EEEE lec 36 20/11/23

DC biasing Basics

Module 5: [BJT operation, CE, CB, CC configuration of BJTs]

[BJT as a switch, & voltage amplifier]

Applications

BJT : Bipolar junction transistor (1948, Bell labs)

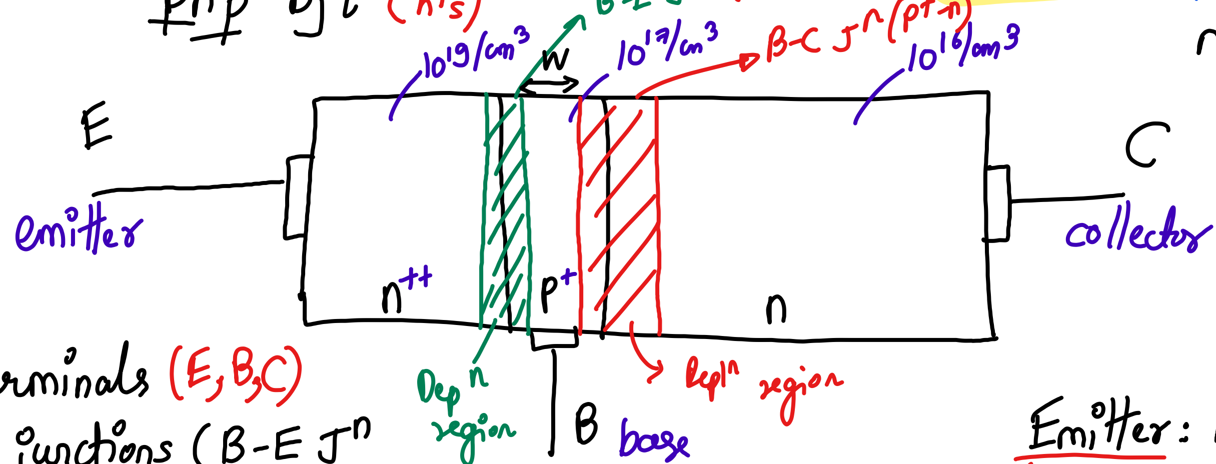
Types : npn bjt (e^-s) – maj. carr

pnp bjt (h^+s) – maj. carr

PN J^n → F.B → W ↓ → I ↑

→ R.B → W ↑ → μA

npn BJT



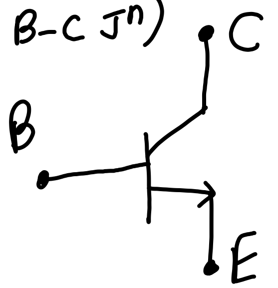
3 terminals (E, B, C)

two junctions (B-E J^n, B-C J^n)

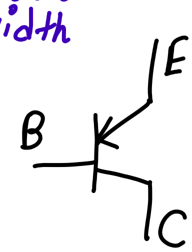
Emitter : heavily doped

Base : moderately doped → narrow width

Collector : lightly doped → wider width



npn BJT Symbol



pnp BJT symbol

Different regions of operation

	BE J^n	BC J^n
Amplifier [① Active region	F.B	R.B
Switch [② Cut-off region (OFF)	R.B	R.B
③ Saturation region (ON)	F.B	F.B
④ Inverse-active region → Avoided (not used)	R.B	F.B

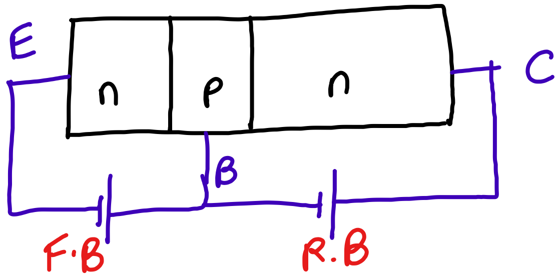
(BJT as amplr)

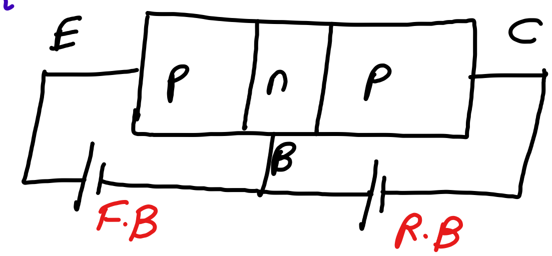
BJT as (switch)

