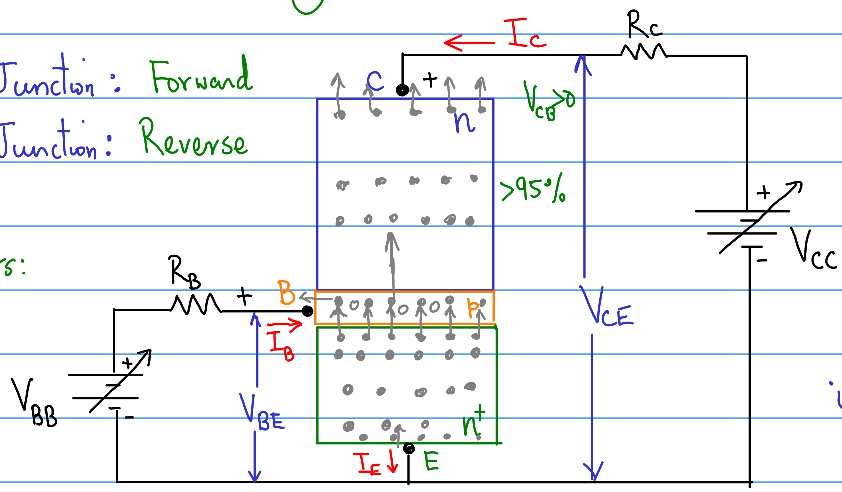
26.10.2023

Current-Voltage Characteristics of the Biased BJTs

Emitter-Base Junction : Forward

Collector-Base Junction : Reverse

n-p-n Transistors:



$I_E = I_B + I_C$

$I_B \sim \mu A$

$I_E, I_C \sim mA$

$I_E \sim I_C$

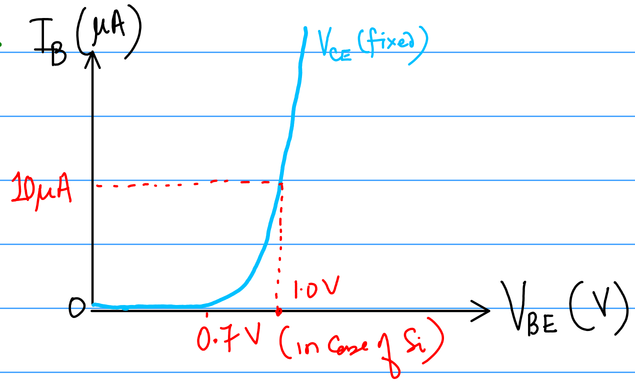
In base region :

i) The electrons have chances to recombine with holes

ii) The electrons may come out from the base terminal & constitute a base current I_B.

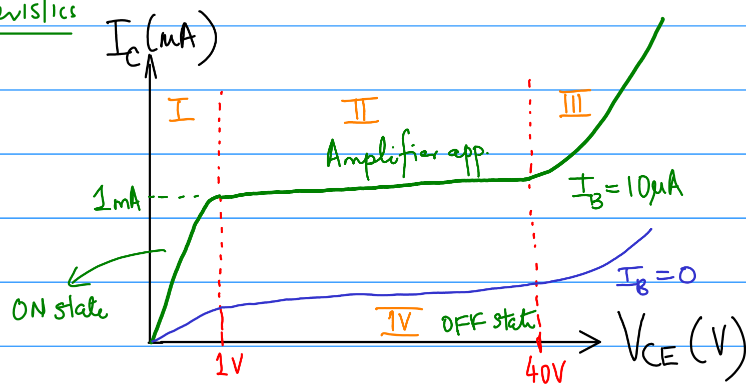
iii) Since the collector-base junction is reverse, the electrons can be collected by the collector.

Input characteristics



Output characteristics

$\beta_{DC} = 100$



Region I : Saturation Region

Region II : Active Region (Normal)

Region III : Breakdown Region

Region IV : Cut-off Region

Region II is the most useful region of operation. It is also called linear region of operation of the BJTs. If the BJT is biased in this region, then the collector current follows the base-current. That is, any change happening in the base ckt. will directly appear across the collector ckt.

