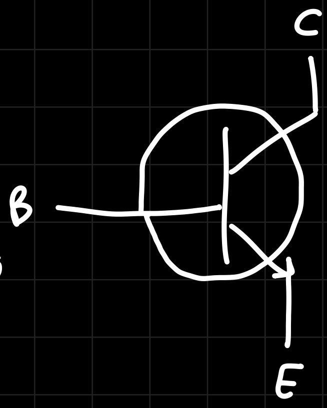
BJT (Revision)



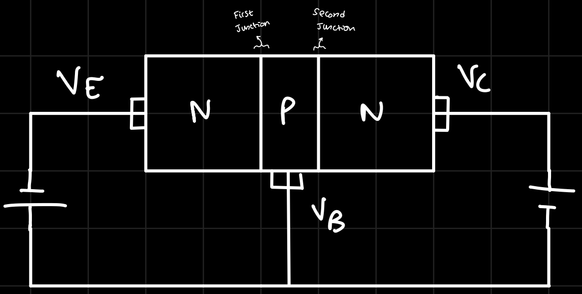
npn

controlling current on one terminal by varying voltage on two terminals

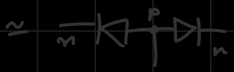
Application:

Amplifier → only in active mode
Switch → saturation and cutoff mode

for NPN BJT →



not exactly but can be related with ≈



Active mode:	FB	and	RB	$V_E < V_B$, $V_B < V_C$
Cutoff mode:	RB	and	RB	$V_E > V_B$, $V_B < V_C$
Saturation mode:	FB	and	FB	$V_E < V_B$, $V_B > V_C$

$$I_C = I_S e^{V_{BE}/V_T}$$

$$\beta = \frac{I_C}{I_B} \quad , \quad \alpha = \frac{I_C}{I_E}$$

$$I_{SE} = \frac{I_S}{\alpha}$$ ≡ saturation current of the emmiter region

Lecture (~Tutorial)

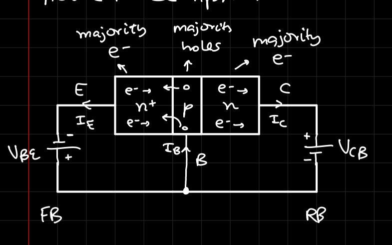
BJT → why bipolar?

because current is flowing through majority and minority charge carriers.

In BJT, we have 2 junctions
↳ Emmiter-base Junction
↳ Collector-base Junction

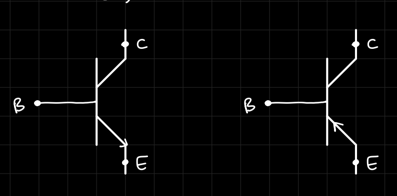
EBJ	CBJ	Mode	Application
FB	RB	Active	Amplifier
RB	RB	Cutoff	off-switch
FB	FB	Saturation	On-switch
RB	FB	Inverted	Not used generally (amp but with very low gain)

Active mode npn →



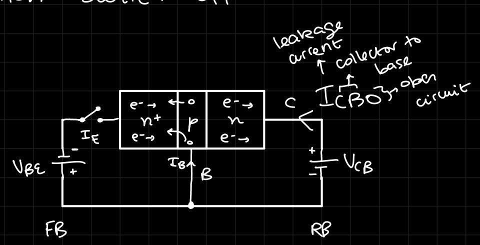
$I_E = I_B + I_C$

Area(C) ~ 50% }
Area(B) ~ 10% } general idea (not actually precise)
Area(E) ~ 40% }



npn pnp

condition : Switch "off"



This is common base configuration

#Generally ↷ $\alpha = \frac{I_C}{I_E}$

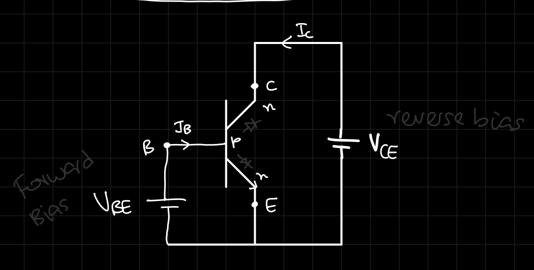
$I_C = \alpha I_E + I_{CBO}$
majority ↲ ↳ minority

$I_E = I_B + I_C$

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

$I_C = \beta I_B + \frac{I_{CBO}}{1 - \frac{\beta}{1+\beta}}$

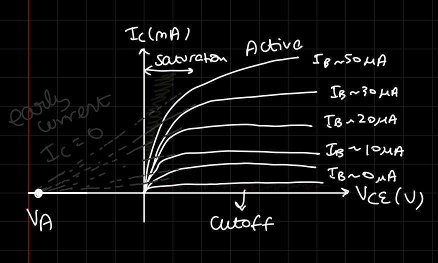
$$\boxed{I_C = \beta I_B + (1+\beta) I_{CBO}}$$



for active mode →
EBJ : FB
CBJ : RB

Depletion layer decreases in CBJ
Base width modulation ↲

VBE fixed
VCE ↑ ✓
depletion layer ↑
Collector region overlap
overall base width ↓
I_C ↑
} Early effect



$i_C = I_S e^{V_{BE}/V_T}$ # $V_T = 25mV$ for room temp

$i_{C_{new}} = I_S e^{V_{BE}/V_T}\left[1 + \frac{V_{CE}}{|V_A|}\right]$

$10V < |V_A| < 100V$

$\frac{\partial i_{C_{new}}}{\partial V_{CE}} = I_S e^{V_{BE}/V_T}\left[0 + \frac{1}{|V_A|}\right]$

$\frac{\partial V_{CE}}{\partial i_{C_{new}}} = \frac{|V_A|}{I_S e^{V_{BE}/V_T}} = \boxed{\frac{|V_A|}{i_C}} = \boxed{r_o}$

early effect impedance

$I_C = \beta I_B$

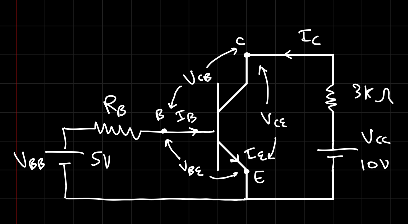
NUMERICAL

Q1) for a given transistor, check whether the transistor works in active or cutoff mode?

