Bipolar Junction Transistors (BJTs)

The bipolar junction transistor (BJT) has three separately doped regions and containing two pn junctions. The bipolar transistor with two pn junctions, therefore has four possible modes of operations depending on the bias condition of each diod pn junction, which is one reason for the versatility of the device.

- It can be used in multitude of applications, ranging from signal amplification to the design of digital logic and memory circuits.
- With three separately doped regions, the bipolar Transistor is a three terminal device. The basic transistor principle is that the voltage between two terminals controls the current flowing through the third terminal. In this way, a three terminal device can be used to realize a controlled source, which is the basis for amplifier design and switch design.
- Current in the transistor is due to the flow of both electrons and holes, hence the name bipolar

Transistor structures

There are two types of BJT : npn & pnp. The npn bipolar transistor contains a thin p-region sandwitched b/n two n-regions. In contrast, the pnp bipolar transistor contains a thin n-region b/n two p-regions.

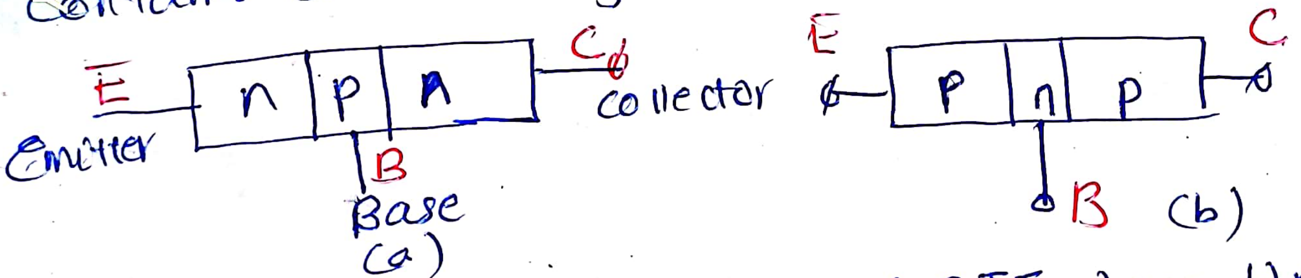


Fig : Simple geometry of BJT a) npn b) pnp

E :- highly doped region
B :- a thin & lightly doped

The transistor consists of two pn-jns, the Emitter-base junction (EBJ) & the collector-base junction (CBJ). Depending on the bias condition of each junctions, there are four different modes of operations:

	EBJ	CBJ	
1. Forward active mode (Active)	Forward	Reverse	Amplifier
2. Reverse active mode	reverse	Forward	limited applns.
3. Cut off	reverse	reverse	switching
4. Saturation	Forward	Forward	switching

npn-Transistor: Forward-Active Mode operation

Operation :-

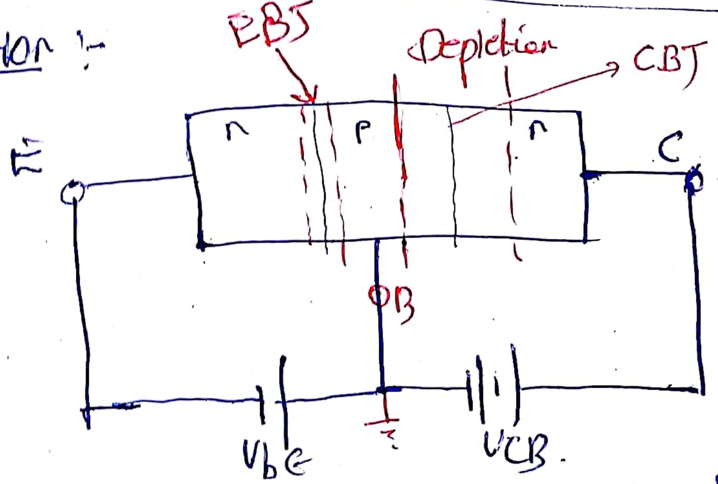
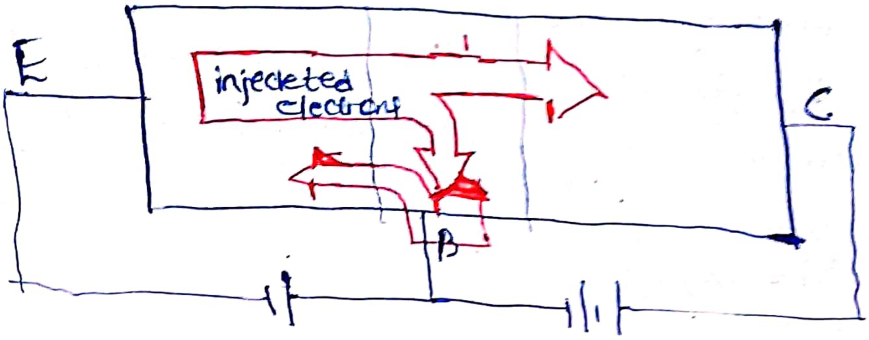


Fig:- npn-transistor biased in active mode

Since the EBJ is forward biased, electrons from the Emitter are injected into a thin base region, creating excess minority carrier concentration in the base. Since the injected base material is very thin and has low conductivity, a very large number of these injected or emitted electrons will diffuse across the reverse biased junction into the n-type material connected to the collector terminal creating the collector current. Similarly, a very small number of injected electrons will take the high resistance path to the base terminal thereby contributing a very small current in the base terminal

Transistor current



* As the EBJ is forward biased, electrons from the n-type emitter are injected into the p-type base. This component of current is called I_{nE}. Similarly, holes from the p-type base are injected into the n-type emitter. This component of emitter current is called I_{pE}. Therefore, the total emitter current I_E is

$$I_E = I_{nE} + I_{pE}$$

But in a commercial transistor, the emitter is heavily doped when compared to the base. Therefore $I_{nE} >> I_{pE}$. Hence

$$I_E \approx I_{nE} = I_{E0}\left(e^{\frac{V_{BE}}{\eta V_T}} - 1\right)$$

$$= I_{E0}\left(e^{\frac{V_{BE}}{\eta V_T}}\right)$$ → the dxn of I_E is out of the terminal

However, not all the injected electrons into the base region cross the CBJ b/c some of them may combine with holes in the base region. Only the rest of the electrons cross the CB-junction, contributing to a current component I_{nC1}

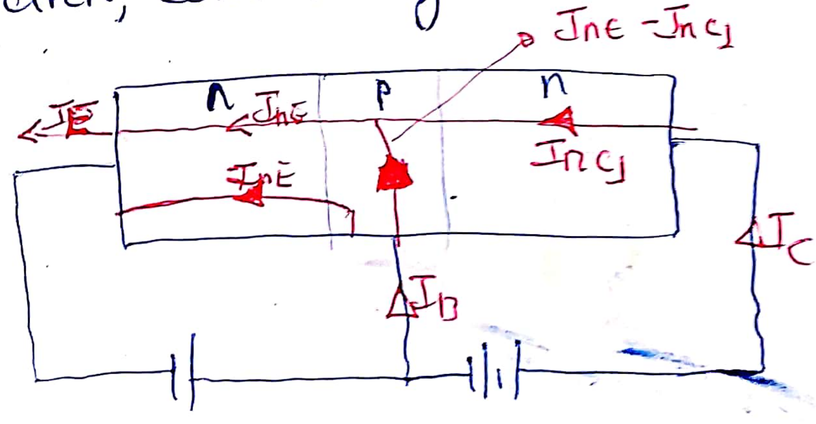


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Fig: current component in npn transistor biased in the active mode

Base Current

Since BE j^n is fwd biased, holes from the base are injected across the BE j^n into the Emitter. However, b/c these holes donot contribute to the collector current, they are not part of the transistor action.

$$i_{B_1} \propto e^{V_{BE}/nV_T}$$

* A few electrons recombine with majority carrier holes in the base. The holes that are lost must be replaced through the base terminal. The flow of such holes (flow of electrons in the valence band) is a second component of the base current. This current is directly proportional to the number of e^-s being injected from the emitter, which in turn is an exponential function of B-E voltage

$$i_{B_2} \propto e^{V_{BE}/V_T}$$

- The total base current

$$i_B \propto e^{V_{BE}/nV_T}$$

Collector current; since the doping concentration in the Emitter is much larger than that in the base region, the vast majority of emitter current is due to the injection of electrons in the base region. The number of these ~~injection~~ injected electrons reaching the collector is the ~~majority~~ major component of collector current.

- The number of electrons reaching the collector per unit time is proportional to the number of electrons injected into the base, which is in turn a function of V_{be}. That is the collector current is proportional to e^{V_{BE}/V_T} and is independent of the reverse biased B-C voltage. The device therefore looks like a constant-current source.

The collector current is controlled by the B-E voltage; in other words, the current at one terminal (the collector) is controlled by the voltage across the other two terminals. This control is the basic transistor action.

