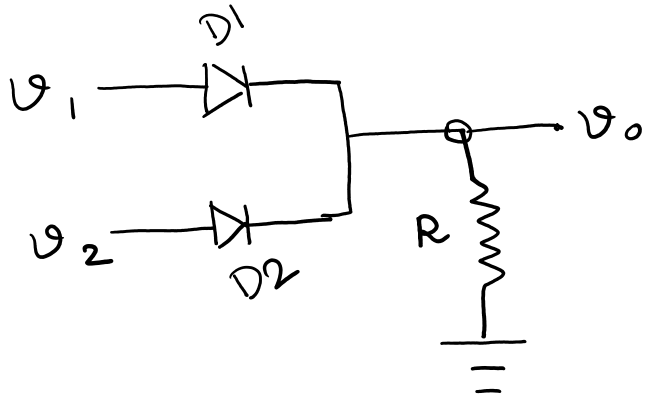
Class - 14.1

OR - Gate

$v_o > 2.5 \Rightarrow$ logic high

$v_o \leq 2.5V \Rightarrow$ logic low



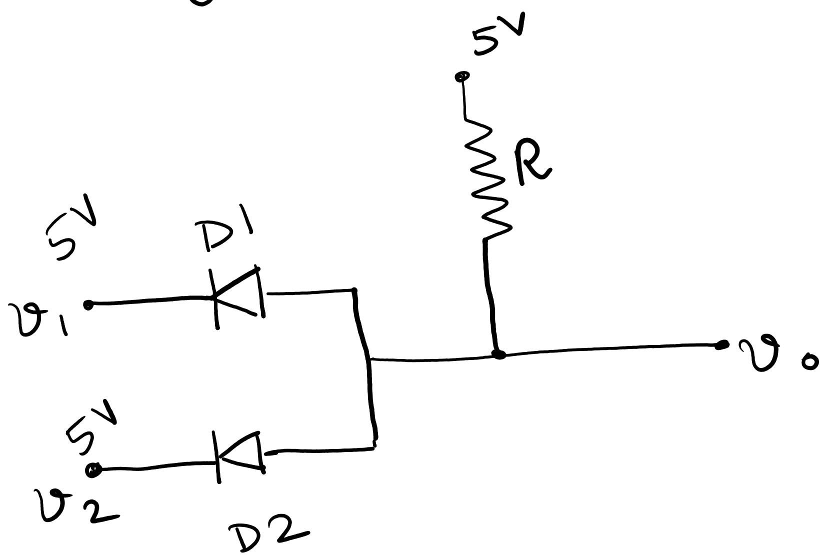
$V_\gamma = 0.7V$

v_1	v_2	v_o
0V	0V	0V
5V	0V	4.3V
0V	5V	4.3V
5V	5V	4.3V

Truth Table

v_1	v_2	v_o
0	0	0
1	0	1
0	1	1
1	1	1

AND gate



v_1	v_2	v_o
0V	0V	0·7V
5V	0V	0·7V
0V	5V	0·7V
5V	5V	5V

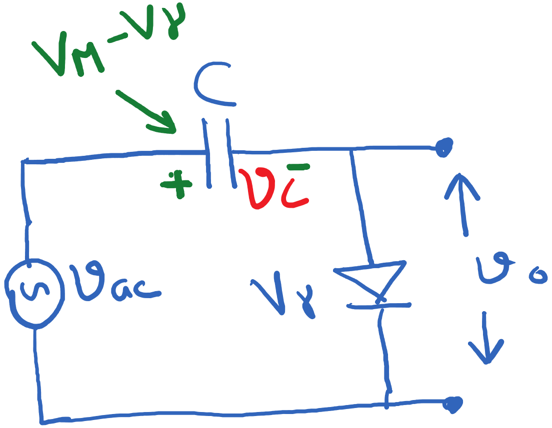
Truth Table

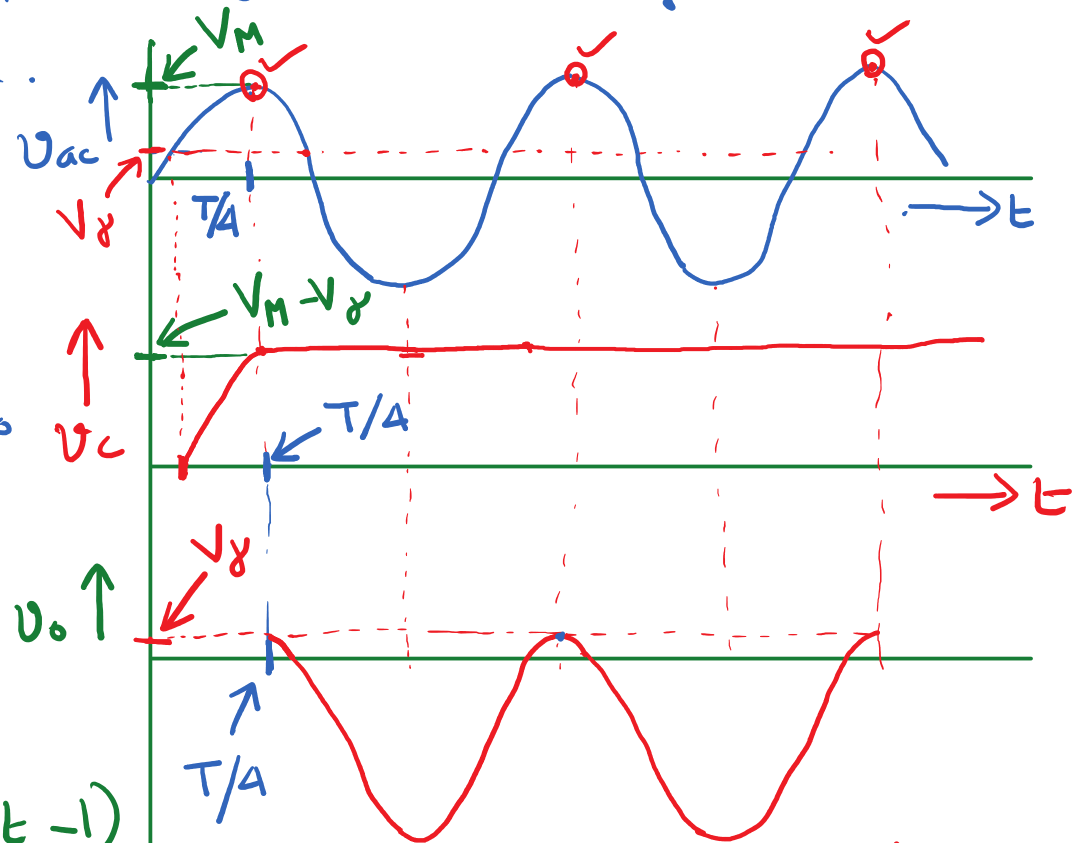
v_1	v_2	v_o
0	0	0
1	0	0
0	1	0
1	1	1

we cant construct not gates with the help of diode.

Class-14.2

Clamper:- Circuits that alter or change the DC level of a signal.



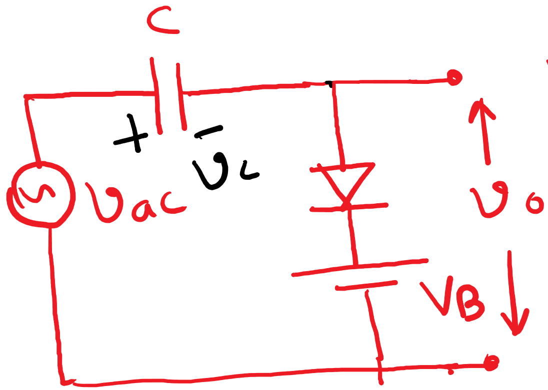


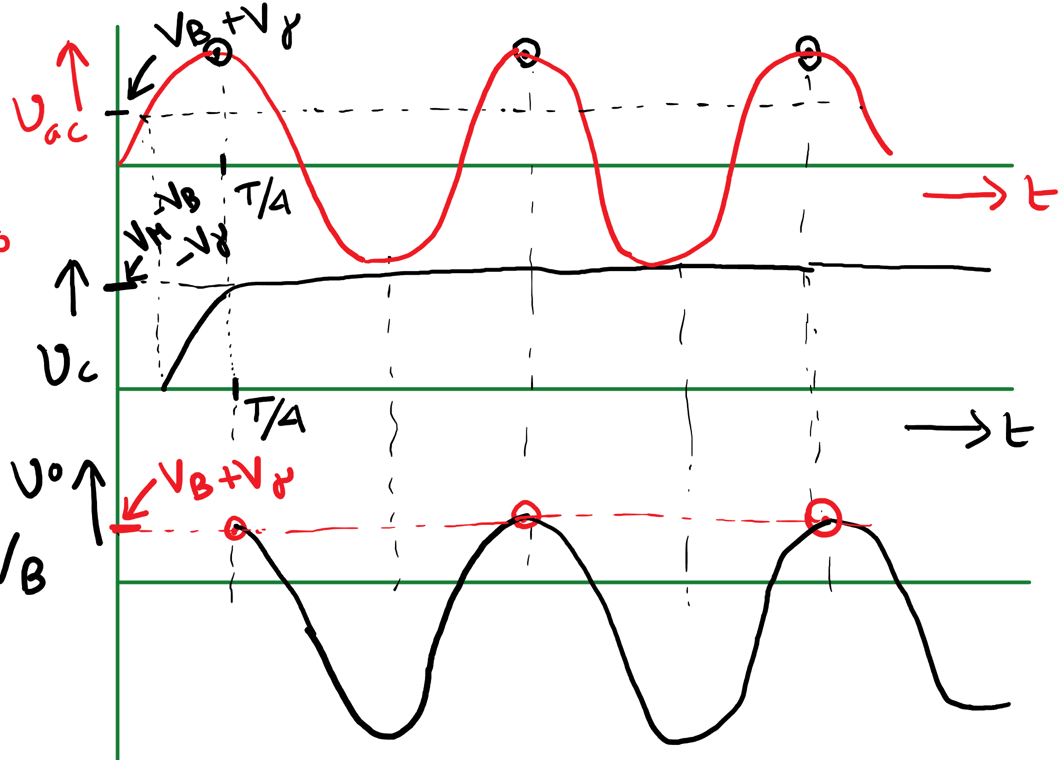
$$v_{ac} = V_M \sin\omega t$$

$$v_o = v_{ac} - v_c$$

$$= V_\gamma + V_M(\sin\omega t - 1)$$

Change in DC level $= V_M - V_\gamma$.





$$v_{ac}^{max} = v_C^{max} + V_\gamma + V_B$$

$$\Rightarrow v_C^{max} = v_{ac}^{max} - (V_\gamma + V_B)$$

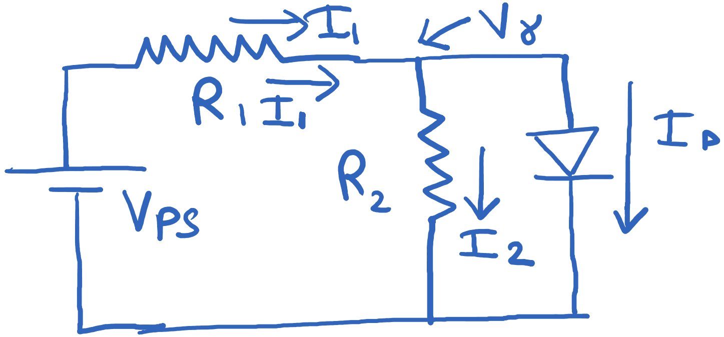
$$= V_M - (V_\gamma - V_B)$$

$$v_{ac} = v_C + v_o \Rightarrow v_o = v_{ac} - v_C$$

$$v_o = V_M \sin\omega t - (\underbrace{V_M - V_B - V_\gamma}_{\text{shift in DC level.}})$$

$V_\gamma = 0.7V$, $5V < V_{PS} < 10V$.

$I_D^{min} = 2mA$, $P_D^{max} = 10mW$.



