Bipolar Junction Transistor (BJT):

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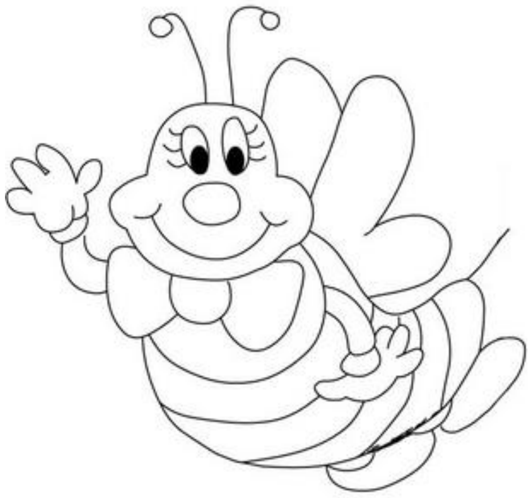
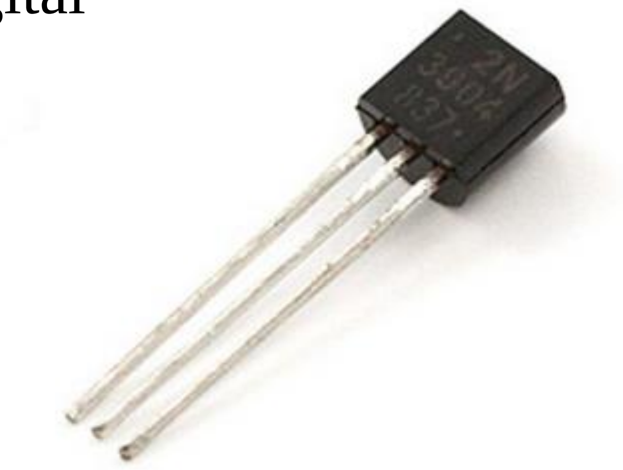


BJT:

1. It’s a semiconductor device that can amplify electrical signals such as radio or television signals.

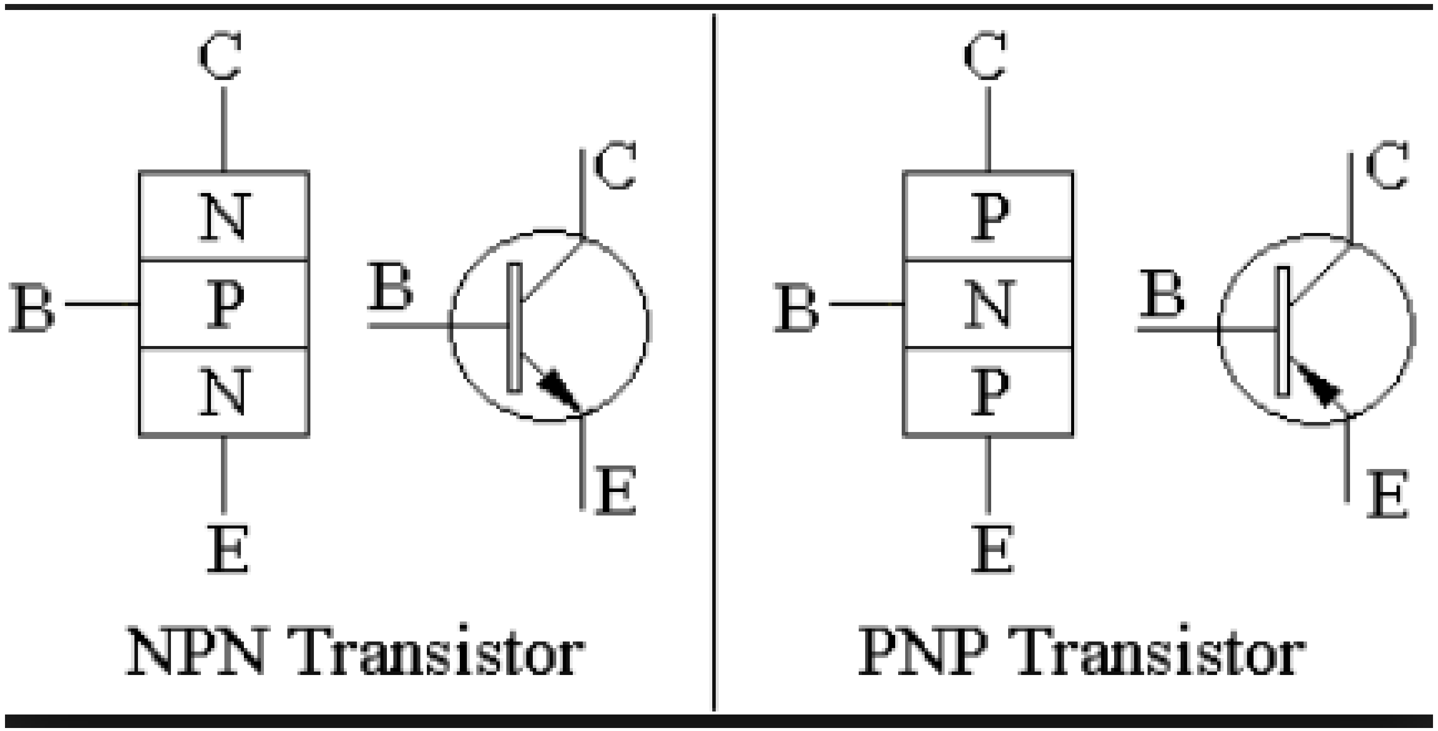
2. Its essential ingredient of every electronic circuits; from the simplest amplifier or oscillator to the most elaborate digital computer.



3. It’s a three terminal device; Base, Emitter, and Collector.

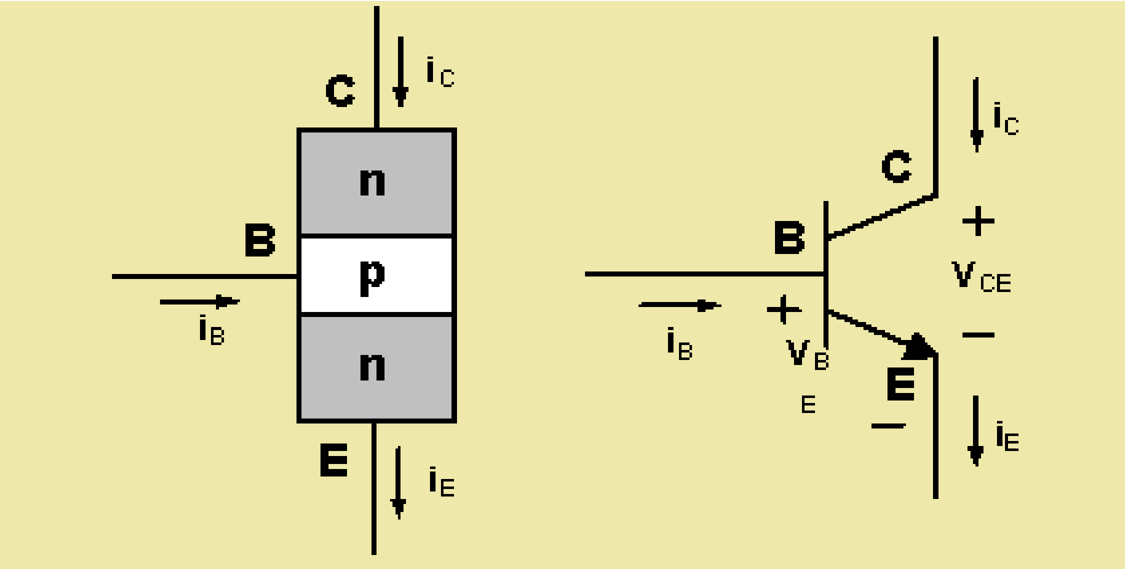
There are two type of BJT:

- **npn** type
- **pnp** type

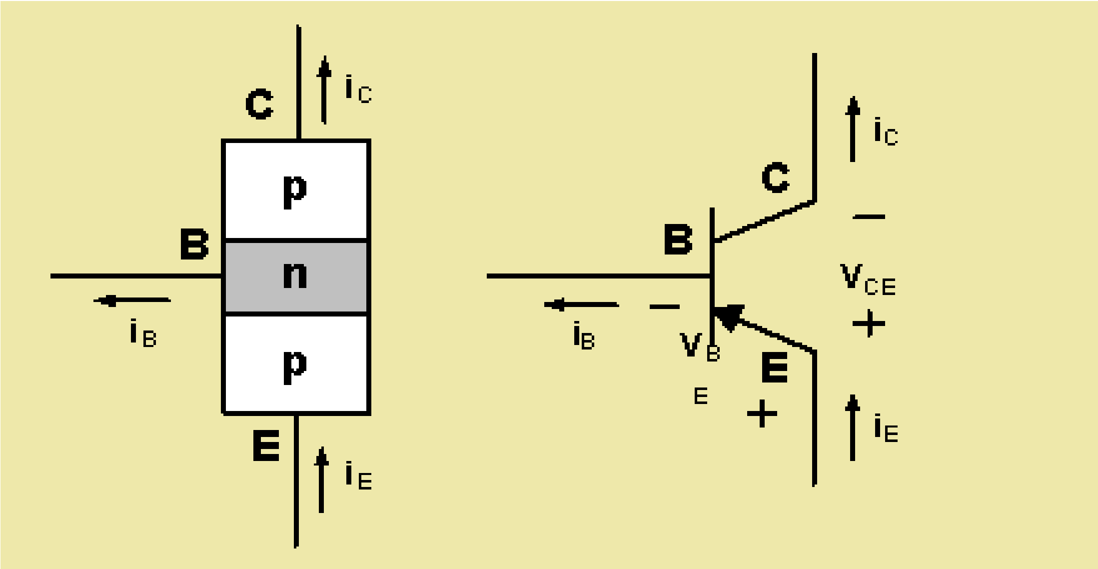


Transistor structure:

- **npn** type



- **pnp** type



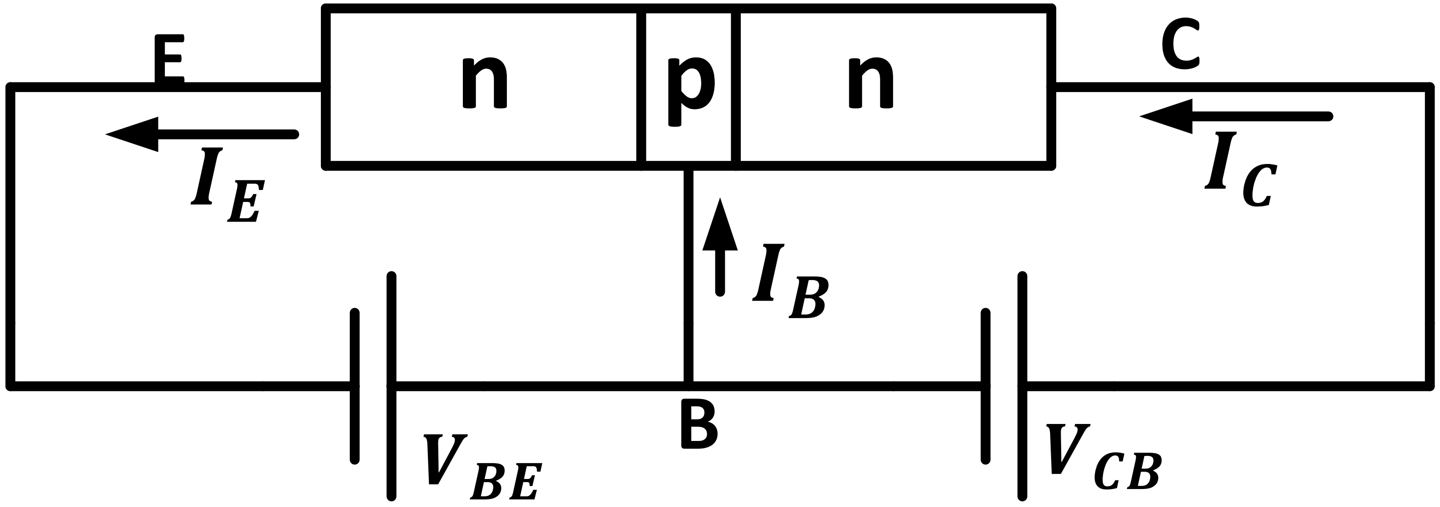
Transistor biasing:

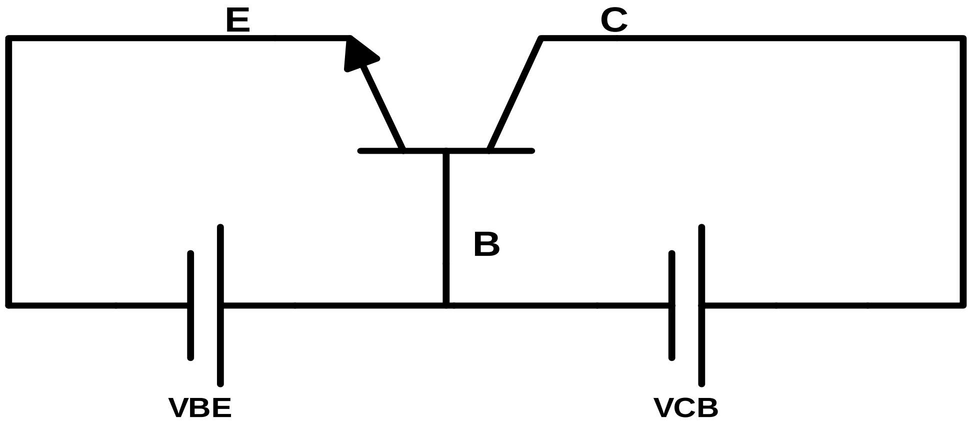
- ✓ In order to operate properly as an amplifier, it's necessary to correctly bias the two pn-junctions with external voltages.
- ✓ Depending upon external bias voltage polarities used; the transistor works in one of **four regions** (modes).
- ✓ For transistor to be used as an Active device **(Amplifier);** the emitter-base junction must be forward bias, while the collector-base junction must be reverse biased.

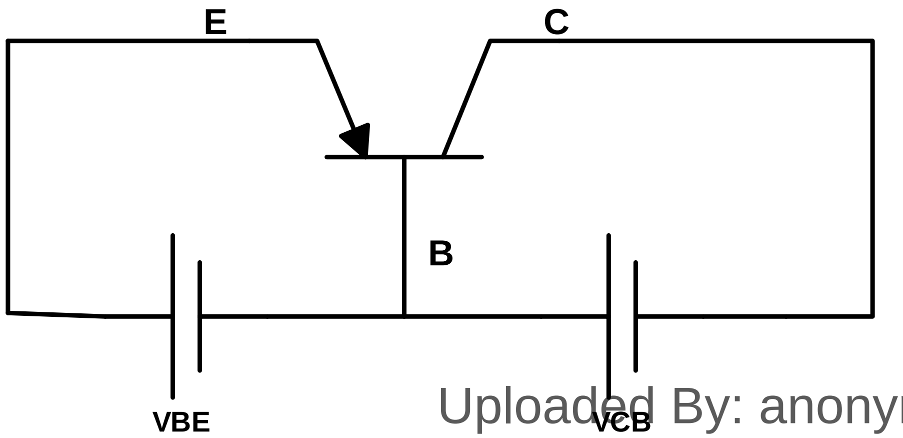
Region	Base-Emitter junction	Base-collector junction
Active	Forward Bias	Revers Bias
Saturation	Forward Bias	Forward Bias
Cut-off	Revers Bias	Revers Bias
Invers	Revers Bias	Forward Bias

In active region

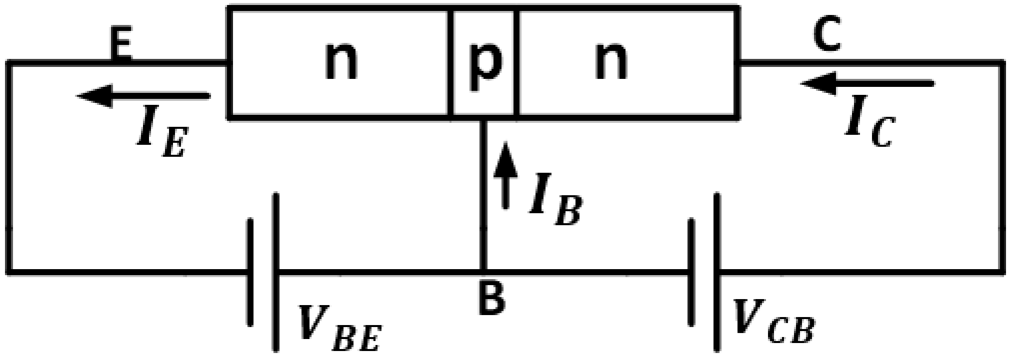
- ✓ The base region is thin and lightly doped
- ✓ The emitter-base junction is forward biased, thus the depletion region at this junction **is reduced**.
- ✓ The base-collector junction is revers biased, thus the depletion region at this junction **is increased**.
- ✓ The forward biased BE-junction causes the electrons in the n-type emitter to flow toward the base; this constitutes the emitter current I_E.
- ✓ As these electrons flow through the P-type base; they tend to recombine with holes in p-type base.







- ✓ Since the base region is **lightly doped**; very few of the electrons injected into the base from the emitter recombine with holes to constitute base current I_B and the remaining large number of electrons cross the base and move through the collector region to the positive terminal of the external DC source; this constitute collector current I_C



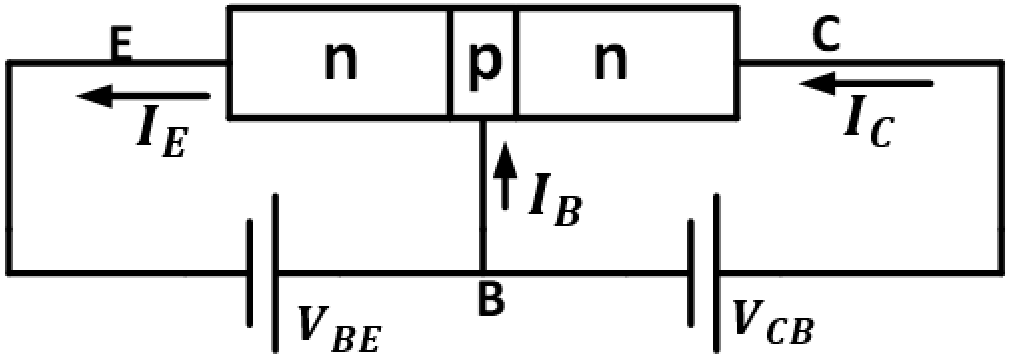
- ✓ There is another component for I_C due to the minority carrier; I_{CBO}

Minority

- ✓ $I_C = \alpha I_E + I_{CBO}$

Majority

$0.998 > \alpha > 0.9$



$$I_C = \alpha I_E + I_{CBo}$$

$$I_E = I_C + I_B$$

$$I_C = \alpha(I_C + I_B) + I_{CBo}$$

- $I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBo}$

Let Beta, $\beta = \frac{\alpha}{1-\alpha}$

- $I_C = \beta I_B + (\beta + 1) I_{CBo}$

$$I_C = \beta I_B + I_{CEo}$$

$$\beta = \frac{\alpha}{1-\alpha}$$

If α =0.99 → $\beta = 99$

If α =0.995 → $\beta = 199$

In active region:

$$I_C = \alpha I_E + I_{CBo}$$

$$\beta = \frac{\alpha}{1-\alpha}$$

$$I_C = \beta I_B + (\beta + 1) I_{CBo}$$

$$I_C = \beta I_B + I_{CEo}$$

$$I_E = I_C + I_B$$

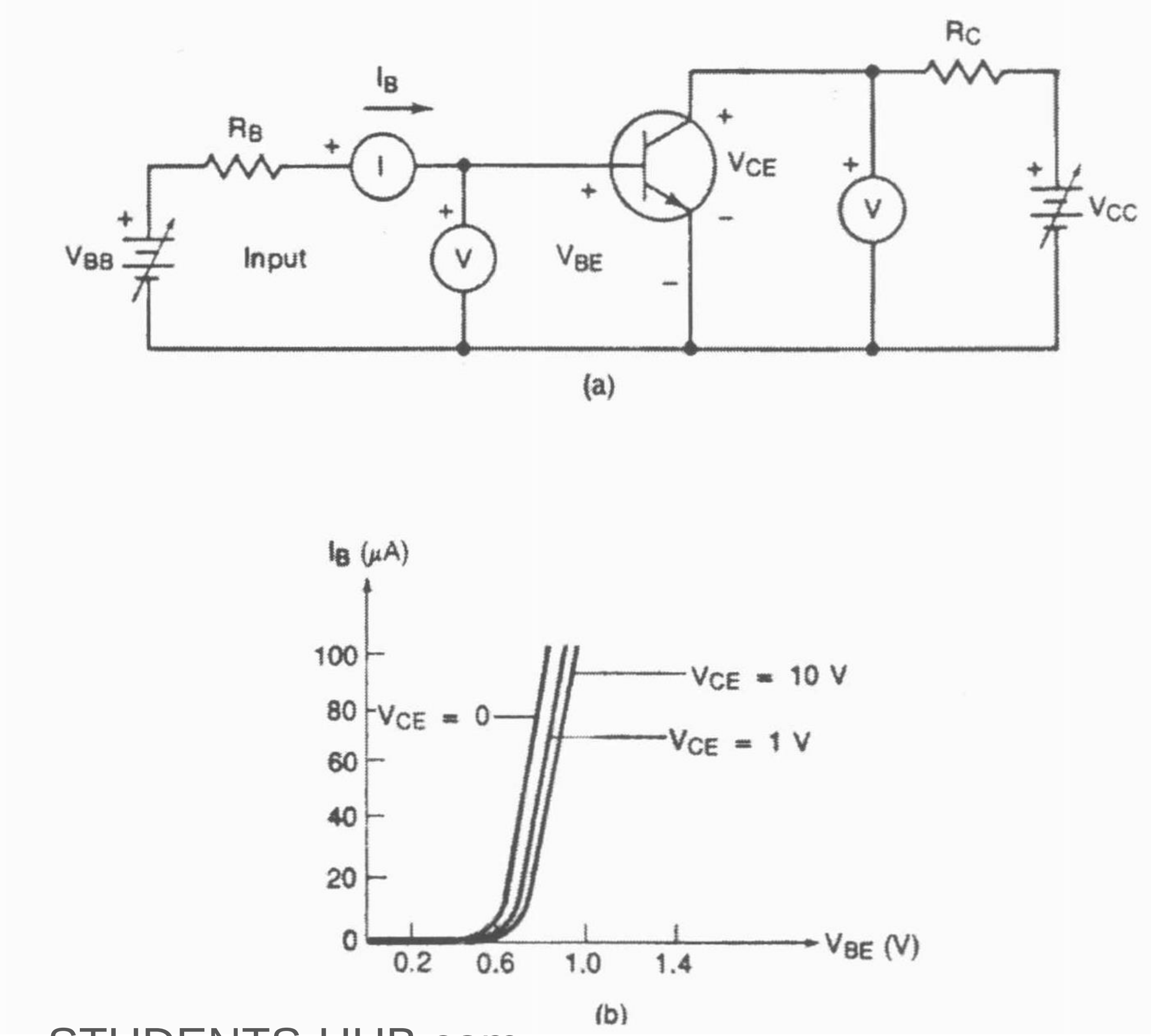
Approximate relationships:

$$I_C \cong \alpha I_E \cong I_E$$

$$I_C \cong \beta I_B$$

$$I_E \cong (\beta+1) I_B$$

Input characteristic curve:



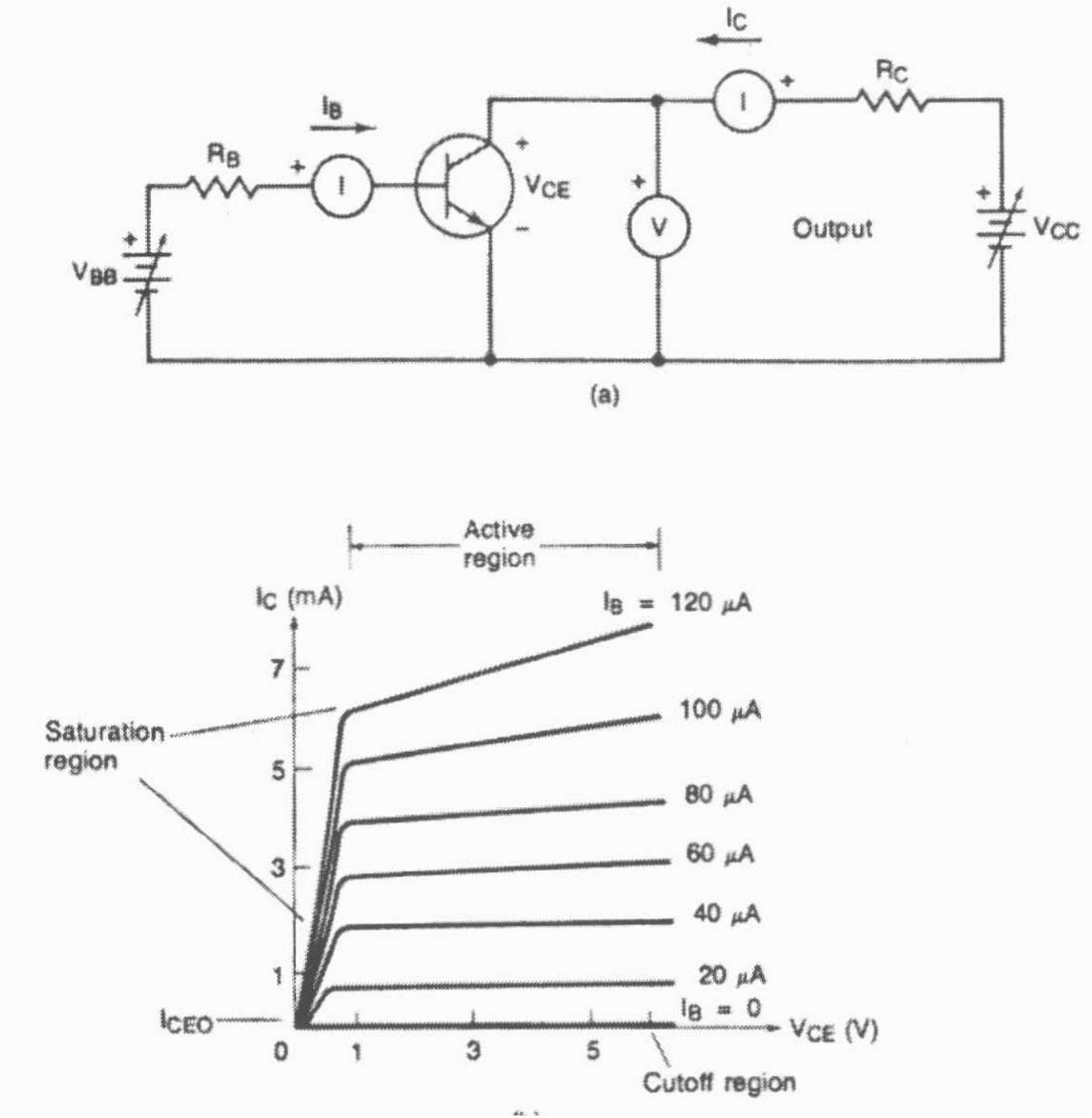
$$i_{B(t)} = I_{Bo}\left(e^{\frac{V_{BE}(t)}{\eta V_T}} - 1\right)$$

$$i_{B(t)} \cong I_{Bo}\left(e^{\frac{V_{BE}(t)}{\eta V_T}}\right)$$

$$i_{C(t)} \cong I_S\left(e^{\frac{V_{BE}(t)}{\eta V_T}}\right)$$

$I_S = \beta \; I_{Bo}$

Output characteristic curve:



1. In the cutoff region :

$$I_B = I_C = I_E = 0$$

2. In the active region :

$$I_C = \alpha I_E$$

$$I_C = \beta \, I_B$$

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

$V_{BE} = 0.7\,V$, Si , npn

$V_{BE} = -0.7\,V$, Si , pnp

$V_{CE} > V_{CE,sat} = 0.2\ V$, Si , npn

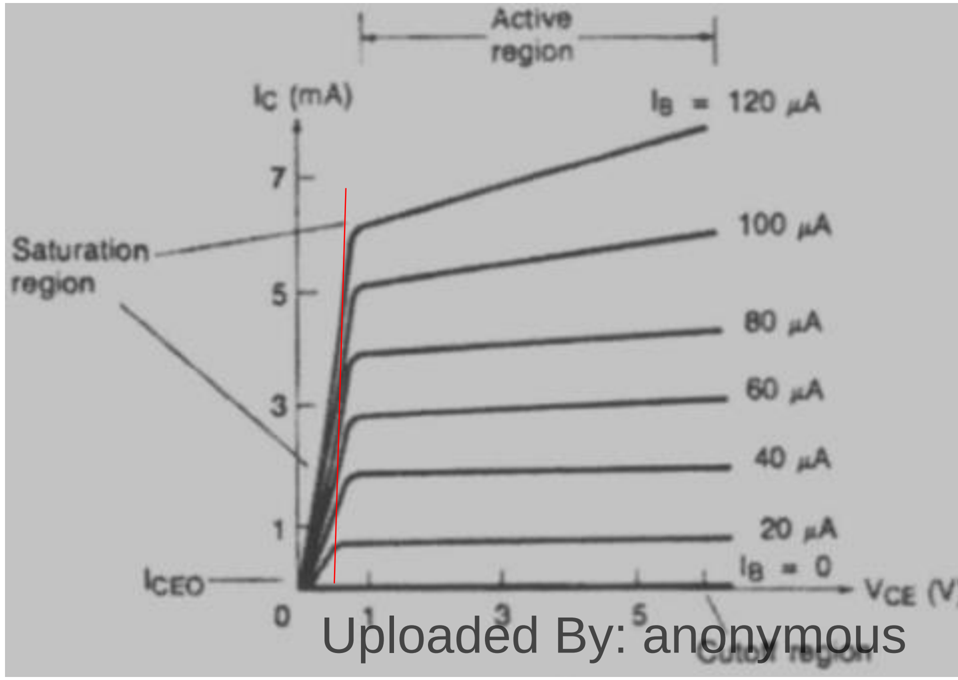
$V_{CE} < V_{CE,sat} = -\,0.2\ V$, Si , pnp

3. In the saturation region :

$$V_{CE} = V_{CE,sat}$$

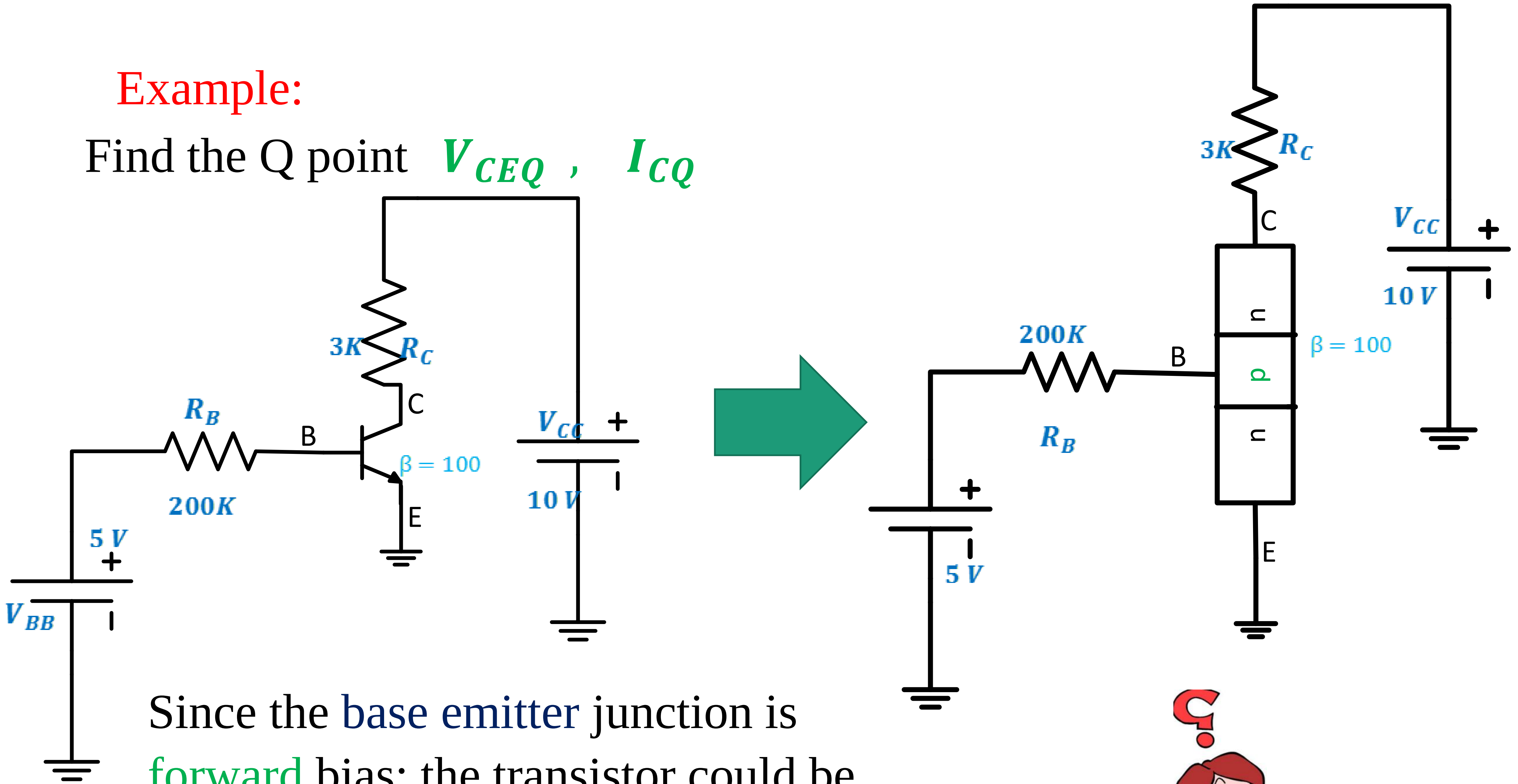
$V_{BE} = 0.8\,V$, Si , npn

$V_{BE} = -0.8\,V$, Si , pnp



Example:

Find the Q point V_{CEQ} , I_{CQ}



Since the base emitter junction is forward bias; the transistor could be either in the active or the saturation region

- Assume that the transistor in the **active** region:

KVL: $5 = 200k\, I_B + V_{BE}$

$$I_B = \frac{5 - 0.7}{200k} = 0.0215\, mA$$

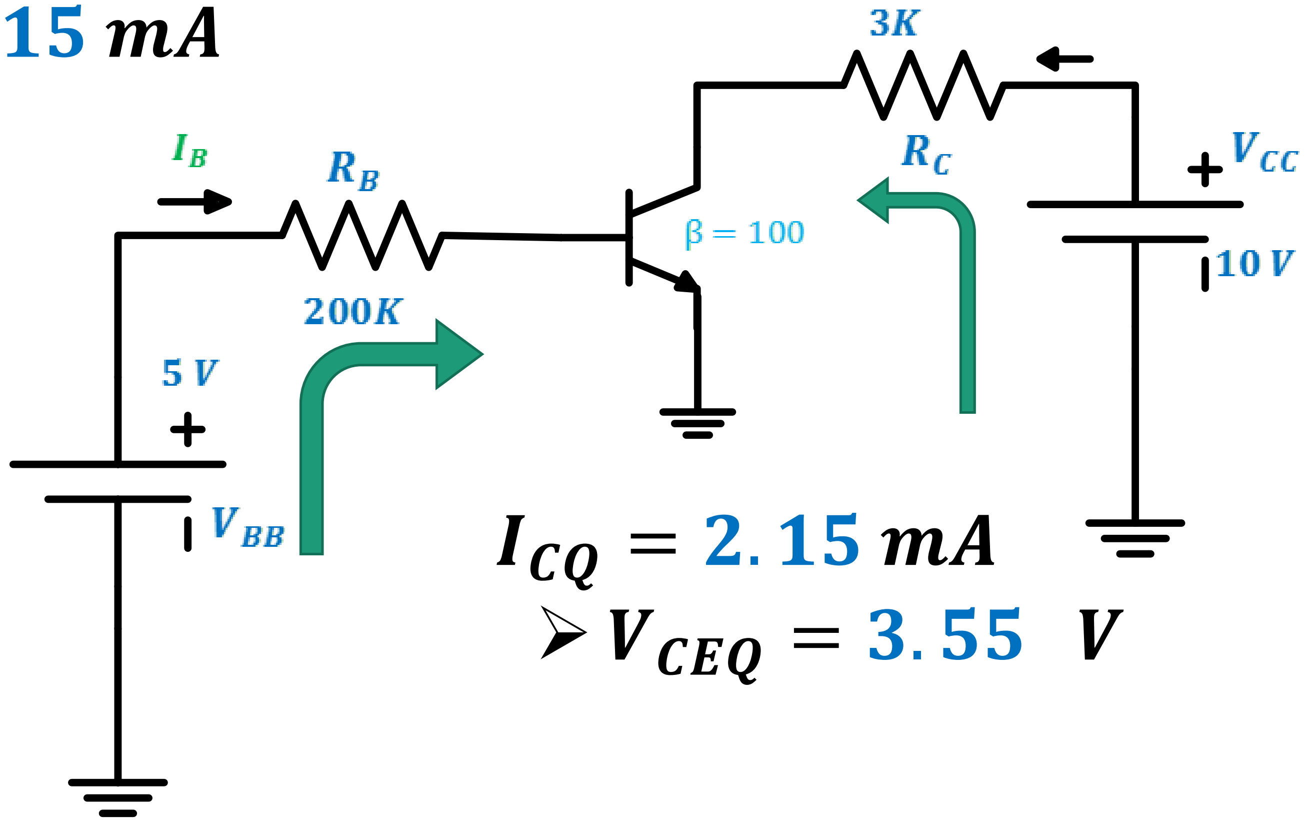
$$I_C = \beta\, I_B = 100 * 0.0215 = 2.15\, mA$$