$I_{nc1} = I_C = \alpha I_E$ α - the fraction of the total Emitter current

leakage current (Reverse current)

* Now let us consider the leakage current due to reverse biased collector junction. For this, let us assume $I_E = 0$ that is open the Emitter lead

$$I_{CO} = I_{nCO} + I_{pCO} \simeq I_{pCO}$$

Since the base is lightly doped

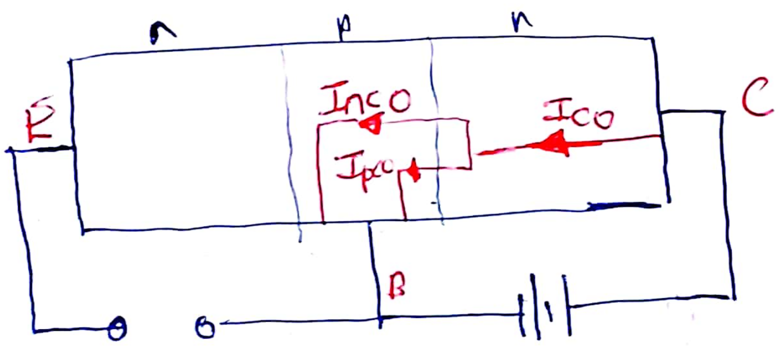


Fig: current components due to reverse biased CBT

TYPES OF CONFIGURATION

When a transistor is to be connected in a circuit, one terminal is used as an input terminal, the other terminal is used as an output terminal and the third terminal is common to the input and output.

Depending upon the input, output and common terminal, a transistor can be connected in three configurations. They are:

I) Common base (CB) configuration :- In this configuration, Emitter is the input terminal, Collector is the output terminal and base is the common terminal

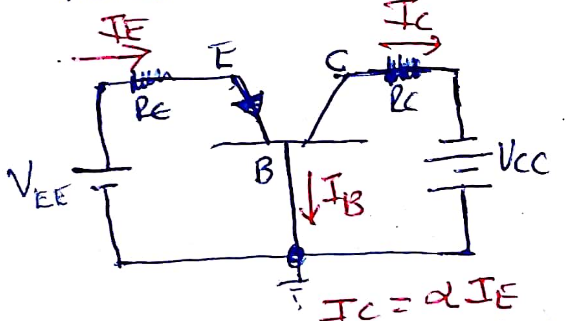
II) Common Emitter (CE) configuration :- This is also called grounded emitter configuration.

base :- Input terminal
Collector :- output terminal
Emitter :- common terminal

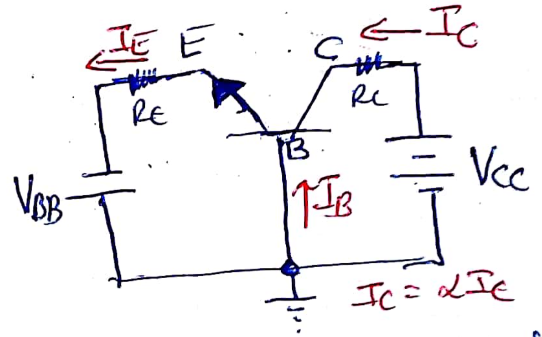
III Common Collector (CC) configuration :- This is also called grounded collector configuration.

base :- input terminal
Emitter : output terminal
Collector :- common terminal

CB-configuration :- The CB-configuration for pnp & npn transistor circuits are shown below



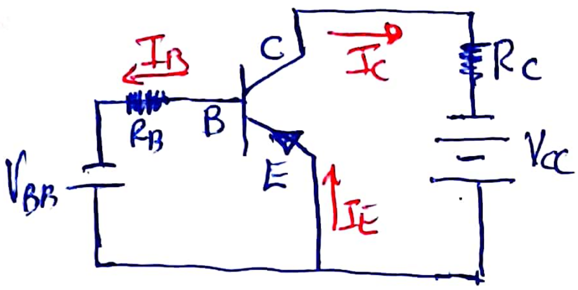
a) pnp-transistor in CB configuration



b) npn-transistor in CB configuration

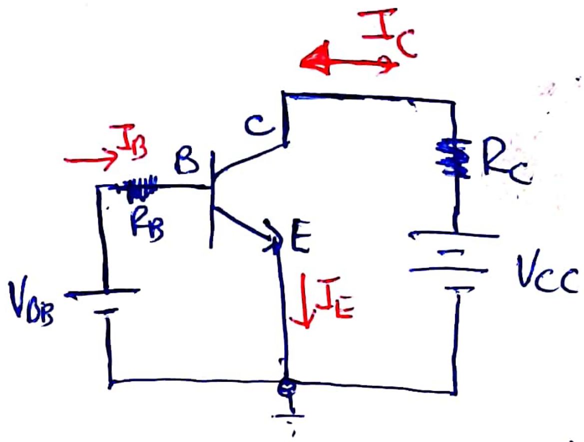
Fig: CB-configuration : a) pnp b) npn

CE-configuration



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

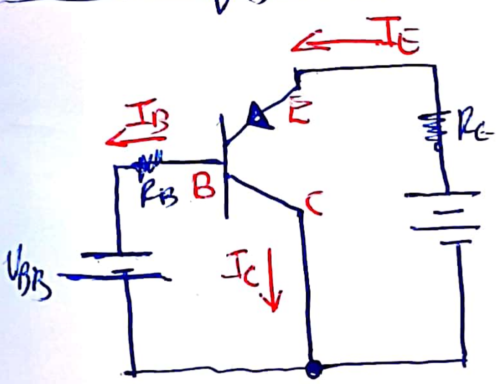
a) pnp-transistor in CE-configuration



b) npn-transistor in CE-configuration

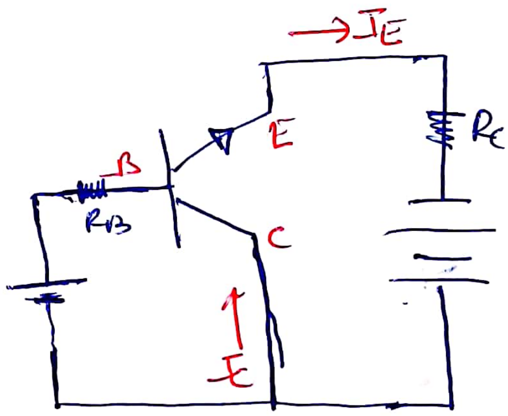
Fig: CE configuration: a) pnp b) npn

CC-configuration



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

a) pnp-transistor in CC configuration



b) npn-transistor in CC configuration

Fig: CC configuration a) pnp b) npn

Current-Voltage Characteristics

To fully describe the behavior of a three-terminal device such as CB requires two sets of characteristics — one for the input parameters and the other for the output side.

CB- Characteristics

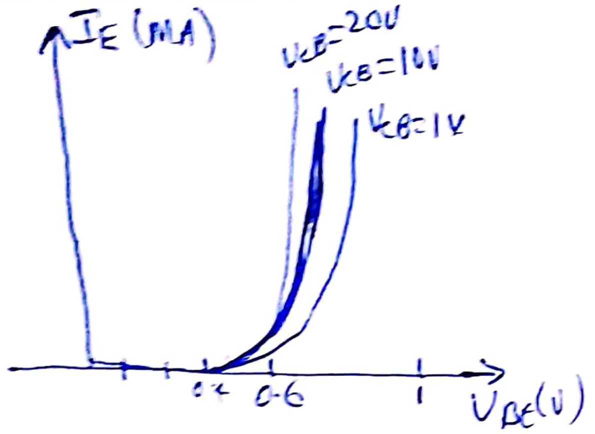


Fig: Input characteristics for CB Configuration

* The input set for CB-Amplifier relates an i/p voltage (V_{BE}), for various levels of o/p voltage (V_{CB})
* When V_{CB} is increased keeping V_{BE} constant, the width of the base region will decrease. This effect results in an increase of I_E.

Output characteristics : To determine the o/p characteristics, I_E is kept constant at a suitable value. Then V_{CB} is increased and I_C is noted for each value of I_E.