Determine appropriate values of R_1 and R_2

A:

$$\begin{cases} I_D^{max} \cong \dfrac{P_D^{max}}{V_\gamma} = \dfrac{10mW}{0.7V} = 14.28mA \\ I_D^{min} = 2mA. \end{cases}$$

$$I_2 \cong \frac{V_\gamma}{R_2}$$

$$\frac{V_{PS}^{max} - V_\gamma}{R_1} = I_D^{max} + I_2 \Rightarrow \frac{9.3}{R_1} = 14.28 + \frac{0.7}{R_2}$$

$$\Rightarrow 9.3/R_1 - 0.7/R_2 = 14.28 \quad \text{— (1)}$$

$$\frac{V_{PS}^{min} - V_\gamma}{R_1} = I_D^{min} + \frac{0.7}{R_2}$$

$$\Rightarrow 4.3/R_1 - \frac{0.7}{R_2} = 2mA \quad \text{— (2)}$$

$$\Rightarrow 4.3/R_1 - \frac{0.7}{R_2} = 2mA \quad — (2)$$

Subtracting 2 from 1 we get

$$5/R_1 = 12\cdot28 \rightarrow R_1 = \frac{5}{12\cdot28} k\Omega = 0\cdot407 k\Omega$$

From 1

$$0\cdot7/R_2 = \frac{9\cdot3}{R_1} - 14\cdot28$$

$$= 22\cdot8 - 14\cdot28$$

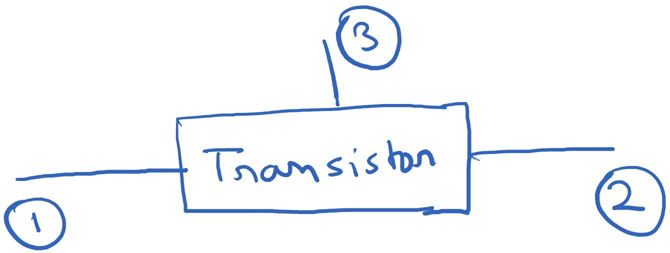
$$= 8\cdot57$$

$$R_2 = \frac{0\cdot7}{8\cdot57} = 0\cdot0816 k\Omega$$

$$\boxed{\begin{aligned} R_1 &= 0\cdot407 k\Omega \\ R_2 &= 0\cdot0816 k\Omega \end{aligned}}$$

Class-15

Bipolar junction Transistor

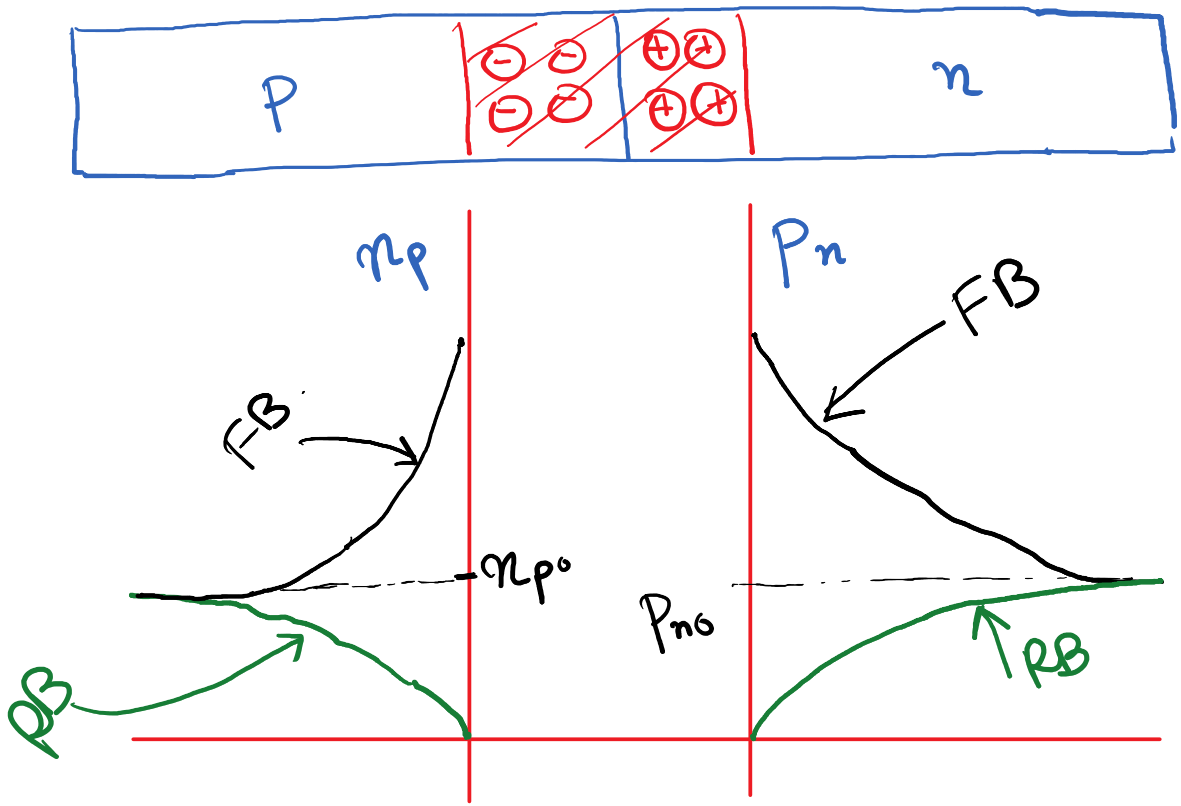


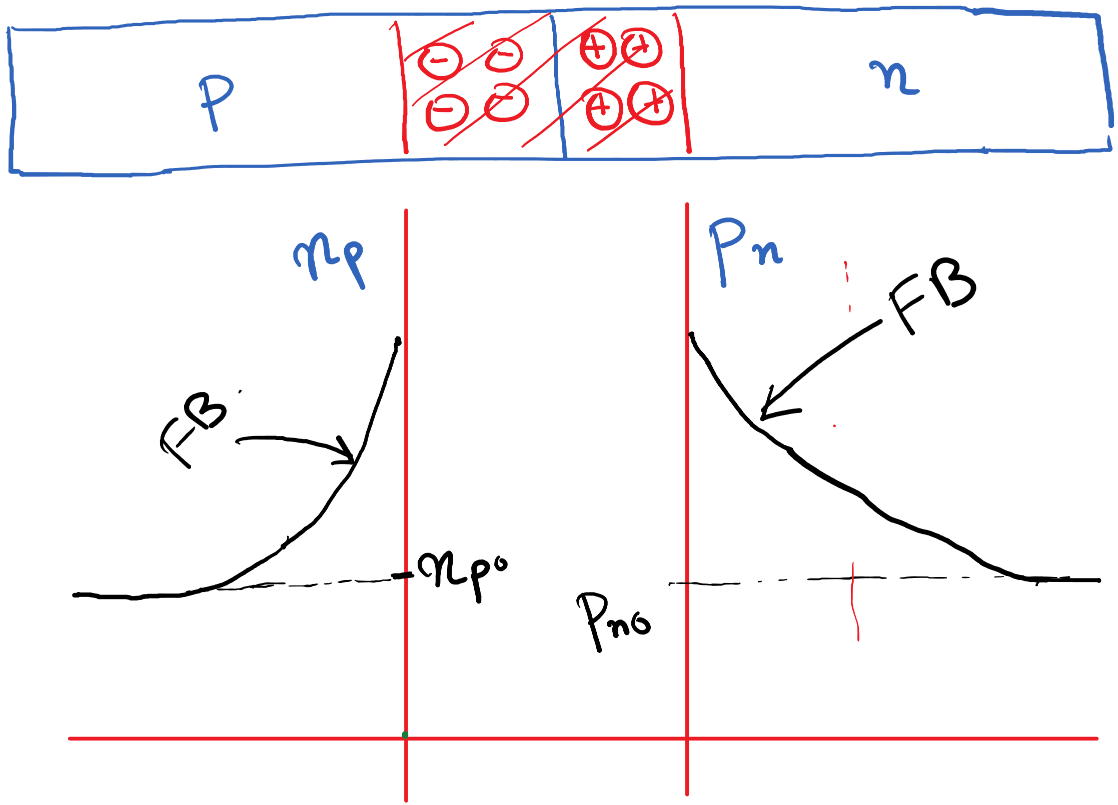
Transistor: Three terminal devices. Conductance between two terminals is controlled by a current or voltage at the 3rd terminal.

Bipolar:- the action of both majority and minority carriers are required for the transistor action.

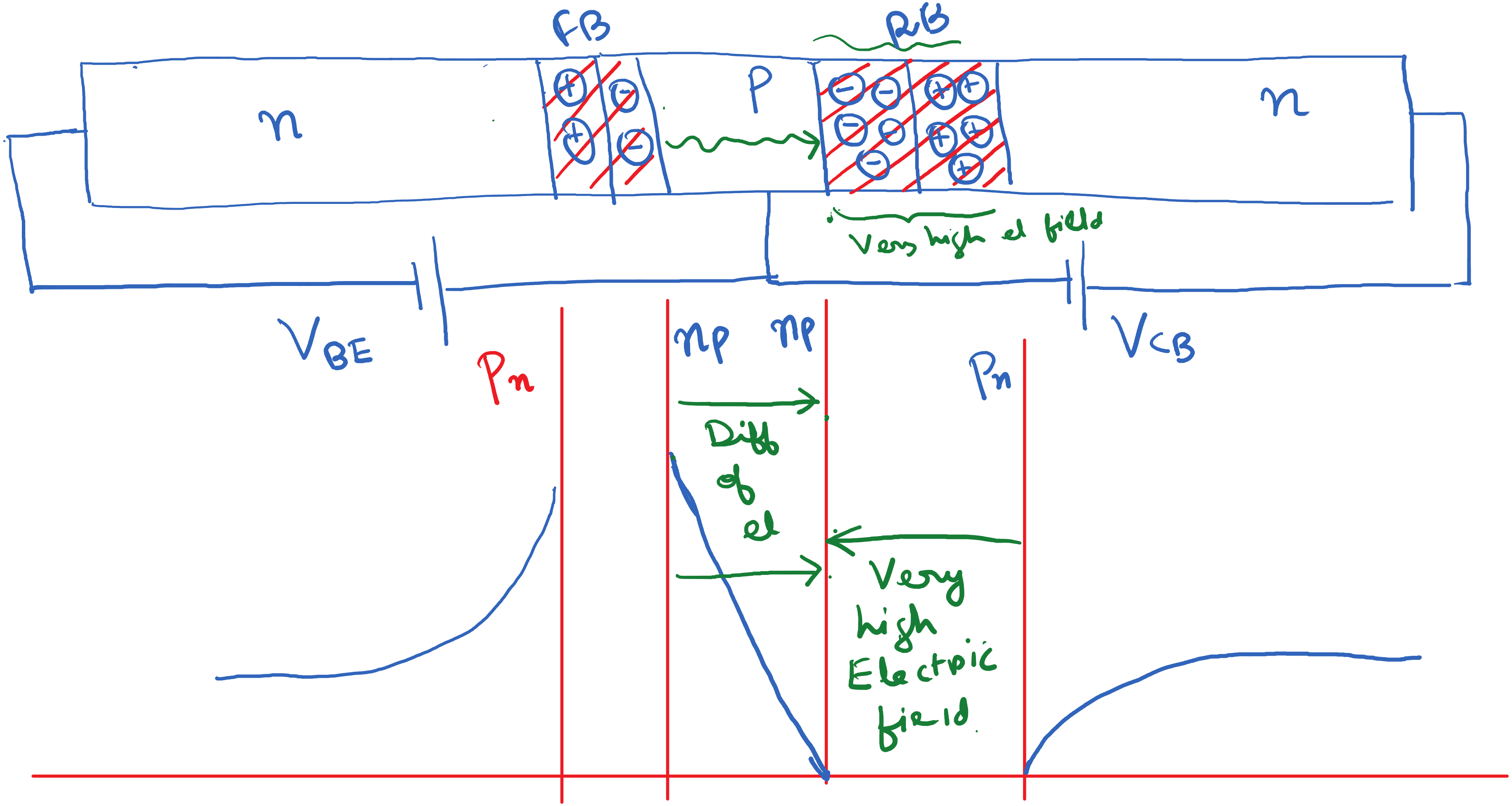
n - type → majority carrier → electrons
→ minority carrier → holes.

p-type → majority carrier → holes
→ minority carrier → electrons.

