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Limitations

2 Terminal can't be controlled

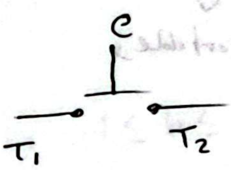
3 terminal device:

i. Linear 3 terminal device (switch)

ii. Non Linear 3 terminal device (BJT, Mosfet)

Switch

$c \rightarrow$ control



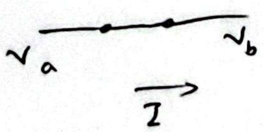
OFF = 0 = False

ON = 1 = True

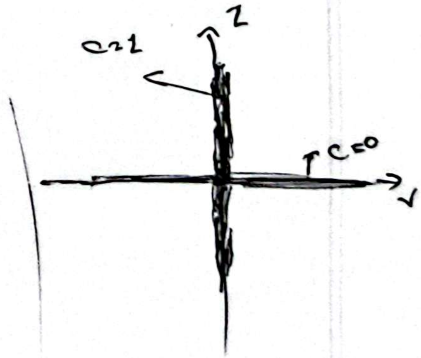
$c = 1$ (ON)

$c = 0$ (OFF)

$c = 1$;



$V = V_a - V_b = 0$



$c = 0$;

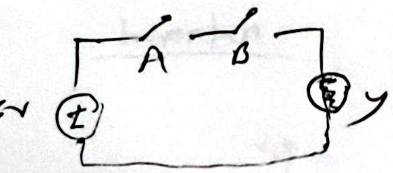
$I = 0$

BJT

1. Bipolar Junction Transistor (current controlled switch)

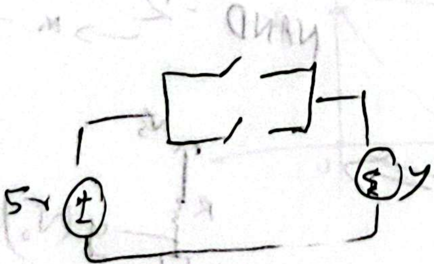
2. Mosfet → Metal oxyde semiconductor field ~~Effect~~ Effect Transistor (voltage controlled switch)

Logic Gate



A	B	y
0	0	0
1	0	0
0	1	0
1	1	1

AND → series

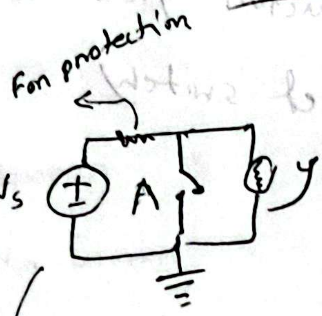


A	B	y
0	0	0
1	0	1
0	1	1
1	1	1

OR → Parallel

Inverter → Not Gate

NOT Gate (Inverter)