F.B → forward bias

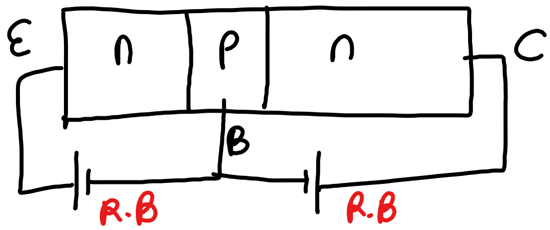
RB → reverse bias

Active region

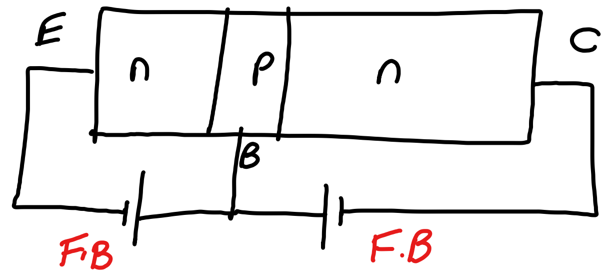




Cut-off region



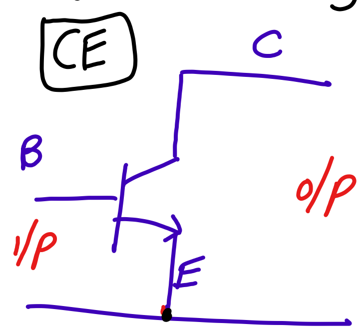
Saturation region

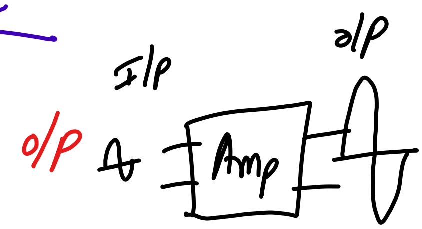


"Bipolar" → charge carriers of both polarities (e^-s & holes) → take part in current conduction process

Principle of BJT : It involves the use of the voltage between (V_{BE}) two terminals to control the current flowing in the 3rd terminal (I_C)

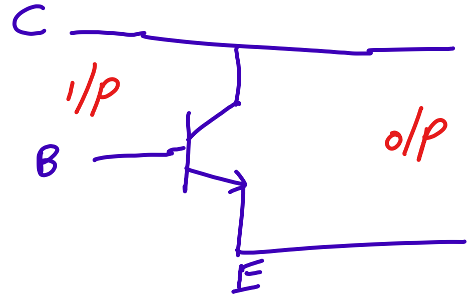
$\boxed{CE}$

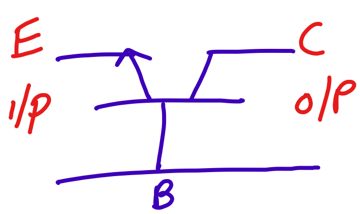




BJT configuration (BJT as ampl^r)

1. Common emitter (CE)
2. Common base (CB)
3. Common collector (CC)

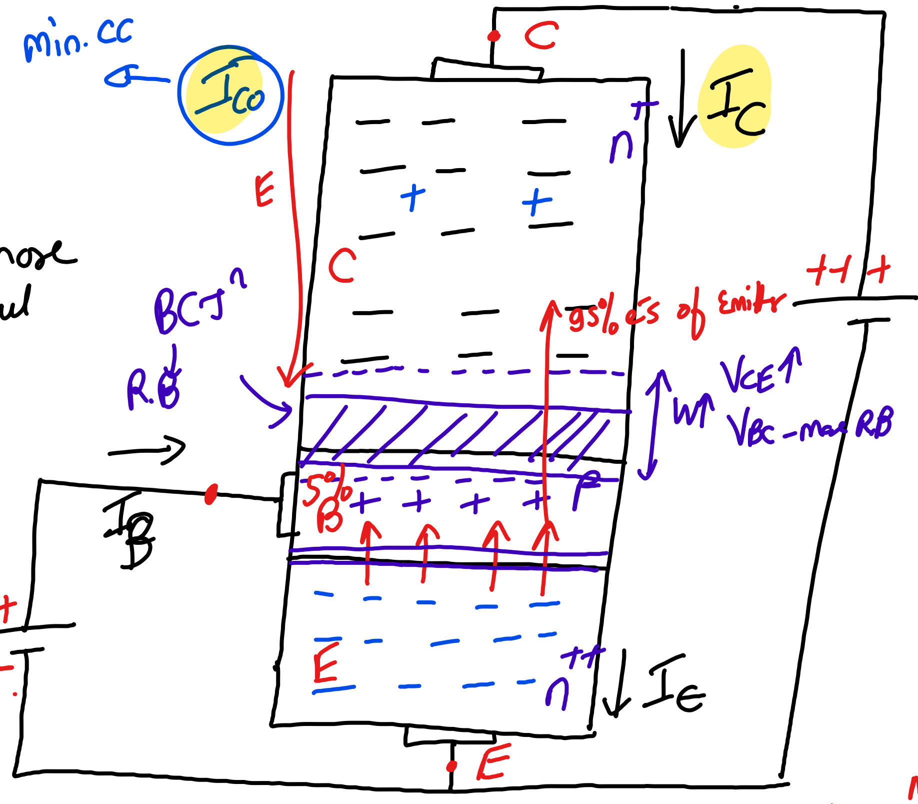




Working of npn BJT in active region (CE configuration)

Active region:
BEJ^n → F.B
BCJ^n → R.B
→ E-field more powerful

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



o/p current "I_C"

I/p current "I_B"

