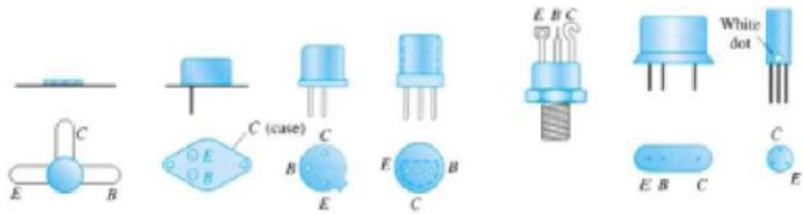


ENEE2360 Analog Electronics

T7:
BJT DC Biasing

Instructor : Nasser Ismail

1

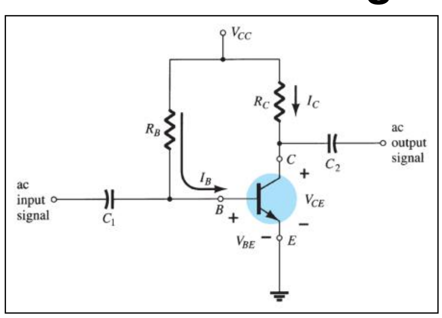
Biasing

Biasing: Applying DC voltages to a transistor in order to establish fixed level of voltage and current.
For Amplifier (active/Linear) mode, the resulting dc voltage and current establish the operation point to turn it on so that it can amplify AC signals.

DC Biasing Circuits

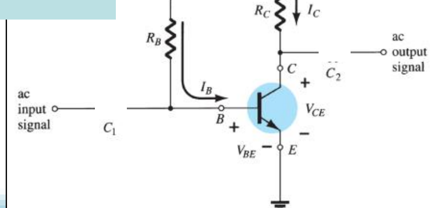
1. Fixed-bias circuit
2. Emitter-stabilized bias circuit
3. DC bias with voltage feedback
4. Voltage divider bias circuit

1)Fixed Bias Configuration



DC equivalent circuit $\Rightarrow$ means $f = 0$

$$\Rightarrow Xc = \frac{1}{2\pi f C} \cong \infty \text{ (open circuit)}$$



The Base-Emitter Loop

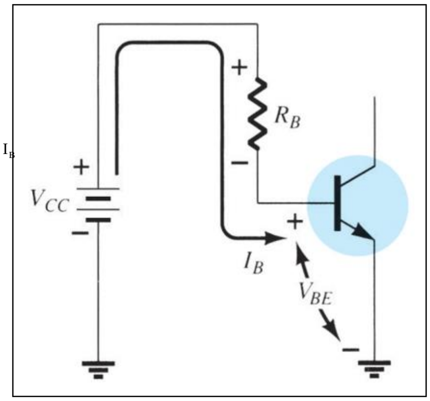
From Kirchhoff's voltage law for Input:

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

Solving for base current:

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

Choosing R_B will establish the required level of I_B



Collector-Emitter Loop

Collector current:

$$I_C = \beta I_B$$

From Kirchhoff's voltage law:

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

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

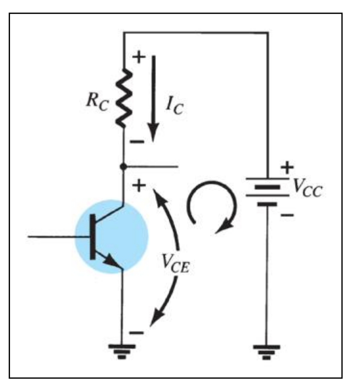
$$\text{Since } V_E = 0 \Rightarrow \therefore V_{CE} = V_C$$

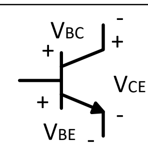
$$V_{CE} = V_{CC} - I_C R_C$$

Also

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

$$\therefore V_{BE} = V_B$$





$$V_{BE} - V_{CE} - V_{BC} = 0$$

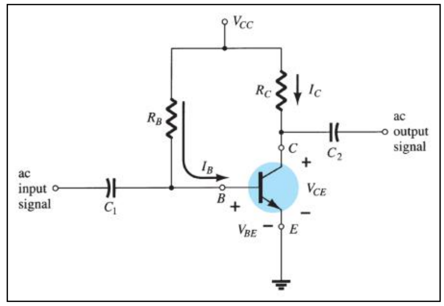
$$\therefore V_{BC} = V_{BE} - V_{CE}$$

Design of Fixed Bias Circuit

Assume VCC $=10\text{V}, \beta_{\text{nominal}}=100, \beta_{\min}=50, \beta_{\max}=150$

Design for Q-point : $V_{CEQ}=5\text{V}, I_{CQ}=1\text{mA}$ (i.e find unknown component values R_B and R_C)

Solution



$$I_{BQ}=\frac{I_{CQ}}{\beta_{\text{nominal}}}=\frac{1\,\text{mA}}{100}=10\,\mu\text{A}$$

