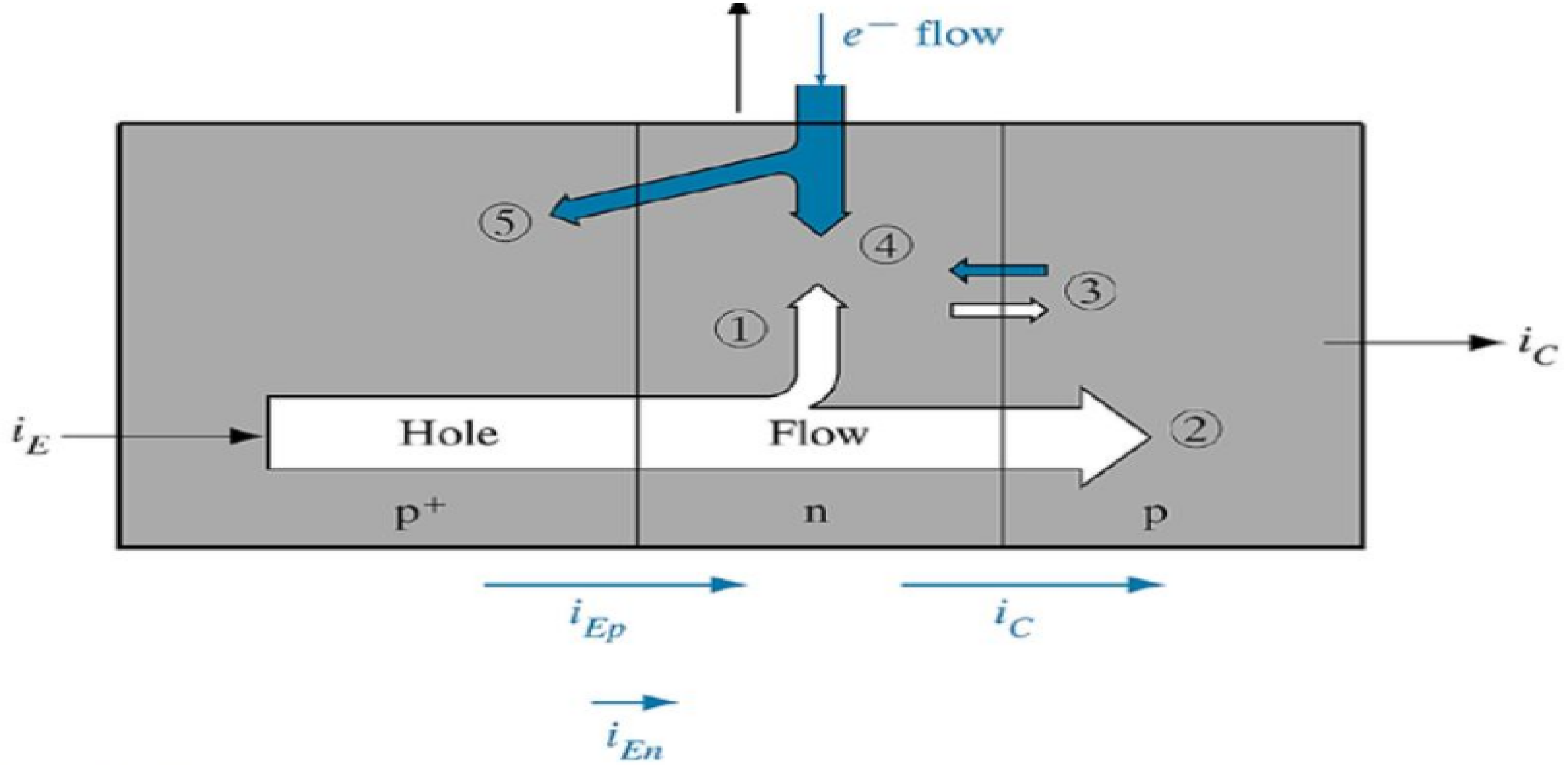
Transistor Configuration

Quote of the day

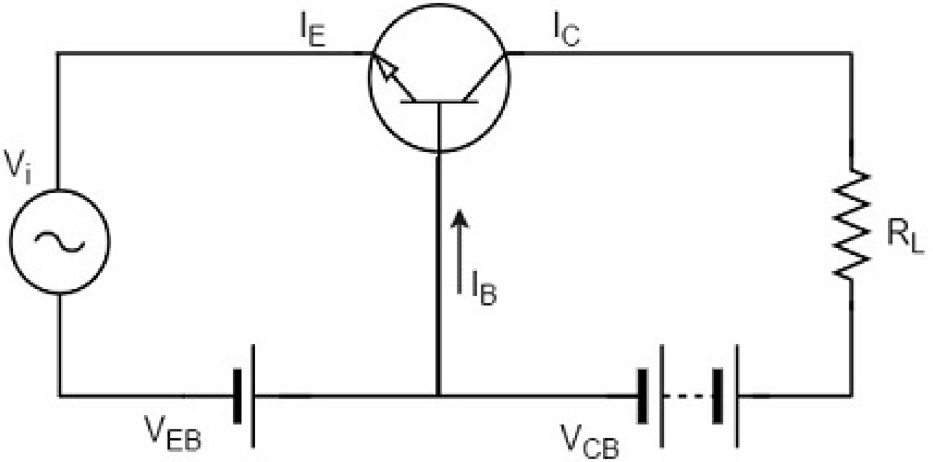
"Try not to become a man of success, but rather try to become a man of value."

— Albert Einstein



Summary of hole and electron flow in a p-n-p transistor with proper biasing: (1) injected holes lost to recombination in the base; (2) holes reaching the reverse-biased collector junction; (3) thermally generated electrons and holes making up the reverse saturation current of the collector junction; (4) electrons supplied by the base contact for recombination with holes; (5) electrons injected across the forward-biased emitter junction.

Transistor as an Amplifier



As the input circuit is forward biased, the input resistance will be low. The input resistance is the opposition offered by the base-emitter junction to the signal flow.

By definition, it is the ratio of small change in base-emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔIB) at constant collector-emitter voltage.

Input resistance, $R_i = \Delta V_{BE} / \Delta I_E$
Where R_i = input resistance, V_{BE} = base-emitter voltage, and I_E = Emitter current

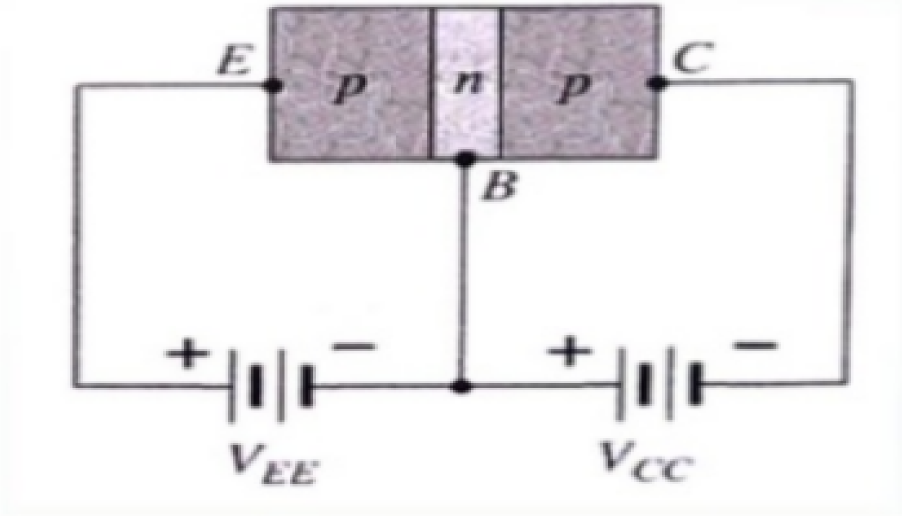
Output Resistance:
The output resistance of a transistor amplifier is very high. The collector current changes very slightly with the change in collector-emitter voltage.
By definition, it is the ratio of change in collector-base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) at constant base current.
Output resistance = $R_o = \Delta V_{CB} / \Delta I_C$
Where R_o = Output resistance, V_{CE} = Collector-emitter voltage, and I_C = Collector-emitter voltage.

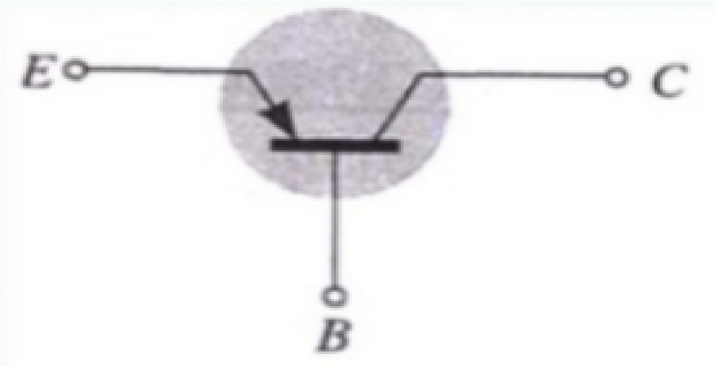
Voltage gain, $A_V = \Delta V_{CB} / \Delta V_{BE} = R_L / R_i$

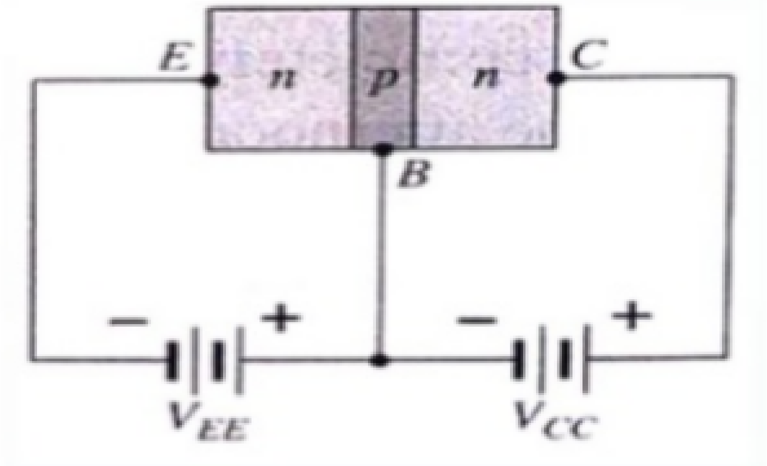
Configuration of Transistor

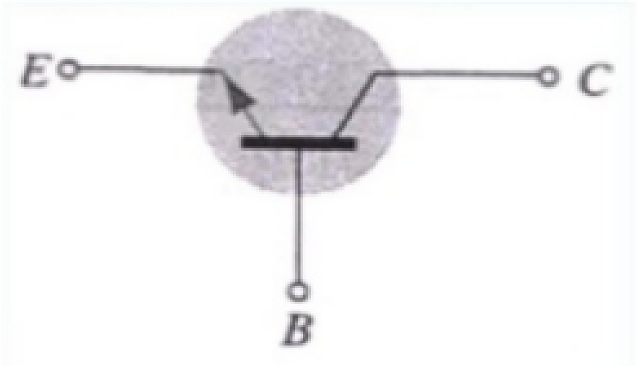
- Common Base (CB) Configuration
- Common Collector (CC) Configurationgain
- Common Emitter (CE) Configuration

Common-Base Configuration

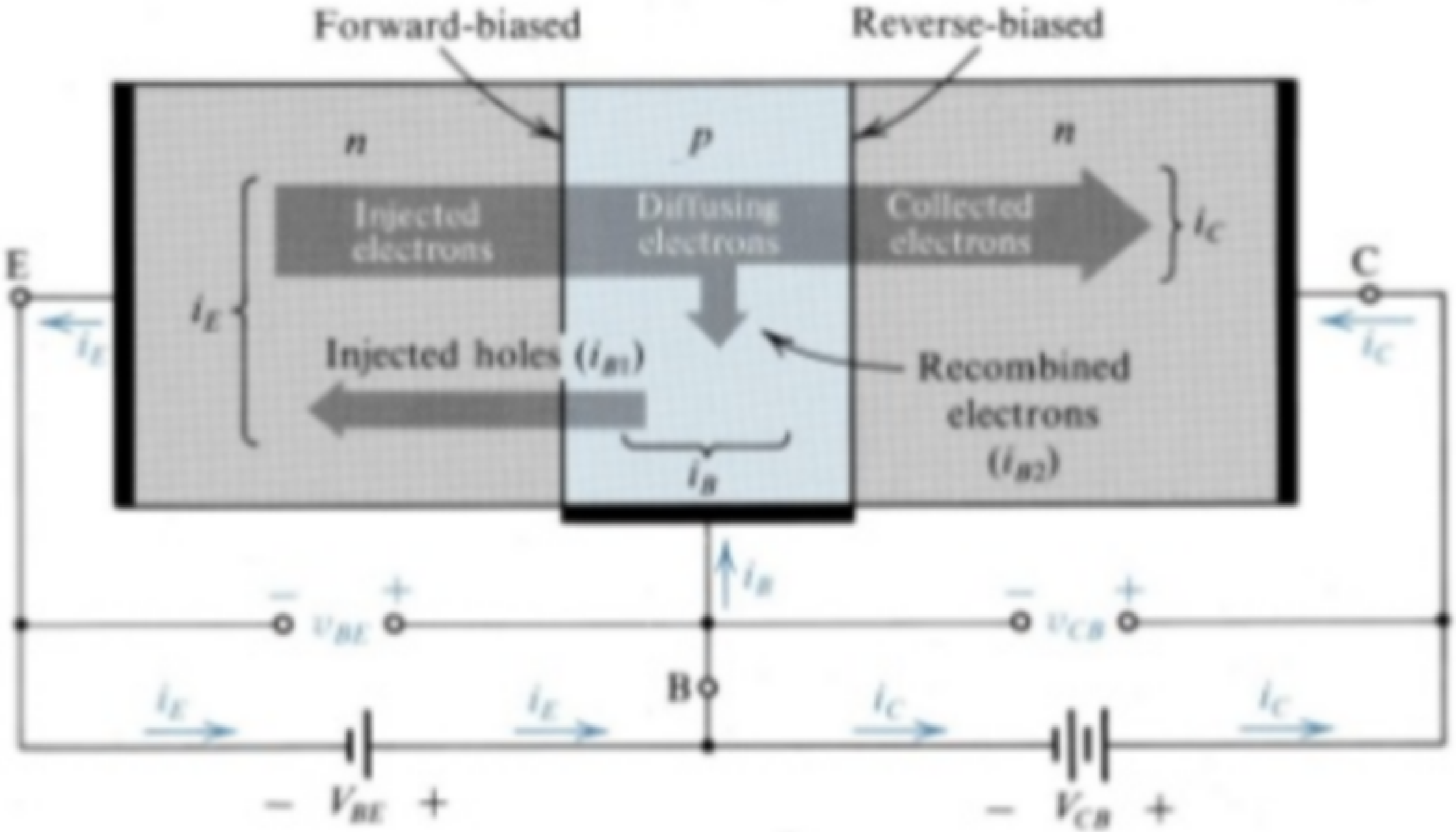








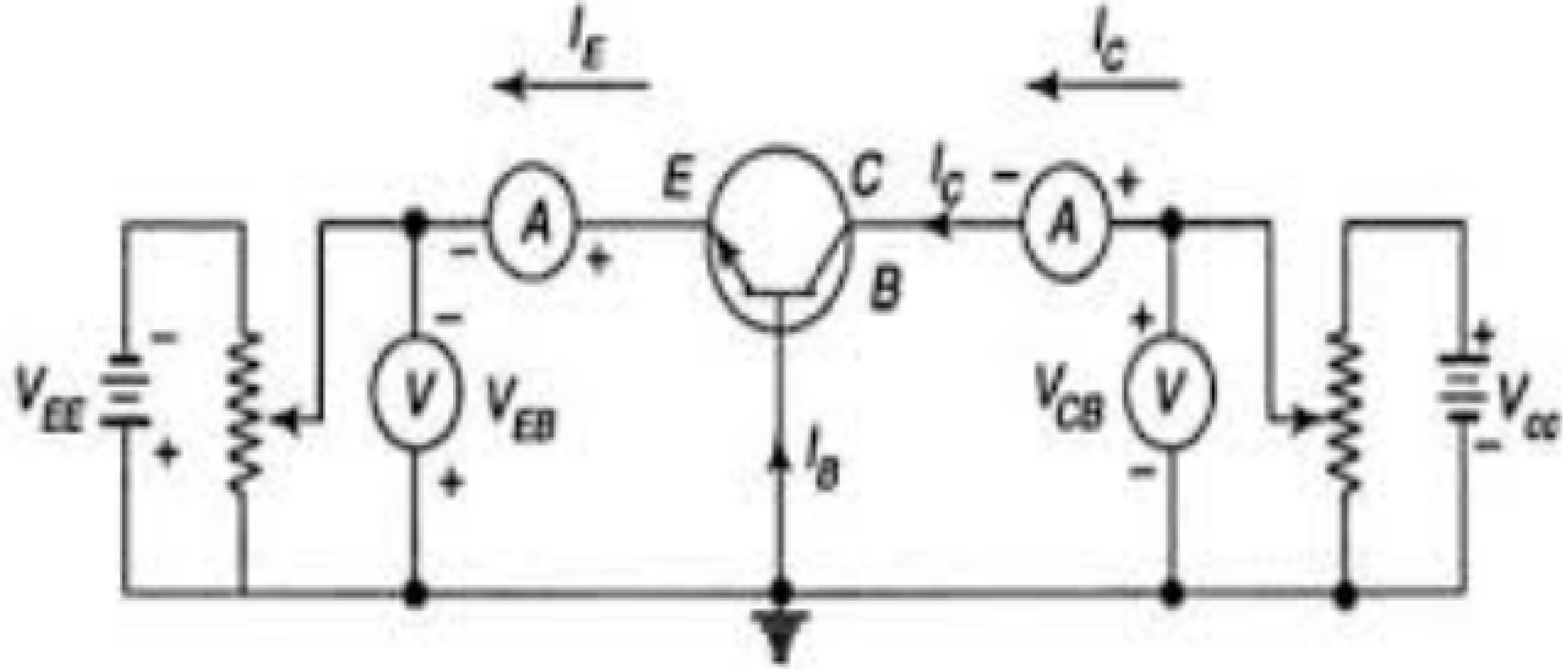
Common Base configuration



Common-Base Configuration

- The common-base configuration with *pnp* and *npn transistors are shown in the figures in the previous slide..*
- The term *common-base is derived from the* fact that the base is common to both the input and output sides of the configuration.
- The arrow in the symbol defines the direction of emitter current through the device.
- The applied biasing are such as to establish current in the direction indicated for each branch.
- That is, direction of I_E *is the same as the* polarity of V_{EE} *and* I_C *to* V_{CC}.
- Also, the equation $I_E = I_C + I_B$ *still holds.*

Common Base configuration



Circuit to determine CB static characteristics

Input characteristics

The *driving point or input parameters are* shown in the figure.