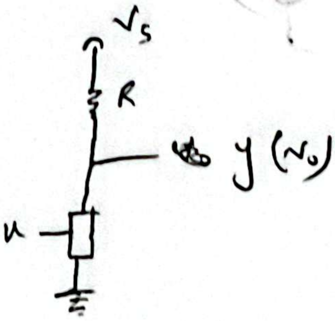


pull up resistor

$y = \bar{A}$

$A = 0 \Rightarrow y = 1$

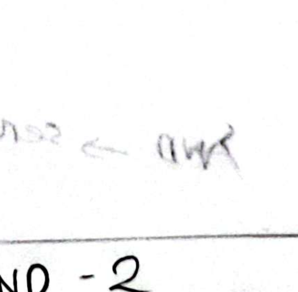
$A = 1 \Rightarrow y = 0$



$y = \bar{x}$

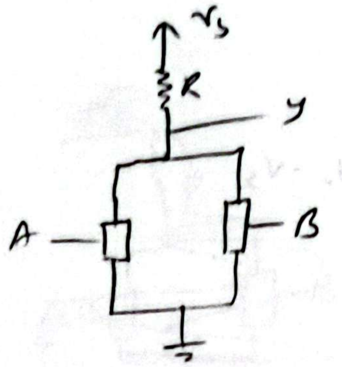
NAND - 2 → No. of input

⇒



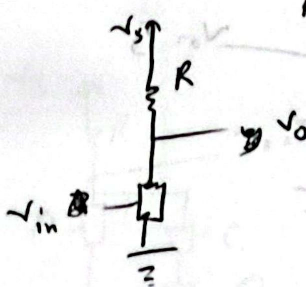
$y = \overline{AB}$

NOR - 2

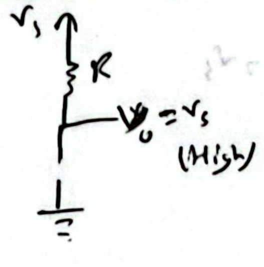


$y = \overline{A+B}$

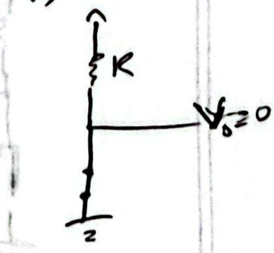
Inverter



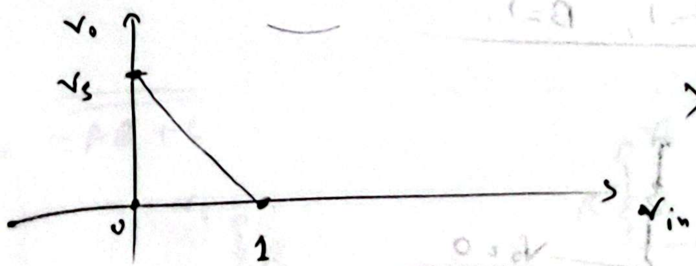
$V_{in} = 0$



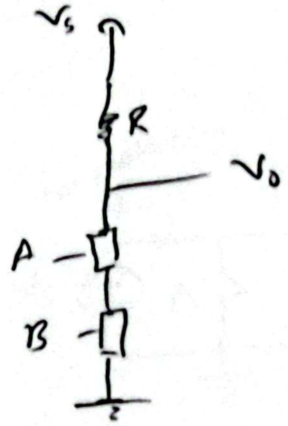
$V_{in} = 1$



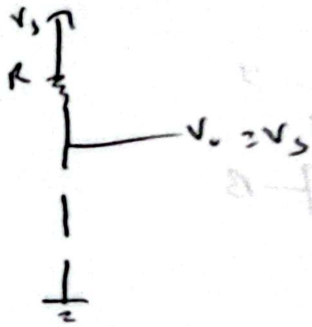
VTC



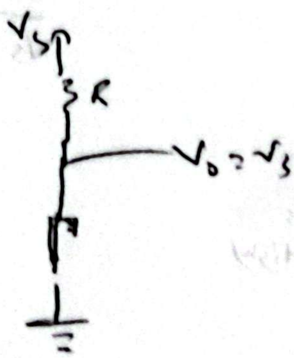
NAND - 2



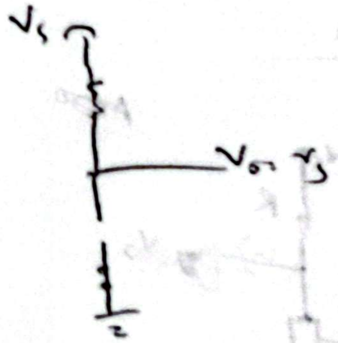
A=0, B=0



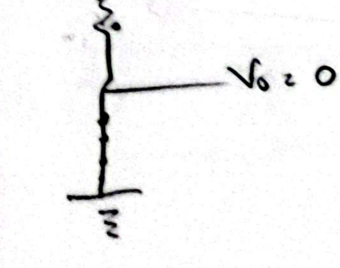
A=1, B=0



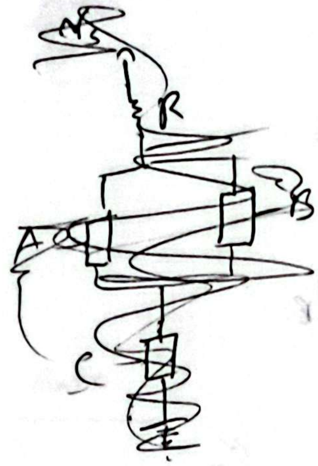
A=0, B=1

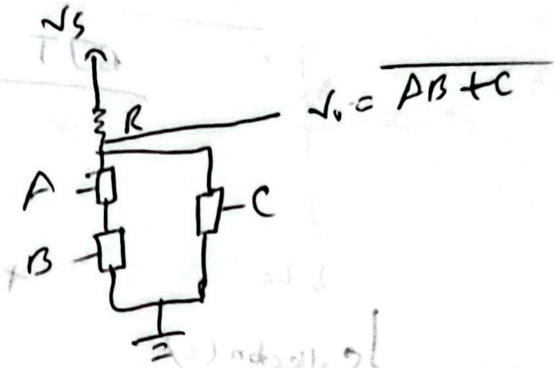


A=1, B=1.

