Bipolar junction Transistor _ (BJT):

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BJT:

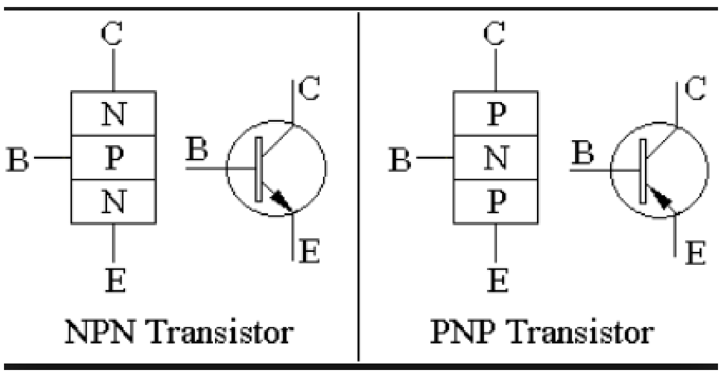
1. It’s a semiconductor device that can amplify electrical signals such as radio or television signals.

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.

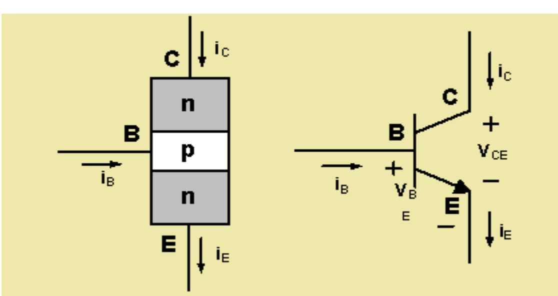
There are two type of BJT:

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

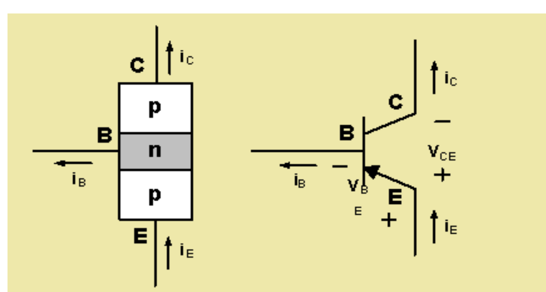


Transistor structure:

- **npn** type



- **pnp** type



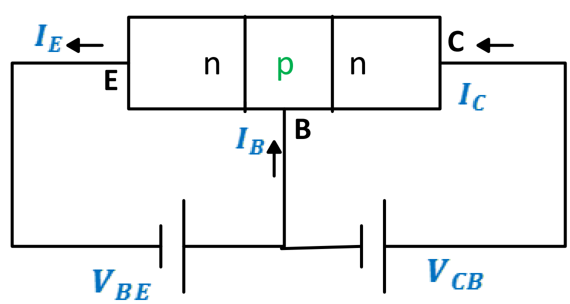
Transistor biasing:

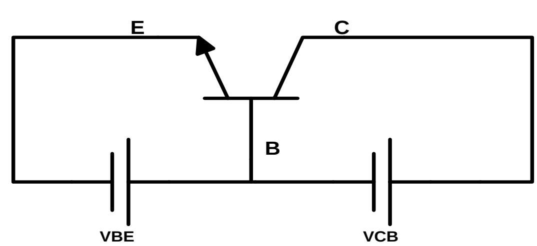
- ✓ In order to operate properly as an amplifier, it's necessary to correctly bias the two pn-junctions with external voltages.
- ✓ Depending upon external bias voltage polarities used; the transistor works in one of **four regions** (modes).
- ✓ For transistor to be used as an Active device **(Amplifier);**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

- ✓ $I_C = \alpha I_E + I_{CBO}$

Majority (αI_E) — Minority (I_{CBO})

$0.998 > \alpha > 0.9$

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

$$I_E = I_C + I_B$$

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

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

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 $\alpha = 0.99$ → $\beta = 99$

If $\alpha = 0.995$ → $\beta = 199$

In active region:

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

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

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

$$I_E = I_C + I_B$$

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

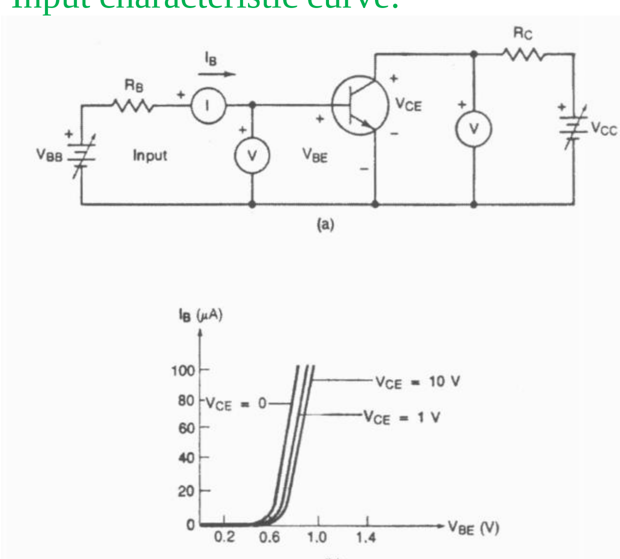
Approximate relationships:

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

$$I_C \cong \beta I_B$$

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

Input characteristic curve:

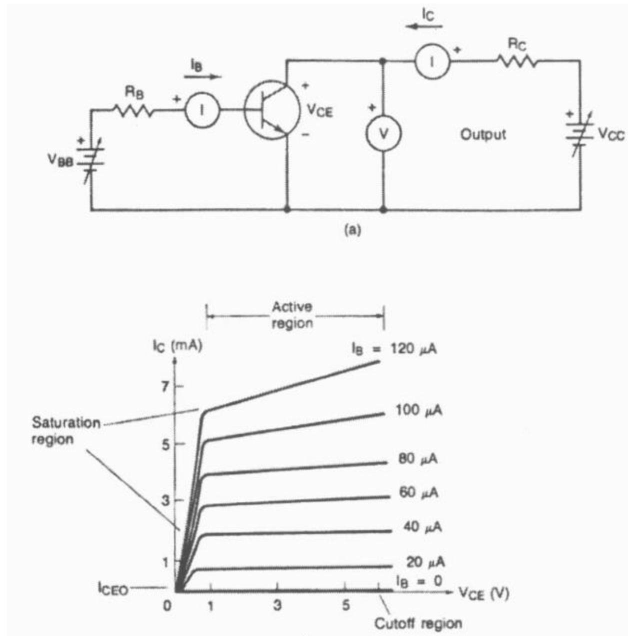


$$i_{B(t)} = I_{Bo}\left(e^{\frac{V_{BE}(t)}{\eta V_T}} - 1\right)$$

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

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

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

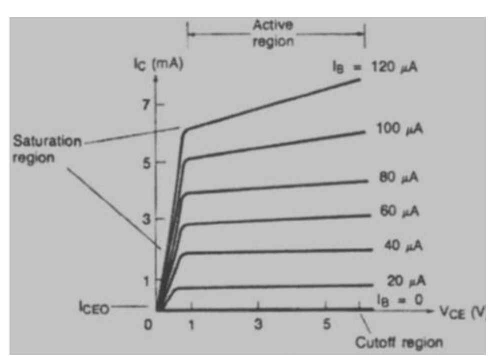
$V_{CE} < V_{CE,sat} = -0.2\ v$, Si , pnp

3. In the saturation region :

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

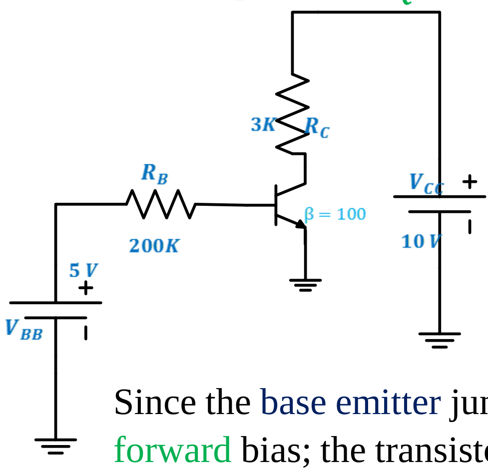
$V_{BE} = 0.8\ v$, Si , npn

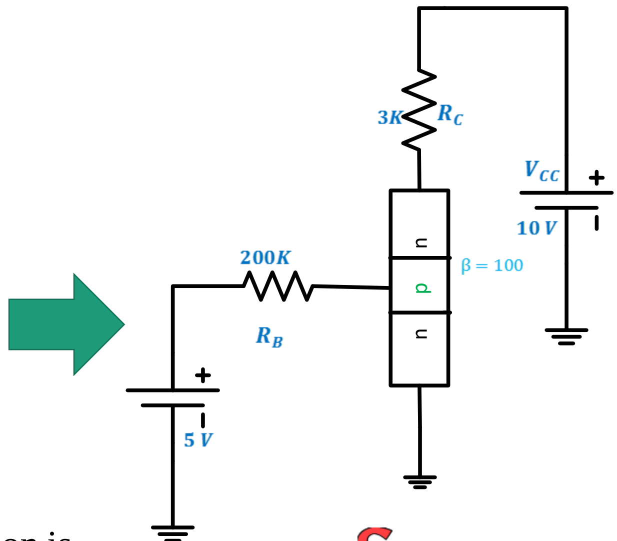
$V_{BE} = -0.8\ v$, Si , pnp



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

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

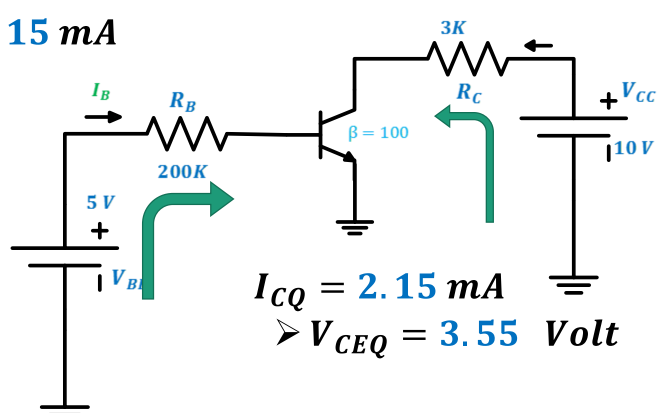
$$I_C = \beta\, I_B = 100 * 0.0215 = 2.15\ mA$$

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

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

❖ $V_{CE} = 10 - 3k * 2.15mA$

❖ $V_{CE} = 3.55\ \ Volt$



$I_{CQ} = 2.15\ mA$

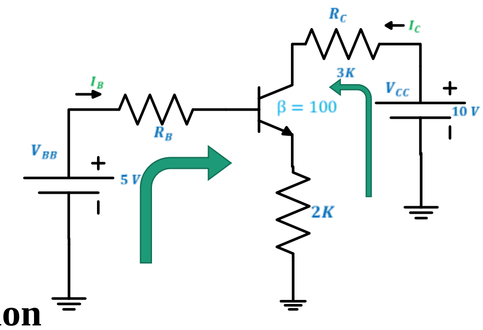
➢ $V_{CEQ} = 3.55\ \ Volt$

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

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

- $V_{CE} = 4.63\ Volt$

Since $V_{CE} > V_{CE,sat}$ >>> The **transistor is in the active region** $V_{CEQ} = 4.63\ Volt$ and $I_{CQ} = 1.07\ mA$