KVL: $10 = R_C I_C + V_{CE}$

$$V_{CE} = 10 - R_c I_c$$

❖ $V_{CE} = 10 - 3k * 2.15mA$

❖ $V_{CE} = 3.55\ V$



$I_{CQ} = 2.15\, mA$

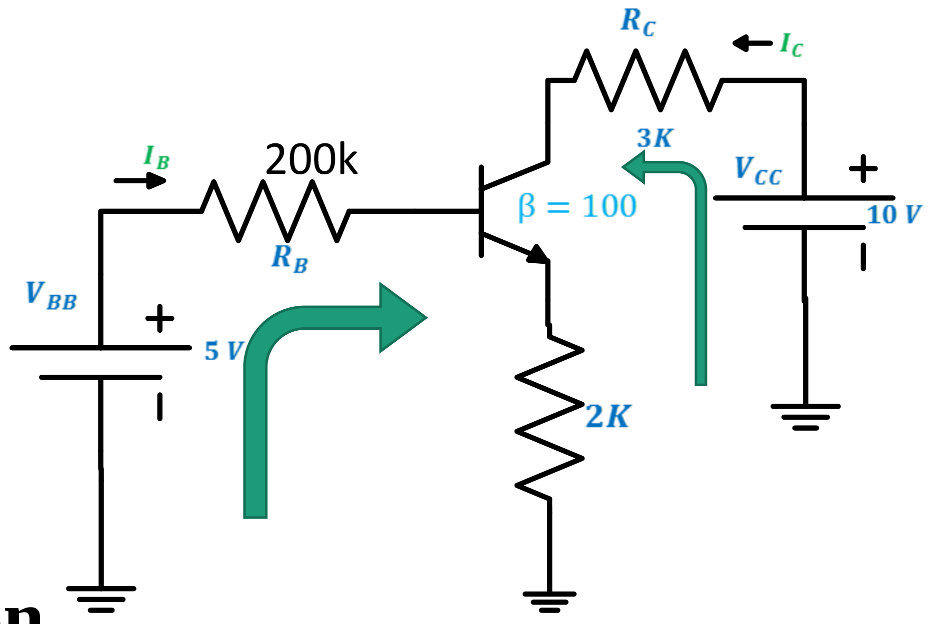
- $V_{CEQ} = 3.55\ V$

- **Since $V_{CE} > V_{CE,sat}$ >>> The transistor is in the active region**

Example Find the Q point V_{CEQ} , I_{CQ}

Solution:

Since the base emitter junction is forward bias ; the transistor could be either in the active or the saturation region



- **Assume that the transistor in the active region**

KVL: $5 = 200k\ I_B + V_{BE} + 2k\ I_E$

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

$$I_B = \frac{5 - 0.7}{200k + 101 * 2k} = 0.0107\ mA$$

$$I_C = \beta\ I_B = 100 * 0.0107 = 1.07\ mA$$

KVL: $10 = R_C I_C + V_{CE} + R_E I_E$

$$V_{CE} = 10 - R_c I_c - R_E I_E$$

- $V_{CE} = 4.63\ V$

Since $V_{CE} > V_{CE,sat}$

∴The **transistor is in the active region**

∴ $V_{CEQ} = 4.63\ V$ *and* $I_{CQ} = 1.07\ mA$

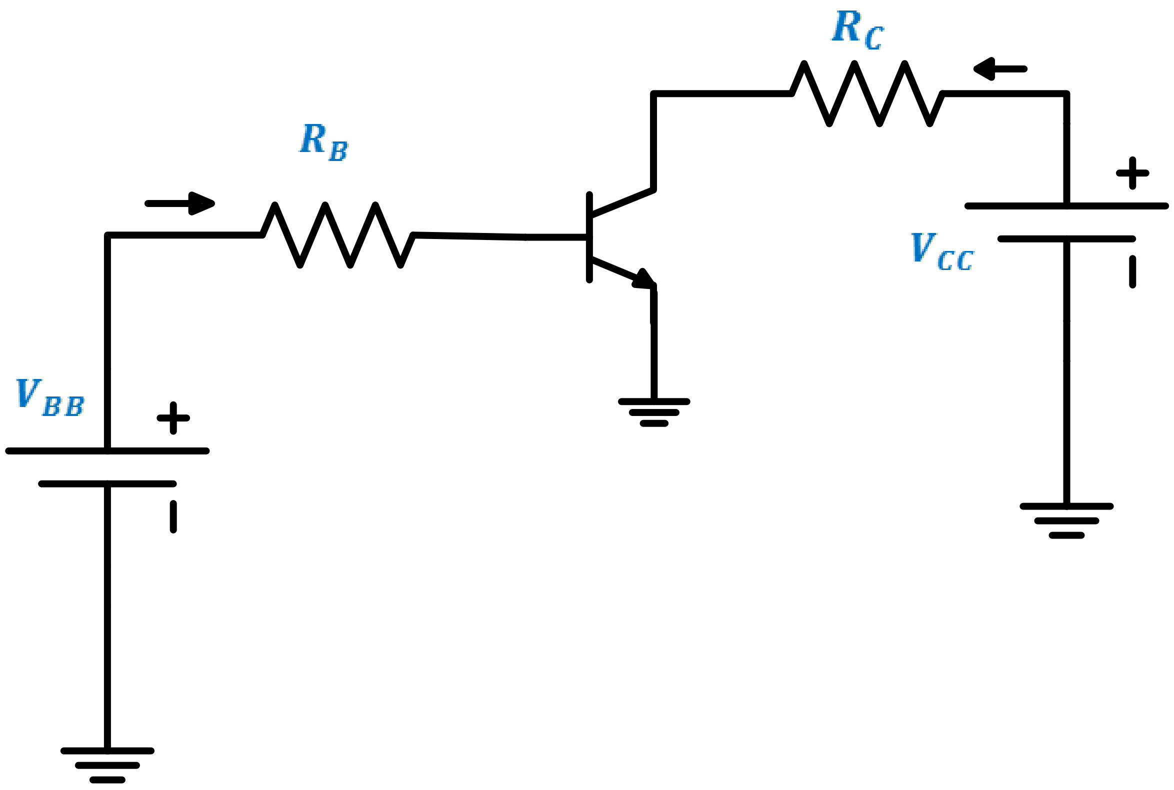
Second method:

1) **In the active region:**

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$$I_C = \beta I_B$$

$$V_{CE} = V_{CC} - R_c I_c$$



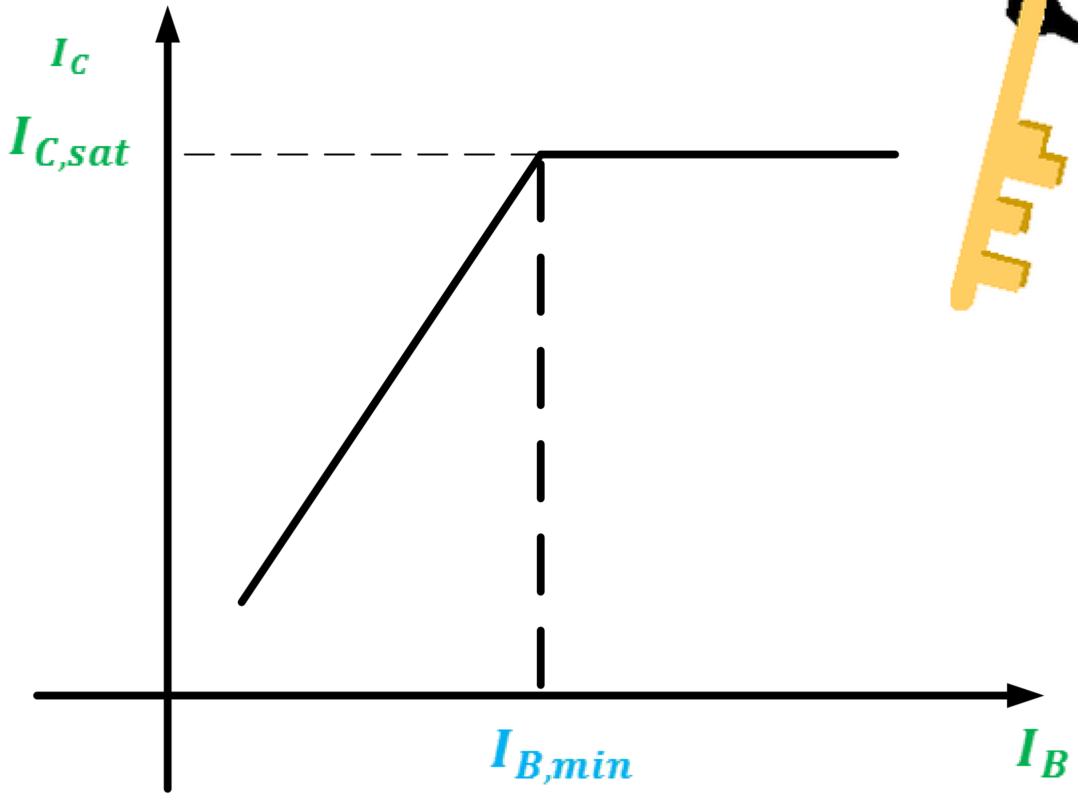
As : $R_B \downarrow$ $I_B \uparrow$ $I_C \uparrow$ $V_{CE} \downarrow$

2) **In the saturation region:**

$V_{CE} = V_{CE,sat} = 0.2\ V$, **Si** , **npn**

$$I_C = I_{C,sat} = \frac{V_{CC} - V_{CE,sat}}{R_C}$$

Let define: $I_B(min) = \dfrac{I_{C,sat}}{\beta}$



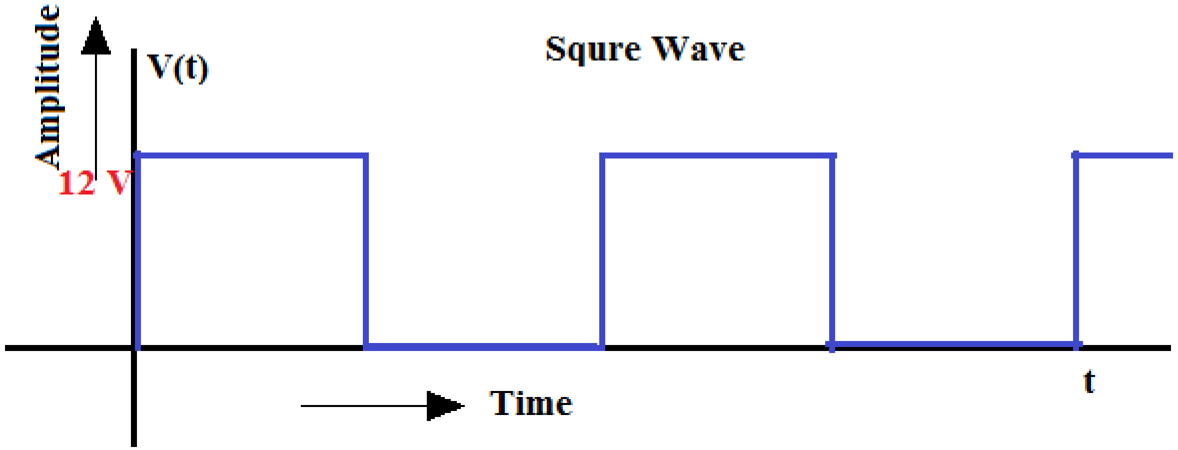
$$I_B(min) = \frac{I_{C,sat}}{\beta}$$

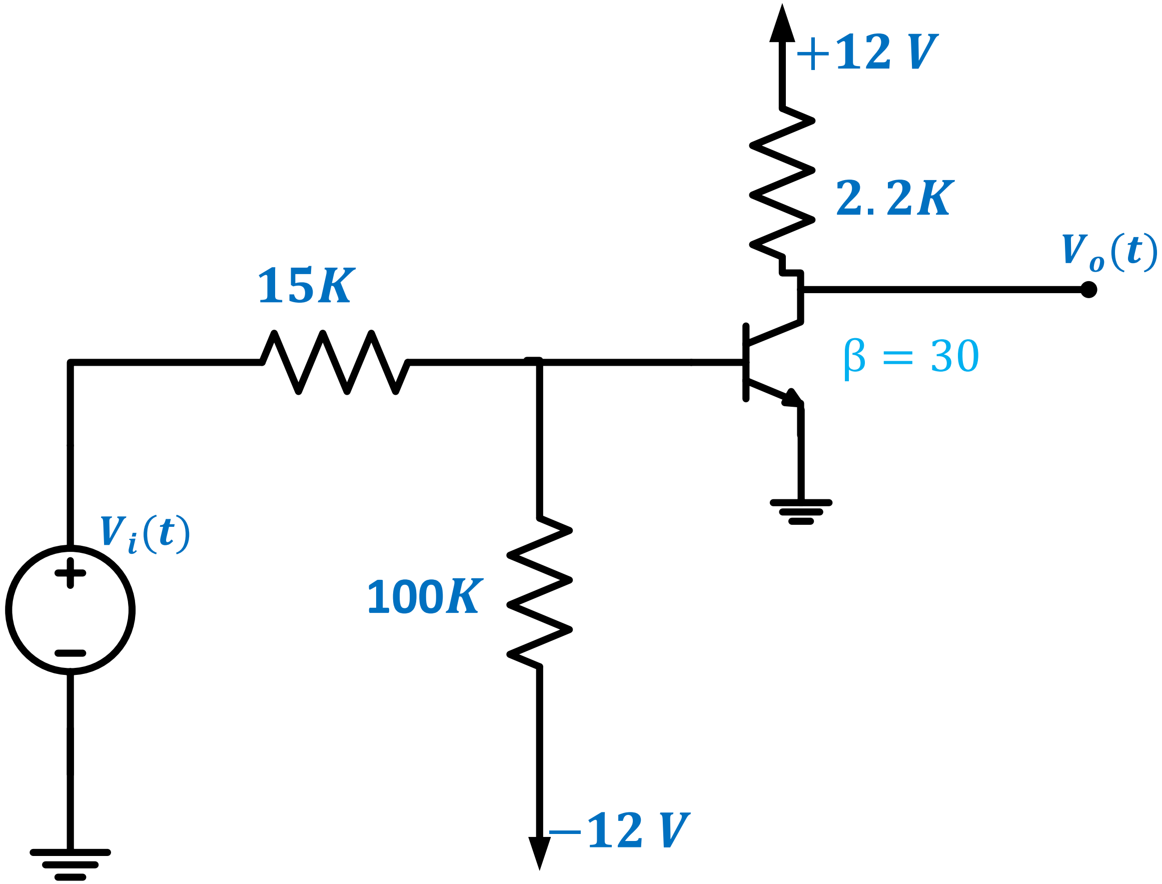
- If $I_B > I_B(min)$ the transistor is in the saturation region.
- If $I_B < I_B(min)$ the transistor is in the Active region.

BJT as switch:

Example:

Find $V_o(t)$ for the input given below:

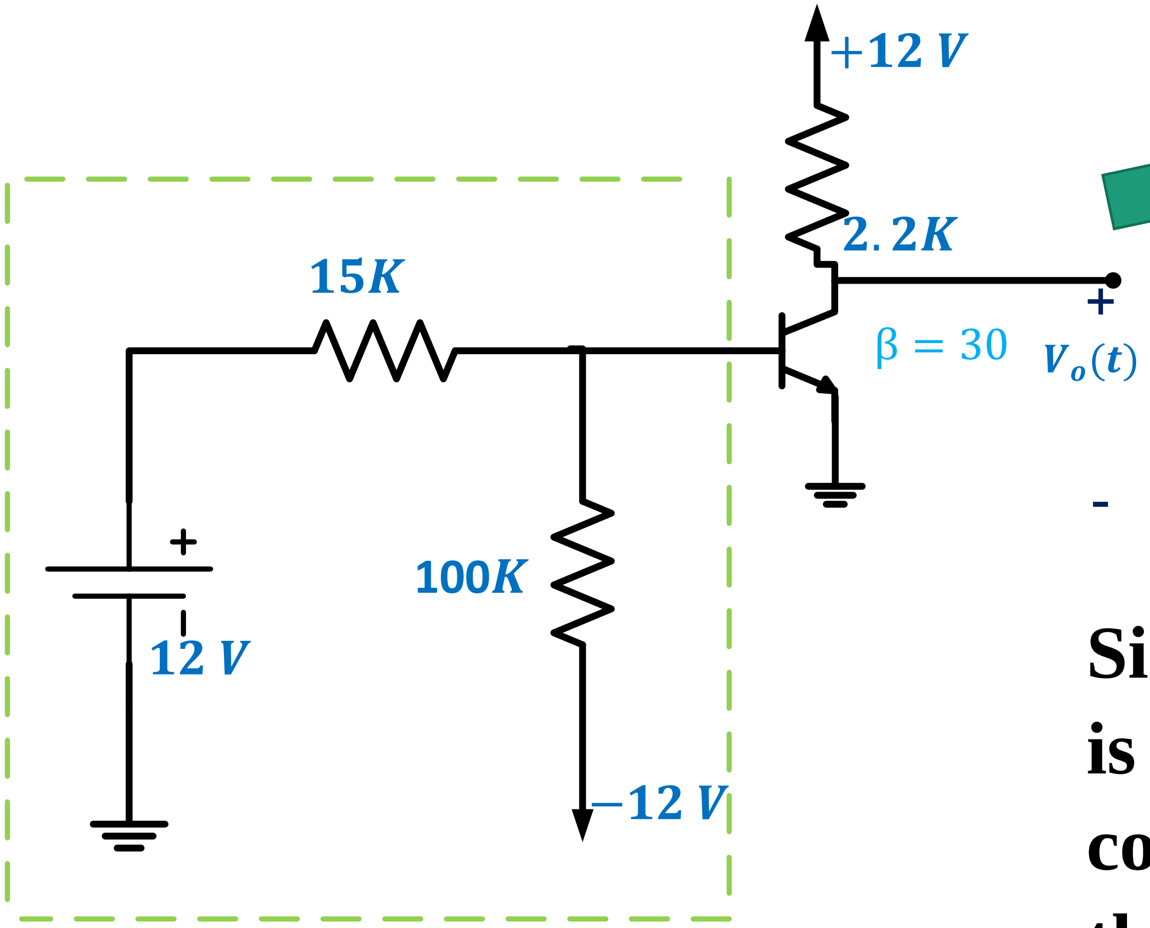


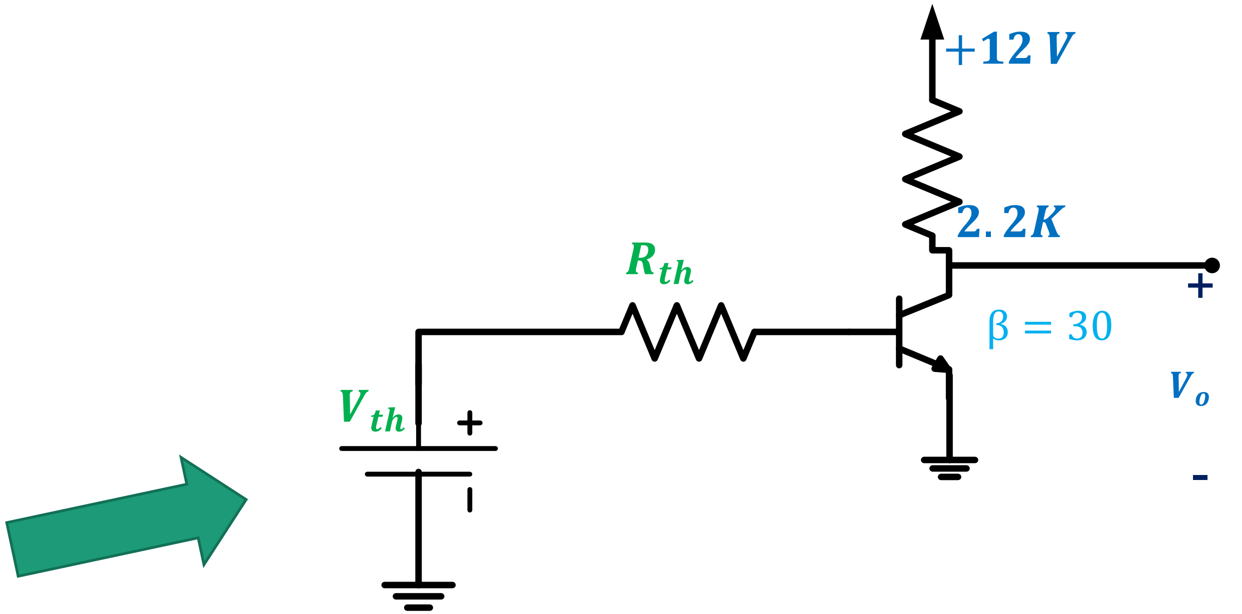


Solution:

❖ **Let $V_i(t) = +12\ volt$**

Calculate V_{th}&R_{th}





$$R_{th} = 15k \,//\, 100k = \frac{100k * 15k}{15k+100k} = 13k$$

$$V_{th} = 8.9\ volt$$ Proof!!

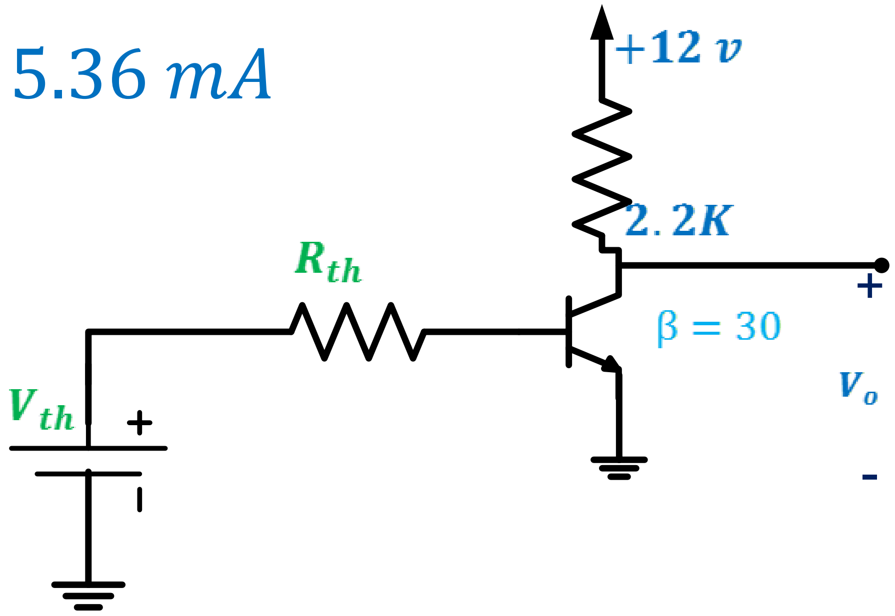
Since the base emitter junction is forward bias; the transistor could be either in the active or the saturation region

- Assume that the transistor in the saturation region

$$I_C = I_{C,sat} = \frac{V_{CC} - V_{CE,sat}}{R_C} = \frac{12 - 0.2}{2.2k} = 5.36\,mA$$

$$I_B(min) = \frac{I_{C,sat}}{\beta} = \frac{5.36mA}{30} = 0.18mA$$

$$I_B = \frac{V_{th} - V_{BE}}{R_{TH}} = \frac{8.9 - 0.8}{13k} = 0.62\,mA$$

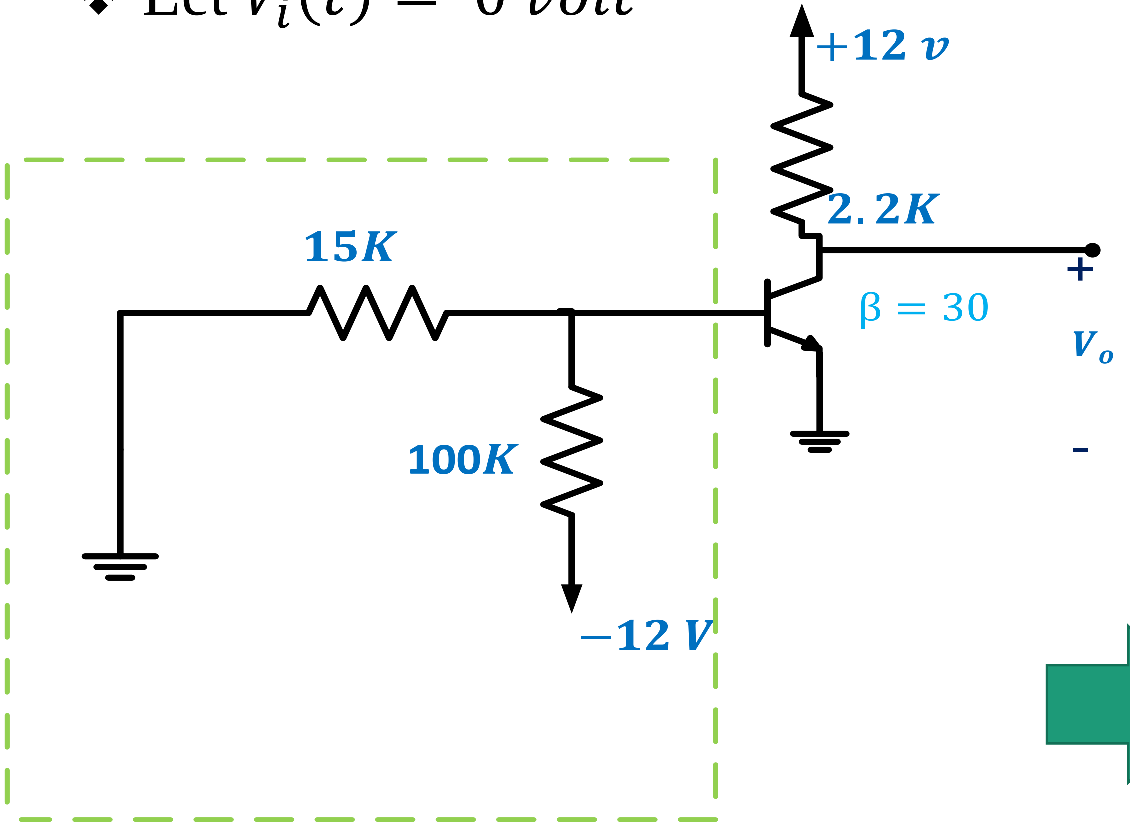


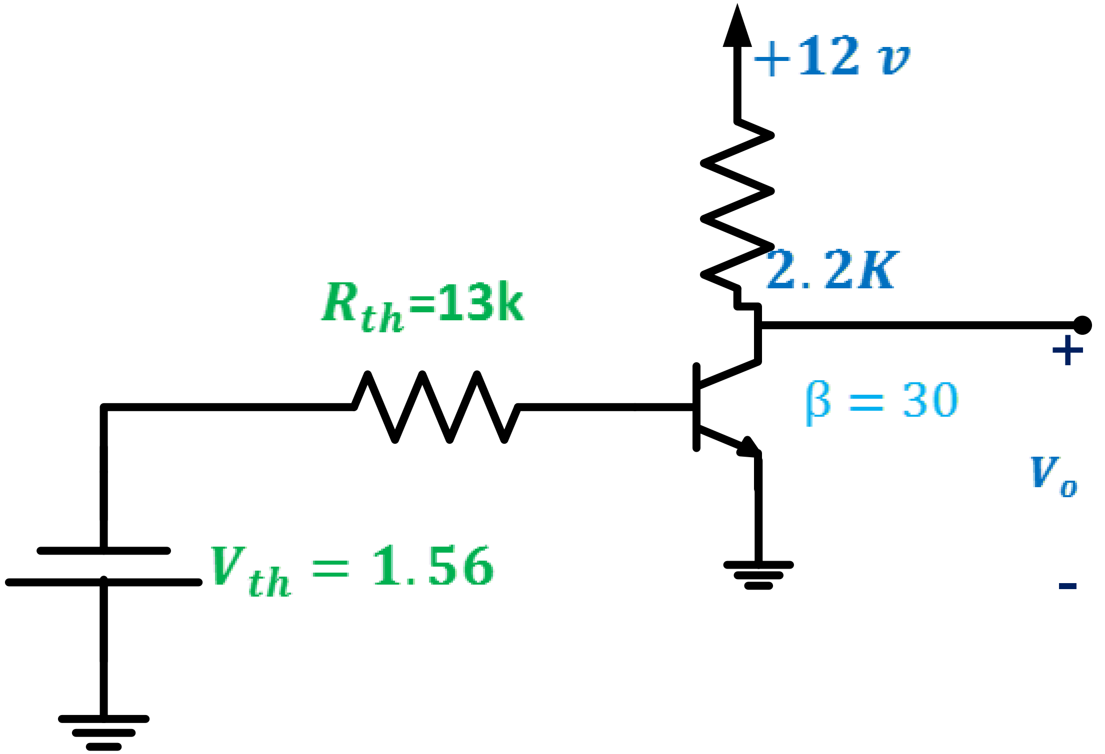
- Since $I_B > I_B(min)$ the transistor is in the saturation region.

✓ $V_o = V_{CE,sat} = 0.2\ volt$

✓ $I_C = 5.36\,mA$

❖ Let $V_i(t) = \ 0\ volt$



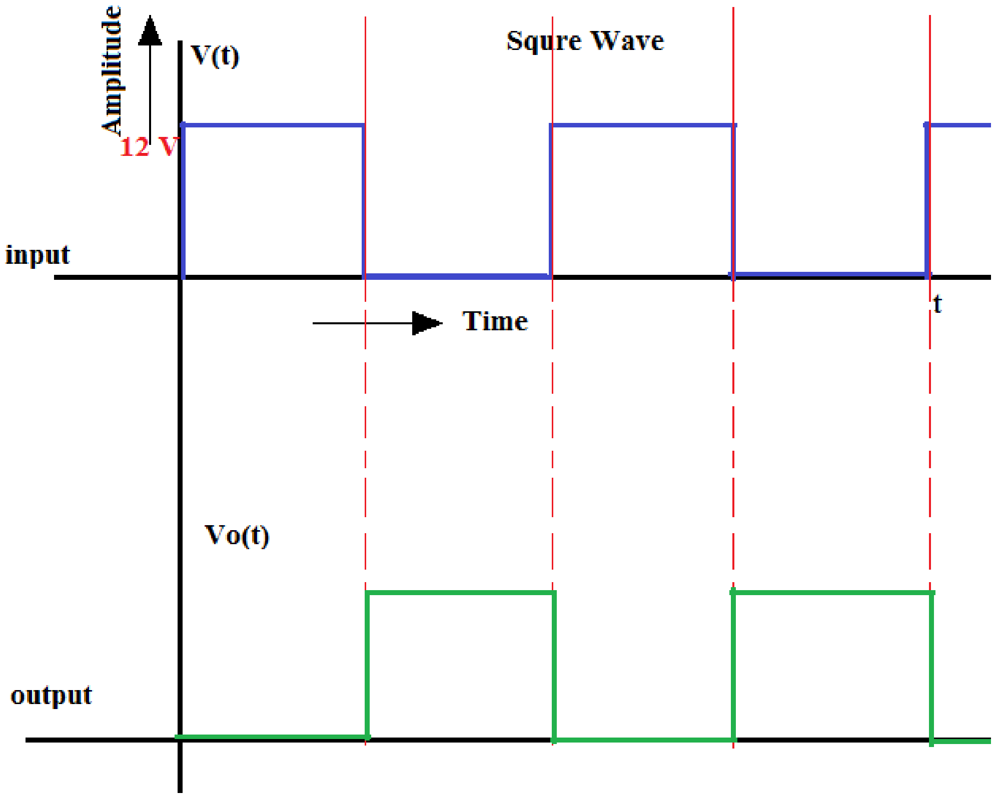


Since $V_{th} = -1.56\ volt$

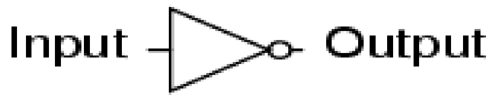
Base emitter junction is revers biased the transistor in cutoff region

✓ $V_o = V_{CE} = 12\ \ volt \quad , \ \ I_C = 0\ mA$

The circuit acts as inverter or not gate



NOT gate truth table



Input	Output
0	1
1	0

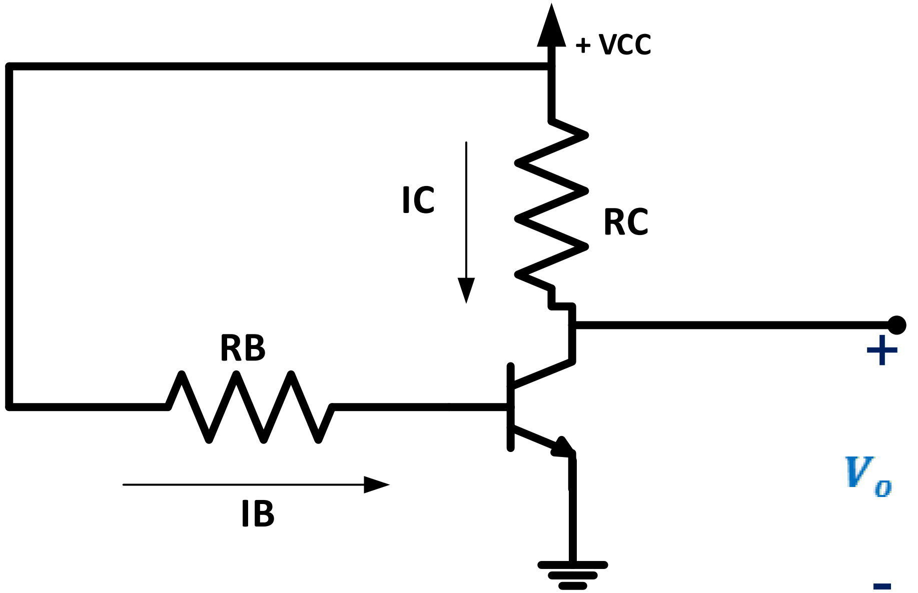
Transistor biasing circuits:

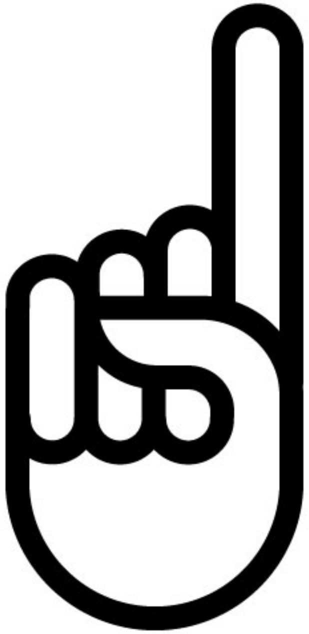
The criteria is **Q POINT STABILITY**

$\Delta I_{CQ} / \Delta\beta$ and $\Delta V_{CEQ} / \Delta\beta$

1. Fixed current bias circuit

KVL : $V_{CC} = R_B I_B + V_{BE}$

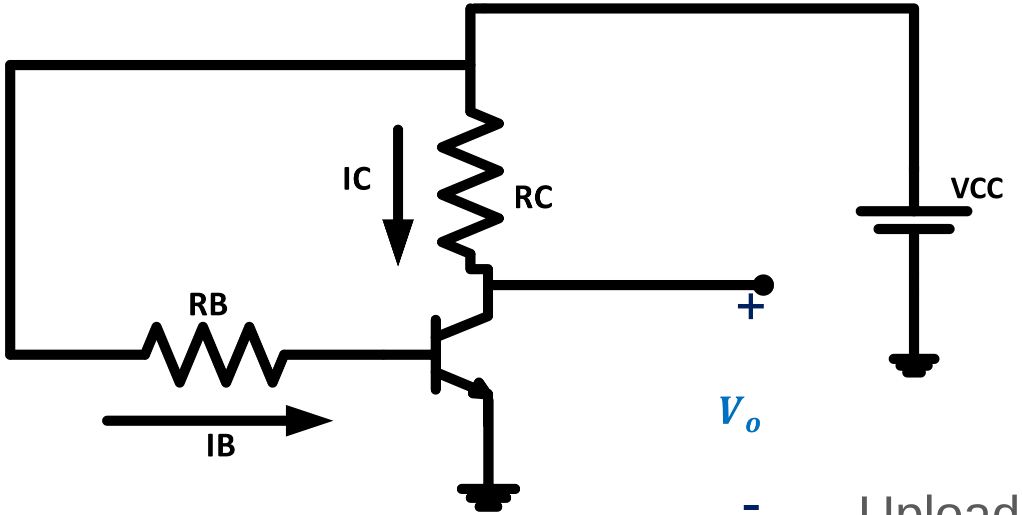




$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

$$I_C = \beta I_B$$

KVL : $V_{CC} = R_c I_c + V_{CE}$



$$V_{CE} = V_{CC} - R_c I_c$$

Transistor biasing circuits:

Example: Design a fixed current bias circuit using a silicon transistor having

$$\beta(min) = 25\,, \quad \beta(max) = 75$$

Such that $I_c = 1mA$,and $V_{CE} = 5\ volt$

given $V_{CC} = 10\ \ volt$

Solution:

Using equations of the fixed current bias circuit:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}\ , \quad V_{BE} = 0.7\,V \qquad -(1)$$

$$V_{CE} = V_{CC} - R_c I_c \qquad -(2)$$

From eq.2:

$$5 = 10 - R_c(1mA)$$

$$\triangleright\ R_c = 5k\Omega$$

$$I_C = \beta\, I_B$$

$$\text{Let } \beta = \frac{25+75}{2} = 50$$

the average between max && min

$$I_B = \frac{I_C}{\beta} = \frac{1mA}{50} = 20\ \mu A$$

From eq.1

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{10 - 0.7}{R_B}$$

$$\triangleright\ R_B = 465\ k\Omega$$

Transistor biasing circuits:

- If $\beta = 50 >>> R_c = 5k\Omega, R_B = 465k\Omega, I_C = 1mA, V_{CE} = 5V$

BUT:

- When $\beta = \beta(min) = 25$

$$I_B = 20\ \mu A$$
$$I_C = 0.5mA$$
$$V_{CE} = 7.5V$$

- When $\beta = \beta(max) = 75$

$$I_B = 20\ \mu A$$
$$I_C = 1.5mA$$
$$V_{CE} = 2.5V$$

For:

$$75 \geq \beta \geq 25$$
$$1.5mA \geq I_C \geq 0.5mA$$

❖ **The fixed current bias circuit is not a very satisfactory circuit of obtaining good bias point stability.**

Transistor biasing circuits:

2. Collector to base feedback bias circuit:

KVL : $V_{CC} = R_c I + R_B I_B + V_{BE}$

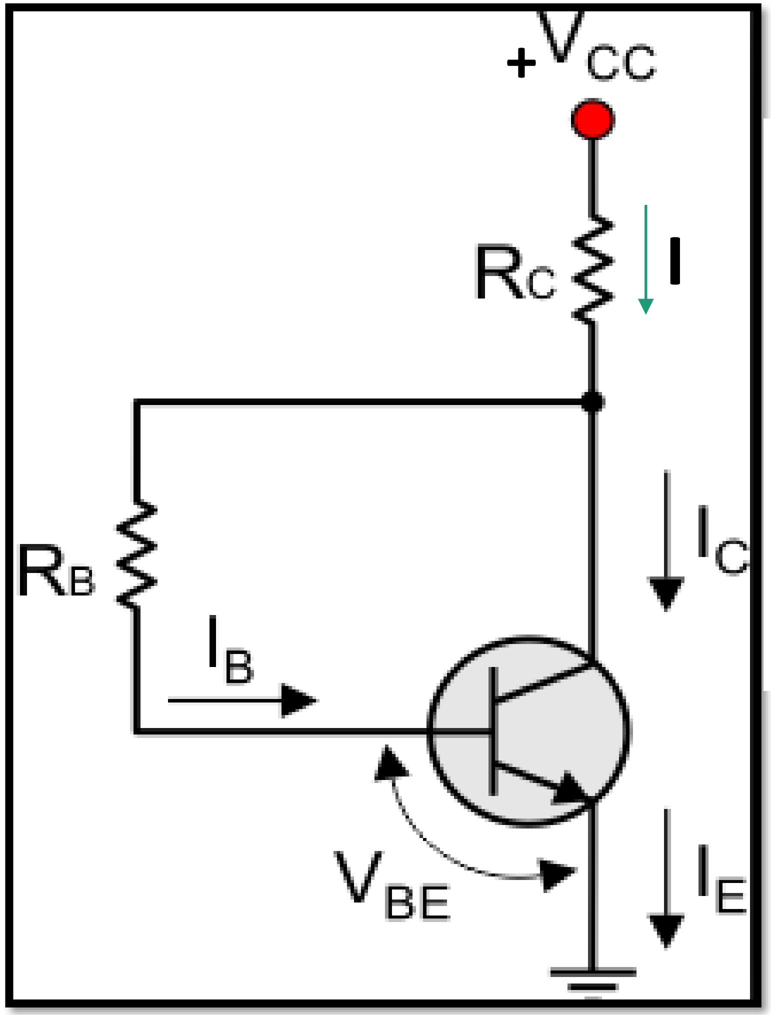
$$I = I_B + I_c$$

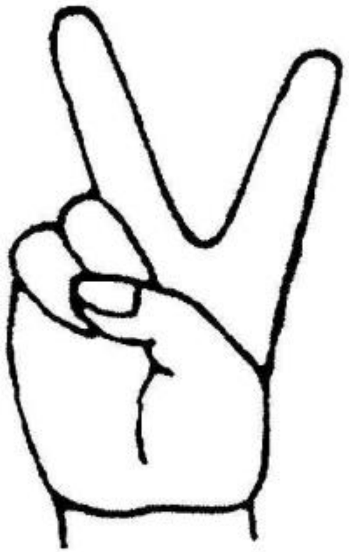
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_c} \; \ldots (1)$$

$$I_C = \beta \, I_B$$

KVL : $V_{CC} = R_c(I_B + I_c) + V_{CE}$

$$V_{CE} = V_{CC} - R_c(I_B + I_c) \; \ldots (2)$$





Transistor biasing circuits:

Example: Design a **collector to base feedback bias circuit** using a silicon transistor having

$$\beta(\min) = 25\,, \qquad \beta(\max) = 75$$

Such that $I_c = 1mA$,and $V_{CE} = 5\ volt$ given $V_{CC} = 10\ \ volt$

Solution:

Let $\boldsymbol{\beta = \frac{25+75}{2} = 50}$ **the average between max && min**

$$I_B = \frac{I_C}{\beta} = \frac{1mA}{50} = 20\ \mu A$$

From eq.2:

$$V_{CE} = V_{CC} - R_c(I_B + I_c)$$

$$5 = 10 - R_c(1mA + 20\mu A)$$

- $R_c \approx 4.9k\Omega$

From eq.1:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_c}$$

$$= \frac{10-0.7}{R_B+(50+1)*4.9k}\ ,,,,\ I_B = 20\mu A$$

- $R_B \approx 215k\Omega$

As before we can proof that:

$$75 \geq \quad \beta \quad \geq 25$$

$$1.19mA \geq \quad I_C \quad \geq 0.68mA$$

There is an improvement over the fixed bias circuit.