Terminals current: $I_C \gg I_B$

I_C, I_E, I_B
mA, mA, μA

"V_{BE}" → control I_B → control "I_C"

$$I_E = I_C + I_B$$
(I_E: mA, I_C: mA, I_B: μA)

$I_E = I_C + I_B$

current gain

$\alpha < 1$

$$\boxed{\beta = \frac{I_C}{I_B}}$$

$I_E = I_C + I_B$
$I_E = \beta I_B + I_B$

$$\boxed{I_E = (1+\beta) I_B}$$

$I_E \approx I_C$; $\boxed{I_C = \alpha I_E}$

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

BJT : current controlled device

V_{BE} (I/p voltage) → I_B (I/p current) → I_C (o/p current)

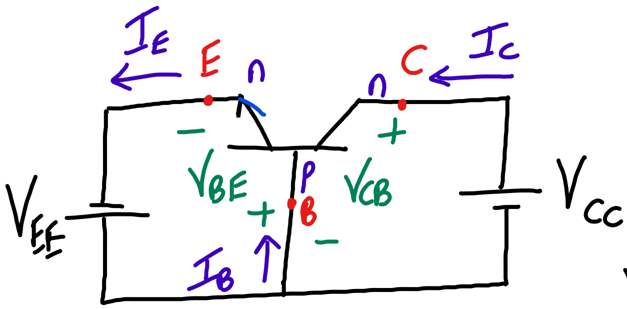
→ $I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B$

$$\boxed{I_C = \beta I_B}$$

β → current gain (50–400)

—×—

EEEE BJT CB configuration



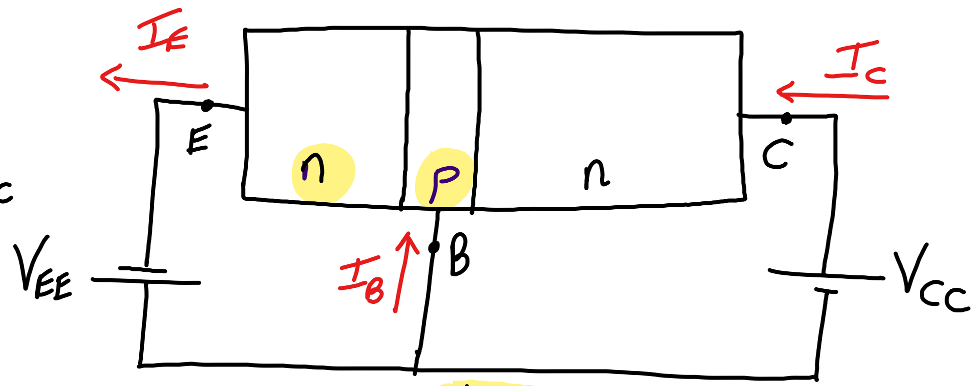


fig 1

① In common base (CB) configuration, input is applied between 'B' and 'E' and output is taken between 'C' and 'B'

② For BJT to be used as an amplifier ⟶ npn bjt should be operated in active region

i.e B-E junction → forward bias
and B-C junction → reverse bias

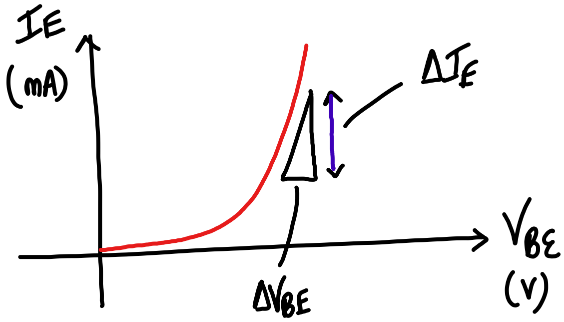
③ Terminal current in bjt,

$$\boxed{I_E = I_C + I_B}$$

④ Behavior of bjt in CB mode can be described by two characteristics :