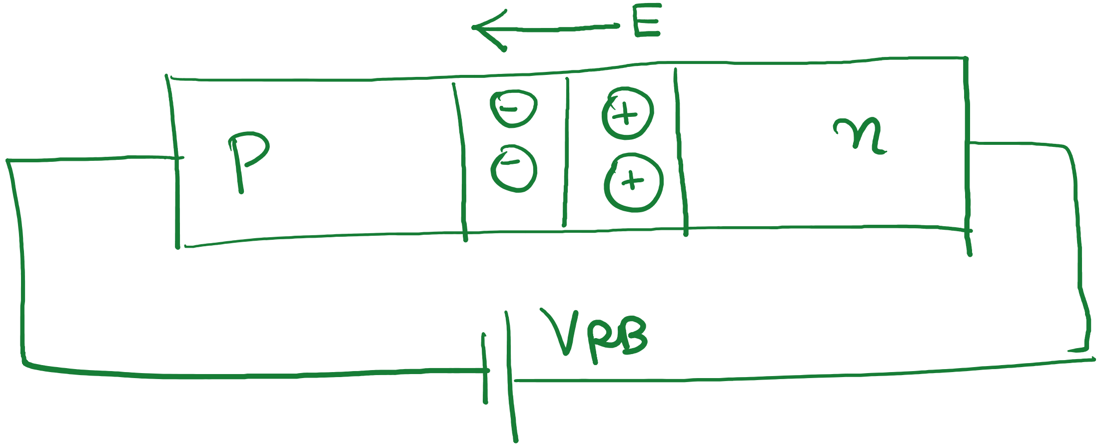

P
n
n_p
P_n
FB
FB
n_{p0}
P_{n0}
RB
RB

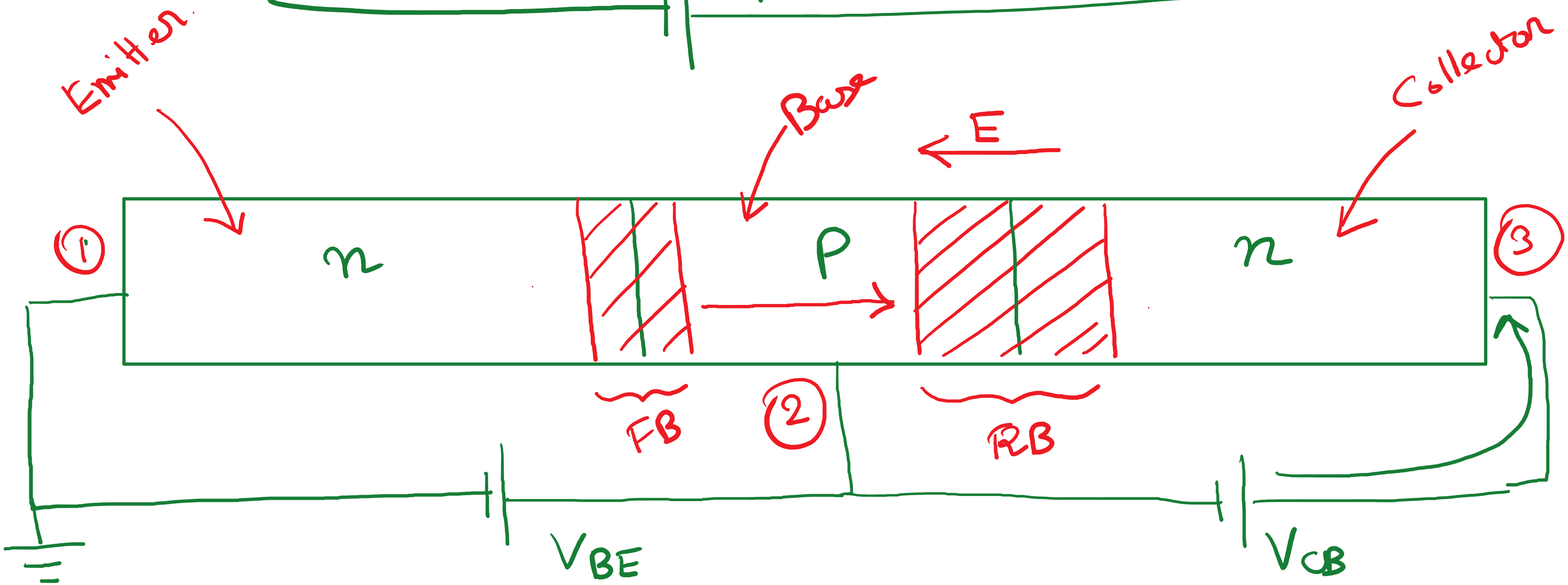


P
n
n_p
P_n
FB
FB
n_{p0}
P_{n0}



FB
RB
n
P
n
Very high el field
V_{BE}
V_{CB}
P_n
n_p
n_p
P_n
Diff of el
Very high Electric field


E
P
n
VRB

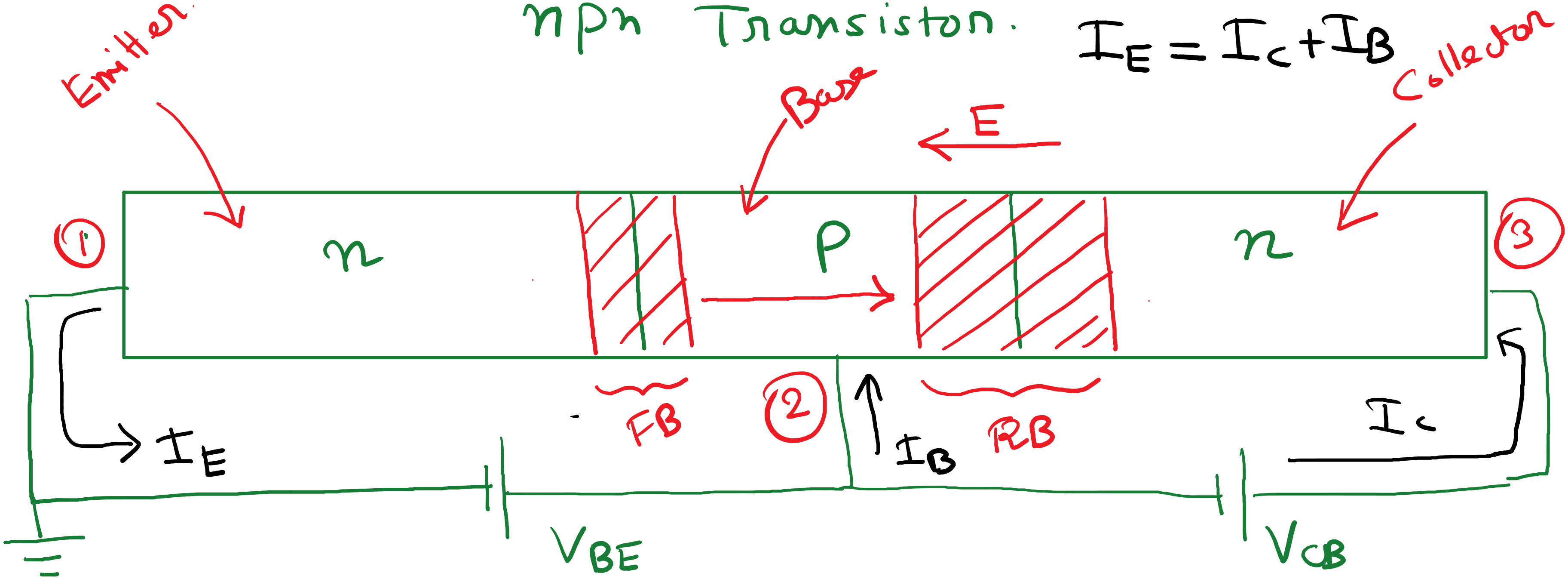

Emitter
Base
Collector
E
1
n
P
n
3
FB
2
RB
VBE
VCB

When V_{BE} increases, more electrons are injected from the emitter into the p-type Base. As the injected electrons in the p-type Base increases, more electrons are swept from the Base into the collector by the reverse biased base to collector junction. So, the collector current increases.

So, with increase in V_{BE}, the collector current increases.

npn Transistor.

$I_E = I_C + I_B$



Components of I_B: ① Some of the electrons injected from the emitter to the Base flows out of the Base terminal.

(2) The Base also injects excess holes in the n-type emitter and these holes that diffuse from the base to the emitter needs to be replenished by the base current.

* Emitter is heavily doped so that more electrons can diffuse from the emitter to the base during forward bias. This increases the electron concentration in the Base.

* Collector is moderately doped. Base is lightly doped.

$$I_E = I_C + I_B$$

Our intention is to control the collector current via the base-to-emitter voltage on the base/emitter current.

For ideal transistor, $I_B = 0$ and we want all the emitter current to flow through the collector.

For a good transistor, base current should be as low as possible.

For a good transistor $\begin{cases} I_B << I_E, I_C \\ I_E \cong I_C \end{cases}$

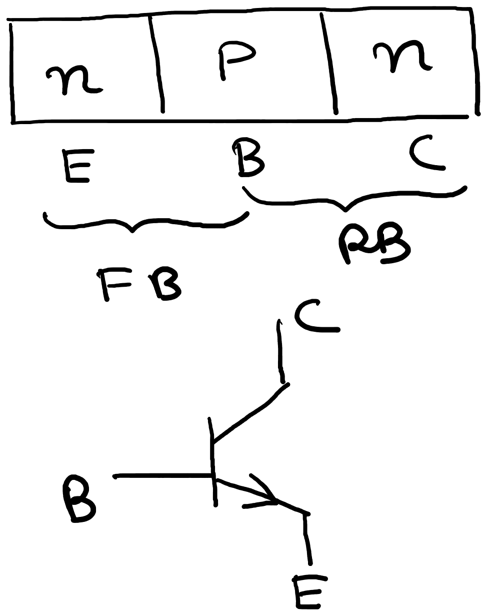
The Base current or the collector current is a fixed fraction of the emitter current.

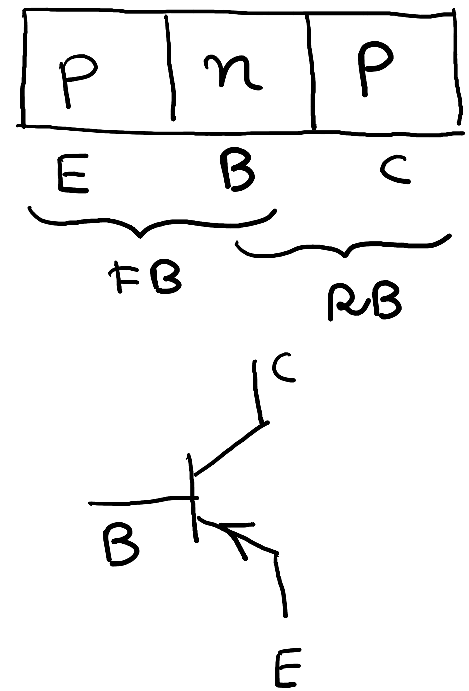
Generally for a good transistor,

$$\frac{I_C}{I_E} > 0.99$$

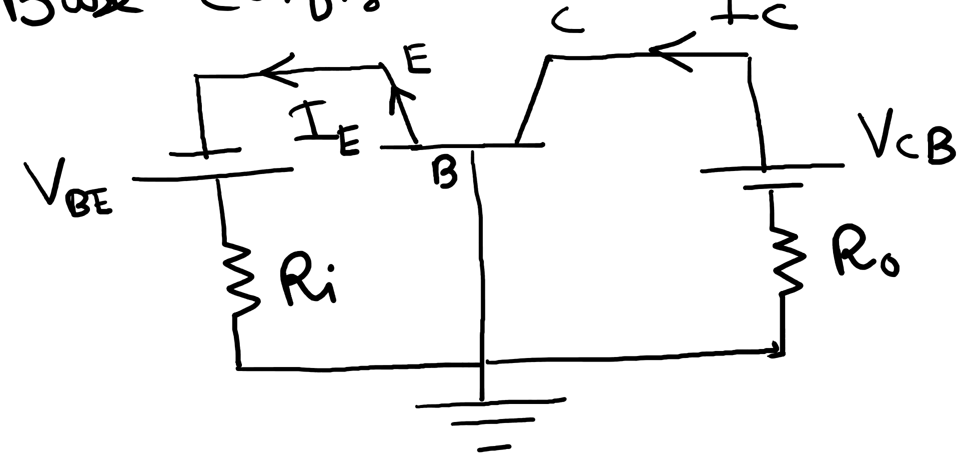
Class-16

$\frac{I_C}{I_E} = \alpha$ = common-Base current gain.