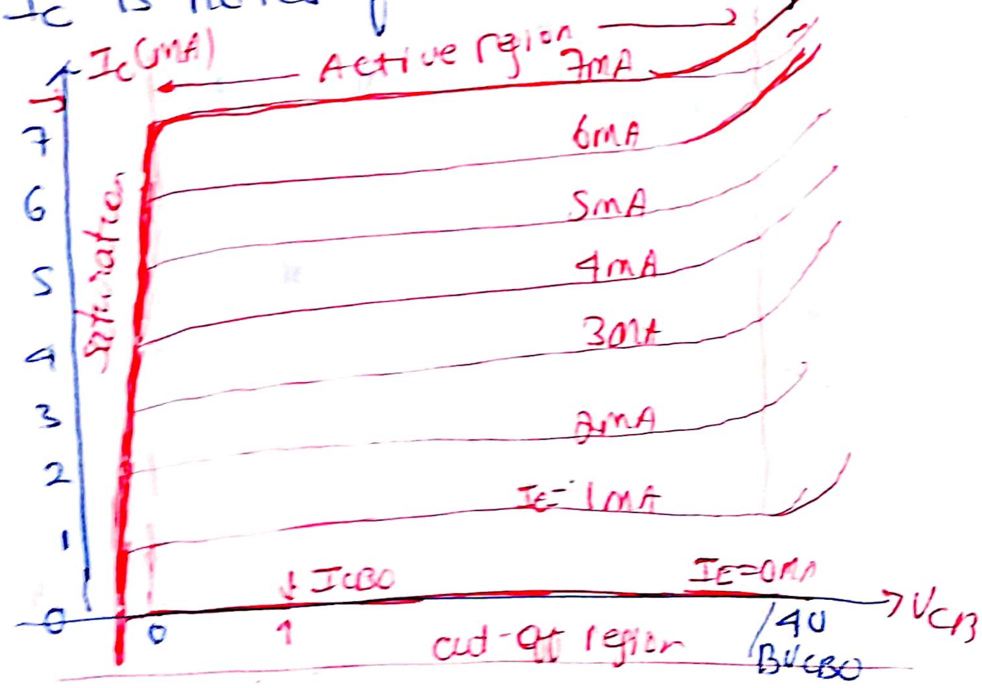
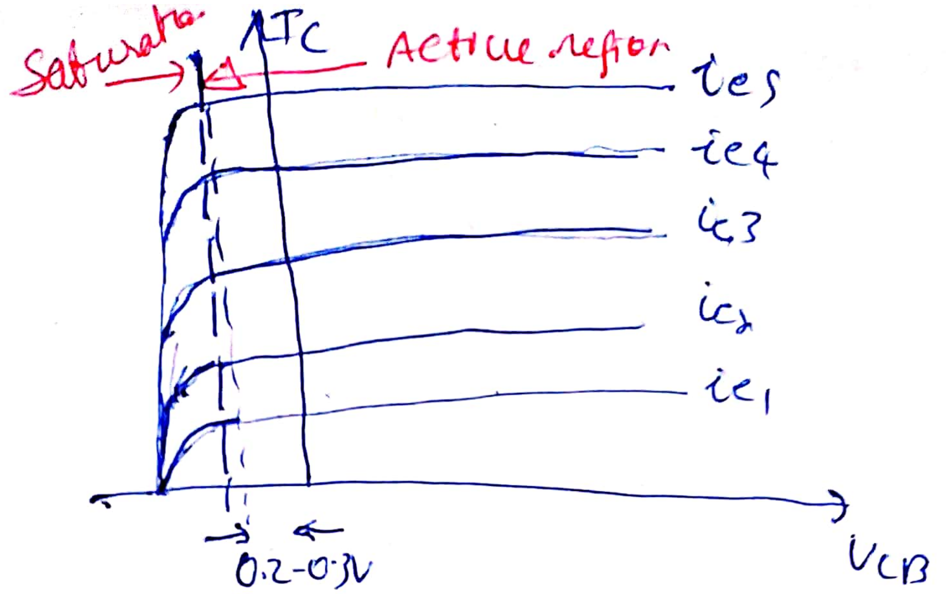


Fig: o/p characteristics of CB Configuration



Alpha (α)

Dc-mode :- In the dc mode the levels of I_C & I_E due to majority carriers are related by a quantity called alpha

$$\alpha_{dc} = \frac{I_C}{I_E} \quad (0.95 - 0.99)$$

$$I_C = I_{C\,majority} + I_{CO\,minority}$$

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

$$= \alpha_{dc} I_E + I_{CBO}$$

$$I_C = \alpha_{dc}(I_C + I_B) + I_{CBO}$$

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

Ac-mode :- For ac situations where the point of operation moves on the curve,

$$\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}\bigg|_{V_{CB}=const}$$

$\alpha \rightarrow$ common base current gain

CE - Characteristics

Input characteristics: V_{CE} is kept constant, I_B is measured for each value of V_{BE}

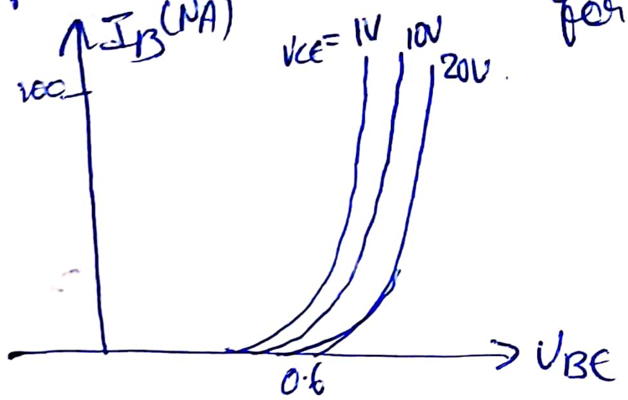
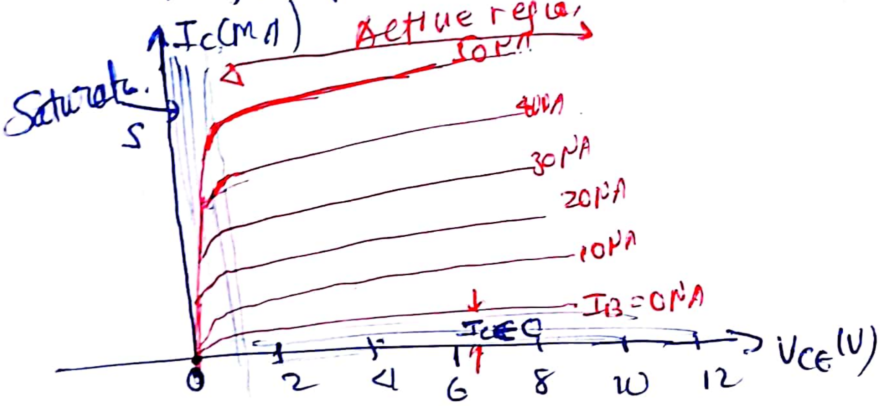


Fig: I/p characteristic



$$I_{CEO} = \frac{I_{CBO}}{1-\alpha}$$

Fig: O/p characteristics

Common Emitter current gain (β)

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

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

$$I_{CEO} = I_C \Big|_{I_B = 0} = \frac{I_{CBO}}{1-\alpha}$$

Relation b/n β & α

~~$I_E = \alpha I_E +$~~

$$I_E = I_C + I_B$$

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

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

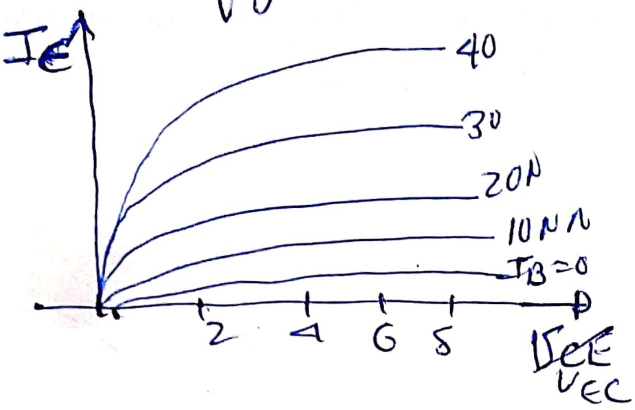
$$\alpha = \beta/\beta+1$$

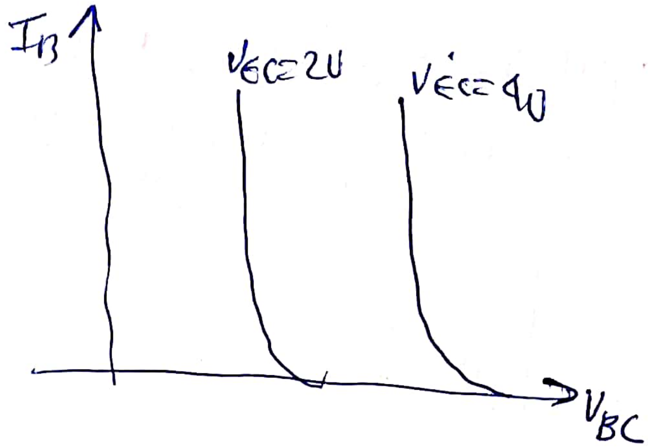
$$\beta = \frac{\alpha}{1-\alpha}$$

$$I_{CEO} = \frac{I_{CBO}}{1-\alpha} = (\beta+1) I_{CBO}$$

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

CC- configuration





Current gain in CC

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

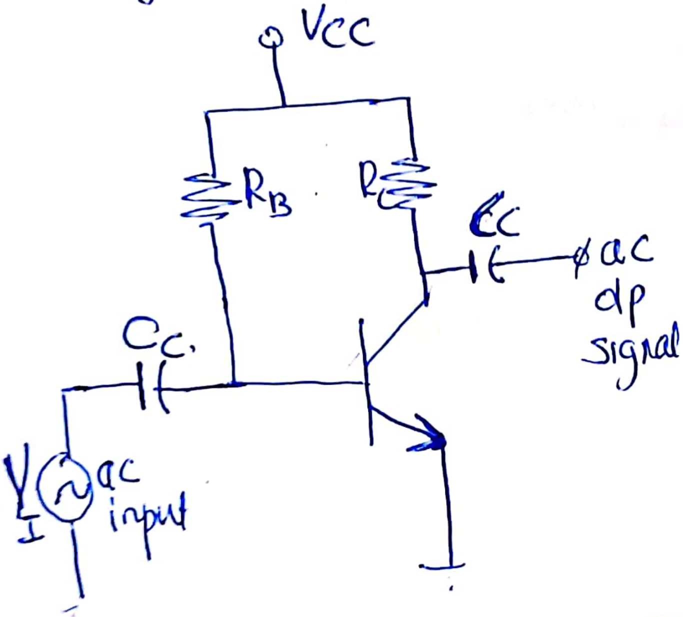
$$\gamma = \frac{1}{1-\alpha} = \beta + 1$$