a) Input characteristics
b) Output characteristics

⑨ From input characteristics, we can find the input impedance of the device

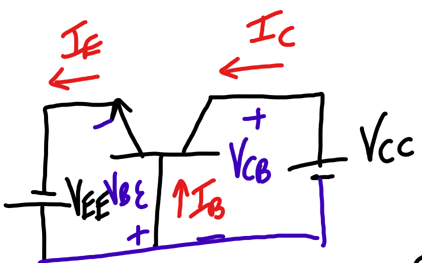


$$R_{in} = \frac{\Delta V_{BE}}{\Delta I_E}\Bigg|_{V_{CB}\ \text{constant}}$$

small changes

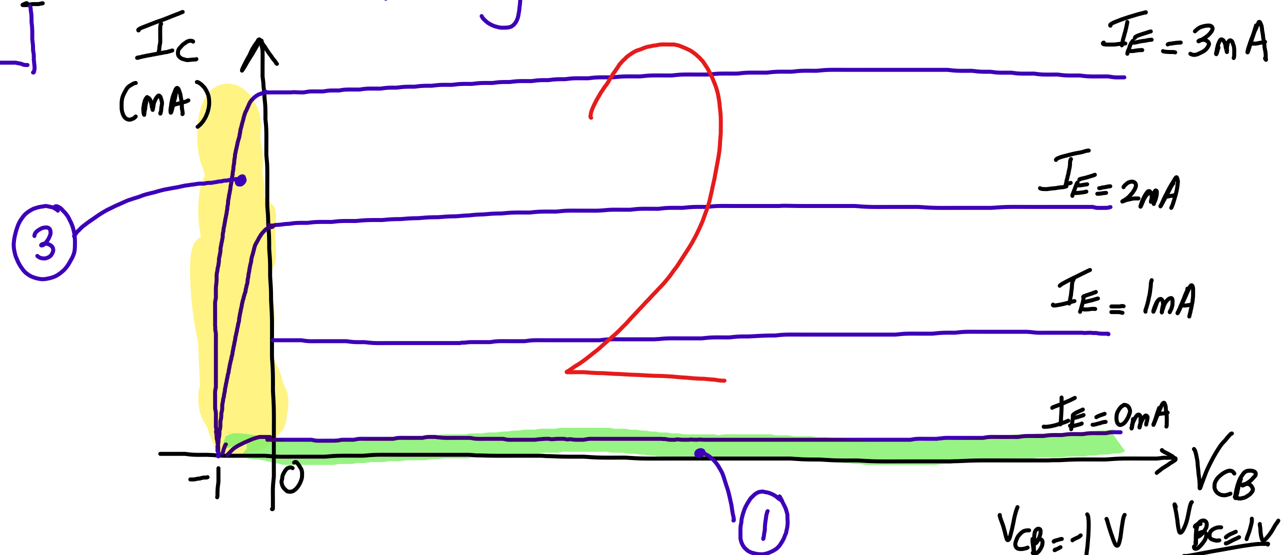
huge changes

Thus, R_{in} is very low (in ohms) for npn BJT in CB configuration



I_C : o/p current

V_{CB} . o/p voltage



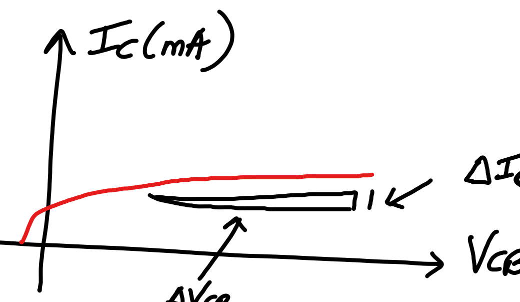
Region 1 : Cut-off

Region 2 : Active

Region 3 : Saturation

fig 3 : Output characteristics of npn bjt in CB configuration

V_{CB} Vs I_C | I_E constant



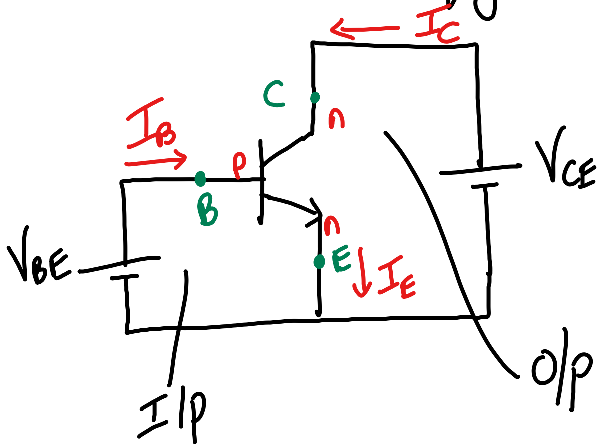
o/p resistance

$$R_{out} = \frac{\Delta V_{CB}}{\Delta I_C}\Bigg|_{I_E\ \text{constant}}$$

v. high for CB configuration

EEEE BJT CE configuration

- most famous configuration for BJT as amplifier



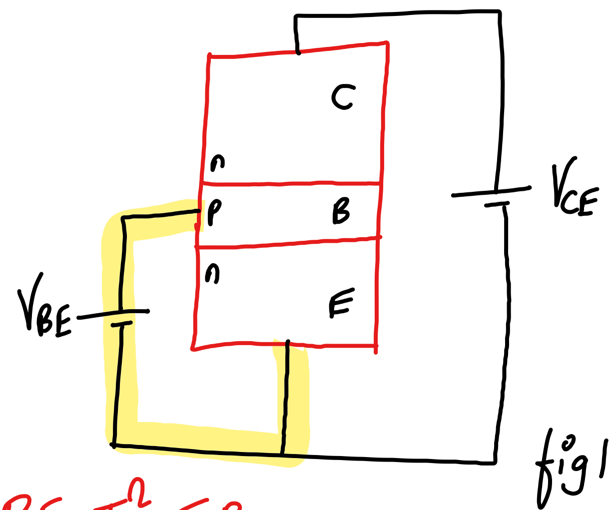
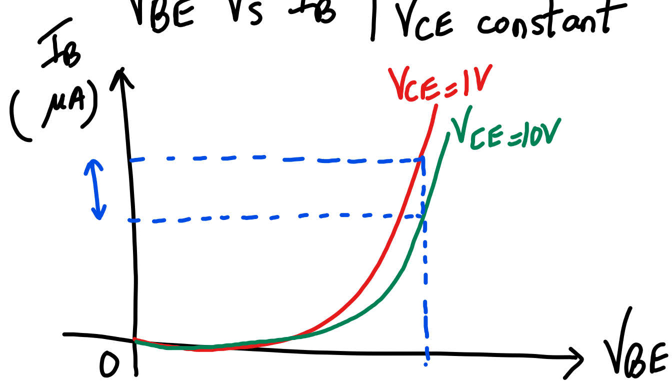