An input current (I_E) *is a function of an* input voltage (V_{BE}) *for various of output* voltage (V_{CB}).

This closely resembles the characteristics of a diode.

In the dc mode, the levels of I_C *and* I_E *at the* operation point are related by:

$$\alpha_{dc} = I_C / I_E$$

Normally, $\alpha \cong 1$.

For practical devices, α is typically from 0.9 to 0.998.

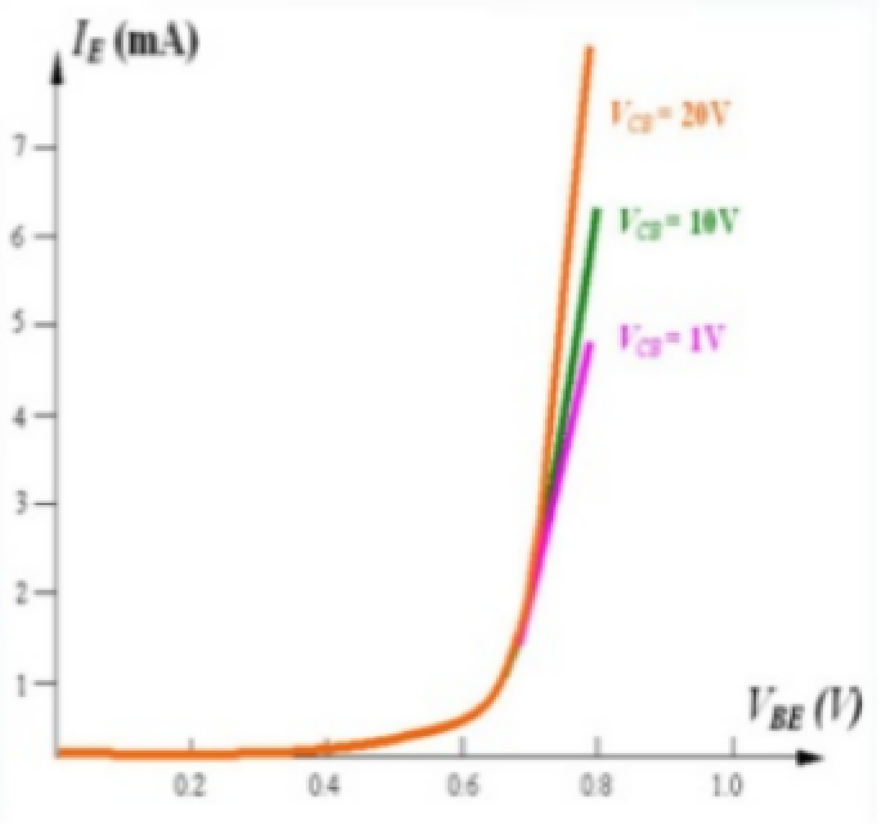
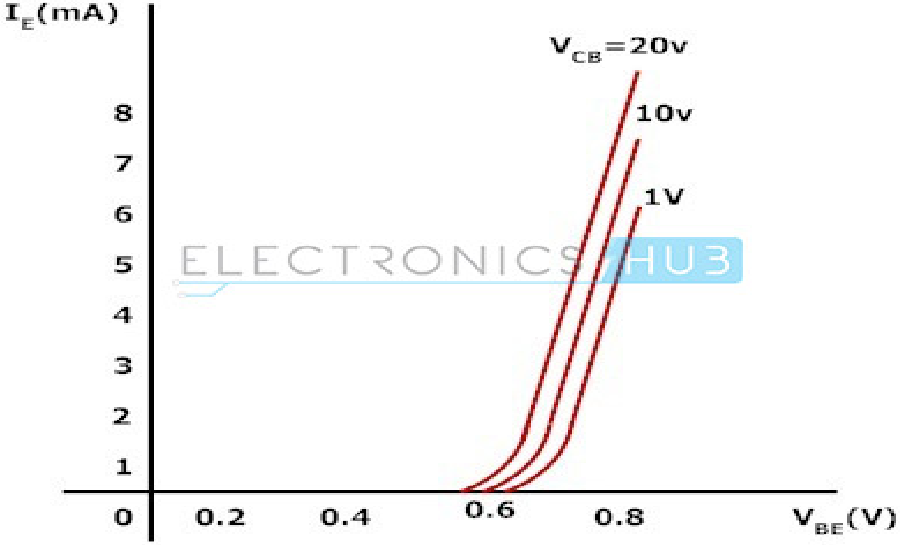
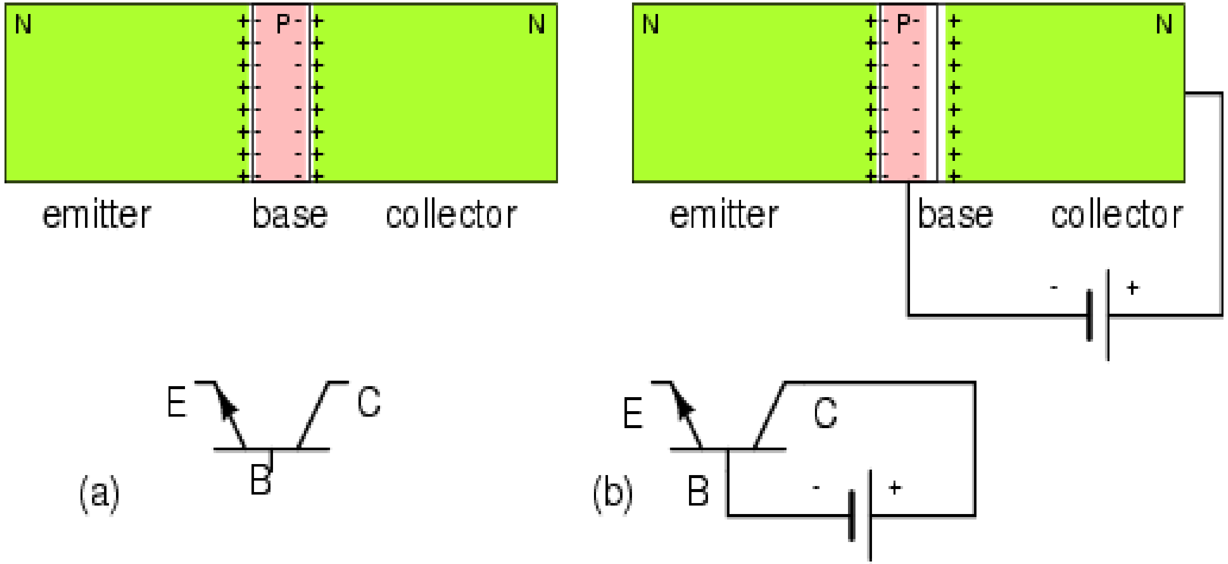


Figure: Input characteristics for common-base transistor

Input Characteristics

Early Effect or Base width Modultion: An increase in the magnitude of the collector-to-base voltage (V_{CB}) causes the emitter current to increase for a fixed V_{EB}. When $|V_{CB}|$ increases, the depletion region in the collector-base junction widens and reduces the base width. This is known as the Early effect or base width modulation





Common Base configuration

Input characteristics contd..

- As an approximation, the change due to changes in V_{CB} *can be ignored.*
- The characteristics can be shown in orange curve.
- If piecewise-linear approach is applied, the magenta green curve is obtain.
- Furthermore, ignoring the slop of the curve and the resistance results the magenta curve.
- It is this magenta curve that is used in the dc analysis of transistors.
- Once a transistor is in “on” state, the *B-E* voltage is assumed to be 0.7V.
- And the emitter current may be at any level as controlled by the external network.

Output characteristics

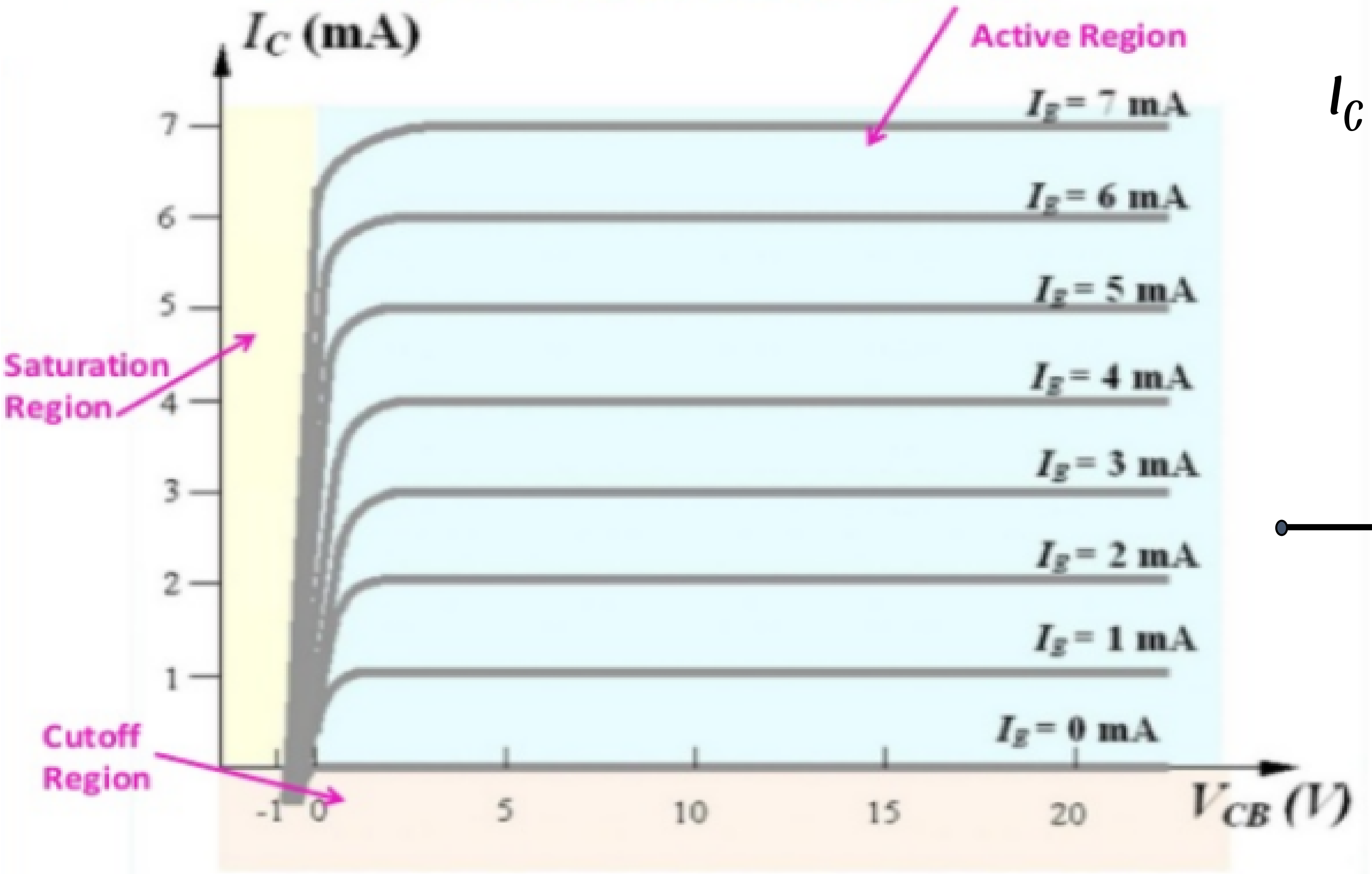
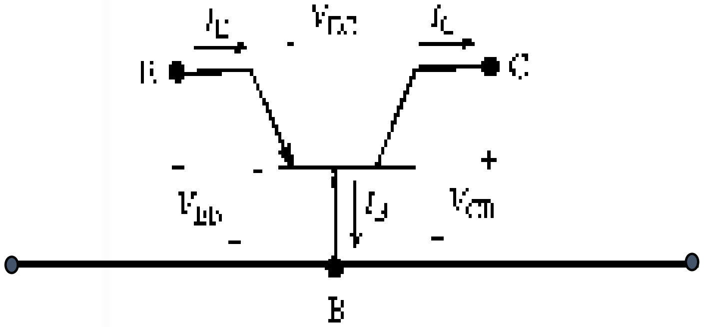


Figure: Output characteristics for common-base transistor

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



Output characteristics

The output set relates an output current (I_C) to an output voltage (V_{CB}) *for various of* level of input current (I_E).

There are three regions of interest:

Active region

- In the active region, the *b-e junction is* forward-biased, whereas the *c-b junction* is reverse-biased.
- The active region is the region normally employed for linear amplifier.

Also, in this region,

$$I_C \cong I_E$$

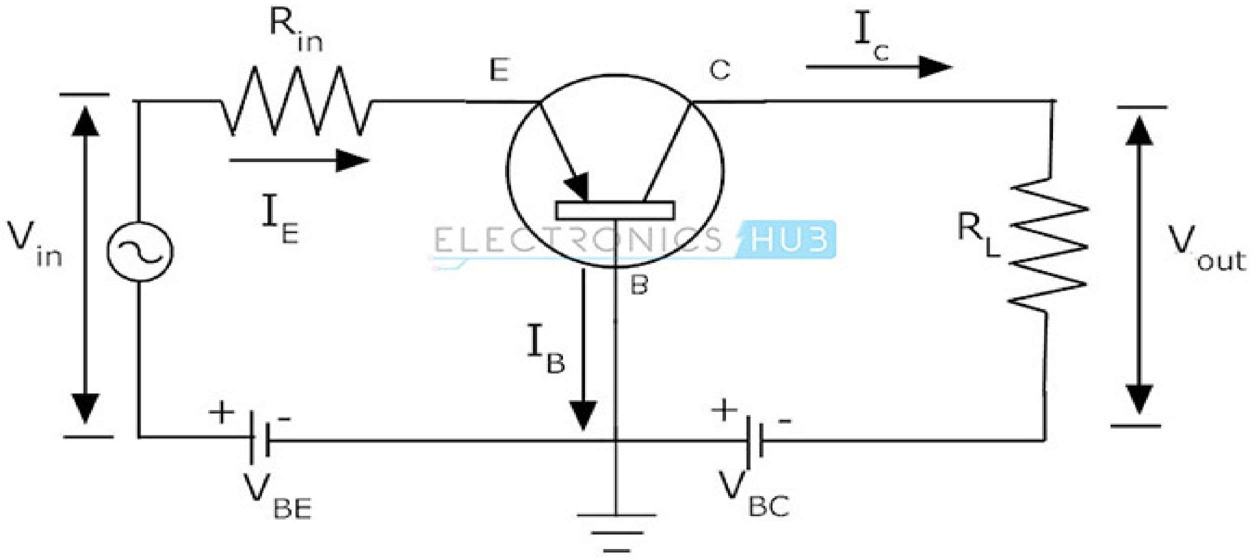
Cutoff region

- The cutoff region is defined as that region where the collector current is 0A.
- In the cutoff region, the *B-E and C-B junctions* of a transistor are both reverse-biased.

Saturation region:

- It is defined as that region of the characteristics to the left of $V_{CB} = 0\ V$.
- In saturation region, the *B-E and C-B* junctions of a transistor are both forward biased.

Voltage and Current Amplification



Voltage gain is given by

$A_V = V_{out}/V_{in} = (I_C*R_L) / (I_E*R_{in})$

Current gain in common base configuration is given as

α = Output current/Input current

$\alpha = I_C/I_E$

Input and Output Resistance of common base conf.