Assume that transistor is Si based

	EBJ	CBJ
→ Active :	FB	RB
Cutoff :	RB	RB

assume $\beta = 100$
(i) 200kΩ
(ii) 50kΩ



$-V_{BB} + I_B R_B + V_{BE} = 0$

$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5 - 0.7}{200} mA$

$I_B = 0.0215 mA$

V_{BE} → replaced by cutoff voltage
here $V_{BE} = 0.7V$

and $V_{CE_{saturation}} = 0.2V$ to $0.3V$

$I_C = \beta I_B = 2.15mA$

in 2nd loop:

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

$V_{CE} = 10 - 3\times10^3 \times 2.15\times10^{-3}$
$= 3.55V >>> V_{BE}$
(Active mode)

(ii) $R_B = 50k\Omega$

$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5 - 0.7}{50} \times mA$

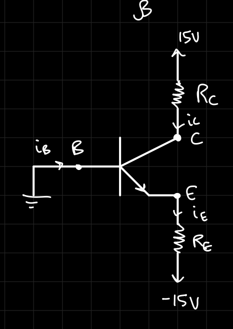
$= 0.086 mA$

$I_C = \beta I_B = 8.6mA$

$V_{CE} = V_{CC} - I_C R_B$
$V_{CE} = 10 - 8.6\times3$
$= -15.8V <<< V_{BE}\ (0.7V)$
↓
saturation mode

Q2) The transistor shown has $\beta = 100$ and exhibits a V_{BE} of 0.7V and $i_C = 2mA$. Design the ckt so that current of 2mA flows through the collector and a voltage of +5V appear at the collector.

→ $i_B = \frac{i_C}{\beta} = 20\mu A$



$i_C = \frac{15 - V_C}{R_C}$
$R_C = \frac{15 - V_C}{i_C}$
$V_C = 5V$ given

$V_{BE} = 0.7V = V_B - V_E$
$V_B - V_E = 0.7V$
$V_E = -0.7V$

$R_C = \frac{15-5}{2} k\Omega$
$= 5k\Omega$

$i_E = \frac{V_E - (-15)}{R_E}$

$\beta = 100$
$\alpha = \frac{\beta}{1+\beta} = \frac{100}{101} = 0.99$

$\alpha = \frac{i_C}{i_E} \Rightarrow i_E = \frac{i_C}{\alpha} = \frac{2}{0.99} mA$

$= 2.02mA$

$R_E = \frac{V_E + 15}{i_E}$

$= \frac{-0.7 + 15}{2.02} k\Omega = 7.079 k\Omega$

$i_{C1} = I_S e^{V_{BE1}/V_T}$

$i_{C2} = I_S e^{V_{BE2}/V_T}$

$\frac{i_{C1}}{i_{C2}} = e^{\frac{V_{BE1} - V_{BE2}}{V_T}}$

$\log_e(0.5) = \frac{V_{BE1} - V_{BE2}}{V_T}$

$\ln\left(\frac{1}{2}\right) = \frac{V_{BE1} - 0.7}{V_T}$

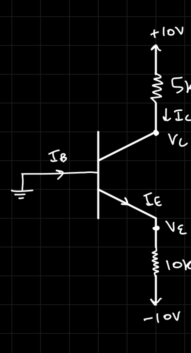
$V_{BE2} = -0.7 - \ln(0.5) V_T$

$= -0.7 - (-0.693 \times 25\times10^{-3})$

$= 0.717V$ ✗

$0.683V$

Q) $V_E = -0.7V$
$\beta = 50$
$i_E, i_B, i_C, V_C = ?$



$I_E = \frac{V_E - (-10)}{10} mA$
$= \frac{10 - 0.7}{10} mA$
$= 0.93mA$

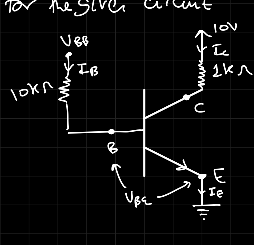
$\alpha = \frac{I_C}{I_E} \Rightarrow I_C = I_E\left(\frac{\beta}{\beta+1}\right) = 0.93 \times \left(\frac{50}{51}\right) mA$
$= 0.91mA$

$V_C = 10 - 5k I_C$

$V_C = 10 - 5\times0.91 = 5.45V$

$I_B = 0.0182mA$

Q) for the given circuit



$V_{BB} = 1.7V$
active mode?

While keeping V_{BB} const find that value to which R_C should be increased in order to obtain →
(a) operation at edge of saturation
(b) operation at deep saturation with $\beta_{forced} = 10$

Hint →
(a) for edge of saturation, consider $V_{CE} = 0.3V$
(b) for deep sat, V_{CE} is considered 0.2V

assume $\beta = 50$

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

$= \frac{1.7 - 0.7}{10} mA$

$= 0.1mA$

$V_{BE} = 0.7V = V_B - \underset{0}{V_E}$

$V_B = 0.7V$

$I_C = \beta I_B = 50 \times 0.1mA$
$= 5mA$

$V_{CC} = I_C R_C + V_{CE} \Rightarrow 5\times1 + V_{CE} = 10$
$V_{CE} = 5V >>> V_{BE}$
(active)

2nd) 1.94kΩ
9.8kΩ