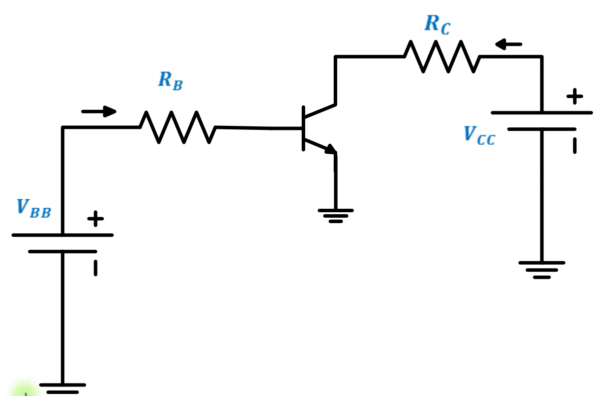
Second method:

1) In the active region:

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

$$I_C = \beta\, I_B$$

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



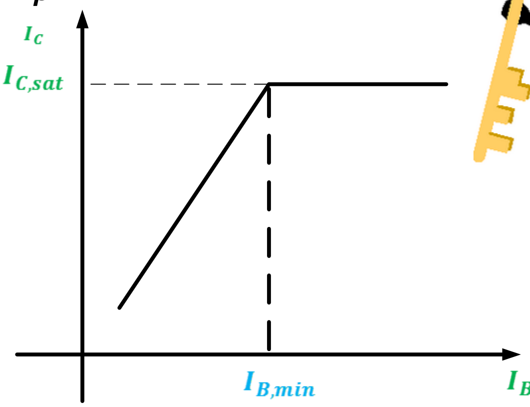
As : $R_B \downarrow$, $I_B \uparrow$, $I_C \uparrow$, $V_{CE} \downarrow$

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



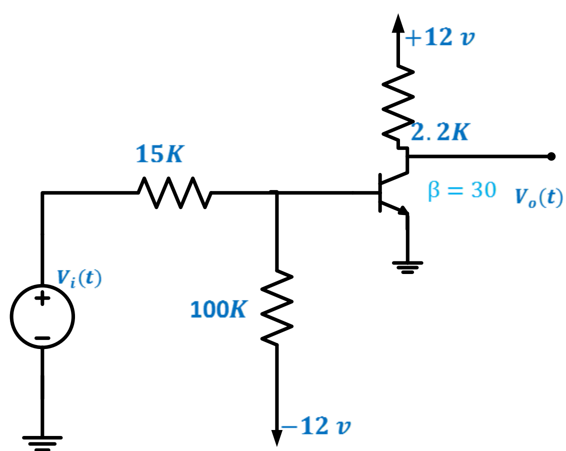
$$I_B(min) = \frac{I_{C,sat}}{\beta}$$

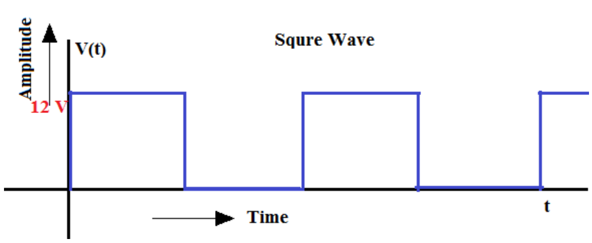
- If $I_B > I_B(min)$ the transistor is in the saturation region.
- If $I_B < I_B(min)$ the transistor is in the Active region.

BJT as switch:

Example:

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

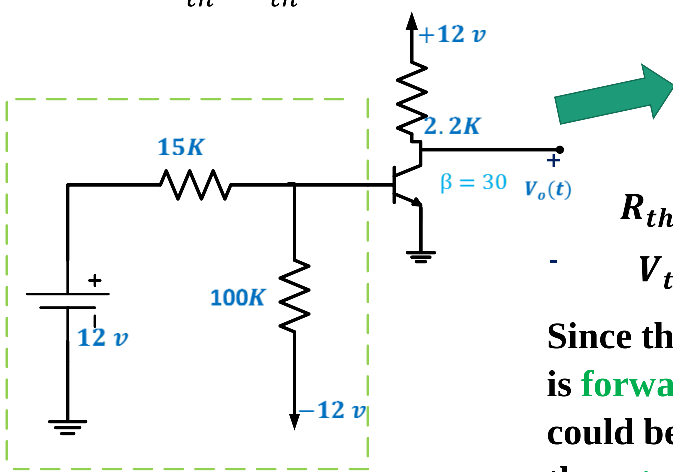


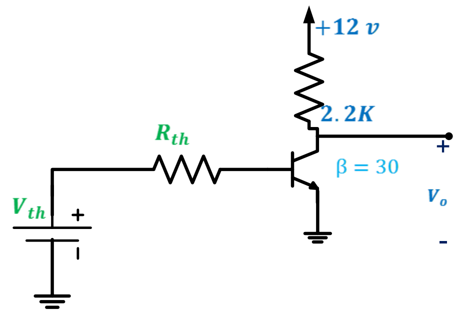


Solution:

❖ **Let $V_i(t) = +12\ volt$**

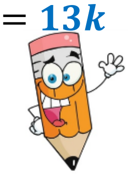
Calculate V_{th}&R_{th}





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

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



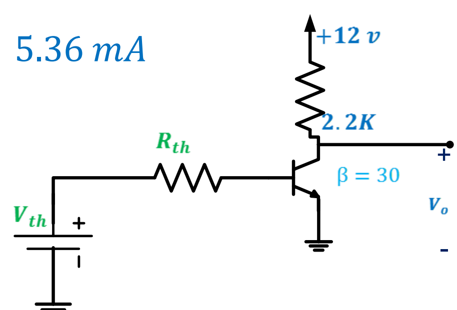
Since the base emitter junction is forward bias; the transistor could be either in the active or the saturation region

➢ **Assume that the transistor in the saturation region**

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

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

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

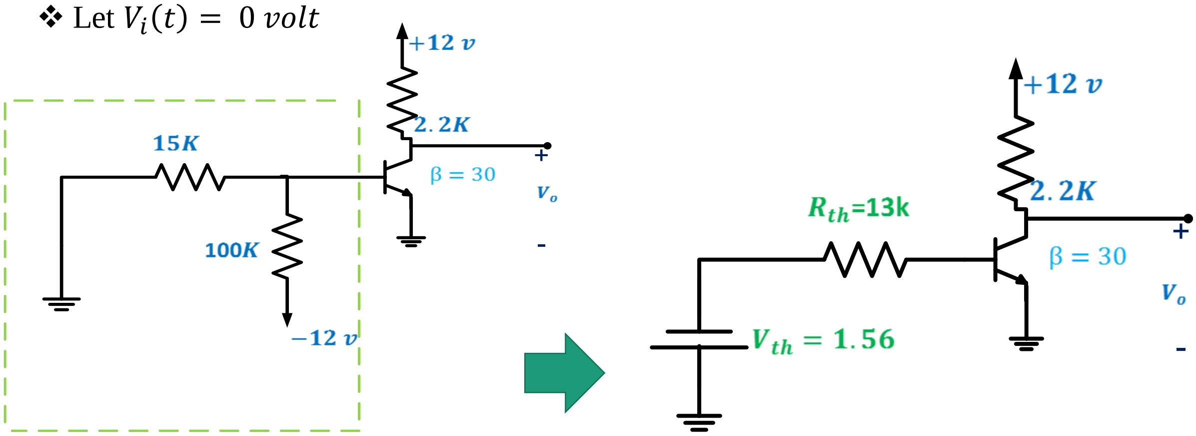


Since $I_B > I_B(min)$ the transistor is in the saturation region.

✓ $V_o = V_{CE,sat} = 0.2\ volt$

✓ $I_C = 5.36\ mA$

❖ Let $V_i(t) = 0\ volt$

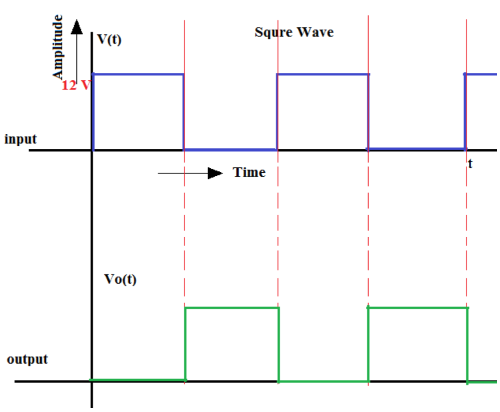


Since $V_{th} = -1.56\ volt$

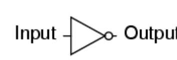
Base emitter junction is revers biased the transistor in cutoff region

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

The circuit acts as inverter or not gate



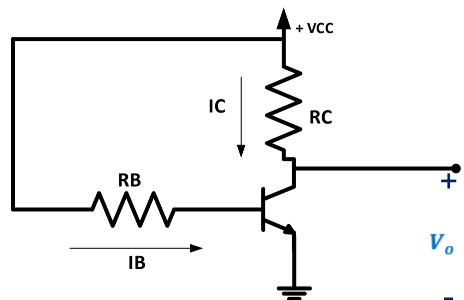
NOT gate truth table



Input	Output
0	1
1	0

Transistor biasing circuits:

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:

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

➢ $R_c = 5k\Omega$

$$I_C = \beta\, I_B$$

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

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

➢ $R_B = 465\ k\Omega$

Transistor biasing circuits:

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

BUT:

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

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

For:

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

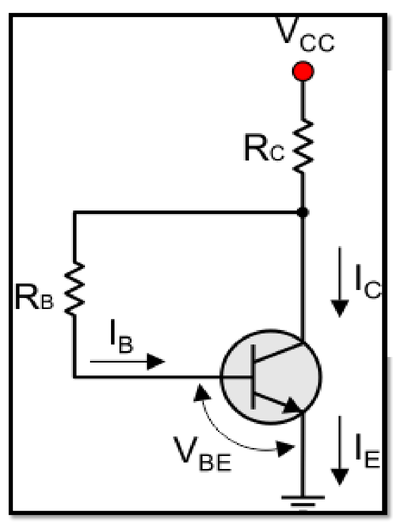
- When $\beta = \beta(max) = 75$

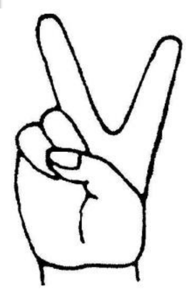
$$I_B = 20\ \mu A$$
$$I_C = 1.5mA$$
$$V_{CE} = 2.5v$$

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

$$I = I_B + I_c$$

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

$$I_C = \beta I_B$$

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

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

Transistor biasing circuits:

Example: Design a **collector to base feedback 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 $\boldsymbol{\beta = \frac{25+75}{2} = 50}$ **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 : $V_{CC} = R_B I_B + V_{BE} + R_E I_E$

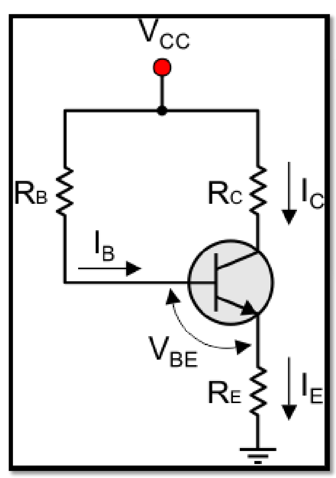
$$I_E = (\beta+1) I_B$$

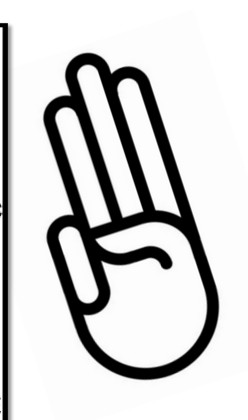
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)R_E} \ ...(1)$$

$$I_C = \beta I_B$$

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

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





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

$V_{RE} = R_E I_E$

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

From eq.2 :