- <u>Input Resistance:</u> The ratio of change in emitter-base voltage to the change in emitter current is called Input Resistance.

$$r_i = \frac{\Delta V_{BE}}{\Delta I_E}$$

- <u>Output Resistance:</u> The ratio of change in collector-base voltage to the change in collector current is called Output Resistance.

$$r_0 = \frac{\Delta V_{BC}}{\Delta I_C}$$

common-emitter configurations

- Most common configuration of transistor is as shown
- *emitter* terminal is common to input and output circuits this is a **common-emitter** configuration
- we will look at the characteristics of the device in this configuration
- The current relations are still applicable, *i.e.*,
- $I_E = I_C + I_B$ *and* $I_C = \alpha I_E$

The common-emitter configuration with *npn* and *pnp transistors are shown in the figures.*

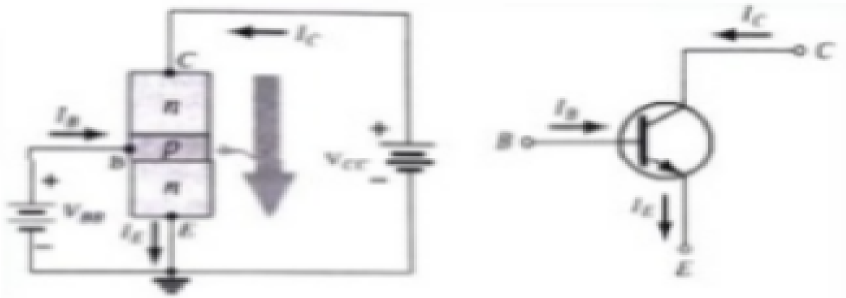


Figure: Common-emitter configuration of *npn transistor*

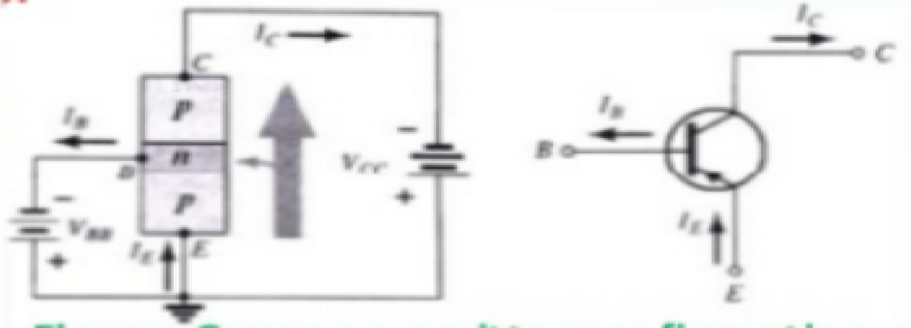
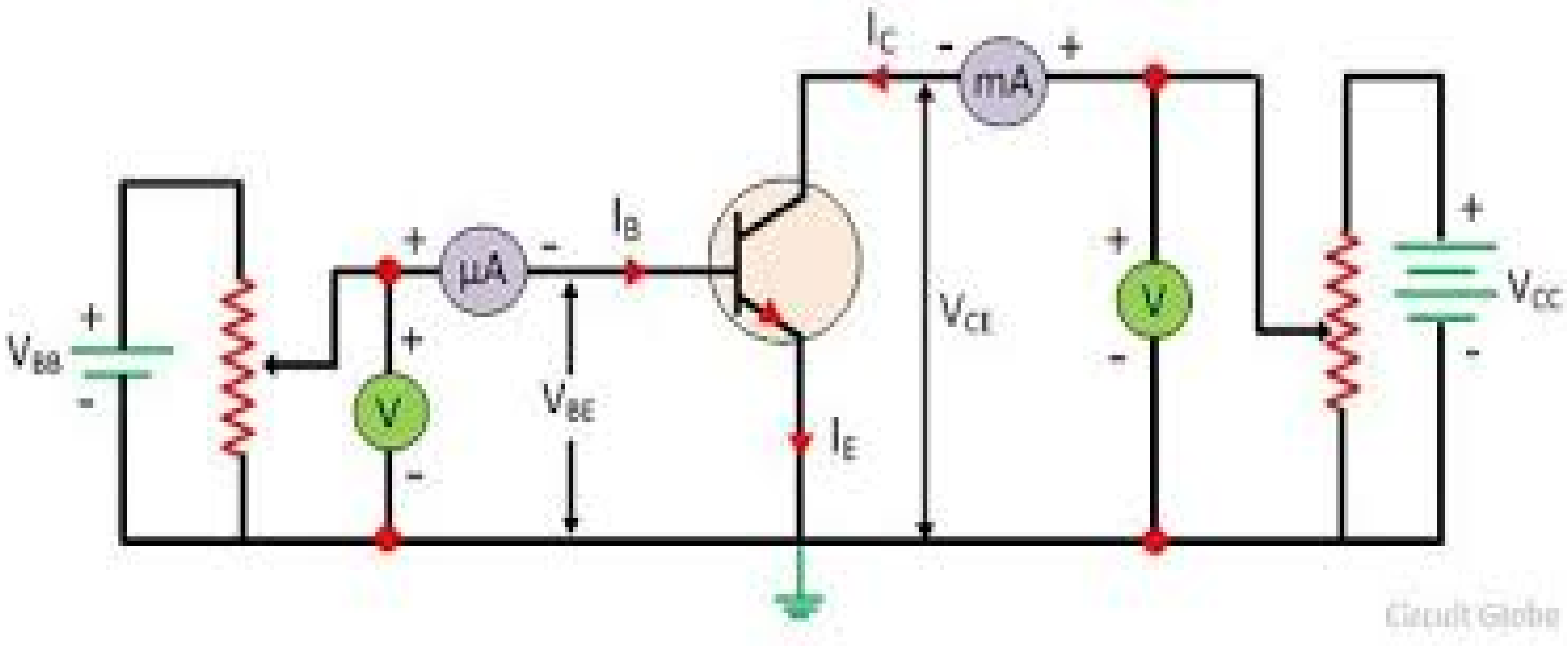


Figure: Common-emitter configuration of *pnp transistor*

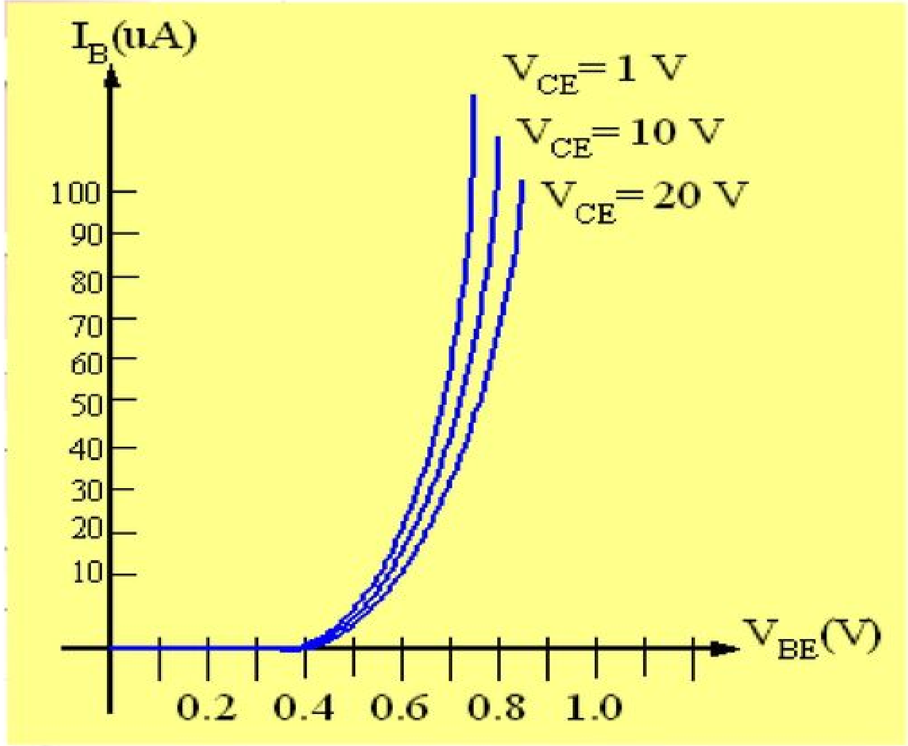
Circuit Diagram to Determine CE Characteristics



Input Characteristics

- The input characteristic is a curve plotted between I_B and $V_{BE.}$ At constant Collecror Emitter voltage $V_{CE.}$
- Keeping V_{CE} constant note down I_B for different $V_{BE.}$
- This will give input characteristic.

INPUT CHARACTERISTICS



Input characteristics for a common-emitter NPN transistor

- I_B is microamperes compared to miliamperes of I_C.
- I_B will flow when V_{BE} > 0.7V for silicon and 0.3V for germanium
- Before this value I_B is very small and no I_B.
- Base-emitter junction is forward bias
- Increasing V_{CE} will reduce I_B for different values.

Input Characteristics

- Observation:--As compared to CB configuration, I_B increases less rapidly with increase of V_{BE}. Therefore input resistance of a CE configuration is higher than that of CB configuration.
- **Input Resistance:-** It is the ratio of change in base emitter voltage(ΔV_{BE}) to the change in base current(ΔI_B) at constant V_{CE}

$$\boxed{r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}}$$

Expression for Collector Current

$$I_C = \alpha (I_C + I_B) + I_{CBO}$$
$$I_C (1-\alpha) = \alpha I_B + I_{CBO}$$
$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

$$I_E = \beta I_B + I_{CEO}$$

where $(1+\beta)I_{CBO} = I_{CEO}$

Current Gain (α): The current gain of the common Base transistor configuration is approximatly unity and it is the ratio of I_C/I_E. A transistors current gain is given the Greek symbol of Alpha (α).

Current Gain (β): The current gain of the common emitter transistor configuration is quite large as it is the ratio of Ic/Ib. A transistors current gain is given the Greek symbol of Beta, (β).

$$\text{Alpha}, (\alpha) = \frac{I_C}{I_E} \quad \text{and} \quad \text{Beta}, (\beta) = \frac{I_C}{I_B}$$

$$\therefore I_C = \alpha . I_E = \beta . I_B$$

$$\text{as:} \quad \alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{1-\alpha}$$

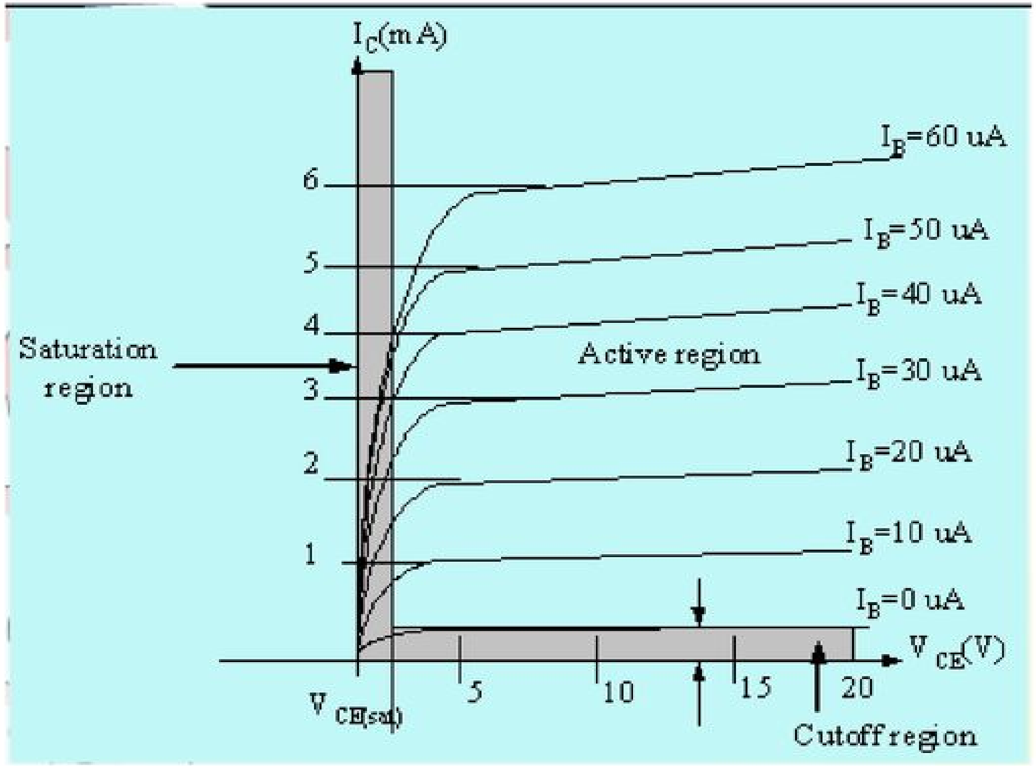
$\alpha = I_C / I_E$ and $\beta = I_C / I_B$

$\alpha = I_C / (I_B + I_C)$ or $1/\alpha = (I_B + I_C)/I_C$

$1/\alpha = 1 + 1/\beta$ or $\alpha = \beta/(1+\beta)$ and

$1/(1-\alpha) = (1+\beta)$

OUTPUT CHARACTERISTICS



- For small V_{CE} ($V_{CE} < V_{CESAT}$), I_C increase linearly with increasing of V_{CE}
- $V_{CE} > V_{CESAT}$ I_C not totally depends on V_{CE} → constant I_C
- I_B(uA) is very small compare to I_C (mA). Small increase in I_B cause big increase in I_C
- I_B=0 A → I_{CEO} occur.
- Noticing the value when I_C=0A. There is still some value of current flows.

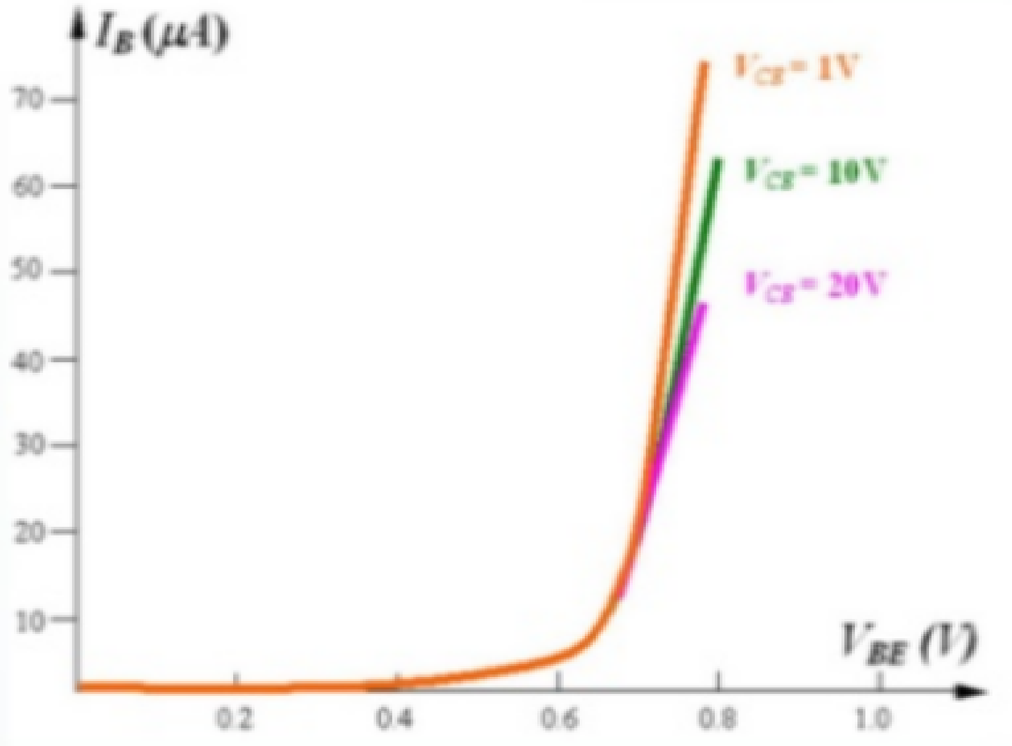
Output Characteristics

- **Observation:-**
- 1.The collector current I_C varies with V_{CE} between 0 and 1V only.After this collector current is almost constant,independent of V_{CE}.
- 2. For any value of V_{CE} above knee voltage, the collector current I_C is approximately equal to βI_B..
- 3. The transistor are operated in the region above knee voltage.
- **Output Resistance**:- It is the ratio of change in collector emitter voltage(ΔV_{CE}) to change in collector current(I_C) at constant I_B.

$$\boxed{r_o = \frac{\Delta V_{CE}}{\Delta I_C} \quad \text{at constant } I_B}$$

Input characteristics

- the input takes the form of a forward-biased *pn* junction
- the input characteristics are therefore similar to those of a semiconductor diode



An input current (I_B) *is a function of an* input voltage (V_{BE}) *for various of output* voltage (V_{CE}).

Expression for Collector Current

$$I_C = \alpha(I_C + I_B) + I_{CBO}$$
$$I_C(1-\alpha) = \alpha I_B + I_{CBO}$$
$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

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

Current Gain (α): the current gain of the common Base transistor configuration is approximatly unity and it is the ratio of I_C/I_E. A transistors current gain is given the Greek symbol of Alpha (α).

Current Gain (β): the current gain of the common emitter transistor configuration is quite large as it is the ratio of Ic/Ib. A transistors current gain is given the Greek symbol of Beta, (β).

$$\text{Alpha}, (\alpha) = \frac{I_C}{I_E} \quad \text{and} \quad \text{Beta}, (\beta) = \frac{I_C}{I_B}$$

$$\therefore I_C = \alpha.I_E = \beta.I_B$$

$$\text{as:} \quad \alpha = \frac{\beta}{\beta+1} \qquad \beta = \frac{\alpha}{1-\alpha}$$

Expression for Collector Current

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

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

$$I_E (1 - \alpha) = I_B + I_{CBO}$$

$$I_E = \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$$

$$I_C \; ; \; I_E = *(\beta + 1) I_B + (\beta + 1) I_{CBO}$$

Output characteristics

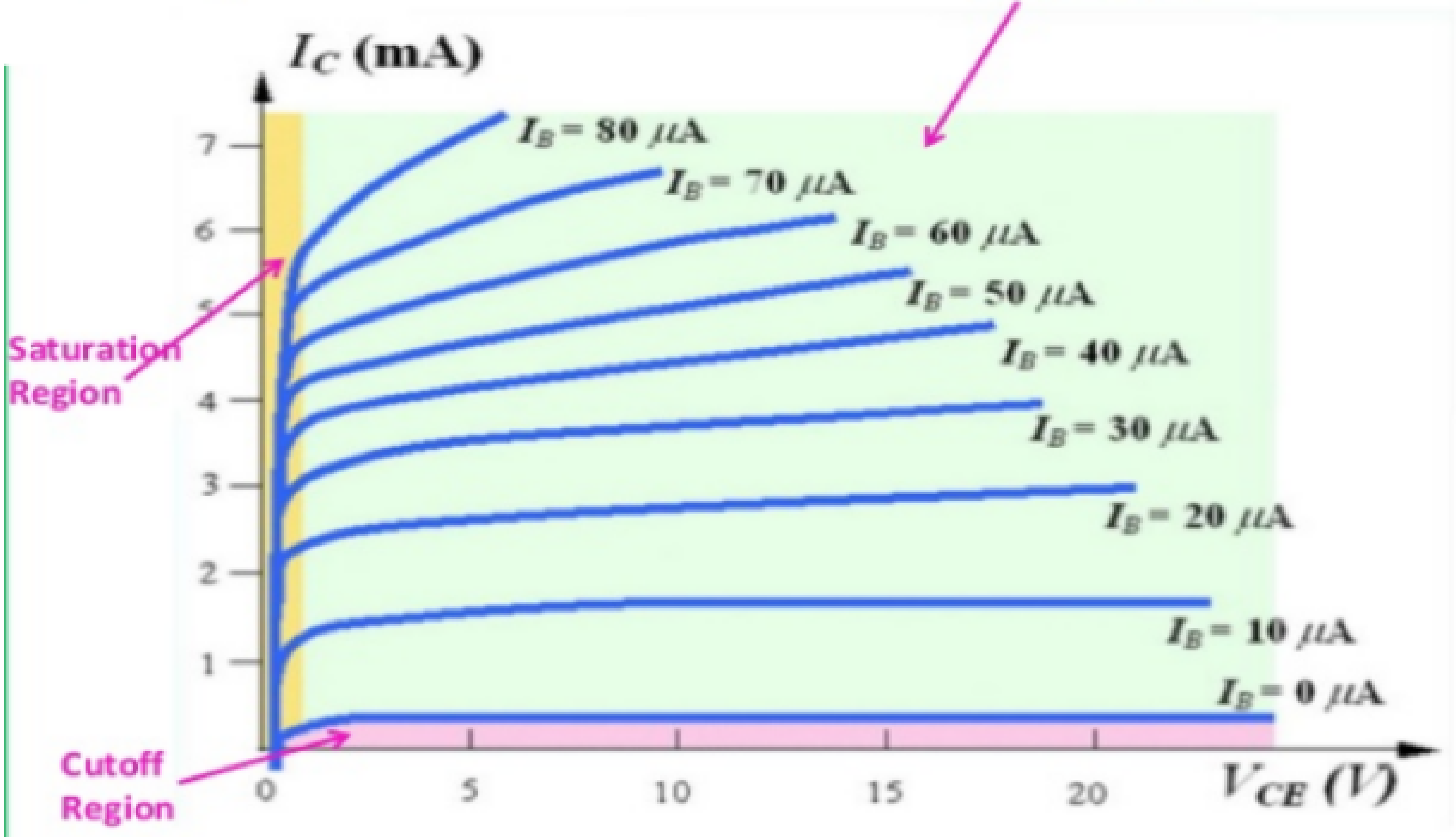


Figure: Output characteristics for common-emitter transistor

Input and Output Resistance of common emitter conf.