Region I & IV are the saturation & Cut-off regions of operation of the BJTs,

In region I : The BJT is in 'ON' state.

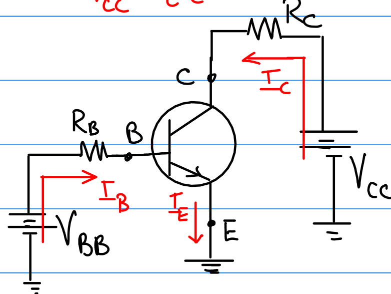
In region IV : The BJT is in "OFF" state

Whenever, you switch from region-I to IV or vice-versa, the BJT is switching from ON-state to OFF-state.

$\Rightarrow$ Operating as an "Electronic - Switch".

Note : In region-III (Breakdown region) ; the BJT burns out. ie, it never return back to normal operation.

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



Input Terminal : $V_{BB} = I_B R_B + V_{BE}$

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

Also, if current gain of the BJT is given, ie, β_{DC}

$$I_C = \beta_{DC} \cdot I_B$$

Output Terminal :

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

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

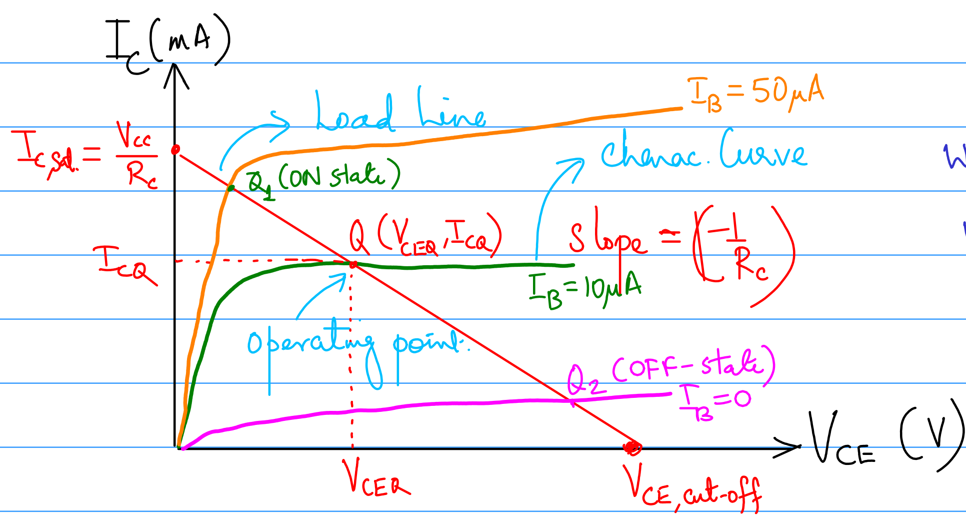
Also,

$$I_C = -\frac{V_{CE}}{R_C} + \frac{V_{CC}}{R_C}$$

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

$Y = (m) X + C$

$\Rightarrow$ st. line eqn



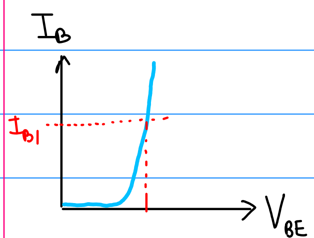
when $V_{CE} = 0$; $I_C = \frac{V_{CC}}{R_C}$

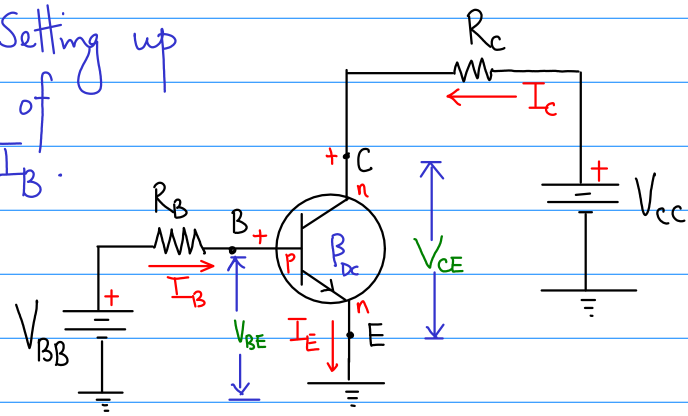
when $I_C = 0$; $V_{CE} = V_{CC}$

BJT Biasing Circuits

{ · Base-Emitter : Forward
  · Collector-Base : Reverse

① Base Bias : Setting up a fixed value of base current I_B.