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

➢ $R_C = 3k\Omega$

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

➢ $R_B = 365k\Omega$

Proof that :

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

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

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**

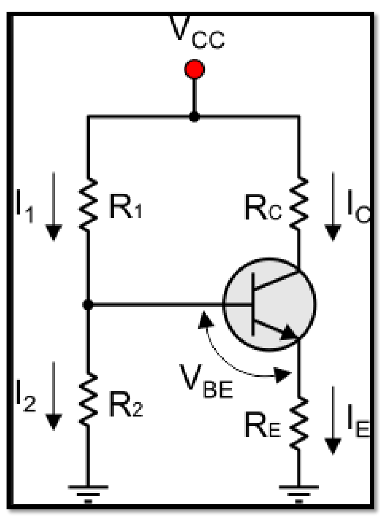
$V_{BE} = V_B - V_E$

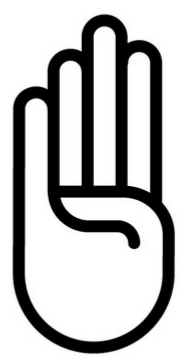
❖ $V_E = V_B - V_{BE}$

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

$I_C = \alpha I_E = I_E$

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



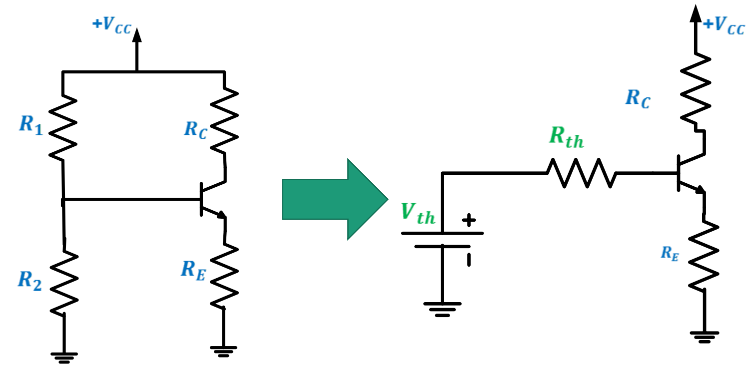


Transistor biasing circuits:

b) Exact method:

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

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



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:

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

To make $I_{E2} \cong I_E$ **:**

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

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

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

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

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

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

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

Solution:

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

$V_{RE} = R_E I_E$

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

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

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

- $R_{th} = 1k\Omega$

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

- $R_c = 4k\Omega$

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 @ $\beta = 50$

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

But:

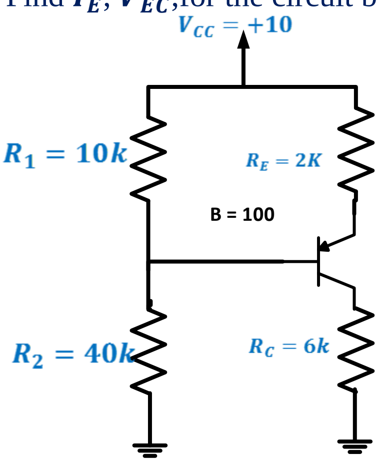
$$75 \geq \beta \geq 25$$

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

Circuit using pnp transistor:

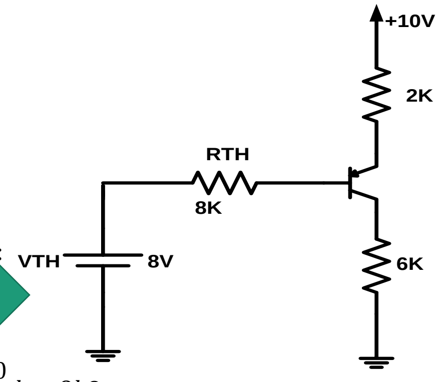
Example:

Find I_E, 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: $10 = 2kI_E + V_{EB} + R_{th}I_B + V_{th}$

- $I_E = 0.625mA$

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

- $V_{EC} = 5volt$

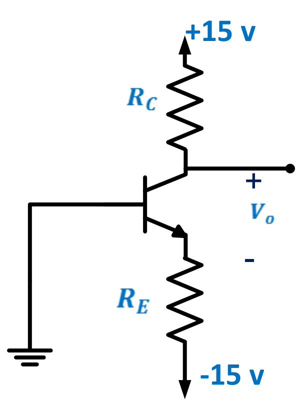
Example:

Design the given circuit so that

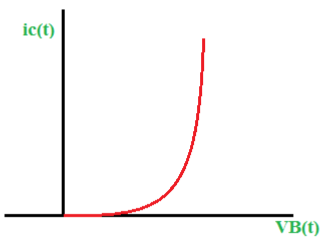
$$I_{CQ} = 2mA \text{ , and } V_C = 5 \ volt$$

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

$$\beta = \infty$$



Solution:



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

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

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

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

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

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

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

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

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

➢ $V_{BE2} = 0.717\ V$

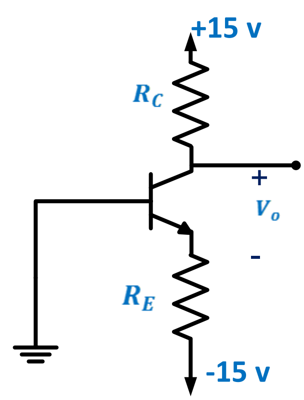
$V_{BE2} = 0.717$ @ $I_C = 2mA$

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

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

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

➢ $R_C = 5k\Omega$



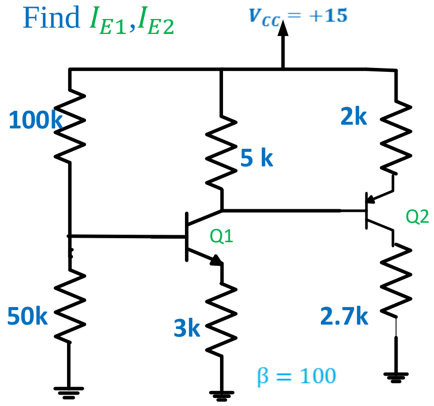
KVL: $V_{BE} + R_E I_E - 15 = 0$

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

➢ $R_E = 7k\Omega$

Example:

Find I_{E1}, I_{E2}

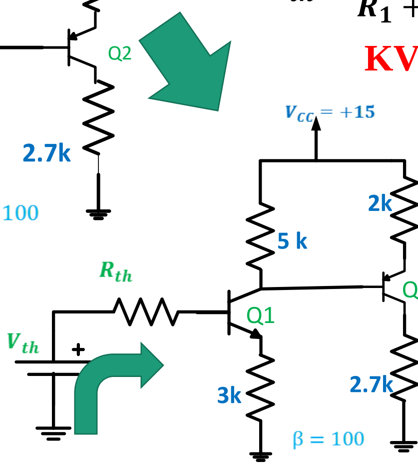


Solution

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

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

KVL:



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

$$= 1.28mA$$

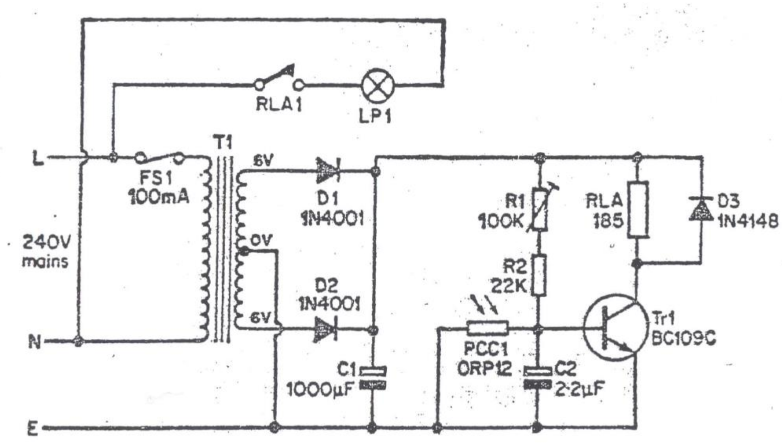
KVL:

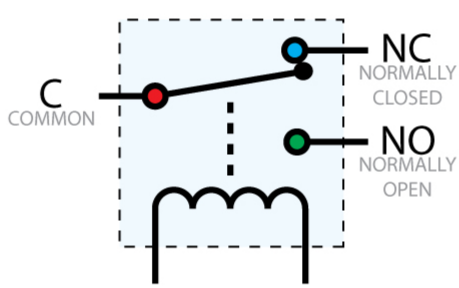
$$2kI_{E2} + V_{EB} - 5k(I_{C1} - I_{B2}) = 0$$

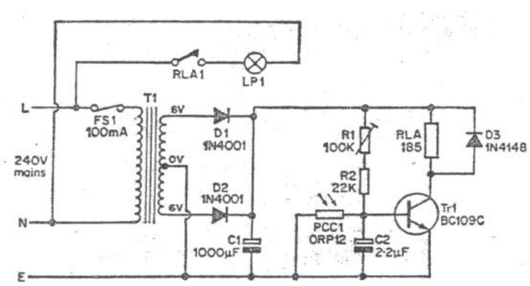
$$I_{E2} = 2.78mA$$

The first project

Automatic Light Controller







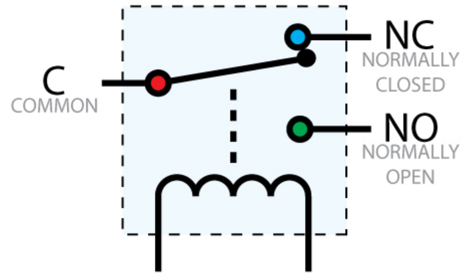


FIGURE 1

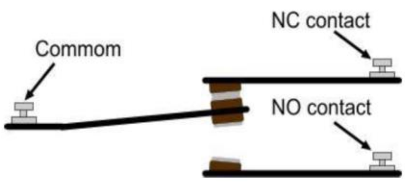
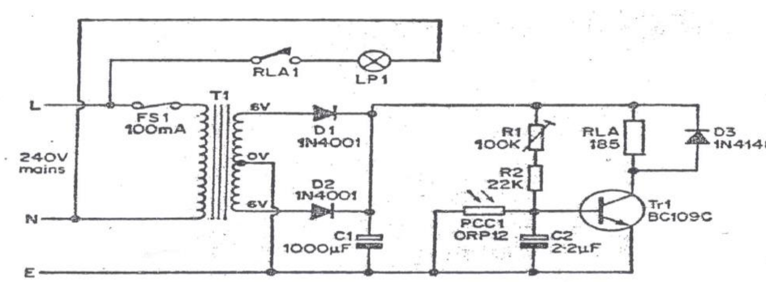


FIGURE 2



In day time

R_{Pc} is small, so that $V_{BE} < 0.7V$

∴ Transistor is in cutoff

∴ Relay is deenergized

∴ Switch is open

∴ Lamp is OFF

At night

R_{Pc} becomes Large, so that $V_{BE} \approx 0.7V$

∴ The Transistor is on

∴ Relay is energized

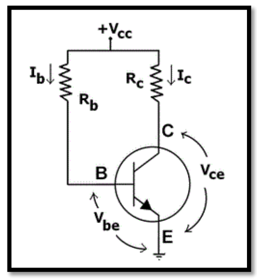
∴ Switch is close

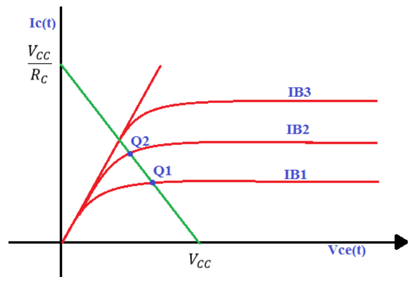
BJT Ac-Small signal analysis using Graphical method:

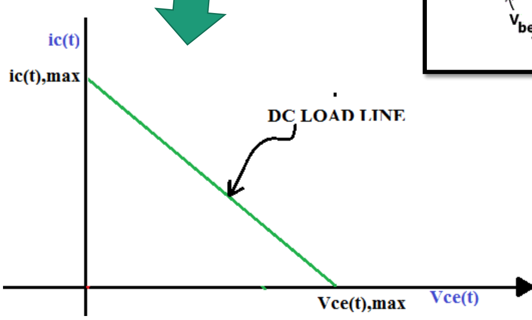
Graphical method:

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

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



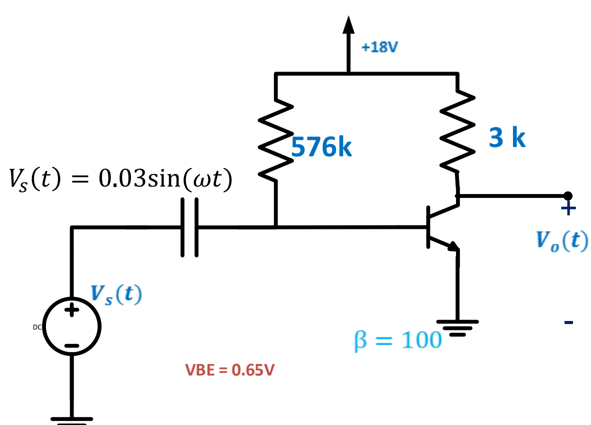




$$i_C(t)_{,max} = \frac{V_{CC}}{R_C} \quad \text{Saturation}$$

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

Small signal BJT amplifier:



DC Analysis:

From KVL:

$$I_B = \frac{V_{cc} - V_{BE}}{R_B} = \frac{18 - 0.65}{576k}$$

- $I_B = 30\mu A$

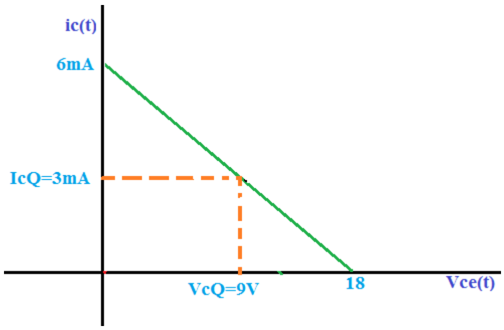
But: $I_C = \beta I_B$

- $I_C = 3mA$

KVL:

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

- $V_{CE} = 9\ volt$



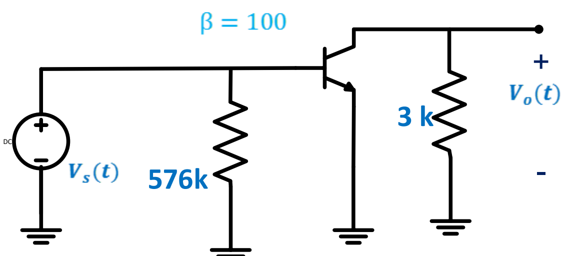
$$V_{BE}(t) = V_{BE} + v_{be}$$

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

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

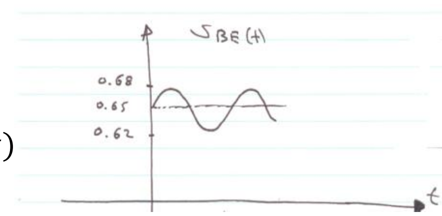
Ac analysis:

Ac equivalent circuit:

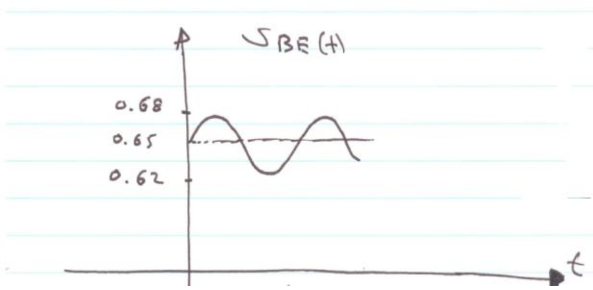


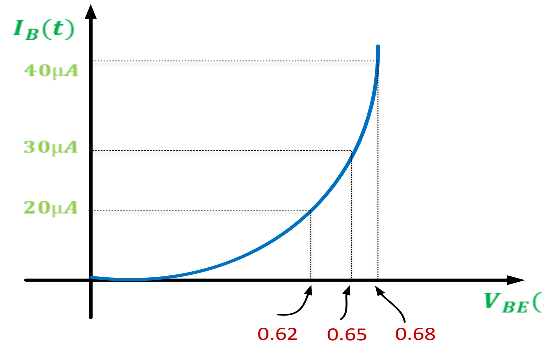
$$v_{be} = V_s(t) = 0.03\sin(\omega t)$$

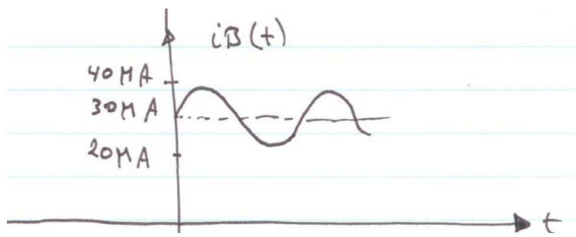
$$V_{BE}(t) = 0.65 + 0.03\sin(\omega t)$$



Ac small signal analysis



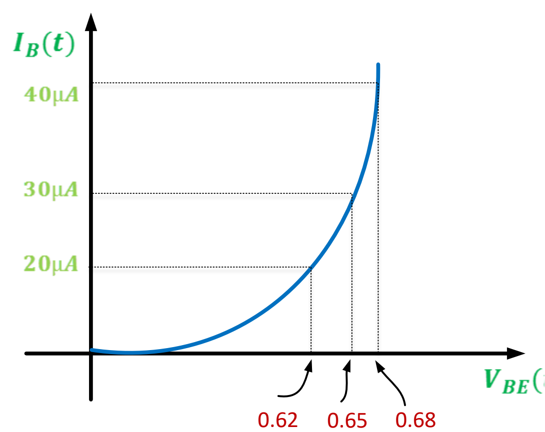




When: $V_{BE}(t) = 0.65$; $i_B(t) = 30\mu A$

$V_{BE}(t) = 0.68$; $i_B(t) = 40\mu A$

$V_{BE}(t) = 0.62$; $i_B(t) = 20\mu A$



Using:

$$i_C(t) = \beta \, i_B(t)$$

$$V_{CE}(t) = V_{CC} - R_c i_c$$

When : $i_B(t) = 30\mu A$; $i_C(t) = 3mA$

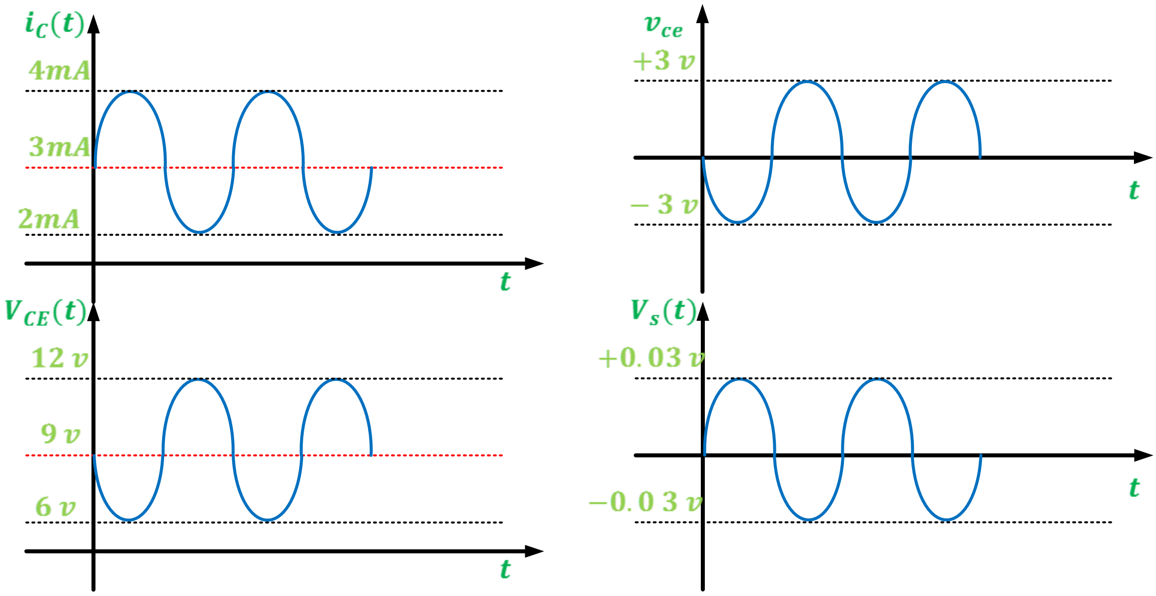
$V_{CE}(t) = 9 \; volt$

When : $i_B(t) = 40\mu A$; $i_C(t) = 4mA$

$V_{CE}(t) = 6 \; volt$

When : $i_B(t) = 20\mu A$; $i_C(t) = 2mA$

$V_{CE}(t) = 12 \; volt$

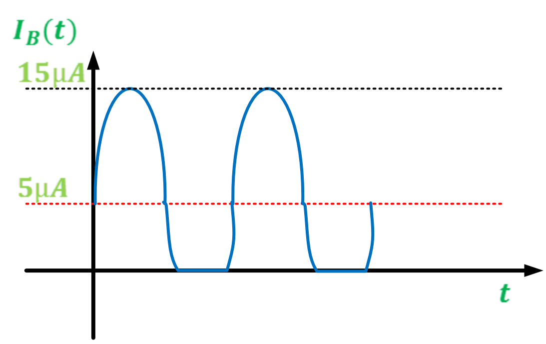


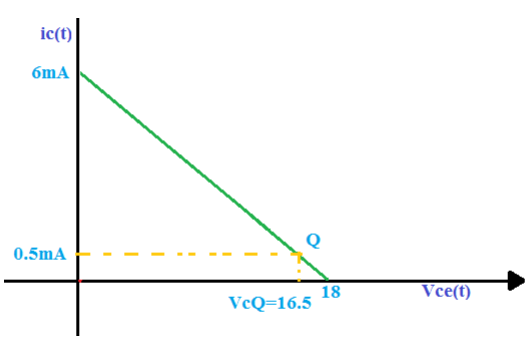
Let $R_B = 3.47M\Omega$

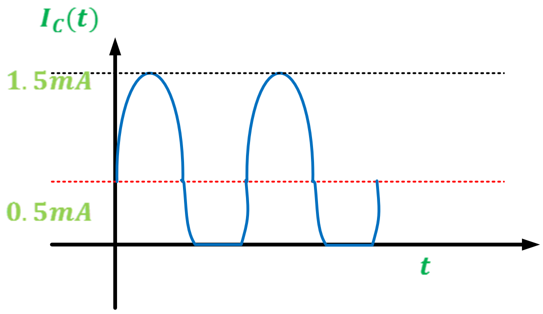
$$I_B = \frac{18 - 0.65}{3.47M} = 5\mu A$$