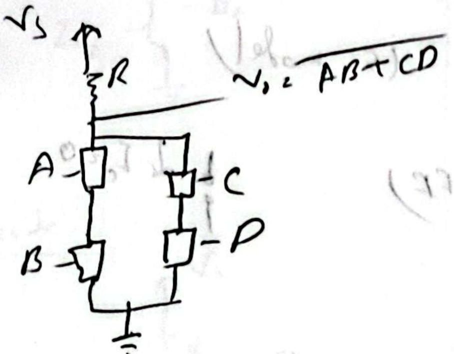


$f = \overline{AB+C}$

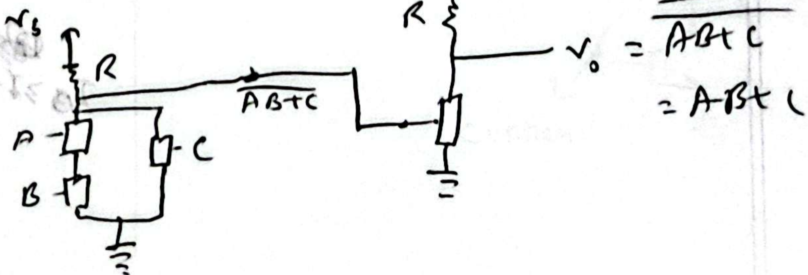




$f = \overline{AB+CD}$



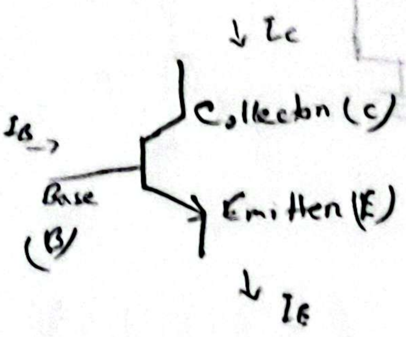
$f = AB+C = \overline{\overline{AB+C}}$



~~BJT~~

current controlled switch

BJT



$+$

$V_{CE} = V_C - V_E$

$-$

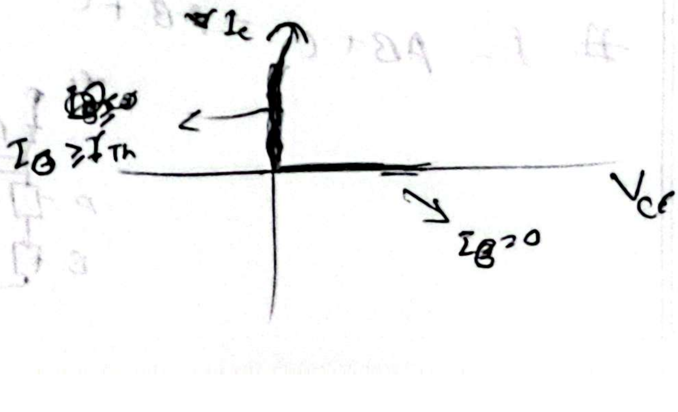
Ideal model of BJT on

(switch model of BJT)

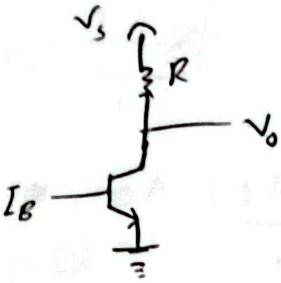
(S model)