Common-Base configuration:-



$I_E \rightarrow$ input current

$I_C \rightarrow$ output current

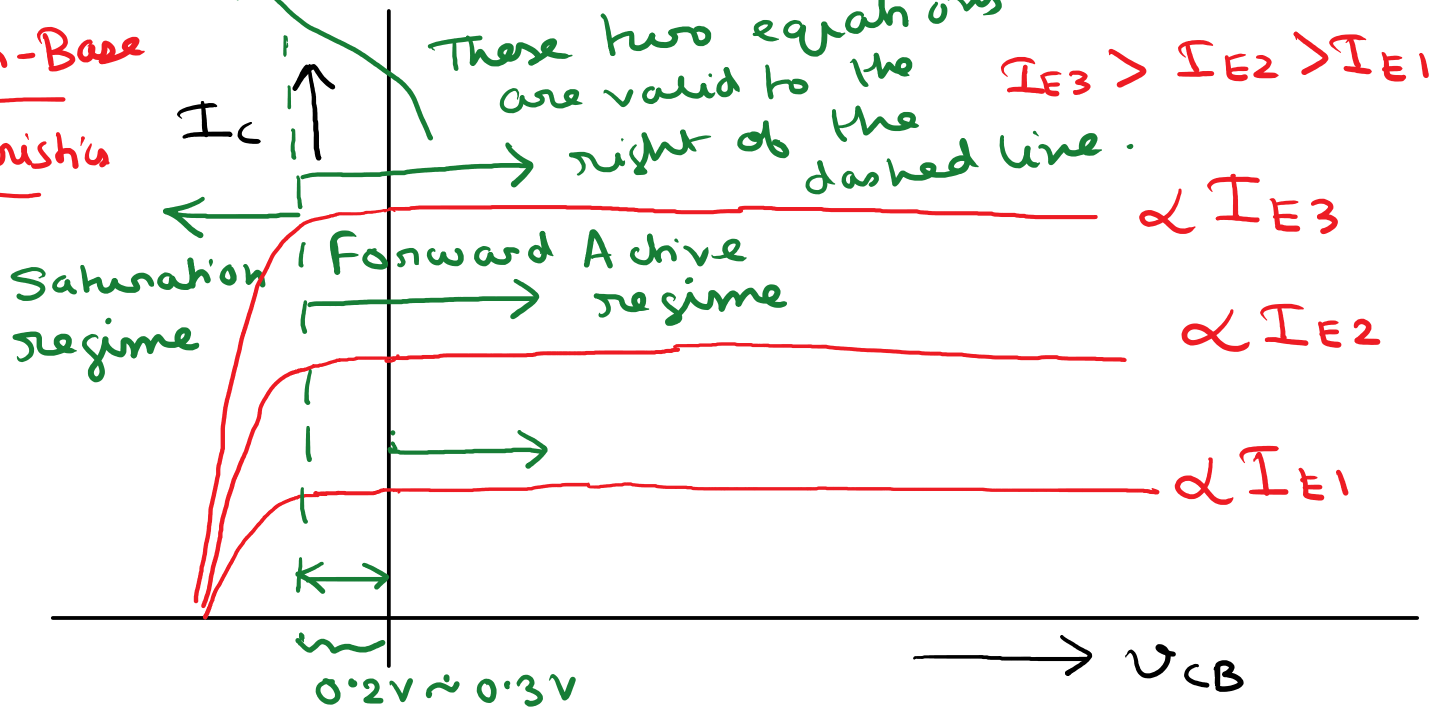
$\frac{I_C}{I_E} = \alpha$ = common-Base current gain

$$I_E \cong I_S \exp\left\{\frac{V_{BE}}{V_T}\right\} \qquad (V_{BE} \gg V_T)$$

$$I_B \cong \frac{I_S}{\beta+1} \exp\left\{\frac{V_{BE}}{V_T}\right\}$$

$$I_C = I_E - I_B = \frac{\beta}{\beta+1} I_S \exp\left\{\frac{V_{BE}}{V_T}\right\}$$

Common-Base Characteristics



Ideally we donot want the collector current to vary with V_{CB}. We only want the collector current to vary with V_{BE}. So, its important to see the variation of I_C with V_{CB}

① Forward Active regime → collector current doesnot vary with v_{CB}

Base-emitter junction is forward Biased $V_{BE} \geq V_{\gamma}$

The collector-Base junction is mainly reverse Biased

② Saturation regime:→ collector current varies with collector to Base voltage

Base-emitter junction is forward biased. $(V_{BE} \geq V_{\gamma})$

The collector to Base junction is forward biased.

(3) Cut-off regime → The Base-to-Emitter is in cut-off.

↓ The Base-Emitter junction is not conducting $(V_{BE} < V_\gamma)$

↓ The Base-Emitter junction is reverse Biased.

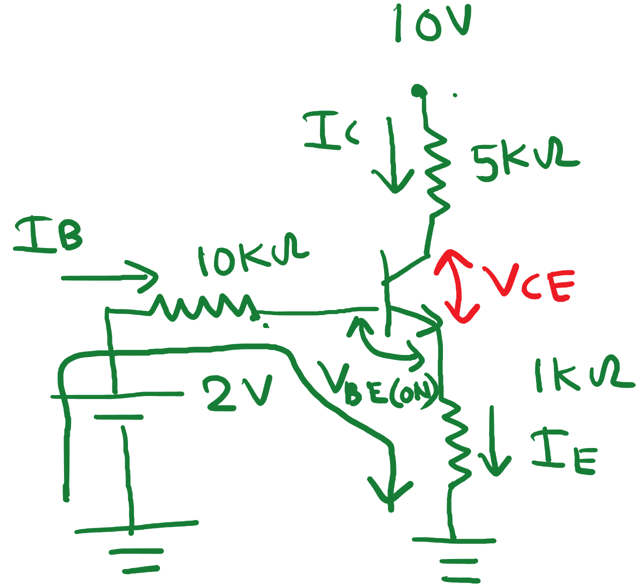
(4) Reverse Active regime → The emitter and collector interchange their action

↓ The Base-emitter junction is reverse Biased

↓ Base-collector junction is forward Biased.

$\alpha = \frac{50}{51}$

I_B, I_C, V_{CE} ?



$I_C = \alpha I_E$

$I_B = I_E - I_C = (1-\alpha) I_E$

$V_{BE(ON)} = V_\gamma = 0.7V$

$2V = I_B \times 10K\Omega + V_{BE(ON)}$
$+ I_E \times 1K\Omega$

$= I_B \times 10K\Omega + 0.7V + \frac{I_B}{1-\alpha} \times 1K\Omega$

$$\boxed{\begin{aligned} 1-\alpha &= \frac{1}{51} \\ \frac{1}{1-\alpha} &= 51 \end{aligned}}$$

$\Rightarrow \quad 1.3V = 10 I_B + 51 I_B = 61 I_B$

$$I_B = \frac{1.3}{61} mA = 0.0213 mA$$

$$I_E = \frac{I_B}{1-\alpha}$$

$$I_C = \alpha I_E = \frac{\alpha}{1-\alpha} I_B = \frac{\frac{50}{51}}{\frac{1}{51}} I_B$$

$$= 50 I_B = 50 \times 0.0213 mA$$

$$= 1.06 mA$$

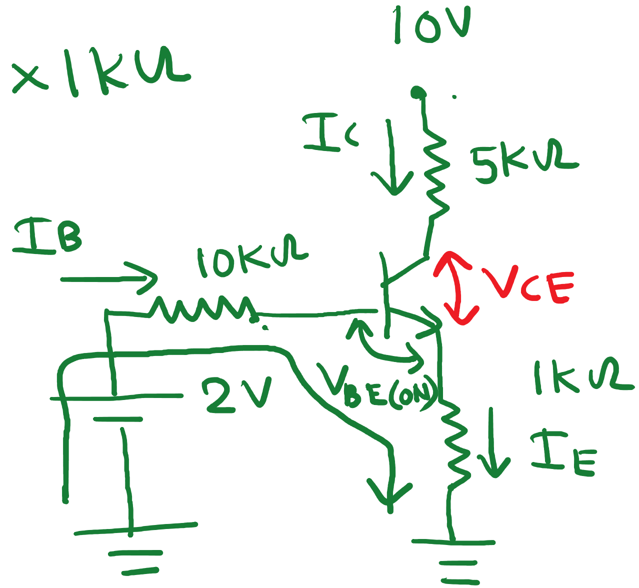
$$10V = 5k\Omega \times I_C + V_{CE} + I_E \times 1k\Omega$$

$$= 5 \times 1.06 + V_{CE}$$

$$+ 51 \times 0.0213$$

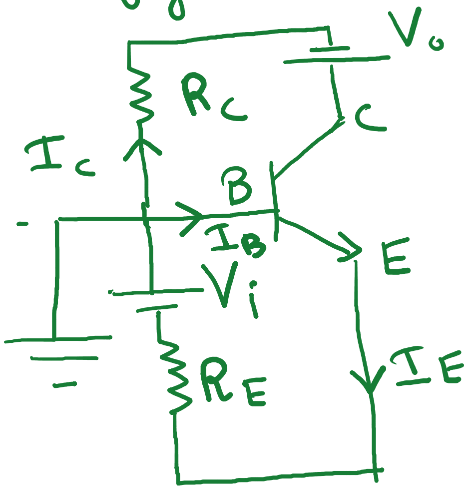
$$\Rightarrow V_{CE} = 10V - 6.45V$$

$$= 3.55V.$$



Class - 17

Common - Base config :-

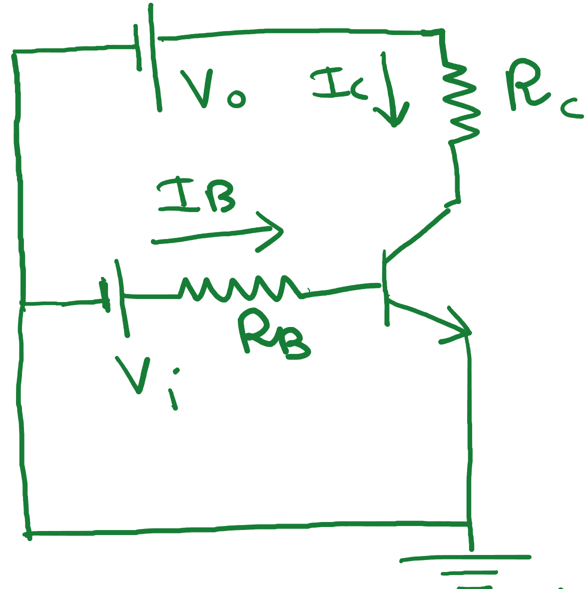


Input current :- I_E

Output current :- I_C

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

Common Emitter Configuration :-



Input current :- Base current

Output current :- Collector current.

$$\frac{I_C}{I_B} = \beta \rightarrow \text{common-emitter current gain.}$$

$$\alpha = \frac{I_c}{I_E} \quad \text{— (1)} \qquad \beta = \frac{I_c}{I_B} \quad \text{— (2)}$$

$$I_E = I_c + I_B \quad \text{— (3)}$$

$$\Rightarrow \frac{I_E}{I_c} = 1 + \frac{I_B}{I_c}$$

$$\Rightarrow \frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

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

$$\boxed{\begin{aligned} &\Rightarrow \beta = \frac{\alpha}{1-\alpha} \\ &\Rightarrow \alpha = \frac{\beta}{1+\beta} \end{aligned}}$$

$$\boxed{\begin{aligned} &I_E = I_c + I_B \\ &\Rightarrow I_E = \beta I_B + I_B \\ &\Rightarrow (\beta+1) I_B = I_E \\ &\Rightarrow I_B = \frac{I_E}{(\beta+1)} \end{aligned}}$$

$$I_C = \alpha I_E$$

$$I_C = \beta I_B$$

$$I_B = \frac{I_E}{\beta + 1}$$

These three eqn are only valid in the Forward Active Mode

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

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

For a good transistor

$\alpha > 0.99$

$\beta > 99$

If the Base-to-emitter junction is a conducting state, then $V_{BE} \cong V_{BE(ON)} = V_\gamma$

$$I_E \cong I_S \exp\left\{\frac{V_{BE}}{V_T}\right\}$$

If $V_{BE} > 0$, then this equation is valid irrespective of the Biasing condition of the collector-Base junction