Transistor biasing circuits:

3. Biasing circuit with stabilization resistor (R_E):

KVL : $V_{CC} = R_B I_B + V_{BE} + R_E I_E$

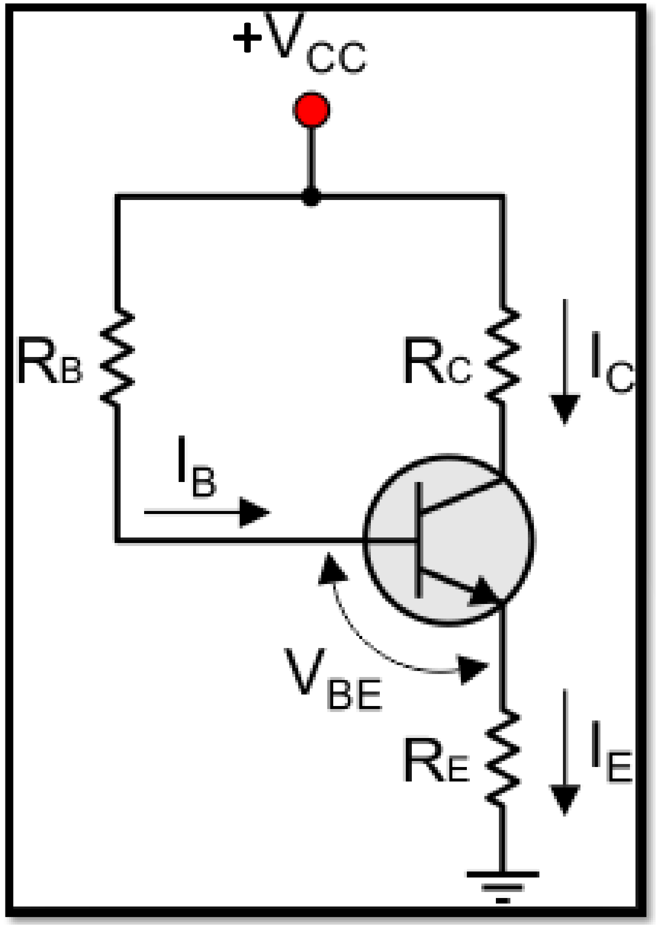
$I_E = (\beta+1) I_B$

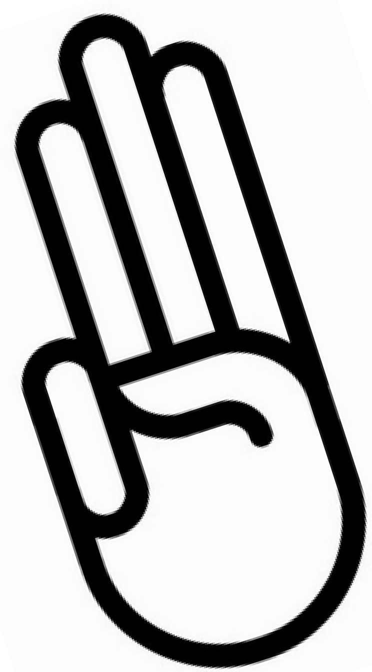
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_E} \quad \dots (1)$$

$I_C = \beta \, I_B$

KVL : $V_{CC} = R_c I_c + V_{CE} + R_E I_E$

$$V_{CE} = V_{CC} - R_c I_c - R_E I_E \dots (2)$$





Transistor biasing circuits:

Example: Design Biasing circuit with stabilization resistor (R_E) using a silicon transistor having

$$\beta(min) = 25\,, \quad \beta(max) = 75$$

Such that $I_c = 1mA$,and $V_{CE} = 5\ volt$ given $V_{CC} = 10\ \ volt$

Solution:

In this circuit we have 3-unknwons (R_B, R_c, R_E) & two equations!

- We must make a new assumption :

$$\frac{V_{CC}}{5} \geq V_{RE} \geq \frac{V_{CC}}{10} \quad ; \quad \beta = 50$$

let $V_{RE} = \frac{V_{CC}}{5} = \frac{10}{5} = 2\ volt$

$V_{RE} = R_E I_E$

- $\boxed{R_E = \frac{2}{1.02\ mA} \cong 2k\Omega}$

From eq.2 :

$$V_{CE} = V_{CC} - R_c I_c - R_E I_E$$

- $\boxed{R_C = 3k\Omega}$

From eq.1 : $I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E}$

- $\boxed{R_B = 365k\Omega}$

Proof that :

$$75 \geq \quad \beta \quad \geq 25$$

$$1.349mA \geq \quad I_C \quad \geq 0.55755mA$$

There is an improvement over the fixed bias circuit.

Transistor biasing circuits:

4) Voltage divider bias circuit:

a) Approximate method:

I_B **Very small** ⋙ $I_B = 0$

❖ $I_1 = I_2$

$$V_B = \frac{R_2}{R_2+R_1} V_{cc}$$

Voltage divider

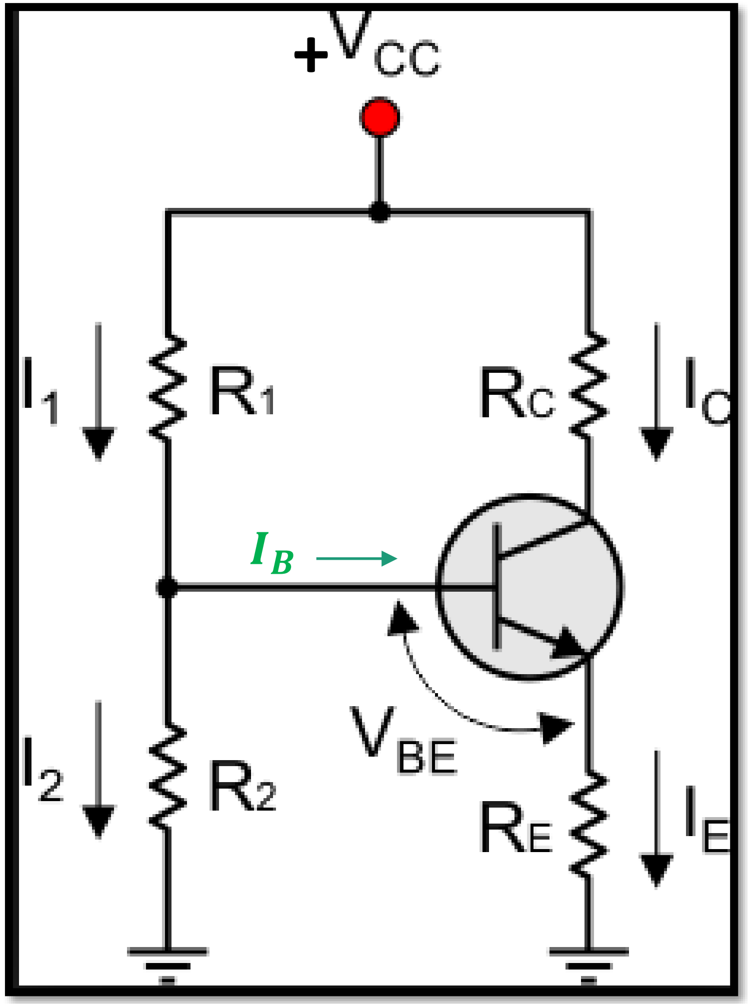
$$V_{BE} = V_B - V_E$$

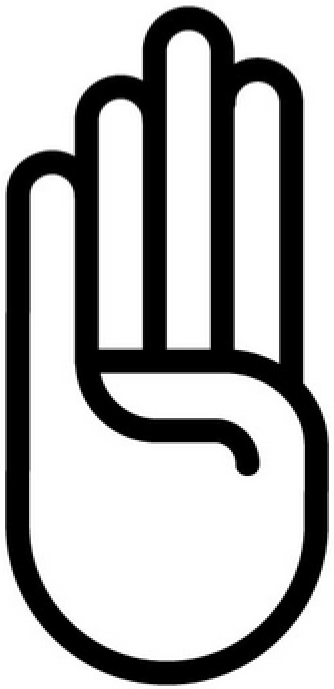
❖ $V_E = V_B - V_{BE}$

$$I_{E1} = \frac{V_E}{R_E} = \frac{V_B - V_{BE}}{R_E}$$

$$I_C = \alpha I_E \approx I_E$$

$$V_{CE} = V_{CC} - R_c I_c - R_E I_E$$





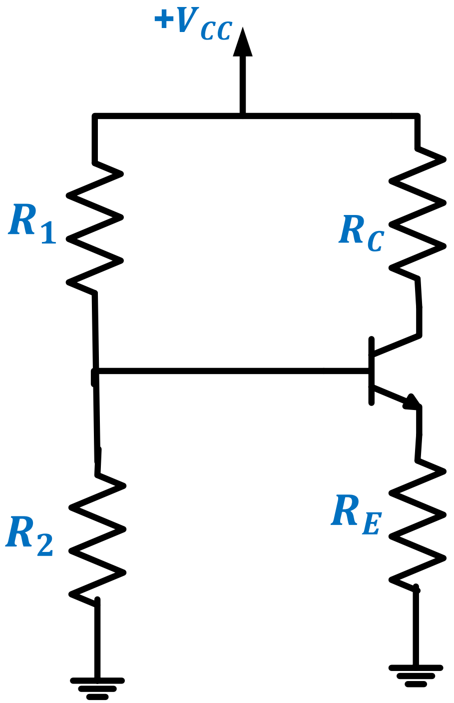
The Q point is completely independent of the Beta

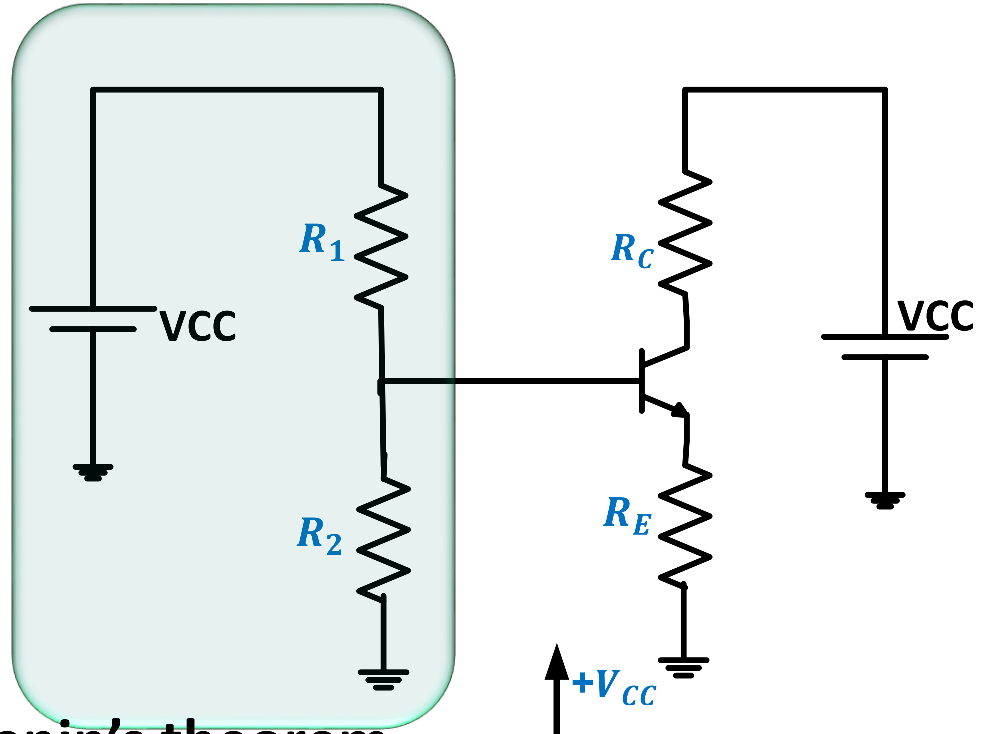
Transistor biasing circuits:

b) Exact method:

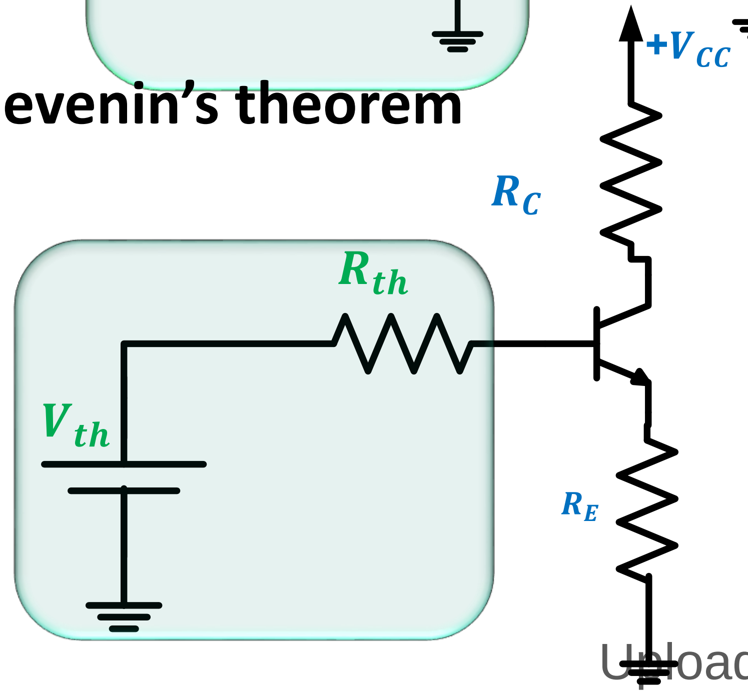
$$R_{th} = \frac{R_1 R_2}{R_1 + R_2}$$

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





Using Thevenin's theorem



KVL: $V_{th} = R_{th} I_B + V_{BE} + R_E I_E$

$$I_E = (\beta+1)\, I_B$$

$$I_{E2} = \frac{V_{th} - V_{BE}}{\frac{R_{th}}{\beta + 1} + R_E}$$

Transistor biasing circuits:

Using approximate method, we get:

$$I_{E1} = \frac{V_B - V_{BE}}{R_E}$$

Where:

$$V_B = \frac{R_2}{R_2 + R_1} V_{cc}$$

Using exact method, we get:

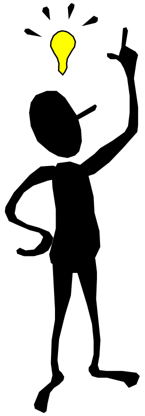
$$I_{E2} = \frac{V_{th} - V_{BE}}{\frac{R_{th}}{\beta + 1} + R_E}$$

Where:

$$R_{th} = \frac{R_1 R_2}{R_1 + R_2} \quad ,,, \quad V_{th} = \frac{R_2}{R_1 + R_2} V_{CC}$$

To make $I_{E2} \cong I_{E1}$:

$$\frac{R_{th}}{\beta + 1} + R_E \cong R_E$$



$$\frac{R_{th}}{\beta + 1} \ll R_E$$

$$R_{th} \ll (\beta + 1) R_E$$

$$R_{th} = \frac{(\beta + 1) R_E}{10,20,30..}$$

Example: **Design a Voltage divider bias circuit using a silicon transistor having**

$$\beta(min) = 25\ ,\quad \beta(max) = 75$$

Such that $I_c = 1mA$ **,and** $V_{CE} = 5\ volt$ **given** $V_{CC} = 10\ \ volt$

Solution:

Let $V_{RE} = \frac{V_{CC}}{10} = \frac{10}{10} = 1\ volt$

$$V_{RE} = R_E I_E$$

$$\boxed{➢\ R_E = \frac{1}{1.02mA} \cong 1k\Omega}$$

From : $R_{th} = \frac{(\beta+1)R_E}{10,20,30..}$

Let $R_{th} = \frac{(\beta+1)R_E}{51}$ **,,where** $\beta = 50$

$$\boxed{➢\ R_{th} \cong 1k\Omega}$$

KVL: $V_{CC} = V_{CE} + R_c I_c + R_E I_E$

$$\boxed{➢\ R_c = 4k\Omega}$$

To find R_1, R_2**,we need to find** R_{th}, V_{th} **:**

From: $I_E = \frac{V_{th} - V_{BE}}{\frac{R_{th}}{\beta+1} + R_E}$

We find $V_{th} = 1.72\ volt$

We have : $V_{th} = 1.72\ volt$ **&&** $R_{th} = 1k\Omega$

From:

$R_{th} = \frac{R_1 R_2}{R_1 + R_2}$ **and** $V_{th} = \frac{R_2}{R_1 + R_2} V_{CC}$

We get:

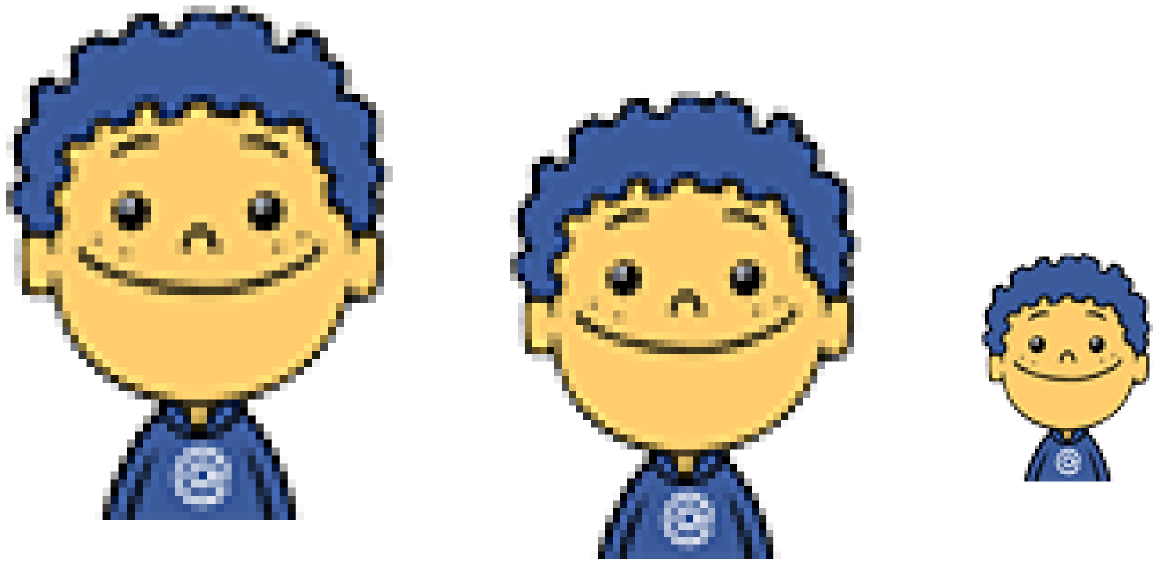
➢ $R_1 = 5.8\ k\Omega$

➢ $R_2 = 1.2\ k\Omega$

Our design @ β = 50

- $R_E = 1k\Omega$
- $R_c = 4k\Omega$
- $R_1 = 5.8\ k\Omega$
- $R_2 = 1.2\ k\Omega$
- $I_c = 1mA\ ,$
- $V_{CE} = 5\ volt$

But:



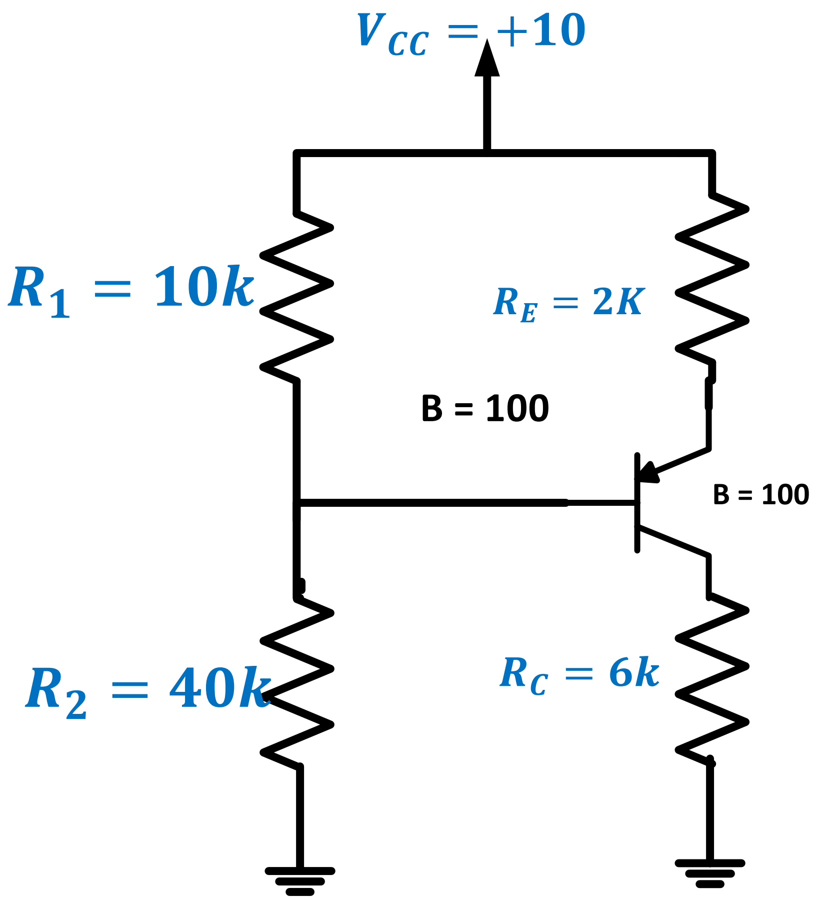
$$75 \geq \quad \beta \quad \geq 25$$

$$1.0067mA \geq \quad I_C \quad \geq 0.982mA$$

Circuit using pnp transistor:

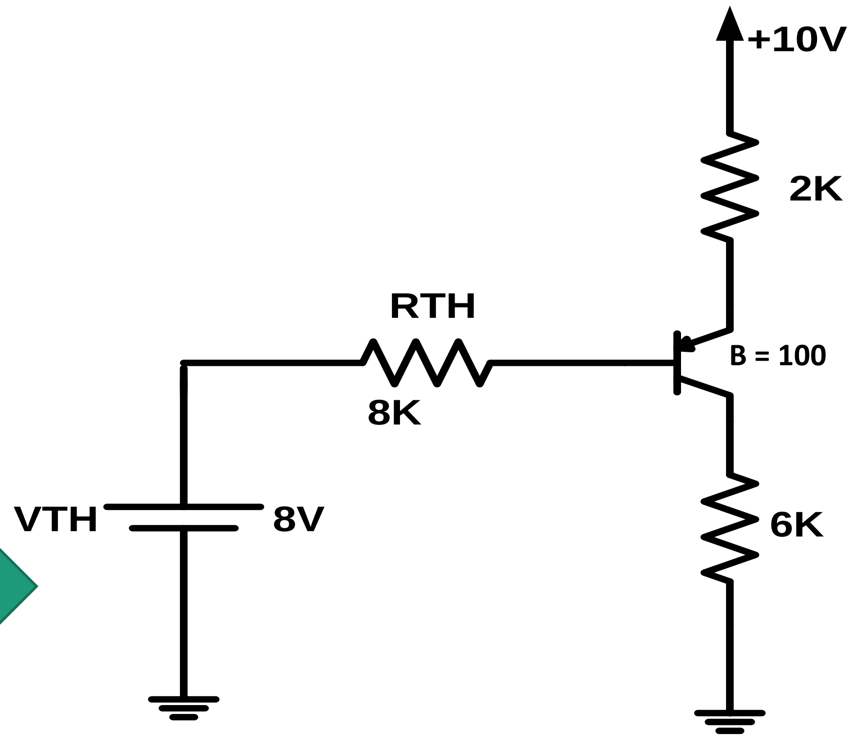
Example:

Find $\boldsymbol{I_E}$, $\boldsymbol{V_{EC}}$, for the circuit below:



solution

Using thevenin's theorem:



$$R_{th} = \frac{R_1 R_2}{R_1 + R_2} = \frac{10 * 40}{10 + 40} k = 8k\Omega$$

$$V_{th} = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{40}{10 + 40} * 10 = 8volt$$

KVL: $10 = 2kI_E + V_{EB} + R_{th} I_B + V_{th}$

- $\boldsymbol{I_E = 0.625mA}$

KVL: $10 = 2kI_E + V_{EC} + 6kI_C$

- $\boldsymbol{V_{EC} = 5volt}$

 $\boldsymbol{V_{CE}}$ = - 5V Which is < - 0.2V

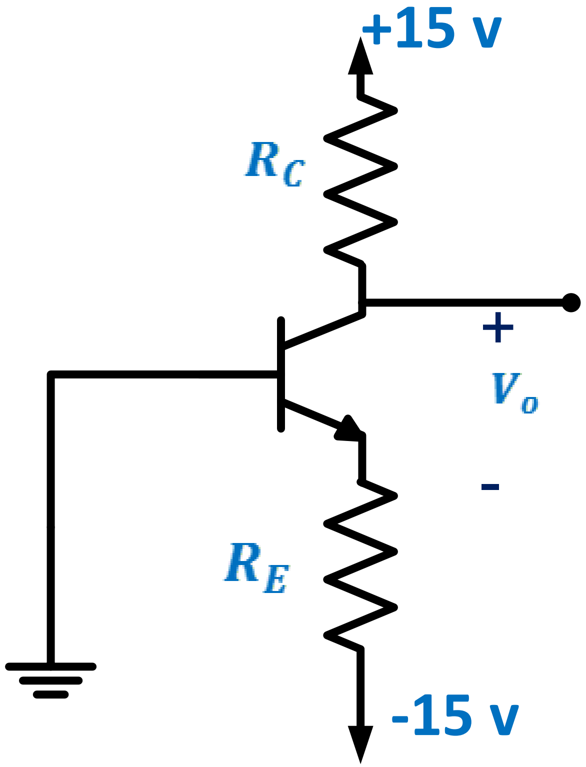
Example:

Design the given circuit so that

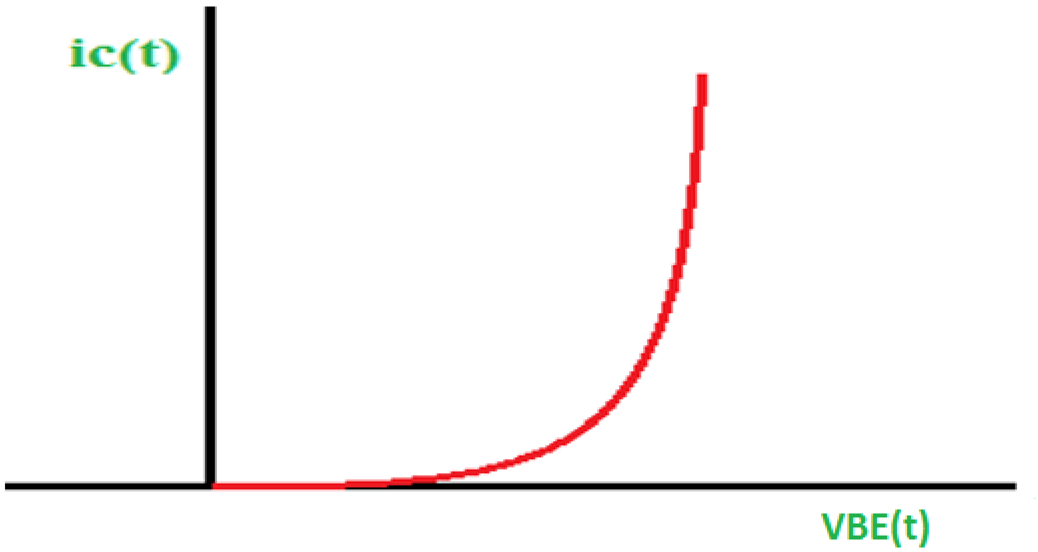
$$I_{CQ} = 2mA \text{ , and } V_C = 5\ volt$$

Given that $V_{BE} = 0.7\ \ volt\ @\ I_C = 1mA$

$$\beta = \infty$$



Solution:



$$i_{C(t)} \cong I_s e^{\frac{V_{BE(t)}}{V_T}}$$

$$I_C \cong I_s e^{\frac{V_{BE}}{V_T}}$$

$$I_s = (69.144)10^{-12}$$

$$V_{BE} = V_T \, ln\left(\frac{I_C}{I_s}\right)$$

➢ $V_{BE2} = 0.717\ V$

In our circuit $I_C = 2mA$ we must find the corresponding V_{BE}??

V_{BE} @ $I_C = 2mA$??

$$V_{BE1} = 0.7 = V_T \ln\left(\frac{1mA}{I_s}\right)$$

$$V_{BE2} = V_T \ln\left(\frac{2mA}{I_s}\right)$$

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

$$V_{BE2} = V_{BE1} + V_T \ln\left(\frac{2mA}{1mA}\right)$$

Let V_T = 25mV

➢ $V_{BE2} = 0.717\ V$

$V_{BE2} = 0.717$ @ $I_C = 2mA$

KVL: $V_C = V_{CC} - R_C I_C$

$$R_C = \frac{(V_{CC} - V_C)}{I_C}$$

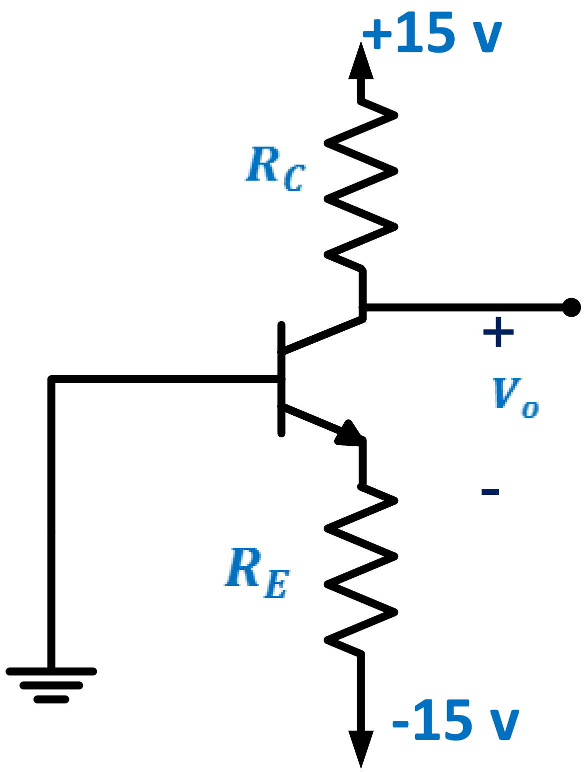
$$R_C = \frac{(15 - 5)}{2mA}$$

➢ $R_C = 5k\Omega$

KVL: $V_{BE} + R_E I_E - 15 = 0$

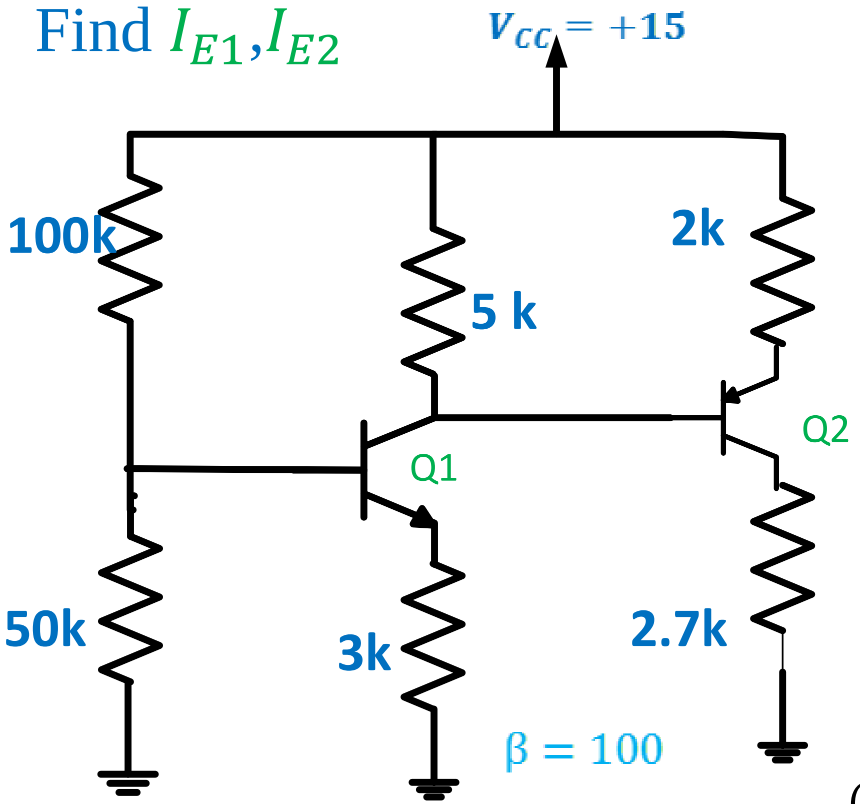
$$R_E = \frac{15 - V_{BE}}{I_E}$$

➢ $R_E = 7k\Omega$



Example:

Find I_{E1},I_{E2}

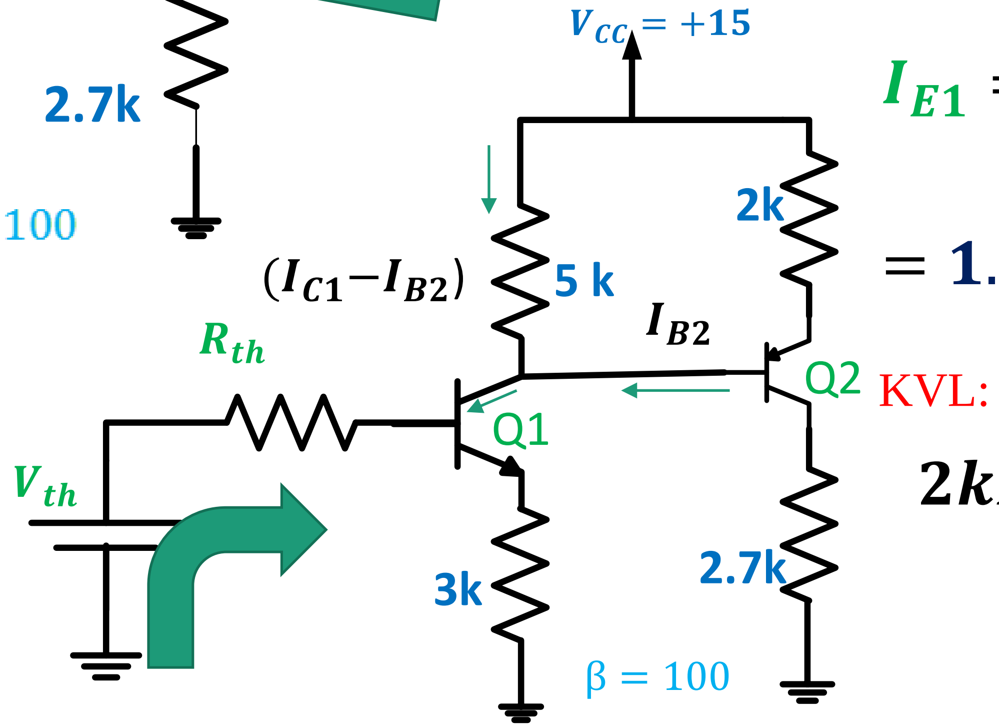


Solution

$$R_{th} = \frac{R_1 R_2}{R_1 + R_2} = \frac{50 * 100}{50 + 100} k = 33.3k\Omega$$

$$V_{th} = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{50}{50 + 100} * 15 = 5\ volt$$