$I_B = 0$ BJT (OFF) $I_C = 0$

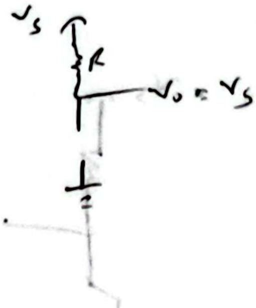
$I_B \geq I_{th}$ BJT (ON) $V_{CE} = 0$



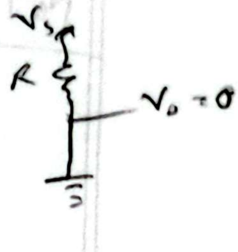
NOT Gate

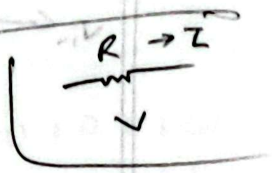


$I_B = 0$

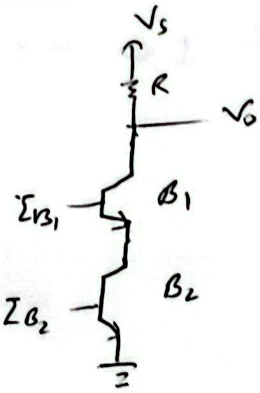


$I_B \geq I_{th}$

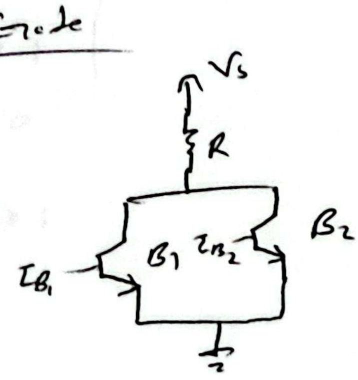




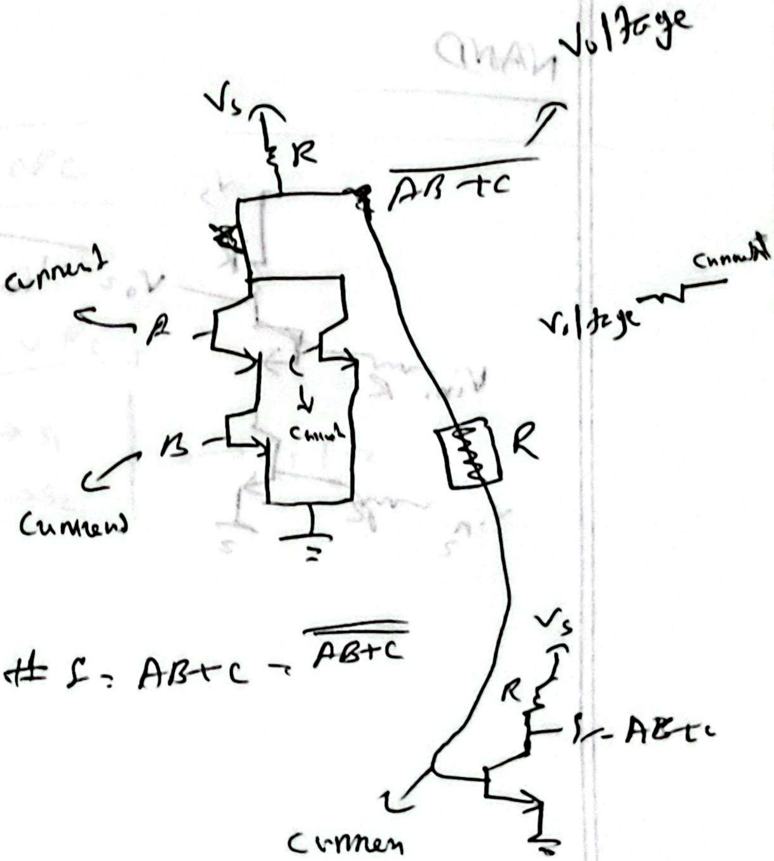
NAND Gate



NOR Gate



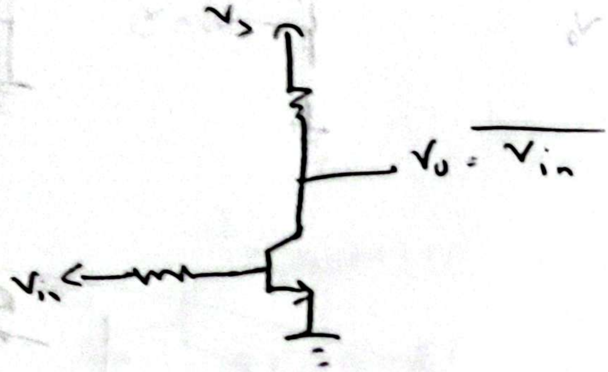
$f = \overline{AB+C}$



$f = AB+C = \overline{\overline{AB+C}}$

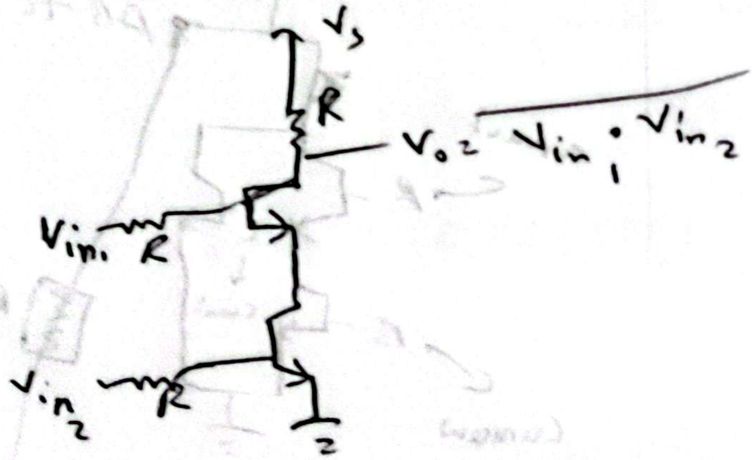
Voltage controlled switch with BJT

NOT



NOR

NAND