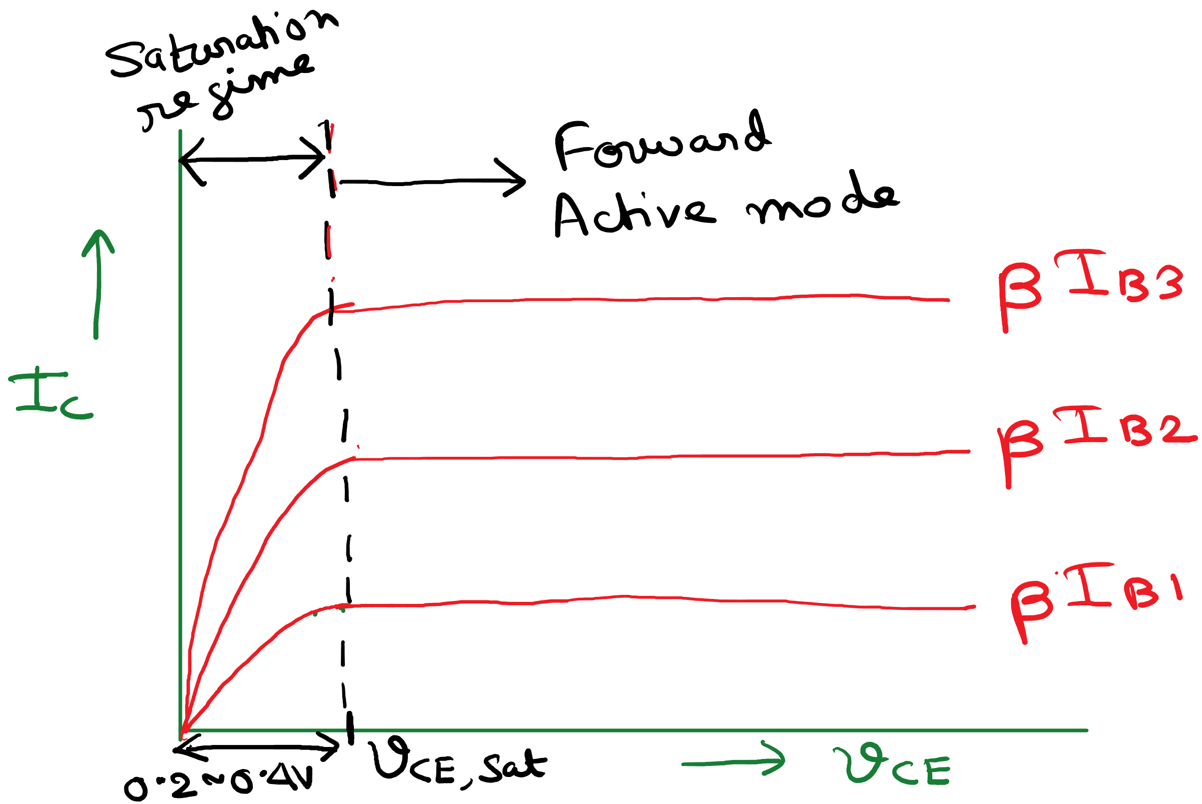
The common Emitter configuration is mostly used in electronic circuits. This is because the emitter current is actually much higher than the base current. For the common Base config emitter current is the input current. So, the common Base config requires a large input current. In amplifiers, the signals to be amplified generally can't generate a large current. So, the common emitter configuration is mostly used because here the input current is the base current which is generally very low.

Common Emitter characteristics :-

$$v_{CE} = v_{BE} + v_{CB}$$

$$\simeq V_\gamma + v_{CB}$$

in $\overline{\text{FA}}$ mode

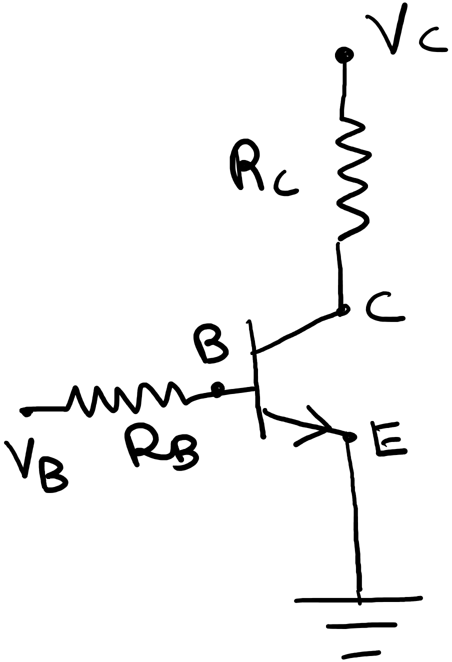


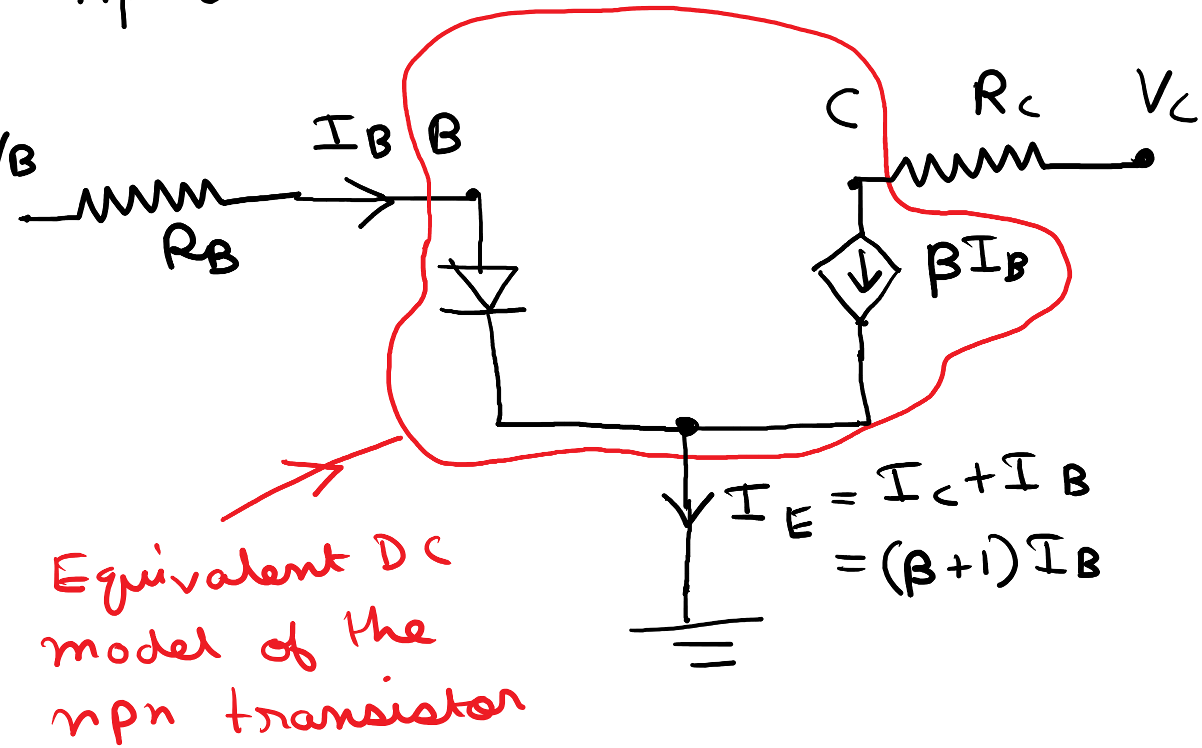
$v_{CE,sat} = 0.2V.$

In the Forward Active mode, the collector current doesnot depend on v_{CE} or v_{BE}. The collector current, in this case, only depends on the Base-to-emitter voltage or the emitter current or the Base current. The minimum value of v_{CE} for which the transistor is in Forward Active mode is denoted by $v_{CE,sat}$. Generally. $v_{CE,sat}$ lies in the range of 0.2V to 0.4V. But we would mostly assume $v_{CE,sat} = 0.2V$.

Equivalent DC models:-

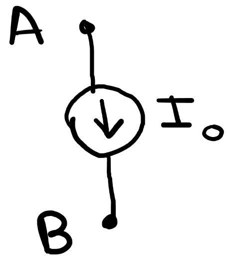
npn



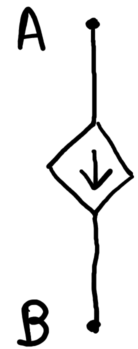


$I_E = I_C + I_B$

$= (\beta + 1) I_B$



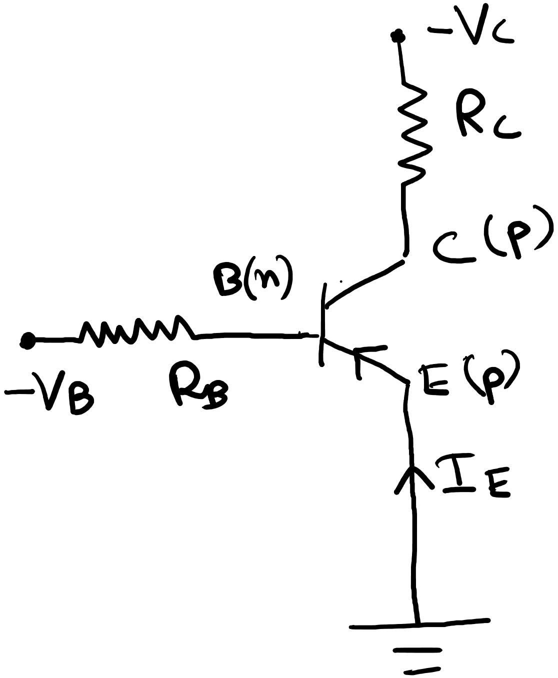
Symbol for independent current source.

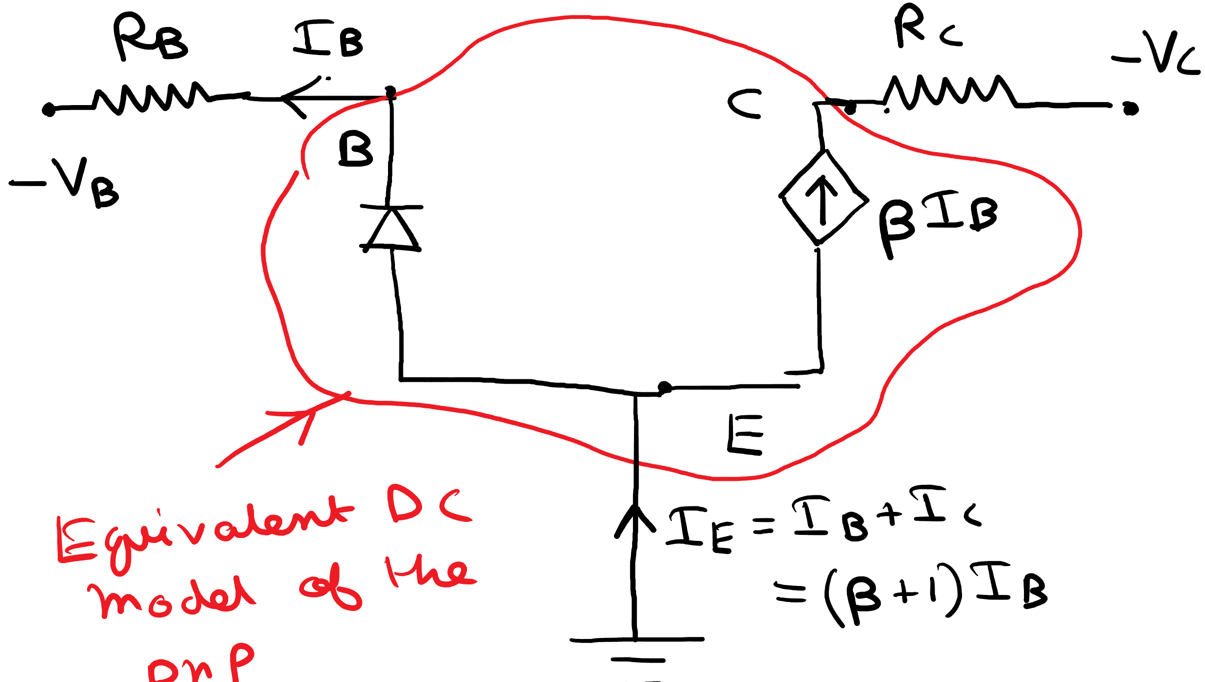


$I_o = f$(other parameters of the system)

Dependent current source.

Equivalent DC model of a pnp transistor.



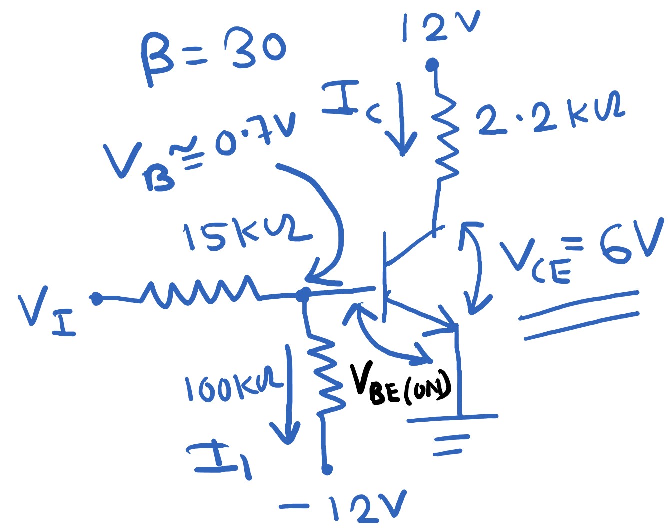


Equivalent DC model of the pnp transistor.