KVL:



$$I_{E1} = \frac{V_{th} - V_{BE}}{\frac{R_{th}}{\beta + 1} + R_E} = \frac{5 - 0.7}{\left(\frac{33.3k}{101}\right) + 3k}$$

$$= 1.28mA$$

KVL:

$$2kI_{E2} + V_{EB} - 5k(I_{C1} - I_{B2}) = 0$$

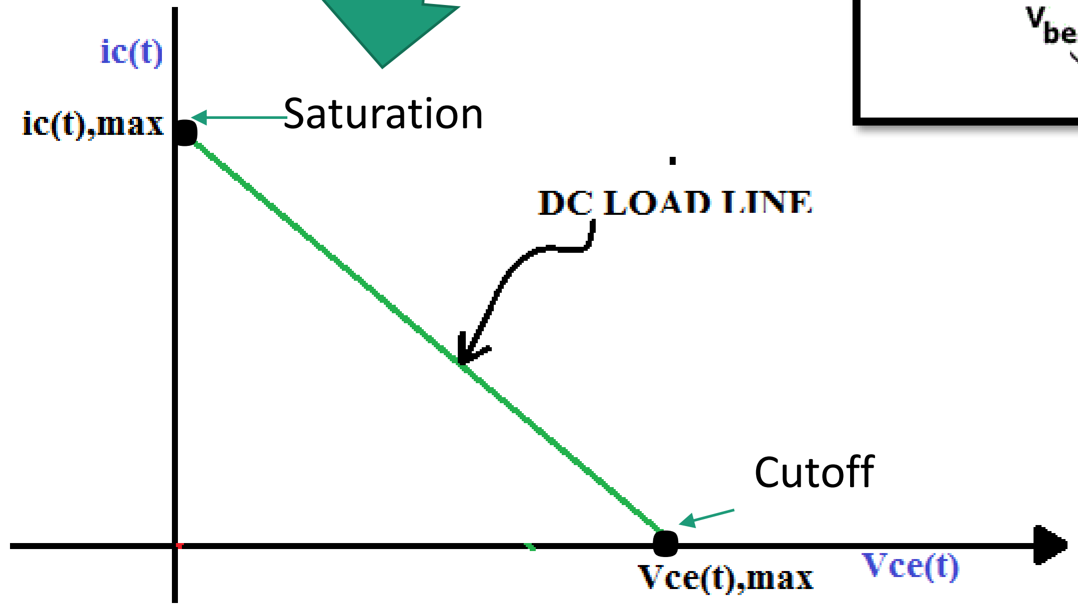
$$I_{E2} = 2.78mA$$

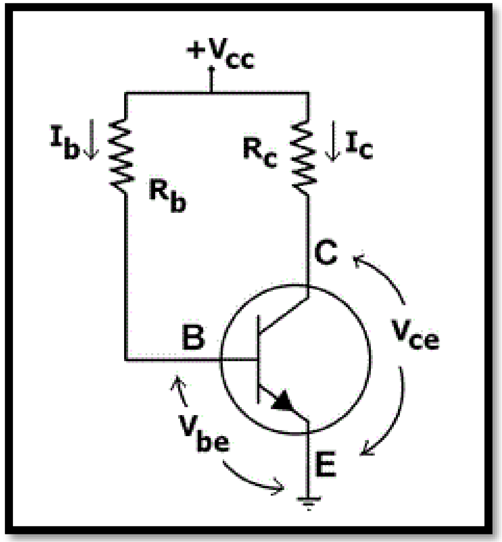
BJT Ac-Small signal analysis using Graphical method:

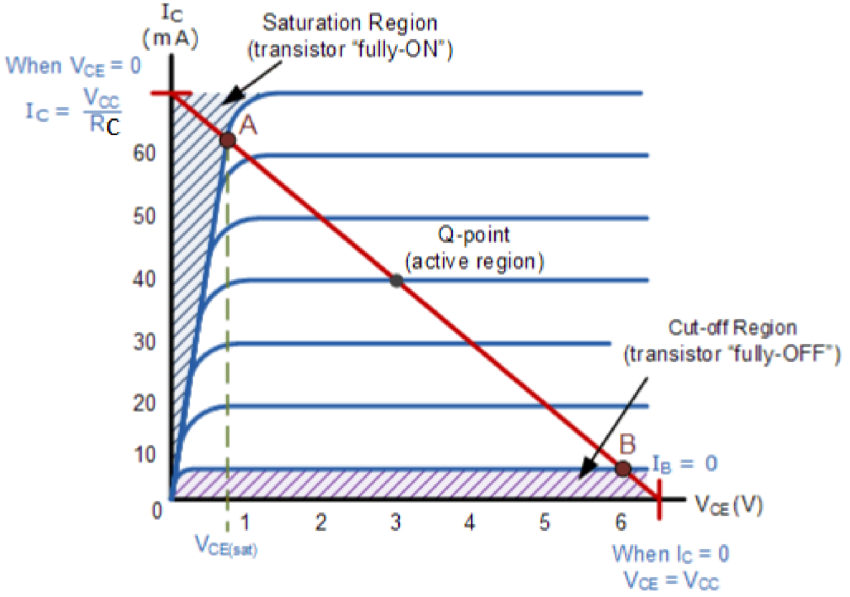
Graphical method:

KVL : $V_{CC} = R_c I_c + V_{CE}$

$$I_c = -\frac{1}{R_c} V_{CE} + \frac{V_{CC}}{R_c}$$







$$i_{C(t),max} = \frac{V_{CC}}{R_C}$$ Saturation

$$V_{CE(t),\max} = V_{CC}$$ Cutoff

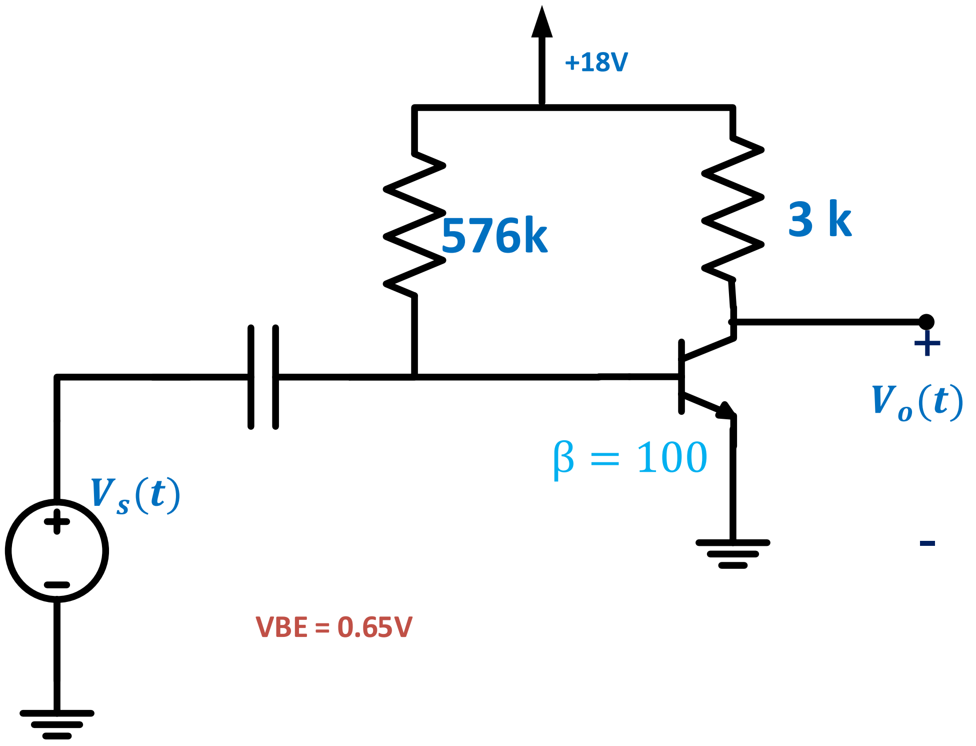
BJT Amplifier

Using superposition

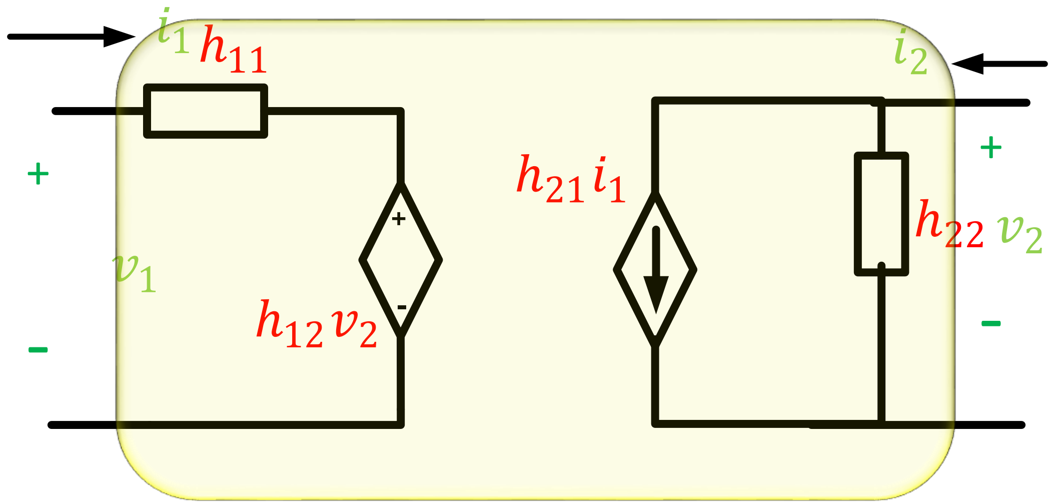
$$V_{BE}(t) = V_{BE} + v_{be}$$

$$i_C(t) = I_{CQ} + i_c$$

$$V_{CE}(t) = V_{CEQ} + v_{ce}$$



Ac small signal equivalent circuits for BJT configuration:

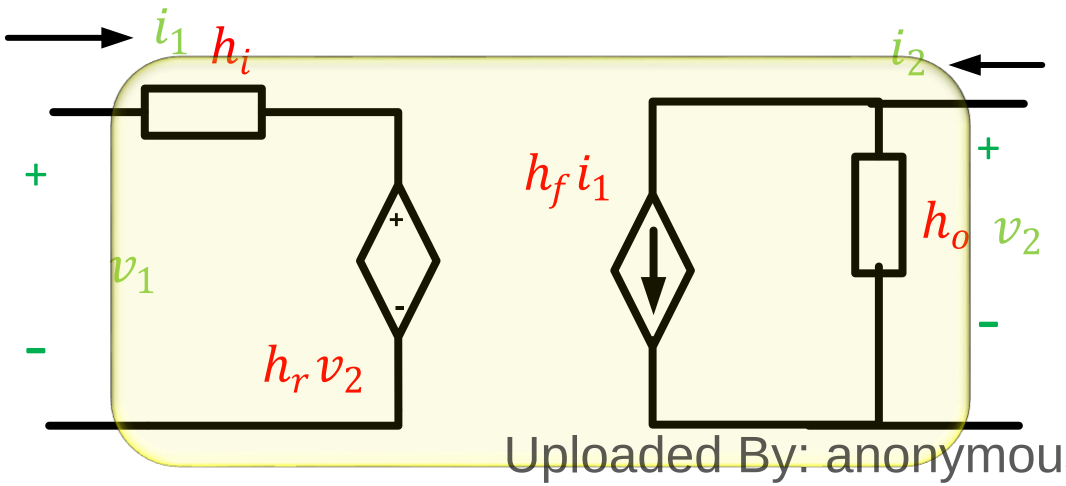


Hybrid parameters "h- parameters":

$$v_1 = h_{11} i_1 + h_{12} v_2$$

$$i_2 = h_{21} i_1 + h_{22} v_2$$

$h_{11} = \frac{v_1}{i_1}\Big|\, v_2 = 0$ Short circuit input impedance, Ω (h_i)



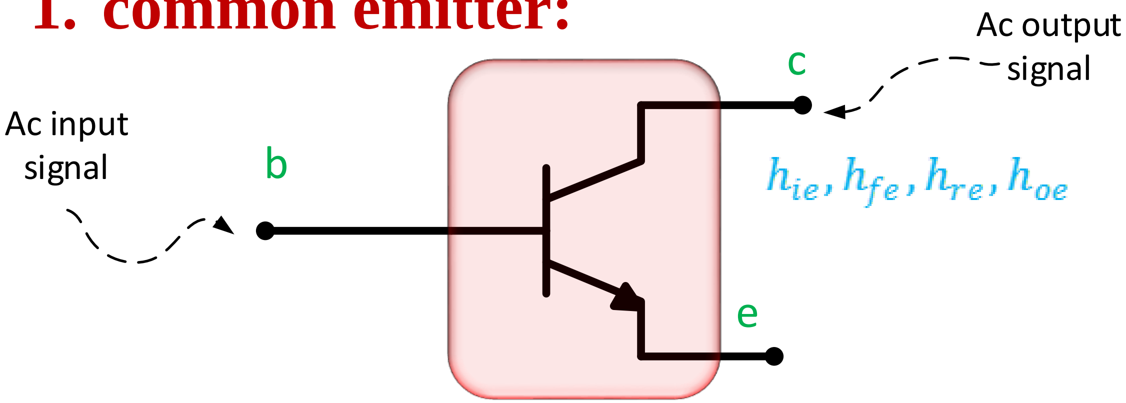
$h_{12} = \frac{v_1}{v_2}\Big|\, i_1 = 0$ Open circuit reverse voltage ratio, (h_r)

$h_{21} = \frac{i_2}{i_1}\Big|\, v_2 = 0$ Short circuit forward current ratio, (h_f)

$h_{22} = \frac{i_2}{v_2}\Big|\, i_1 = 0$ Open circuit output admittance, $℧$ (h_o)

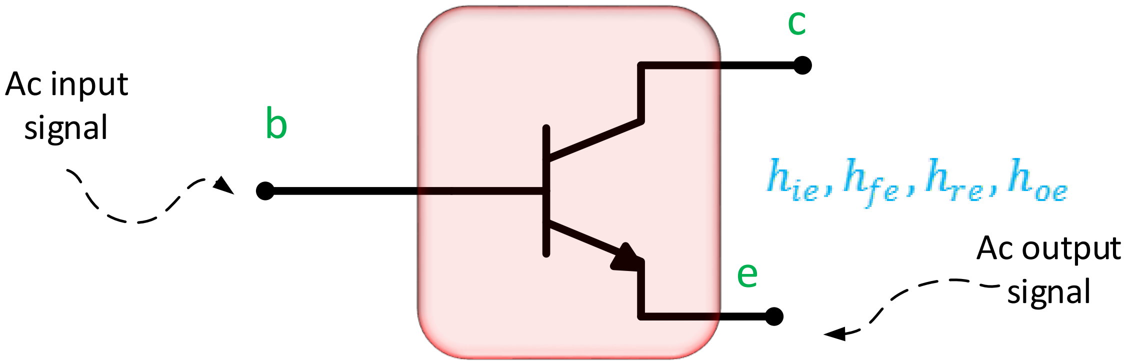
Transistor configuration:

1. common emitter:



$h_{ie}, h_{fe}, h_{re}, h_{oe}$

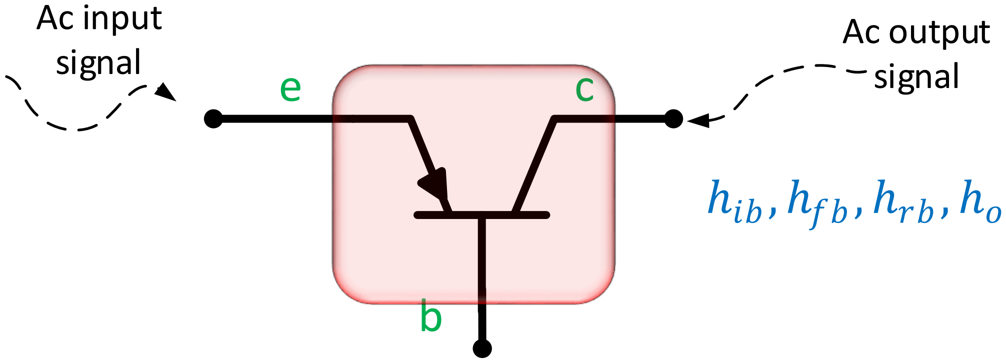
2. common collector



$h_{ie}, h_{fe}, h_{re}, h_{oe}$

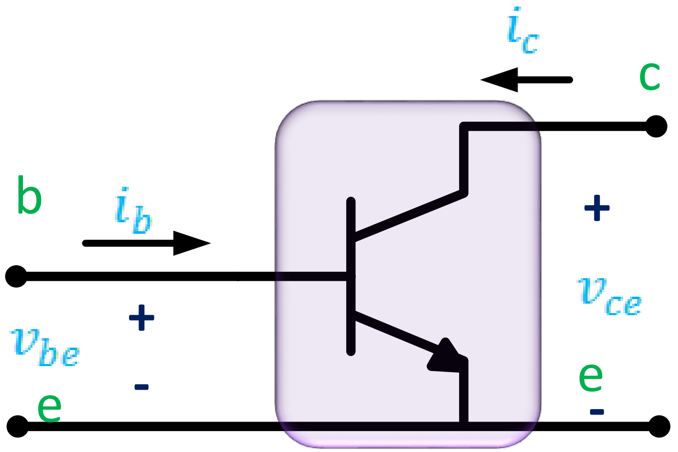
$\boldsymbol{h_{ic}}$, $\boldsymbol{h_{fc}}$, $\boldsymbol{h_{rc}}$, $\boldsymbol{h_{oc}}$

3. common base



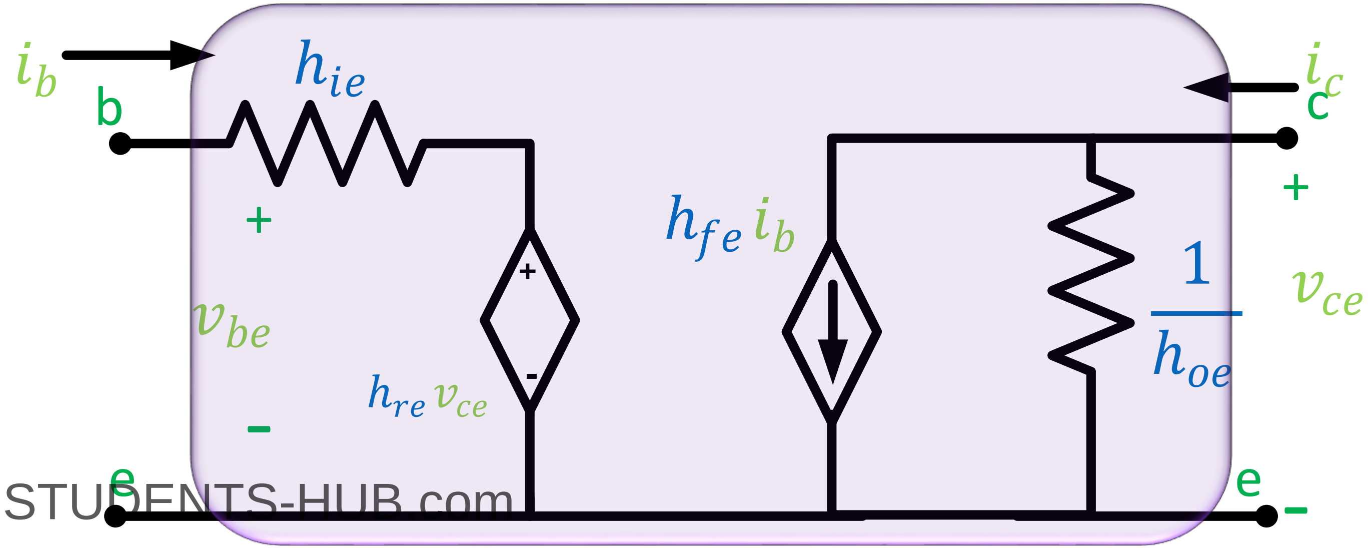
$h_{ib}, h_{fb}, h_{rb}, h_{ob}$

Common emitter & common collector:

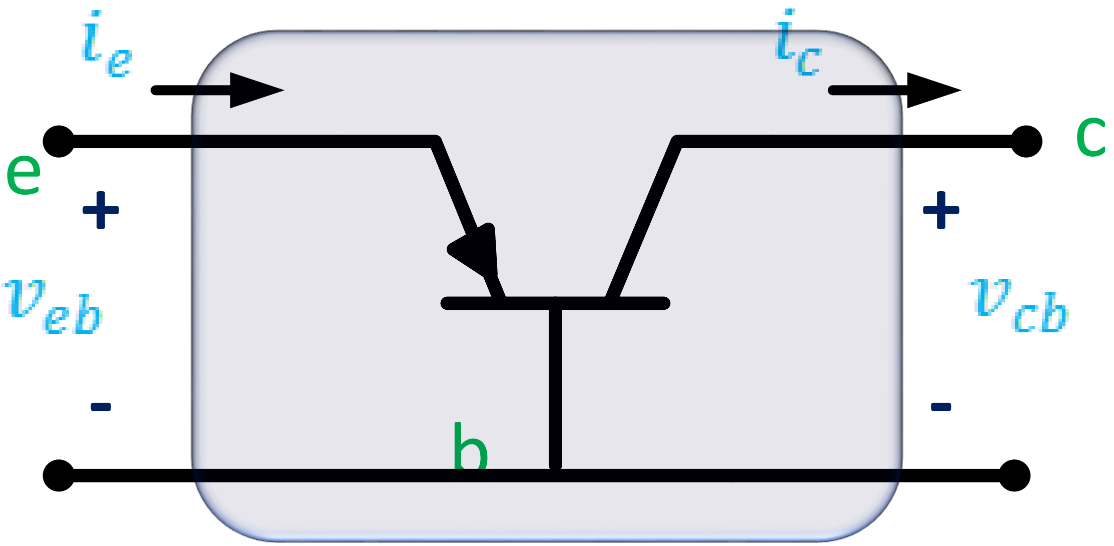


$$v_{be} = h_{ie} i_b + h_{re} v_{ce}$$

$$i_c = h_{fe} i_b + h_{oe} v_{ce}$$

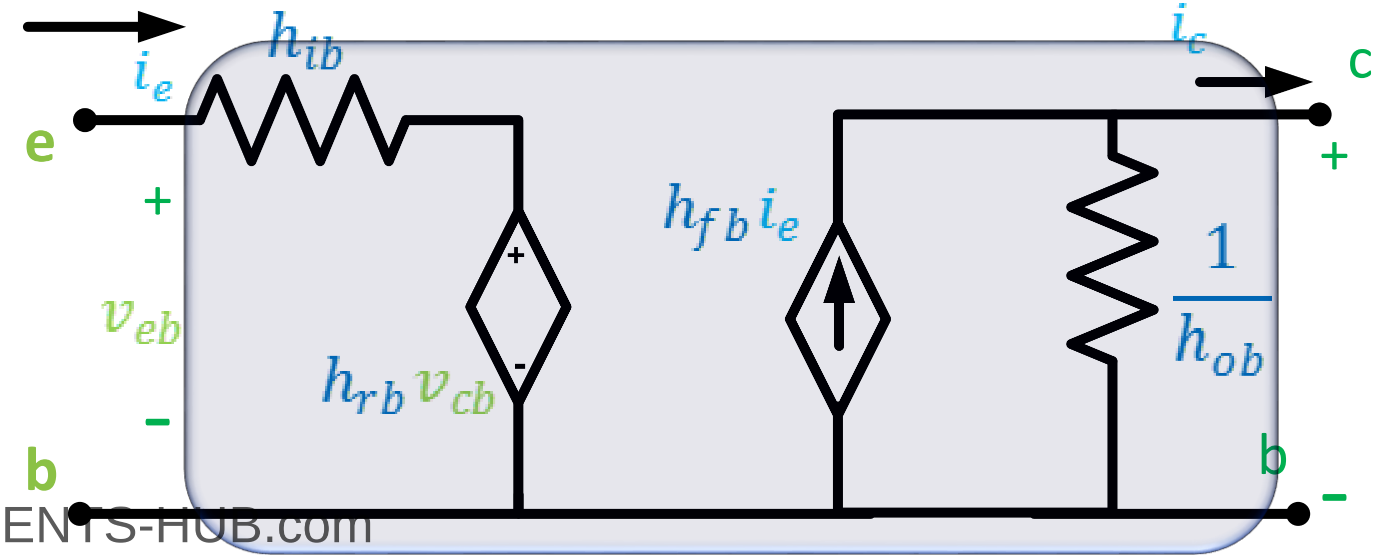


Common base:

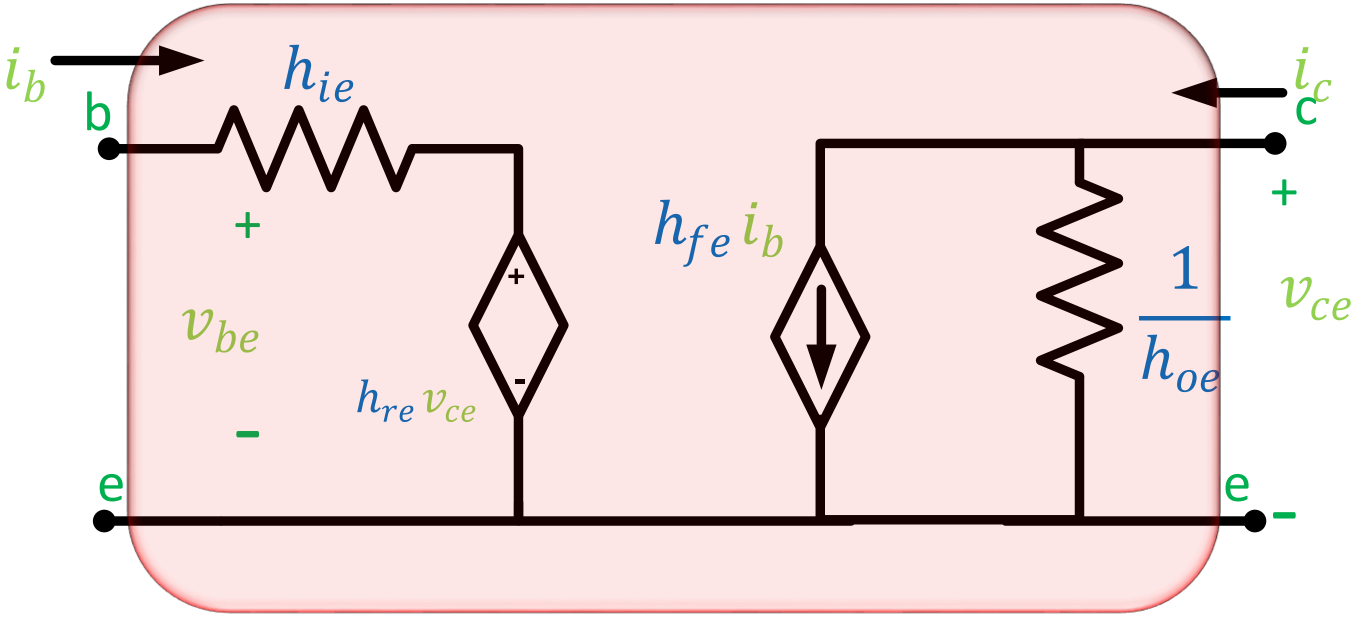


$$\boldsymbol{v_{eb} = h_{ib} i_e + h_{rb} v_{cb}}$$

$$\boldsymbol{i_c = h_{fb} i_e + h_{ob} v_{cb}}$$



h-parameter typical value:



$$\boldsymbol{h_{ie} = 1600\Omega}$$

$$\boldsymbol{h_{oe} = 20 * 10^{-6}\ \mho}$$

$$\boldsymbol{h_{fe} = 80}$$

$$\boldsymbol{h_{re} = 20 * 10^{-4}}$$

$$h_{oe} = 20 * 10^{-6}\ \mho \longrightarrow 0$$

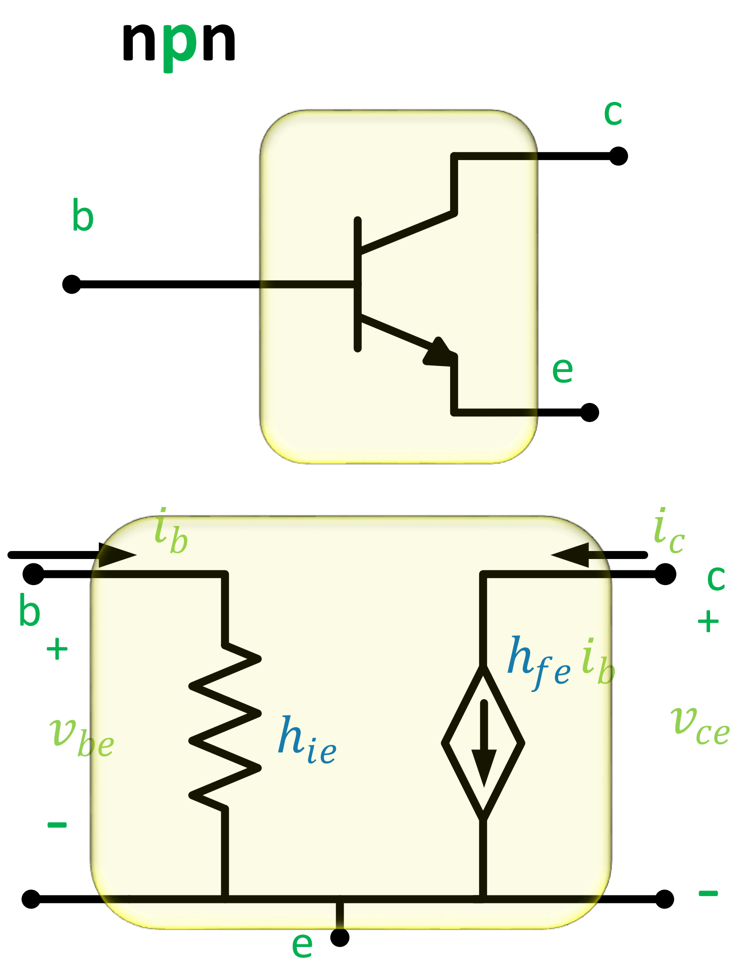
We replace $\frac{1}{h_{oe}}$ with open circuit.

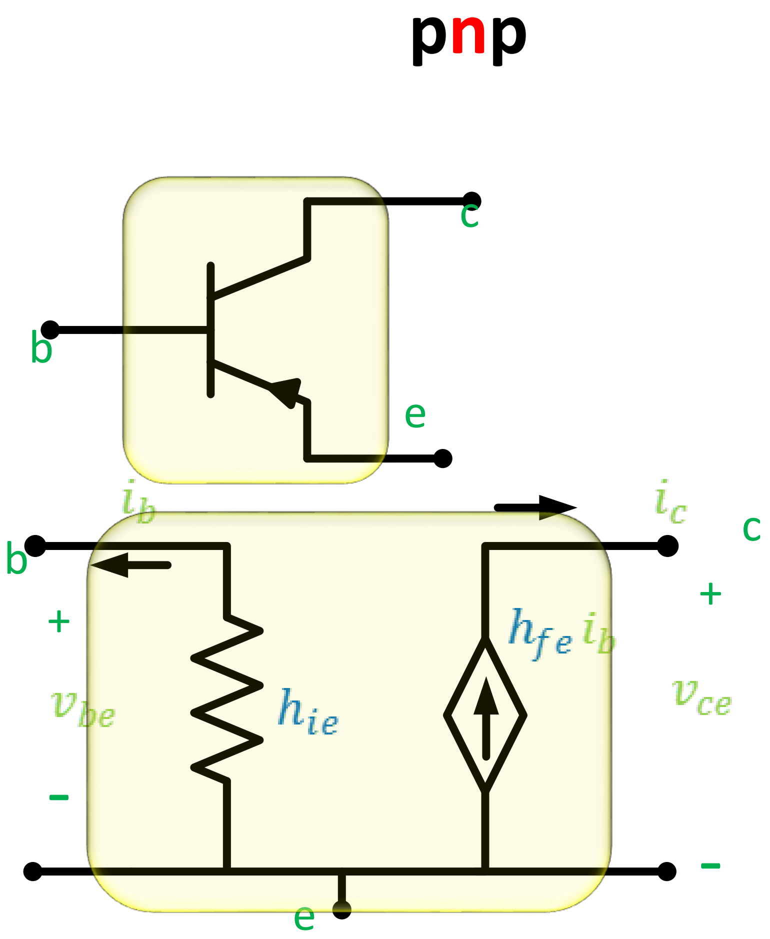
$$\boldsymbol{h_{re} = 20 * 10^{-4} \longrightarrow 0}$$

We replace $h_{re} v_{ce}$ with short circuit.