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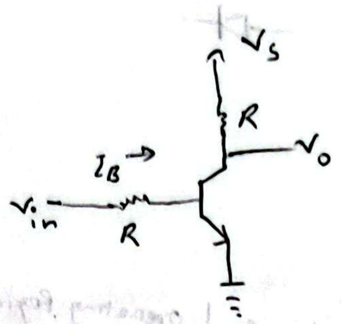
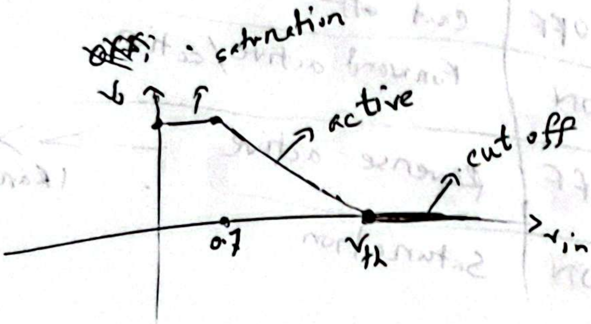
VTC of BJT (Voltage controlled) Inverter:



off, $I_B = 0$

ON: $I_B \geq I_{th}$



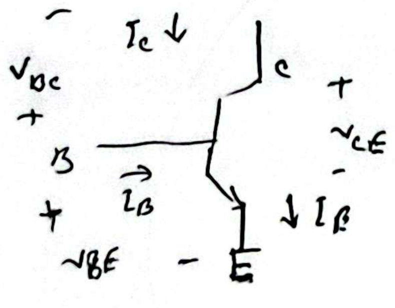
off, $V_{in} < 0.7$

ON, $V_{in} > V_{th}$

$V_{in} < 0.7$ $\therefore V_o = V_s$

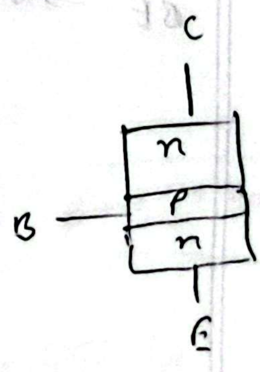
$V_{in} > V_{th}$ $\therefore V_o = 0$

Over simplified operation of BJT



$V_{CE} = V_C - V_E$

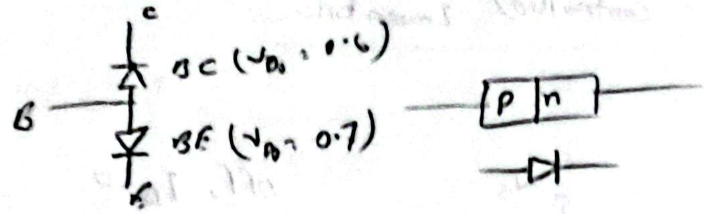
$\Rightarrow$



$I_E = I_B + I_C$

Base $\to$ Less width

Emitter ~~collector~~ $\to$ Highly dopped



(diode equivalent ckt)