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

Class-18

Q: what is the value of V_I, such that $V_{CE} = 6V$



A:

$$12V = 2.2k\Omega \times I_C + V_{CE}$$

$$\Rightarrow I_C = \frac{12 - V_{CE}}{2.2} mA$$

$$= \frac{12-6}{2.2} mA = 2.72 mA$$

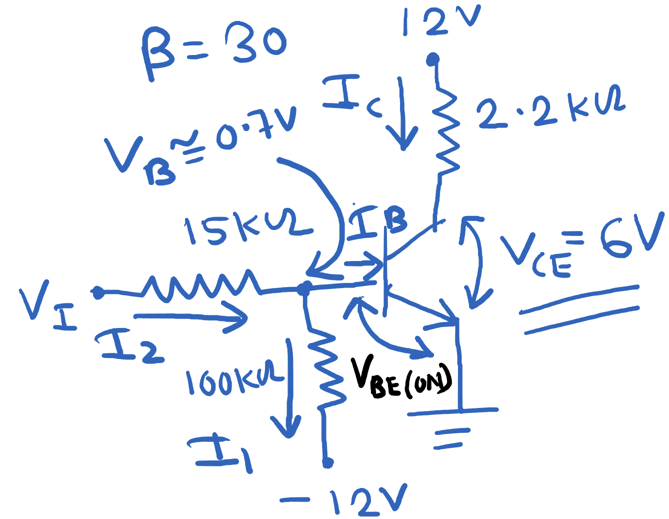
$$I_B = \frac{I_C}{\beta} = \frac{2.72 mA}{30} \cong 0.09 mA$$

In the Forward active mode, $V_{BE} \cong V_{BE(ON)} = 0.7V$

$$I_1 = \frac{0.7V - (-12V)}{100k\Omega} = \frac{12.7}{100} mA = 0.127 mA$$

$$I_2 = \frac{V_I - V_B}{15\,k\Omega}$$

$$= \frac{V_I - 0.7V}{15\,k\Omega} \quad \text{—} \; (1)$$



$$I_2 = I_1 + I_B$$

$$= (0.127\,mA + 0.09\,mA)$$

$$= 0.217\,mA \quad \text{—} \; (2)$$

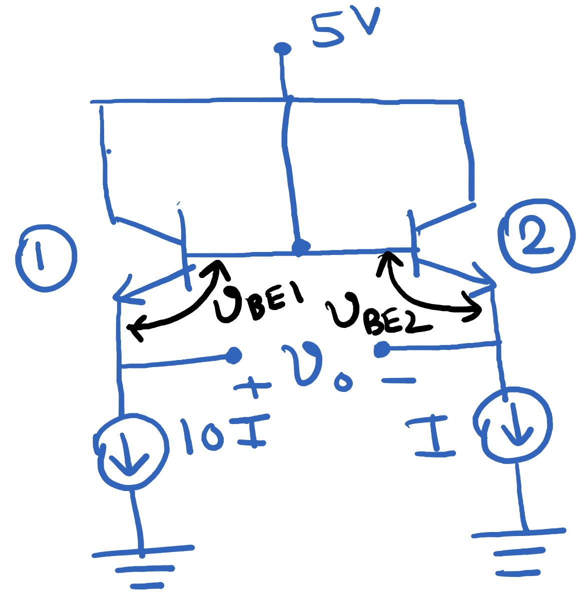
$$\Rightarrow \frac{V_I - 0.7V}{15\,k\Omega} = 0.217\,mA \quad (\text{from } 1 \text{ and } 2)$$

$$\Rightarrow V_I = 0.7V + 15 \times 0.217V = 3.955V$$

Q: $v_o = ?$

A:

$$v_{CB1} = 0 = v_{CB2}$$



The two transistors are therefore operating in forward active mode.

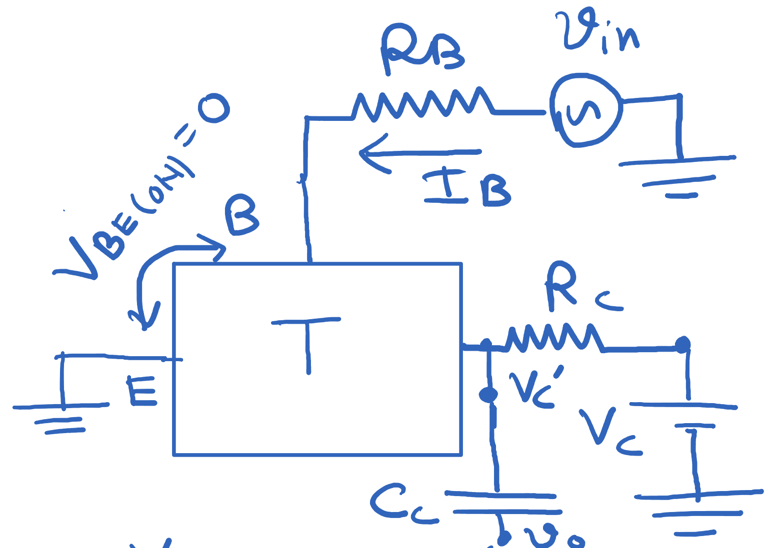
$$10I \cong I_s \exp\left\{\frac{v_{BE1}}{V_T}\right\} \quad \text{— ①}$$

$$I \cong I_s \exp\left\{\frac{v_{BE2}}{V_T}\right\} \quad \text{— ②}$$

$$10 = \exp\left\{\frac{v_{BE1} - v_{BE2}}{V_T}\right\} = \exp\left\{\frac{-(\overbrace{v_{E1} - v_{E2}}^{v_o})}{V_T}\right\}$$

$$\Rightarrow 10 = \exp\left\{\frac{-v_o}{V_T}\right\} \Rightarrow \underline{v_o = -V_T \ln 10 = \frac{KT}{q} \ln 10}.$$

Amplifications:



$V_{BE(ON)} = 0$ (ideal case)

$$v_{in} = V_{BE(ON)} + I_B R_B$$

$$= I_B R_B \quad (\because V_{BE(ON)} = 0)$$

$$\Rightarrow I_B = \frac{v_{in}}{R_B}$$

$$I_c = \beta I_B = \frac{\beta v_{in}}{R_B}$$

$$V_c' = V_c - I_c R_c$$

$$= V_c - \frac{\beta v_{in} R_c}{R_B} = \overset{\nearrow DC}{V_c} - \underbrace{\beta \frac{R_c}{R_B} v_{in}}_{AC}$$

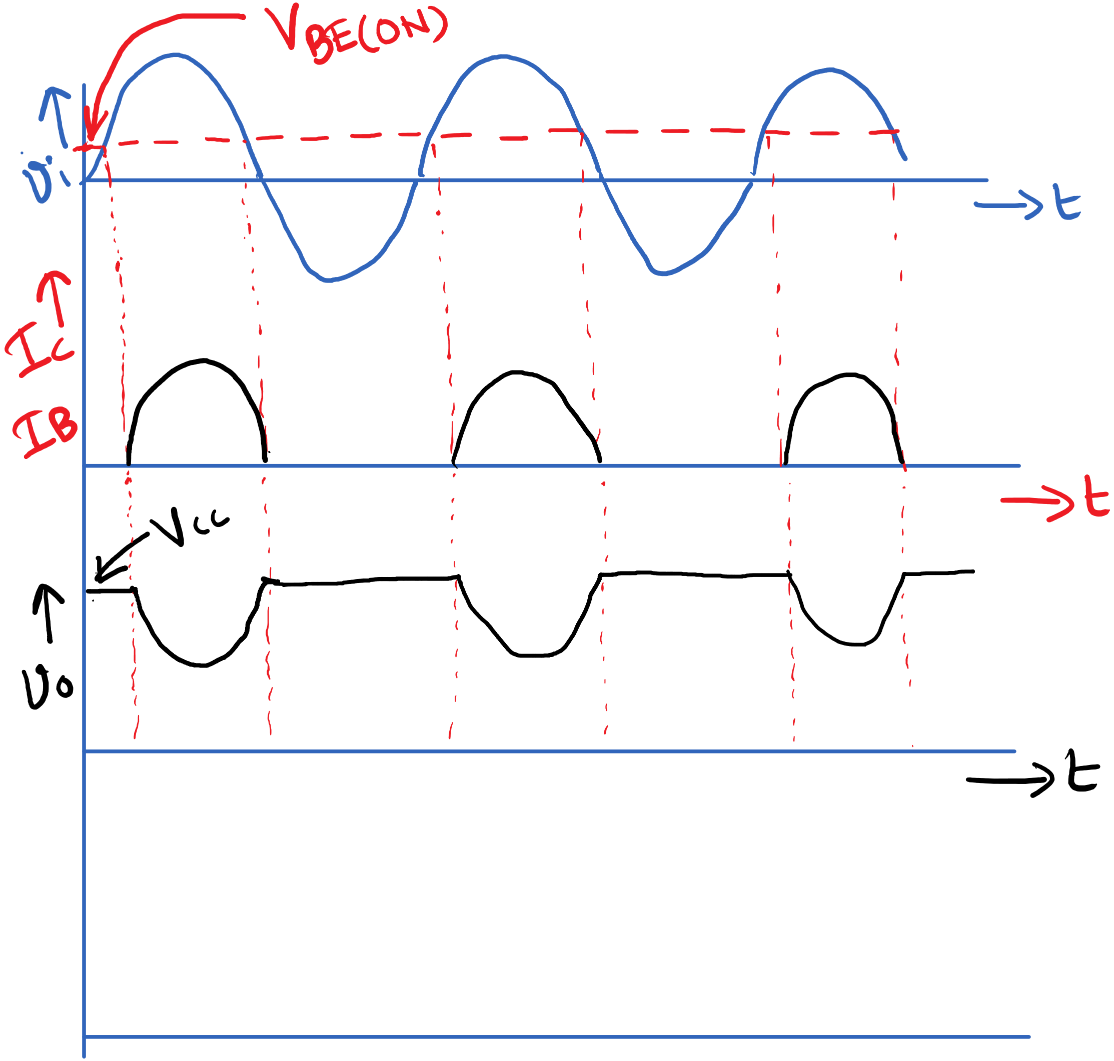
$$v_o = \text{ac component of } V_c'$$

$$= -\beta \frac{R_c}{R_B} v_{in}$$

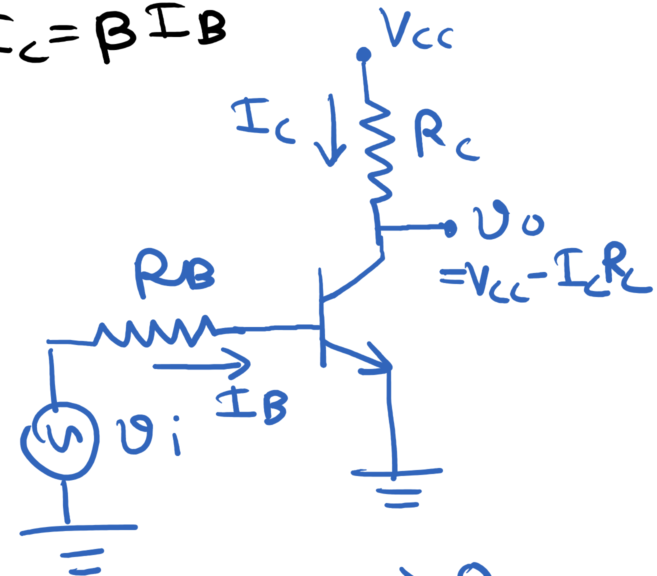
$$v_o = -\beta \frac{R_C}{R_B} v_{in}$$

The negative sign denotes that the output waveform is shifted in phase by 180° with respect to the input waveform.