Approximate BJT models:

1) Common emitter & common collector:



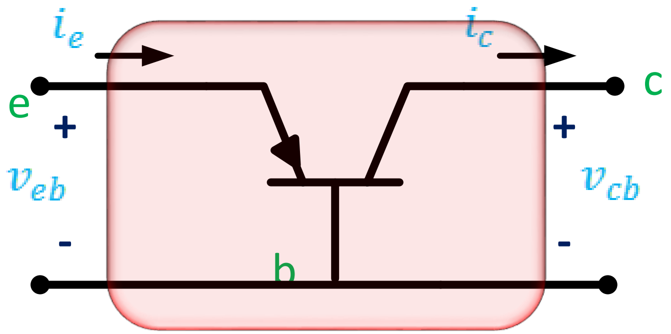


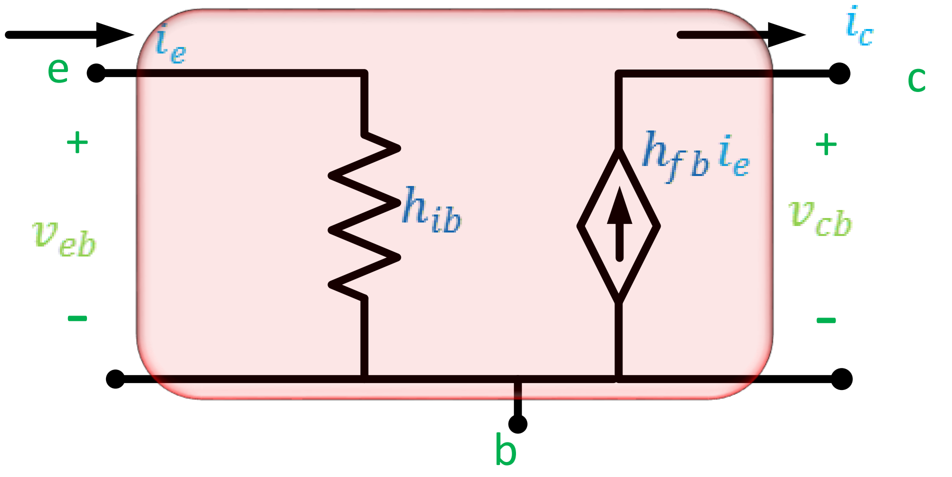
$$i_c = h_{fe}\, i_b = \beta\, i_b$$

➢ $h_{fe} = \beta$

$$h_{ie} = \frac{V_T}{I_B} = \frac{\beta V_T}{I_C} = \frac{(\beta + 1) V_T}{I_E}$$

2-commom base:





$$i_c = h_{fb}\, i_e = \alpha\, i_e$$

- $h_{fb} = \alpha$

$$h_{ib} = \frac{V_T}{I_E}$$

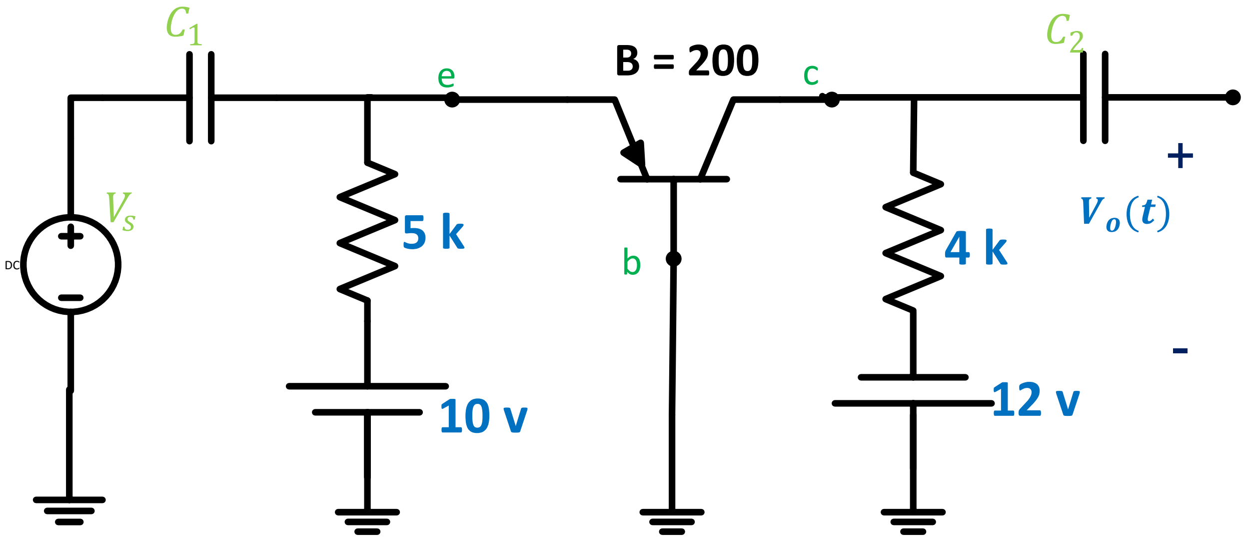
$$h_{ie} = (h_{fe} + 1)h_{ib}$$

BJT ac amplifiers:

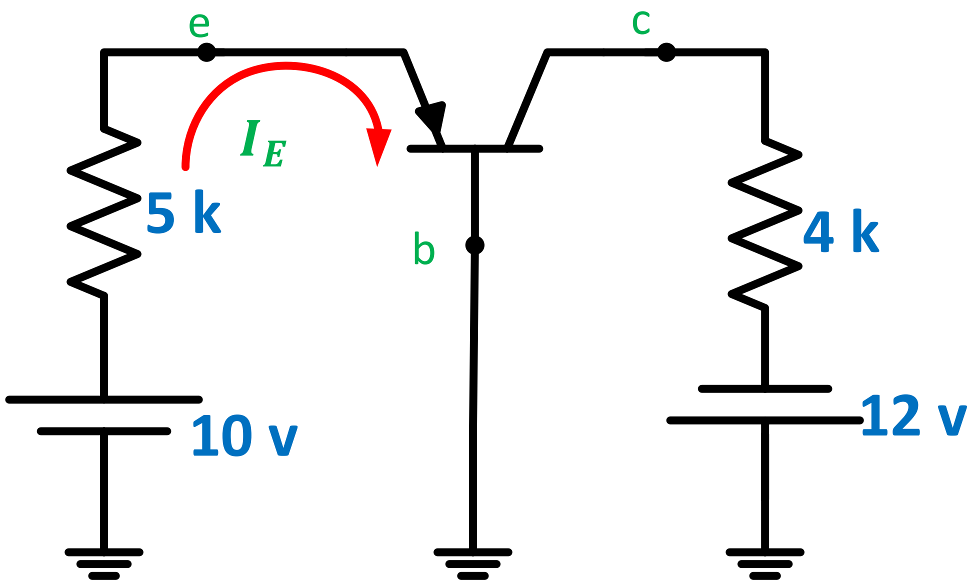
1-common base amplifiers:

Find :

1. voltage gain
2. Current gain
3. output impedance
4. Input impedance



a) Dc analysis:



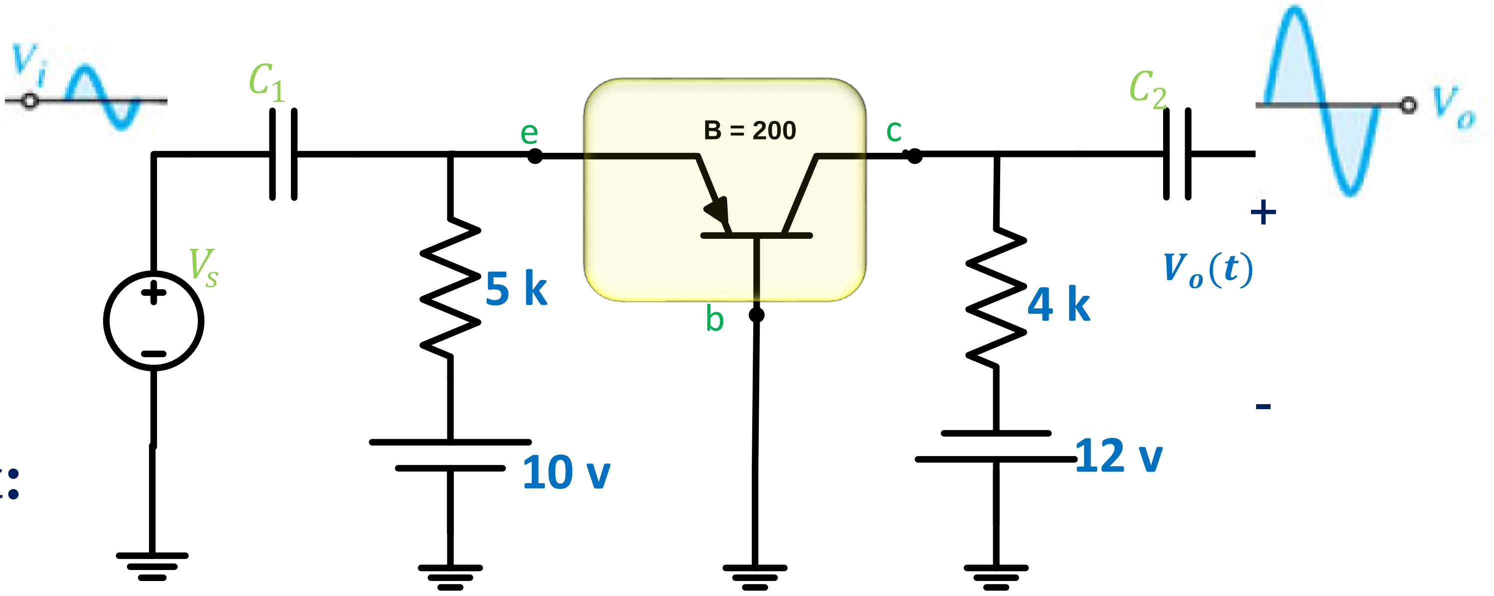
$$I_E = \frac{10 - V_{EB}}{5k} = \frac{10 - 0.7}{5k} = 1.86mA$$

$$h_{ib} = \frac{V_T}{I_{EQ}} = 13.98\Omega$$

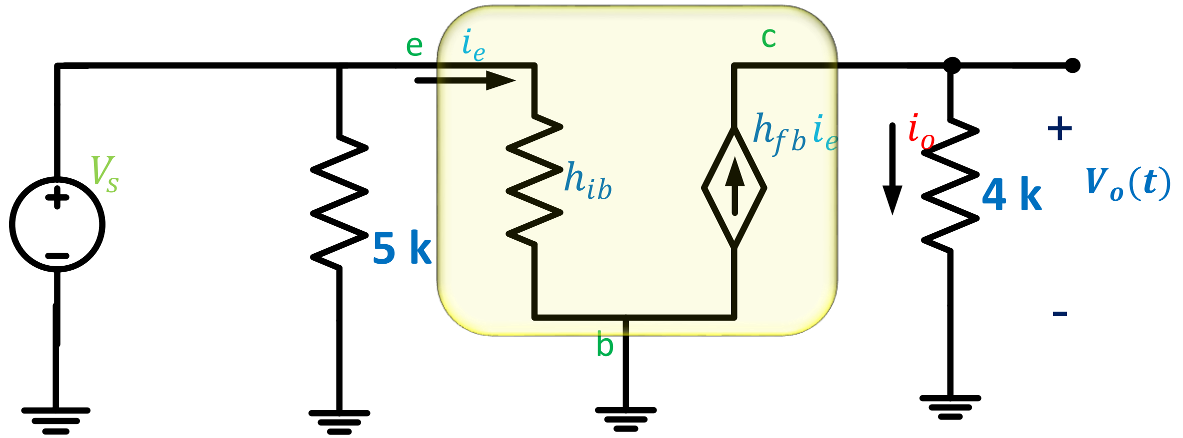
BJT ac amplifiers:

1-common base amplifiers:

b) Ac small signal analysis:



Ac small signal equivalent circuit:



1. Voltage gain $A_v = \frac{V_o}{Vs}$

$$V_o = h_{fb}\, i_e(4k)$$

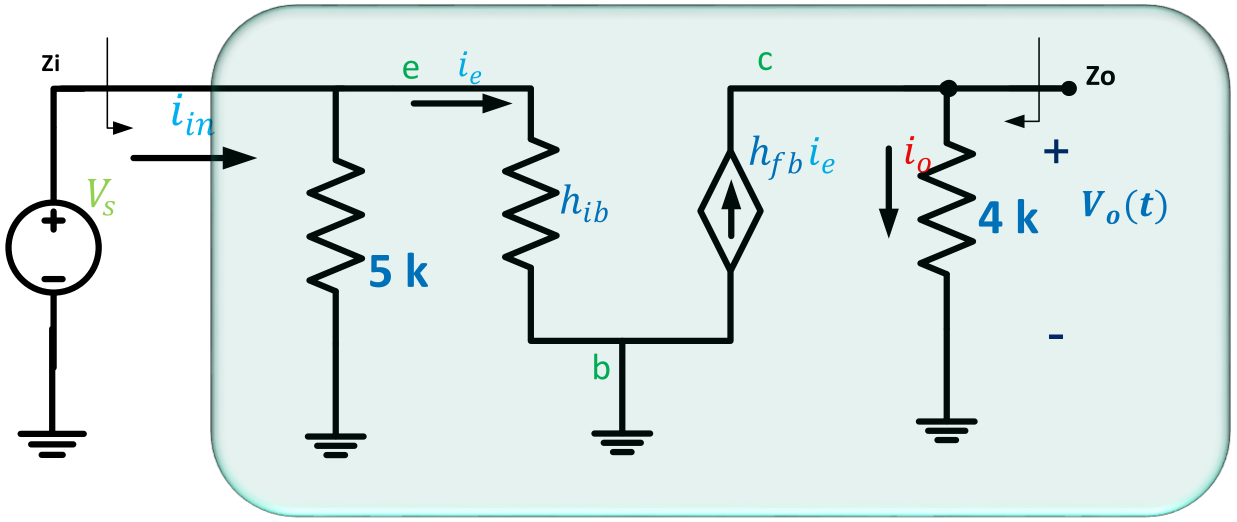
$$i_e = \frac{V_s}{h_{ib}}$$

$$A_v = \frac{V_o}{Vs} = \frac{h_{fb}(4k)}{h_{ib}} = 286 > 1$$

$$h_{fb} = \frac{h_{fe}}{h_{fe+1}}$$

V_s is in phase with V_o

2. **Current gain** $A_i = \frac{i_o}{i_{in}}$



$$i_o = h_{fb}\, i_e$$

$$i_e = i_{in}\frac{5k}{5k + h_{ib}}$$

$$A_i = \frac{5k}{5k + h_{ib}} h_{fb} \quad < 1$$

$$h_{fb} = \frac{h_{fe}}{h_{fe+1}}$$

3. **Input impedance** Z_i

Z_i is R_{th} seen by the source

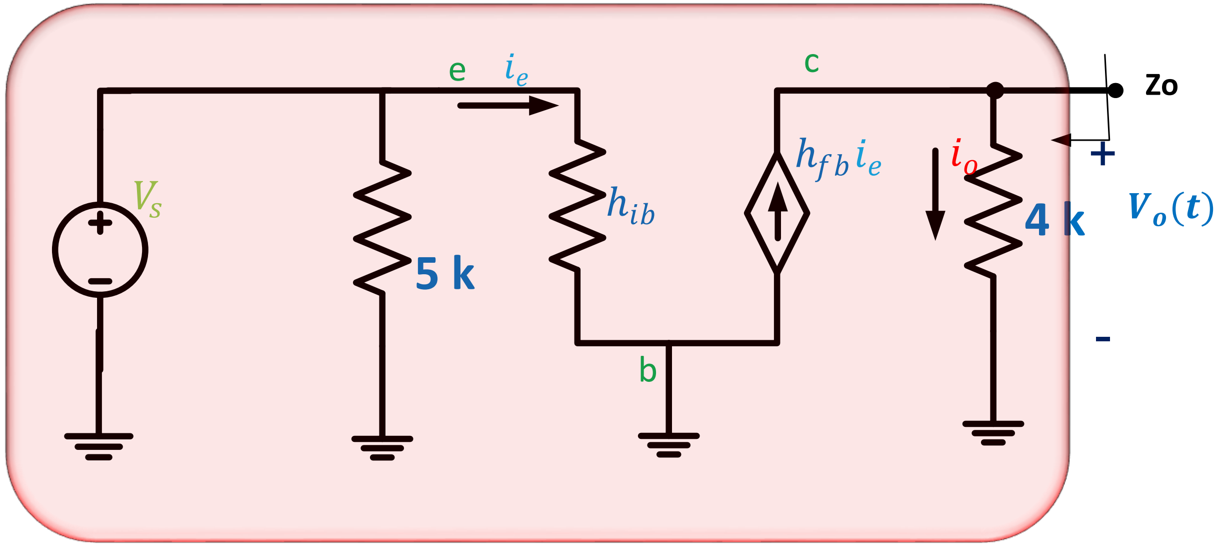
$$Z_i = \frac{V_s}{i_{in}}$$

$$i_{in} = \frac{V_s}{5k} + \frac{V_s}{h_{ib}}$$

$$\frac{V_s}{i_{in}} = (5k||h_{ib}) \cong h_{ib}$$

$Z_i \cong h_{ib}$ **Very small;**

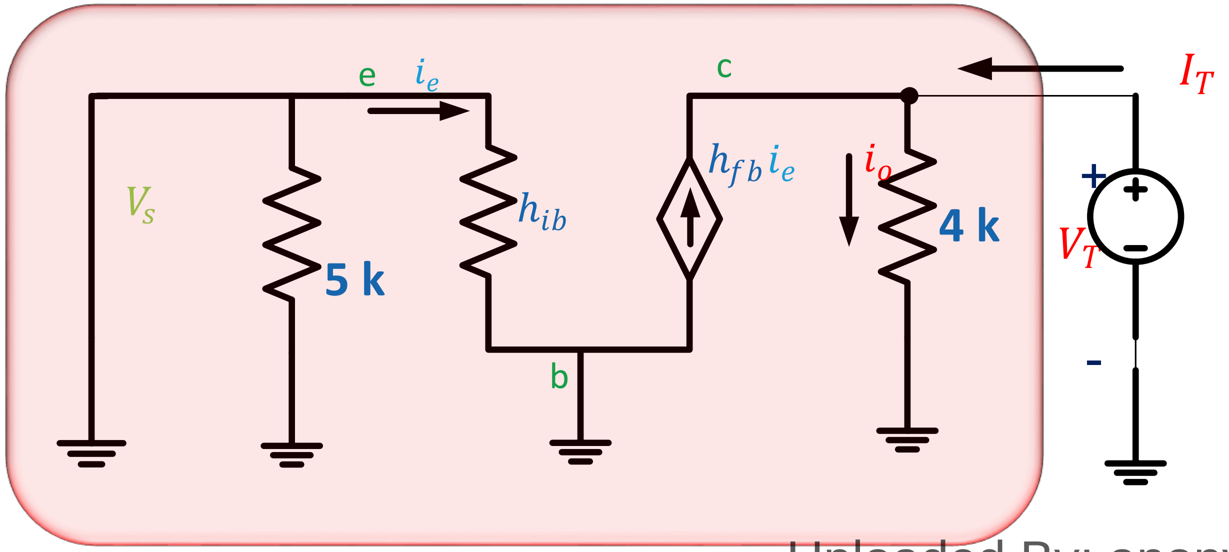
4. Output impedance Z_o



Z_o **is** R_{th} **seen by the load**

RL = ∞

$$Z_o = \frac{V_T}{I_T}\Bigg| V_s = 0$$



$$I_T = \frac{V_T}{4k} - h_{ib}i_e$$

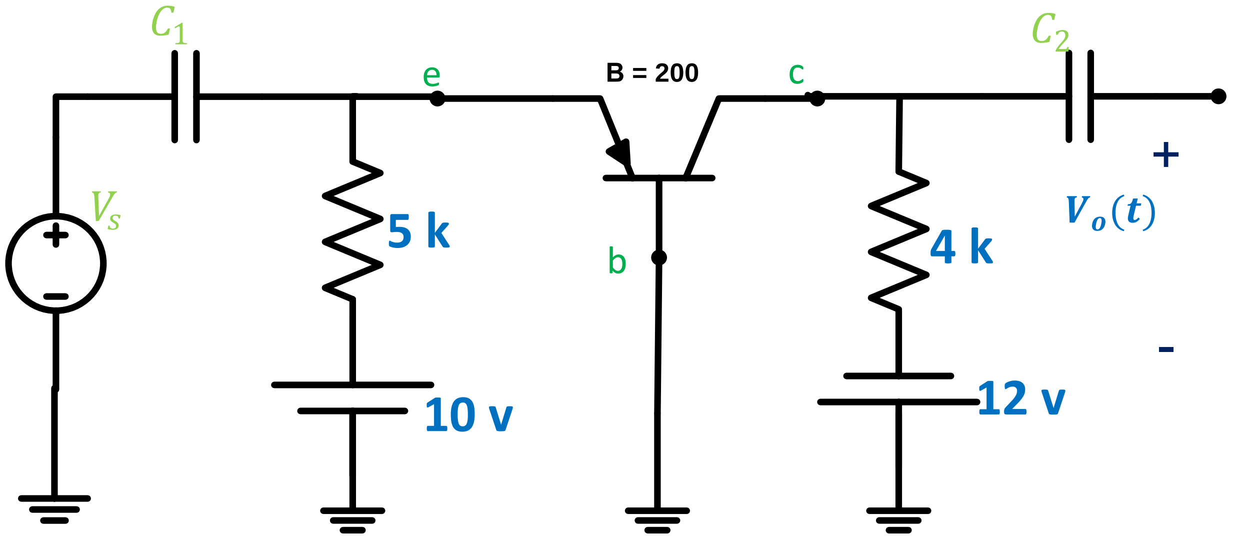
$$i_e = 0$$

$$\frac{V_T}{I_T} = 4k \quad \text{(Large)}$$

Common base amplifier

$$A_v = \frac{V_o}{Vs} = \frac{h_{fb}(4k)}{h_{ib}} = 286 > 1$$

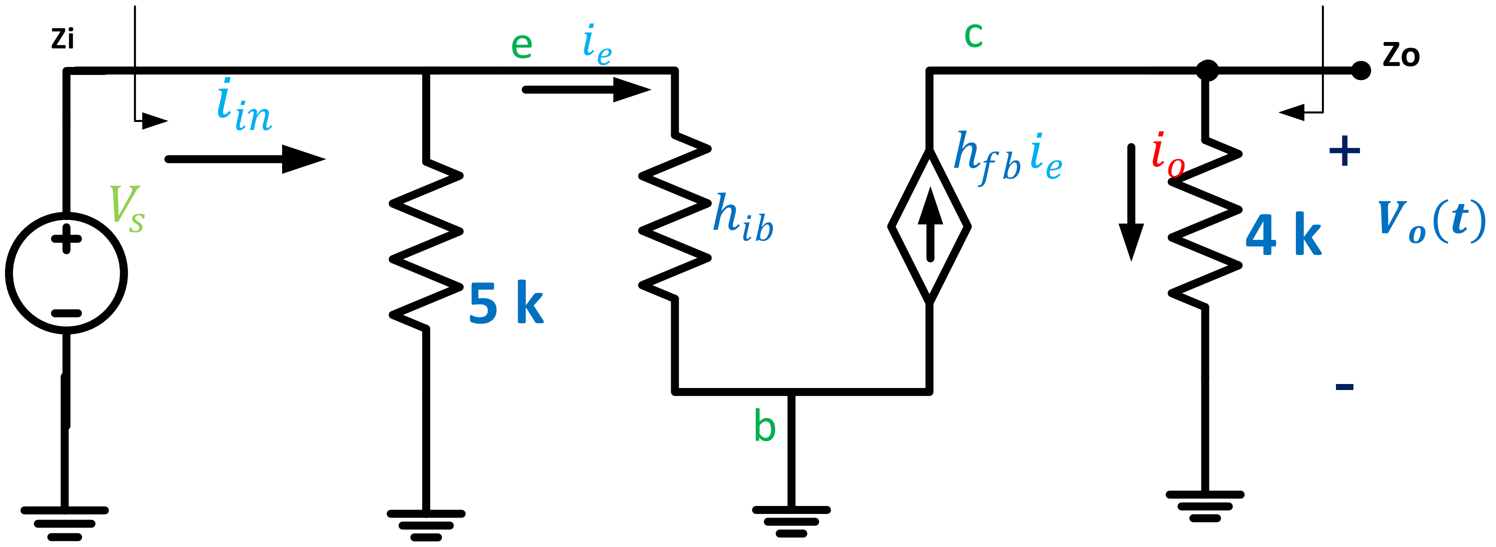
$$A_i = \frac{5k}{5k + h_{ib}} h_{fb} \quad < 1$$



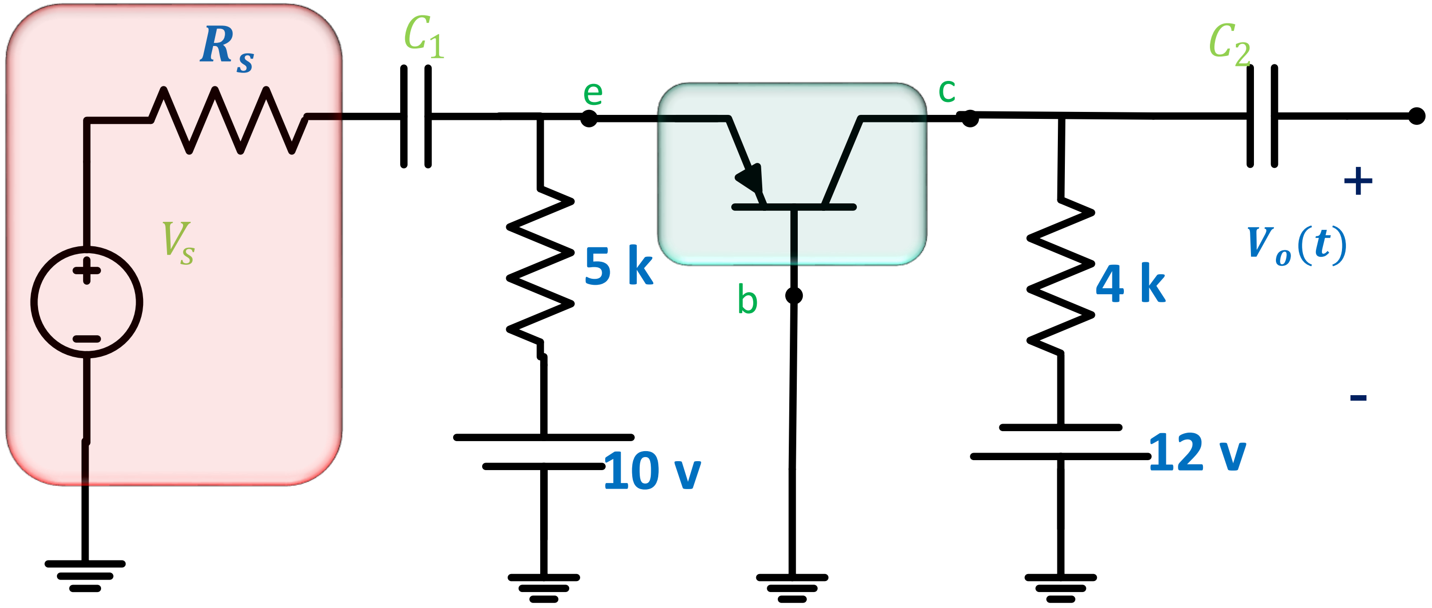
Zi $= (5k||h_{ib})$

$Z_i \cong h_{ib}$ (Very small)

$Z_o = 4k$ (Large)



The effect of R_s



$$V_o = h_{fb}\, i_e(4k)$$

$$i_e = \frac{V_i}{h_{ib}}$$

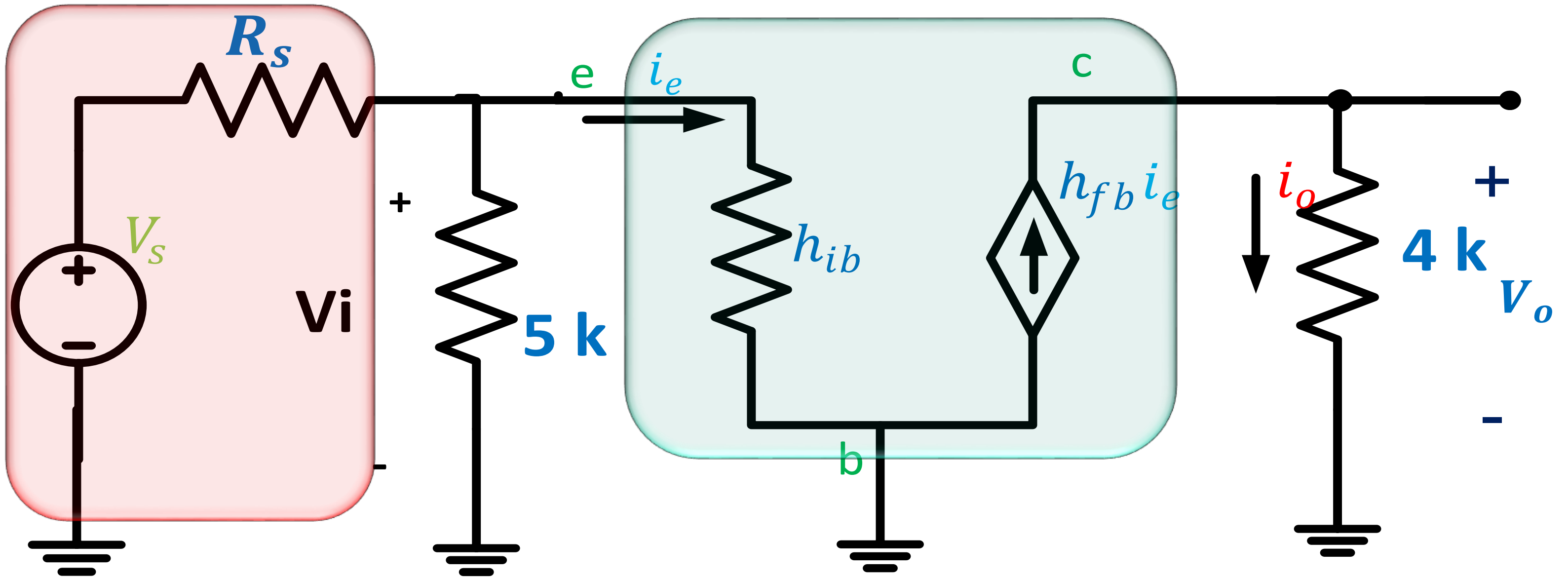
$$V_i = (5k||\, h_{ib})/((5k||\, h_{ib}) + R_s)V_s$$

$$V_i = \frac{Z_i}{Z_i + R_s} * V_s$$

$$A_{vs} = \frac{V_o}{V_s} = \frac{h_{fb}(4k)}{h_{ib}}\frac{Z_i}{Z_i+R_s}$$

$$A_{vs} = \begin{cases} 62.5 & R_s = 50\Omega \\ 0.4 & R_s = 10k\Omega \end{cases}$$

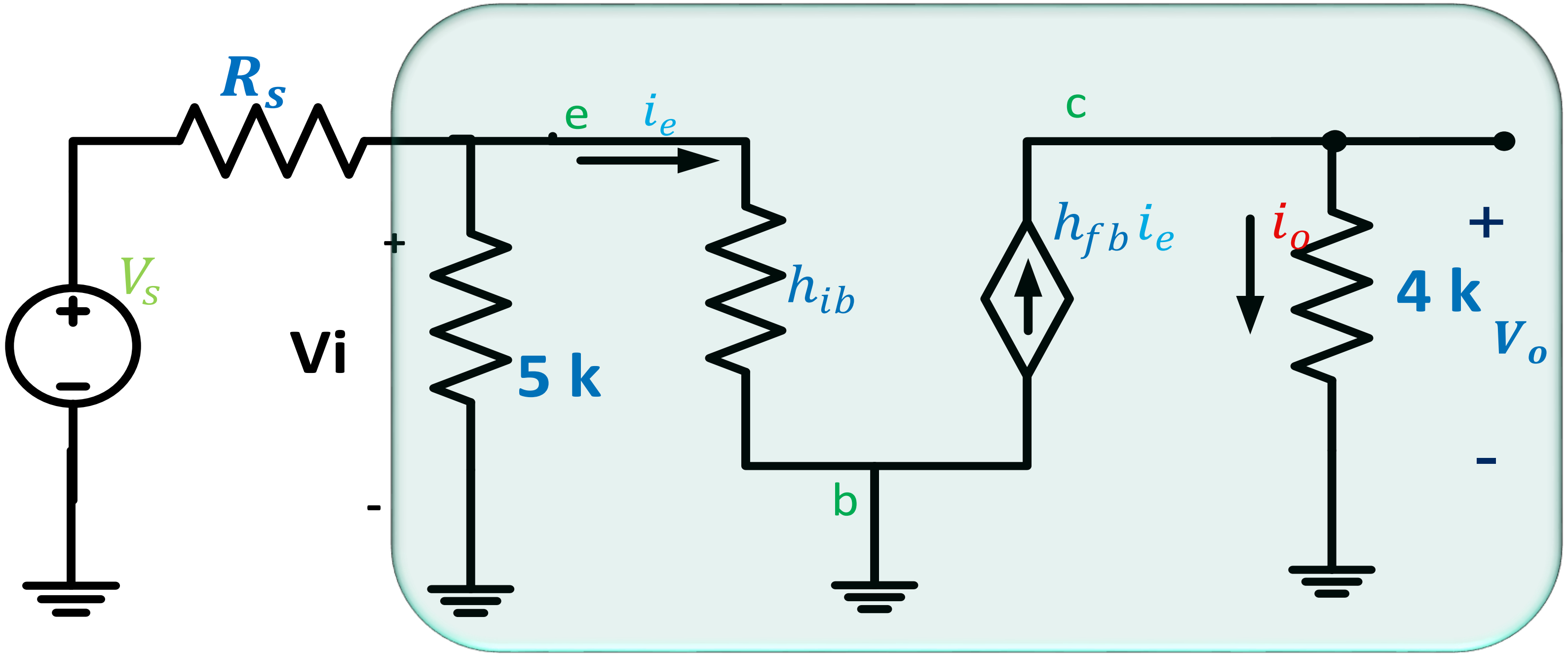
Ac small signal equivalent circuit:



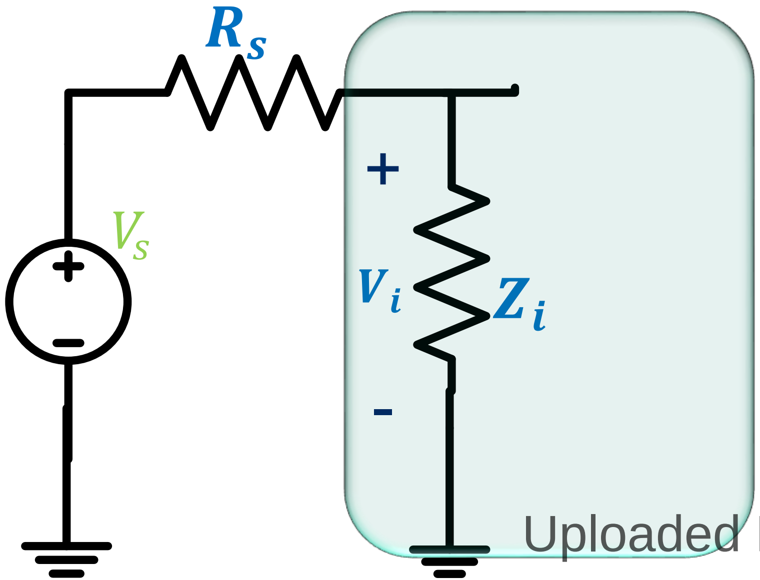
$$V_o = 286\, V_i$$

$$V_i = \frac{Z_i}{Z_i + R_s} * V_s$$

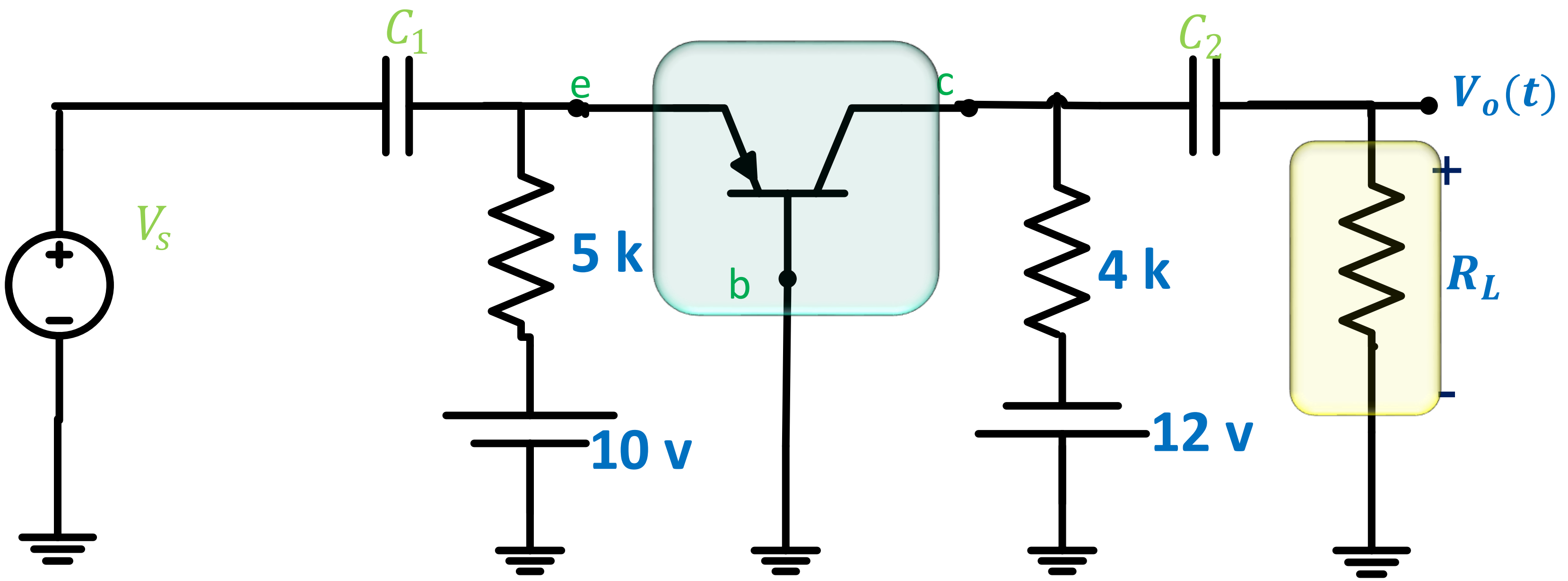
$$V_o = \frac{Z_i}{Z_i + R_s} 286\, V_s$$



Z_i **Must be as large as could be**



The effect of R_L



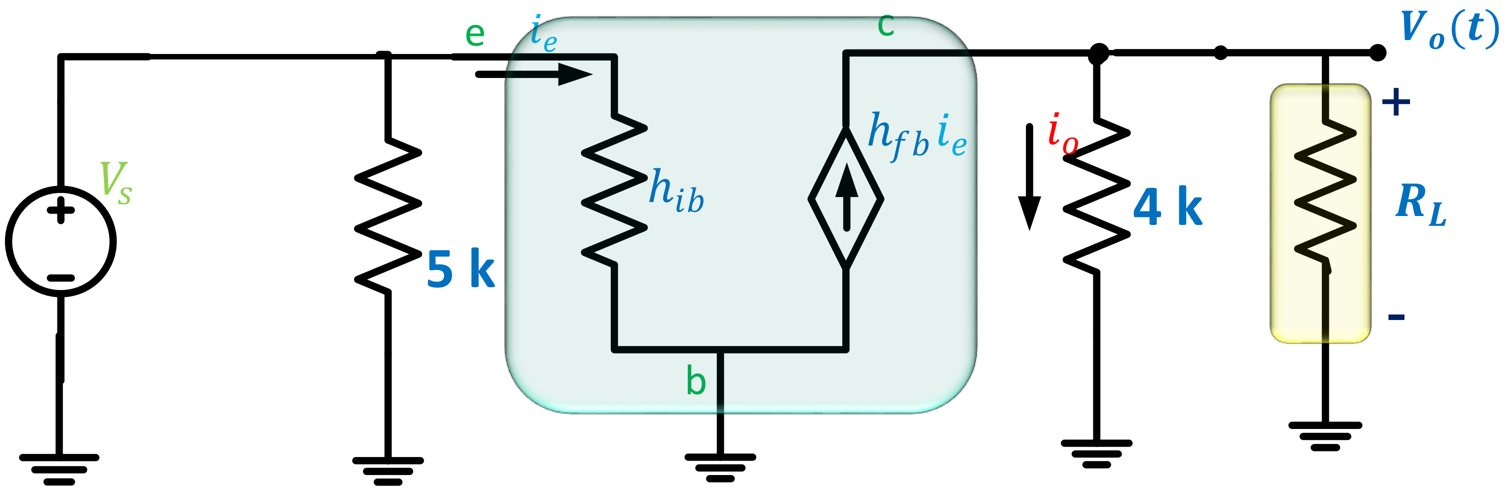
$$V_o = h_{fb}\, i_e(4k||R_L)$$

$$i_e = \frac{V_s}{h_{ib}}$$

$$A_v = \frac{V_o}{V_s} = \frac{h_{fb}(4k||R_L)}{h_{ib}}$$

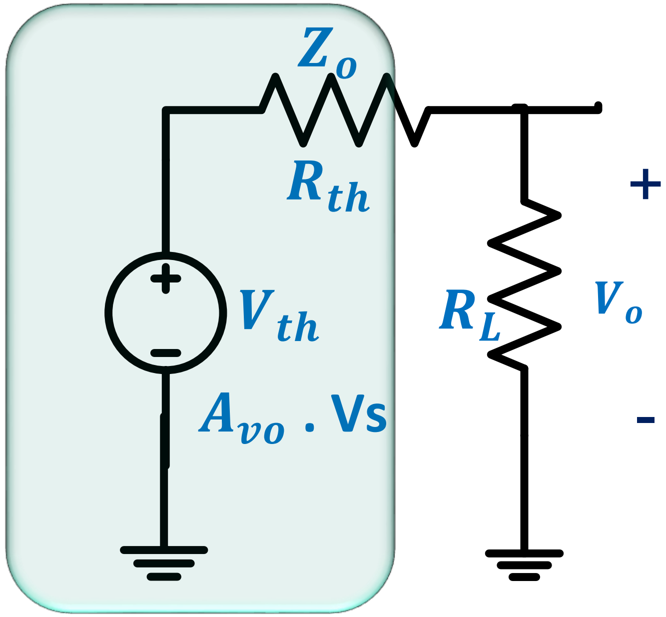
$$A_v = \begin{cases} 0.7135 & R_L = 10\Omega \\ 204.4 & R_L = 10k\Omega \end{cases}$$

Ac small signal equivalent circuit:



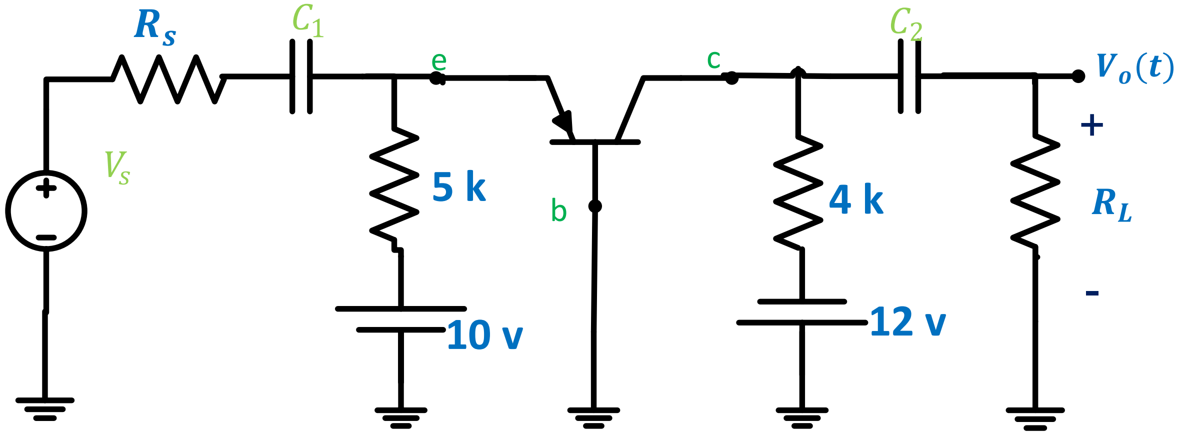
The effect of R_L and R_s

Using thevenin's theorem:

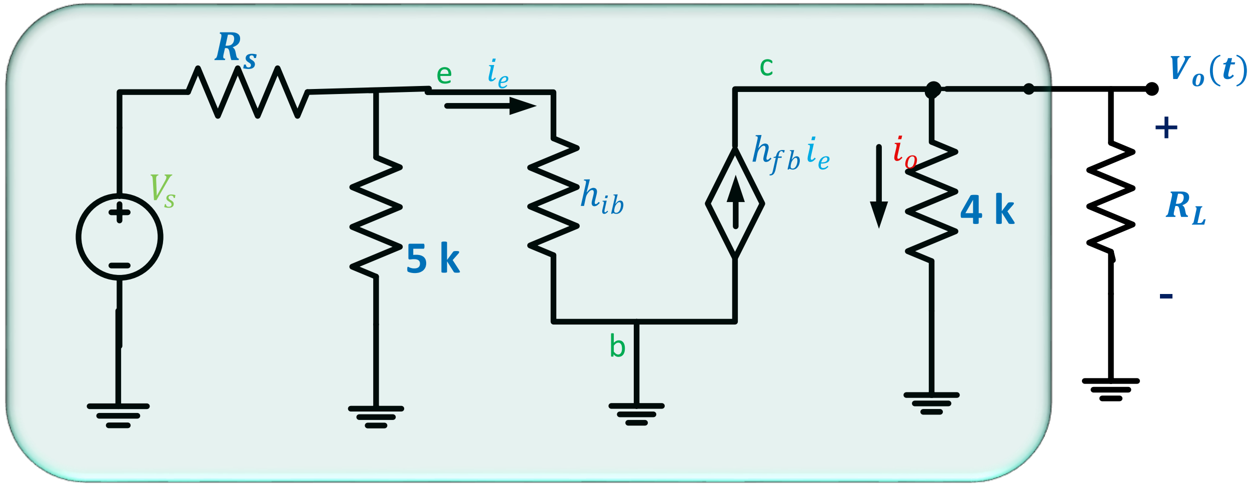


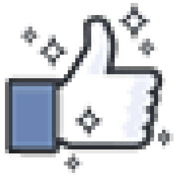
$$V_o = \frac{R_L}{R_L + Z_o} A_{Vo} V_s$$

Z_o Must be as small as could be;



Ac small signal equivalent circuit:

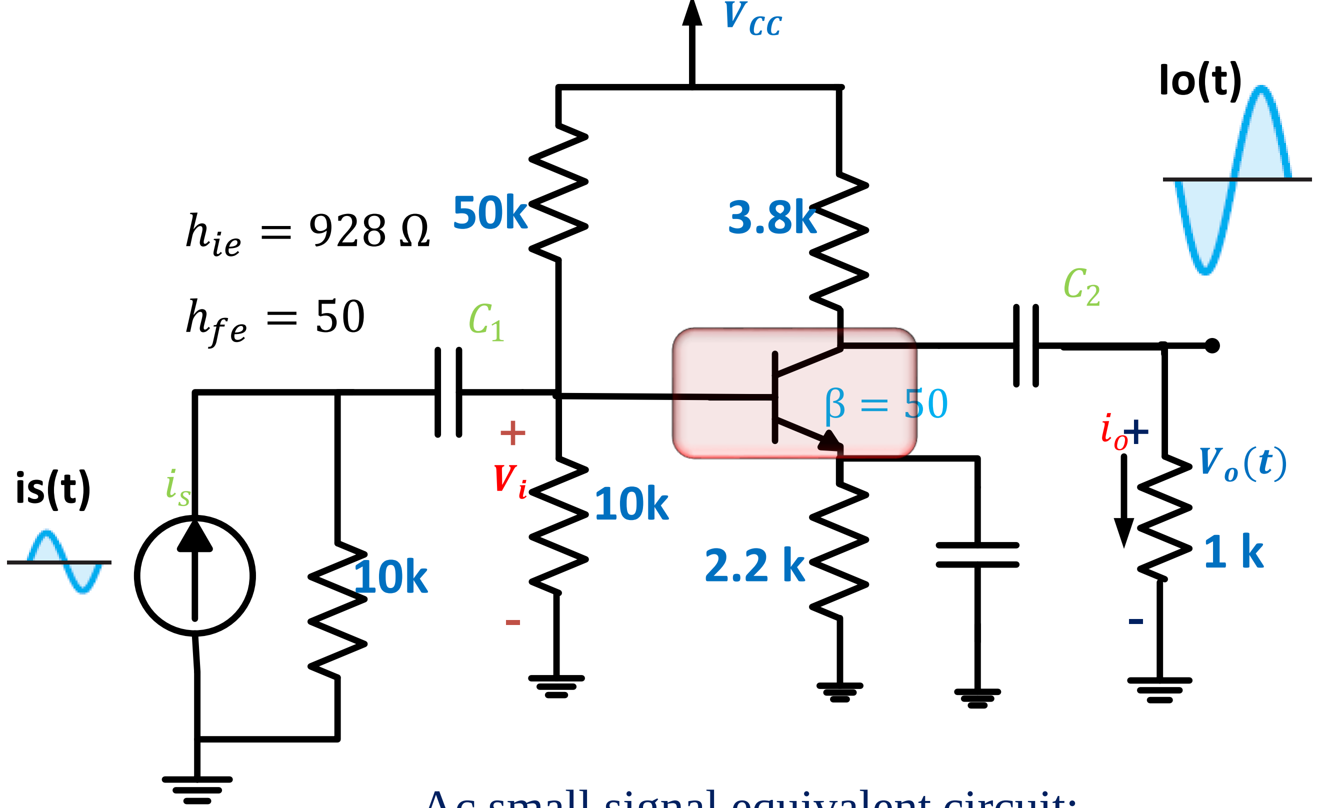




2) Common emitter amplifier:

Find:

1. voltage gain
2. Current gain
3. output impedance
4. Input impedance



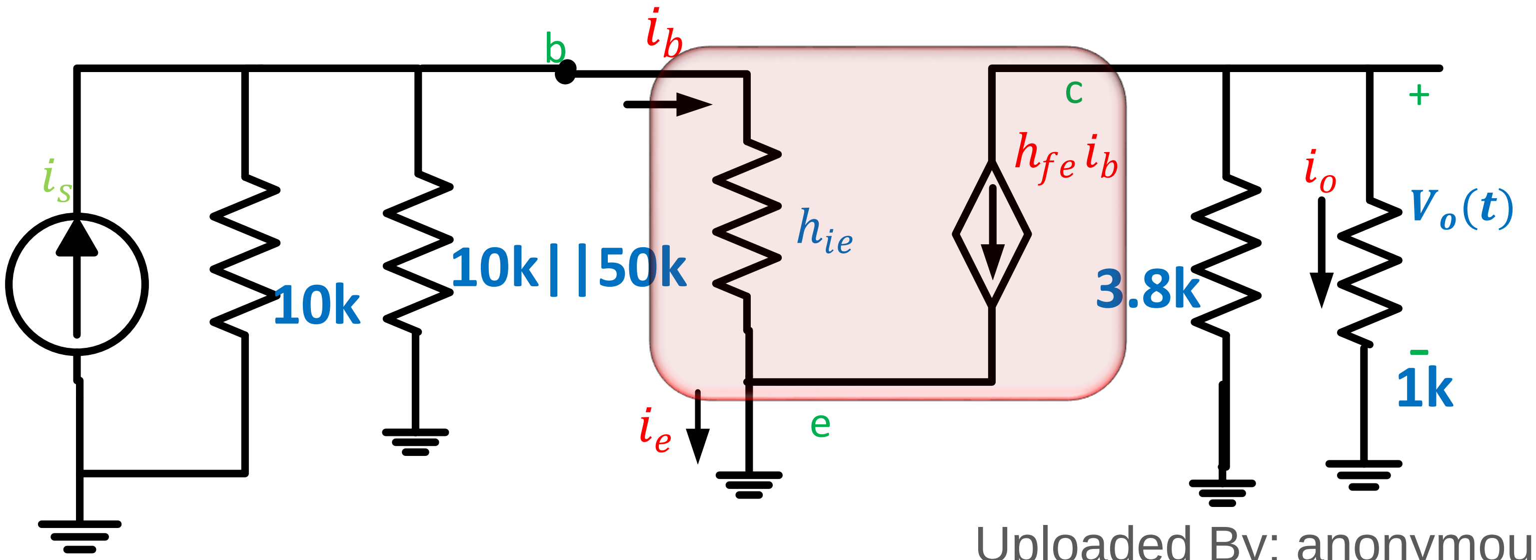
$$A_i = \frac{i_o}{i_s}$$

$$i_o = -h_{fe} i_b * \frac{3.8k}{3.8 + 1k}$$

$$i_b = i_s \cdot \frac{10k||10k||50k}{10k||10k||50k + h_{ie}}$$

➢ $A_i = -33$

Ac small signal equivalent circuit:



For Common emitter amplifier:

$$A_v = \frac{V_o}{V_i}$$

$$V_o = -h_{fe} i_b (1k||3.8k)$$

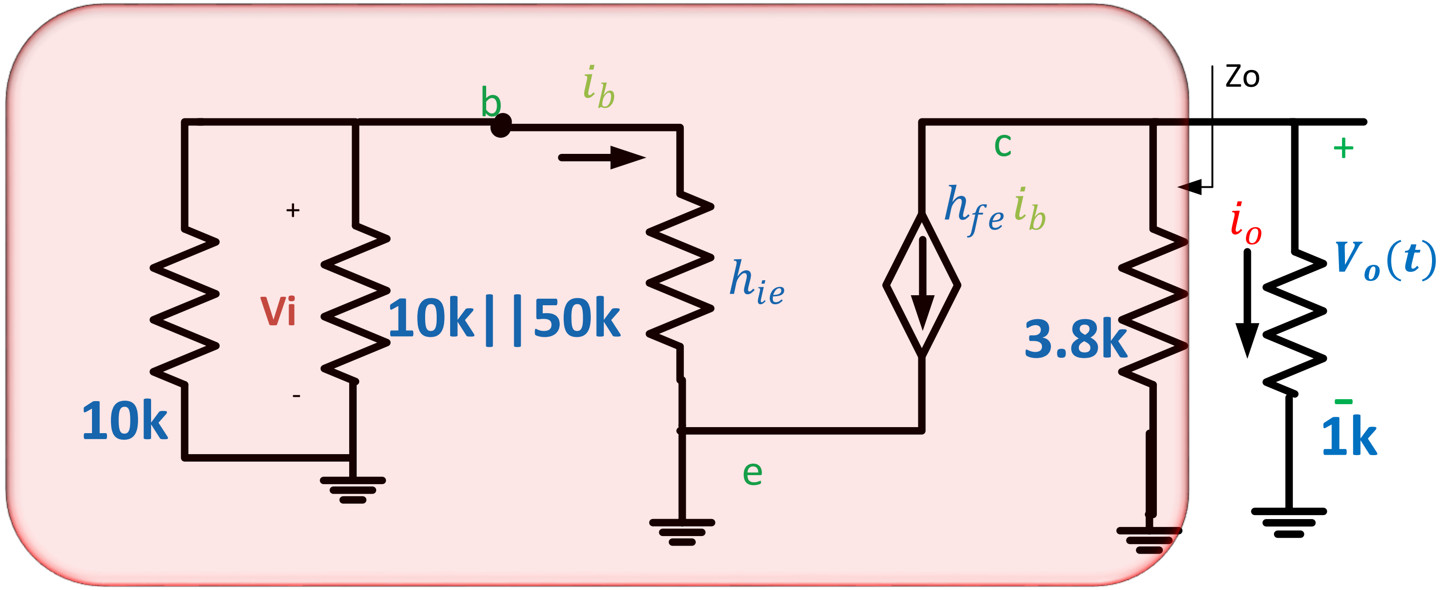
$$i_b = \frac{V_i}{h_{ie}}$$

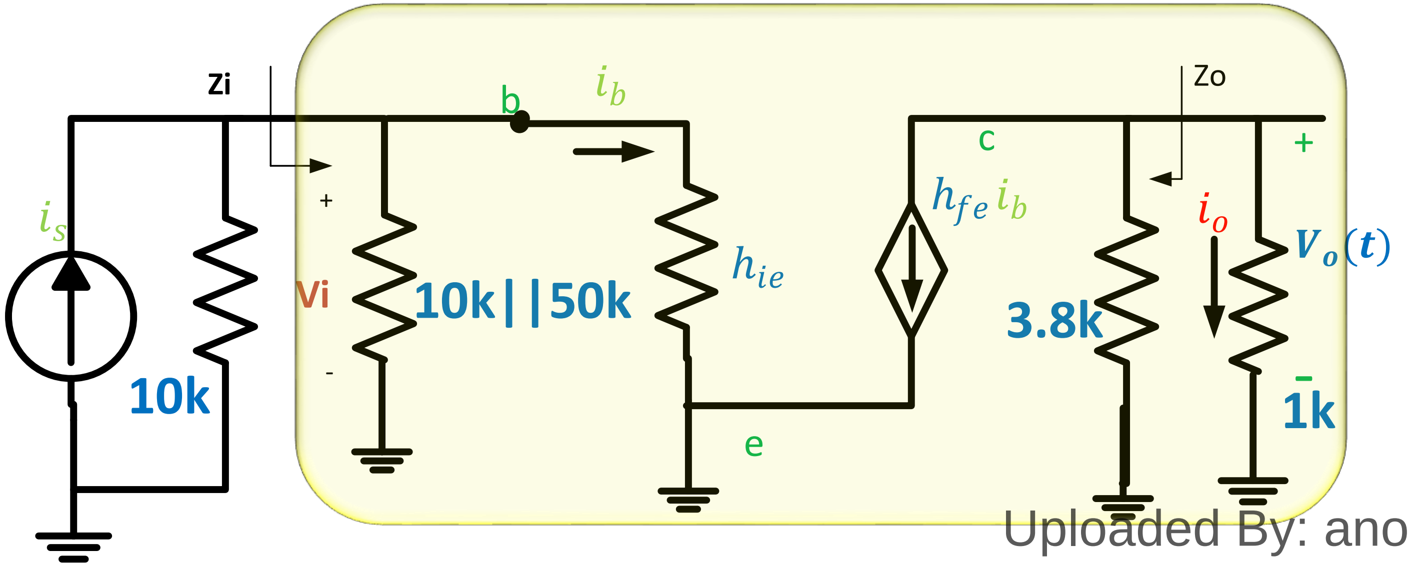
➢ $A_v = \frac{V_o}{V_i} = -42.7$

➢ $Z_i = 10k||50k||h_{ie}$

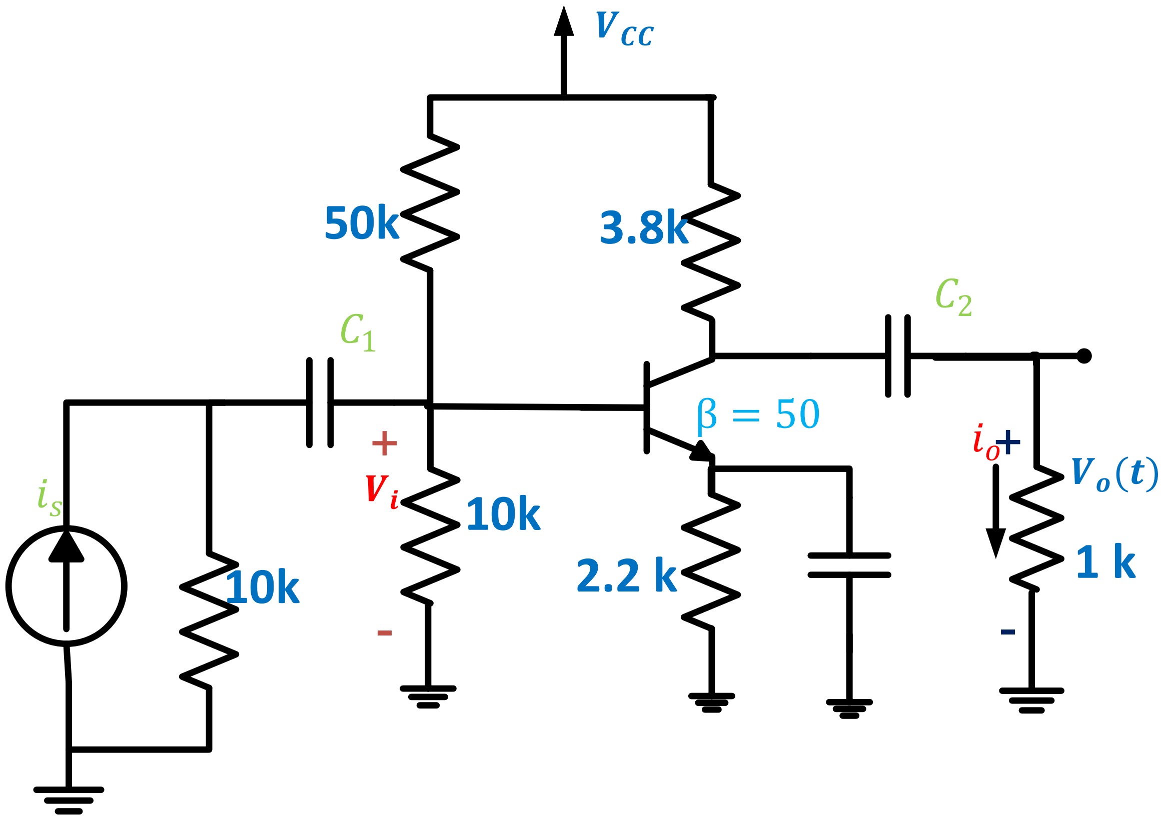
➢ To find Z_o

➢ $Z_o = 3.8k$





For Common emitter amplifier:



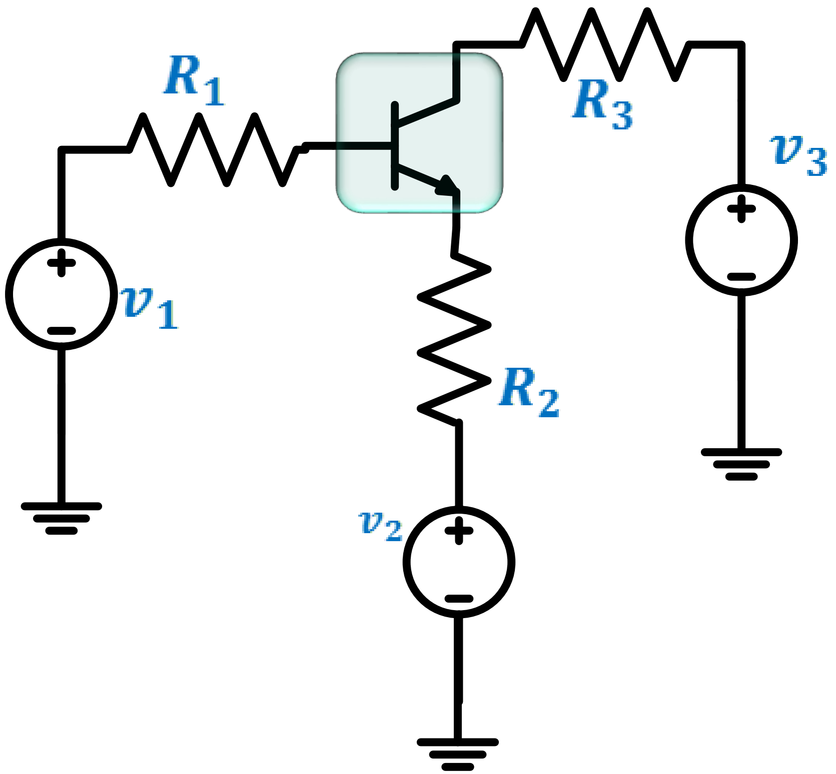
$$|A_V| > 1$$

$$|A_i| > 1$$

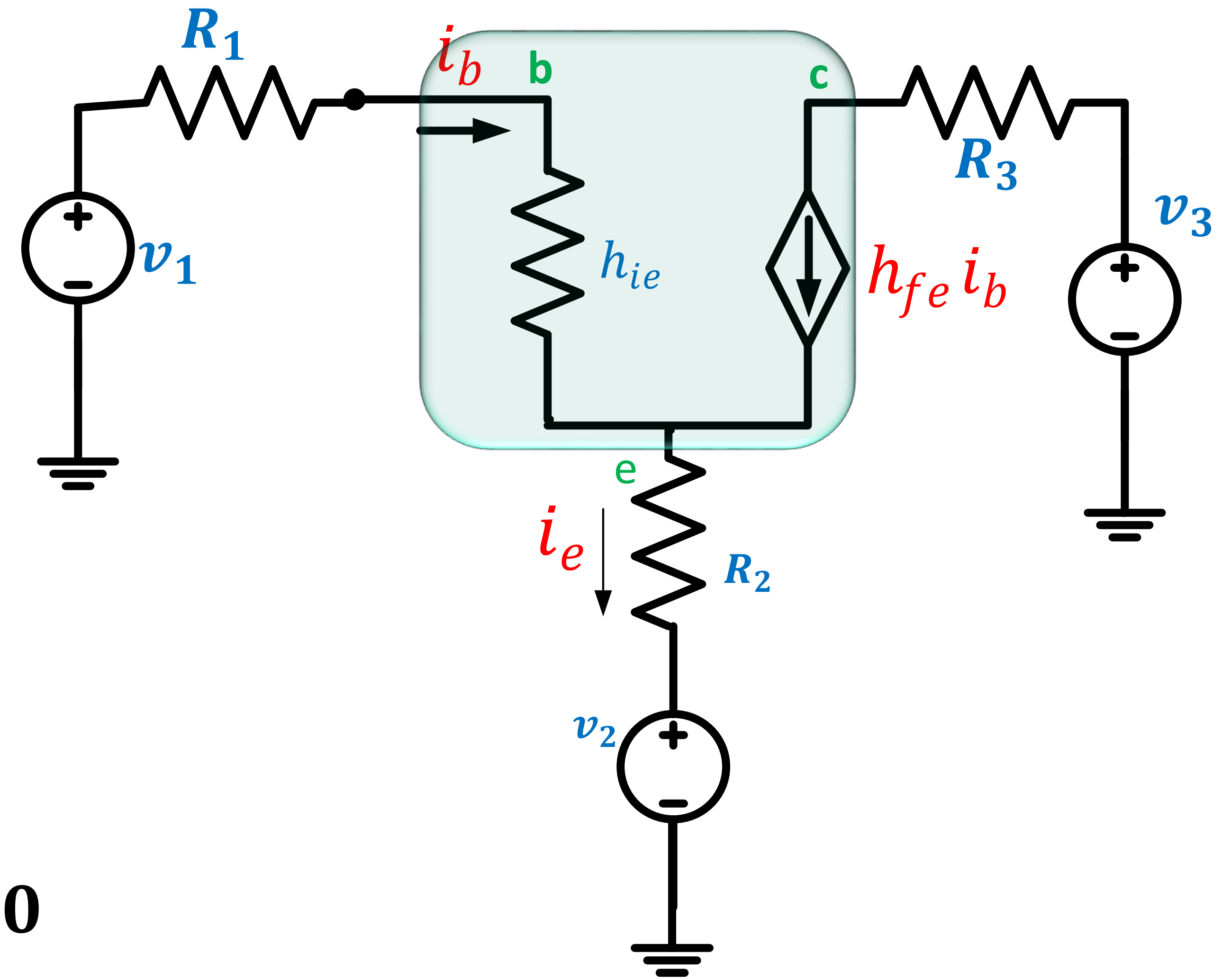
Z_i **Large**

Z_o **Large**

Impedance reflection:



Ac small signal equivalent circuit:

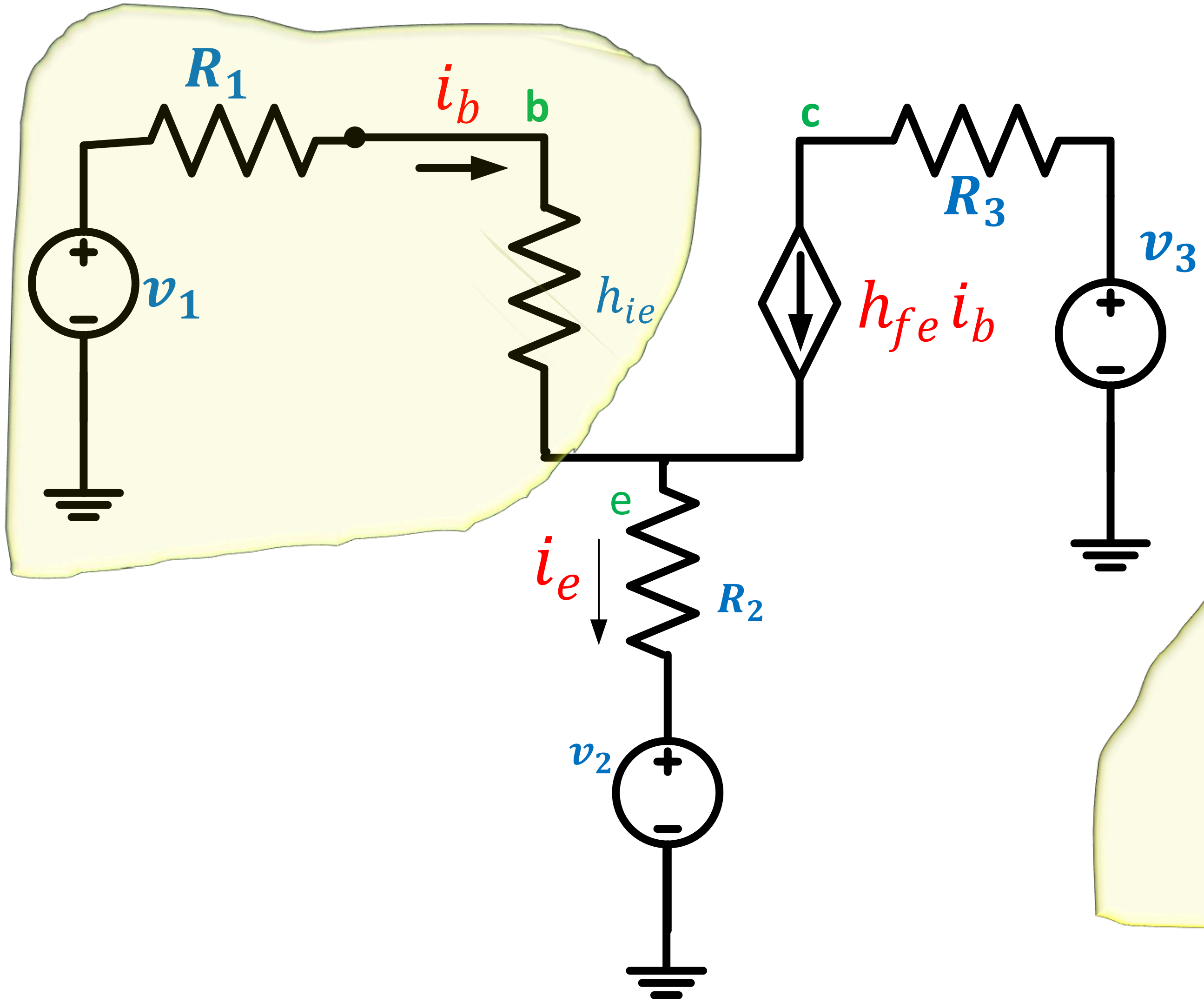


KVL :

$$-v_1 + (R_1 + h_{ie})i_b + R_2 i_e + v_2 = 0$$

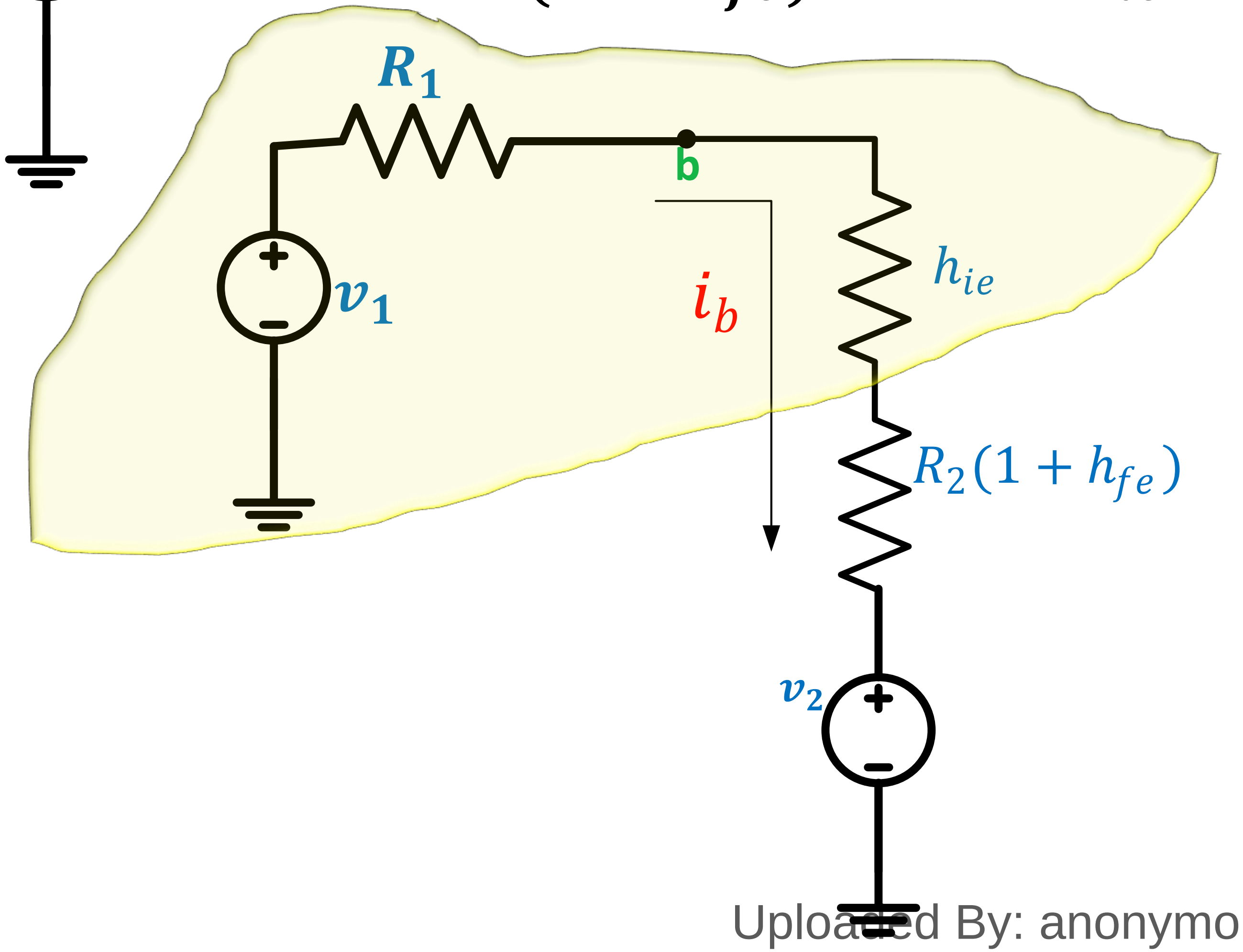
$$i_e = (h_{fe+1})i_b$$

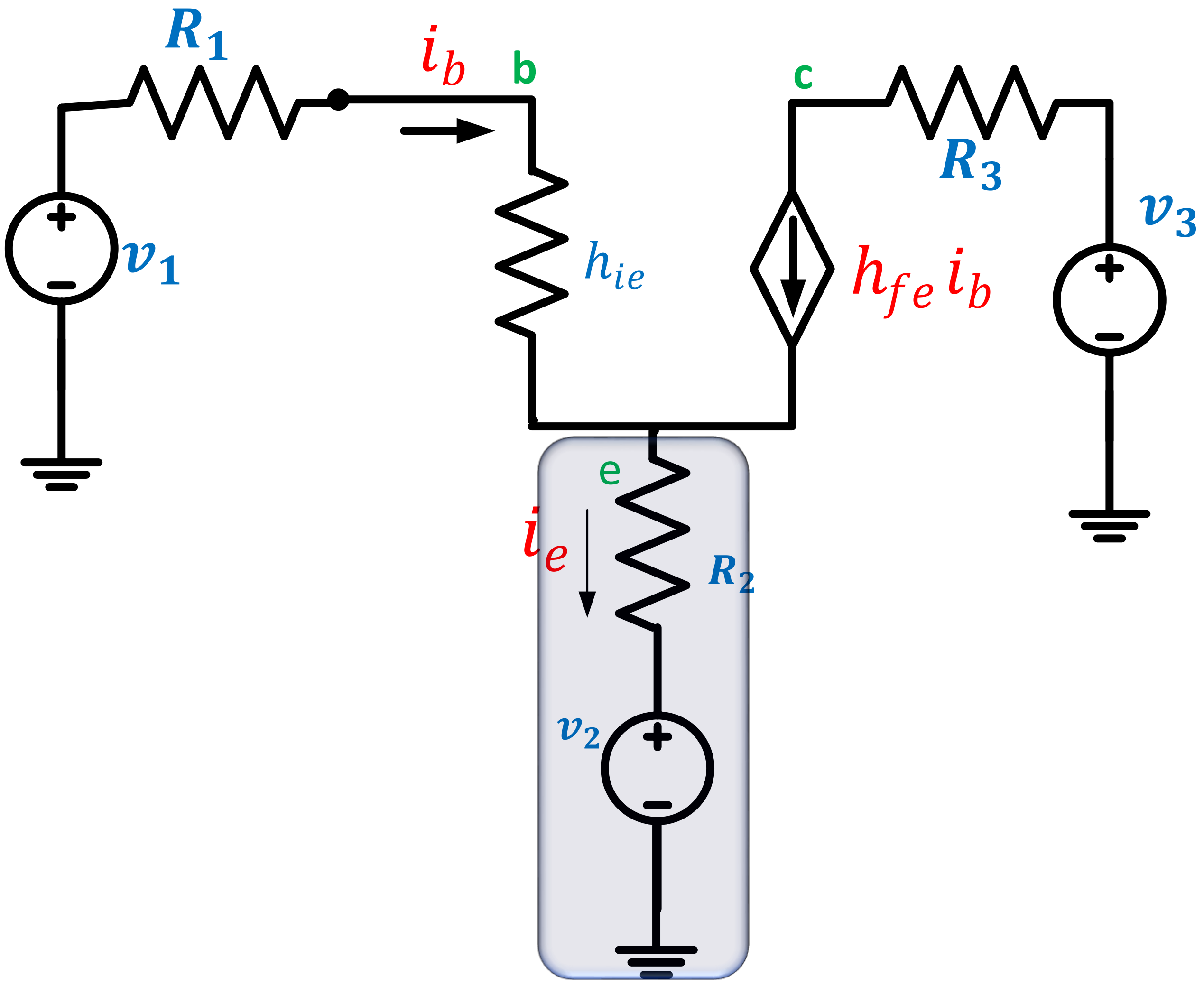
$$i_b = \frac{v_1 - v_2}{R_2(1 + h_{fe}) + R_1 + h_{ie}}$$



Base equivalent circuit:

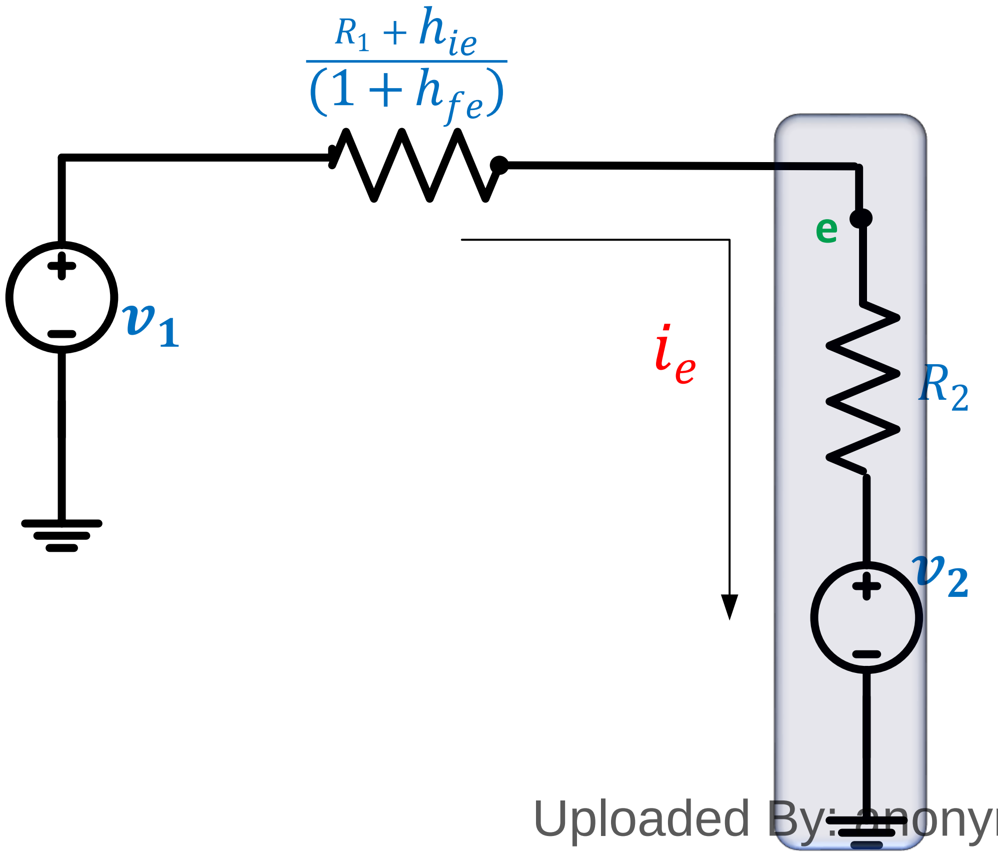
$$i_b = \frac{v_1 - v_2}{R_2(1 + h_{fe}) + R_1 + h_{ie}}$$