- Input Resistance: The ratio of change in emitter-base voltage to the change in base current is called Input Resistance.

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B}$$

- Output Resistance: The ratio of change in collector-emitter voltage to the change in collector current is called Output Resistance.

$$r_0 = \frac{\Delta V_{CE}}{\Delta I_C}$$

Output characteristics

- The magnitude of I_B *is in μA and not as* horizontal as I_E *in common-base circuit*.
- The output set relates an output current (*Ic)* to an output voltage (*VCE) for various of* level of input current (*IB*).

- **There are three portions as shown:**

Active region

- The active region, located at upper-right quadrant, has the greatest linearity.
- The curve for *IB are nearly straight and* equally spaced.
- In active region, the *B-E junction is* forward-biased, whereas the *C-B junction* is reverse-biased.
- The active region can be employed for voltage, current or power amplification.

Cutoff region

- The region below $I_B = 0\mu A$ *is defined as* cutoff region.
- For linear amplification, cutoff region should be avoided.

Saturation region:

- The small portion near the ordinate, is the saturation region, which should be avoided for linear application.
- In the dc mode, the levels of *IC and IB at the* operation point are related by: Normally, β *ranges from 50 to 400.*

$$\beta_{dc} = I_C / I_B$$

For ac situations, β *is defined as*

$$\boxed{\beta_{ac} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=constant}}$$

Common-Collector Configuration

- The common-collector configuration with *npn and pnp transistors are shown in the* figures.

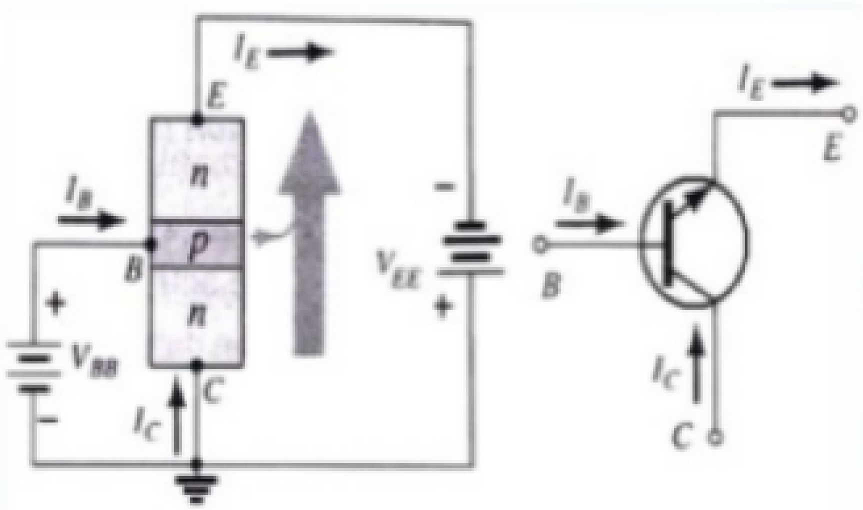


Figure: Common-collector configuration of *npn transistor*

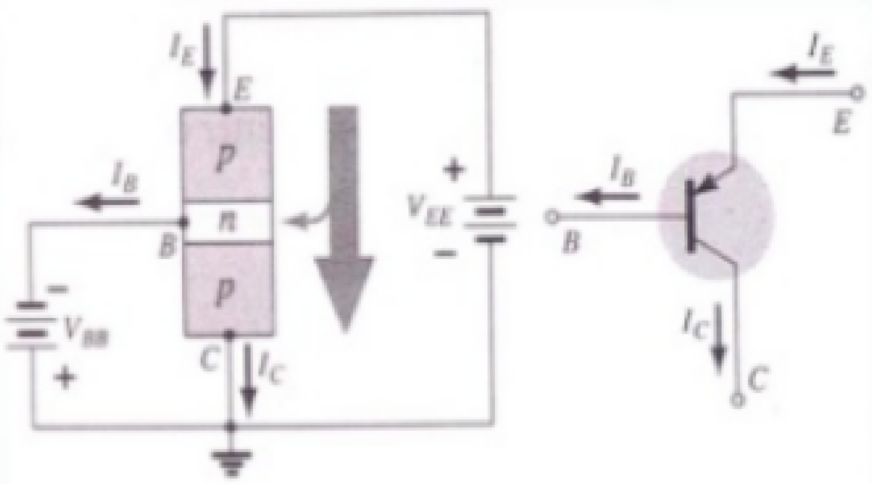


Figure: Common- collector configuration of *pnp transistor*

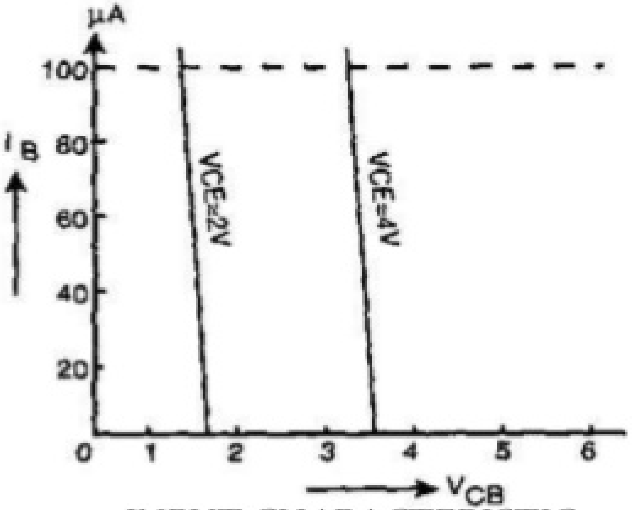
Common-Collector Configuration

- It is used primarily for impedance-matching purpose since it has a high input impedance and low output impedance.
- The load resistor can be connected from emitter to ground.
- The collector is tied to ground and the circuit resembles common-emitter circuit.
- The output set relates an output current (I_E) to an output voltage (V_{CE}) *for various of* level of input current (I_B).

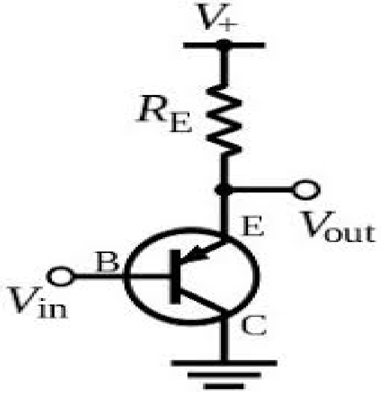
WORKING :INPUT CHARACTERISTICS

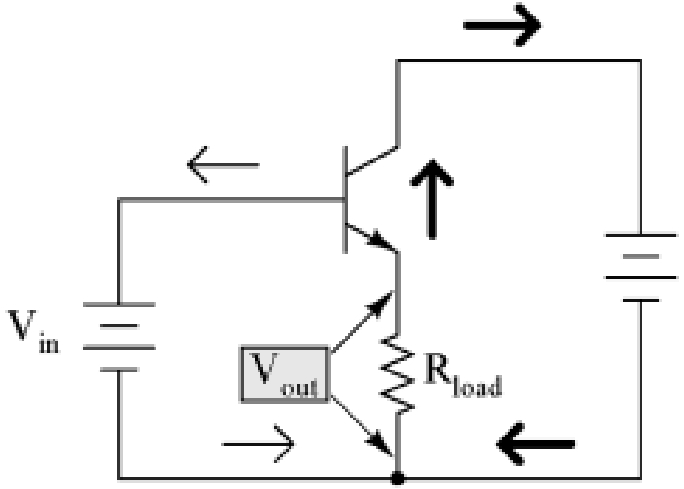
- The CC input characteristics are quite different from CB & CE characteristics.
- This is because input voltage V_{BC} is largely determined by output voltage V_{EC}
- $V_{EB} = V_{EC} - V_{BC}$

  As V_{BC} increases with V_{EC} constant V_{EB} decreases hence I_B decreases



INPUT CHARACTERISTIC





$V_{in} = V_{BE} + V_{EC}$ or $V_{BC} = V_{BE} + V_{EC}$

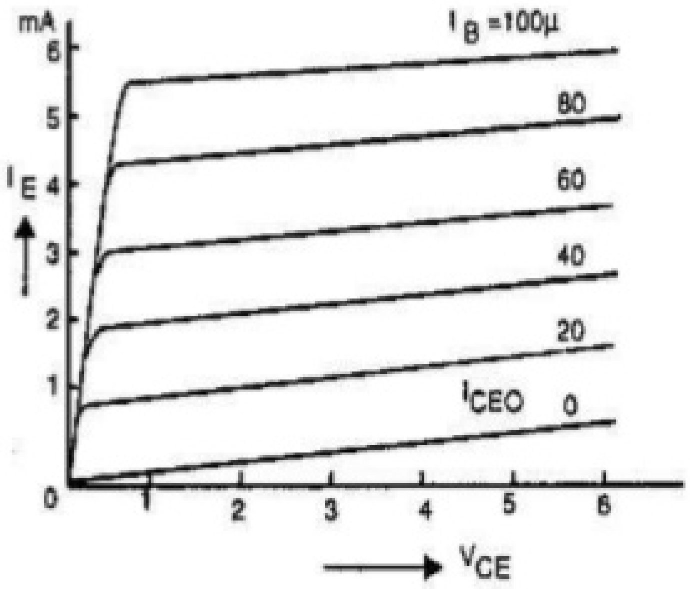
$V_{BC} - V_{EC} = V_{BE}$

$-V_{BE} = -V_{BC} + V_{EC}$

$V_{EB} = V_{CE} - V_{CB}$

OUTPUT CHARACTERISTICS

- Here V_{CE} increases I_E also increases.
- Just as in common emitter output characteristics I_C increases with increasing I_B ,so I_E also increases here with increasing I_B
- Hence for constant V_{EC}, I_E increases with I_B



APPLICATION

- It is useful as an impedance matching device since its input impedance is much higher than its output impedance. It is also termed a “buffer" for this reason and is used in digital circuits with basic gates.
- When the voltage divider used but it is a poor voltage source because it is so strongly affected by the value of the load resistor. The same voltage divider with the transistor buffer will supply power to keep the voltage constant over its range of operation.
- It is also used for cascade amplifier.

Modes of Operation

Modes	EBJ	CBJ	Application
Cutoff	Reverse	Reverse	Switching application in digital circuits
Saturation	Forward	Forward	
Active	Forward	Reverse	Amplifier

Expression for Collector Current

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

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

$$I_E(1-\alpha) = I_B + I_{CBO}$$

$$I_E = \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$$

$$I_C \; ; \; I_E = {}^{*}(\beta + 1) I_B + (\beta + 1) I_{CBO}$$

$$\beta = \frac{\alpha}{1-\alpha} \quad \therefore \quad \beta + 1 = \frac{\alpha}{1-\alpha} + 1 = \frac{1}{1-\alpha}$$

Comparison of Transistor Configurations

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

Q1. Which type of amplifiers exhibits the current gain approximately equal to unity ----------------

- a) CE
- b) CB
- c) CC
- d) Cascade

Q2. The configuration in which voltage gain of transistor amplifier is lowest is ____________

- a) common collector
- b) common emitter
- c) common base
- d) common emitter & base

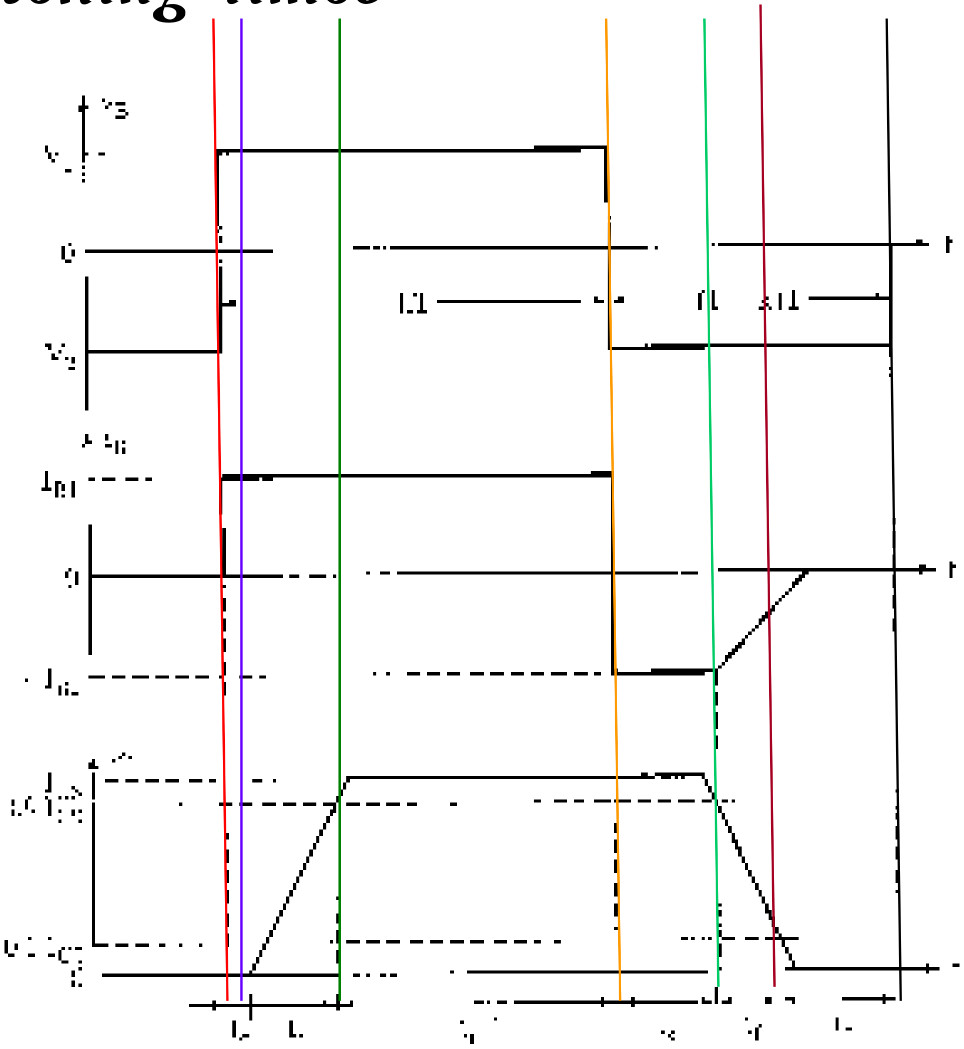
Q3. The configuration in which input impedance of transistor amplifier is lowest is ____________

- a) common collector
- b) common emitter
- c) common base
- d) common emitter & base

Q4. The configuration in which output impedance of transistor amplifier is highest is ____________

- a) common collector
- b) common base
- c) common emitter
- d) common collector and base

Transistor Switching Times



Switching Times – turn on

- Input voltage rises from 0 to V_1
- Base current rises to I_{B1}
- Collector current begins to rise after the delay time, t_d
- Collector current rises to steady-state value I_{CS}
- This "rise time", t_r allows the Miller capacitance to charge to V_1
- turn on time, $t_{on} = t_d + t_r$

Switching Times – turn off

- Input voltage changes from V_1 to $-V_2$
- Base current changes to $-I_{B2}$
- Base current remains at $-I_{B2}$ until the Miller capacitance discharges to zero, storage time, t_s
- Base current falls to zero as Miller capacitance charges to $-V_2$, fall time, t_f
- turn off time, $t_{off} = t_s + t_f$

Thank You

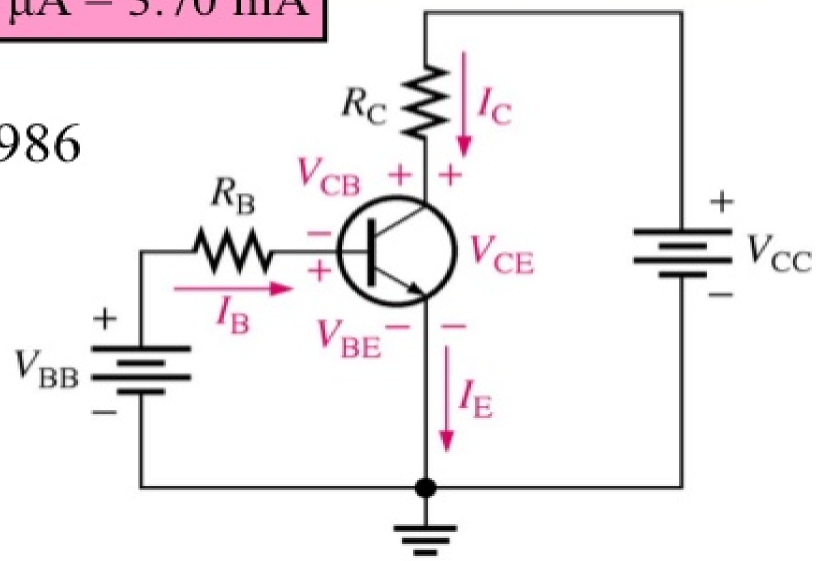
Transistor Biasing

Ex 4-1 Determine β_{DC} and I_E for a transistor where $I_B = 50\ \mu A$ and $I_C = 3.65\ mA$.

$$\beta_{DC} = \frac{I_C}{I_B} = \frac{3.65mA}{50\mu A} = 73$$

$$I_E = I_C + I_B = 3.65\ mA + 50\ \mu A = 3.70\ mA$$

$$\alpha_{DC} = \frac{I_C}{I_E} = \frac{3.65mA}{3.70mA} = 0.986$$



BJT Circuit Analysis

There are three key dc voltages and three key dc currents to be considered. Note that these measurements are important for troubleshooting.