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

$$R_B=\frac{V_{CC}-V_{BE}}{I_B}=\frac{10-0.7}{10\,\mu\text{A}}$$

$$=930\,\text{k}\Omega$$

$$V_{CE}=V_{CC}-I_CR_C$$

$$V_{CEQ}=5=10-I_CR_C$$

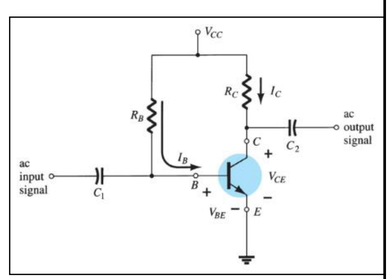
$$\therefore\ R_C=\frac{5}{1\,\text{mA}}=5\,\text{k}\Omega$$

Fixed bias Stability

Assume VCC $=10\text{V}, \beta_{\text{nominal}}=100, \beta_{\min}=50, \beta_{\max}=150$

Design for Q-point : $V_{CEQ}=5\text{V}, I_{CQ}=1\text{mA}$

Solution – continued



If $\beta=\beta_{\min}=50$

$I_B=10\,\mu\text{A}$

$I_C=\beta I_B=(50)(10\,\mu\text{A})=0.5\,\text{mA}$

$V_{CE}=V_{CC}-I_CR_C$

$V_{CEQ}=10-(0.5\,\text{mA})(5\,\text{k}\Omega)=7.5\,\text{V}$

If $\beta=\beta_{\max}=150$

$I_B=10\,\mu\text{A}$

$I_C=\beta I_B=(150)(10\,\mu\text{A})=1.5\,\text{mA}$

$V_{CE}=V_{CC}-I_CR_C$

$V_{CEQ}=10-(1.5\,\text{mA})(5\,\text{k}\Omega)=2.5\,\text{V}$

for

$50\le\beta\le150$

$I_B=10\,\mu\text{A}$ fixed

$0.5\,\text{mA}\le I_C\le1.5\,\text{mA}$

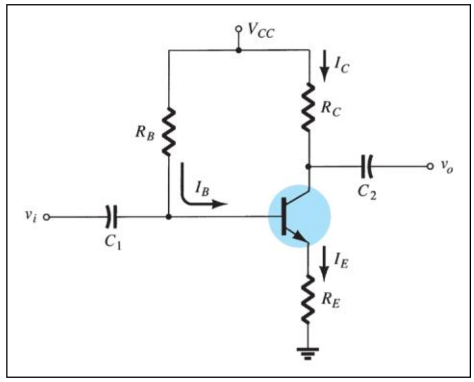
$7.5\,\text{V}\ge V_{CE}\ge2.5\,\text{V}$

$$\therefore\ \frac{I_{C(\max)}}{I_{C(\min)}}=\frac{1.5\,\text{mA}}{0.5\,\text{mA}}=3$$

Not very stable

2) Emitter-Stabilized Bias Circuit

Adding a resistor (R_E) to the emitter circuit stabilizes the bias circuit.



Base-Emitter Loop

From Kirchhoff's voltage law:

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

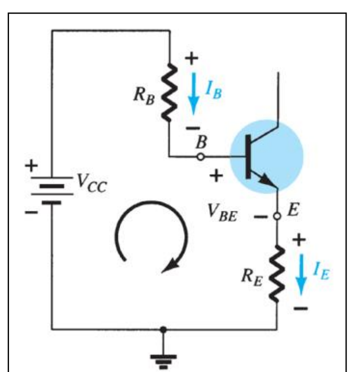
Since $I_E = (\beta + 1) I_B$:

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

Solving for I_B:

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

$(\beta + 1) R_E$ ← is the emitter resistor as it appears in the base emitter loop



Base-Emitter Loop

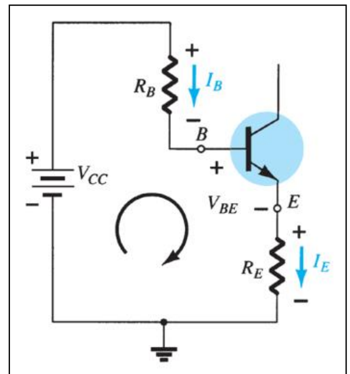
Solving for I_E:

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

In order to get IE almost independant of B we choose:

$$R_E >> \frac{R_B}{(\beta+1)}$$

$$\Rightarrow I_E \cong \frac{V_{CC} - V_{BE}}{R_E}$$



Also, in order to guarantee operation in linear mode we choose $0.1\,V_{CC} \leq V_E < 0.2V_{CC}$

Collector-Emitter Loop

From Kirchhoff's voltage law:

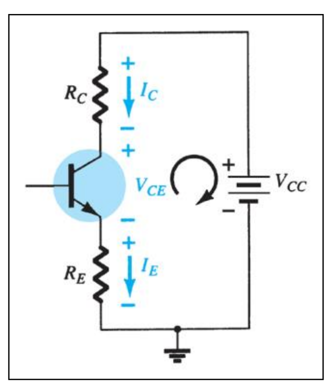
$$I_E R_E + V_{CE} + I_C R_C - V_{CC} = 0$$

Since $I_E \cong I_C$:

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

Also:

$$V_E = I_E R_E$$
$$V_C = V_{CE} + V_E = V_{CC} - I_C R_C$$
$$V_B = V_{CC} - I_R R_B = V_{BE} + V_E$$



Design: Emitter Stabilization bias

Assume VCC $= 10V$, $\beta_{nominal} = 100$, $\beta_{min} = 50$, $\beta_{max} = 150$

Design for Q-point: $V_{CEQ} = 5V$, $I_{CQ} = 1mA$

Solution

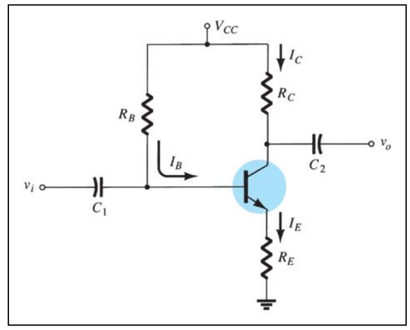
$-$let $V_E = 0.1\,V_{CC}$

$V_E = 1V$

$$I_E = \frac{V_E}{R_E} \Rightarrow R_E = \frac{1\,V}{1.01\,mA} \cong 1\,k\Omega$$

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

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



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

$$V_{CEQ} = 5 = 10 - 1 - I_C R_C$$

$$\therefore\ R_C = \frac{4}{1\,mA} = 4\,k\Omega$$

Emitter bias Stability

If $\beta = \beta_{min} = 50$

$$I_B = \frac{9.3}{829k\Omega + 51k\Omega} = 10.56\,\mu A$$

$$I_C = \beta I_B = (50)(10.56\,\mu A) = 0.528\,mA$$

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

$$V_{CEQ} = 10 - (0.528\,mA)(4\,k\Omega) - 1 = 6.89\,V$$

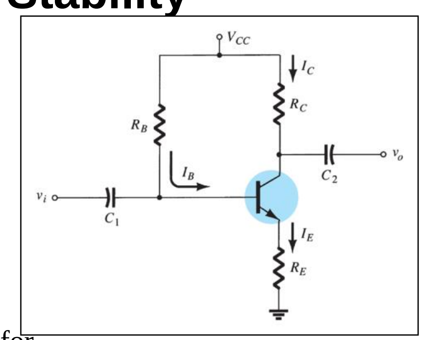
If $\beta = \beta_{max} = 150$

$$I_B = \frac{9.3}{829k\Omega + 151k\Omega} = 9.489\,\mu A$$

$$I_C = \beta I_B = (150)(9.489\,\mu A) = 1.423\,mA$$

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

$$V_{CEQ} = 10 - (1.423\,mA)(4\,k\Omega) - 1 = 3.31\,V$$



for

$50 \le \beta \le 150$

$10.56\,\mu A \ge I_B \ge 9.489\,\mu A$

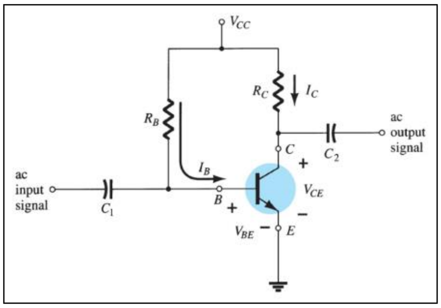
$0.528\,mA \le I_C \le 1.423\,mA$

$6.89\,V \ge V_{CE} \ge 3.31\,V$

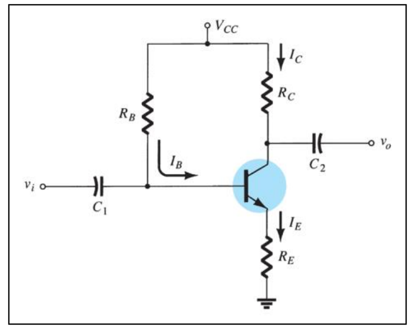
$$\therefore \frac{I_{C(max)}}{I_{C(min)}} = \frac{1.423\,mA}{0.528\,mA} \cong 2.7$$

Improved, but not very stable

Fixed bias



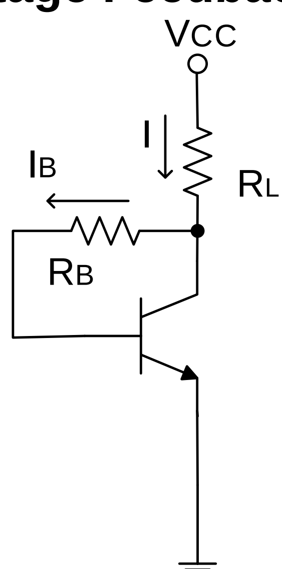
Emitter Stabilization bias



3) DC Bias With Voltage Feedback

Another way to improve the stability of a bias circuit is to add a feedback path from collector to base.