$I_E = I_B + I_C$

$I_C = \beta_{DC} \cdot I_B$

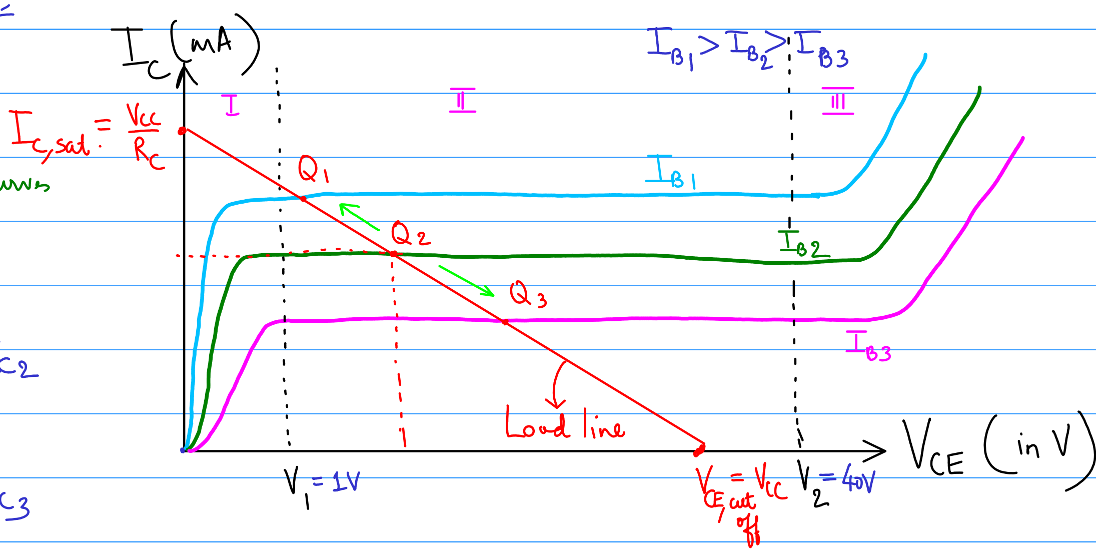
$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$ ... sets-up the base current.

Typically, for Silicon BJTs, $V_{BE} = 0.7V$

$$I_B \uparrow = \frac{V_{BB}\uparrow - 0.7V}{R_B}$$

Once, I_B is fixed, then we see the variation of I_C with V_{CE}.

For different set of value of I_B, we have different output characteristic curves



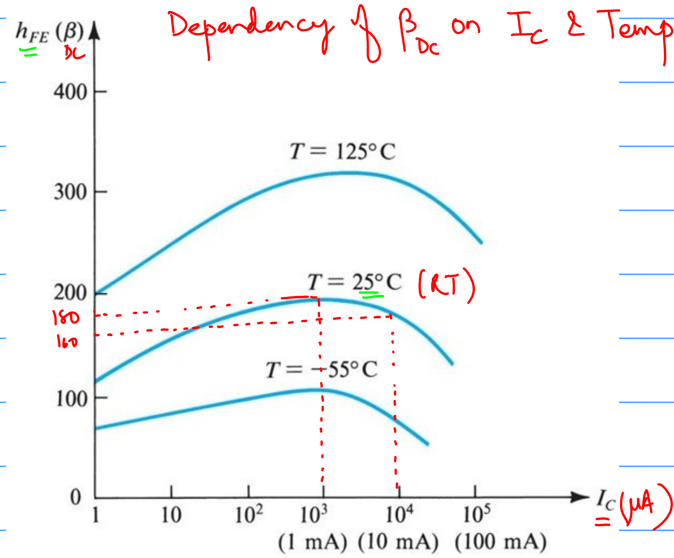
Operating points
- Q_1 : V_{CE1}, I_{C1}
- Q_2 : V_{CE2}, I_{C2}
- Q_3 : V_{CE3}, I_{C3}

$$I_C = \left(\frac{-1}{R_C}\right) V_{CE} + \frac{V_{CC}}{R_C}$$ ... st. line eqn. ($Y = mx + c$)