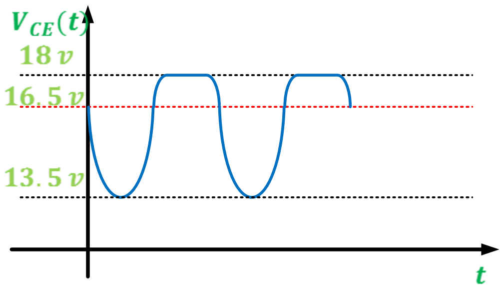
$I_C = 0.5mA$

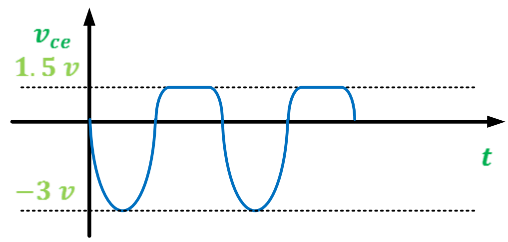
$V_{CE} = 16.5\ volt$



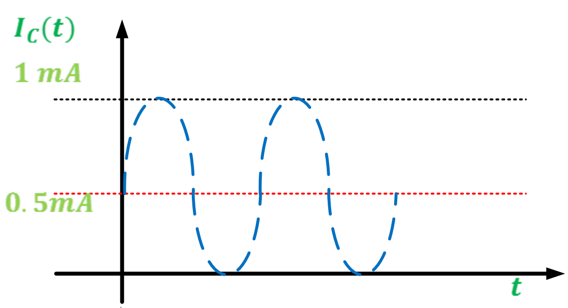


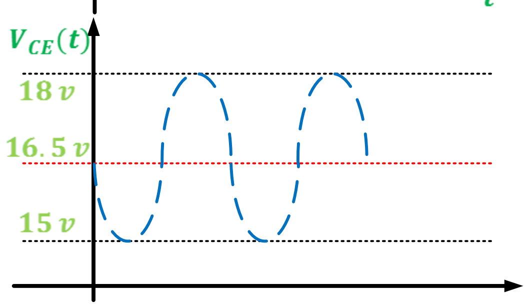




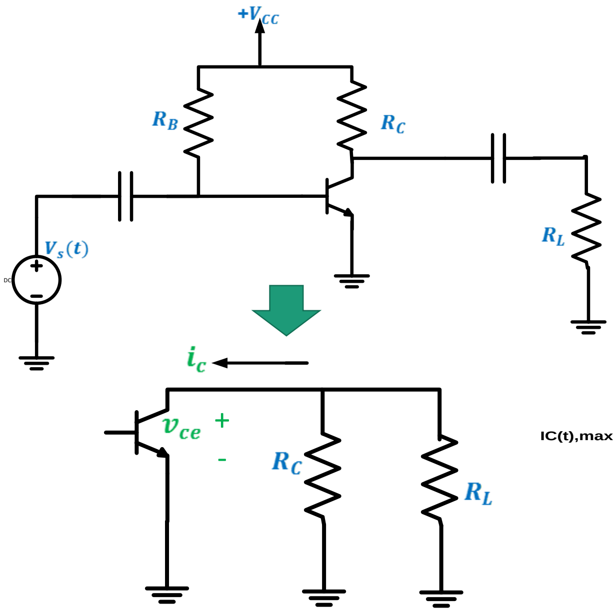


Maximum possibility swing:





Ac load line:



$$v_{ce} = -(R_c||R_L)i_c \ ;$$

$$v_{ce} = -R_{ac}i_c \ ;$$

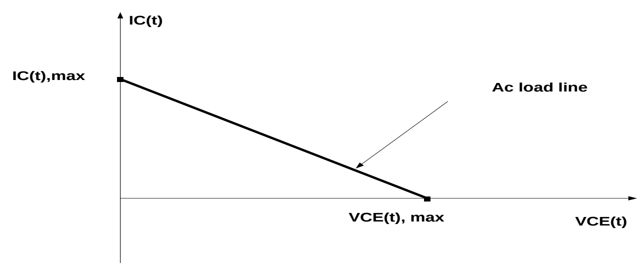
$$V_{CE}(t) - V_{CEQ} = -R_{ac}(i_c(t) - I_{CQ})$$

To find $i_{c,max}(t)$ set $V_{CE}(t) = V_{CE,sat} \cong 0$

- $i_{c,max}(t) = I_{CQ} + \frac{V_{CEQ}}{R_{ac}}$

To find $V_{CE,max}(t)$ set $i_c(t) = 0$

- $V_{CE,max}(t) = V_{CEQ} + R_{ac}\, I_{CQ}$



For maximum symmetrical swing:

$$I_{CQ} = \frac{1}{2} i_{c,max}(t)$$

$$i_{c,max}(t) = I_{CQ} + \frac{V_{CEQ}}{R_{ac}} = 2I_{CQ}$$

- $I_{CQ} = \frac{V_{CEQ}}{R_{ac}}$

For DC condition:

$$V_{CC} = R_C I_C + V_{CE}$$

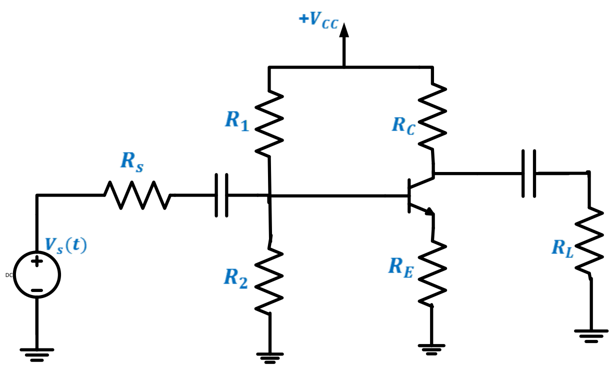
$$V_{CC} = R_{dc} I_C + V_{CE}$$

$$V_{CC} = R_{dc} I_C + R_{ac} I_C$$

- $I_C = \frac{V_{CC}}{R_{dc}+R_{ac}}$

Example:

Find R_{dc} , R_{ac}



For maximum symmetrical swing:

- $I_C = \frac{V_{CC}}{R_{dc}+R_{ac}}$

$$R_{dc} = R_C + R_E$$

$$R_{ac} = R_E + (R_C||R_L)$$

$$V_{CEQ} = R_{ac} * I_{CQ}$$

Ac small signal equivalent circuits for BJT configuration:

Hybrid parameters "h- parameters":

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

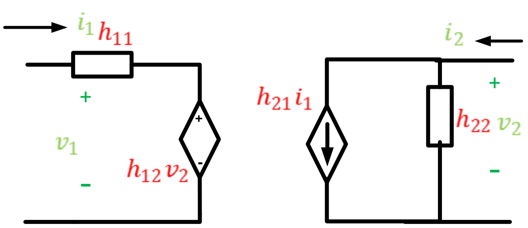
$$i_2 = h_{21}i_1 + h_{22}v_2$$

$h_{11} = \frac{v_1}{i_1}\Big| v_2 = 0$ **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)**

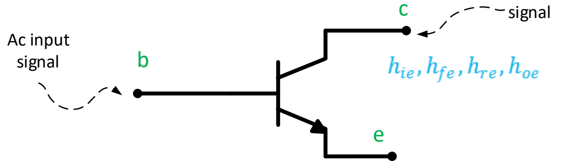
$h_{21} = \frac{i_2}{i_1}\Big| v_2 = 0$ **Short circuit forward current ratio, (h_f)**

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

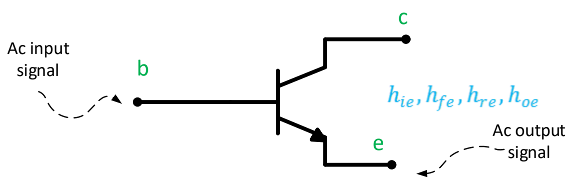


Transistor configuration:

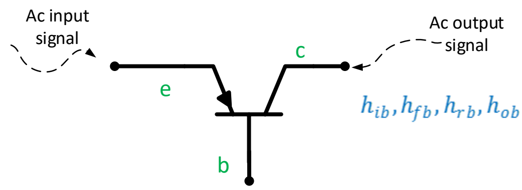
1. common emitter:



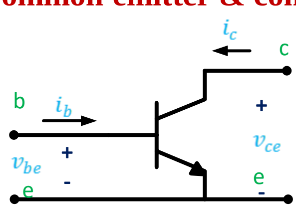
2. common collector



3. common base

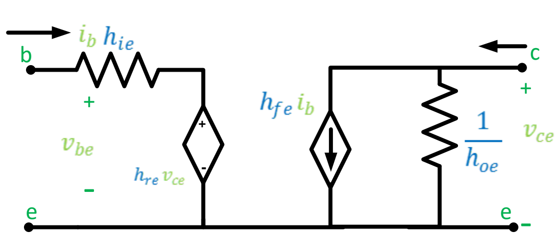


Common emitter & common collector:

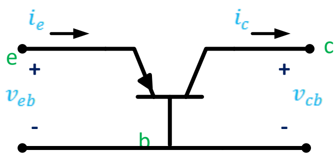


$$v_{be} = h_{ie} i_b + h_{re} v_{ce}$$

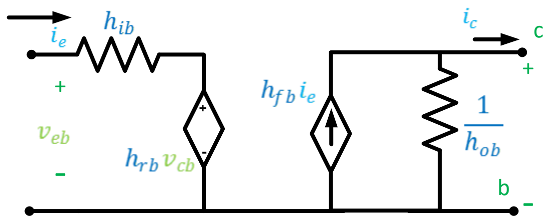
$$i_c = h_{fe} i_b + h_{oe} v_{ce}$$



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:

$$\boldsymbol{h_{ie} = 1600\Omega}$$
$$\boldsymbol{h_{oe} = 20 * 10^{-6}\ \mathrm{S}}$$
$$\boldsymbol{h_{fe} = 80}$$
$$\boldsymbol{h_{re} = 20 * 10^{-4}}$$

$h_{oe} = 20 * 10^{-6}$ S ⟶ 0;

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

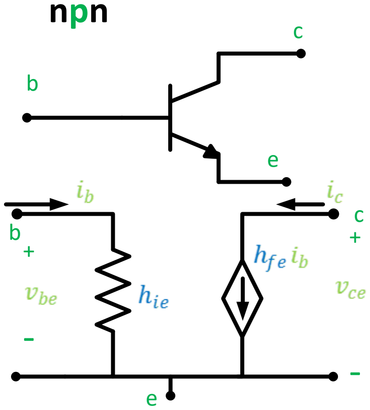
$\boldsymbol{h_{re} = 20 * 10^{-4}}$ ⟶ **0;**

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

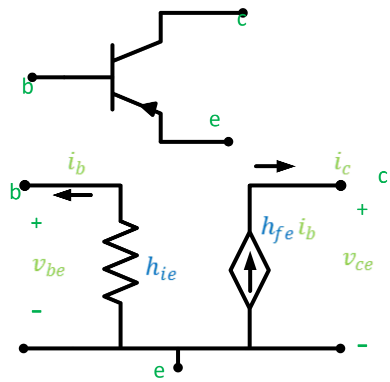
Approximate BJT models:

1) Common emitter & common collector:

npn



pnp

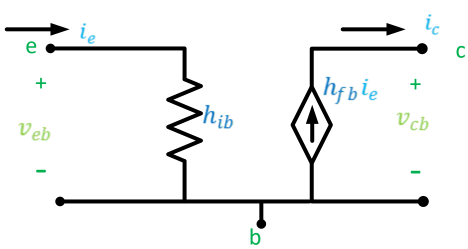


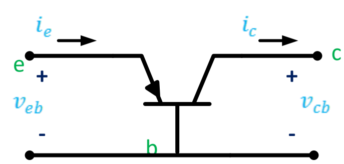
$$i_c = h_{fe}\, i_b = \beta\, i_b$$

➢ $h_{fe} = \beta$

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

2-commom base:





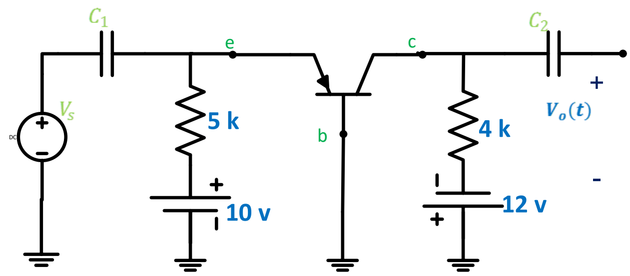
$$i_c = h_{fb}\, i_e = \alpha\, i_e$$

➢ $h_{fb} = \alpha$

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

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

BJT ac amplifiers:

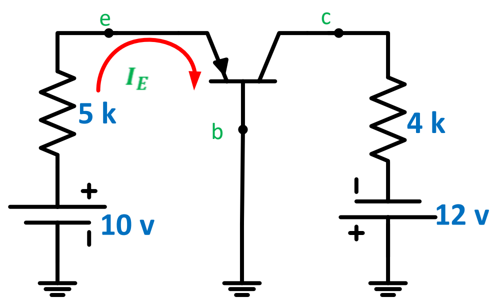


1-common base amplifiers:

Find :

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

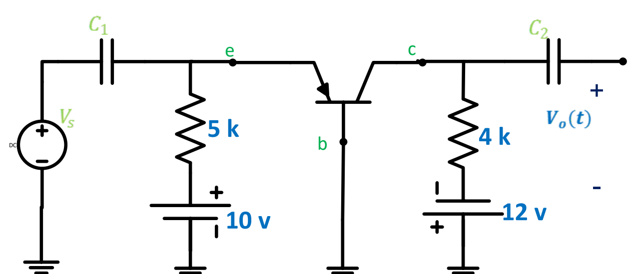
a) Dc analysis:



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

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

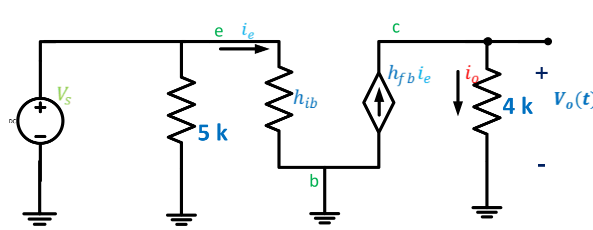
BJT ac amplifiers:



1-common base amplifiers:

b) Ac small signal analysis:

Ac small signal equivalent circuit:



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

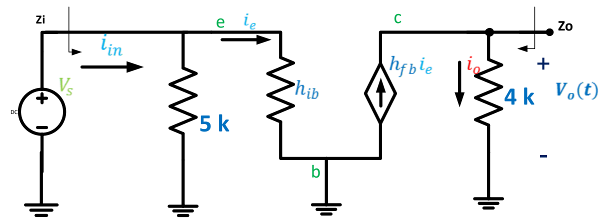
$$V_o = h_{fb}\, i_e(4k)$$

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

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

V_s **Is in phase with** V_o

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



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

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

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

3. **Input impedance** Z_i

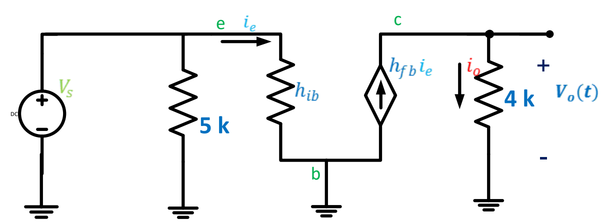
$$Z_i = \frac{V_s}{i_{in}}$$

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

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

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

Output impedance Z_o



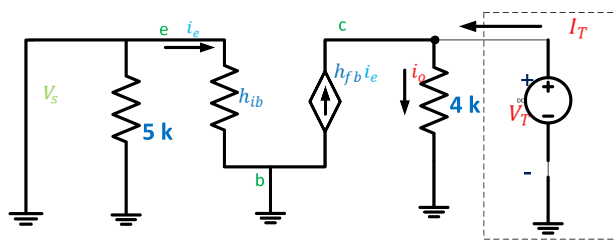
Z_o **Is** R_{th}**seen by the load**

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

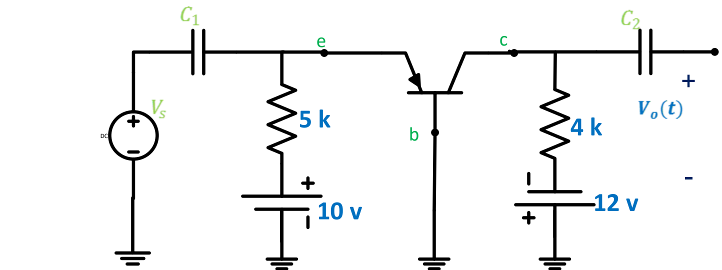
$$I_T = \frac{V_T}{4k} - h_{ib} i_e$$

$$i_e = 0$$

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



Common base amplifier



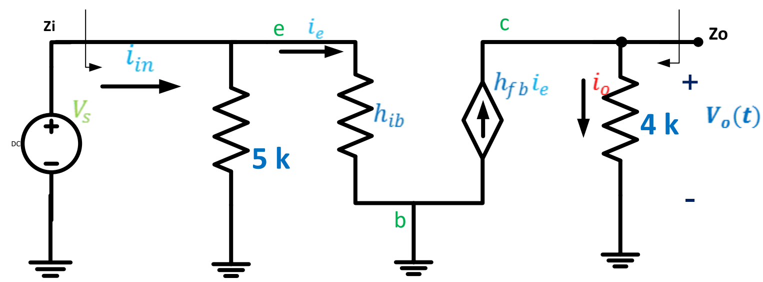
$A_v = \frac{V_o}{Vs} = \frac{h_{fb}(4k)}{h_{ib}} = 286 > 1$

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

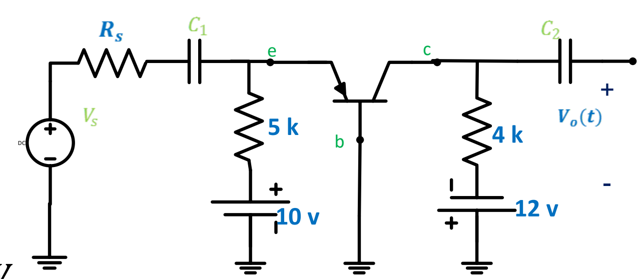
$\text{Zi} = (5k||h_{ib})$

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

$Z_o = 4k$ (Large)



The effect of R_s



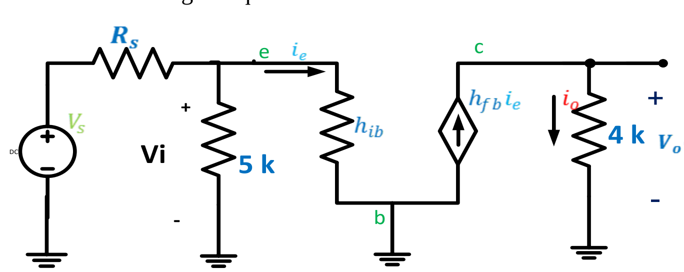
$V_o = h_{fb}\, i_e(4k)$

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

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

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

Ac small signal equivalent circuit:



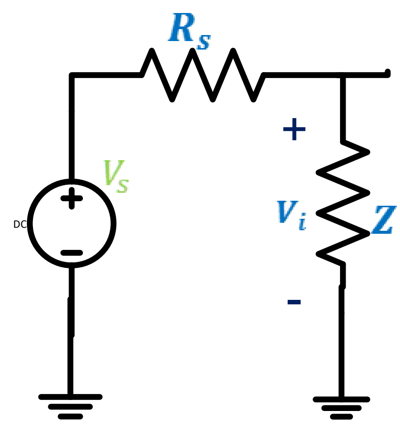
$A_{vs} = \frac{V_o}{V_s} = \frac{h_{fb}(4k)}{h_{ib}} \frac{Z_i}{Z_i + R_s}$

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

$V_o = 286\, V_i$

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

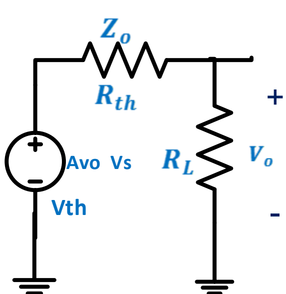
$$V_o = \frac{Z_i}{Z_i + R_s} 286\, V_i$$



Z_i Must be as large as could be

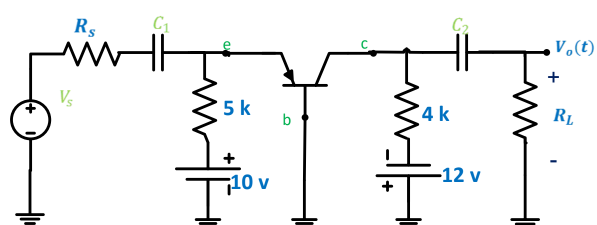
The effect of R_L

Using thevenin's theorem:

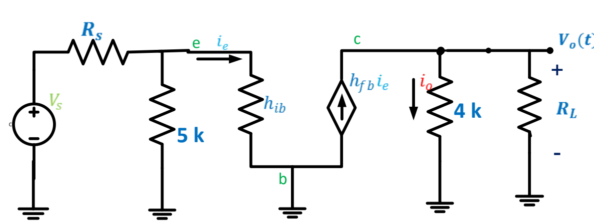


$$V_o = \frac{R_L}{R_L + Z_o} A_{Vo}\, V_s$$

Z_o Must be as small as co



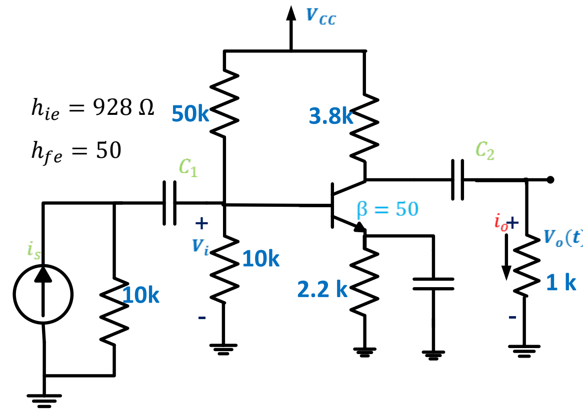
Ac small signal equivalent circuit:



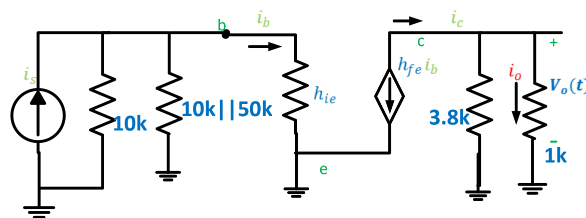
2) Common emitter amplifier:

Find:

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



Ac small signal equivalent circuit:



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

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

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

➢ $A_i = -33$

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

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

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

➢ $A_v = \frac{V_o}{V_i} = -42.7$

➢ $Z_i = 10k||50k||h_{ie}$

➢ $Z_o = 3.8k$

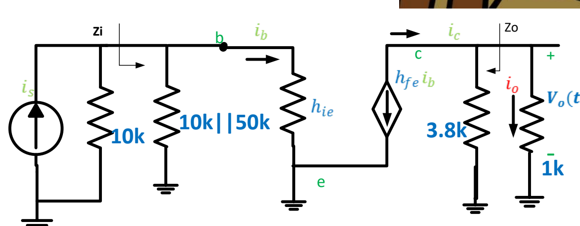
For Common emitter amplifier:

$|A_V| > 1$

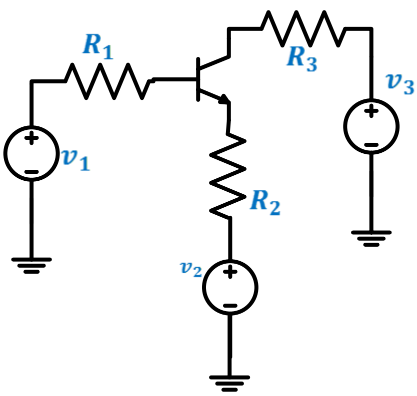
$|A_i| > 1$

Z_i Large

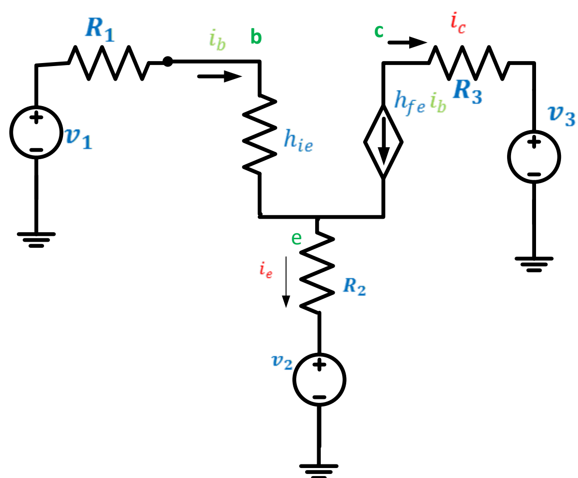
Z_o Large



Impedance reflection:

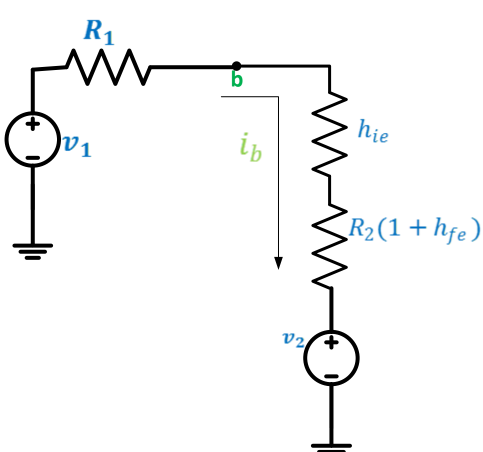


Ac small signal equivalent circuit:



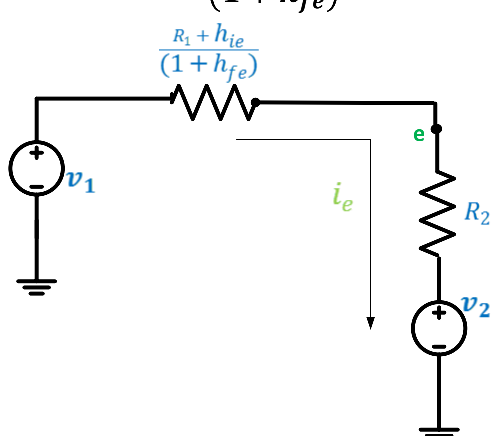
Base equivalent circuit:

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

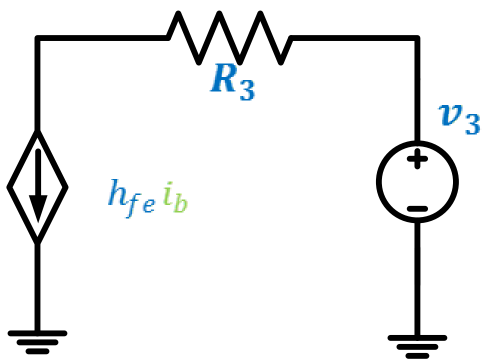


Emitter equivalent circuit:

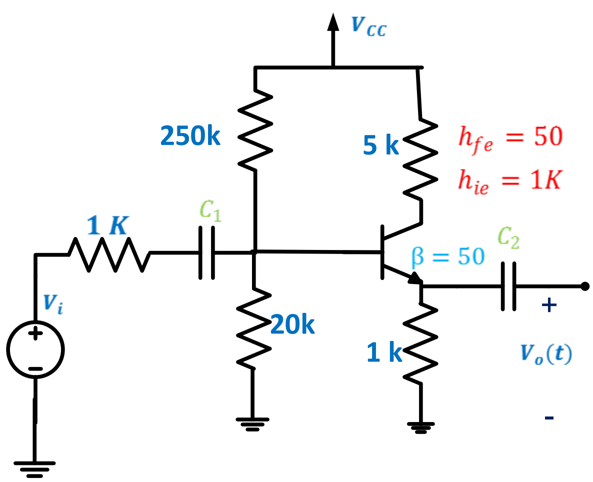
$$i_e = \frac{v_1 - v_2}{R_2 + \dfrac{R_1 + h_{ie}}{(1 + h_{fe})}}$$



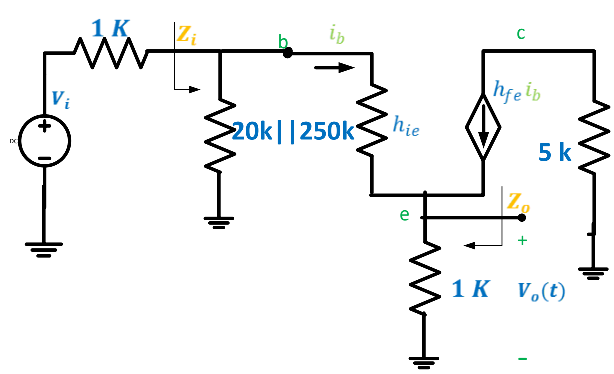
Collector equivalent circuit:

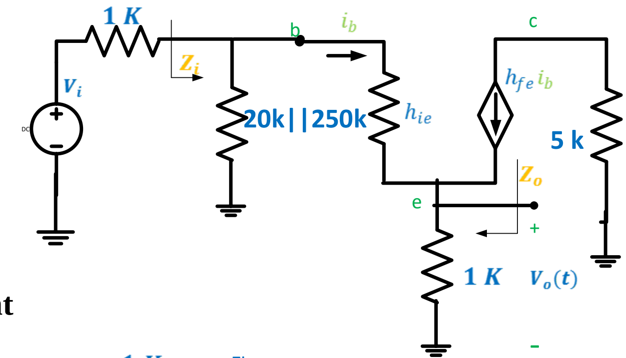


3) Common collector amplifier:



Ac small signal equivalent circu





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

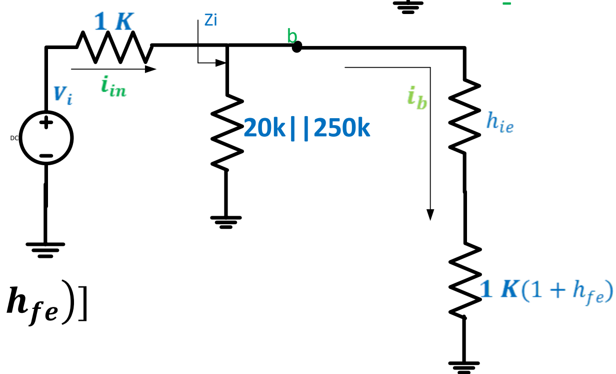
$$V_o = 1k * i_e$$

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

To find i_b base equivalent circuit:

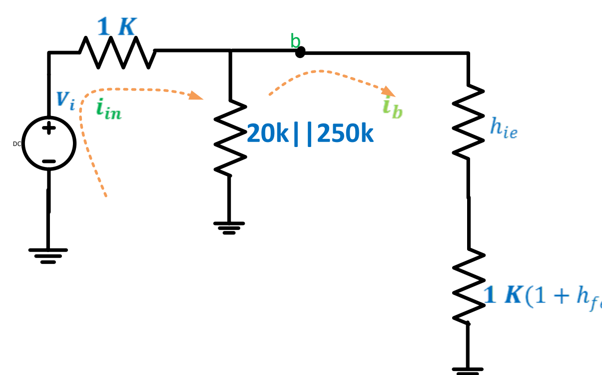
$$i_b = \frac{(20k||250k) i_{in}}{(20k||250k) + h_{ie} + 1k(1 + h_{fe})}$$

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



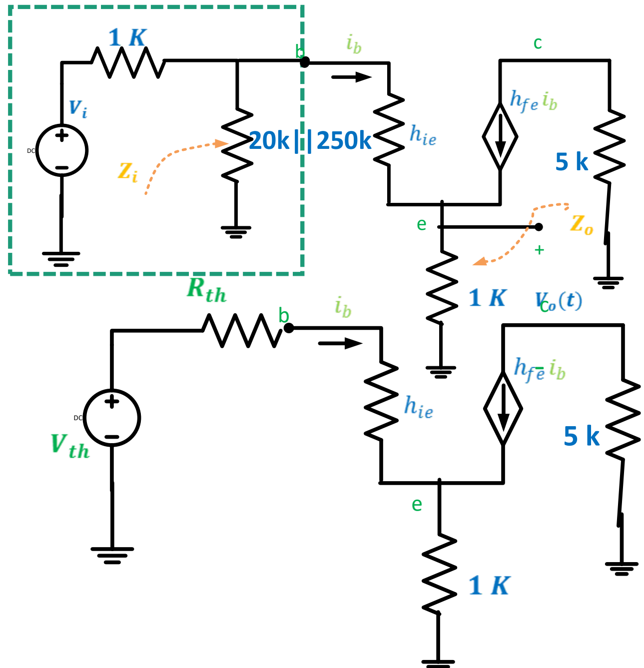
$$Z_{in} = [(20k||250k)]||[h_{ie} + 1k(1 + h_{fe})]$$

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



- $Z_{in} = 13.66K$
- $A_v = \frac{V_o}{V_{in}} = 0.9149$
- $A_i = \frac{i_o}{i_{in}} = 13.9$

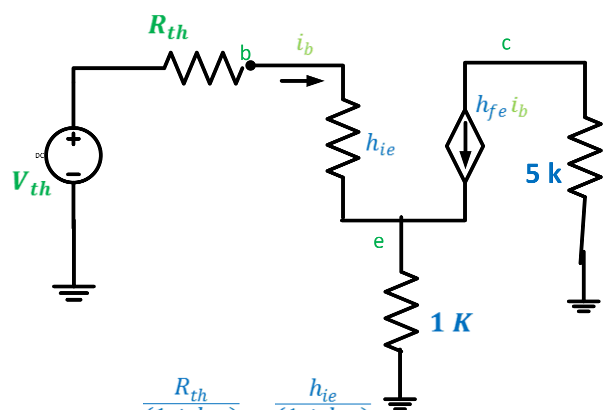
To find Z_o ;emitter equivalent circuit:



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

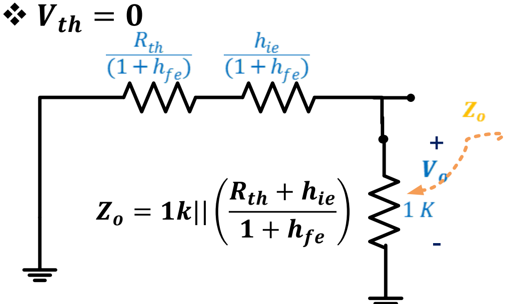
$$V_{th} = \frac{(20k||250k)}{(20k||250k) + 1k} V_{in}$$