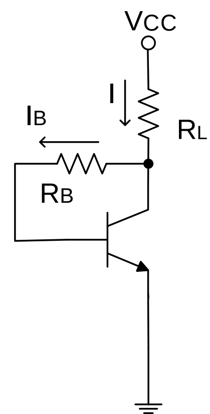
In this bias circuit the Q-point is only slightly dependent on the transistor beta, β.



Base-Emitter Loop

From Kirchhoff's voltage law:

$$V_{CC} - I.R_L - I_B R_B - V_{BE} = 0$$
$$I = I_C + I_B$$
$$I_C = \beta I_B$$



Solving for I_B:

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

$$V_{CC} = I.R_L + V_{CE}$$
$$I = I_C + I_B$$
$$V_{CE} = V_{CC} - (I_C + I_B)R_L$$

suppose $\beta \uparrow, I_B \downarrow, I_C = \uparrow \beta . I_B \downarrow \cong$ const

there is some kind of compensation effect

Design: Voltage feedback bias

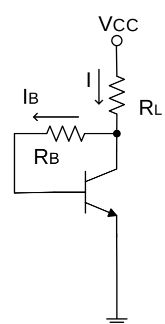
Assume VCC = 10V, $\beta_{nominal} = 100$, $\beta_{min} = 50$, $\beta_{max} = 150$

Design for Q-point: $V_{CEQ} = 5V$, $I_{CQ} = 1mA$

Solution

$$R_L = \frac{V_{CC} - V_{CE}}{I_C + I_B} = \frac{10-5}{1mA + \frac{1mA}{100}}$$

$$= 4.95\,k\Omega$$



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

$$\therefore R_B = 430\,k\Omega$$

If $\beta = \beta_{min} = 50$

$I_B = 0.013627\,mA$

$I_C = 0.68\,mA$

If $\beta = \beta_{max} = 150$

$I_B = 0.00793\,mA$

$I_C = 1.19\,mA$

for

$50 \le \beta \le 150$

$0.68\,mA \le I_C \le 1.19\,mA$

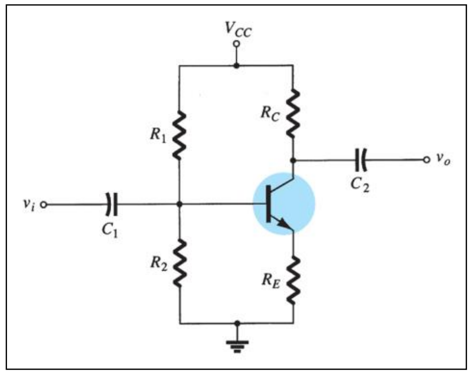
$$\therefore \frac{I_{C(max)}}{I_{C(min)}} = \frac{1.19\,mA}{0.68\,mA} \cong 1.75$$

Better Q-point stability

4) Voltage Divider Bias

This is a very stable bias circuit.

The currents and voltages are nearly independent of any variations in β if the circuit is designed properly



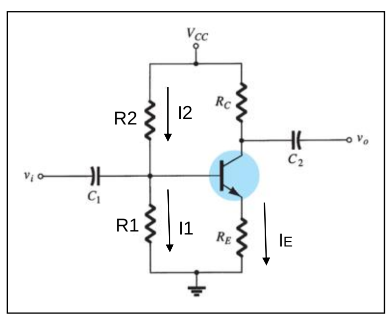
Approximate Analysis

Where $I_B << I_1$ and $I_1 \cong I_2$:

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

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

$$I_{E(approximate)} = \frac{V_E}{R_E} = \frac{V_B - V_{BE}}{R_E}$$



From Kirchhoff's voltage law:

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

$$I_E \cong I_C$$

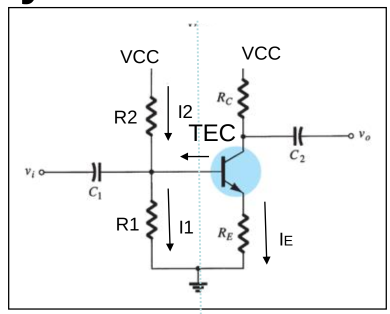
$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