I_B: dc base current

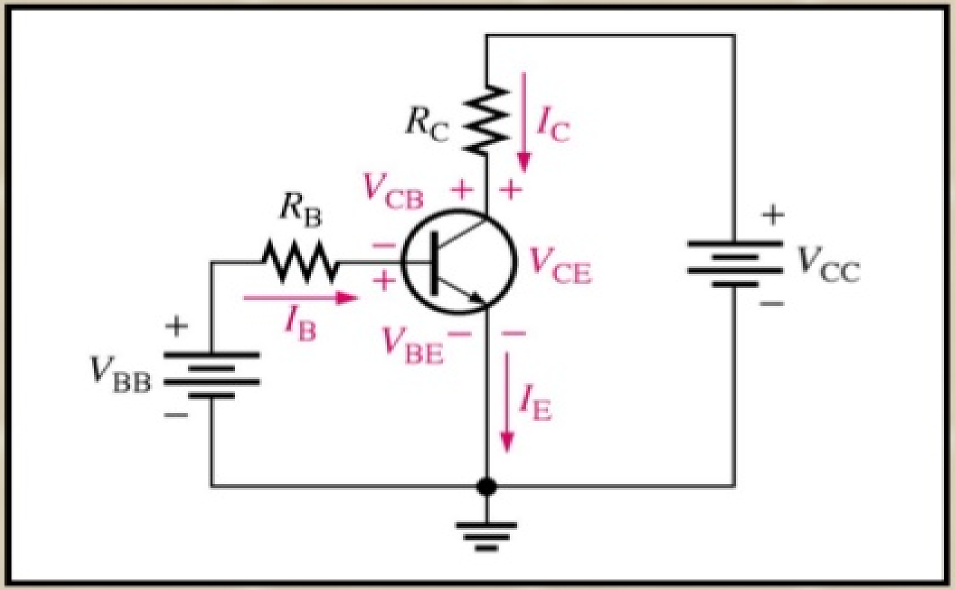
I_E: dc emitter current

I_C: dc collector current

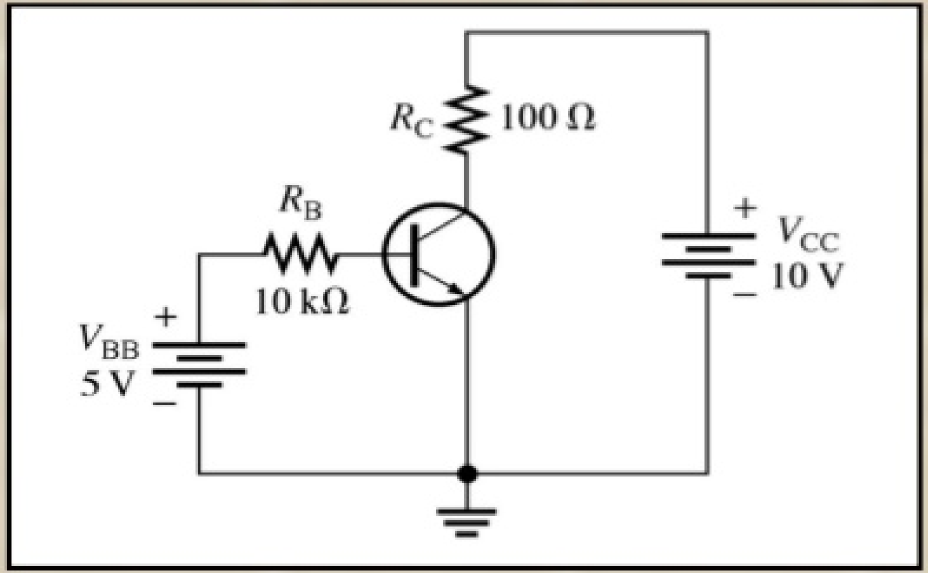
V_{BE}: dc voltage across base-emitter junction

V_{CB}: dc voltage across collector-base junction

V_{CE}: dc voltage from collector to emitter



Ex 4-2 Determine I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB} in the circuit of Figure. The transistor has a $\beta_{DC} = 150$.



Ex 4-2 Determine I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB} in the circuit of Figure. The transistor has a $\beta_{DC} = 150$.

When the base-emitter junction is forward-biased,

$$V_{BE} \cong 0.7\ V$$

$$I_B = (V_{BB} - V_{BE}) / R_B$$

$$= (5\ V - 0.7\ V) / 10\ k\Omega = 430\ \mu A$$

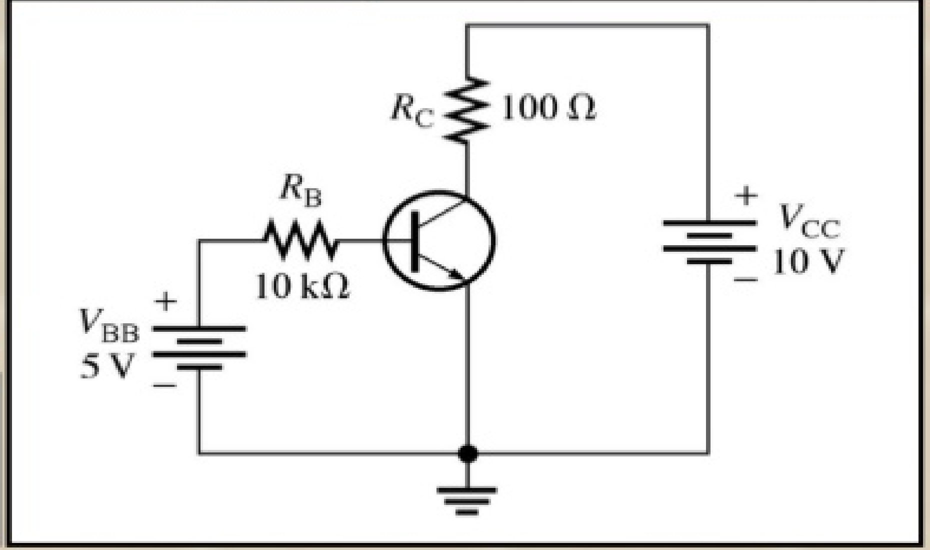
$$I_C = \beta_{DC} I_B$$
$$= (150)(430\ \mu A)$$
$$= 64.5\ mA$$

$$I_E = I_C + I_B$$
$$= 64.5\ mA + 430\ \mu A$$
$$= 64.9\ mA$$

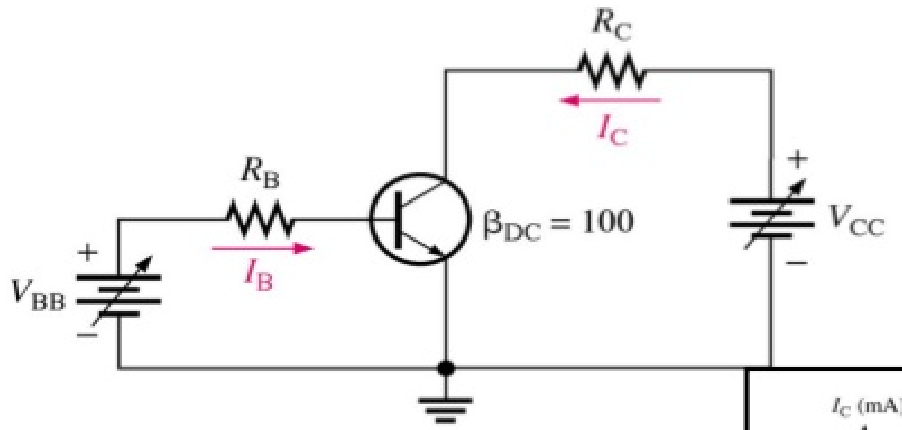
$$V_{CE} = V_{CC} - I_C R_C$$
$$= 10\ V - (64.5\ mA)(100\ \Omega)$$
$$= 3.55\ V$$

$$V_{CB} = V_{CE} - V_{BE}$$
$$= 3.55\ V - 0.7\ V$$
$$= 2.85\ V$$

Since the collector is at a higher voltage than the base, the collector-base junction is reverse-biased.

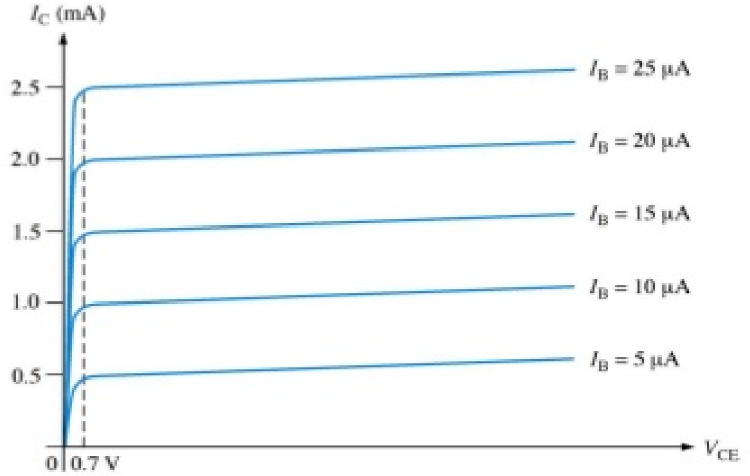


Sketch an ideal family of collector curves for the circuit in Figure for $I_B = 5\ \mu A$ to $25\ \mu A$ in $5\ \mu A$ increment. Assume $\beta_{DC} = 100$ and that V_{CE} does not exceed breakdown.



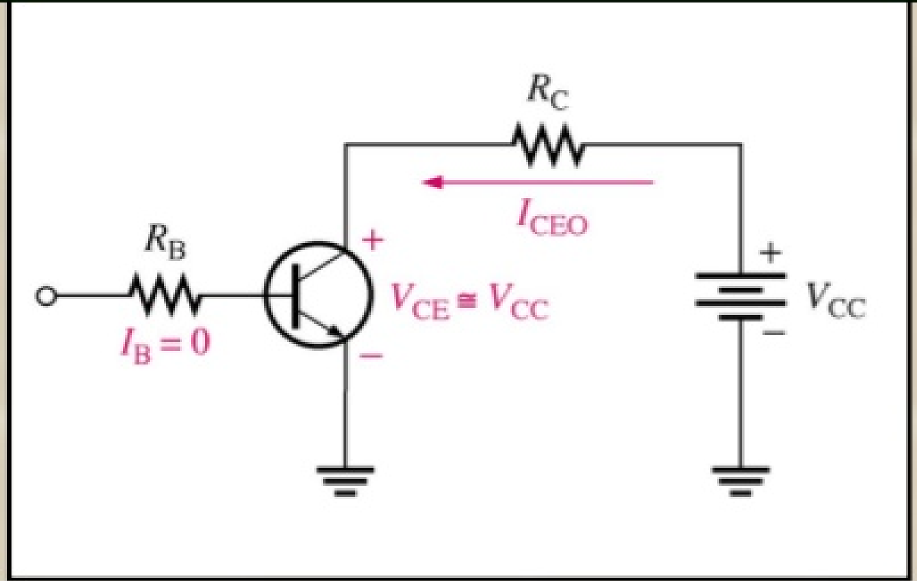
$$I_C = \beta_{DC} I_B$$

I_B	I_C
5 µA	0.5 mA
10 µA	1.0 mA
15 µA	1.5 mA
20 µA	2.0 mA
25 µA	2.5 mA



Cutoff

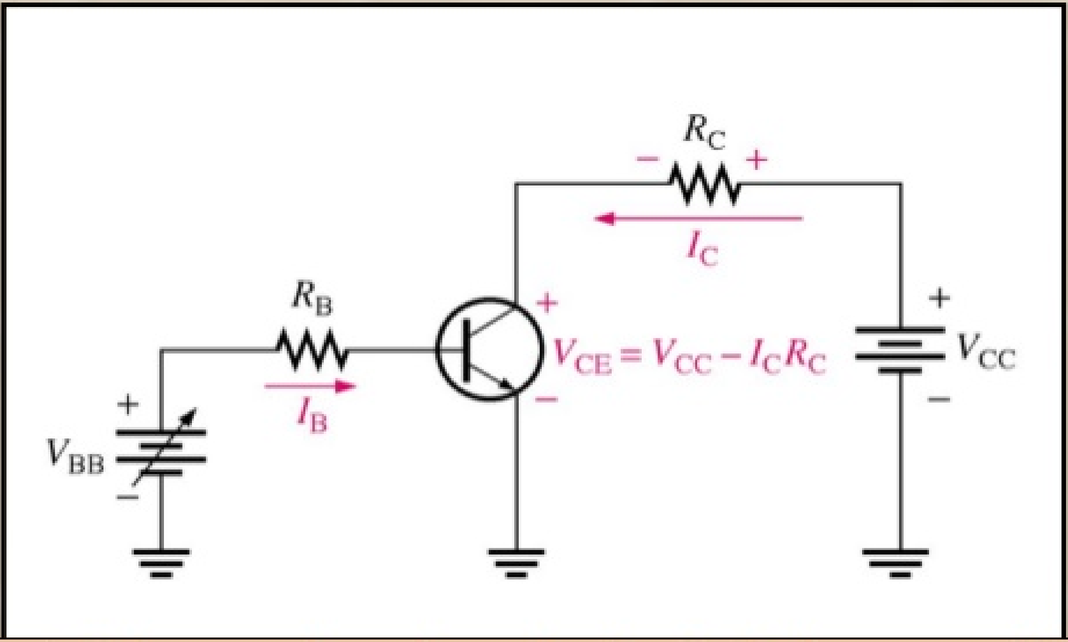
With no I_B, the transistor is in the **cutoff** region and just as the name implies there is **practically no current flow in the collector** part of the circuit. With the transistor in a cutoff state, the **full V_{CC} can be measured across the collector and emitter(V_{CE}).**



Cutoff: Collector leakage current (I_{CEO}) is extremely small and is usually neglected. Base-emitter and base-collector junctions are **reverse-biased.**

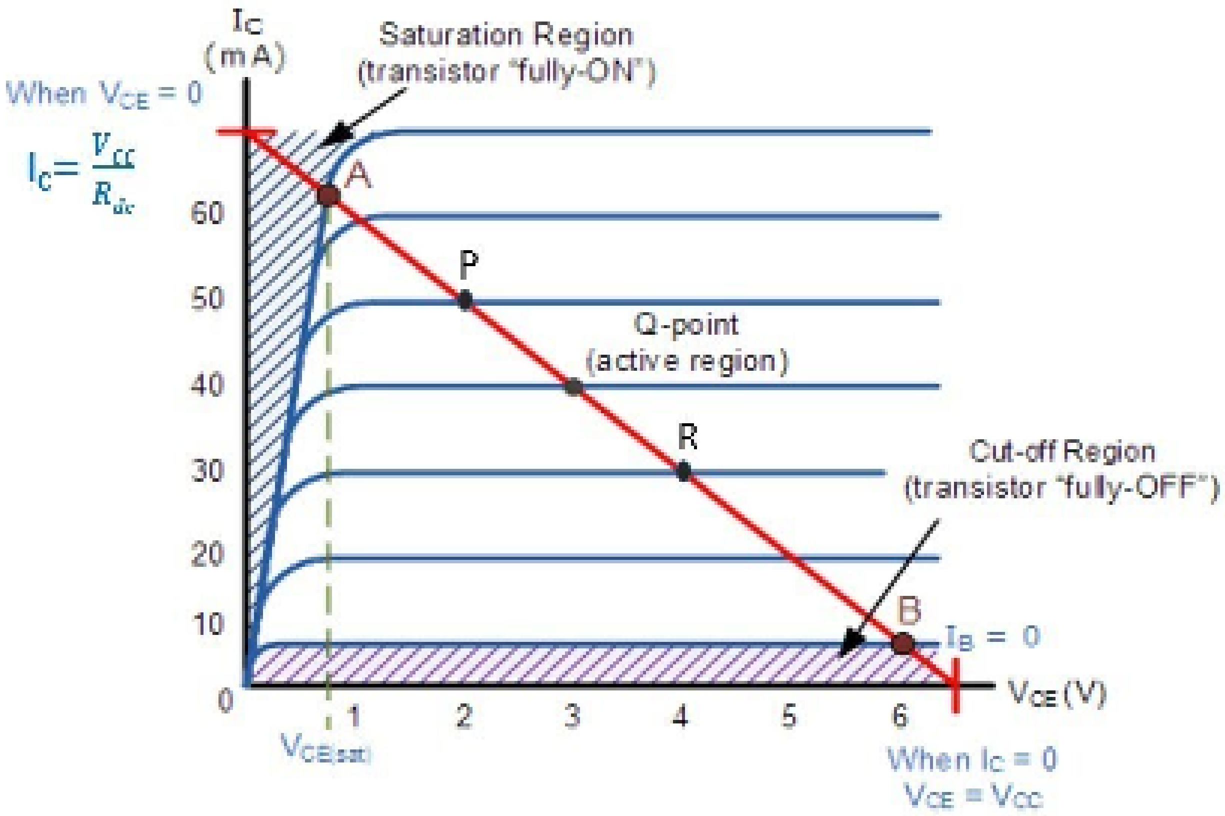
Saturation

Once V_{CE} reaches its maximum value, the transistor is said to be in **saturation**.



Saturation: As I_B increases due to increasing V_{BB}, I_C also increases and V_{CE} decreases due to the increased voltage drop across R_C. When the transistor reaches saturation, I_C can increase no further regardless of further increase in I_B. Base-emitter and base-collector junctions are **forward-biased**.

DC LOAD LINE AND OPERATING POINT



Typical junction voltages

Transistor	Vce sat	Vbe sat	Vbe active	Vbe cut-in	Vbe cut-off
Si	0.2 V	0.8 V	0.7 V	0.5 V	0 V
Ge	0.1 V	0.3 V	0.2 V	0.1 V	-0.1 V

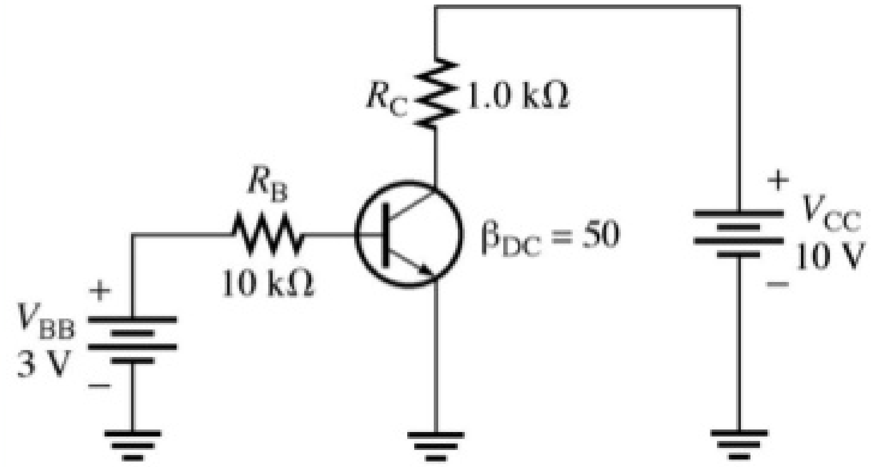
- In the saturation region $I_c > \beta I_b$
- For active region $V_{ce} > V_{ce(sat)}$

Ex 4-4 Determine whether or not the transistors in Figure is in saturation. Assume $V_{CE(sat)} = 0.2$ V.