Here, the operating point Q (V_{CEQ}, I_{CQ}) depends upon the value of I_B and the ckt. elements (V_{CC}, V_{BB}, R_C, R_B) and the value of 'β_{DC}'.

$$\text{Since,}\quad I_C = \underbrace{\beta_{DC}}_{\text{dependency of } \beta_{DC}} I_B$$

Dependency of β_{DC} on I_C & Temperature T (°C)

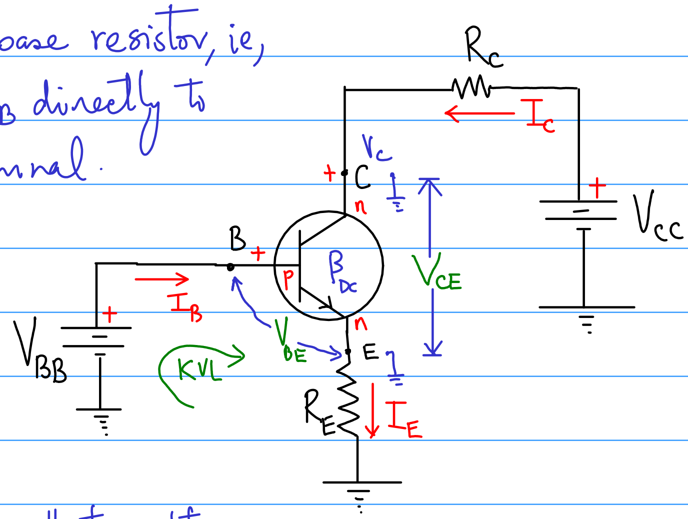


- Typically, the base bias ckt is simple biasing ckt to understand the operation of a BJT, however it is heavily dependent on the value of β_{DC}.
- For amplifier ckt, the active region of the characteristic curve is used. Therefore, we need to immune the ckt. such that it withstand the the changes due to β_{DC}. — ie, design a biasing ckt which is independent of the value of β_{DC}.

Therefore, we need to re-design a bias ckt. to make it β_{DC} independent.

(2) Emitter-Biasing ckt.

- Removing the base resistor, ie, connect the V_{BB} directly to the base terminal.



- Connect a resistor R_E to the emitter terminal.
- No change in the collector ckt.

$$V_{BB} = V_{BE} + I_E R_E$$

$$\Rightarrow \quad I_E = \frac{V_{BB} - V_{BE}}{R_E}$$

(here, assume $V_{BE} = 0.7\,V$ for Silicon BJTs)

Since, $I_C \approx I_E$ (Since $I_E = I_B + I_C$; $I_B = \mu A$; $I_C \sim mA$)

$$\Rightarrow \quad V_C = V_{CC} - I_C R_C$$

(wrt ground)

From this, we can determine,

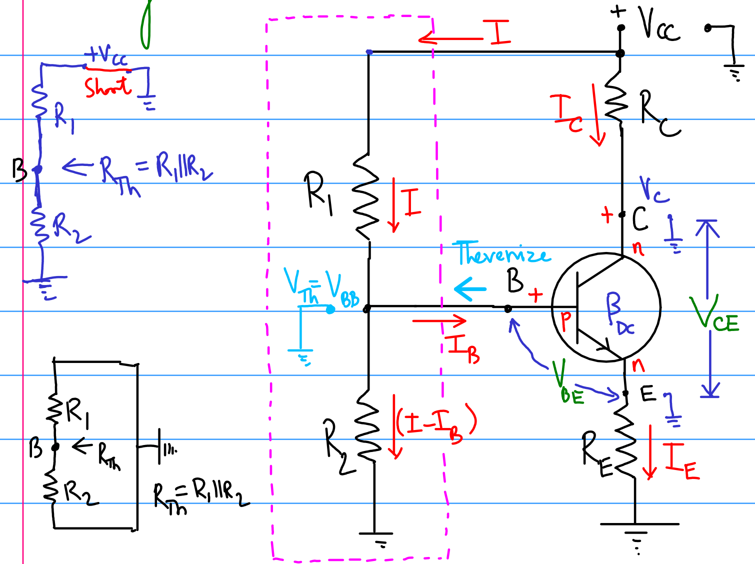
$$V_{CE} = V_C - V_E \quad \text{where, } V_E = I_E R_E$$