Here we got Ic independent of β which provides good Q-point stability

Exact Analysis

We must try to make I_B as close as possible to zero

Thevenin Equivalent circuit for the circuit left of the base is done



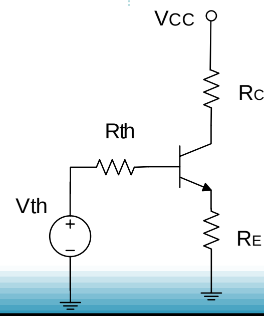
$$V_{th} = \frac{R_1 V_{CC}}{R_1 + R_2}$$

$$R_{th} = R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

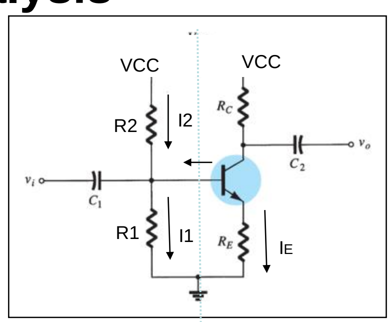
$$V_{th} = I_B R_{th} + V_{BE} + I_E R_E$$

$$\text{but } I_B = \frac{I_E}{\beta + 1}$$

$$\therefore I_{E(exact)} = \frac{V_{th} - V_{BE}}{\frac{Rth}{\beta + 1} + R_E}$$



Exact Analysis



$$\therefore I_{E(exact)} = \frac{V_{th} - V_{BE}}{\frac{Rth}{\beta + 1} + R_E}$$

if we compare to approximate solution

$$I_{E(approximate)} = \frac{V_B - V_{BE}}{R_E}$$

$$\Rightarrow \text{we must make the quantity } \frac{Rth}{\beta + 1} << R_E$$

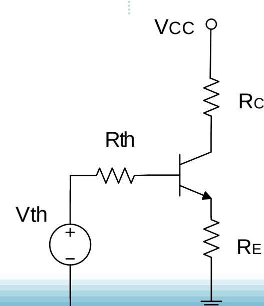
Here we got Ic independent of β

$$\therefore \quad Rth << (\beta + 1) R_E$$

$$\text{as a rule let } Rth << \frac{(\beta + 1) R_E}{10}$$

or

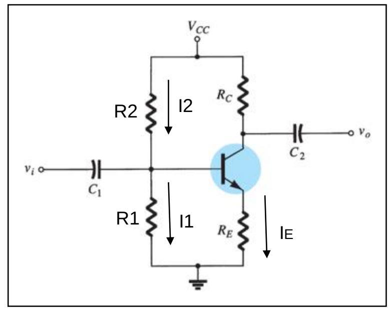
$$Rth << \frac{\beta R_E}{10}$$



Design: Voltage Divider bias

Assume $VCC = 10V, \beta_{nominal} = 100, \beta_{min} = 50, \beta_{max} = 150$

Design for Q-point: $V_{CEQ} = 5V, I_{CQ} = 1mA$



Solution

1) let $V_E = 0.1\,V_{CC}$

$V_E = 1V$

$$I_E = \frac{V_E}{R_E} \Rightarrow R_E = \frac{1\,V}{1.01\,mA} \cong 1\,k\Omega$$

2) let $Rth = \frac{R_E . \beta_{nominal}}{50} = \frac{1\,k\Omega.100}{50} = 2\,k\Omega$

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

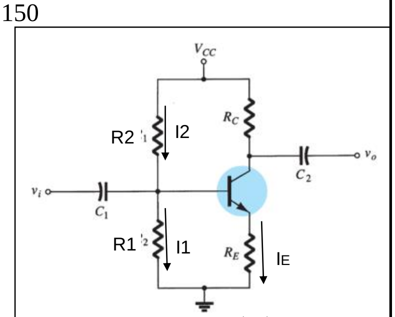
$V_{CEQ} = 5$

$$\therefore R_C = \frac{V_{CC} - V_{CE} - V_E}{1mA} = \frac{10-5-1}{1\,mA} = 4\,k\Omega$$

Design: Voltage Divider bias

Assume $VCC = 10V, \beta_{nominal} = 100, \beta_{min} = 50, \beta_{max} = 150$

Design for Q-point: $V_{CEQ} = 5V, I_{CQ} = 1mA$



Solution – continued

$$4)\, I_E = \frac{V_{th} - V_{BE}}{\frac{Rth}{\beta+1} + R_E}$$

$$\therefore V_{th} = \frac{R_1 V_{CC}}{R_1 + R_2} = I_E\left(\frac{Rth}{\beta+1} + R_E\right) + V_{BE} = 1.72V \quad ...(1)$$

$$R_{th} = R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2} = 2\ k\Omega \quad ....(2)$$

solving (1) & (2) yields:

$R_1 = 2.42\,k\Omega$

$R_2 = 11.64\,k\Omega$

Voltage Divider bias Stability

$$\text{If } \beta = \beta_{min} = 50$$
$$I_C = 0.982\,\text{mA}$$
$$\text{If } \beta = \beta_{max} = 150$$
$$I_C = 1.0069\,\text{mA}$$

for

$$50 \le \beta \le 150$$
$$0.982\,\text{mA} \le I_C \le 1.0067\,\text{mA}$$
$$\therefore \frac{I_{C(max)}}{I_{C(min)}} = \frac{1.0067\,\text{mA}}{0.982\,\text{mA}} \cong 1.0254$$