8.B

BJT - BIASING

* In order to create a linear amplifier, we must keep the transistor in the forward active mode, establish a Q-point near the center of the load line and couple the time-varying input signal to the base.
- The biasing problem is that of establishing a constant dc current in the collector of the BJT. This current has to be calculable, predictable and insensitive to variations in temperature and to the large variations in the value of β.
- Locating the Q-point at the center allows a maximum output swing.

Single Base Resistor Biasing (Fixed-bias configuration)



C_c - Coupling capacitor

- It separates the dc-source from ac-input signal.
- for dc-Analysis C_c acts as an open circuit and for ac-analysis C_c acts as a short circuit

Fig: CE cct with a single biase resistor in the base

Forward bias of the Base-Emitter

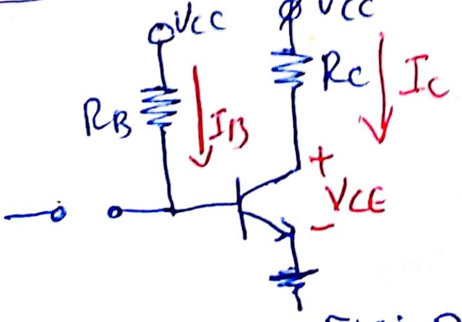


Fig: DC-Equivalent

using KVL for B-E loop

$$V_{CC} - I_B R_B - V_{BE} = 0$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{V_{CC} - 0.7}{R_B}$$

Collector Emitter loop

$$I_C = \beta I_B$$

$$V_{CC} - I_C R_C - V_{CE} = 0$$

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

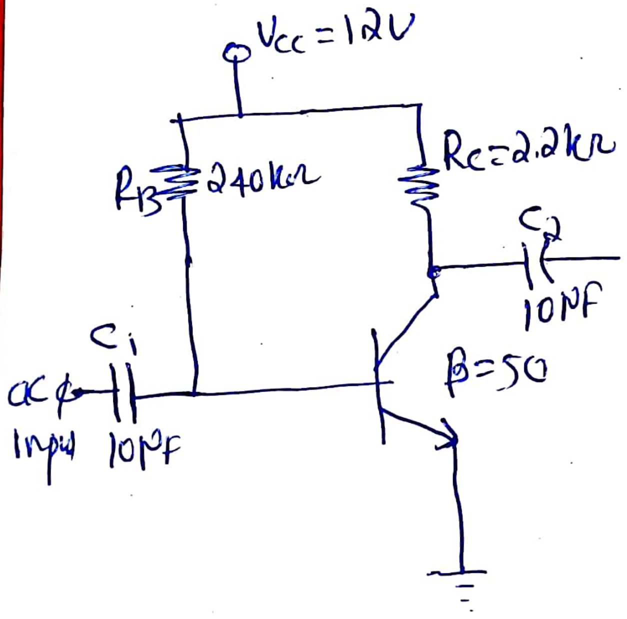
Since $V_E = 0$

$$V_{CE} = V_C \quad \& \quad V_{BE} = V_b$$

Ex Determine the following for the fixed-bias configuration shown below

a) I_{BQ} & I_{CQ} c) V_B & V_C

b) V_{CEQ} d) V_{BC}



Soln

a) $I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{(12 - 0.7)V}{240k\Omega}$

$= \frac{11.3V}{240k\Omega} = 47.1\mu A$

$I_{CQ} = \beta I_{BQ} = 50 \times 47.1\mu A$

$= 2355\mu A = 2.35mA$

b) $V_{CEQ} = V_{CC} - I_{CQ} R_C$

$= 12 - 2.35 \times 2.2$

$= 6.83V$

c) $V_{BE} = V_B - V_E = 0.7$

$V_B - V_E = 0.7$

$V_B = 0.7$

$V_C = V_{CE} = 6.83V$

d) $V_{BC} = V_B - V_C$

$= 0.7 - 6.83$

$= -6.13$

Since $V_{BC} < 0$, the transistor is indeed operating in forward active mode.

Ex Design a circuit with a single base resistor to meet a set of specifications

Specifications: The circuit is to be biased with $V_{CC} = +12V$. The transistor quiescent values are to be $I_{CQ} = 1mA$ & $V_{CEQ} = 6V$. Assume $\beta = 100$

Soln

$$R_C = \frac{V_{CC} - V_{CEQ}}{I_{CQ}} = \frac{12-6}{1} = 6k\Omega$$

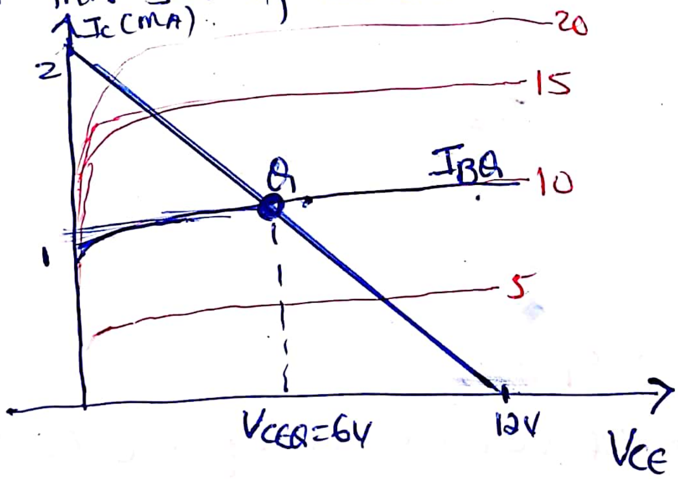
The base current is

$$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{1mA}{100} = 10\mu A$$

and the base resistance is

$$R_B = \frac{V_{CC} - V_{BE(ON)}}{I_{BQ}} = \frac{12-0.7}{10\mu A} = 1.13M\Omega$$

The transistor characteristics, load line and Q-point for this set of conditions are shown below



* the load line is defined by the load resistance

Fig:- Load line

Remarks

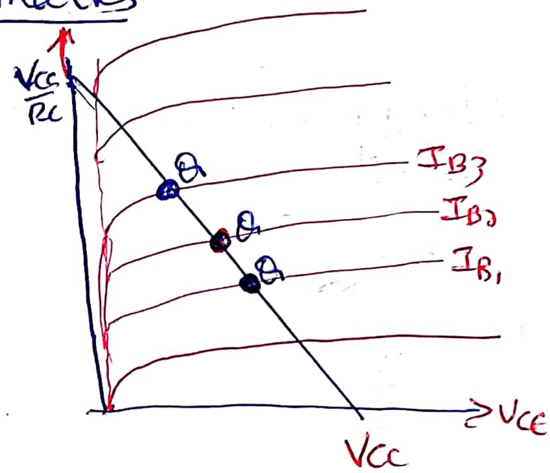


Fig:- movement of Q-point with increasing level of I_B (for fixed Rc & Vcc)