$\Rightarrow$ Operating point Q (V_{CE}, I_C) becomes independent of β_{DC}

<u>Note</u>: In previous biasing ckts (Base-Bias / Emitter-Bias), we are using two sources, ie, V_{BB} & V_{CC}.

Can we design a biasing ckt. with only one source? YES

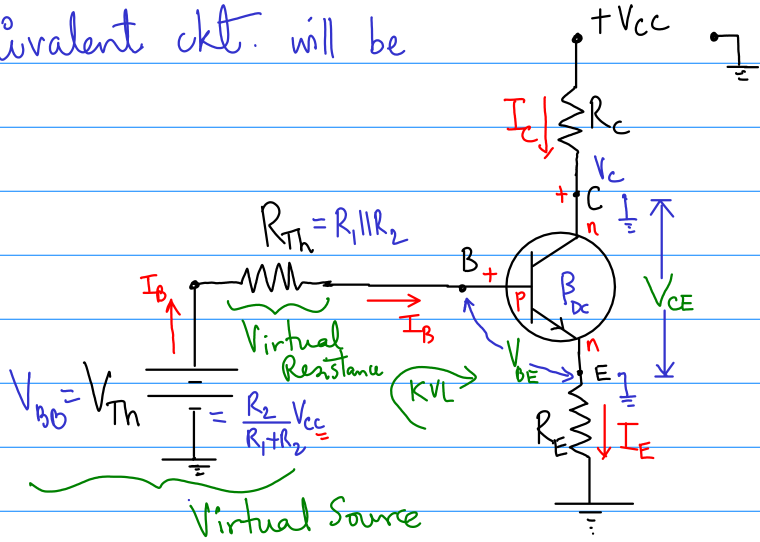
(3) Voltage-Divider Bias Circuit: Use single dc source V_{CC} to bias the BJT.



$$V_{Th} = V_{BB} = \frac{R_2}{R_1+R_2} V_{CC}$$

$$R_{Th} = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2}$$

Equivalent ckt. will be



$$I_E = I_B + I_C$$

$$V_{Th} = I_B \cdot R_{Th} + V_{BE} + I_E R_E$$

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

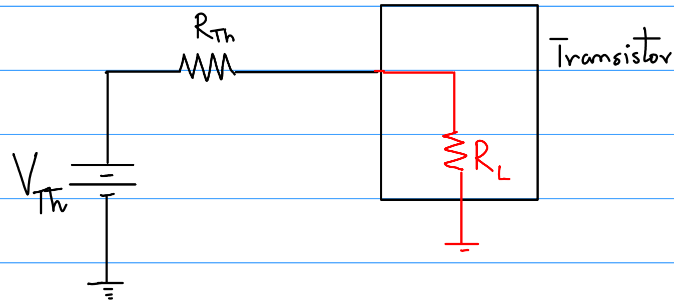
$$Q\,(V_{CEQ}, I_{CQ}) = ?$$

Reference: Chapter 6 & 7 from Malvino & Bates.

Effectively, one can say that V_{Th} is the source voltage which bias the base-emitter junction, whereas, R_{Th} is the base resistance.

For, V_{Th} to drop across R_L,

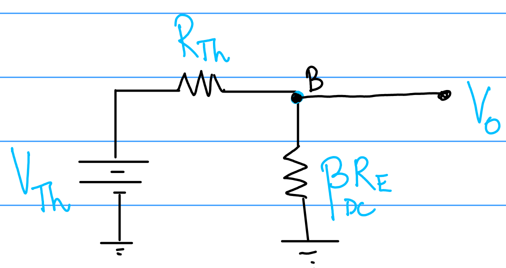
$$\boxed{R_L \geq 100 R_{Th}}$$ stiff Cond^n.