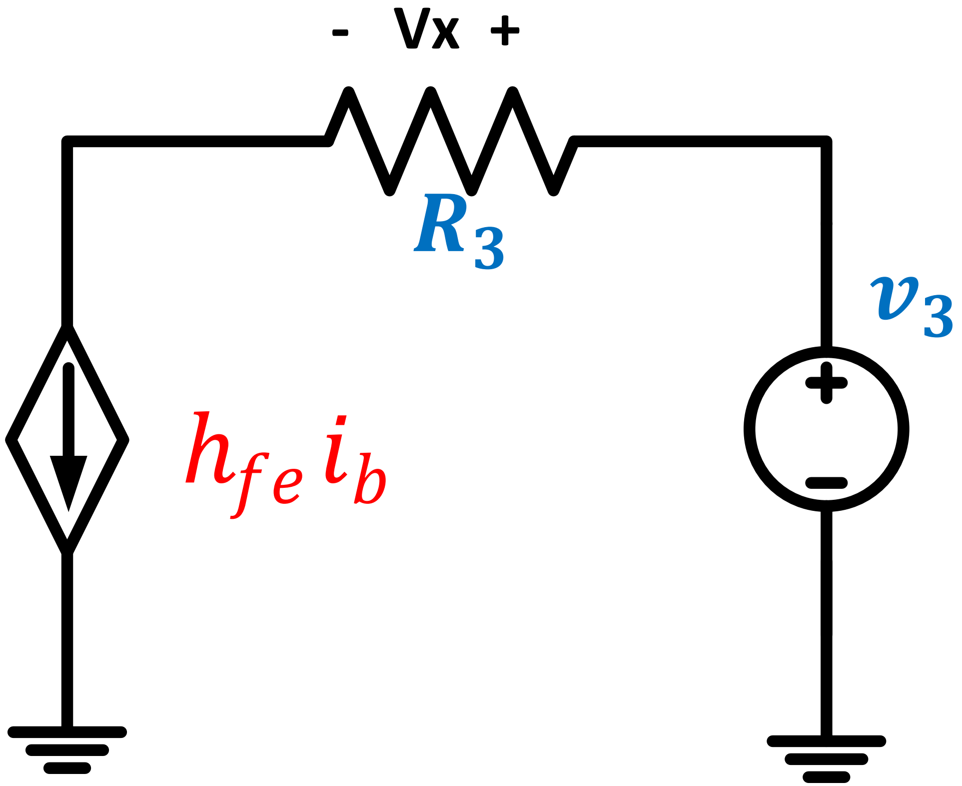
Emitter equivalent circuit:

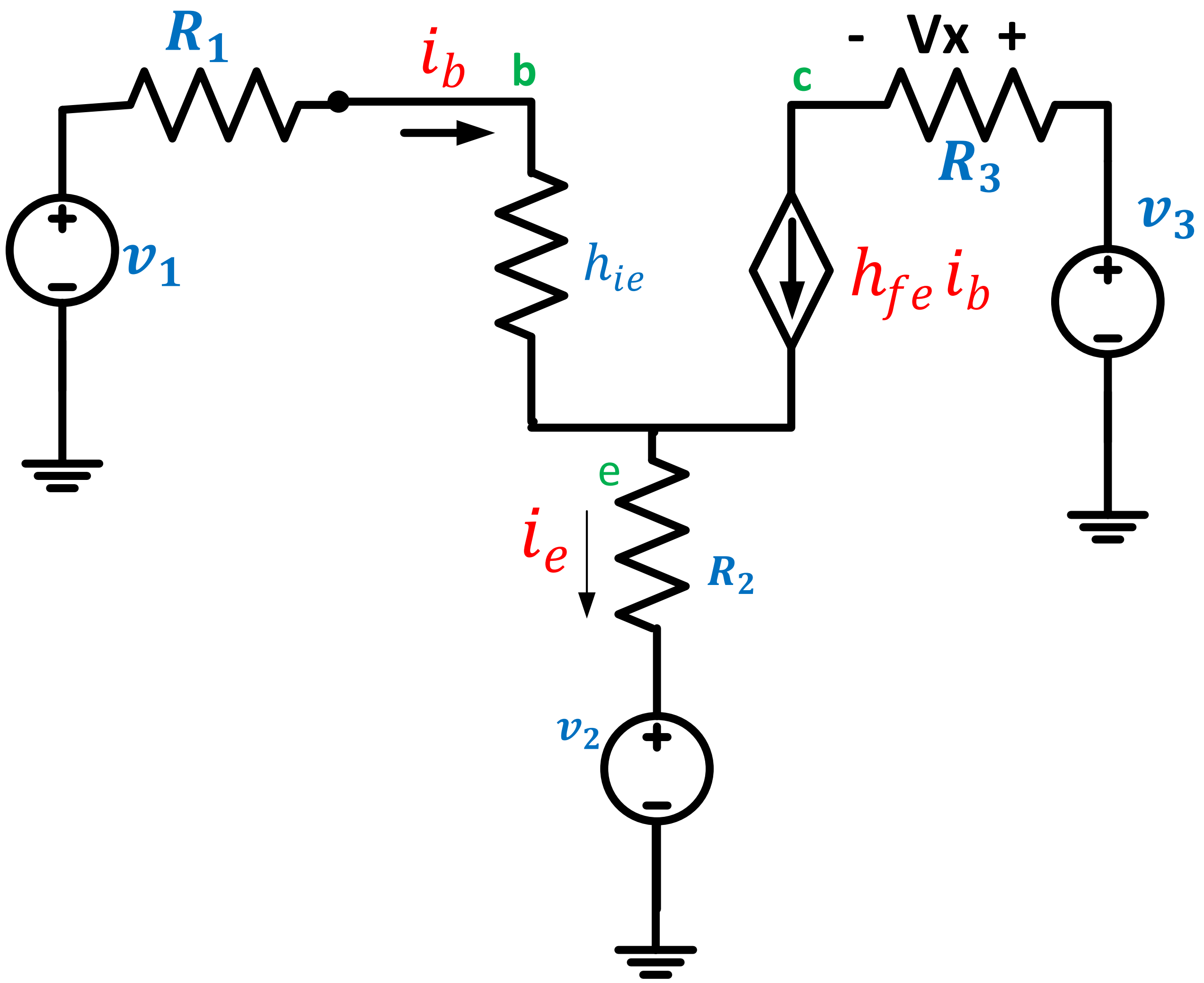
$$i_e = \frac{v_1 - v_2}{R_2 + \dfrac{R_1 + h_{ie}}{(1 + h_{fe})}}$$



$$i_b = \frac{v_1 - v_2}{R_2(1 + h_{fe}) + R_1 + h_{ie}}$$

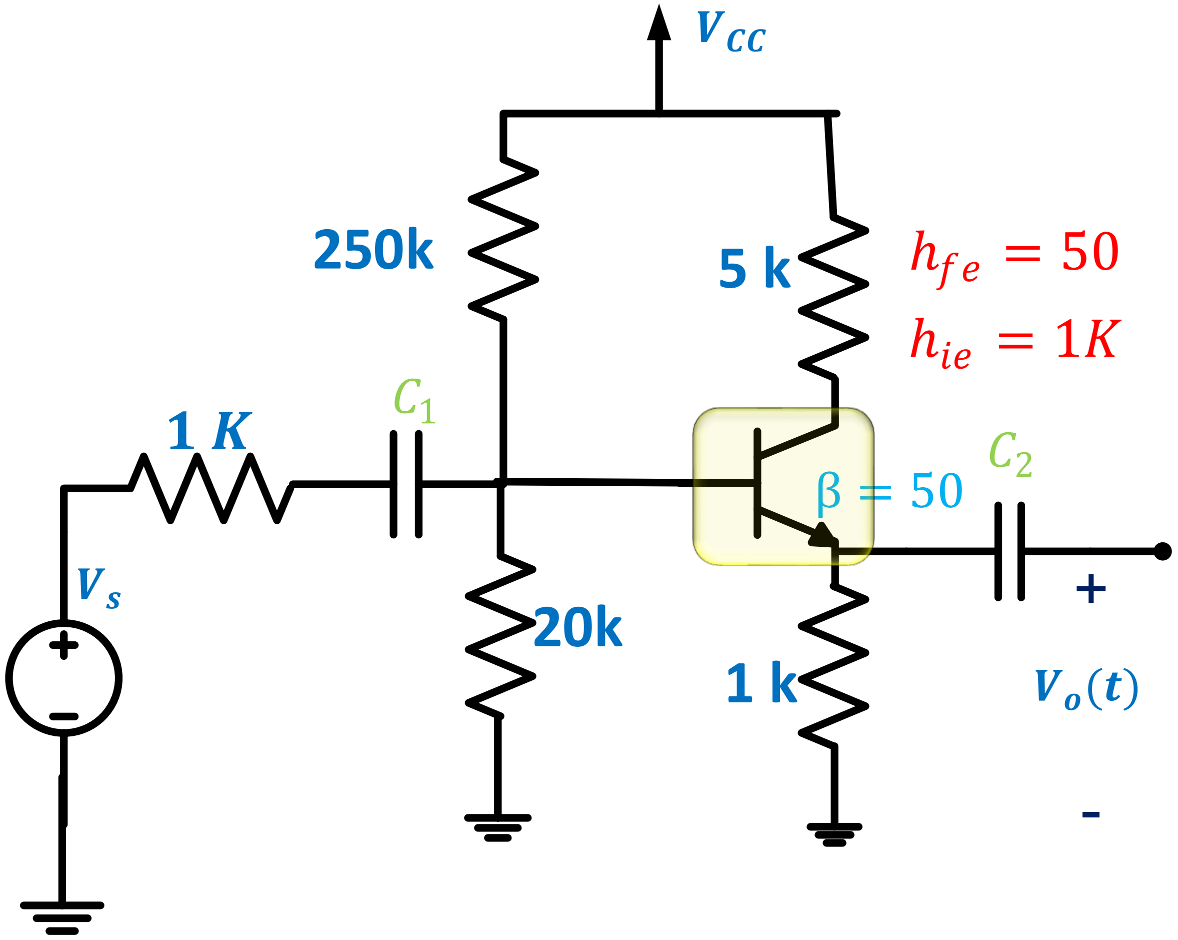
Collector equivalent circuit:



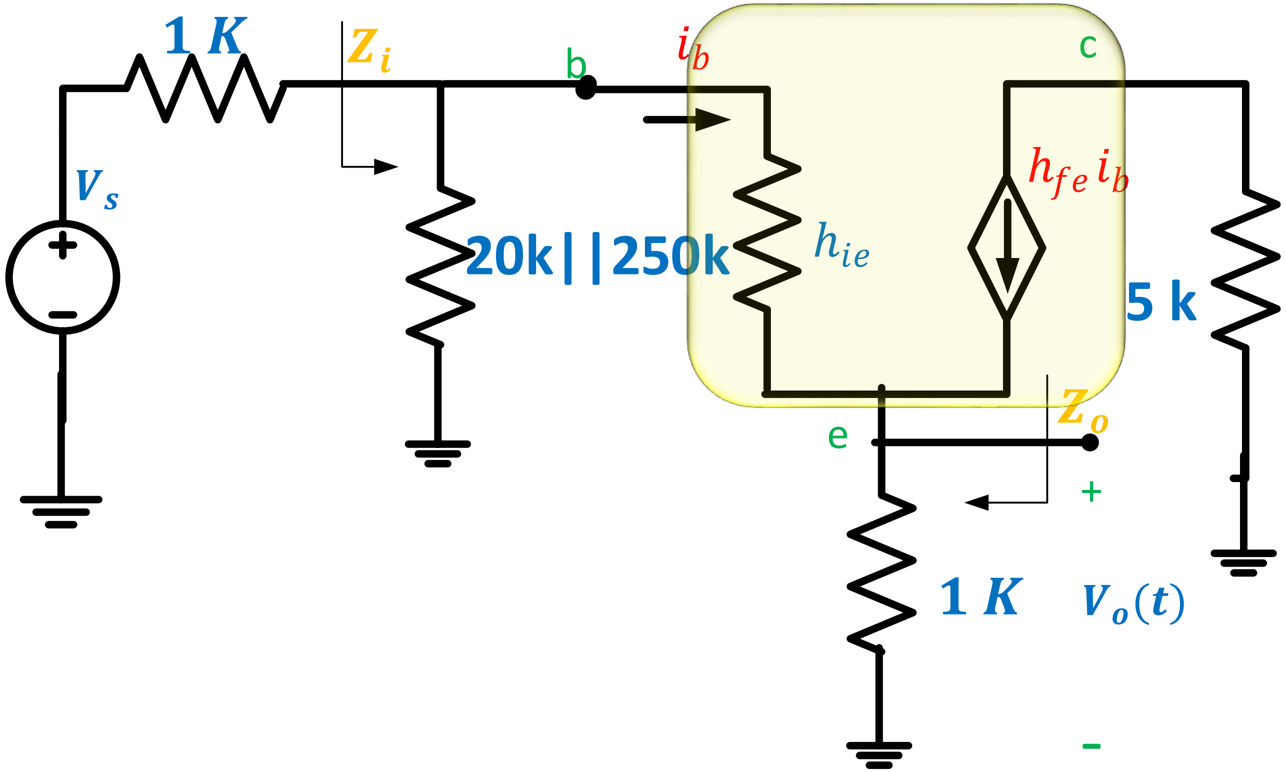


Vx = R3 hfe ib

3) Common collector amplifier:



Ac small signal equivalent circuit:



$$A_v = \frac{V_o}{V_s}$$

$$V_o = 1k * i_e$$

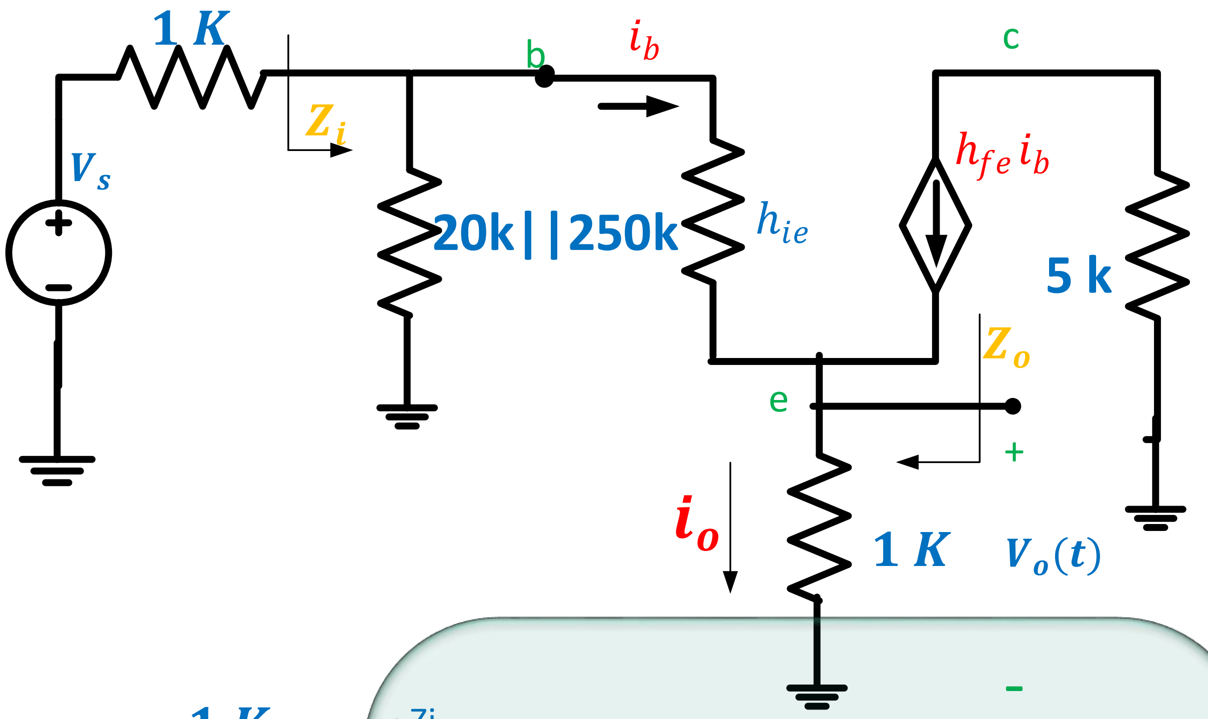
$$i_e = (1 + h_{fe})i_b$$

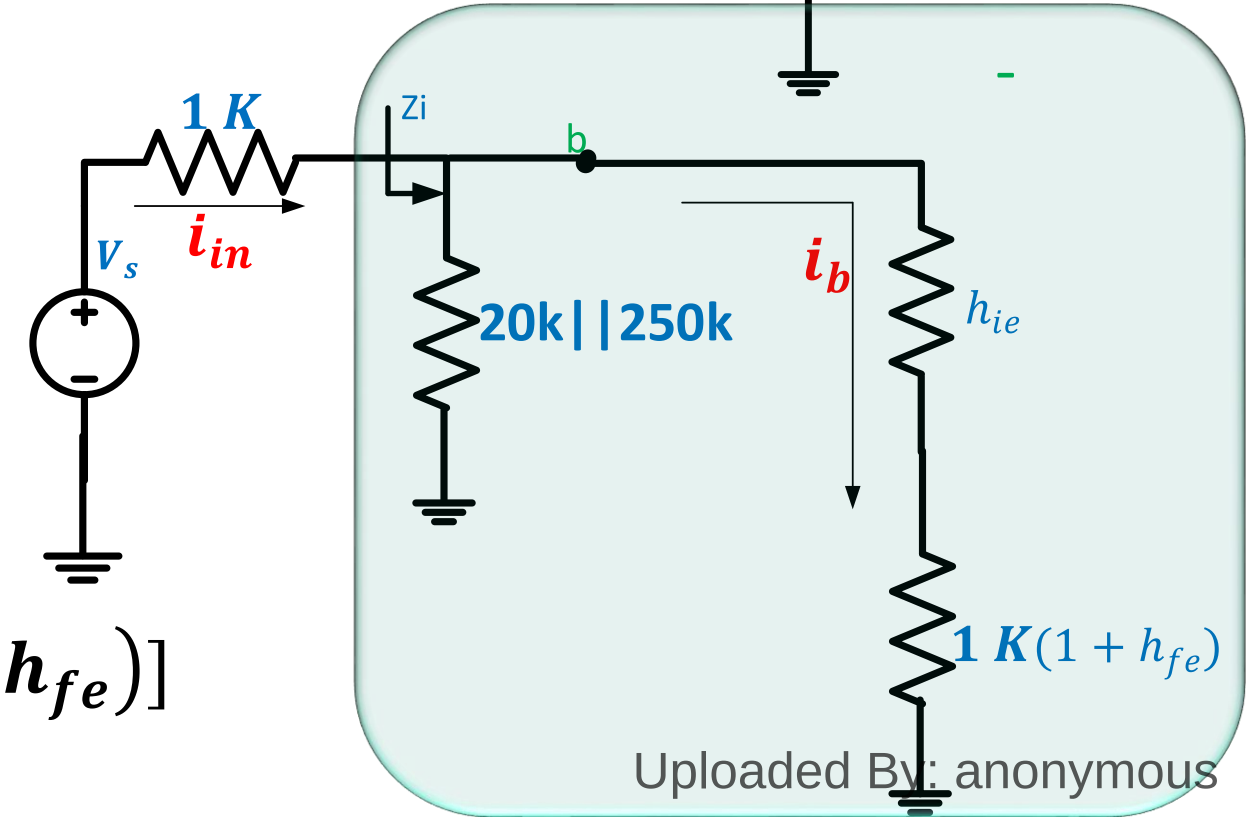
To find i_b → base equivalent circuit:

$$i_b = \frac{(20k||250k)i_{in}}{(20k||250k) + h_{ie} + 1k(1 + h_{fe})}$$

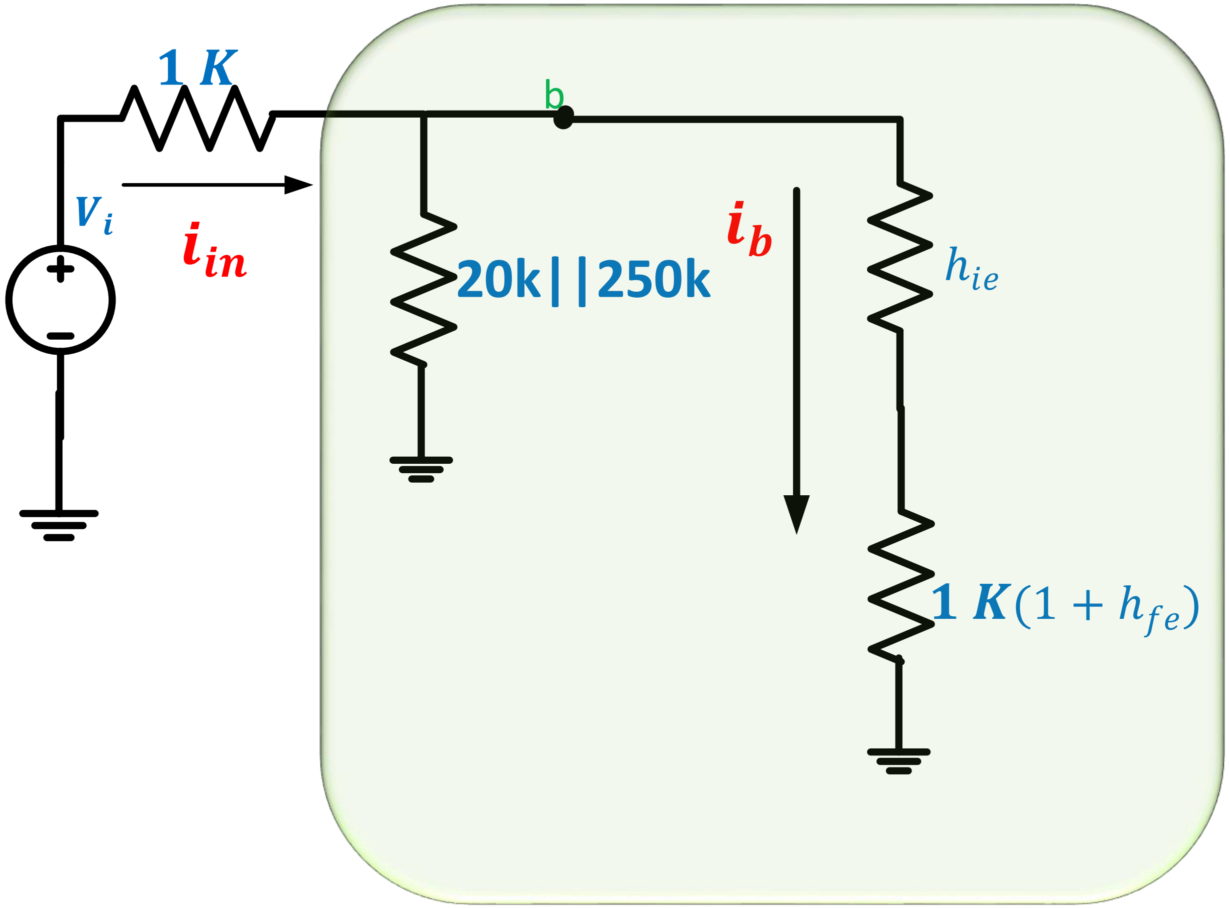
$$i_{in} = \frac{v_s}{1k + Z_{in}}$$

$$Z_{in} = [(20k||250k)]||[h_{ie}+1k(1 + h_{fe})]$$





$$i_{in} = \frac{v_{in}}{1k + [(20k||250k)]||[h_{ie}+1k(1 + h_{fe})]}$$



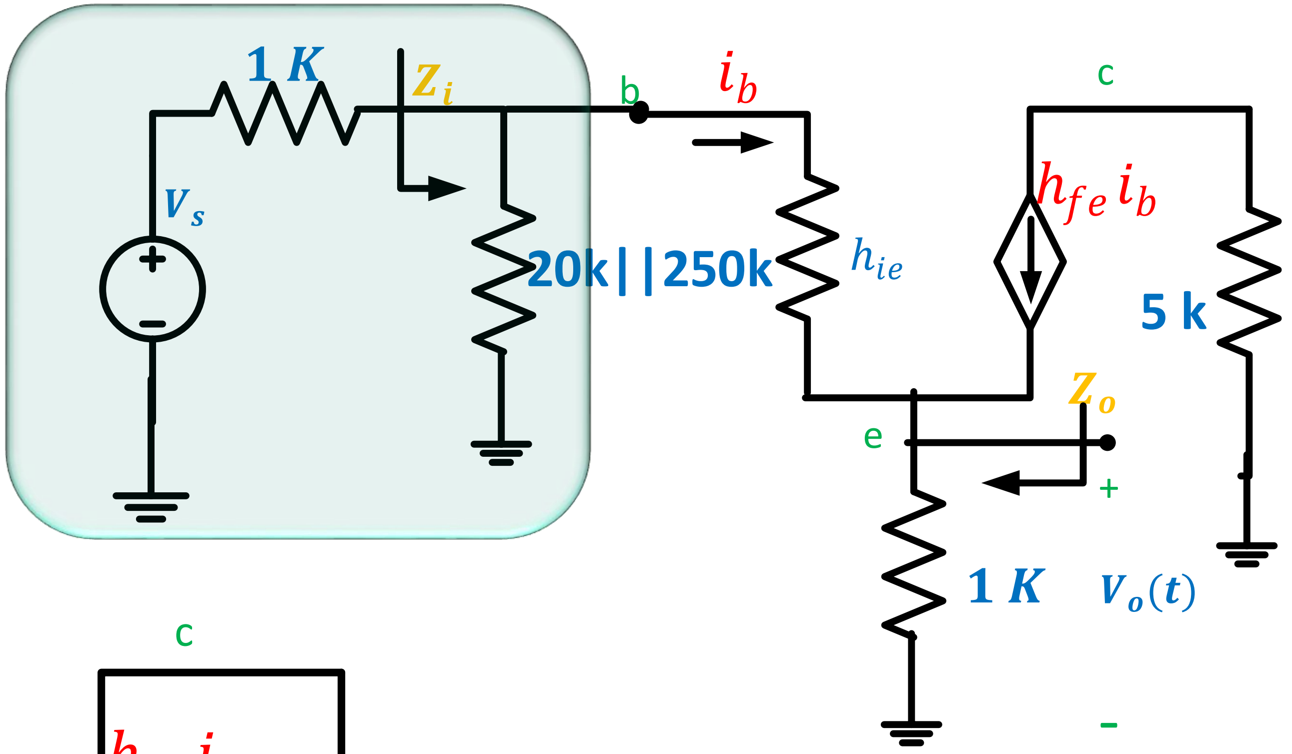
- $Z_{in} = 13.66K$

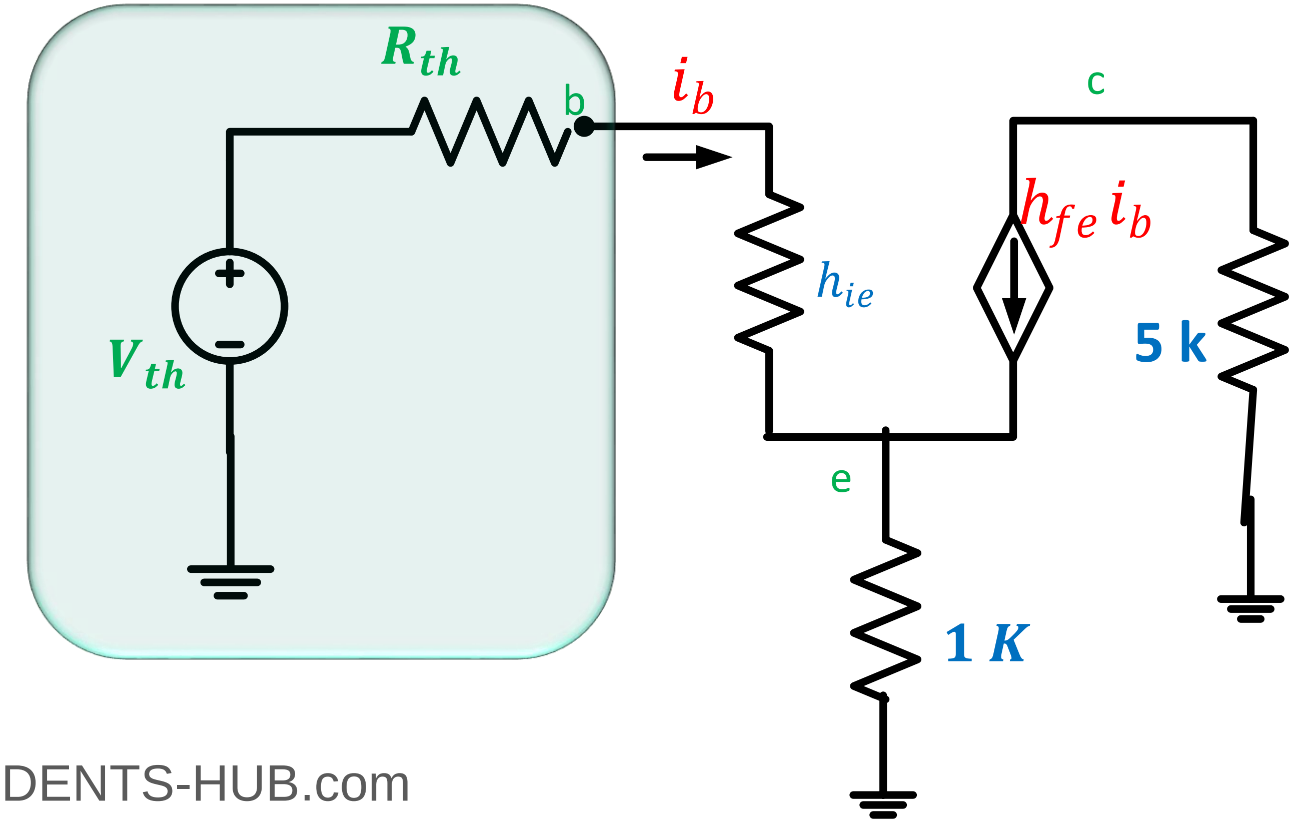
- $A_v = \frac{V_o}{V_{in}} = 0.9149$
- $A_i = \frac{i_o}{i_{in}} = 13.9$

To find Z_o ;emitter equivalent circuit:

$$R_{th} = 1k \backslash\backslash 20k \backslash\backslash 250k$$

$$V_{th} = \frac{(20k||250k)}{(20k||250k) + 1k} V_{in}$$

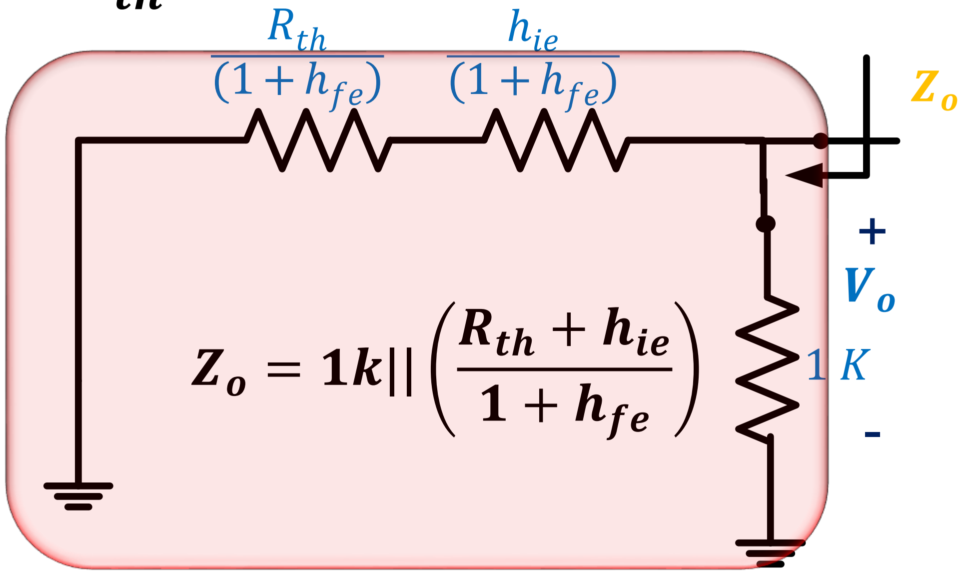




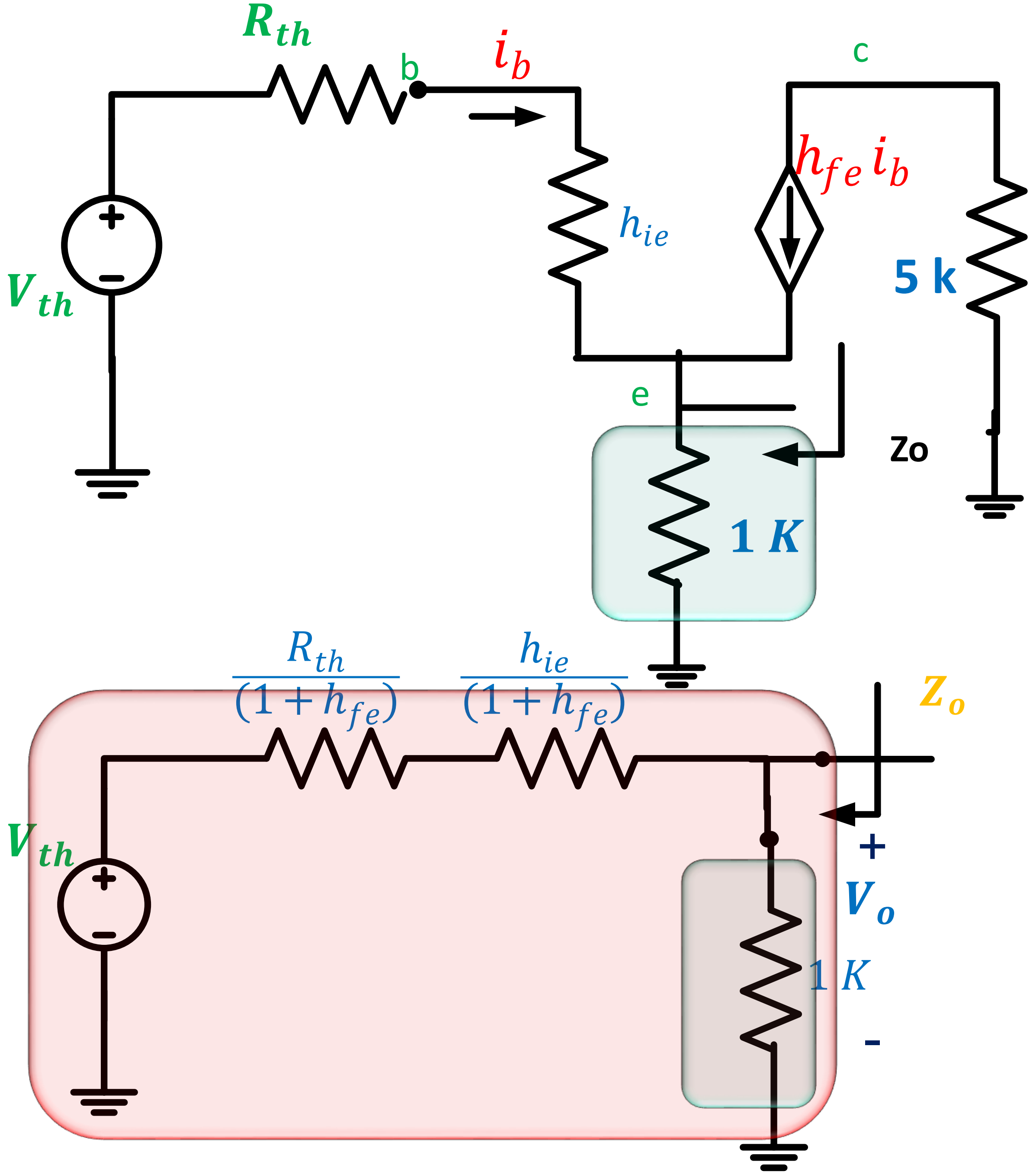
Emitter equivalent circuit:

To find Z_o we set $V_{in} = 0$

❖ $V_{th} = 0$



$$Z_o = 1k||\left(\frac{R_{th} + h_{ie}}{1 + h_{fe}}\right)$$



$$Z_o = 1k\backslash\backslash\left(\frac{1k\backslash\backslash 20k\backslash\backslash 250k + h_{ie}}{1 + h_{fe}}\right) = 36.8\Omega$$

For common collector amplifier:

$A_v < 1$

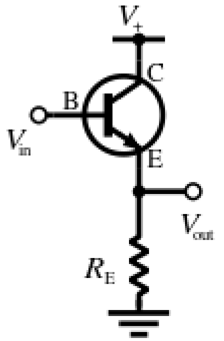
$A_i > 1$

Z_o *very small*

$Z_i = very\ larg$

The common collector as a buffer:

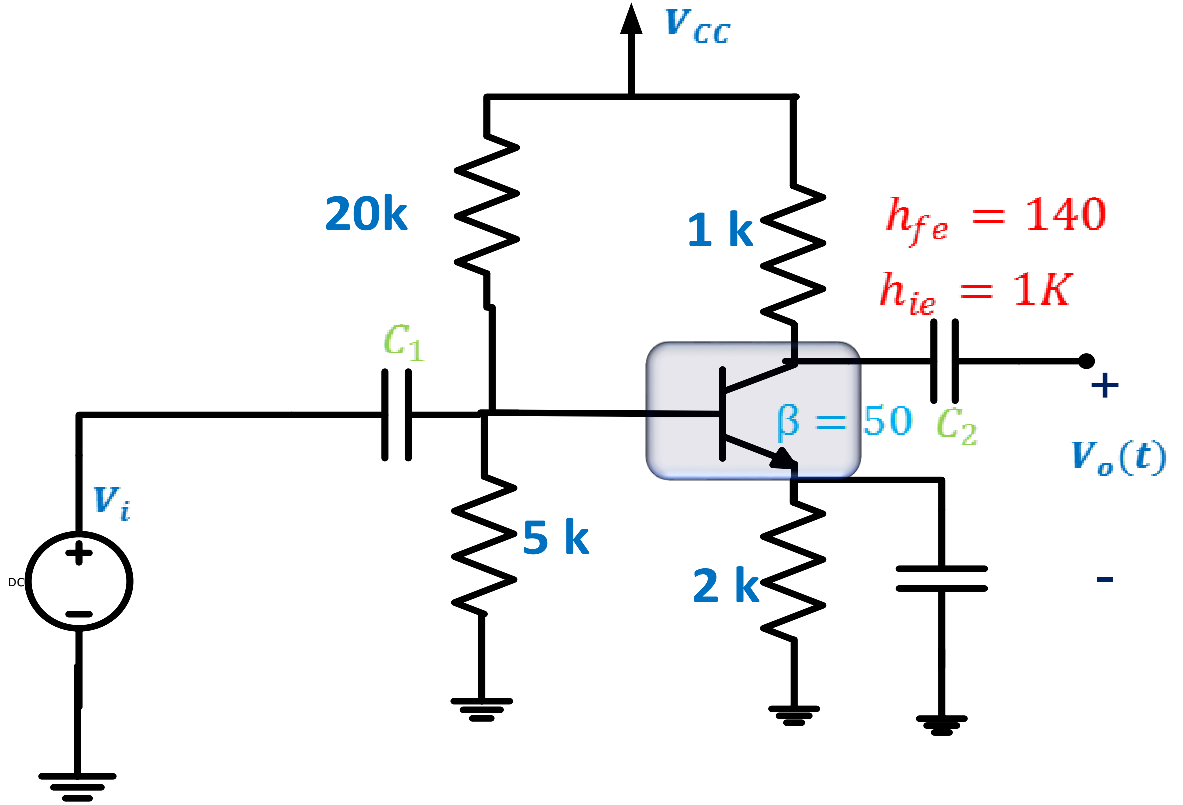
Although the small signal voltage gain of the common collector (emitter follower) is less than 1, it can be used to improve the total voltage gain of a multistage amplifier.