Very good Q-point stability

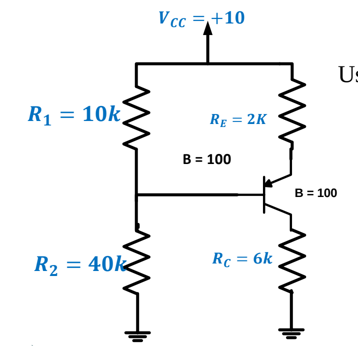
PNP Transistors

The analysis for *pnp* transistor biasing circuits is the same as that for *npn* transistor circuits. The only difference is that the currents are flowing in the opposite direction.

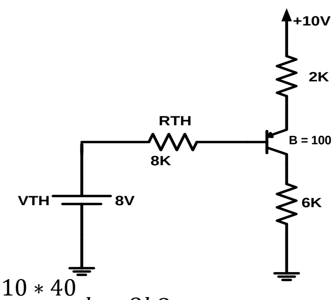
Circuit using pnp transistor:

Example:

Find I_E, V_{EC}, for the circuit below; solution



Using thevenin's theorem:



$$R_{th} = \frac{R_1 R_2}{R_1 + R_2} = \frac{10 * 40}{10 + 40} k = 8k\Omega$$

$$V_{th} = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{40}{10 + 40} * 10 = 8volt$$

KVL: $10 = 2kI_E + V_{EB} + R_{th} I_B + V_{th}$

- $I_E = 0.625mA$

KVL: $10 = 2kI_E + V_{EC} + 6kI_C$

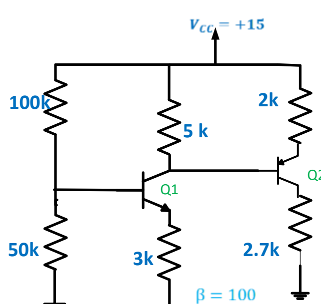
- $V_{EC} = 5volt$

$V_{CE} = -5V$ Which is $< -0.2V$

Example:

Find I_{E1}, I_{E2}

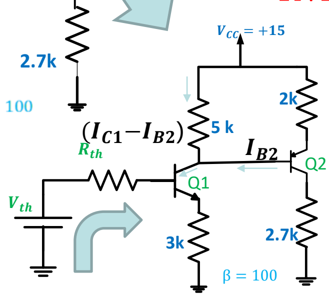
Solution



$$R_{th} = \frac{R_1 R_2}{R_1 + R_2} = \frac{50 * 100}{50 + 100} k = 33.3k\Omega$$

$$V_{th} = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{50}{50 + 100} * 15 = 5\ volt$$

KVL:



$$I_{E1} = \frac{V_{th} - V_{BE}}{\frac{R_{th}}{\beta + 1} + R_E} = \frac{5 - 0.7}{\left(\frac{33.3k}{101}\right) + 3k}$$

$$= 1.28mA$$

KVL:

$$2kI_{E2} + V_{EB} - 5k(I_{C1} - I_{B2}) = 0$$

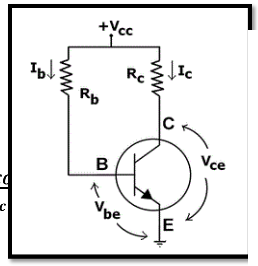
$$I_{E2} = 2.78mA$$

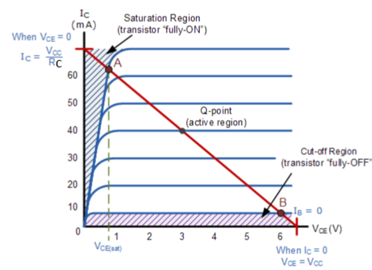
BJT Ac-Small signal analysis using Graphical method:

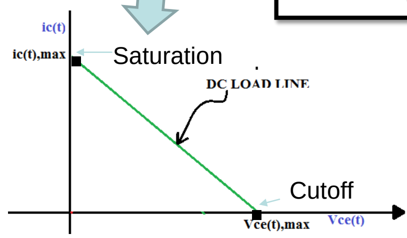
Graphical method:

KVL : $V_{CC} = R_c I_c + V_{CE}$

$$I_c = -\frac{1}{R_c} V_{CE} + \frac{V_{CC}}{R_c}$$







$$i_{C(t),max} = \frac{V_{CC}}{R_C}$$ Saturation

$$V_{CE(t),max} = V_{CC}$$ Cutoff

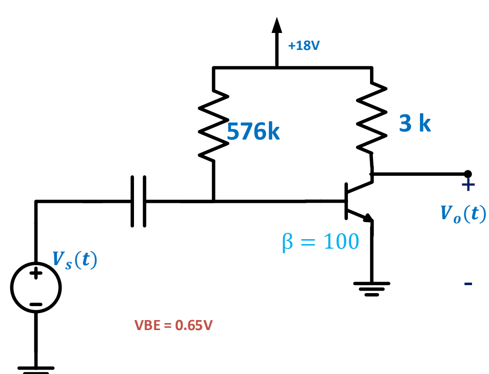
BJT Amplifier

Using superposition

$$V_{BE}(t) = V_{BE} + v_{be}$$

$$i_C(t) = I_{CQ} + i_c$$

$$V_{CE}(t) = V_{CEQ} + v_{ce}$$



DC Load Lines

Assume VCC = 18V, β = 100

$R_B = 576\,k\Omega$; $R_C = 3k\Omega$; $V_{BE} = 0.7\,V$

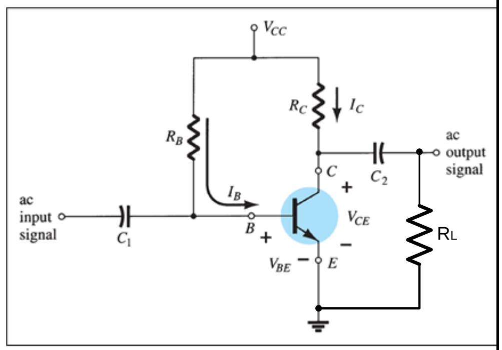
FIRST : DC ANALYSIS

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

$$I_C = -\frac{1}{R_C} V_{CE} + \frac{V_{CC}}{R_C} \Leftarrow I_C = f(V_{CE})$$

This is a straight line equation

$$Y = mX + b$$



$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{18 - 0.7}{576\ \ k\Omega} = 30\,\mu A$$

$$I_C = \beta I_B = 3\,mA$$

$$V_{CE} = V_{CC} - I_C R_C = 18 - (3mA)(3k\Omega)$$
$$= 9\,V$$

DC Load Line

I_{Csat}

$$I_{Csat} = \frac{V_{CC}}{R_C}$$

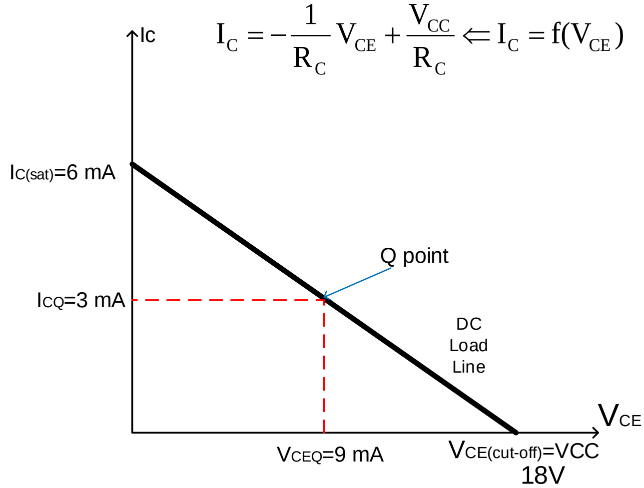
$$V_{CE} = V_{CE(sat)} \cong 0\ V$$

$V_{CEcutoff}$

$V_{CE(cutoff)} = V_{CC}$

I_C = 0 mA

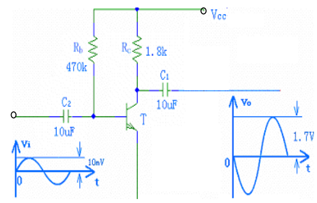
$$I_C = -\frac{1}{R_C} V_{CE} + \frac{V_{CC}}{R_C} \Leftarrow I_C = f(V_{CE})$$

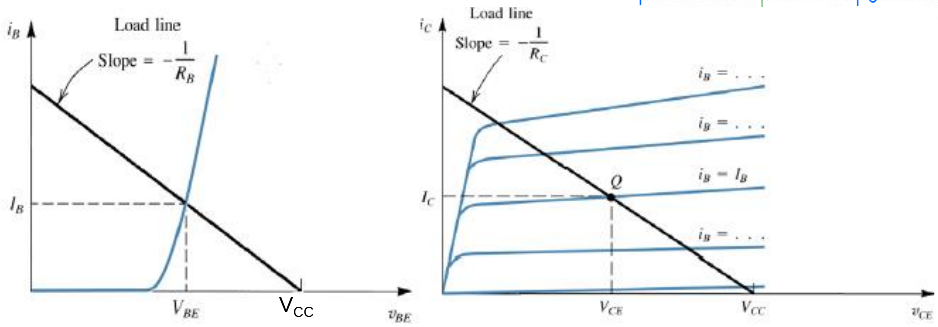


Basic BJT Amplifiers Circuits (for info only)

Graphical Analysis

- Can be useful to understand the operation of BJT circuits.
- First, establish DC conditions by finding I_B (or V_{BE})
- Second, figure out the DC operating point for I_C





Can get a feel for whether the BJT will stay in active region of operation

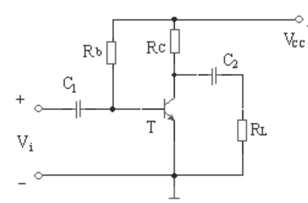
– What happens if R_C is larger or smaller?