Here, to estimate the effective load to the base terminal, we can compare the base-current (I_B) with emitter current (I_E)

Since $I_E \approx I_C = \beta_{DC} I_B$

Since $\boxed{I \propto \frac{1}{R}}$ $\Rightarrow$ Effective load as seen from the base terminal is $\beta_{DC} R_E$



$$V_0 = \frac{\beta_{DC} R_E}{\beta_{DC} R_E + R_{Th}} \cdot V_{Th}$$

$$\beta_{DC} R_E \geq 100 R_{Th}$$ --- stiff condition.

$V_0 \approx V_{Th}$

$$\Rightarrow \boxed{\beta_{DC} R_E \geq 100 \, (R_1 \| R_2)}$$

Summary: For designing a voltage-divider bias ckt.

- Verify the condition for 'stiff' voltage source ie,

$$\beta_{DC} R_E \geq 100 (R_1 \| R_2)$$

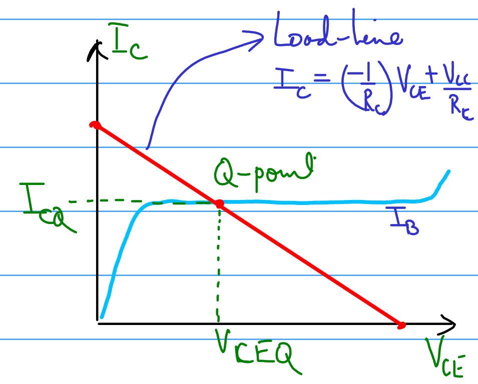
- $I_E = \dfrac{V_E}{R_E}$

- $I_C = I_E$

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

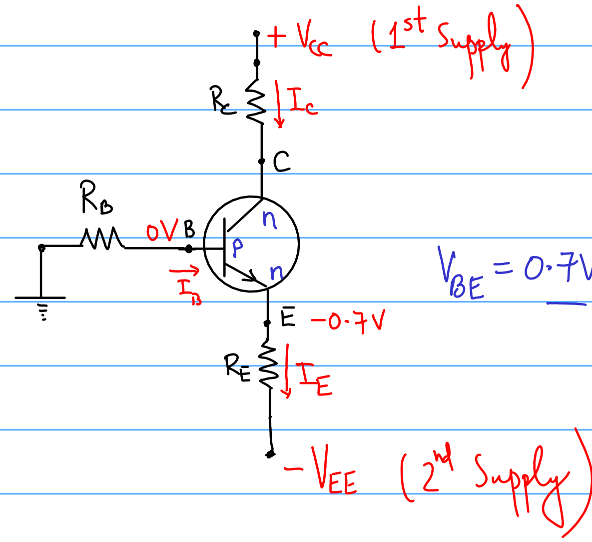
- $V_{CE} = V_C - V_E$

- Q-point (V_{CEQ}, I_{CQ})



(4) Two-supply Emitter Bias :

- $V_B = 0\,V$
- $V_E = -0.7V$
- $I_E = \dfrac{V_{EE} - 0.7V}{R_E}$ ✓
- $I_C \approx I_E$
- $V_C = V_{CC} - I_C R$
- $V_{CE} = V_C - V_E = V_C + 0.7V$

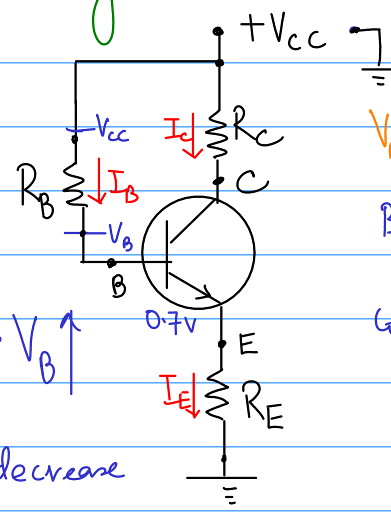


$\underline{V_{BE} = 0.7V}$

- Operating point (Q-point) : V_{CEQ}, I_{CQ}

(5) Feedback Bias Ckt. : Primarily design to ensure stable operating point.