First, determine $I_{C(sat)}$

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C}$$

$$= \frac{10V - 0.2V}{1.0k\Omega} = 9.8\ mA$$



Now, see if I_B is large enough to produce $I_{C(sat)}$.

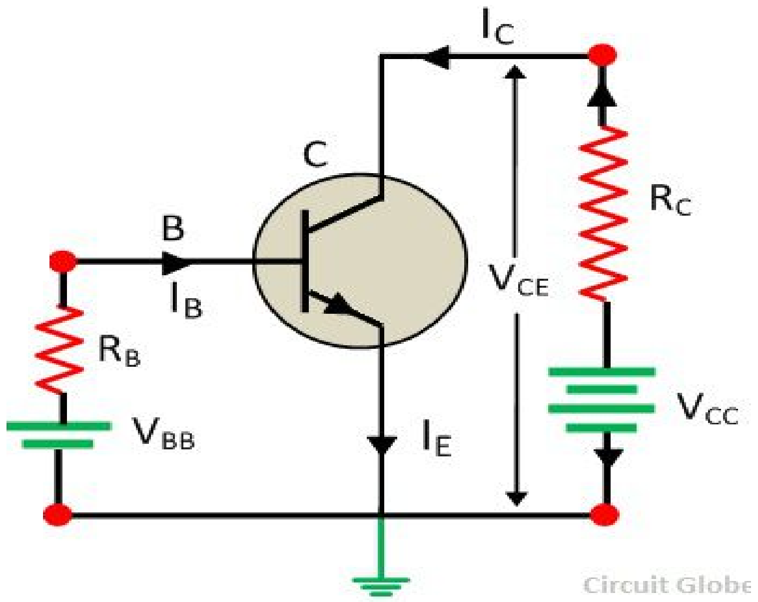
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{3V - 0.7V}{10k\Omega} = \frac{2.3V}{10\ k\Omega} = 0.23\ mA$$

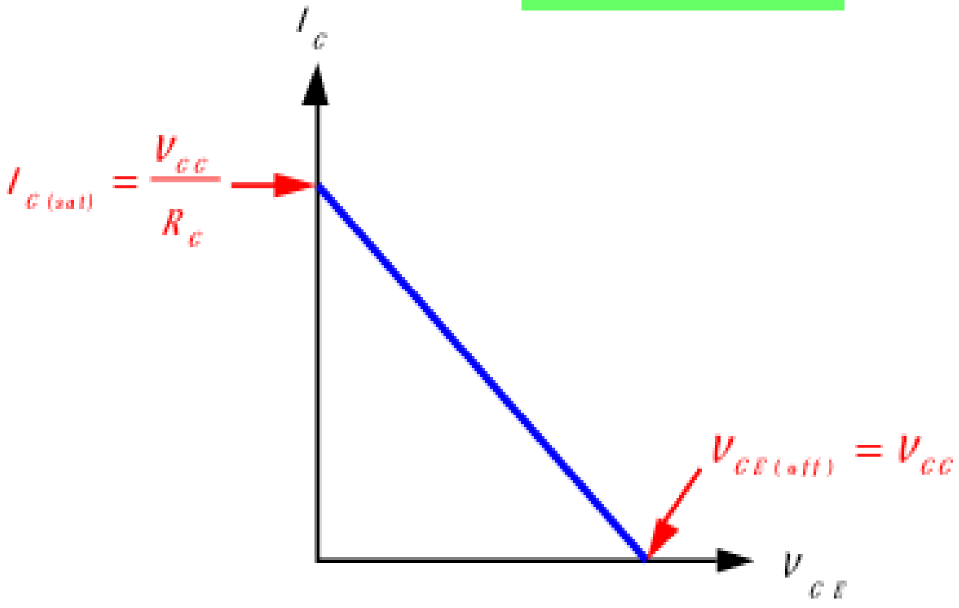
$$I_C = \beta_{DC} I_B = (50)(0.23\,mA) = 11.5\ mA$$

Thus, I_C greater than $I_{C(sat)}$. Therefore, the transistor is saturated.

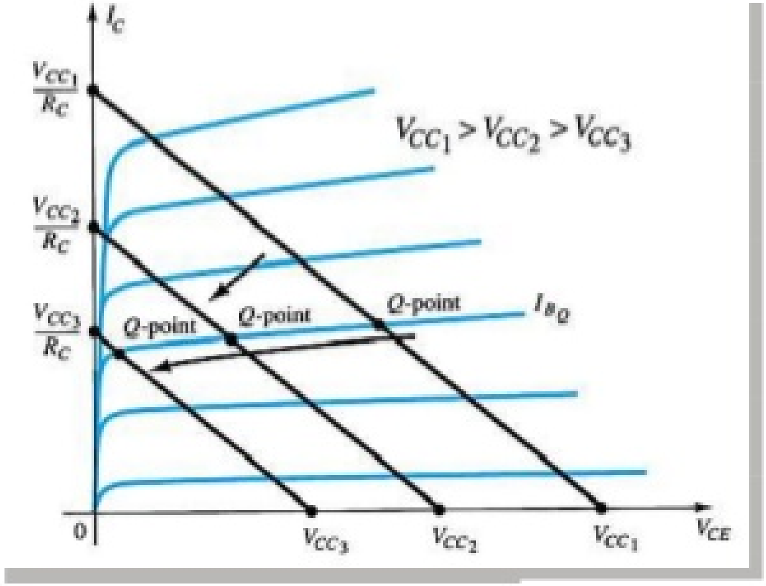
DC Load Line

$$I_C = \frac{V_{CC} - V_{CE}}{R_C}$$

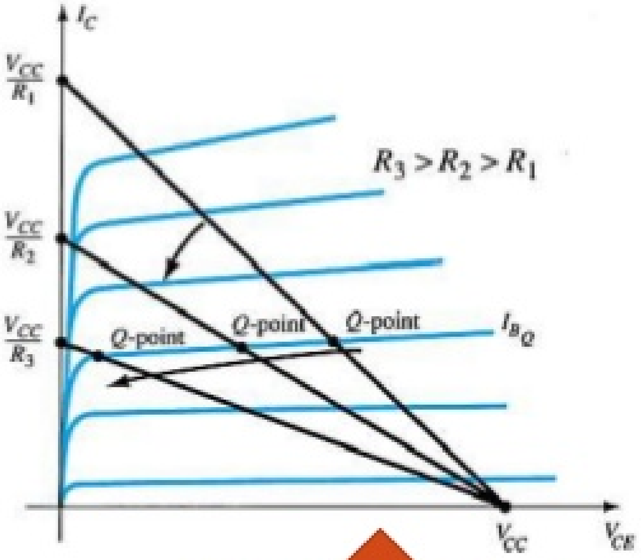




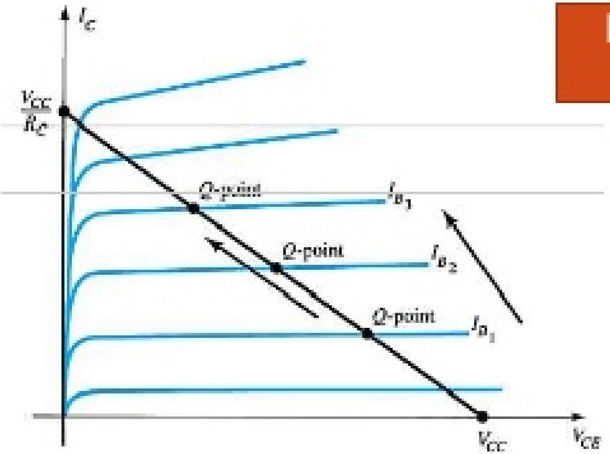
Circuit Values that Affect the Q-Point



Decreasing Vcc



Increasing Rc

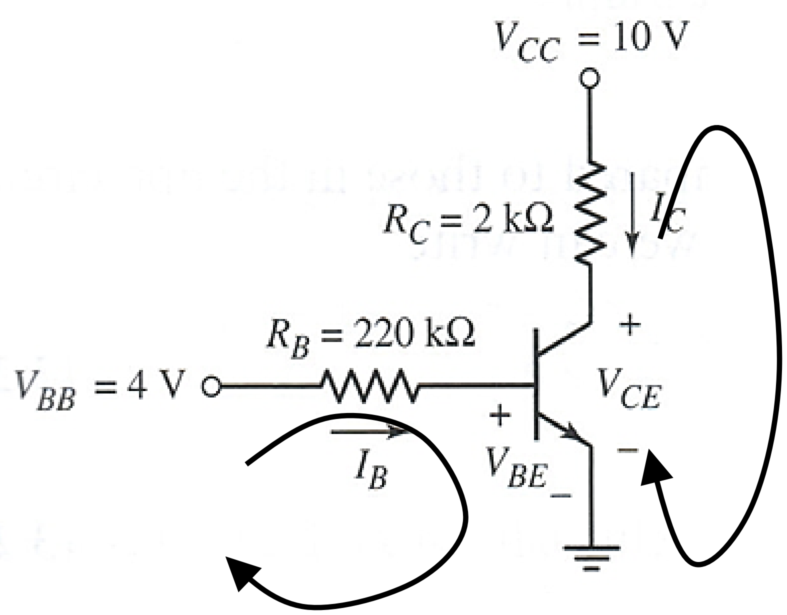


Varying Ib

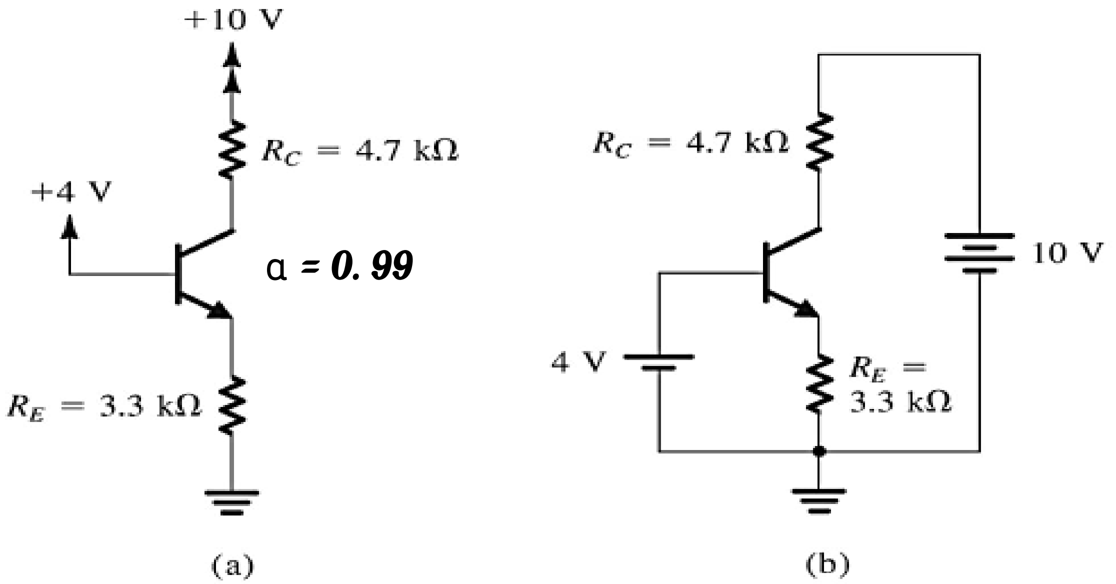
Common-Emitter Circuit

Example 1:

Calculate the base, collector and emitter currents and find Q-point for a common-emitter circuit by considering $V_{BB} = 4$ V, $R_B = 220$kΩ, $R_C = 2$ kΩ, $V_{CC} = 10$ V, $V_{BE}(on) = 0.7$ V and $\beta = 100$.



Example 2: Calculate the currents I_B, I_C and I_E for the circuit shown in figure



KVL at BE loop: $0.7 + I_E R_E - 4 = 0$

$I_E = 3.3 / 3.3 = \underline{1\ mA}$

Hence, $I_C = \alpha\, I_E = \underline{0.99\ mA}$

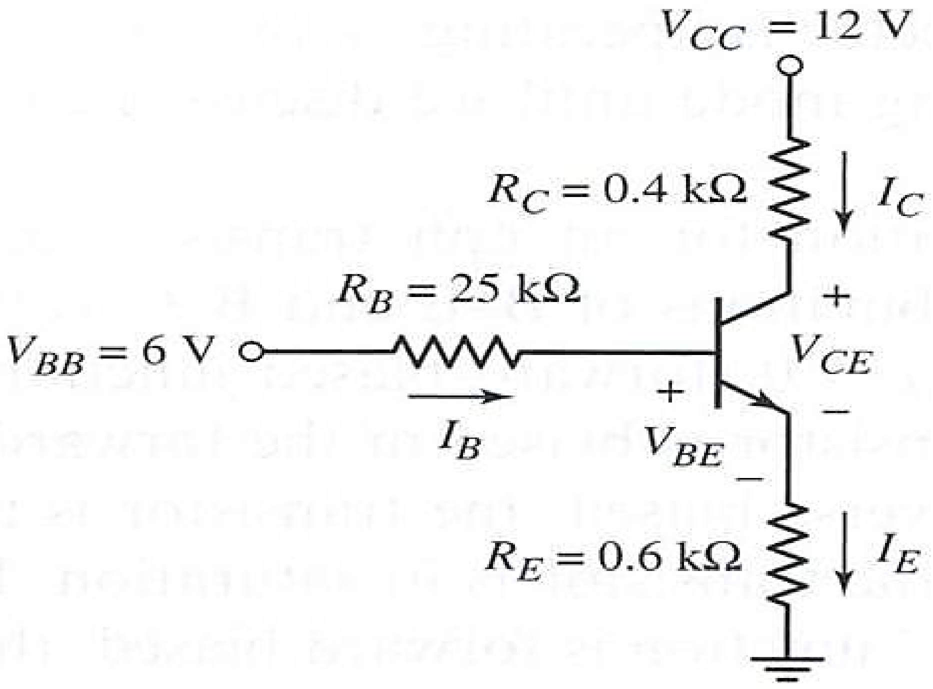
$I_B = I_E - I_C = \underline{0.01\ mA}$

KVL at CE loop: $I_C R_C + V_{CE} + I_E R_E - 10 = 0$

$V_{CE} = 10 - 3.3 - 4.653 = \underline{2.047\ V}$

Example 3: DC Analysis and Load Line

Calculate the characteristics of a circuit containing an emitter resistor and plot the output load line and operating point. For the circuit, let $V_{BE}(on) = 0.7$ V and $\beta = 75$.



Output Load Line

Use KVL at B-E loop to find the value of I_B

Solution:

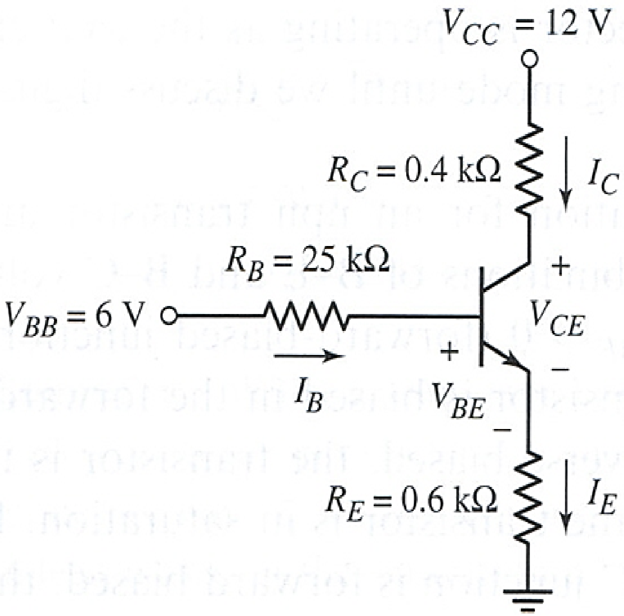
Q-Point Values:

Writing the Kirchhoff's voltage law equation around the B–E loop, we have

$$V_{BB} = I_B R_B + V_{BE}(\text{on}) + I_E R_E$$

Assuming the transistor is biased in the forward-active mode, we can write $I_E = (1+\beta)I_B$. We can then solve for the base current:

$$I_B = \frac{V_{BB} - V_{BE}(\text{on})}{R_B + (1+\beta)R_E} = \frac{6 - 0.7}{25 + (76)(0.6)} \Rightarrow 75.1\ \mu\text{A}$$