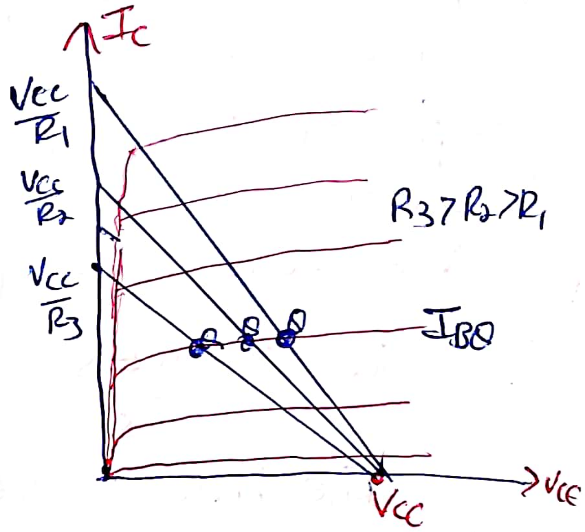


Fig: Effect of variations of Rc on the load line & Q-point for fixed RB & Vcc

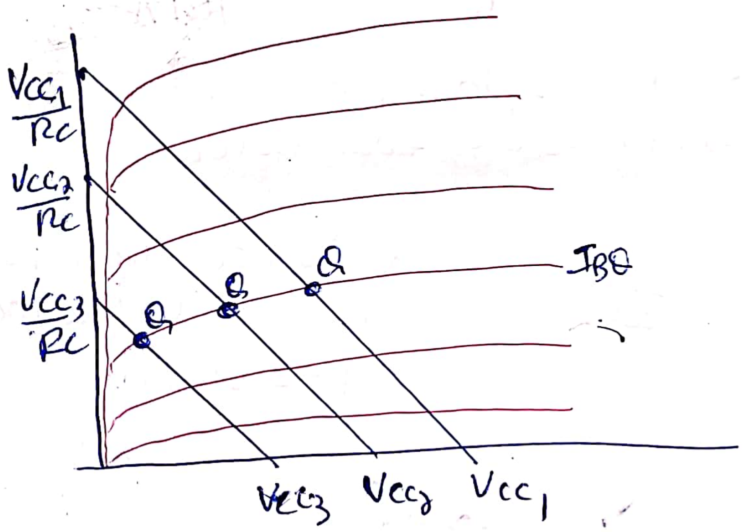


Fig:- Effect of variations of Vcc on the load line

Adv:- • It is simple to shift the operating point in the active region by changing the base resistor (R_B)

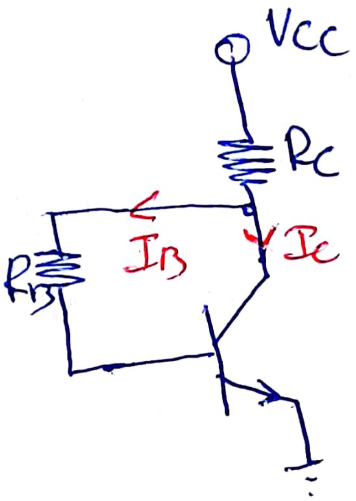
• Simple circuit

disadvantage:- • Ic does not remain constant with variation in temperature or power supply voltage

• Change in value of β can change Q-point

Collector to base bias

* This configuration employs negative feedback to prevent thermal runaway and stabize the operating point



Analysis

$$V_{CC} - (I_B + I_C)R_C - I_B R_B - V_{BE} = 0$$

$$V_{CC} - I_B(\beta+1)R_C - I_B R_B - V_{BE} = 0$$

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

$$\cong \frac{V_{CC} - V_{BC}}{R_B + \beta R_C}$$

Output section

$$I_C = \beta I_B$$

$$V_{CC} - \left(\frac{\beta+1}{\beta}\right) I_C R_C - V_{CE} = 0$$

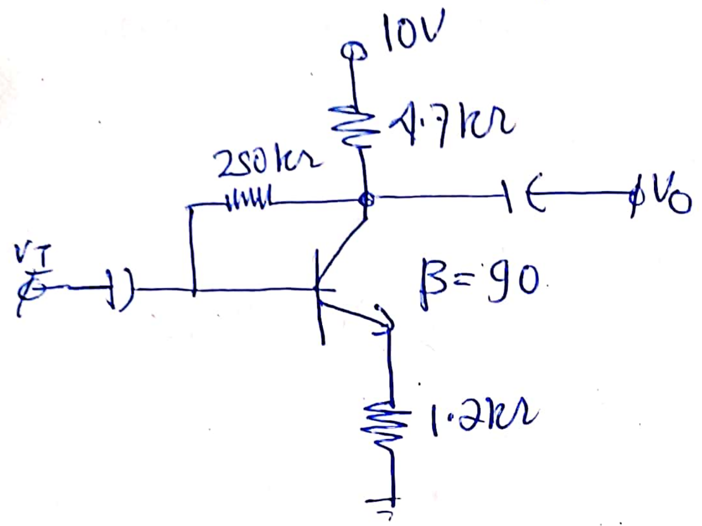
$$V_{CE} = V_{CC} - I_C R_C$$

Adv :- circuit stablizes the operating point against variations in temperature and β

disadv :- To keep I_C independent of β, $\beta R_C >> R_b$

1. If R_C is large, a high V_{CC} is necessary, which increases cost
2. If R_B is low, the reverse bias of CB region is small, which limits the range of collector voltage swing i.e it leaves the active region of operation
3. Due to feedback resistor R_B, the voltage gain of the Amplifier is reduced

Ex. Determine the quiescent levels of I_{CQ} & V_{CEQ} for the network. Repeat for $\beta = 135$ & compare the results



Soln

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

$$= \frac{(10-0.7)V}{250k\Omega + 91 \times (4.7k\Omega + 1.2k\Omega)}$$

$$= \frac{9.3V}{250k\Omega + 91 \times (5.9k\Omega)}$$

$$= \frac{9.3V}{250k\Omega + 531k\Omega} = 11.91\mu A$$

$I_{CQ} = \beta I_B = 90 \times 11.91\mu A = 1.07mA$

$V_{CEQ} = V_{CC} - I_C(R_C + R_E)$

$= 10V - 1.07mA(4.7k\Omega + 1.2k\Omega)$

$= \underline{3.69V}$

For $\beta = 135$

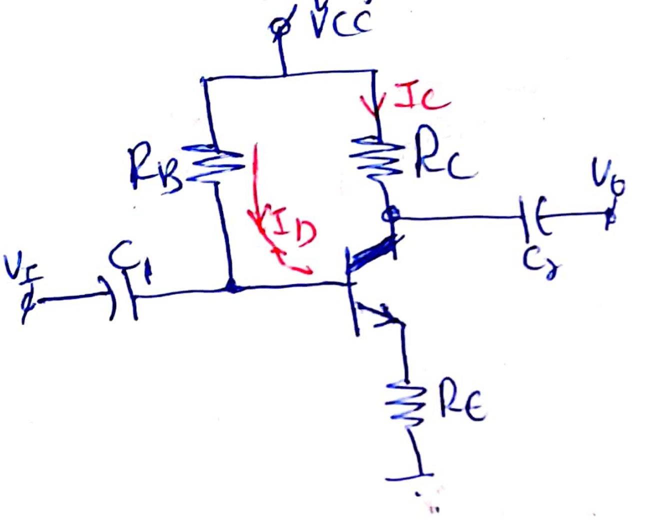
$I_B = 8.89\mu A$

$I_{CQ} = \beta I_B = 1.2mA$

$V_{CEQ} = 2.92V$

Emitter bias Configuration

The dc-bias network shown below contains an Emitter resistor to Improve the stability level over that of the fixed bias configuration



Base Emitter loop

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{CC} - I_B R_B - V_{BE} - (\beta+1) R_E I_B = 0$$

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

$$R_i = (\beta+1) R_E$$

Collector-Emitter loop

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

$$V_{CE} = V_{CC} - I_C \left(R_C + \frac{\beta+1}{\beta} R_E\right)$$

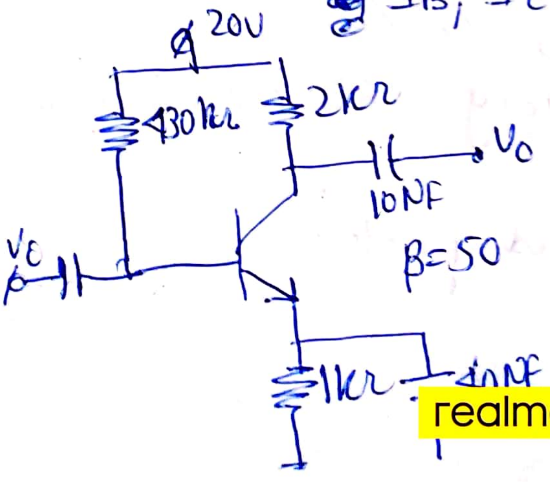
$$\cong V_{CC} - I_C (R_C + R_E)$$

$$V_E = I_E R_E \quad \& \quad V_{CE} = V_C - V_E$$

$$V_C = V_{CE} + V_E = V_{CC} - I_C R_C$$

$$V_B = V_{CC} - I_B R_B$$

Ex For the Emitter-bias network, determine I_B, I_C, V_{CE}, V_C, V_E, V_B, V_{BC}



Sol^n $I_B = \frac{20 - 0.7}{430k\Omega + 51k\Omega} = 40.1\,\mu A$

$$I_C = \beta I_B = 50 \times 40.1\,\mu A$$

$$= 2.005\,mA \cong 2.01\,mA$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

$$= 20 - 2.01\,mA \times 3\,k\Omega$$

$$= 13.97\,V$$

(B-5)

