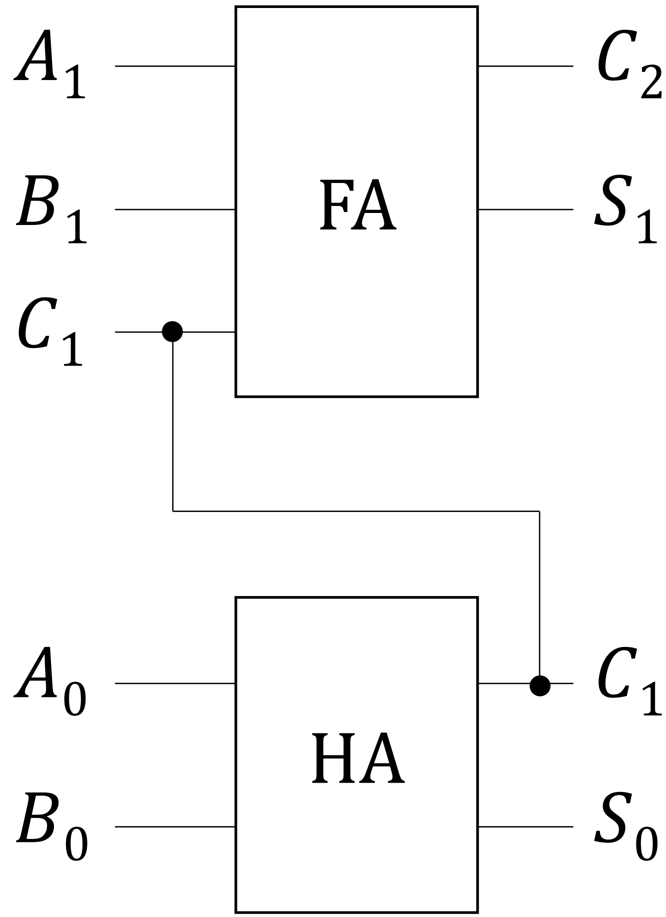
00	00	00	00	01	01	01	01
+ 00	+ 01	+ 10	+ 11	+ 00	+ 01	+ 10	+ 11
000	001	010	011	001	010	011	100

10	10	10	10	11	11	11	11
+ 00	+ 01	+ 10	+ 11	+ 00	+ 01	+ 10	+ 11
010	011	100	101	011	100	101	110

Pause the video and answer the problem.

Exercise 14.5 (Answer)





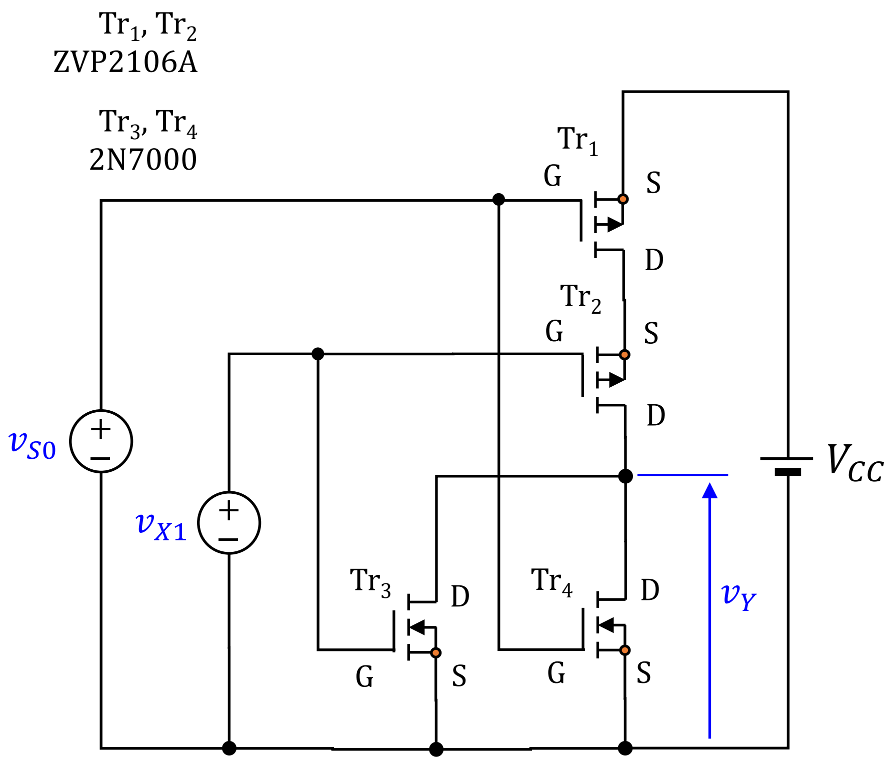
Exercise 15.3 (Homework)

Exercise 15.3 (Homework)

Exercise 15.3 (Homework)

Design a CMOS NOR gate by using two PMOSs and two NMOSs.

Exercise 15.3 (Answer)



Exercise 15.4 (Homework)

Exercise 15.4 (Homework)

Exercise 15.4 (Homework)

Design a CMOS OR gate by using 3 PMOSs and 3 NMOSs.

Exercise 15.3 (Answer)