Use KVL at C-E loop - to obtain the linear equation

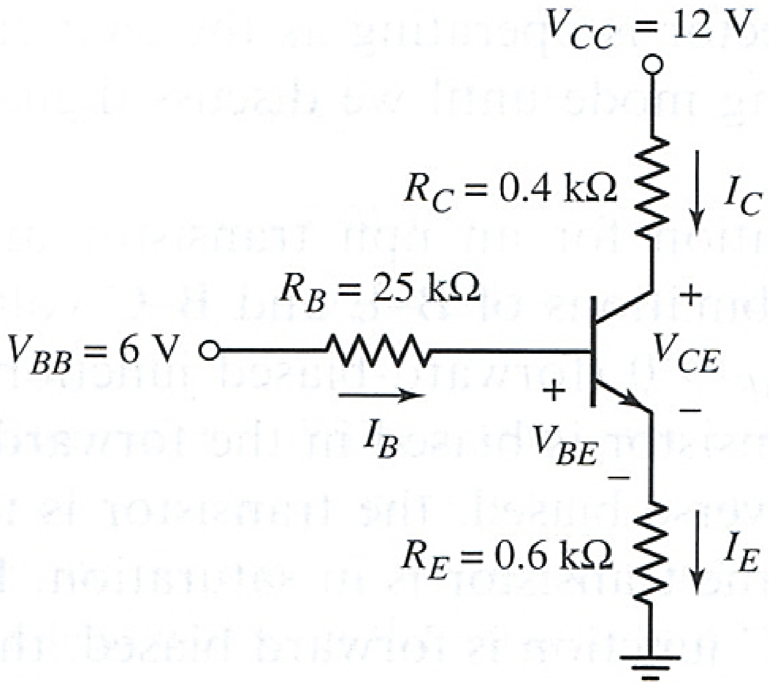
$$I_C R_C + V_{CE} + I_E R_E - 12 = 0$$

$$I_C R_C + V_{CE} + (I_C/\alpha)R_E - 12 = 0$$

$$V_{CE} = V_{CC} - I_C\left[R_C + \left(\frac{1+\beta}{\beta}\right)R_E\right] = 12 - I_C\left[0.4 + \left(\frac{76}{75}\right)(0.6)\right]$$

or

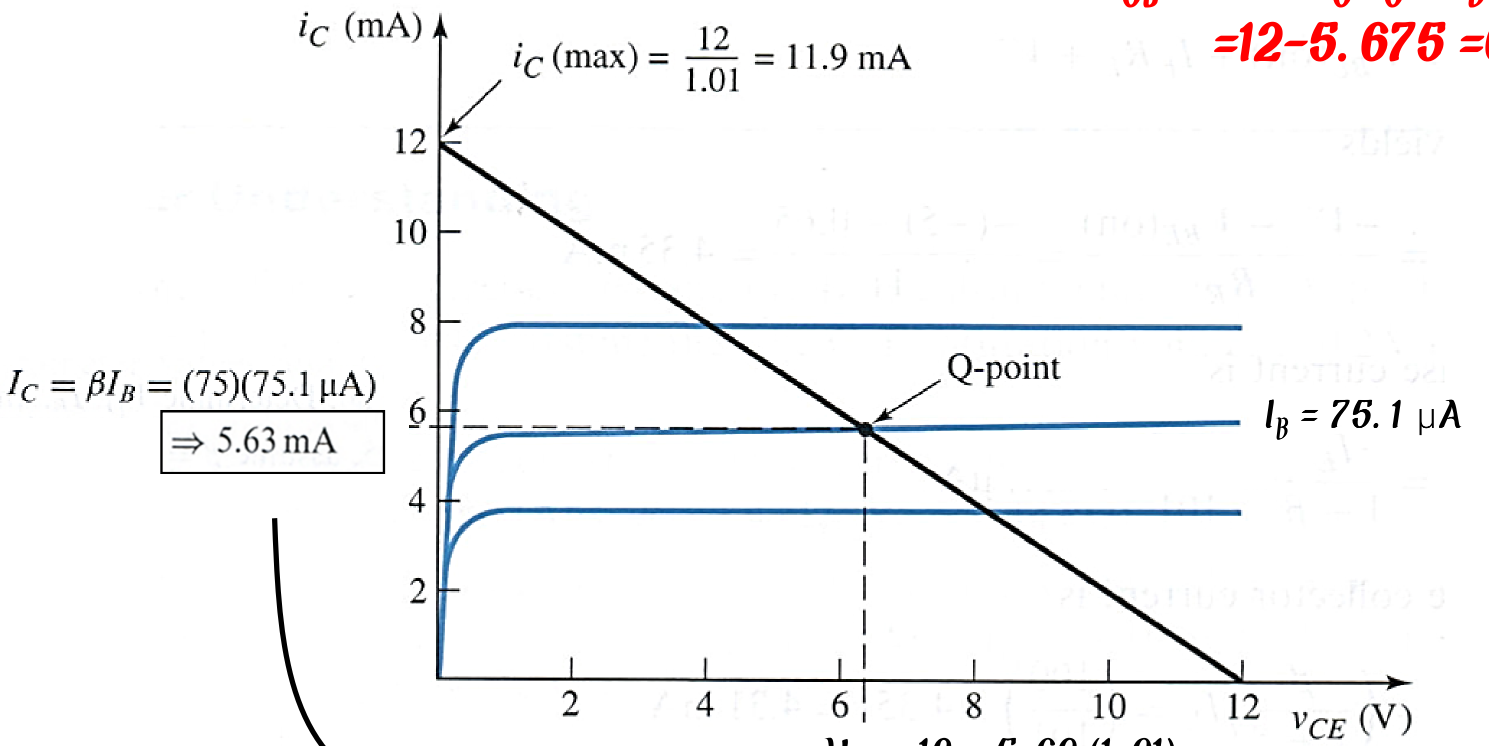
$$V_{CE} = 12 - I_C(1.01)$$



$$I_C = \beta I_B = 75 \times 75\mu A = 5.63 \text{ mA}$$

$$V_{CE} = 12 - [I_C R_C + (I_B + I_C) R_E]$$

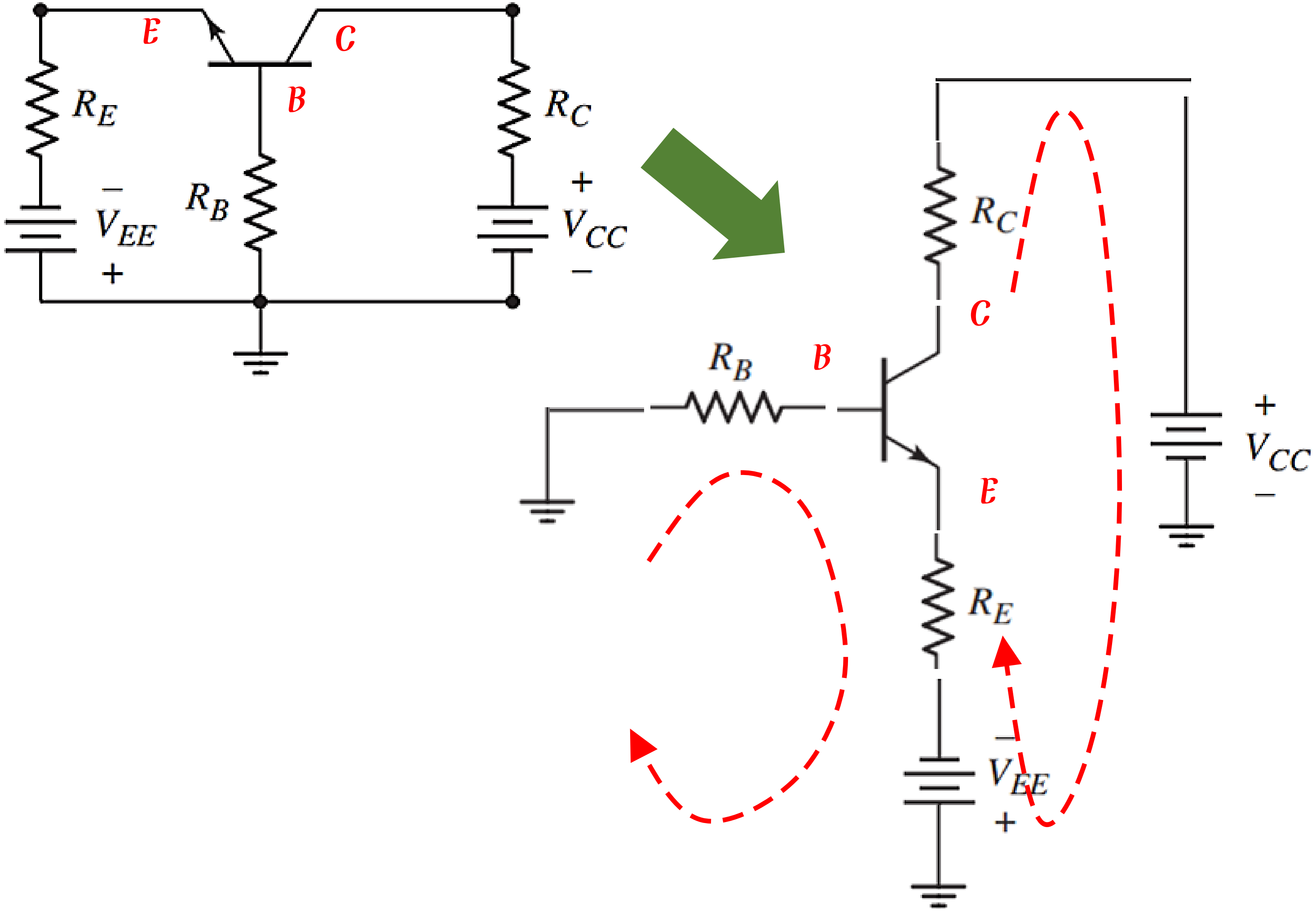
$$= 12 - 5.675 = 6.32 \text{ V}$$

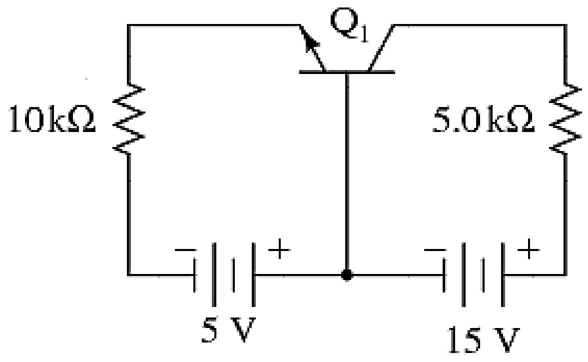


$$V_{CE} = 12 - 5.63\,(1.01)$$

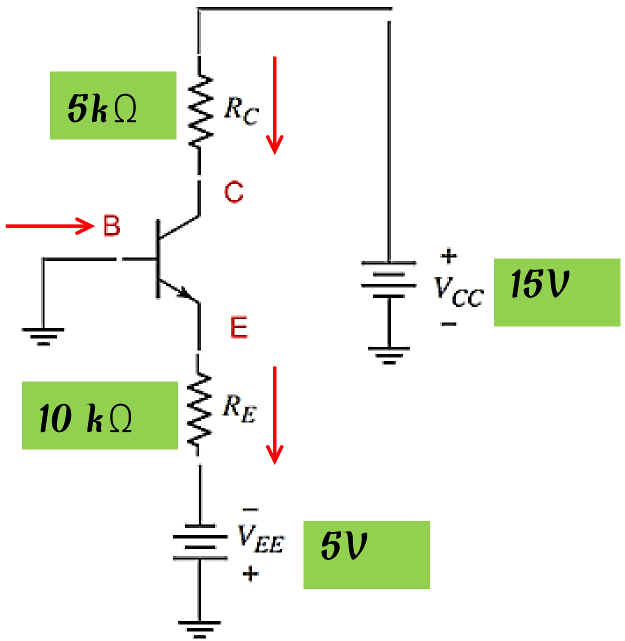
$$V_{CE} = 6.31 \text{ V}$$

Example: DC Analysis – Common Base (npn)



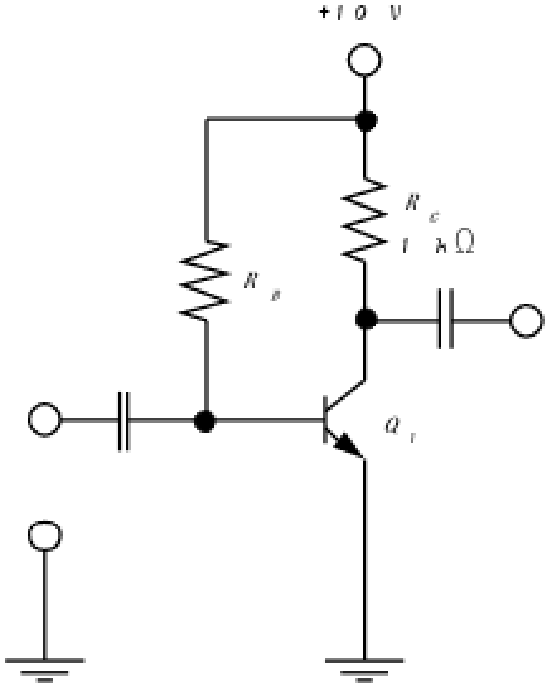


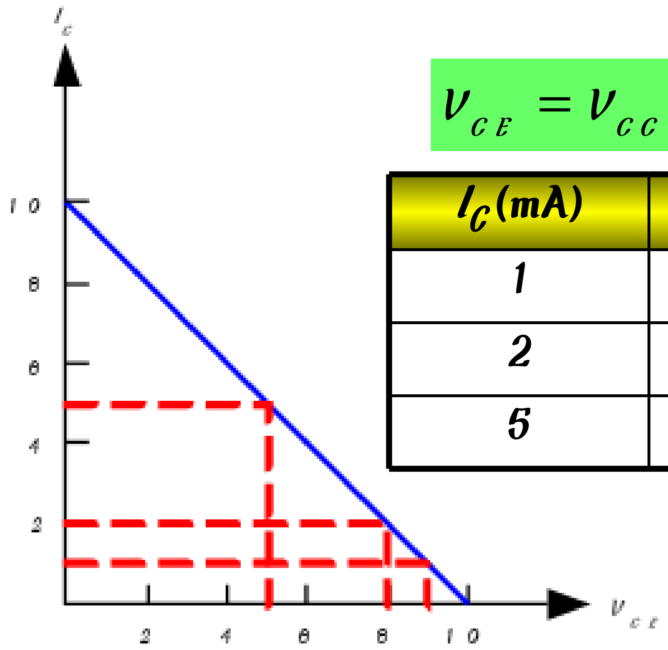
$\beta = 100$



Example.

Plot the dc load line for the circuit shown in Fig. Then, find the values of V_{CE} for $I_C = 1, 2, 5$ mA respectively.

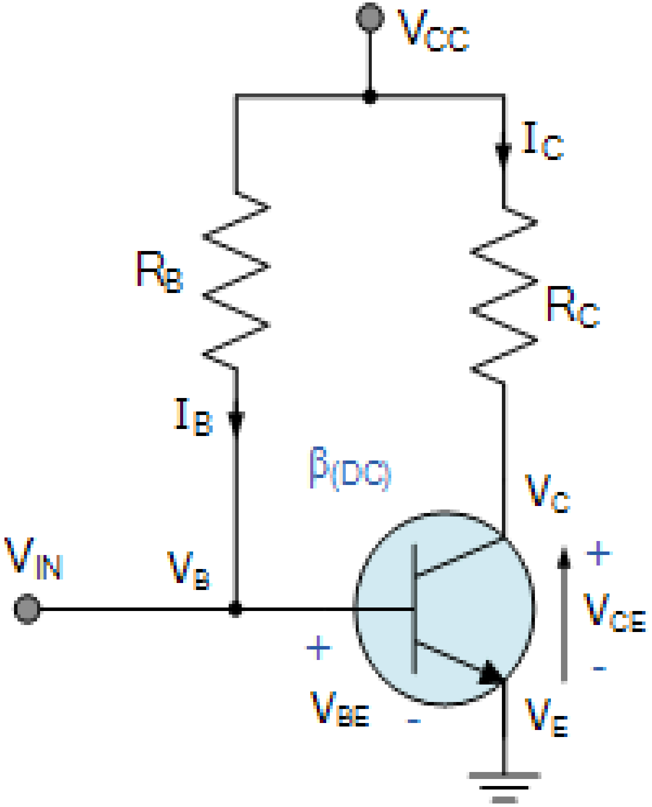




$$V_{CE} = V_{CC} - I_C R_C$$

I_C (mA)	V_{CE} (V)
1	9
2	8
5	5

Fixed Bias



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

$$V_{CE} = V_C - V_E$$

$$V_E = 0v$$

$$V_B = V_{BE}$$

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

$$I_C = \beta_{(DC)} I_B$$

$$I_E = (I_C + I_B) \cong I_C$$

Biasing

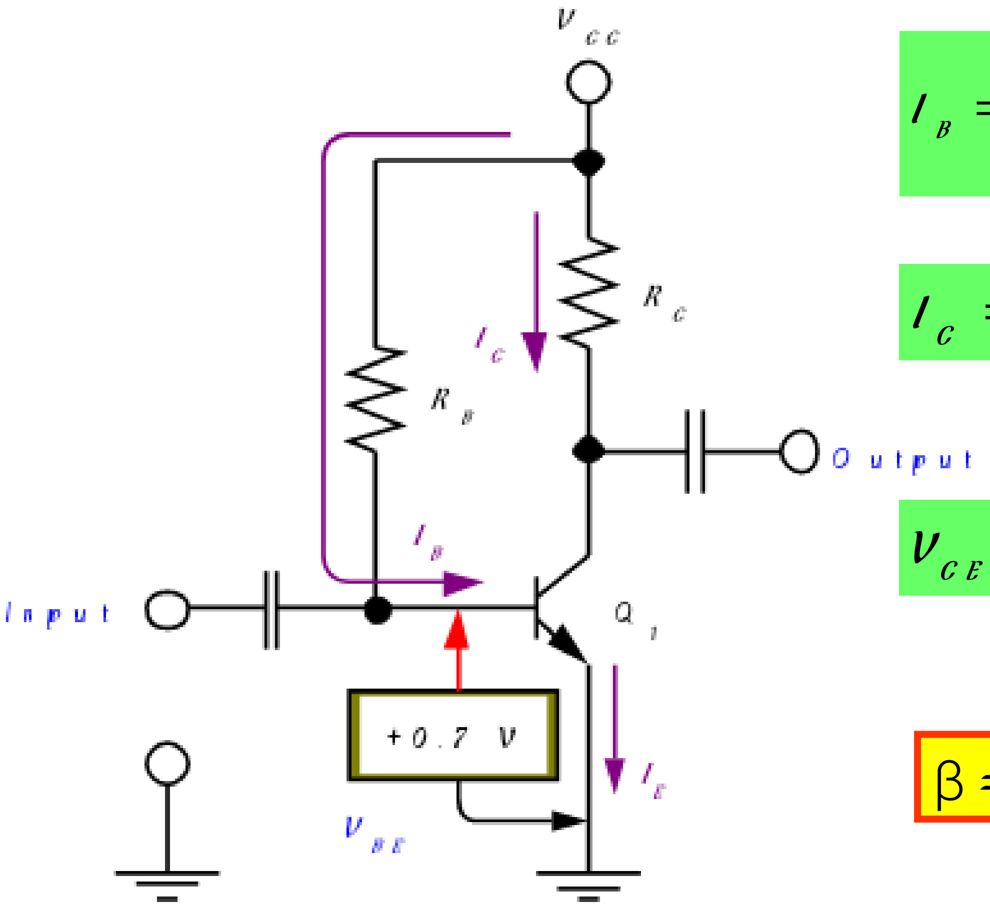
If transistor is used as an amplifier, for this transistor is biased to make the emitter base junction forward biased and collector base junction reverse biased, so that it can be operated in active region.