	BC	BE	Operating Region
case 1.	OFF	OFF	cut off
case 2.	OFF	ON	Forward active/active
case 3.	ON	OFF	Reverse active → ✕ (Rare case)
	ON	ON	Saturation

BC → OFF, $V_{BC} \le 0.6$

BE → OFF, $V_{BE} \le 0.7$

$$V_{BC} = V_B - V_C$$
$$= V_B + V_E - V_E - V_C$$
$$= (V_B - V_E) - (V_C - V_E)$$
$$= V_{BE} - V_{CE}$$

$\therefore V_{BE} - V_{CE} \le 0.6 \Rightarrow V_C \geq V_{BE} - 0.6$

case-1
(cut off)

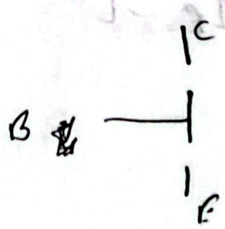
BC ⇒ OFF.

$V_{CE} \geq V_{BE} - 0.6$

BE ⇒ off

$V_{BE} \leq 0.7$

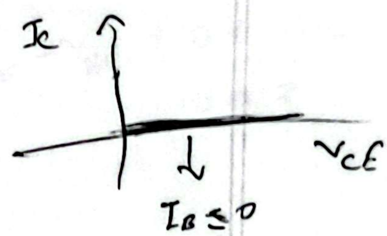
diode equivalent ckt



$I_B = 0$

$I_C = 0$

$I_E = 0$



$V_{CE} = V_{BE} - 0.6 = 0.7 - 0.6 = 0.1$

Case-2
(Forward active)

BC ⇒ OFF

$V_{CE} \geq V_{BE} - 0.6$

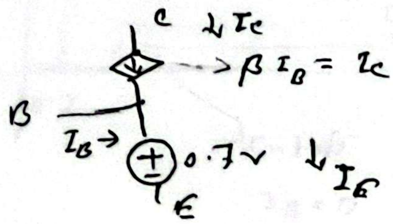
$\therefore V_{CE} = 0.7 - 0.6 = 0.1$

BE ⇒ ON

$I_{BE} > 0$

$\boxed{\beta \Rightarrow 50 \text{ to } 200}$

diode equivalent ckt



$I_C \propto I_B$

$\Rightarrow I_C = \beta I_B$

$$I_E = I_B + I_C$$

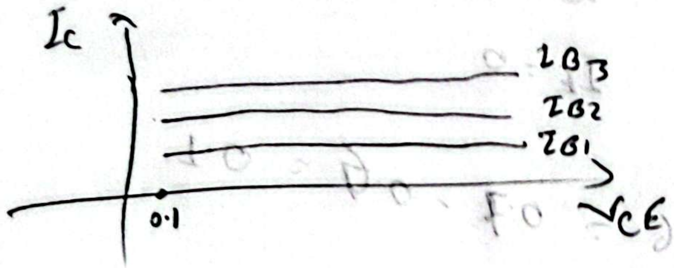
$$\boxed{\alpha \to 0.9592.}$$

$$= \frac{I_C}{\beta} + I_C$$

$$= I_C\left(\frac{1}{\beta} + 1\right)$$

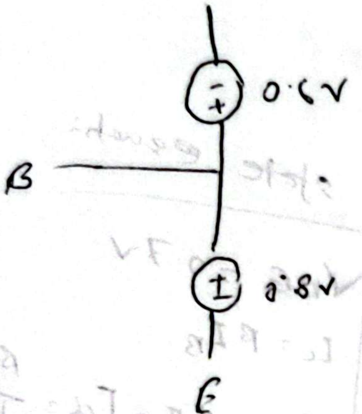
$$= I_C\left(\frac{1+\beta}{\beta}\right)$$

$$I_C = \left(\frac{\beta}{1+\beta}\right) I_E \quad = \alpha I_E \quad \because \left[\alpha = \frac{\beta}{1+\beta}\right]$$



$$I_{B_3} > I_{B_2} > I_{B_1}$$

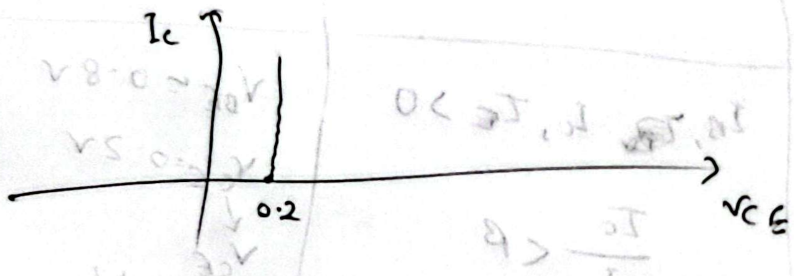
case-3 : BC → ON BE → ON
(saturation)