fig 1

npn BJT in active region → BE J^n F.B
BC J^n R.B

① Input characteristics:

V_{BE} Vs $I_B \,|\, V_{CE}$ constant



② I/p characteristics is similar to PN J^n characteristics since BE J^n is forward-biased

i.e As $V_{BE}\uparrow$, $I_B \uparrow$ses exponentially for constant V_{CE} value (i.e BC J^n is R.B)

③ As $V_{CE}\uparrow$ses → I_B is reducing? why?

a) $V_{CE} = V_{CB} + \underline{V_{BE}}$ ..... ($V_{CB} = V_{CE} - V_{BE}$)

∴ with V_{BE} constant, if $V_{CE}\uparrow \rightarrow V_{CB}\uparrow$ses

↳ emitter is common terminal

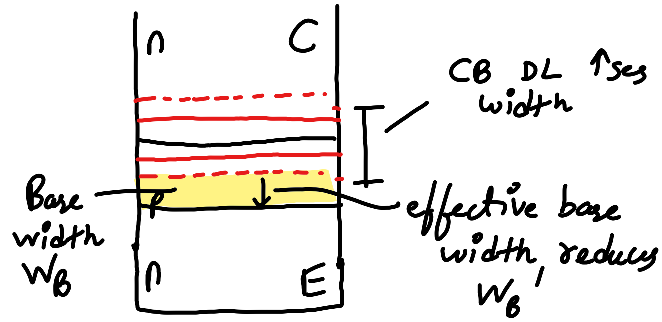
b) As $V_{CB}\uparrow$ses, CB J^n is more R.B

↓

c) i.e CB depletion region width ↑ses

↓

i.e effective base width reduces from W_B to W_B'



↓

d) i.e Possibility of e^--holes recombination in base region will reduce

↓

e) i.e Most of e^-s travelling from emitter to base gets collected at collector.

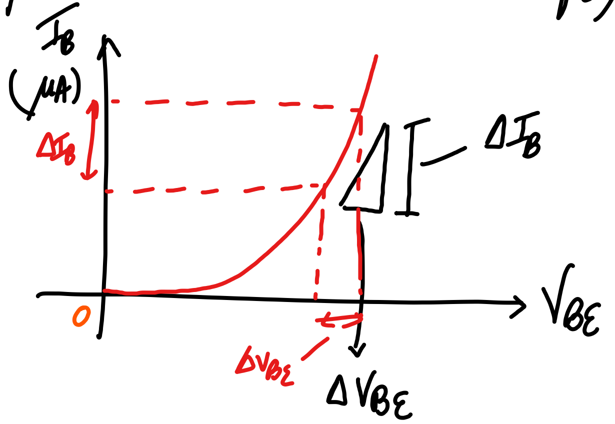
i.e I_B reduces

∴ As V_{CE} ↑ses → I_B ↓ses i.e curve shifts Left hand side

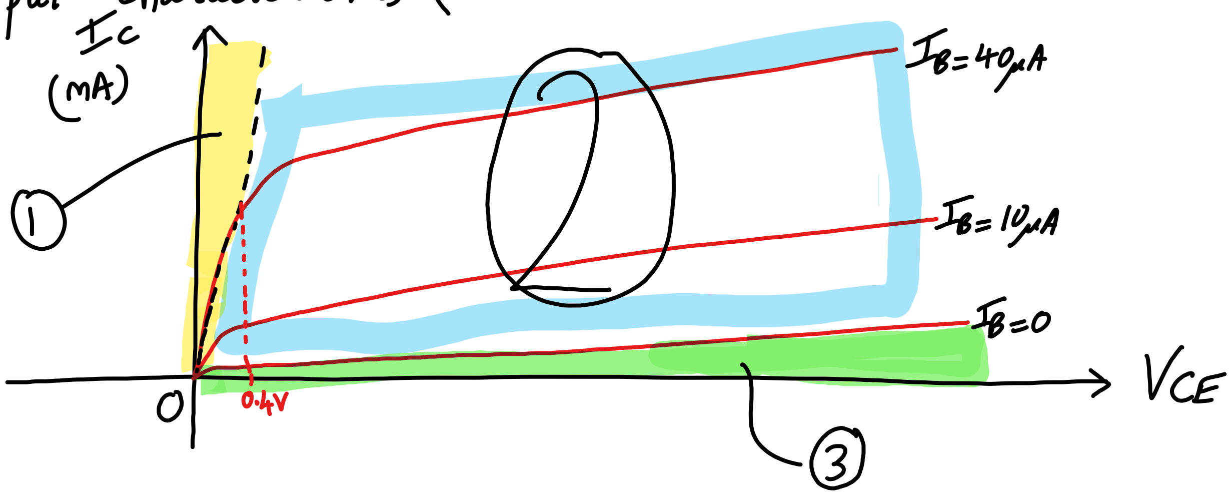
④ Input resistance (R_{in}) from input characteristics (CE config)

$$\boxed{R_{in} = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE}\ \text{constant}}}$$