$V_C = V_{CC} - I_C R_C$
$= 20V - 2.01mA \times 2k\Omega$
$= 15.98V$

$V_C - V_E = V_{CE}$
$V_E = V_C - V_{CE}$
$= 15.98V - 13.97V$
$= 2.01V$

$V_B - V_E = V_{BE} = 0.7V$
$V_B = V_E + 0.7$
$= 2.01 + 0.7 = 2.71V$

$V_{BC} = V_B - V_C = 2.71V - 15.98$
$= -13.27V$ (reverse biased as required)

Advantages
* It has a tendency to stablize the operating point against changes in temperature & β-value

disadvantage :- In order to keep I_C independent of β the following condition must be met

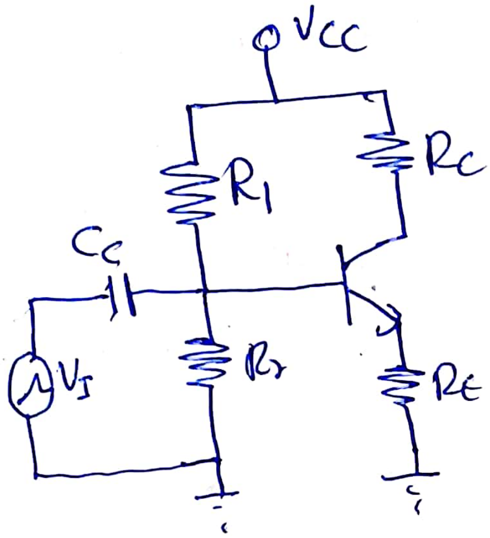
$$I_C = \beta I_B = \frac{\beta(V_{CC} - V_{BE})}{R_B + (\beta+1)R_E} \simeq \frac{V_{CC} - V_{BE}}{R_E}$$

if $R_B + (\beta+1)R_E >> R_B$

This can be achieved if R_E is very large which means high V_{CC} & high cost

- R_E reduces the gain of the amplifier

Voltage divider biasing



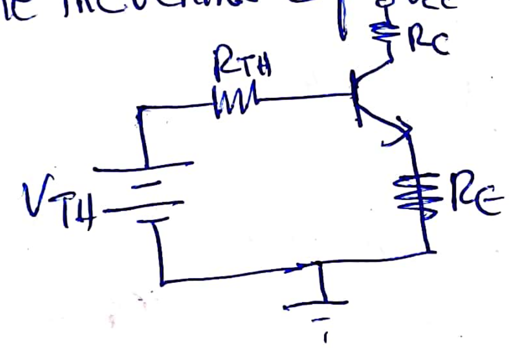
Analysis Using thevenin Equivalent circuit

$$V_{TH} = \frac{R_2}{R_1+R_2} V_{CC}$$

&

$$R_{TH} = R_1 \,||\, R_2$$

The thevenins Equivalent cct is shown below



Input Loop

$$V_{TH} = I_B R_{TH} + V_{BE} + I_E R_E$$

$$= I_B(R_{TH} + (\beta+1)R_E) + V_{BE}$$

$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta+1)R_E}$$

Output loop

$$I_C = \beta I_B = \frac{\beta(V_{TH} - V_{BE})}{R_{TH} + (\beta+1)R_E}$$

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

Ex For the voltage divider bias cct, let $V_{CC} = 3.3V$, $R_E = 500\Omega$, $R_C = 4k\Omega$, $R_1 = 85k\Omega$, $R_2 = 35k\Omega$ & $\beta = 150$

a) Determine R_{TH} & V_{TH}

b) Find I_{BQ}, I_{CQ} & V_{CEQ}

c) Repeat for part (b) for $\beta = 75$

Soln

a) $R_{TH} = R_1 || R_2 = \frac{85 \times 35}{120} = 24.8k\Omega$

$V_{TH} = \frac{[illegible]}{120} \times 3.3V = [illegible]$

b) $I_{BQ} = \frac{V_{TH} - V_{BE(ON)}}{R_{TH} + (\beta+1)R_E} = \frac{0.9625V - 0.7V}{24.8k\Omega + 151 \times 0.5k\Omega}$

$= \frac{0.2625}{100.3} = 2.62 \mu A$

$I_{CQ} = \beta I_{BQ} = 150 \times 2.62 \mu A = 0.393 mA$

$V_{CEQ} = V_{CC} - I_C(R_C + R_E)$

$= 3.3 - 0.393(4.5)$

$= 1.53V$

c) $I_{BQ} = \frac{0.9625 - 0.7}{24.8k\Omega + 76 \times 0.5} = 4.18 \mu A$

$I_{CQ} = \beta I_{BQ} = 75 \times 4.18 \mu A = 0.314 mA$

$V_{CEQ} = V_{CC} - I_C(R_C + R_E)$

$= 3.3V - 0.314 \times 4.5 = 1.89V$

In general for a bias stable cct, the requirement is

$R_{TH} << (1+\beta)R_E$

$I_{CQ} \cong \frac{\beta(V_{TH} - V_{BE\,ON})}{(\beta+1)R_E}$

$\doteq \frac{V_{TH} - V_{BE}}{R_E}$

* The general rule is that a cct is considered bias stable when

$R_{TH} \cong 0.1(1+\beta)R_E$

Approximate analyses

The reflected resistance b/n base and Emitter is defined by $R_i = (\beta+1)R_E$. If R_i is much larger than R_2, the base current I_B is much smaller than I_2 and R_1 & R_2 can be considered as series elements.

- with this approximation ($\beta R_E \geq 10 R_2$)

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2}$$

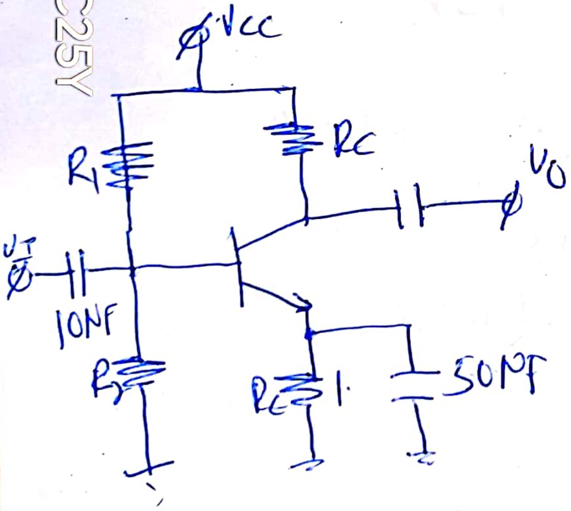
$$V_E = V_B - V_{BE}$$

$$I_E = \frac{V_E}{R_E}$$

$$I_{CQ} \cong I_E$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$
$$= V_{CC} - I_C (R_C + R_E)$$

Ex Determine the dc bias voltage V_{CE} and the current I_C for the voltage divider configuration. Consider $R_1 = 39\,k\Omega$, $R_2 = 3.9\,k\Omega$, $R_C = 10\,k\Omega$, $R_E = 1.5\,k\Omega$, & $\beta = 100$, $V_{CC} = 22V$



a) use Exact method
b) use Approximate method
c) Repeat part 'a' if $\beta = 50$

<u>Soln</u> a) Exact Method

$$V_{TH} = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{3.9}{39 + 3.9} \times 22$$

$$= \frac{3.9}{42.9} \times 22V = 2V$$

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} = \frac{39 \times 3.9}{39 + 3.9}\,k\Omega$$

$$= 3.55\,k\Omega$$

$$I_B = \frac{E_{TH} - V_{BE}}{R_{TH} + (\beta+1) R_E} = \frac{(2-0.7)V}{3.55k\Omega + (101)\times 1.5k\Omega}$$

$$= \frac{1.3V}{3.55k\Omega + 151.5k\Omega} = 8.38 \mu A$$

$$I_C = \beta I_B = 100 * 8.38\mu A = 0.838 mA \simeq 0.84 mA$$

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$

$$= 22V - 0.84 mA(10k\Omega + 1.5k\Omega)$$

$$= 22V - 0.84 * 11.5 V$$

$$= 22V - 9.66V = \underline{12.34V}$$

using Approximate Method

<u>check</u> $\beta R_E \geq 10 R_2$

$100 * 1.5k\Omega \geq 10\times 3.9 k\Omega$

$150k\Omega \geq 39k\Omega$ (satisfied)