(i) Emitter-Feedback ckt. (Negative Feedback)



$V_{R_B}\downarrow = V_{CC} - V_B\uparrow$

Base-Emitter: Forward

Collector-Base: Reverse

In this ckt., suppose while operation, the collector-current increases.

ie,

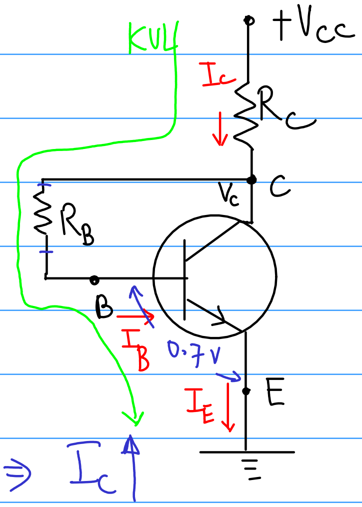
$$I_C \uparrow \Rightarrow I_E \uparrow \Rightarrow V_E \uparrow \Rightarrow V_B \uparrow$$

effectively, the voltage drop across R_B decrease

$$V_{R_B}\downarrow \Rightarrow I_B\downarrow \Rightarrow I_C\downarrow$$ ... Since $I_C=\beta I_B$

ie, any increase in the value of I_C, the ckt. behaves as "negative feedback", and effectively reduces the value of I_C. $I_C\uparrow\downarrow \Rightarrow Q\uparrow\downarrow$ or $I_C\downarrow\uparrow \Rightarrow Q\downarrow\uparrow$

(ii) Collector-Feedback ckt:



$V_C\downarrow = V_{CC} - I_C R_C\uparrow$

- $I_C\uparrow \Rightarrow V_C\downarrow \Rightarrow V_{R_B}\downarrow \Rightarrow I_B\downarrow$

  $\Rightarrow I_C\downarrow$

or,

- $I_C\downarrow \Rightarrow V_C\uparrow \Rightarrow V_{R_B}\uparrow \Rightarrow I_B\uparrow \Rightarrow I_C\uparrow$

$$V_{CC} = I_C R_C + I_B R_B + V_{BE}$$

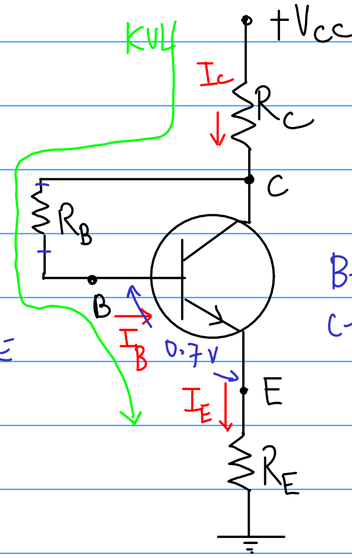
$$V_{CC} - V_{BE} = I_C R_C + \frac{I_C}{\beta_{DC}} R_B$$

$$\Rightarrow I_C = \frac{V_{CC} - V_{BE}}{R_C + \frac{R_B}{\beta_{DC}}}$$

Therefore, $V_C = V_{CC} - I_C R_C$

Q-point (V_{CEQ}, I_{CQ})

(iii) Emitter-Collector feedback ckt.



B-E Junct: Forward

C-B Junct: Reverse

$$V_{CC} = I_C R_C + I_B R_B + V_{BE} + I_E R_E$$

Since, $I_C \approx I_E$; $I_B = \dfrac{I_C}{\beta_{DC}}$

$$\Rightarrow V_{CC} = I_C R_C + \frac{I_C}{\beta_{DC}} R_B + V_{BE} + I_E R_E$$

$$\Rightarrow I_C = \frac{V_{CC} - V_{BE}}{R_C + \dfrac{R_B}{\beta_{DC}} + R_E}$$

Therefore, $V_C = V_{CC} - I_C R_C$

$$V_E = I_E R_E$$

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

Q-point (V_{CEQ}, I_{CQ})