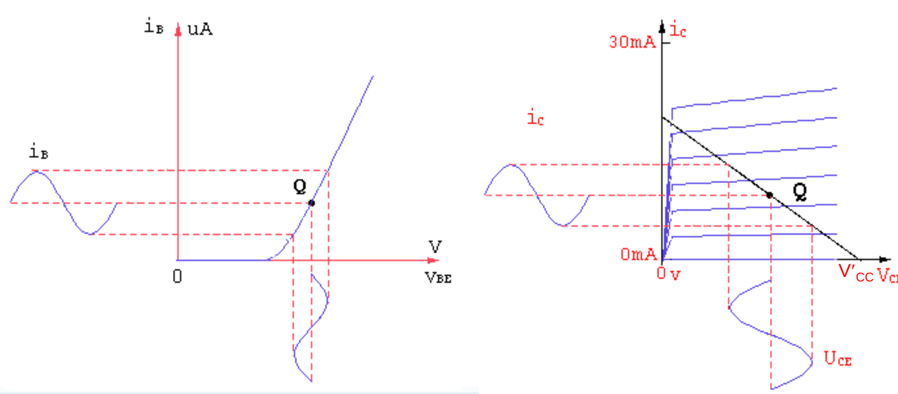
Basic BJT Amplifiers Circuits

(for info only)

Graphical Analysis

Q-point is centered on the ac load line:



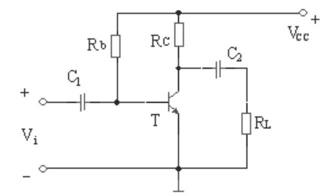


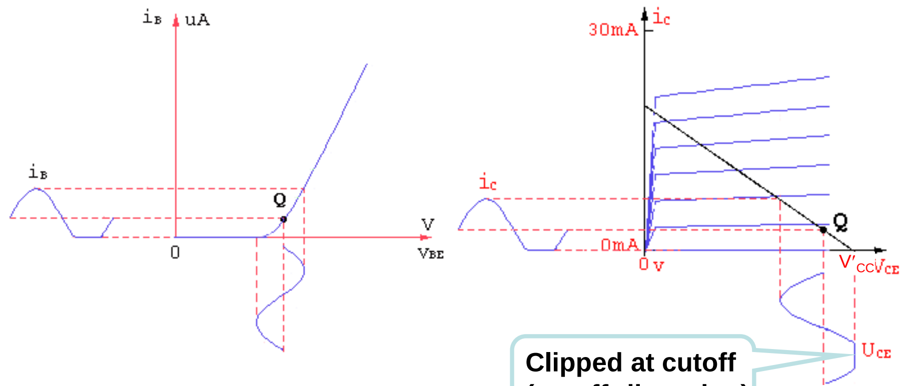
Basic BJT Amplifiers Circuits

(for info only)

Graphical Analysis

Q-point closer to cutoff:





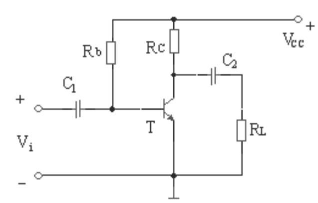
Clipped at cutoff (cutoff distortion)

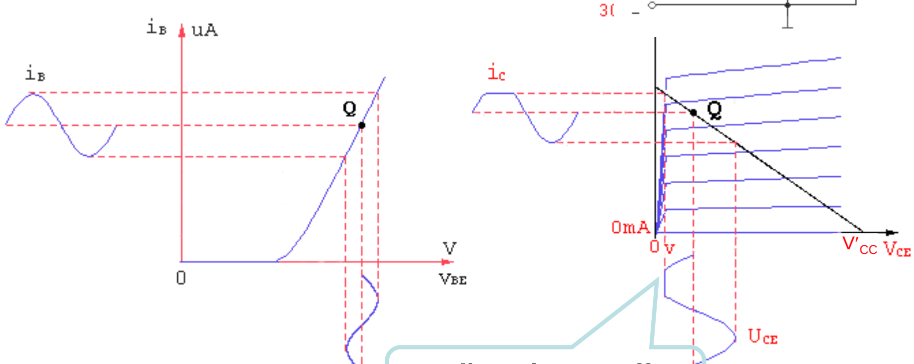
Basic BJT Amplifiers Circuits

(for info only)

Graphical Analysis

Q-point closer to saturation:





Clipped at cutoff (saturation distortion)

Basic BJT Amplifiers Circuits

(for info only)

Graphical Analysis