→ large value (in kΩ)



⑤ Output characteristics (V_{CE} Vs I_C at constant I_B value)



Region 1 – Saturation

Region 2 – Active

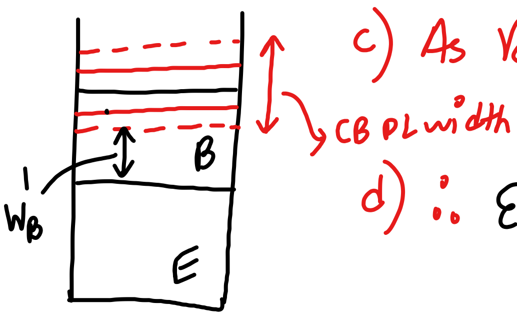
Region 3 – Cut-off

⑥ In active region → As I_B ↑ses → I_C ↑ses ($I_C = \beta I_B$)

→ As V_{CE} ↑ses → I_C also ↑ses slightly

a) Since $V_{CE} = V_{CB} + V_{BE}$

b) V_{BE} being constant (I_B constant) → As V_{CE} ↑ → V_{CB} ↑ses



c) As V_{CB} ↑ses, CB depletion layer width ↑ses

d) ∴ Effective base width will reduce (W_B')

e) i.e I_B contribution will reduce (as less of electron's will recombine with holes in base region)

f) i.e most of $\bar{e}$s travelling via base will be collected by collector

i.e I_C ↑ses

∴ As V_{CE} ↑ses → I_C ↑ses with it slightly

(BJT is used as an amplifier in active region of bjt)

⑦ Since, I_B – I/p current , $I_C = \beta I_B$ — o/p current

$$\boxed{\beta_{dc} = \frac{I_C}{I_B}}$$

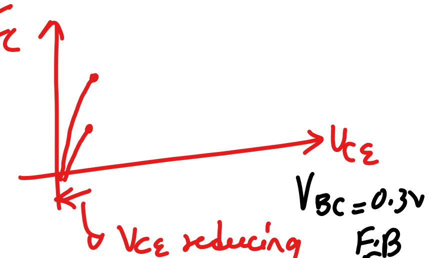
→ "DC" CE current gain

$$\boxed{\beta_{AC} = \frac{\Delta I_C}{\Delta I_B}}$$

β_{dc} almost same as β_{AC}

⑧ In saturation region, as the value of V_{CE} reduces

a) $V_{CE} = V_{CB} + \underbrace{V_{BE}}_{\text{constant}}$



i.e As $V_{CE} \downarrow \rightarrow V_{CB} \downarrow$ses

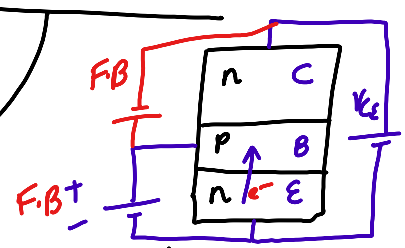
$V_{CB} = -9.3V$

$V_{BC} = 0.3V$ F.B

V_{CE}	= V_{CB}	+ V_{BE}
10V	9.3V	0.7
0.4V	−0.3V	0.7V
0V	−0.7V	0.7V

b) CB becomes lesser R.B & finally at very low value of V_{CE} → CB J^n becomes F.B

c) BE J^n is already F.B



d) As CB J^n becomes F.B → e^- will not reach collector & ∴ I_C reduces to zero as V_{CE} is reduced to lower value

e) i.e BJT operates in saturation region

⑨ npn bjt operates in cut-off region when $I_B = 0$ but here $I_C \neq 0$?

$I_C = \beta I_B + \_\_\_$

a) When $I_E = 0 \rightarrow$ leakage current $I_C = \underline{I_{CBO}}$

leakage

i.e $\boxed{I_C = \alpha I_E} + I_{CBO}$ — (1)

but $I_E = I_C + I_B$

i.e $I_C = \alpha (I_C + I_B) + I_{CBO}$

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

i.e $I_C = \dfrac{\alpha}{1-\alpha} I_B + \left(\dfrac{1}{1-\alpha}\right) I_{CBO}$

i.e $I_C = \beta I_B + \left(\dfrac{1}{1-\alpha}\right) I_{CBO}$

In cut-off region $\rightarrow I_B = 0$

$\therefore I_C \approx \left(\dfrac{1}{1-\alpha}\right) I_{CBO}$

$\dfrac{1}{1-\alpha}$ - large value

i.e $\boxed{I_C \approx (\beta + 1) I_{CBO}}$ when $I_B = 0$

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

$1 + \beta = \dfrac{1}{1-\alpha}$

value of leakage current at $I_B = 0$

called as "I_{CEO}" $\longrightarrow$ Collector to emitter leakage current with base open