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{3.9 k\Omega (22V)}{39k\Omega + 3.9k\Omega} = 2V$$

$$V_E = V_B - V_{BE} = (2-0.7)V = 1.3V$$

$$I_{CQ} = I_E = \frac{V_E}{R_E} = \frac{1.3V}{1.5k\Omega} = 0.867 mA$$

$$V_{CEQ} = V_{CC} - I_C(R_C + R_E)$$

$$= 22V - 0.867mA(10k\Omega + 1.5k\Omega)$$

$$= \underline{12.03V}$$

B - 7

c) $R_{TH} = 3.55k\Omega$, $E_{TH} = 2V$

$$I_B = \frac{E_{TH} - V_{BE}}{R_{TH} + (\beta+1)R_E} = \frac{2-0.7}{3.55k\Omega + 51 \times 1.5k\Omega}$$

$$= \frac{1.3V}{3.55k\Omega + 76.5k\Omega} = 16.24\mu A$$

$$I_{CQ} = \beta I_B = 50 \times 16.24\mu A = 0.81mA$$

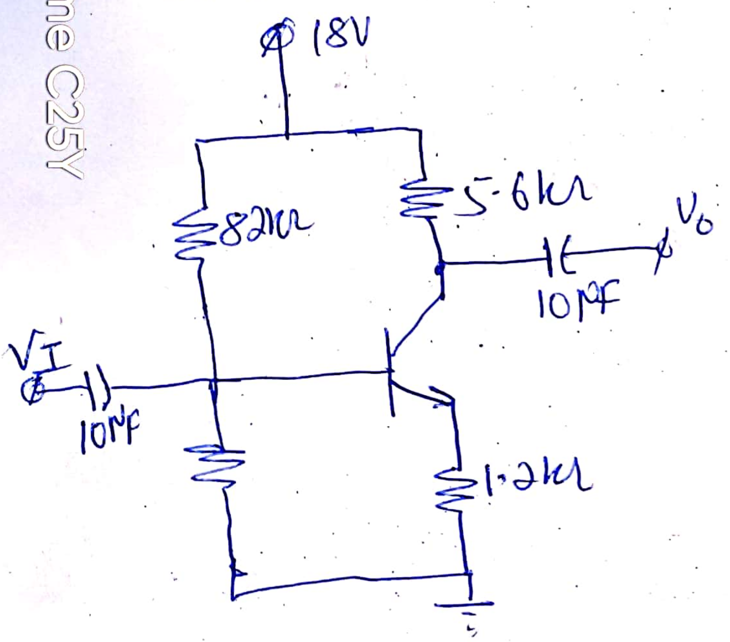
$$V_{CEQ} = V_{CC} - I_C(R_C + R_E)$$

$$= 22V - 0.81mA(10k\Omega + 1.5k\Omega)$$

$$= 12.69V$$

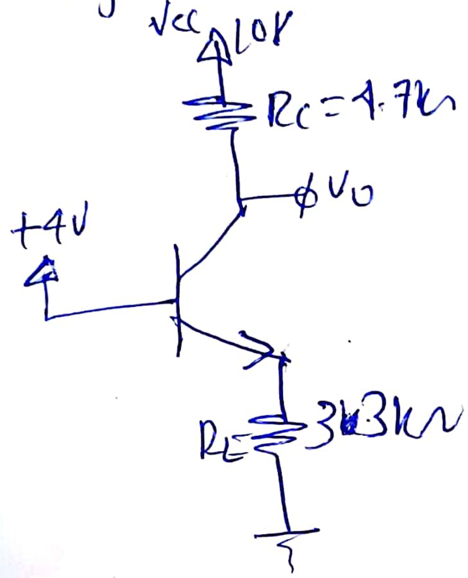
β	I_{CQ} (mA)	V_{CEQ} (V)
100	0.84mA	12.34V
50	0.81mA	12.69V

Q. Ex Determine the levels of I_{CQ} & V_{CEQ} for the cct shown using Exact & approximate techniques & compare solutions



DC- Analysis

Ex Consider the cct shown in Fig 1a. Determine all the node voltages. Assume $\beta = 100$



Soln $V_{BE} = 0.7V$

$V_B - V_E = 0.7V$

$V_E = V_B - 0.7V$

$= 4 - 0.7 = 3.3V$

$I_E = \frac{V_E}{R_E} = \frac{3.3V}{3.3k\Omega} = 1mA$

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

$I_C = \alpha I_E = 0.99 \times 1mA$

$= 0.99\ mA$

$V_C = V_{CC} - I_C R_C$

$= 10 - 0.99 \times 4.7$

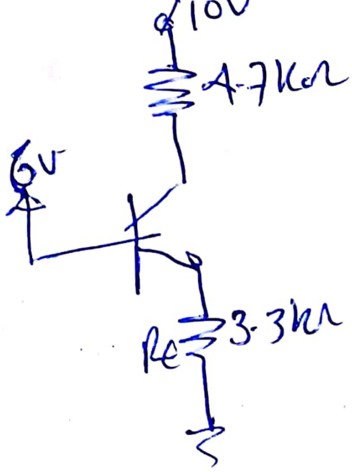
$= 5.347V$

Since $V_B = 4V$, the collector base junction is reverse biased.

i.e $V_{BC} = 4 - 5.347$

$= -1.347V < 0$

Ex Determine the voltages at all nodes for the cct shown below. Assume that the transistor β is at least 50.



Soln Assuming Active mode

$V_E = V_B - V_{BE} = 6 - 0.7 = 5.3V$

$I_E = \frac{5.3}{3.3} = 1.6mA$

$I_C = \frac{\beta}{\beta+1} I_E = 0.98 \times 1.6mA$

$= 1.568\ mA$

$V_C = 10 - 1.568 \times 4.7$

$= 2.63V$

Since the collector voltage is less than the base voltage by 3.37V, it follows that our assumption of active mode is incorrect.

Assuming saturation mode

$V_E = 6 - 0.7 = 5.3V$

$I_E = 1.6mA$

$V_C = V_E + V_{CE\,sat} = 5.3 + 0.2 = 5.5V$

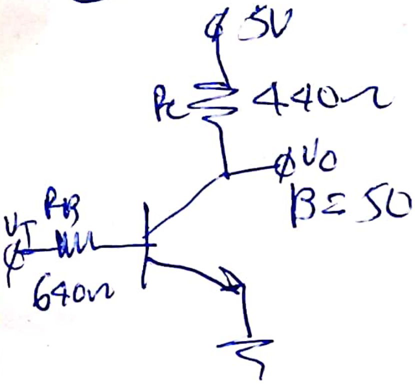
$I_C = \frac{10 - 5.5}{4.7} = 0.96mA$

$I_B = I_E - I_C = 1.6 - 0.96 = 0.64mA$

$\beta_{forced} = \frac{I_C}{I_B} = \frac{0.96}{0.64} = 1.5$

Since $\beta_{forced} < \beta$, the transistor indeed operating in saturation mode

Ex Assume $V_{BE\,on} = 0.7V$, $V_{CE(sat)} = 0.2V$



Determine V_O, I_B, I_C for

a) $V_I = 0.2V$ (ans $I_B = I_C = 0$, $V_O = 5V$, $P = 0$)

b) $V_I = 3.6V$ ($I_B = 4.53$, $I_C = 10.9mA$, $P = 5.35mW$)

Soln (b) $I_B = \frac{V_I - V_{BE}}{R_B} = \frac{3.6 - 0.7}{640} = \frac{2.9}{640}$

$= 4.53\ mA$

$I_C = \beta I_B = 50 \times 4.53mA = 0.226A$

$V_{CE} = 5 - I_C R_C = 5 - 440 \times 0.226$

< 0 (

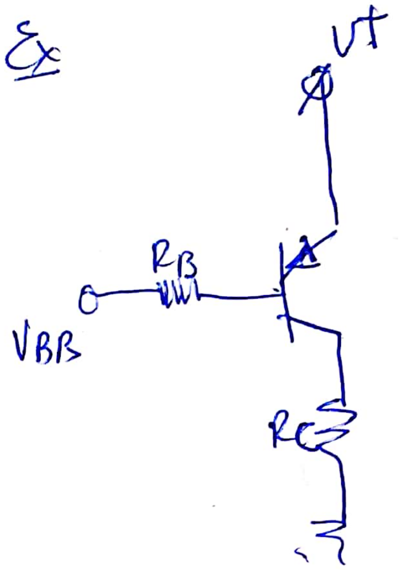
Saturation

$I_C = \frac{5 - 0.2}{440} = 10.9mA$

$P_T = 10.9 \times 0.2 + 4.53 \times 0.7 \times 10^{-3}$

$= 5.351\ mA$

Ex



Consider the cct shown. Assume $V_{EB(on)} = 0.7V$, $V_{EC}(sat) = 0.2V$
$\beta = 110$, $V^+ = 3.3V$, $R_C = 5k\Omega$
$R_B = 150k\Omega$. Calculate I_B, I_C, V_{EC}
for a) $V_{BB} = 2V$ b) $V_{BB} = 1V$