If $\beta \frac{R_C}{R_B} > 1$, then we get a amplified but opposite phase version of the input signal at the output. For a good amplifier $\beta \frac{R_C}{R_B} >> 1$.



$$I_C = \beta I_B$$



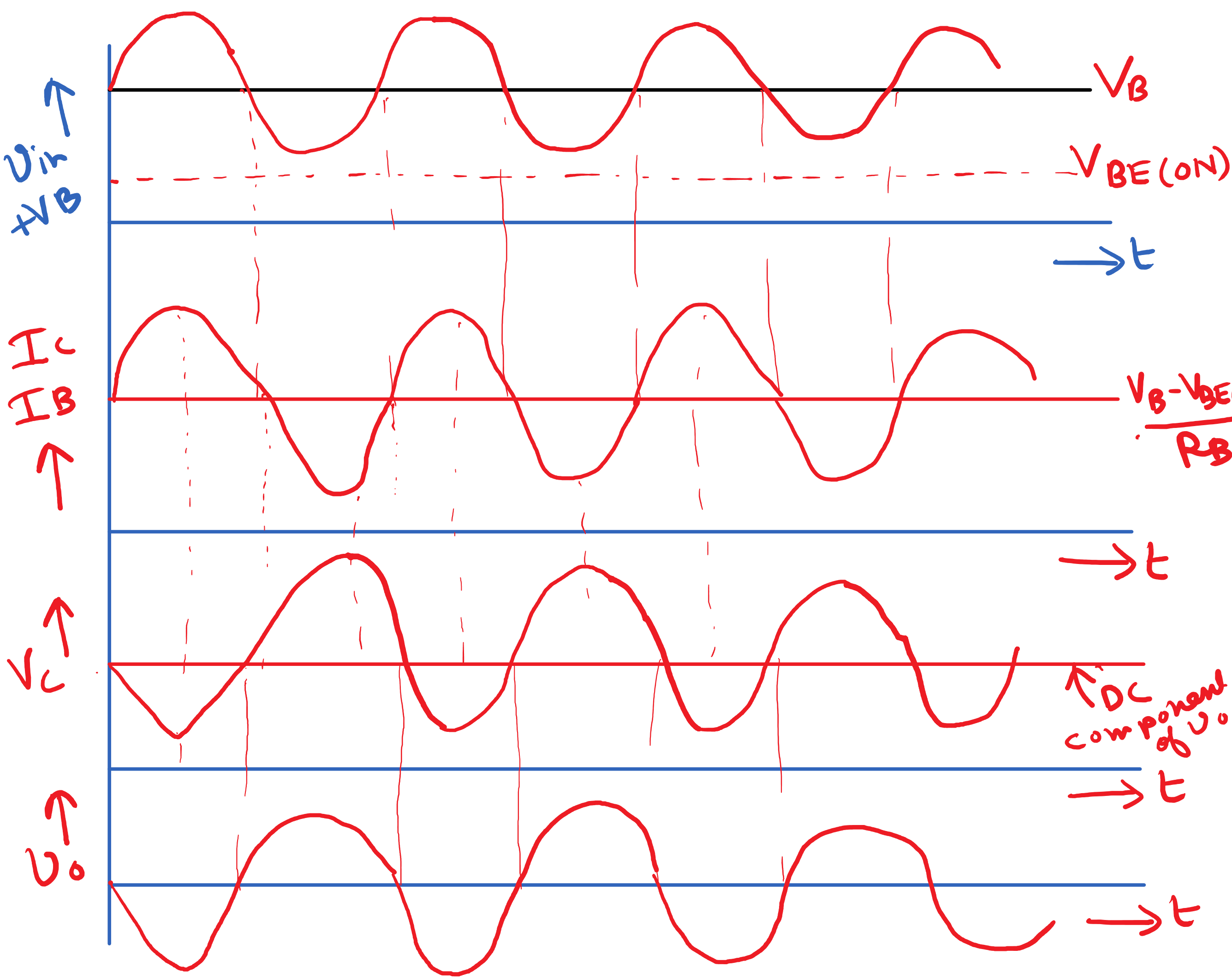
$$V_{BE(ON)} > 0$$

$$I_B \cong \frac{v_i - V_{BE(ON)}}{R_B} \quad \text{if } v_i > V_{BE(ON)}$$

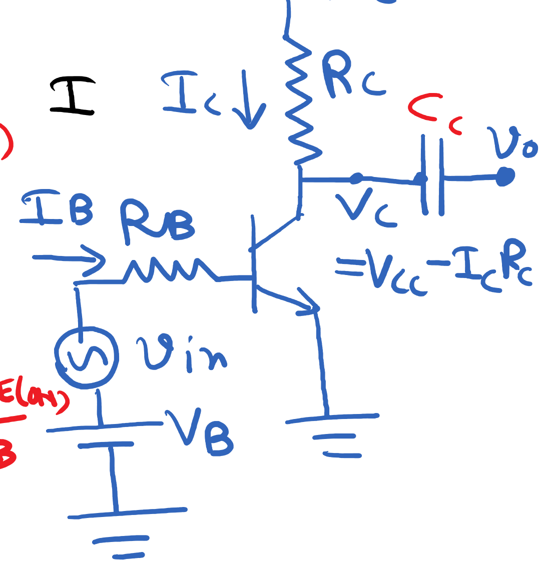
$$I_B \cong 0 \quad \text{if } v_i < V_{BE(ON)}$$

If v_i is directly connected to the Base through a resistor, then we donot get a replica or a scaled version of the input signal at the output.

In most of the cases, the amplitude of v_i is less than $V_{BE(ON)}$. The amplitude of v_i is of the order of tens to hundreds of millivolts. In these cases, the transistor would never turn-on because the input voltage is always less than $V_{BE(ON)}$. So, there is no Base current. So, we get a constant voltage at v_o.



$I_C = \beta I_B$



$$I_B \cong \frac{V_B + v_{in} - V_{BE(ON)}}{R_B}$$

$$= \frac{\left\{\overbrace{V_B - V_{BE(ON)}}^{DC}\right\} + \overbrace{v_{in}}^{AC}}{R_B}$$

$$= \underbrace{\frac{V_B - V_{BE(ON)}}{R_B}}_{DC} + \underbrace{\frac{v_{in}}{R_B}}_{AC}$$

DC AC

The process of surpassing the cut-in voltage of the Base-emitter junction by applying a DC voltage in series with the input signal is called Biasing or DC biasing of the transistor. Both V_{cc} and V_B are a part of DC biasing of the transistor. DC biasing of the transistor is actually necessary for proper amplification and to get a scaled replica of the input signal at the output.

Class - 19

Fixed Biasing Scheme

Q:

$V_{CE} = 2.5V$, $I_C = 5mA$, $\beta = 120$

$R_B, R_C = ?$

A: $V_{CE} = 2.5V$

$V_{R_C} = 5V - V_{CE} = 5V - 2.5V = 2.5V$

$I_C = \frac{V_{R_C}}{R_C} = \frac{2.5V}{R_C} = 5mA$

$\Rightarrow R_C = \frac{2.5V}{5mA} = 0.5 k\Omega$

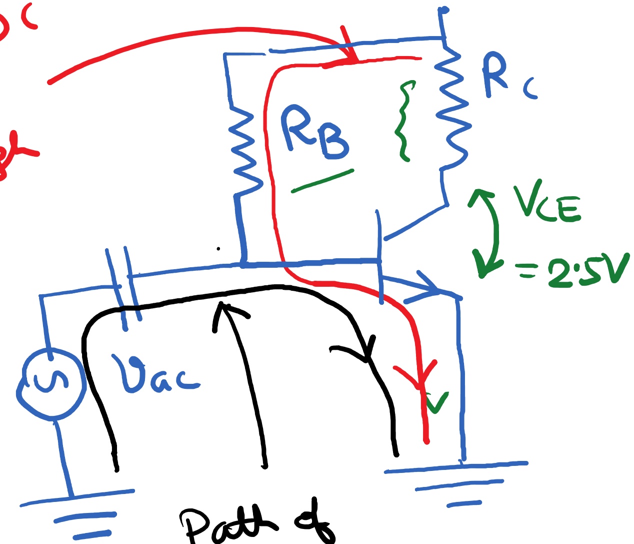
$I_B = \frac{I_C}{\beta} = \frac{5mA}{120} = \frac{1}{24} mA$

$5V = I_B R_B + V_{BE(ON)} = I_B R_B + 0.7V$

$\Rightarrow R_B = \frac{5V - 0.7V}{I_B} = 4.3 \times 24 k\Omega$

$= 103.2 k\Omega$

Path of DC current flow through the Base-emitter junction



Path of AC current flow through the Base to emitter junction

R_B basically controlls the DC base current, which in-turn controlls the DC collector current ($I_C = \beta I_B$).
So, to get a particular value of I_C, we need to manipulate R_B.

Once we get a desired DC value of the collector current, we can manipulate R_C to manipulate the DC value of the collector to emitter voltage.

If $V_I < V_{BE(ON)}$, $I_B = 0$, $I_C = 0$, $V_o = V_{CC}$

If $V_I > V_{BE(ON)}$

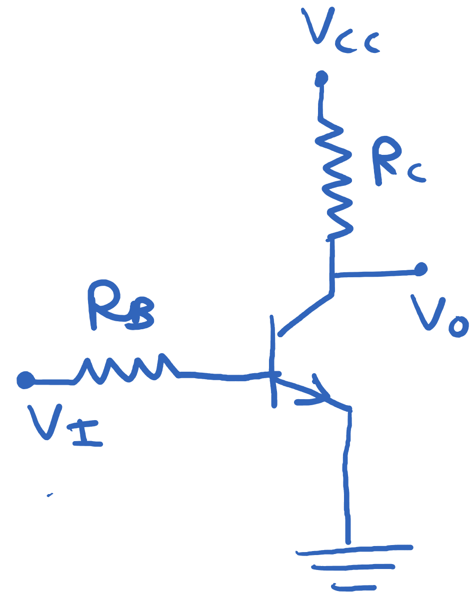
① $I_B \simeq \dfrac{V_I - V_{BE(ON)}}{R_B}$

② $I_C = \beta I_B = \beta \dfrac{(V_I - V_{BE(ON)})}{R_B}$

③ $V_o = V_{CC} - I_C R_C = V_{CC} - \beta \dfrac{R_C}{R_B}(V_I - V_\gamma)$

$= \left(V_{CC} - \beta \dfrac{R_C}{R_B} V_{BE(ON)}\right) - \beta \dfrac{R_C}{R_B} V_I$

④ $\dfrac{dV_o}{dV_I} = -\beta \dfrac{R_C}{R_B}$



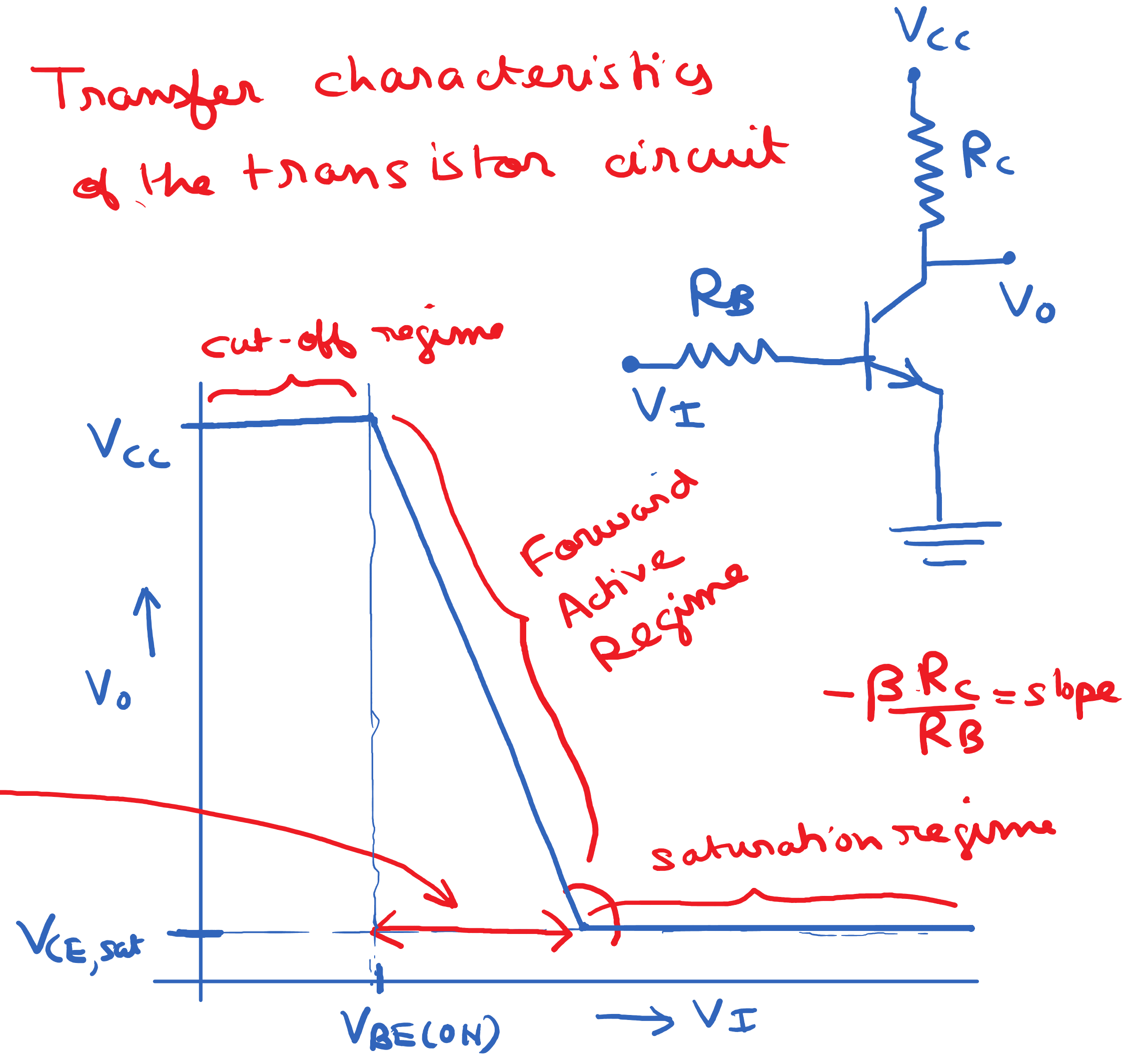
$V_I > V_{BE(ON)}$
$V_o > V_{CE,sat}$
Valid in Forward Active mode.