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

(10) Properties of CE configurations:

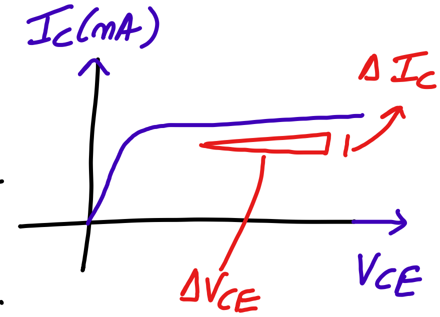
a) Moderate current gain

b) Moderate voltage gain

c) Moderate R_{in} & R_{out}

d) High power gain

o/p resistance from o/p characteristics



$$\boxed{R_{out} = \frac{\Delta V_{CE}}{\Delta I_C}\Bigg|_{I_B \text{ constant}}}$$

large value (in kΩ)

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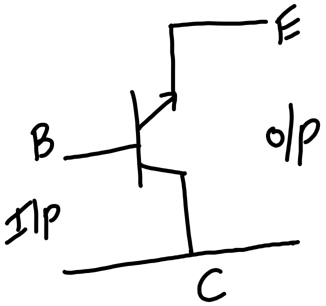
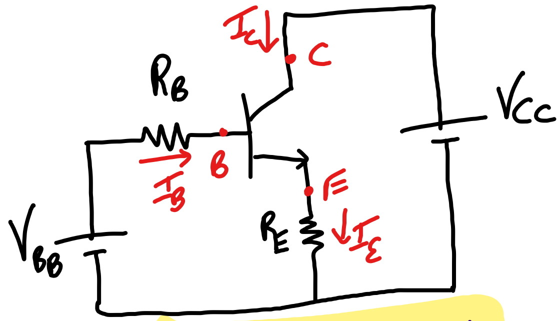
EEEE Common Collector configuration



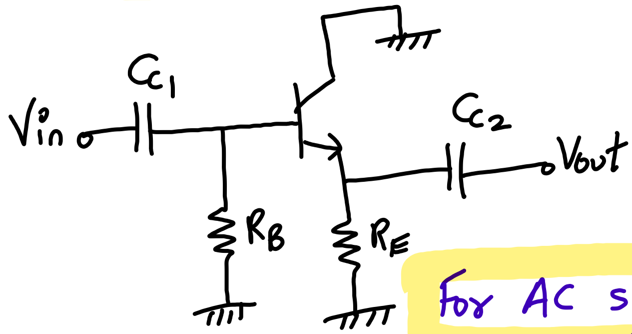


For DC signal

B-E J^n is F.B

B-C J^n is R.B

I/p side	O/p side
I_B	I_E
V_{CB}	V_{CE}
I/p chr	o/p chr
V_{CB} Vs I_B	V_{CE} Vs I_E