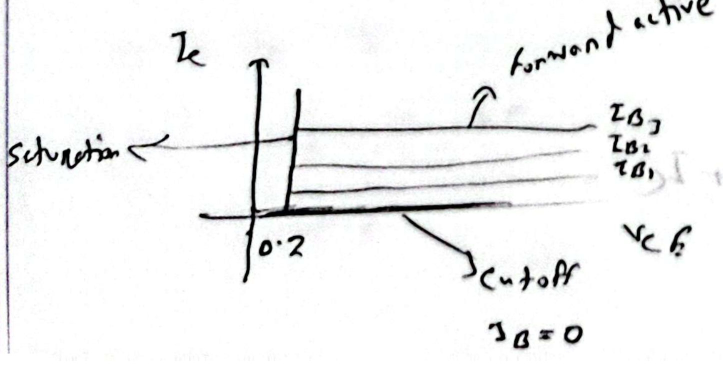
$V_{BE} = 0.8V$

$V_{BC} = 0.6V$

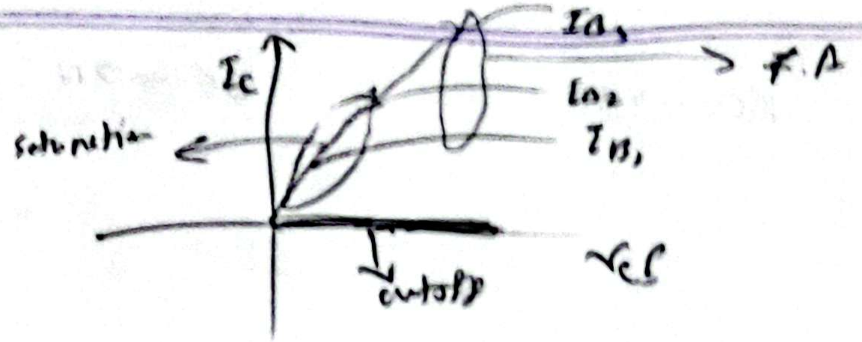
$V_{CE} = V_{BE} - V_{BC} = 0.8 - 0.6 = 0.2$



Oven simplified I-V



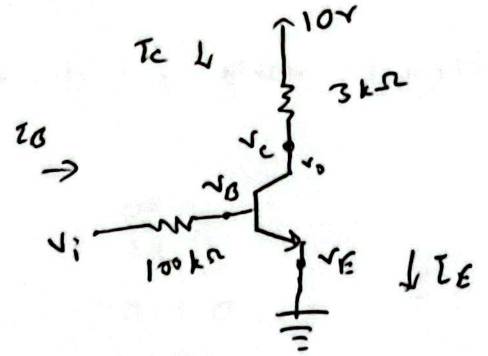
$I_{B_3} > I_{B_2} > I_{B_1}$



Operating Region	Condition	state equation
Forward Active	$I_B, I_C, I_E > 0$ $V_{CE} > 0.2V$	$V_{BE} = 0.7V$ $I_C = \beta I_B$ $I_C = \alpha I_E \left[\alpha = \frac{\beta}{1+\beta}\right]$
saturation	$I_B, I_C, I_E > 0$ $\frac{I_C}{I_B} < \beta$	$V_{BE} = 0.8V$ $V_{CE} = 0.2V$ ↓ $V_{CE(sat)}$
cut off	$V_{BE} \leq 0.7V$ $V_{BC} \leq 0.6V$	$I_B = I_C = I_E = 0$

$$I_E = I_B + I_C$$

Ex-1 :



find V_B . when $V_i = 1V$, $\beta = 100$.

sol:

Assuming.