Establishing the correct '**operating point**' requires the proper selection of DC bias voltages, bias resistors and load resistance.

Different biasing schemes

(i) Fixed bias (base resistor biasing)
(ii) Collector base bias
(iii) Emitter bias
(iv) Voltage divider bias

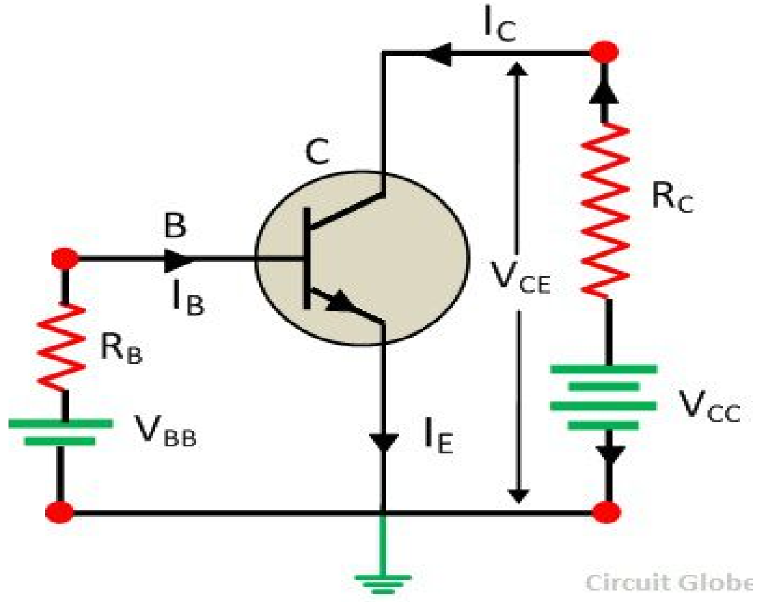
1. Fixed bias or Base bias



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

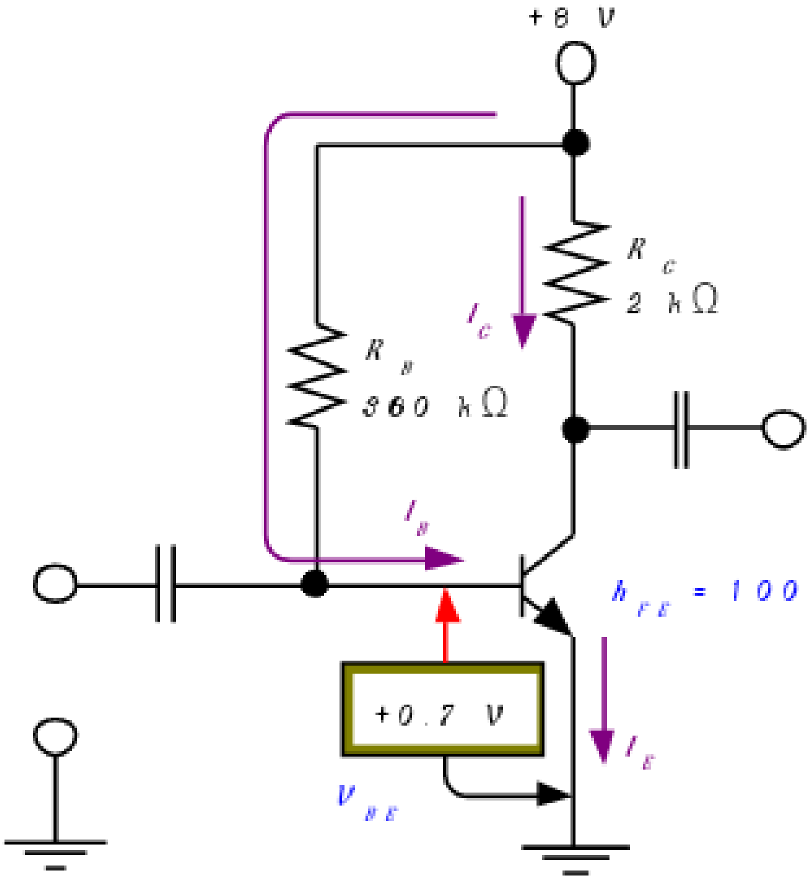
$$I_C = \beta I_B$$

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



β = dc current gain = h_{FE}

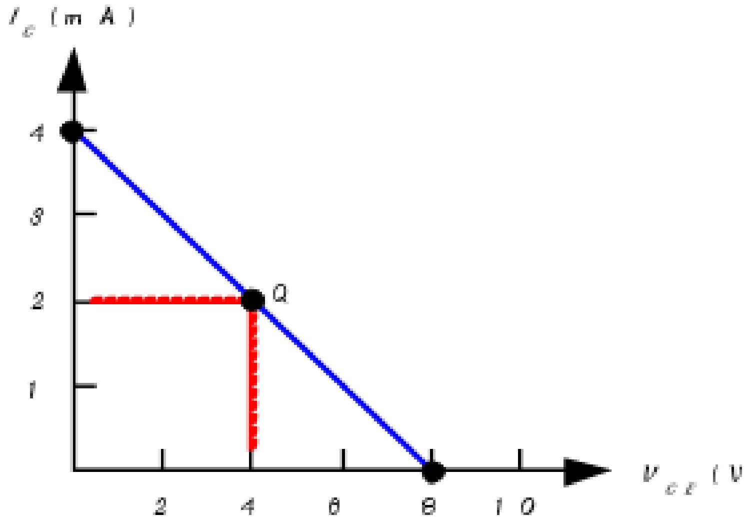
Example 1.



$$I_B = \frac{V_{CC} - 0.7\,V}{R_B} = \frac{8\,V - 0.7\,V}{360\,k\Omega}$$
$$= 20.28\mu A$$

$$I_C = h_{FE} I_B = (100)(20.28\mu A)$$
$$= 2.028\,mA$$

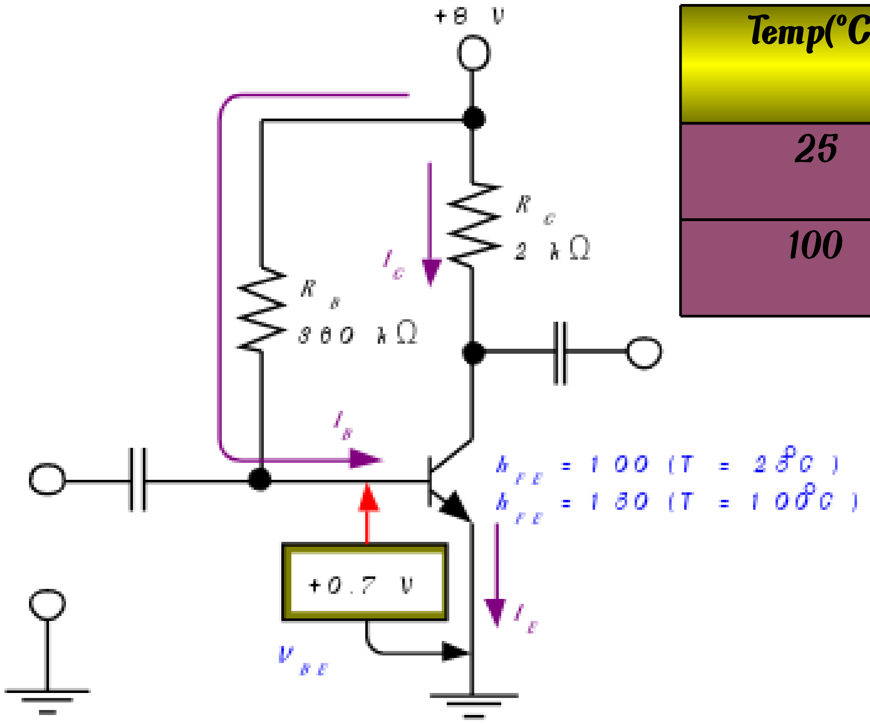
$$V_{CE} = V_{CC} - I_C R_C$$
$$= 8\,V - (2.028\,mA)(2\,k\Omega)$$
$$= 3.94\,V$$



The circuit is midpoint biased.

Example of Q-point shift with Temperature variatio

The transistor in Fig. has values of $h_{FE} = 100$ when $T = 25\ ^oC$ and $h_{FE} = 150$ when $T = 100\ ^oC$. Determine the Q-point values of I_C and V_{CE} at both of these temperatures.



Temp(°C)	I_B (μA)	I_C (mA)	V_{CE} (V)
25	20.28	2.028	3.94
100	20.28	3.04	1.92

CALCULATION OF STABILITY FACTORS

❖ **Stability Factor *S*:-** The stability factor *S, as the change of collector current with respect to the reverse saturation* current, keeping β *and* V_{BE} *constant. This can be written as:*

$$S \equiv \frac{\partial I_C}{\partial I_{CO}}$$

❖ **Stability Factor *S'*:-** The variation of I_C *with* V_{BE} *is given by the stability factor S defined by the partial derivative:*

$$S' \equiv \frac{\partial I_C}{\partial V_{BE}} \approx \frac{\Delta I_C}{\Delta V_{BE}}$$

❖ **Stability Factor *S''*:-** The variation of I_C *with respect to β is represented by the stability factor, S'', given as:*

$$S'' \equiv \frac{\partial I_C}{\partial \beta} \approx \frac{\Delta I_C}{\Delta \beta}$$

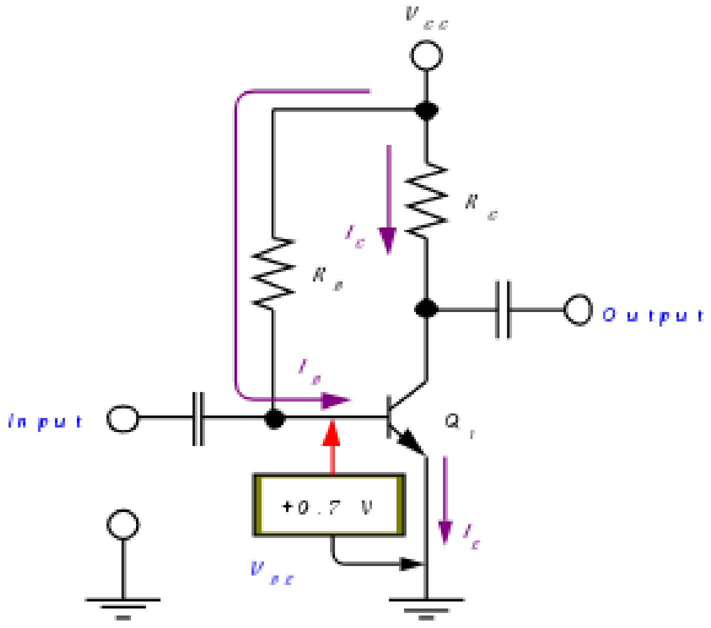
Stability Factor

➢ The rate of change collector current I_C with respect to the collector leakage current I_{CBO} at constant β and I_B is called stability factor, denoted by S.

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

Differentiating equation (1) w.r.t I_C

$$1 = \beta\left(\frac{dI_B}{dI_C}\right) + (\beta+1)\frac{dI_{CBO}}{dI_C} \qquad 1 = \beta\left(\frac{dI_B}{dI_C}\right) + \frac{(\beta+1)}{S} \qquad S = \frac{(\beta+1)}{1-\beta\left(\frac{dI_B}{dI_C}\right)}$$



Stability in case of Fixed bias:
Applying KVL to Base-emitter circuit

$V_{CC} = I_B R_B + V_{BE}$
or $I_B = (V_{CC} - V_{BE})/R_B$

$dI_B/dI_C = 0$ Hence, stability factor for Fixed bias is $S = (1+\beta)$

Fixed Bias

Advantages:

- Operating point can be shifted easily anywhere in the active region by merely changing the base resistor (R_B).
- A very small number of components are required.

Disadvantages:

- Poor stabilization
- High stability factor($S=\beta+1$ because I_B is constant so $dI_B/dI_C=0$), hence prone to thermal runaway

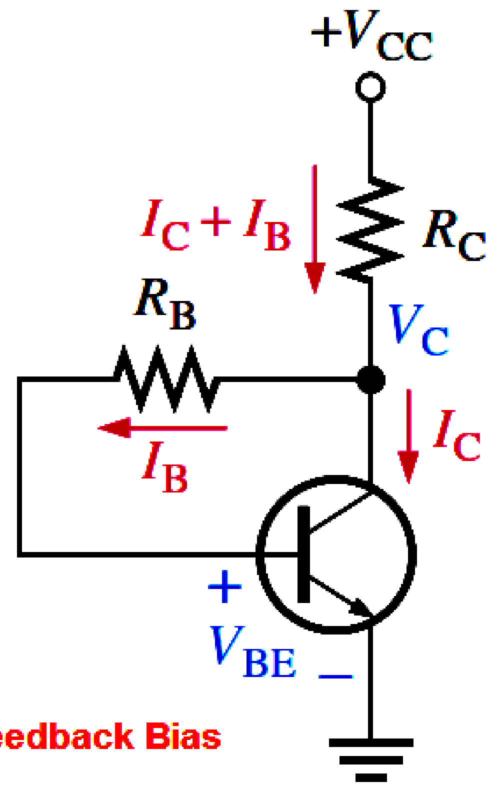
Usage:

- Due to the above inherent drawbacks, fixed bias is rarely used in linear circuits (i.e., those circuits which use the transistor as a current source). Instead, it is often used in circuits where transistor is used as a switch.

How the Q point is affected by changes in V_{BE} and I_{CBO} in fixed bias?

$I_B = (V_{CC}-V_{BE})/R_B \qquad I_C = \beta I_B$

2. Collector to Base Bias



Collector Feedback Bias

This configuration employs negative feedback to prevent thermal runaway and stabilize the operating point. In this form of biasing, the base resistor R_F is connected to the collector instead of connecting it to the DC source V_{CC}. So any thermal runaway will induce a voltage drop across the R_C resistor that will throttle the transistor's base current.

by applying KVL to Base Emitter loop

$$V_{CC} = (I_B+I_C)R_C + I_BR_B + V_{BE}$$

$$V_{CC} = I_BR_c + I_CR_C + I_BR_B + V_{BE} = I_B(R_B+(1+\beta)R_C) + V_{BE}$$

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

$$I_B = (V_{CC}-V_{BE})/(R_B+\beta R_C) \qquad \text{if } \beta >> 1$$

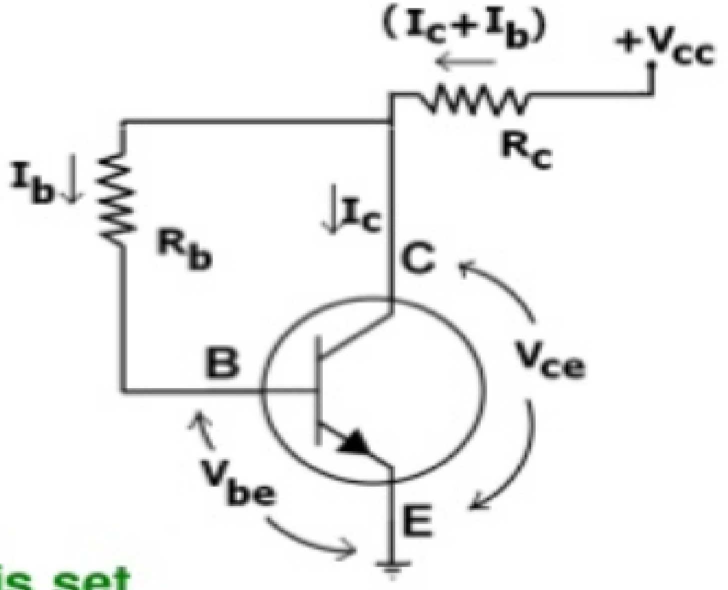
$V_{CE} = V_{CC} - (I_B+I_C)R_C$ *and* $I_C = \beta I_B$

Collector base bias

➢ This configuration employs negative feedback to prevent thermal runaway and stabilize the operating point.

➢ In this form of biasing, the base resistor R_B is connected to the collector instead of connecting it to the DC source V_{cc}.

➢ So any thermal runaway will induce a voltage drop across the R_C resistor that will throttle the transistor's base current.



Applying KVL

$$V_{CC} = (I_C+I_B)R_C + V_{CE} \qquad (1)$$

$$V_{CE} = I_B R_B + V_{BE} \qquad (2)$$

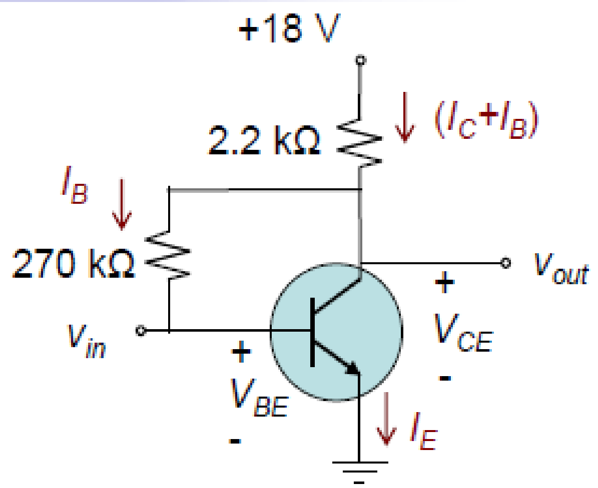
Since, $I_C = \beta I_B$ so from equation (1) & (2)

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

$Q(V_{CE}, I_C)$ is set

Collector-To-Base Bias

Calculate the Q-point values for β = 100. Calculate the new values if β is changed to 50.



npn transistor in collector-to-base bias configuration.

Solutions:

For β = 100:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + R_C(\beta+1)}$$
$$= 35.1 \mu A.$$
$$\therefore I_{CQ} = \beta I_B = 3.51 \text{ mA.}$$
$$V_{CEQ} = V_{CC} - R_C(I_C + I_B)$$
$$= 10.2 \text{ V.}$$

For β = 50:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + R_C(\beta+1)}$$
$$= 45.3 \mu A.$$
$$\therefore I_{CQ} = \beta I_B = 2.31 \text{ mA.}$$
$$V_{CEQ} = V_{CC} - R_C(I_C + I_B)$$
$$= 12.82 \text{ V.}$$

- Observe that the change in Q-point values in comparison to base-bias case is much smaller.
- In this case I_B is also a function of β.

Thank You