For AC signal

① Input characteristics (V_{CB} Vs I_B) @ V_{CE} constant

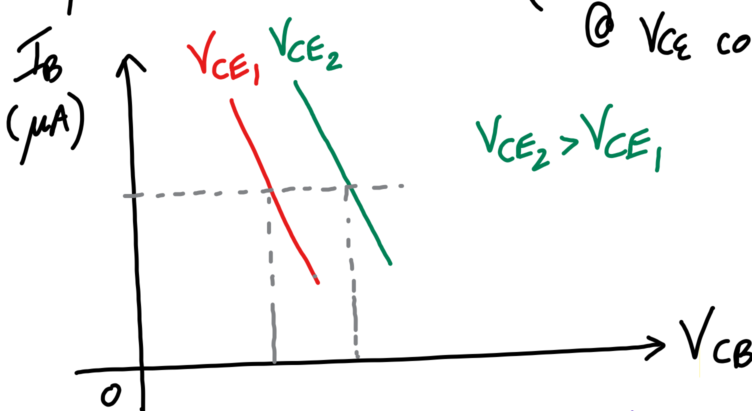


fig 2: Input characteristics of npn bjt in CC configuration

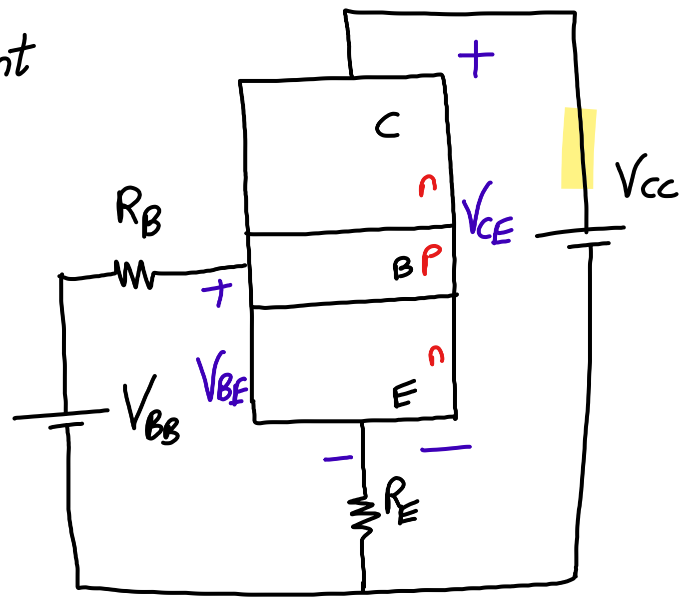


fig 1

② As V_{CB} ↑ses → I_B ↓ses ? why ?

a) $V_{CE} = V_{CB} + \underbrace{V_{BE}}_{\text{fixed}}$

↓

b) As V_{CE} ↑ses → V_{CB} ↑ses

↓

c) As V_{CB} ↑ses → width of BC DL ↑ses → effective base width reduces

↓

DL - Depletion layer

d) i.e Probability of recombination of EHP in base reduces
↓ (EHP: e^--hole pair)

e) i.e $I_B \downarrow$ses

i.e As $V_{CB} \uparrow$ses $\rightarrow I_B \downarrow$ses

③ For fixed value of V_{CB} ; $V_{CE} = \underbrace{V_{CB}}_{\text{fixed}} + V_{BE}$

↓

i.e As $V_{CE} \uparrow$ses $\longrightarrow V_{BE} \uparrow \longrightarrow$ more $\bar{e}$s pushed towards base region by emitter

↓

i.e $I_B \uparrow$ses

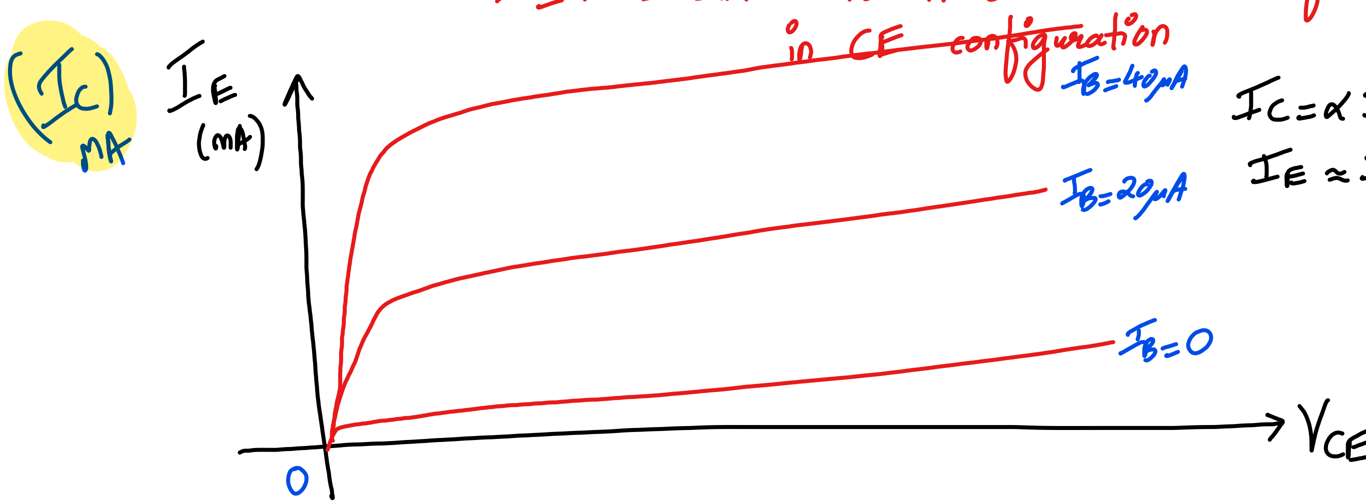
④ $$\frac{I_E}{I_B} = \gamma \rightarrow \text{gamma}$$

I_E — o/p current

I_B — I/p current

⑤ o/p characteristics (I_C Vs V_{CE} | I_B constant)

→ It is similar to o/p characteristics of npn bjt in CE configuration



$I_C = \alpha I_E$

$I_E \approx I_C$

⑥ $I_E = I_C + I_B$; $\gamma = \dfrac{I_E}{I_B}$; $I_C \approx \beta I_B$

$$\gamma = \frac{I_C + I_B}{I_B}$$

i.e $\gamma = \frac{I_C}{I_B} + 1 \approx \beta + 1$

i.e $\boxed{\gamma = 1 + \beta}$

Also, $\gamma = \frac{\alpha}{1-\alpha} + 1 = \frac{1}{1-\alpha}$

i.e $\gamma = 1+\beta = \frac{1}{1-\alpha}$

7. <u>Common collector</u> ~~properties~~:

1. High input resistance
2. Low output resistance
3. High current gain ($= 1+\beta$)
4. Low voltage gain (≈ 1)
5. Low power gain

——×——