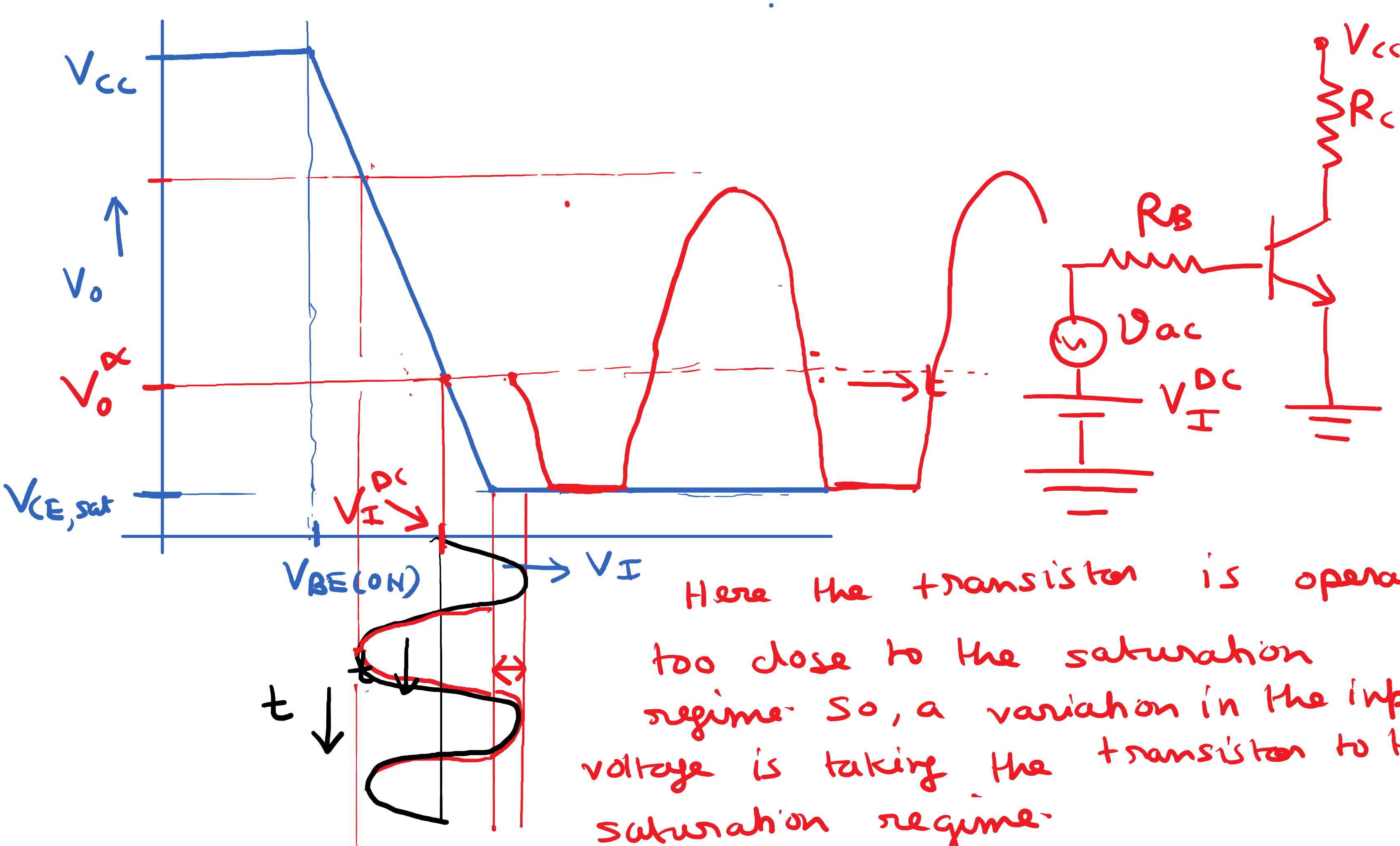
For amplification, $\left|\dfrac{dV_o}{dV_I}\right| > 1$

$\Rightarrow \beta R_C / R_B > 1$

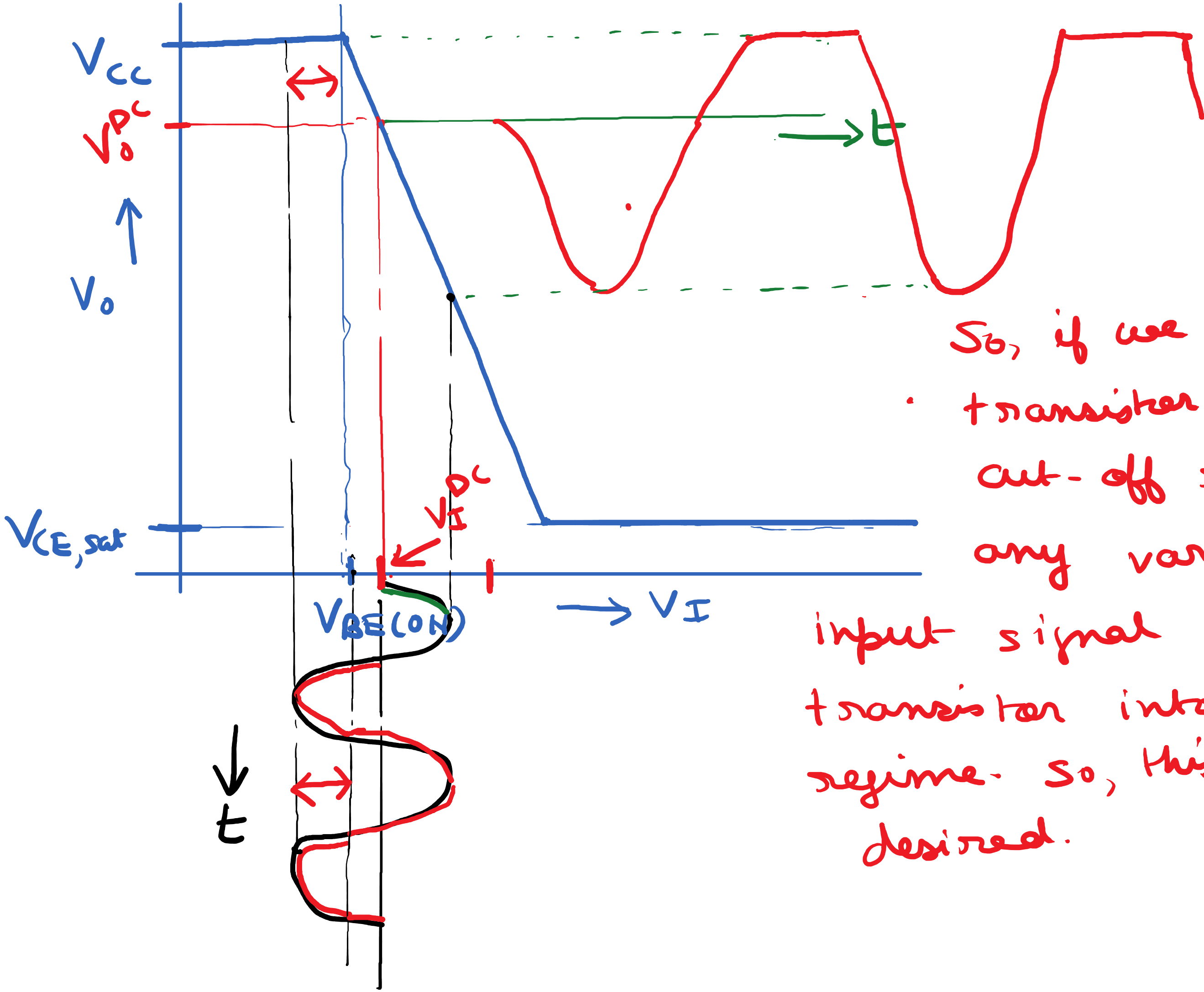
The output voltage varies with the input voltage only in this regime. So, for any value of the input signal, the total voltage at the input must be confined within this regime: Only in this regime the transistor is in the forward active mode.

Transfer characteristics of the transistor circuit

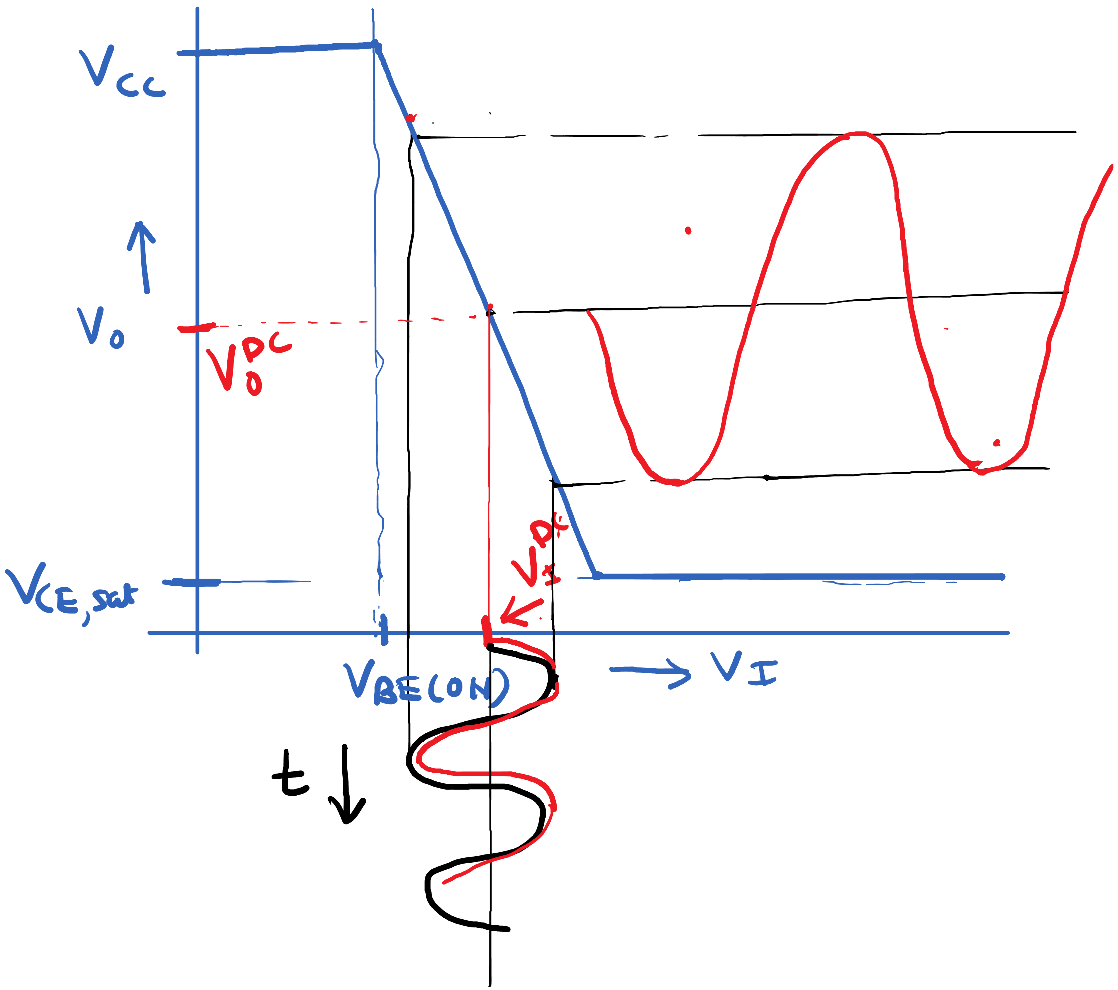




Here the transistor is operating too close to the saturation regime. So, a variation in the input voltage is taking the transistor to the saturation regime.



So, if we bias the transistor close to the cut-off regime, then any variation of the input signal may take the transistor into the cut-off regime. So, this is not desired.



To ensure that the transistor is biased in the Forward Active mode for the entire range of variation of the input signal, a suitable value of V_I^{DC} is somewhere near the the midpoint of the Forward active regime