Soln Assume active mode

$$I_B = \frac{V^+ - V_{EB} - V_{BB}}{R_B} = \frac{3.3 - 0.7 - 2}{150k\Omega} = \frac{0.6}{150k\Omega}$$

$$= 4\mu A$$

$$I_C = 0.44 mA$$

$$V_{EC} = V^+ - I_C R_C = 3.3 - 0.44 \times 5$$
$$= 3.3 - 2.20 = 1.1V$$

Since $V_{EC} > V_{EC(sat)}$ the transistor is in active mode

b) $$I_B = \frac{V^+ - V_{EB} - V_{BB}}{R_B} = \frac{3.3 - 0.7 - 1}{150} = \frac{1.6}{150} = 10.67\mu A$$

assuming active mode

$$I_C = \beta I_B = 110 \times 10.67\mu A = 1.174 mA$$

$$V_{EC} = V^+ - I_C R_C = 3.3 - 1.174 \times 5 = -2.57V$$

⇒ the transistor is not operating in active mode

Assuming saturation

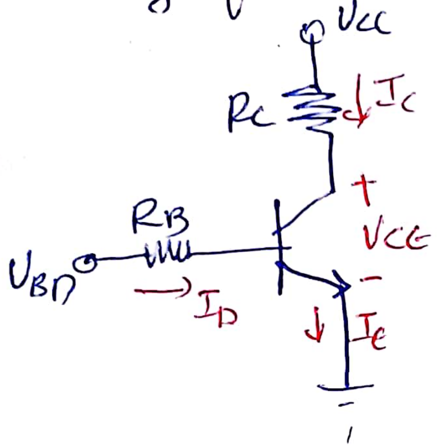
$$I_C = \frac{V^+ - V_{EC}(sat)}{R_C} = \frac{3.3 - 0.2}{5 k\Omega} = \frac{3.1V}{5 k\Omega} = 0.62 mA$$

DC- Analysis of Transistor ccts

Ex Calculate the base, collector, and Emitter currents & the CE Voltage for a CE cct. calculate the power dissipation.

$V_{BB} = 4V$ $\quad R_C = 2k\Omega$ $\quad \beta = 200$

$V_{CC} = 10V$ $\quad R_B = 220k\Omega$



Soln

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

$$= \frac{4 - 0.7}{220k\Omega} = \frac{3.3V}{220k\Omega} = 15\mu A$$

$$\alpha = \frac{\beta}{\beta+1} = \frac{200}{201} = 0.995$$

$$I_C = \beta I_B = 200 \times 15\mu A = 3000\mu A = 3mA$$

$$I_E = (\beta+1) I_B = 201 \times 15\mu A = 3.015 mA = 3.02 mA$$

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

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

$$= 10 - 3 \times 2 = 4V$$

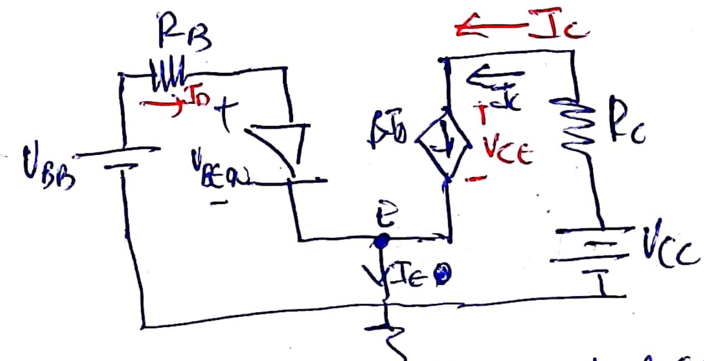


Fig dc- Equivalent cct

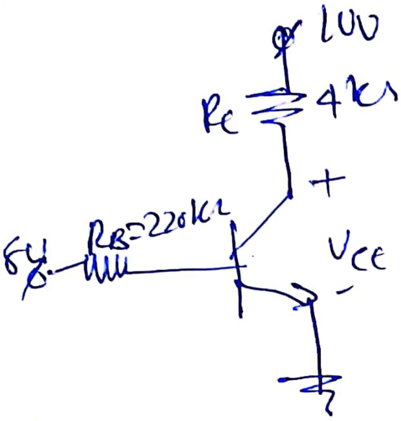
power dissipated

$$P_T = I_B V_{BE(ON)} + I_C V_{CE}$$

$$\simeq I_C V_{CE}$$

$$\cong 3mA \times 4V = 12mW$$

Ex Calculate the currents [illegible] in [illegible] when the transistor is driven into saturation. $\beta = 100$, $V_{BE\,ON} = 0.7V$, $V_{CE\,sat} = 0.2V$



Soln

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{8 - 0.7}{220} = 33.2\mu A$$

If we assume that the transistor is in active mode,

$$I_C = \beta I_B = 100 \times 33.2\mu A = 3.32mA$$

$$V_{CE} = V_{CC} - I_C R_C = 10 - 3.32 \times 4$$
$$= -3.28V$$

Since $V_{CE} < 0$, our assumption is not correct

Set $V_{CE}(sat) = 0.2V$

$$I_{C\,sat} = \frac{V_{CC} - V_{CE}(sat)}{R_C} = \frac{10 - 0.2}{4} = 2.45mA$$

Assume that B-E voltage is still equal to $V_{BE}(on) = 0.7V$,

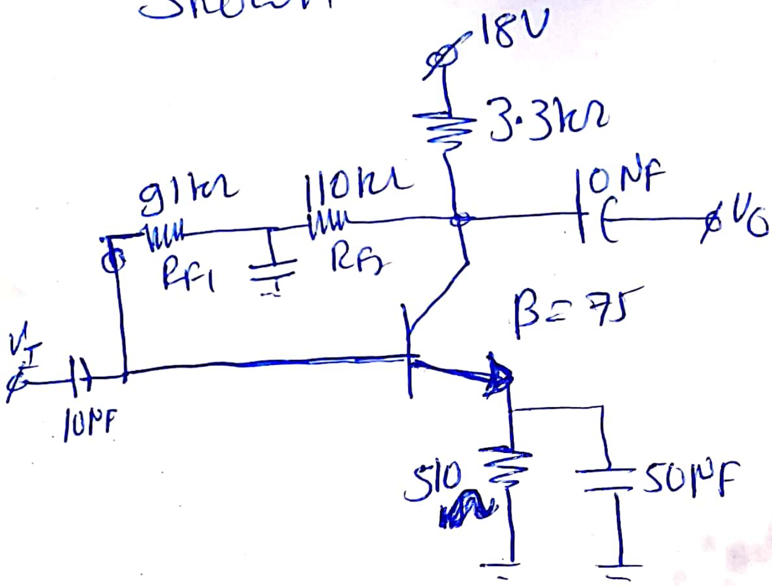
$I_B = 33.2\mu A$

$$\frac{I_C}{I_B} = \frac{2.45}{0.0332} = 74 < \beta$$

$$I_E = I_C + I_B = 2.45 + 0.033 = 2.48mA$$

$$P_T = I_B V_{BE}(on) + I_C V_{CE} = 0.0332 \times 0.7 + 2.45 \times 0.2$$
$$= 0.513mW$$

Ex Determine the dc level of I_B & V_C for the n/w shown



Soln

$R_B = R_{F1} + R_{F2} = 201\,k\Omega$

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

$$= \frac{18V - 0.7V}{201k\Omega + 75(3.3k\Omega + 0.51k\Omega)}$$

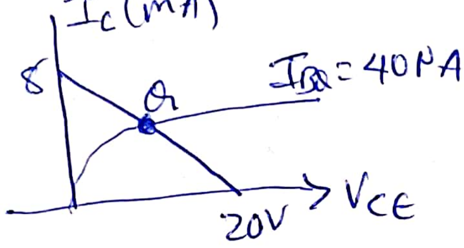
$$= \frac{17.3V}{201k\Omega + 285.75k\Omega} = 35.5\mu A$$

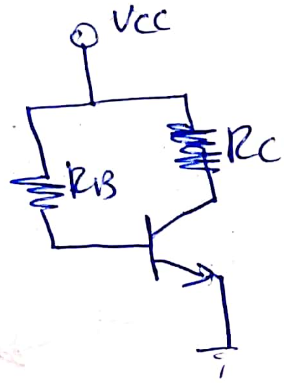
$I_C = \beta I_B = 75 \times 35.5\mu A = 2.66mA$

$V_C = V_{CC} - I_C R_C = 18V - 2.66mA \times 3.3k\Omega$

$= 18V - 8.78V = 9.22V$

Ex Given the device characteristic of figure, determine V_{CC}, R_B & R_C for the fixed bias ckt.





Soln $V_{CC} = 20V$

$$I_C = \frac{V_{CC}}{R_C}\Big|_{V_{CE}=0V}$$

$$R_C = \frac{V_{CC}}{I_C} = \frac{20V}{8mA} = 2.5k\Omega$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{(20-0.7)V}{R_B} = \frac{19.3V}{R_B}$$

$$R_B = \frac{19.3V}{I_B} = \frac{19.3V}{40\mu A} = 482.5k\Omega$$

standard resistor values are

$R_C = 2.4k\Omega$

$R_B = 470k\Omega$

using standard resistor values

$I_B = 41.1\mu A$