$B_1 \rightarrow$ Forward active

$V_{BE} = 0.7$

$I_{CB} = \beta I_B$

$I_C = \alpha I_E$

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

$V_{BE} = V_B - V_E$

$\Rightarrow 0.7 = V_B - 0$

$\therefore V_B = 0.7$

Ohms law on 100kΩ,

$$I_B = \frac{V_{in} - V_B}{100}$$

$$= \frac{1 - 0.7}{100}$$

$$= 0.003 \text{ mA}$$

$$I_C = \beta I_B = 100 \times 0.003 = 0.3 \text{ mA}$$

$$I_E = I_C + I_B = 0.003 + 0.3 = 0.303 \text{ mA}$$

Ohms law on 3kΩ,

$$I_C = \frac{10 - V_C}{3}$$

$$\Rightarrow 0.3 = \frac{10 - V_C}{3}$$

$$\therefore V_C = 9.1 \text{ V}$$

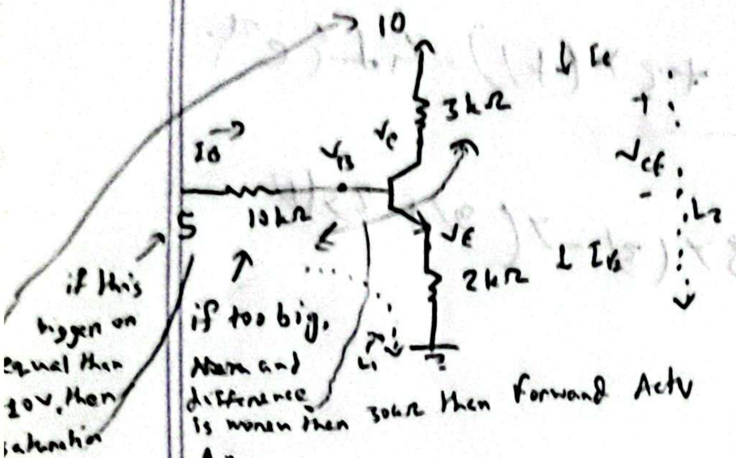
$$V_{CE} = V_C - V_E = 9.1 - 0 = 9.1 \text{ V}$$

Verification

$I_C, I_B, I_E > 0$
$V_{CE} = 9.1 > 0.2V$ } correct Assumption

$$V_o = V_C = 9.1 \text{ V}$$

Eu-2:



Given $\beta = 100$

find I_B, I_C, I_E

Apiss

Ans:

Assumption:

$\beta \Rightarrow$ Active

$V_{BE} = \cancel{0.7} \; 0.7\,V$

$I_C = \beta I_B$

$I_C = \alpha I_E$

$\alpha = \frac{\beta}{1+\beta} = \frac{100}{101}$

$I_E = I_B + I_C$

need to show, $I_B, I_C, I_E > 0$

$V_{CE} > 0.2$

KVL along L_1,

$5 - 0 = 10 I_B + V_{BE} + 2 I_E$

$\Rightarrow 5 = 10 I_B + 0.7 + 2 I_E$

$I_C = \beta I_B$

$\alpha I_E = \beta I_B$

$\therefore I_E = \frac{\beta}{\alpha} I_B$

$\Rightarrow 5 = 10 I_B + 0.7 + 2 \times \frac{\beta}{\alpha} I_B$

$\therefore I_B = 0.02\ mA$

$I_C = 2\ mA$

$I_E = 0.02 + 2$

$= 2.02$

KVL along L_2,

$10-0 = 3I_C + V_{CE} + 2I_E \Rightarrow 10 = 3\times 2 + V_{CE} + 2\times 2.02 \Rightarrow V_{CE} = -0.04$

Verification:

$I_B, I_C, I_E > 0$

$V_{CE} = -0.04 \not> 0.2$

Assumption wrong.

Assumption-2:

$B \rightarrow$ saturation

$V_{BE} = 0.8$

$V_{CE} = 0.2$

need to show, $\frac{I_C}{I_B} < \beta$

KVL along L_1,

$5-0 = 10I_B + V_{BE} + 2I_E$

$10I_B + 2I_E - 4.2 = 0 \;..(i)$

KVL along L_2,

$10-0 = 3I_C + V_{CE} + 2I_E$

$3I_C + 2I_E - 9.8 = 0 \;..(ii)$

$I_E = I_B + I_C$

$I_B + I_C - I_E = 0 \;..(iii)$

$I_B = 0.025$

$I_C = 1.95$

$I_E = 1.975$

$\frac{I_C}{I_B} = 78 < \beta = 100$

$\therefore$ Assumption correct