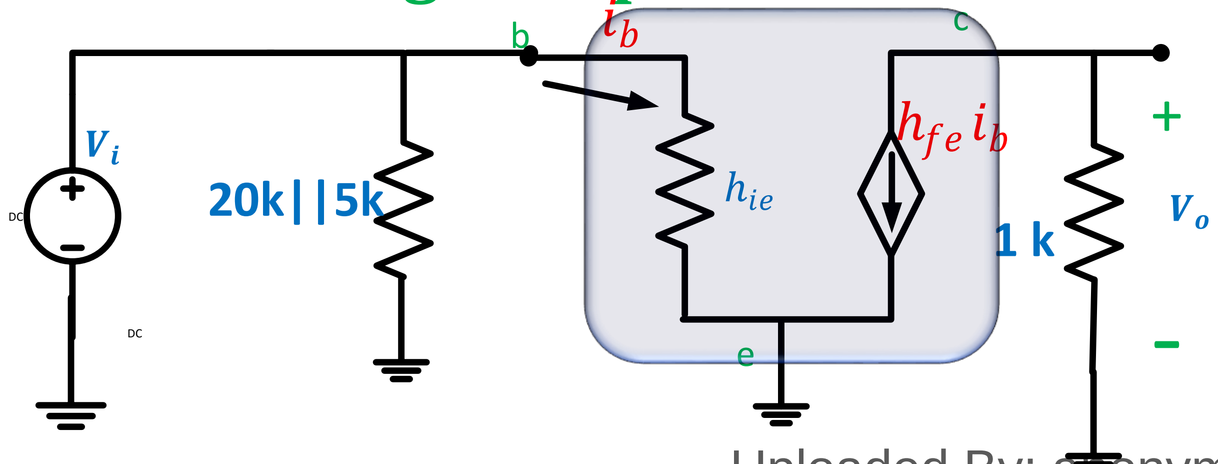
Common emitter amplifier

$$A_v = \frac{V_o}{V_{in}} = -140$$

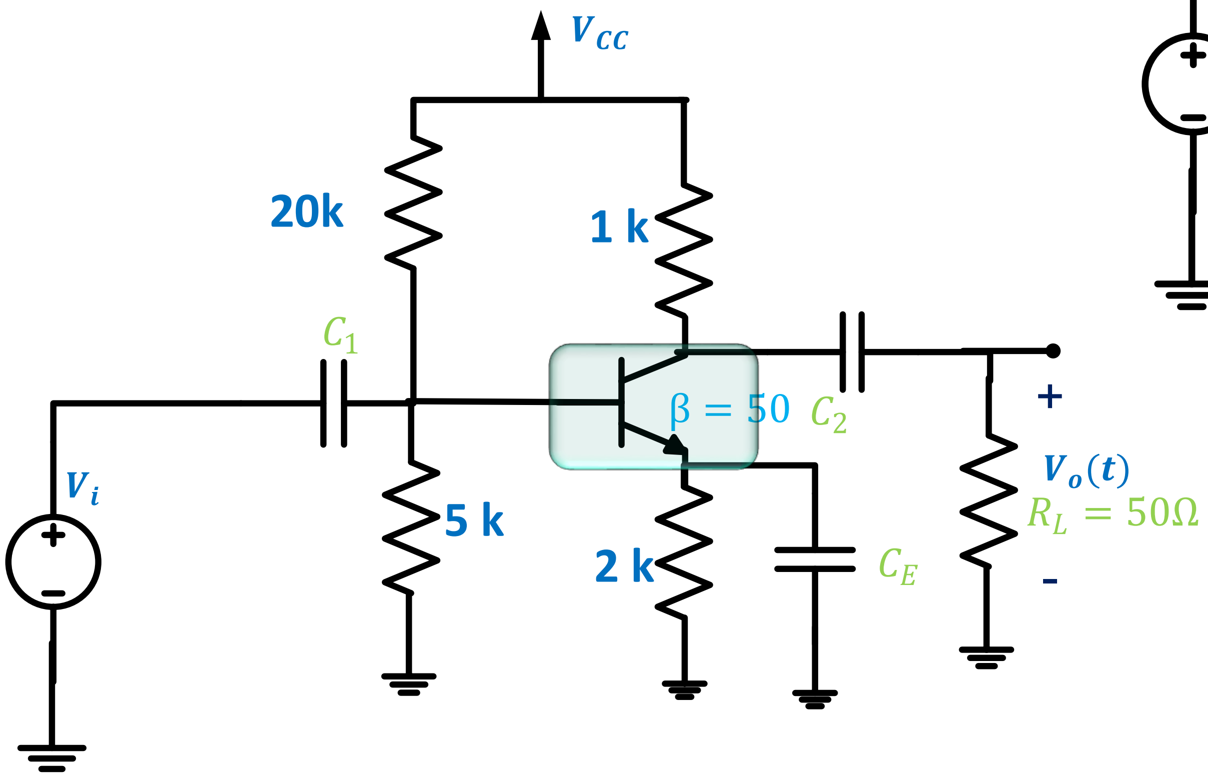
Proof!!

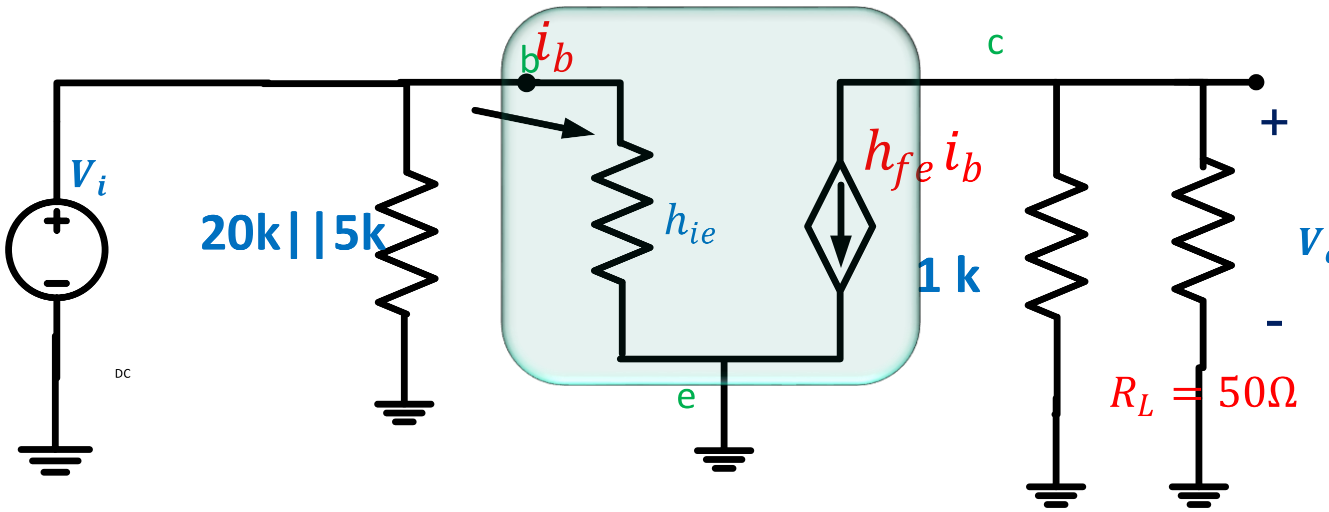


Ac small signal equivalent circuit:



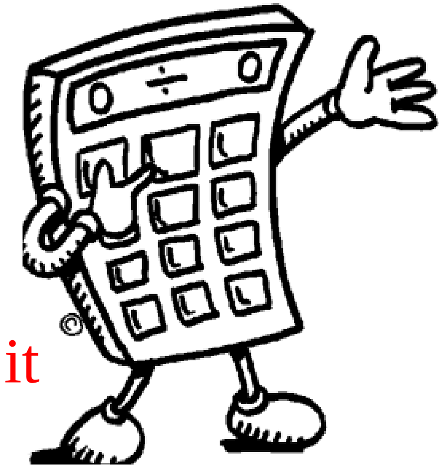
Common emitter amplifier with R_L:





Ac small signal equivalent circuit:

$$A_v = \frac{V_o}{V_{in}} = -6.67$$



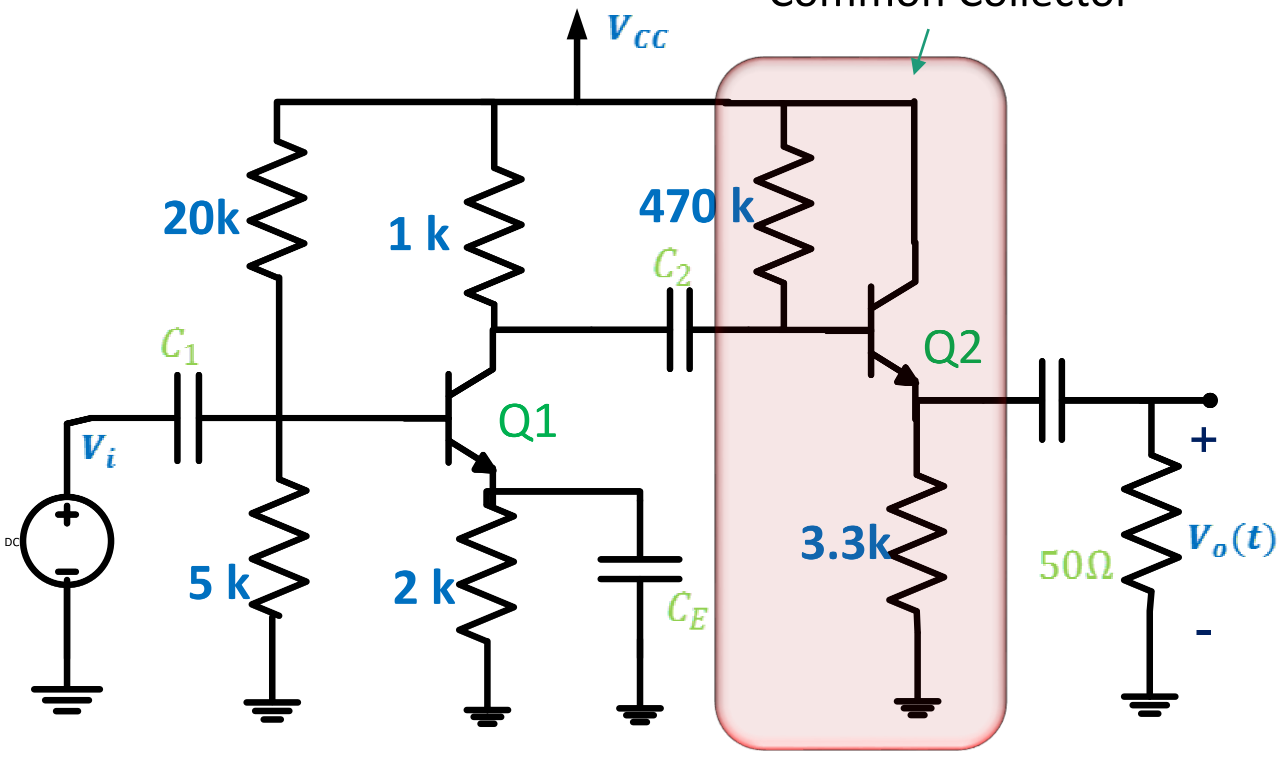
Do it

Multistage amplifier:

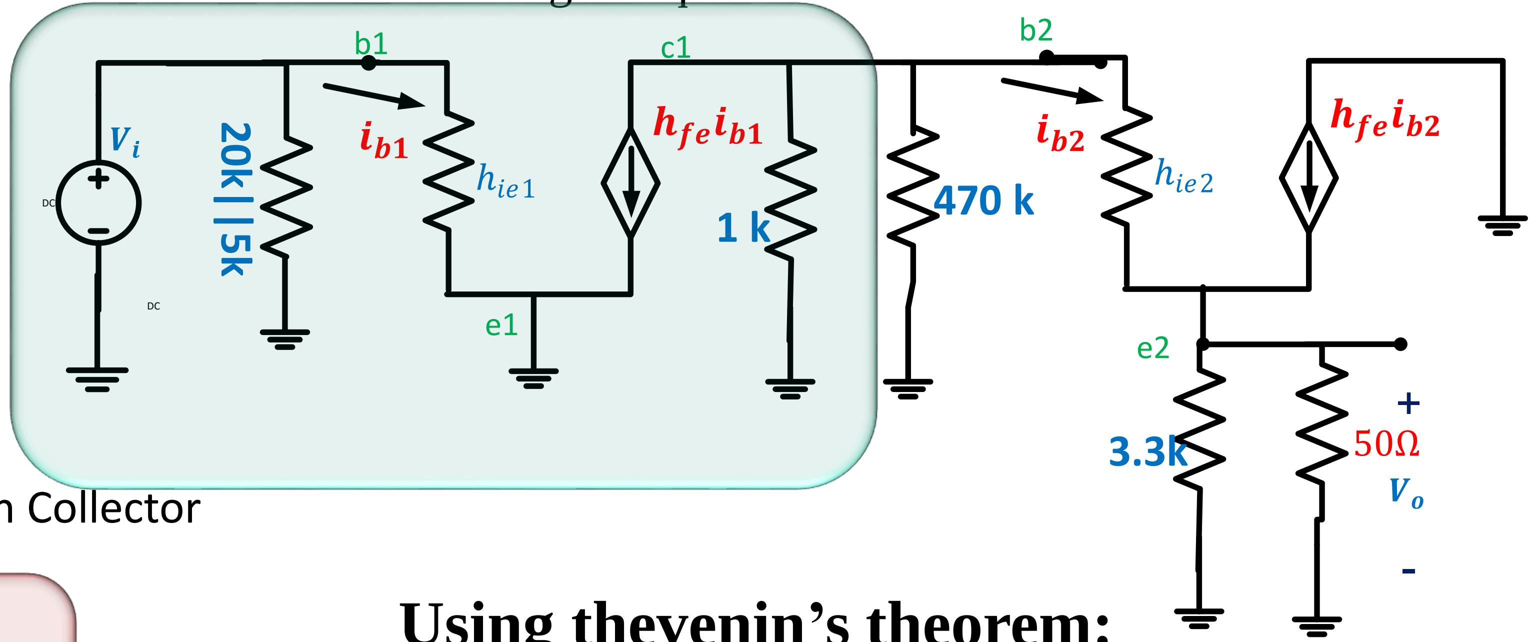
Find the voltage gain

$$h_{ie1} = 1k, \quad h_{ie2} = 2.24k,$$

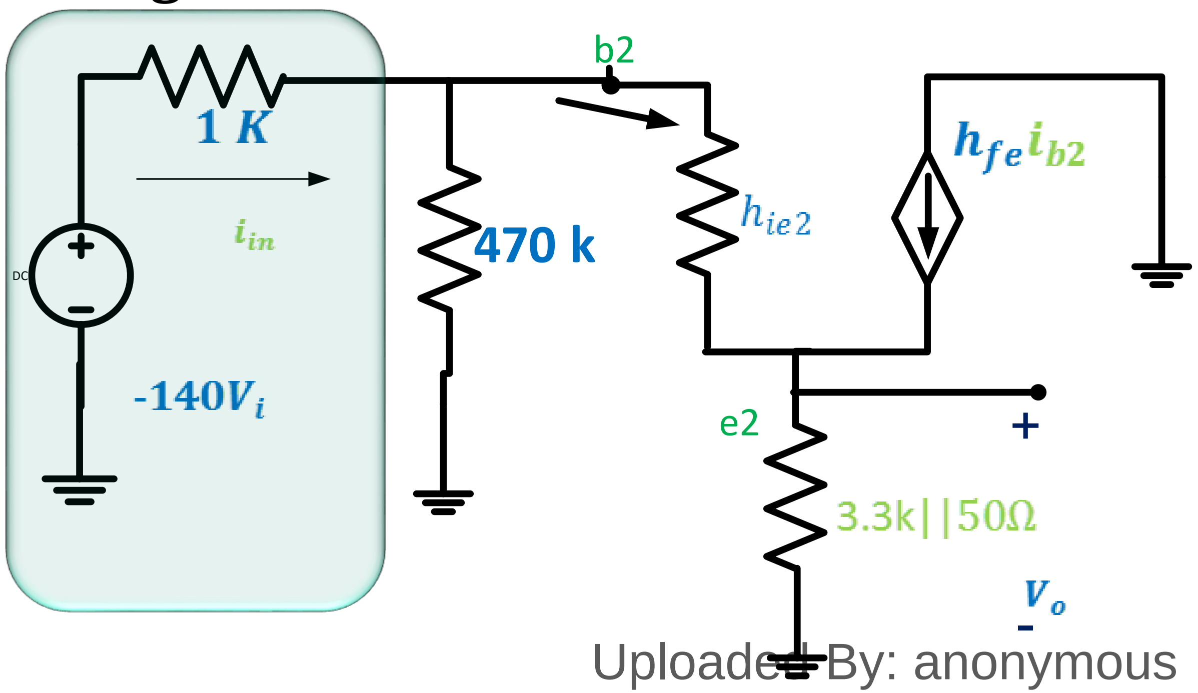
$$h_{fe1} = 140, \quad h_{fe2} = 100$$



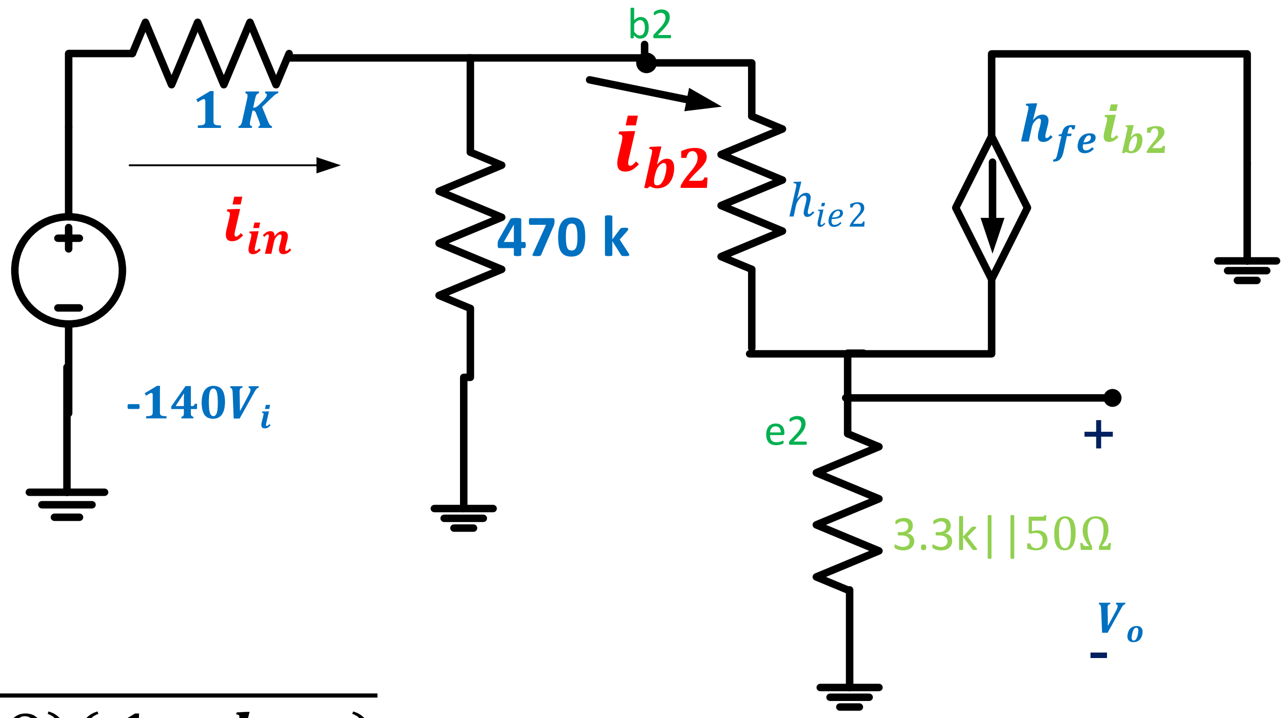
Ac small signal equivalent circuit:



Using thevenin's theorem:



To Find the voltage gain



$$V_o = (3.3k\backslash\backslash 50\Omega)(1 + h_{fe2})i_{b2}$$

$$i_{b2} = i_{in} * \frac{470k}{470k + h_{ie2} + (3.3k\backslash\backslash 50\Omega)(1 + h_{fe2})}$$

$$i_{in} = \frac{-140v_{in}}{1k + 470k\backslash\backslash[h_{ie2} + (3.3k\backslash\backslash 50\Omega)(1 + h_{fe2})]}$$

- $A_v = \frac{V_o}{V_{in}} = -85$

The common emitter amplifier design:

Design a common emitter amplifier using a transistor having

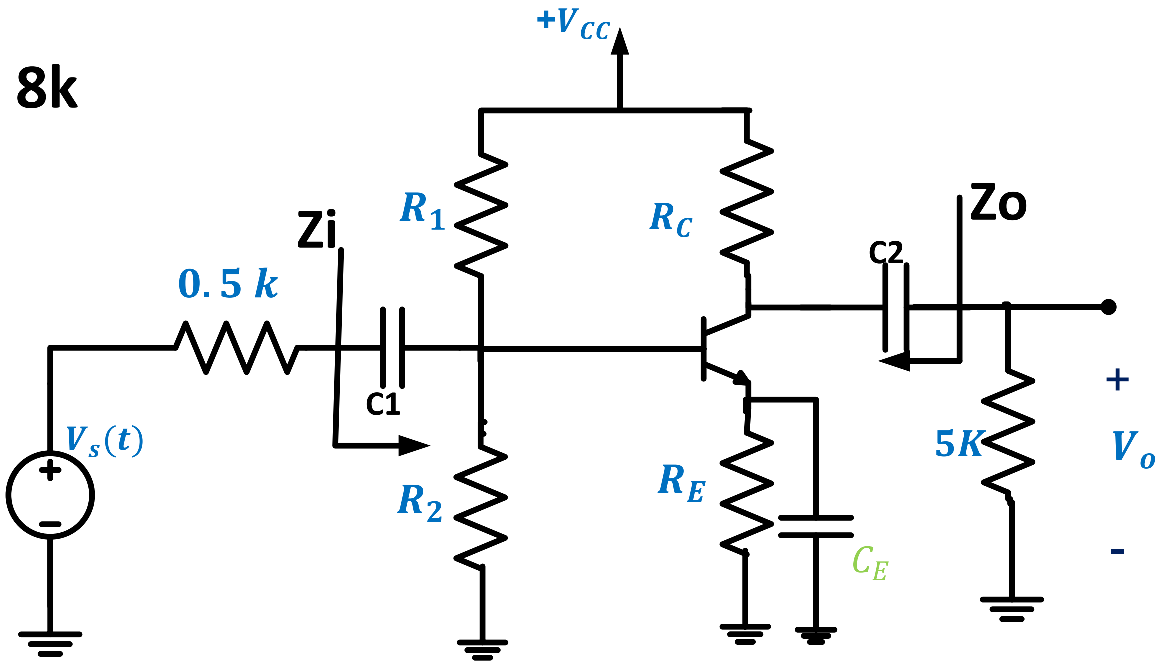
$$\boldsymbol{\beta(min) = 480\,, \quad \beta(max) = 1500}$$

To provide a voltage gain $\left|\frac{V_o}{V_s}\right| \geq 200$, between a small signal voltage source having a resistance 500Ω and load $R_L = 5k$

Its specified that $Z_{in} \geq 5k$

Its specified that Z_o = 8k

Solution :



Solution:

Ac small signal equivalent circuit:

$$V_o = -(R_C \backslash\backslash R_L) h_{fe} i_b$$

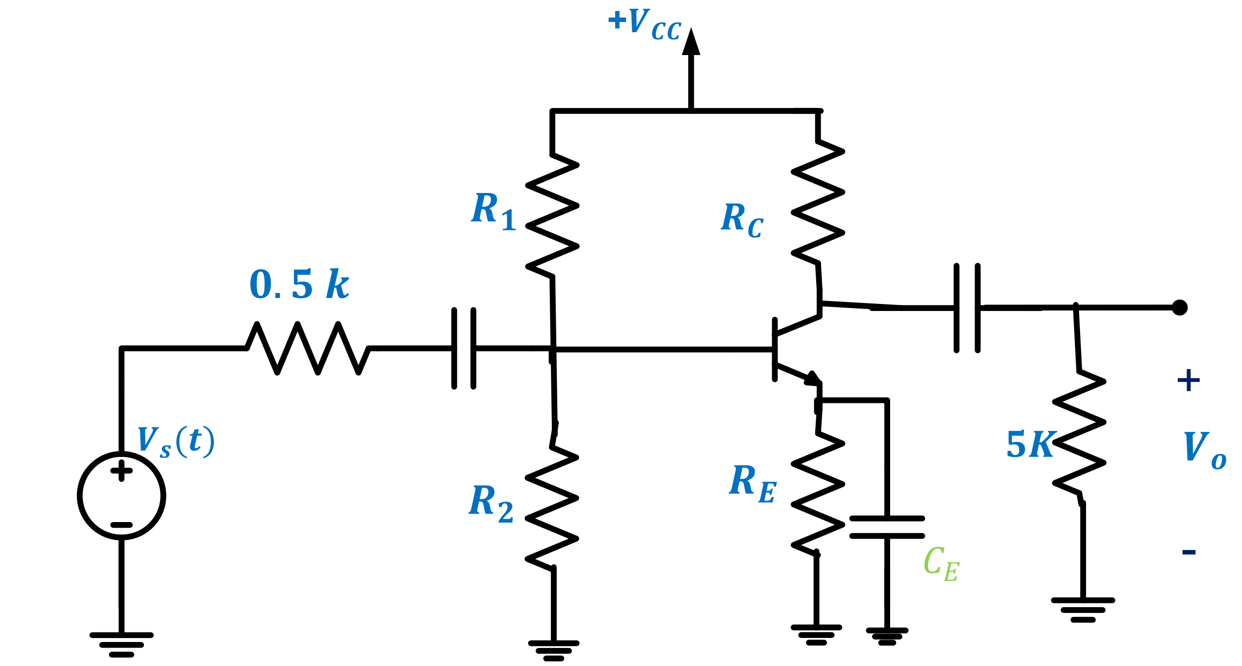
$$i_b = \frac{V_i}{h_{ie}}$$

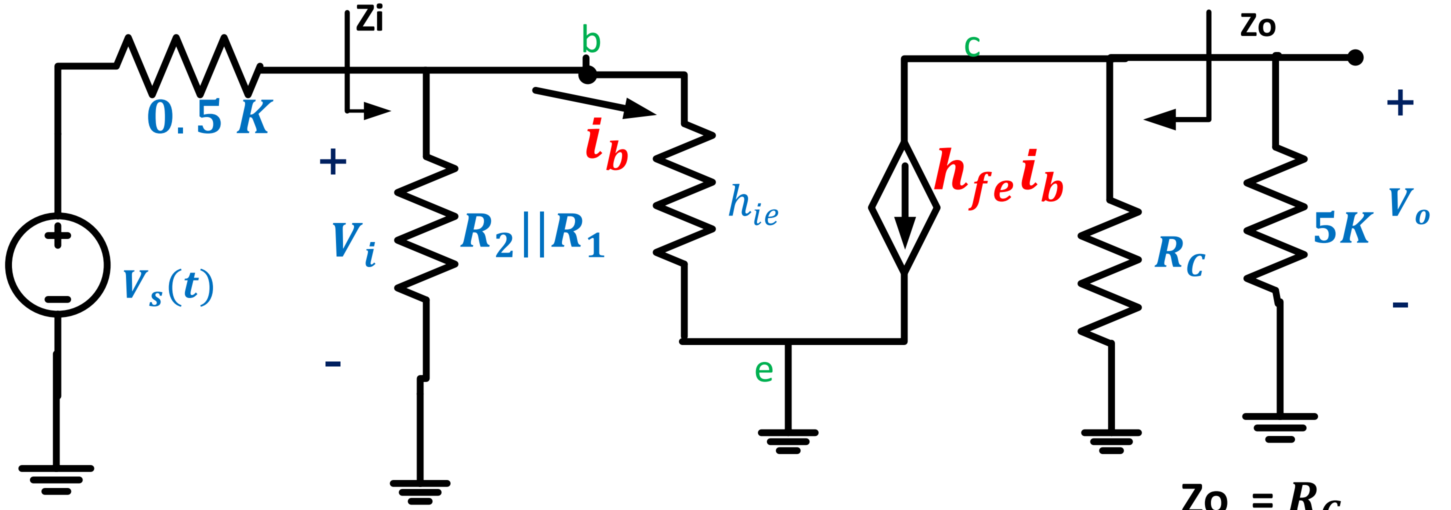
$$V_i = \frac{Z_i}{Z_i + R_s} V_s$$

❖ $|A_v| = \frac{h_{fe}}{h_{ie}} \frac{Z_i}{Z_i + R_s} (R_C \backslash\backslash R_L)$

$$1 > \frac{Z_i}{Z_i + R_s} > 0.9$$

❖ $|A_v| = \frac{h_{fe}}{h_{ie}} (0.9) (R_C \backslash\backslash 5k)$





Zo $= R_C$

$Z_i = R_{th}$ || hie = 5k

Let $g_m = \frac{h_{fe}}{h_{ie}} = \frac{ICQ}{VT} = 38.92\ I_{CQ}$ $\quad h_{ie} = \frac{\beta V_T}{I_C} = \frac{h_{fe} V_T}{I_C}$

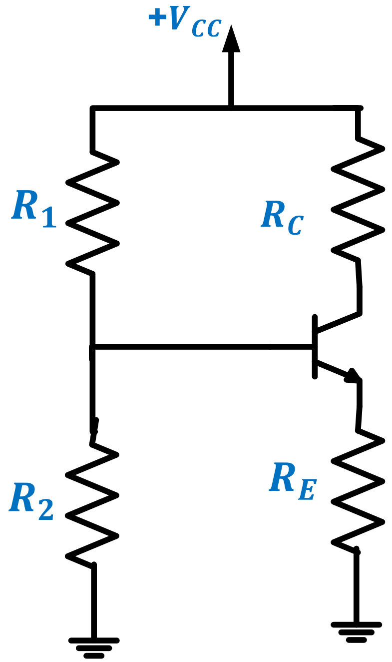
❖ $|A_v| = (g_m)(0.9)(R_C \backslash\backslash 5k) \geq 200$

Its specified that $Z_o = 8\ k$

$\therefore\ R_C = 8k,$ **then** $g_m \geq 72.2$

Let $g_m = 77.86$ **, then** $I_{CQ} = 2mA$

Since $V_{RC} = 16V$**; let** $V_{CC} = 30V$



$V_{th} = 6.81\ volt$

Let $V_{RE} = \frac{V_{CC}}{5} = 6volt$

$$R_E = \frac{V_{RE}}{I_E} = 3k\Omega$$

Z_i **=** R_{th} **|| hie = 5k**

$$h_{ie} = \frac{\beta V_T}{I_C} = 6.165K \qquad \therefore R_{th} = 26.45k$$

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

$$R_{th} = \frac{R_1 R_2}{R_1 + R_2}$$

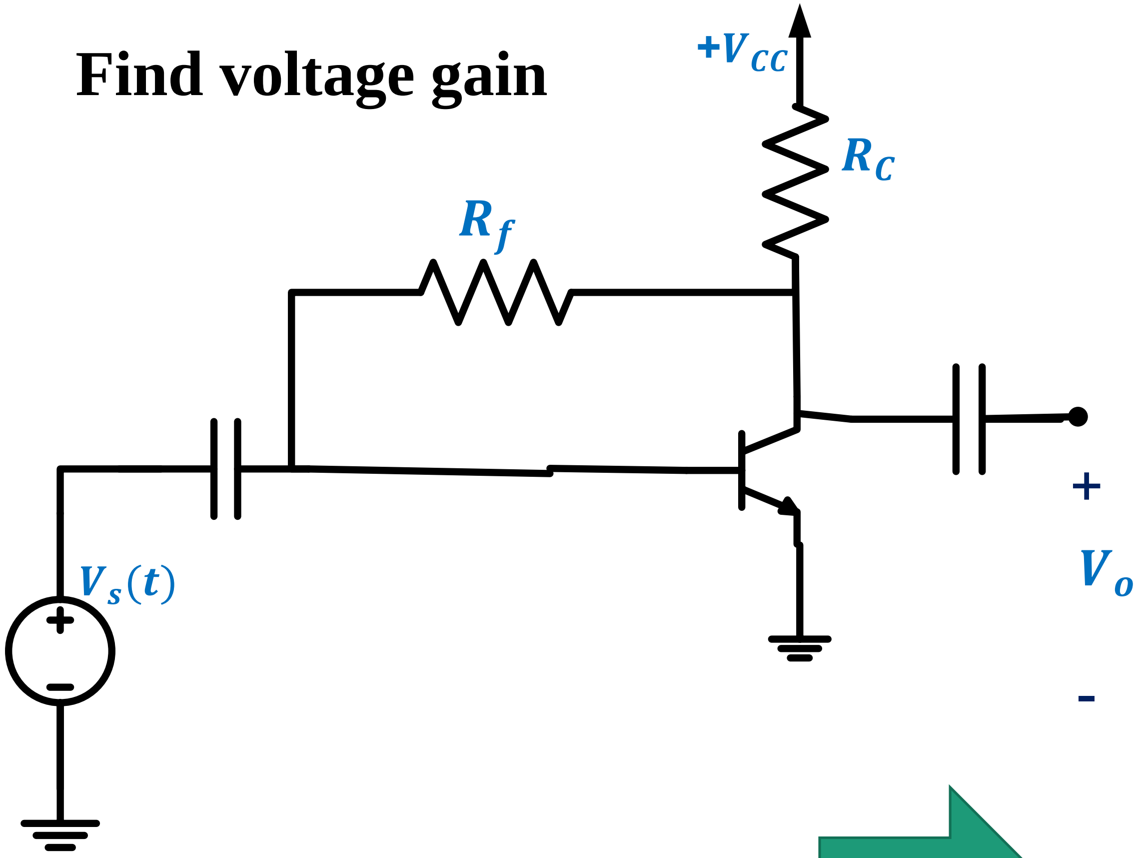
➢ $R_1 = 34.22k$

➢ $R_2 = 116.5.6k$

From : $I_E = \frac{V_{th} - V_{BE}}{\frac{R_{th}}{\beta+1} + R_E}$

Example :

Find voltage gain

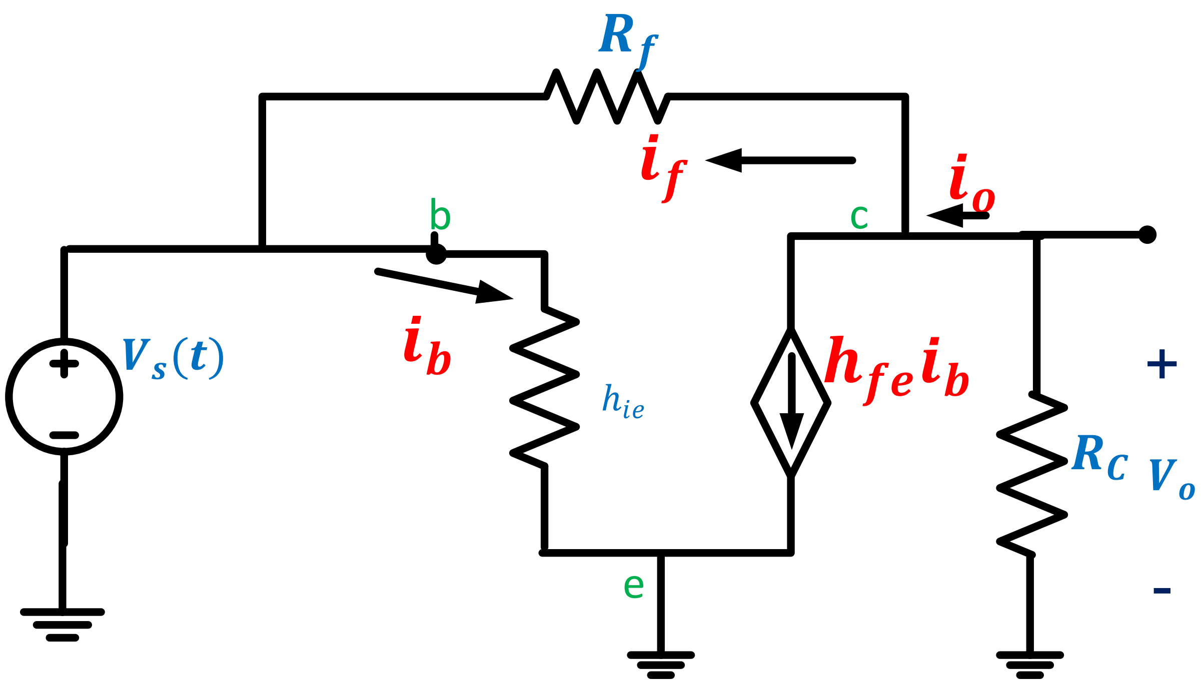


$$V_o = -R_C i_o$$

$$i_o = h_{fe} i_b + i_f$$

$$i_f = \frac{V_o - V_s}{R_f}$$

Ac small signal equivalent circuit:



$$i_b = \frac{V_s}{h_{ie}}$$

$$A_v = -\frac{\frac{R_C}{R_E} - R_C \frac{h_{fe}}{h_{ie}}}{1 + \frac{R_C}{R_E}}$$