Emitter equivalent circuit:

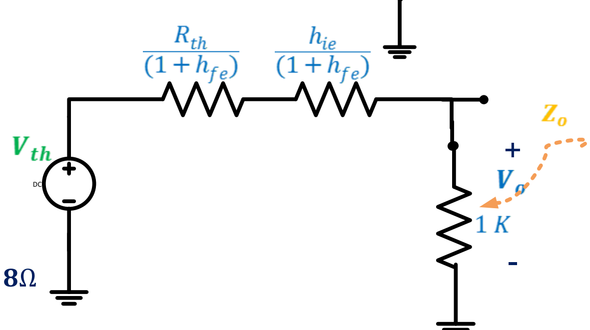


To find Z_o we set $V_{in} = 0$

❖ $V_{th} = 0$



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



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

For common collector amplifier:

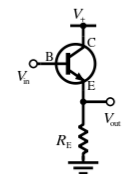
$A_v < 1$

$A_i > 1$

Z_o *very small*

$Z_i =$ *very larg*

The common collector as a buffer:

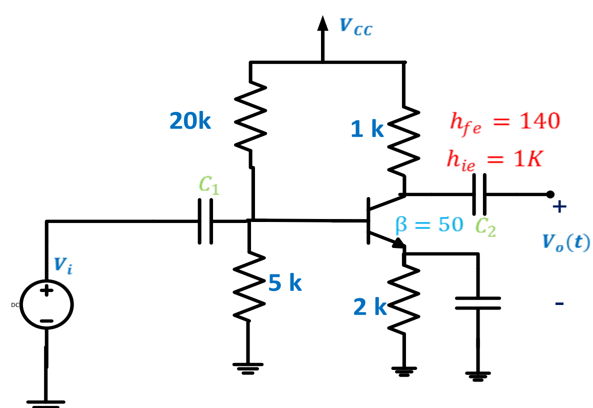


Although the small signal voltage gain of the common collector (emitter follower) is less than 1, it can be used to improve the total voltage gain of a multistage amplifier.

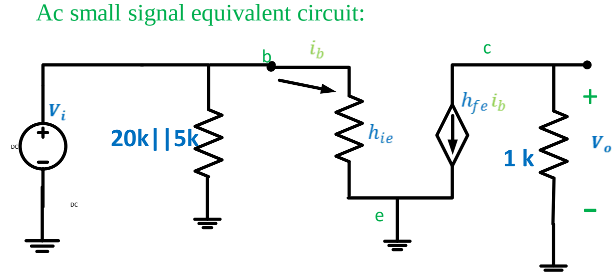
Common emitter amplifier

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

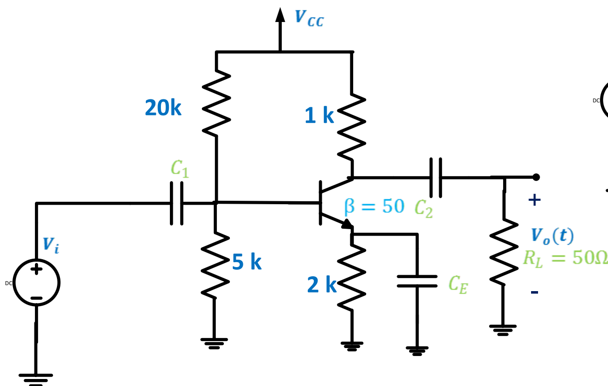
Proof!!

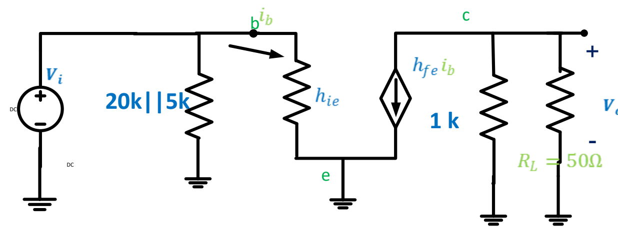


Ac small signal equivalent circuit:



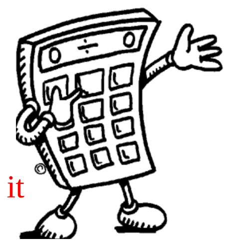
Common emitter amplifier with R_L:





Ac small signal equivalent circuit:

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

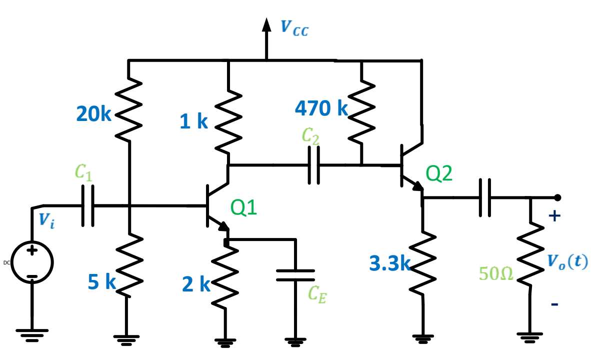


Do it

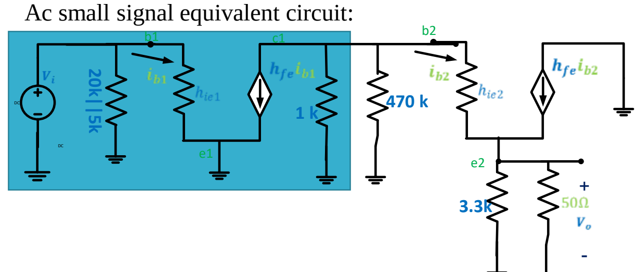
Multistage amplifier:

Find the voltage gain

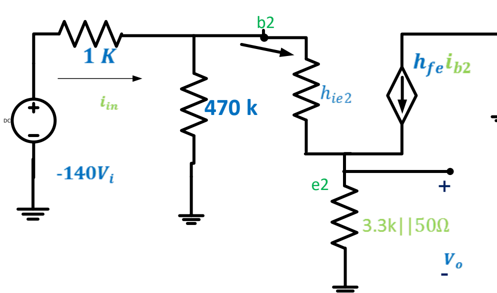
$$h_{ie1} = 1k, h_{ie2} = 2.24k, h_{fe1} = 140, h_{fe2} = 100$$



Ac small signal equivalent circuit:



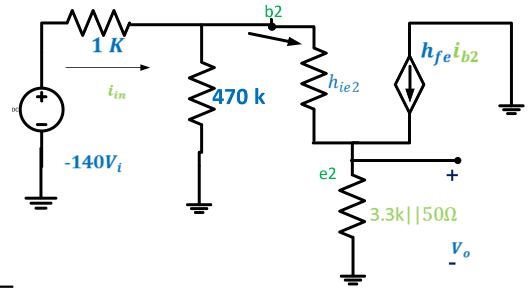
Using thevenin's theorem:



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

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

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



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

The common emitter amplifier design:

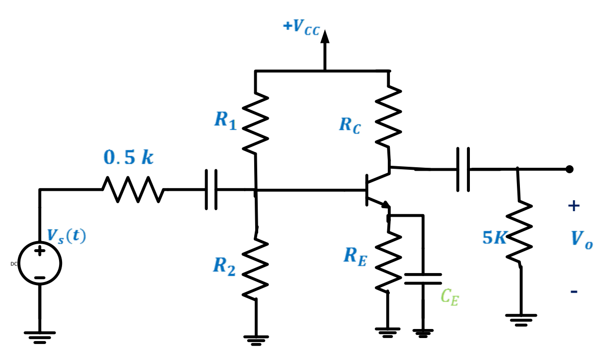
Design a common emitter amplifier using a transistor having

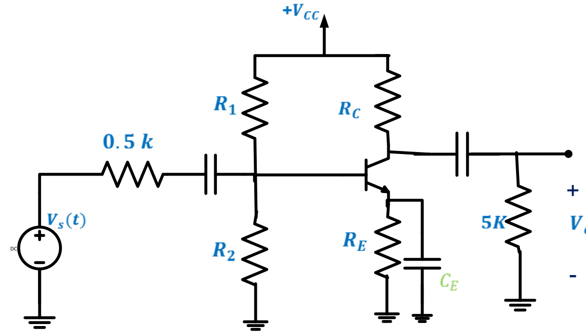
$\beta(min) = 480$, $\beta(max) = 1500$

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 $Z_{in} \geq 5k$

Solution :





Solution:

Ac small signal equivalent circuit:

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

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

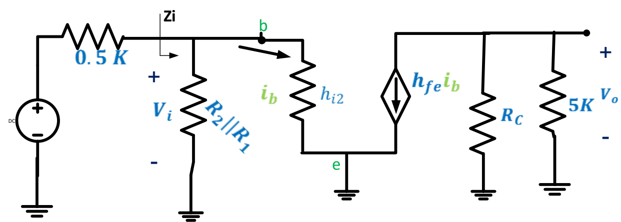
$$V_i = \frac{Z_i}{Z_i + R_s} V_s$$

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

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

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

Let $g_m = \frac{h_{fe}}{h_{ie}} = 38.92\, I_{CQ}$



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

Let $R_C = 8k$, then: $g_m \geq 72.2$

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

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

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

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

$$R_{th} = \frac{\beta(min) R_E}{20} = 72k\Omega$$

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

$$V_{th} = 7\ volt$$

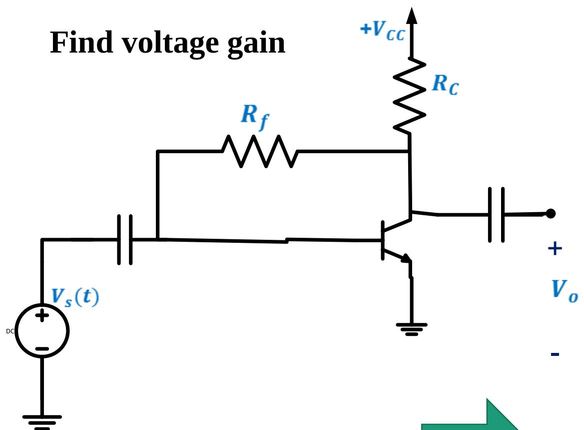
$$V_{th} = \frac{R_2}{R_1 + R_2} V_{CC}$$

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

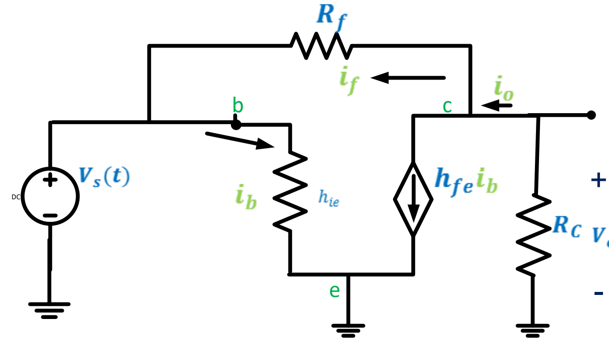
- $R_1 = 93.9k$
- $R_2 = 308.6k$

Example :

Find voltage gain



Ac small signal equivalent circuit:



$$V_o = -R_C i_o$$
$$i_o = h_{fe} i_b + i_f$$
$$i_f = \frac{V_o - V_s}{R_f}$$

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

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

Early voltage V_A

$$\frac{1}{h_{oe}} = \frac{V_{CEQ} + V_A}{I_{CQ}}$$

$$\frac{1}{h_{oe}} \cong \frac{V_A}{I_{CQ}}$$

$$V_A = 100, 150, 200$$

If V_A is given, we must include $\frac{1}{h_{oe}}$ in Ac small signal equivalent circuit: