

L11 - part 2
29/7



Instructor : Nasser Ismail

1

Biasing $\xrightarrow{\text{for}}$ active } mode Linear }

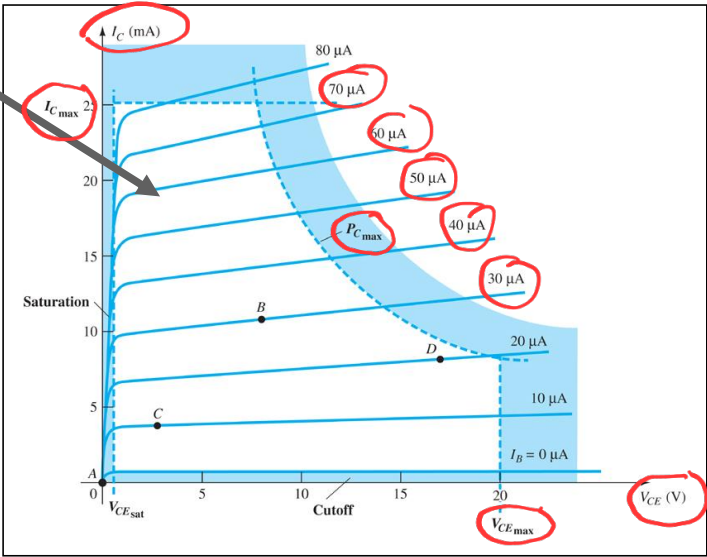
Biasing: Applying DC voltages to a transistor in order to establish fixed level of voltage and current.

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.

Safe
Operating
Area “SOA”

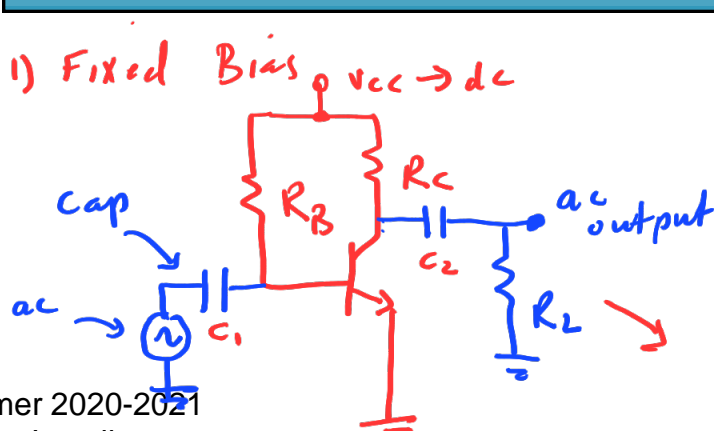
Operating Point

The DC input
establishes an
operating or
quiescent point
called the ***Q-point***.

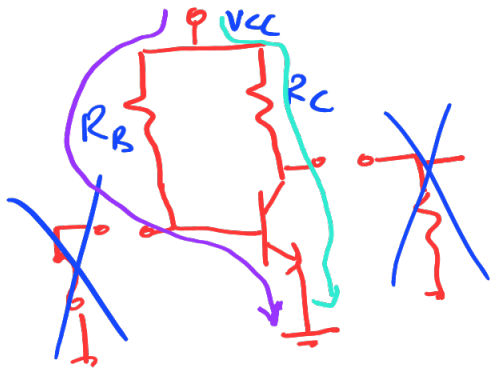


DC Biasing Circuits

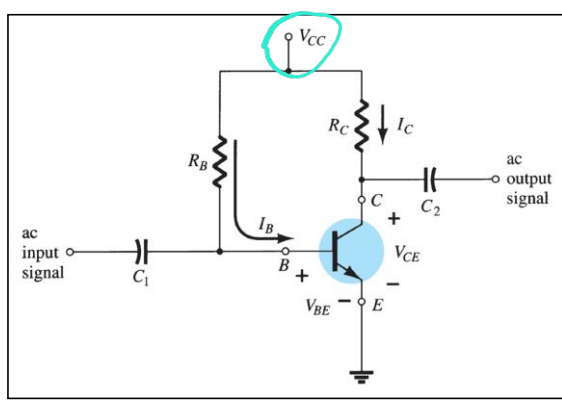
1. Fixed-bias circuit
2. Emitter-stabilized bias circuit
3. DC bias with voltage feedback
4. Voltage divider bias circuit



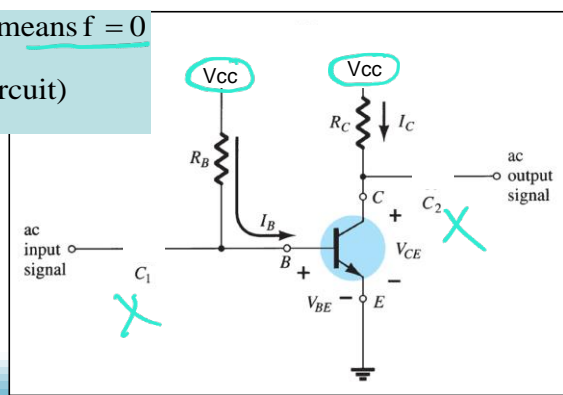
DC analysis \rightarrow ac sources killed
 $f = 0$
 $X_C = \frac{1}{2\pi f C} \approx \infty$ open
 \downarrow caps treated as open circuit



1)Fixed Bias Configuration



DC equivalent circuit \Rightarrow means $f = 0$
 $\Rightarrow X_C = \frac{1}{2\pi f C} \cong \infty$ (open circuit)



The Base-Emitter Loop

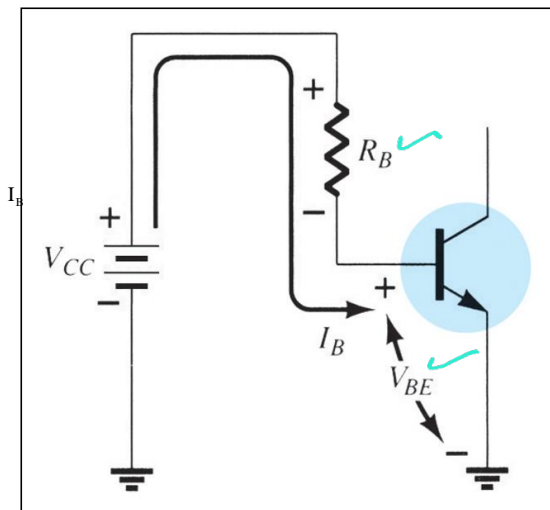
From Kirchhoff's voltage law for Input:

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

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:

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

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

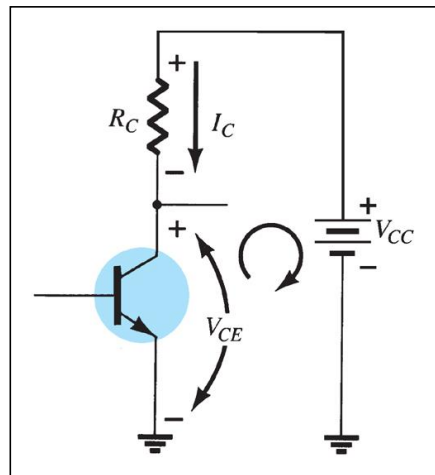
Since $V_E = 0 \Rightarrow \therefore V_{CE} = V_C$

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

Also

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

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



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

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

	min	nom	max
β	50	100	150

Design of Fixed Bias Circuit

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

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

dc only

Solution

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

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

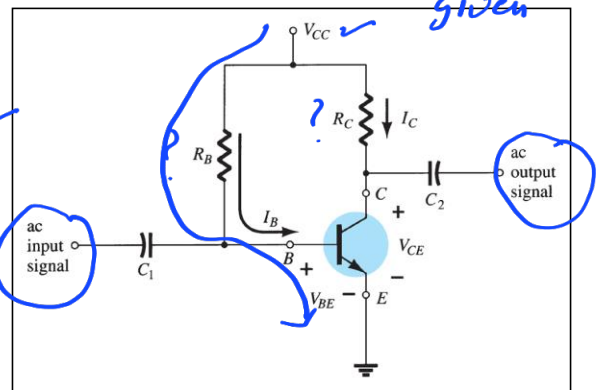
$$R_B = \frac{V_{CC} - V_{BE}}{I_B} = \frac{10 - 0.7}{10\mu A}$$

$$= 930 k\Omega$$

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

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

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



Fixed bias Stability

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

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

Solution – continued

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

$$I_B = 10 \mu A$$

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

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

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

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

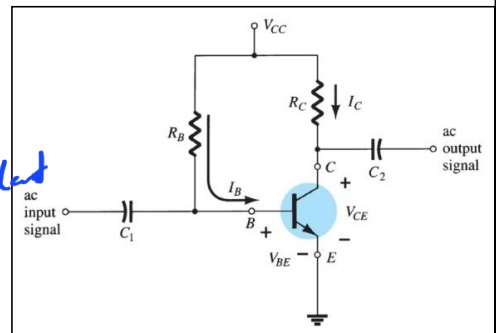
$$I_B = 10 \mu A$$

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

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

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

$$I_B \approx \frac{V_{CC} - V_{BE}}{R_B} \text{ independent of } \beta$$



for

$$50 \leq \beta \leq 150$$

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

$$0.5 \text{ mA} \leq I_C \leq 1.5 \text{ mA}$$

$$7.5 \text{ V} \geq V_{CE} \geq 2.5 \text{ V}$$

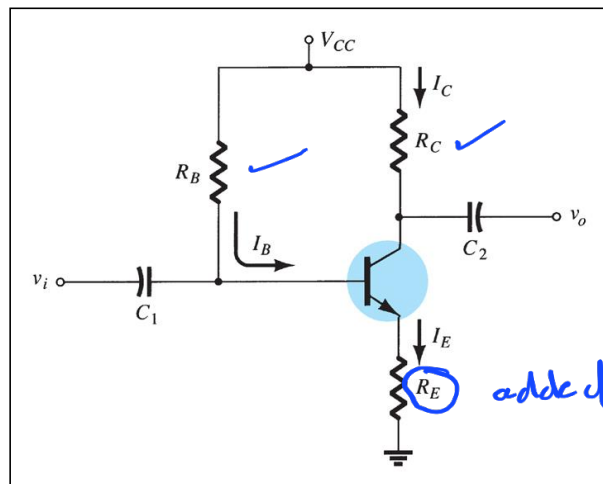
$$\therefore \frac{I_{C(\text{max})}}{I_{C(\text{min})}} = \frac{1.5 \text{ mA}}{0.5 \text{ mA}} = 3$$

Not very stable

→ to compare with other bias circuits

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:

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

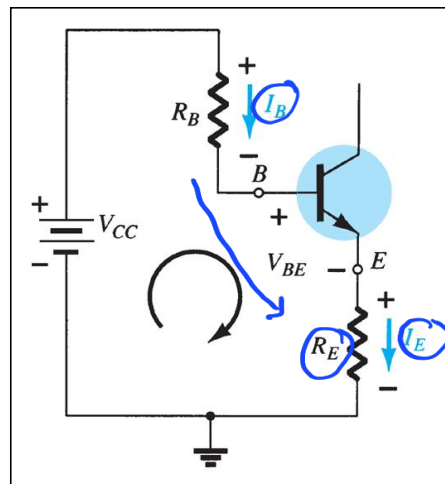
Since $I_E = (\beta + 1)I_B$:

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

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 :

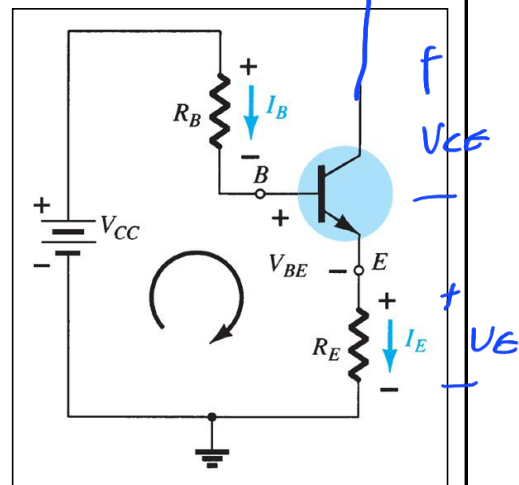
$$I_E = \frac{V_{CC} - V_{BE}}{\frac{R_B}{(\beta + 1)} + R_E} \quad \checkmark$$

In order to get I_E almost independent of β
we choose:

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

Also, in order to guarantee operation in linear mode

we choose $0.1 V_{CC} \leq V_E < 0.2 V_{CC} \quad \checkmark$



Collector-Emitter Loop

From Kirchhoff's voltage law:

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

Since $I_E \cong I_C$:

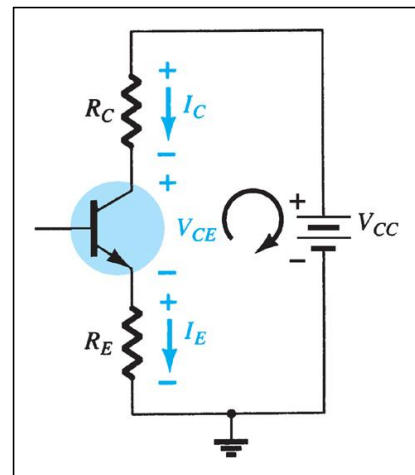
$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

Also:

$$V_E = I_E R_E$$

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

$$V_B = V_{CC} - I_R R_B = V_{BE} + V_E$$



* assumption to be used in design problems only if R_E is unknown

$$0.1V_{CC} \leq V_E \leq 0.2V_{CC}$$

Design: Emitter Stabilization bias

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

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

Solution

— let $V_E = 0.1 V_{CC}$ ✓

$V_E = 1V$ ✓

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

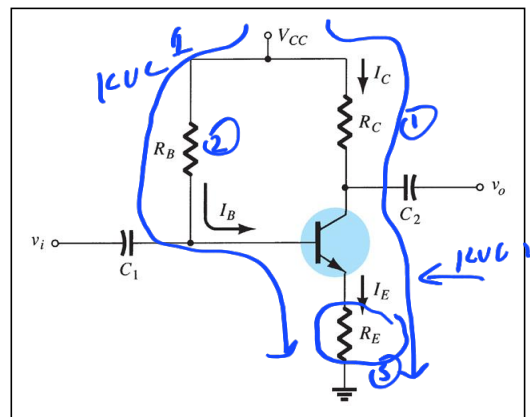
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} \Rightarrow$$

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

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

$$= \frac{10 - 0.7 - 10\mu A (100 + 1) 1k\Omega}{10\mu A}$$

$$= 829k\Omega$$



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

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

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

Emitter bias Stability

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

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

$$I_C = \beta I_B = (50)(10.56 \mu A) = 0.528 \text{ mA}$$

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

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

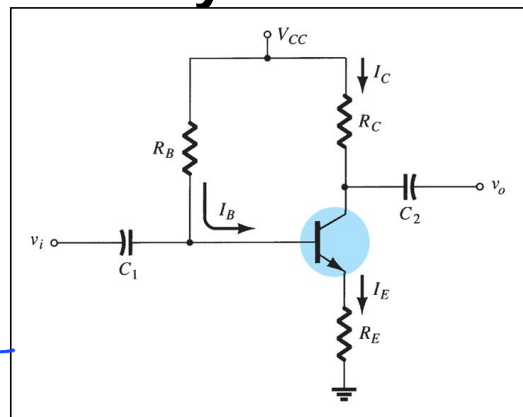
If $\beta = \beta_{\max} = 150$

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

$$I_C = \beta I_B = (150)(9.489 \mu A) = 1.423 \text{ mA}$$

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

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



for

$$50 \leq \beta \leq 150$$

$$10.56 \mu A \geq I_B \geq 9.489 \mu A$$

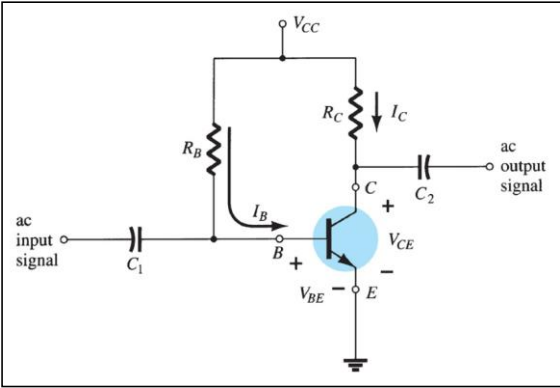
$$0.528 \text{ mA} \leq I_C \leq 1.423 \text{ mA}$$

$$6.89 \text{ V} \geq V_{CE} \geq 3.31 \text{ V}$$

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

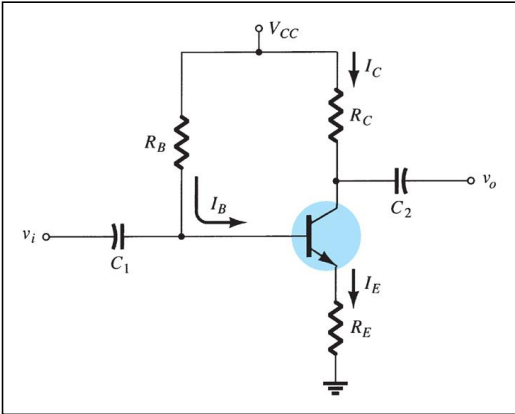
Improved,
but not
very
stable

Fixed bias



①

Emitter Stabilization bias

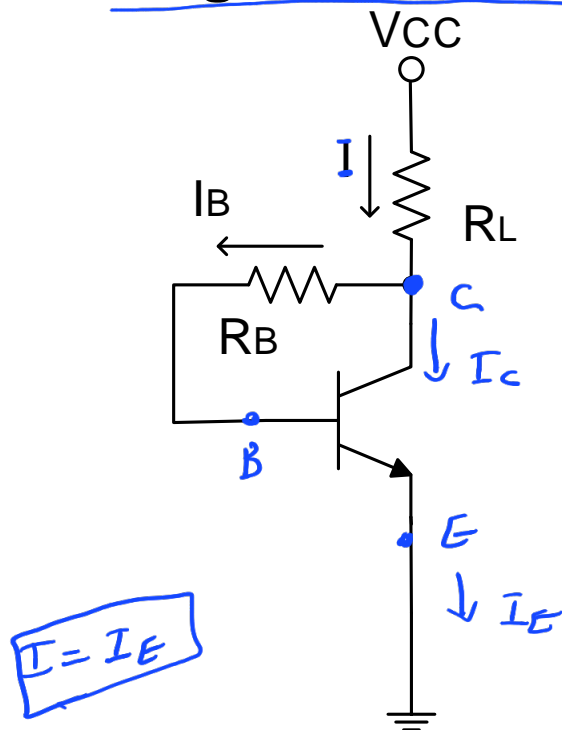


②

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:

$$\begin{aligned} V_{CC} - I R_L - I_B R_B - V_{BE} &= 0 \quad \leftarrow \\ I &= I_C + I_B \\ I_C &= \beta I_B \end{aligned}$$

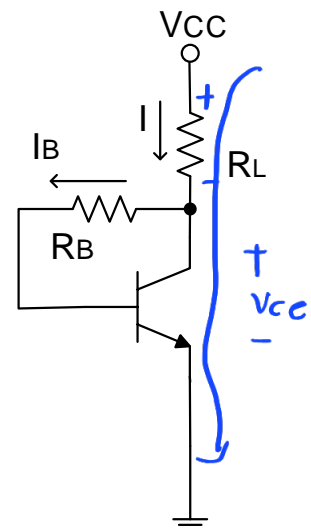
Solving for I_B :

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

$$V_{CC} = I R_L + V_{CE}$$

$$I = I_C + I_B$$

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



suppose $\beta \uparrow$, $I_B \downarrow$, $I_C = \beta \cdot I_B \downarrow \cong \text{const}$
there is some kind of compensation effect

Design: Voltage feedback bias

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

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

Solution

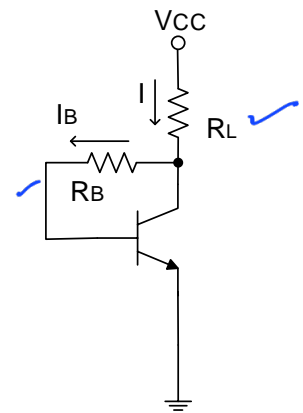
$$\rightarrow R_L = \frac{V_{CC} - V_{CE}}{I_C + I_B} = \frac{10 - 5}{1mA + \frac{1mA}{100}} = 4.95 k\Omega$$

KVL output

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

KVL input

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



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

$$I_B = 0.013627 \text{ mA}$$

$$I_C = 0.68 \text{ mA}$$

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

$$I_B = 0.00793 \text{ mA}$$

$$I_C = 1.19 \text{ mA}$$

for

$$50 \leq \beta \leq 150$$

$$0.68 \text{ mA} \leq I_C \leq 1.19 \text{ mA}$$

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

Better
Q-point
stability

1)
↓
3

2)
2.7

3)
1.75

4)
↓
target

$$\frac{I_{C(\text{max})}}{I_{C(\text{min})}} \cong 1$$

End of L 11
End of Quiz
Material
Monday 2/8

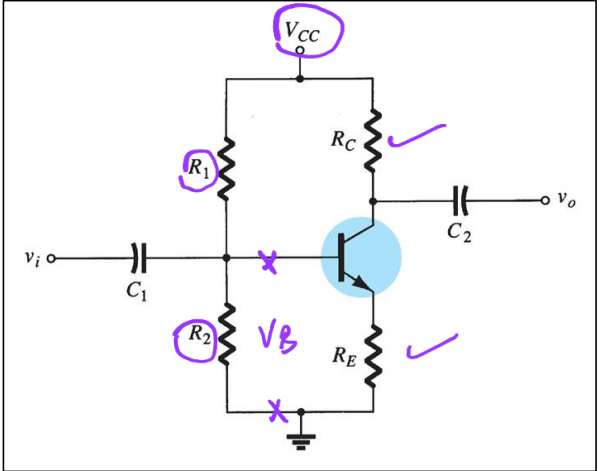
$$\frac{I_{c(max)}}{I_{c(min)}} = 1$$

← target to have I_c almost constant and independent of β change

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



only today →

approximate

فقط اليوم

exact

لا صفا فقط
نستخدم

Approximate Analysis

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

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

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

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

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

From Kirchhoff's voltage law:

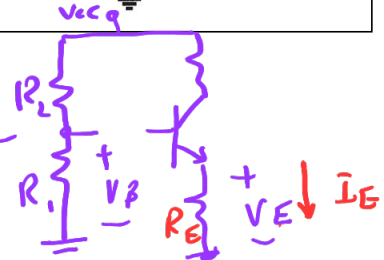
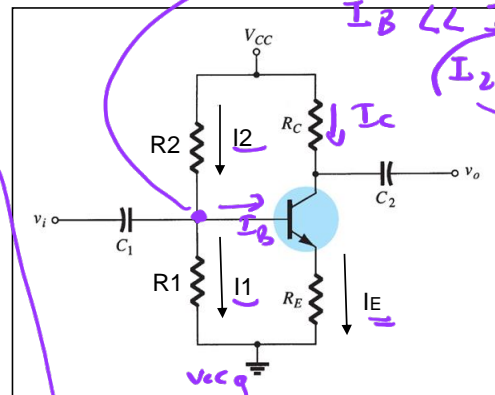
$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

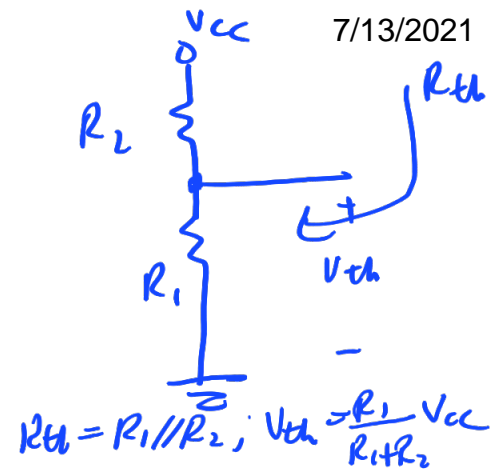
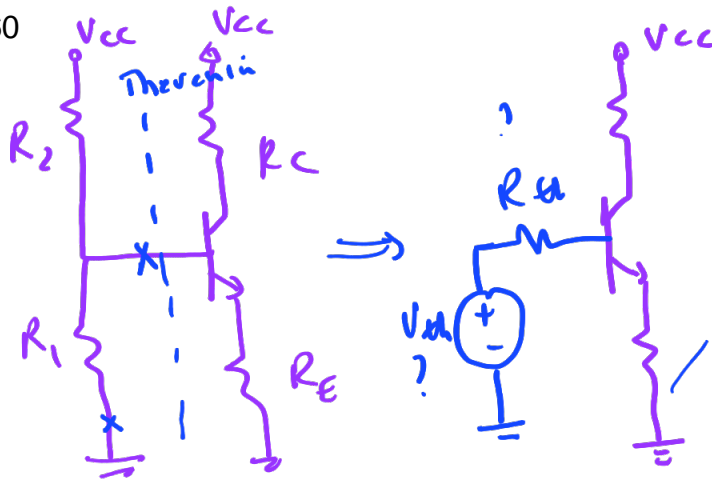
$$I_E \cong I_C$$

$$I_E = I_C + I_B$$

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

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





Exact Analysis (dc)

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

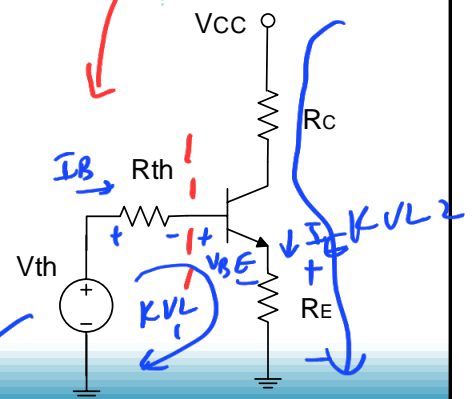
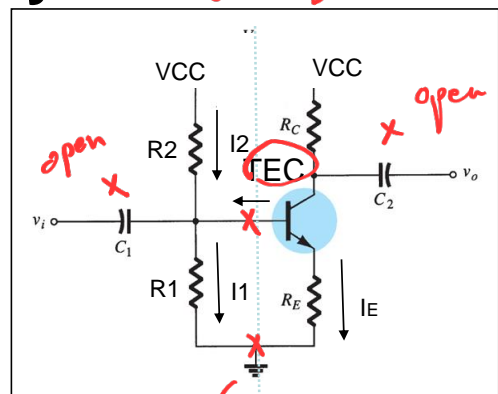
$$V_{th} = \frac{R_1 V_{CC}}{R_1 + R_2}$$

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

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

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

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



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

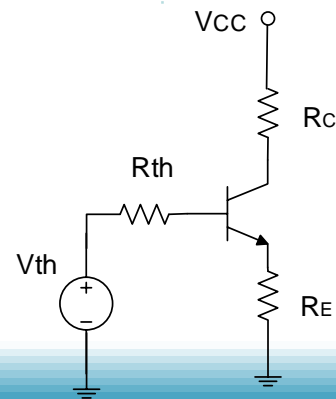
$$V_{th} - I_B R_{th} - V_{BE} - I_E R_E = 0$$

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

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

$$RE \geq \frac{10 R_u}{\beta + 1} \Rightarrow$$

$$* R_u \leq \frac{(\beta + 1) RE}{10} \quad \text{can}$$

$$R_{th} \ll \frac{\beta R_E}{10}$$


Design: Voltage Divider bias

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

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

Solution

1) let $V_E = 0.1 V_{CC}$ $0.1V_{CC} \leq V_E \leq 0.2V_{CC}$

$$V_E = 1V$$

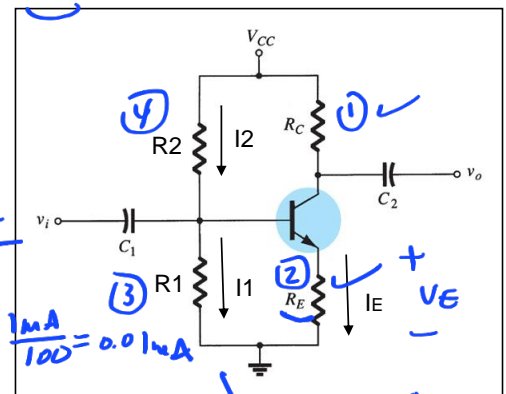
$$I_E = \frac{V_E}{R_E} \Rightarrow R_E = \frac{1V}{1.01mA} \cong 0.99k\Omega$$

$$2) \text{ let } R_{th} = \frac{R_E (\beta_{\text{nominal}} + 1)}{50} = \frac{1k\Omega \cdot 100}{50} = 2k\Omega$$

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

$$V_{CEQ} = 5$$

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



$$\underbrace{V_{th}}_{?} - \underbrace{I_B R_{th}}_{\checkmark} - \underbrace{V_{BE}}_{0.7} - \underbrace{I_E R_E}_{V_E = 10} = 0 \Rightarrow$$

$$V_{th} = 1.72 = \frac{R_1}{R_1 + R_2} \cdot 10$$

Design: Voltage Divider bias

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

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

Solution – continued

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

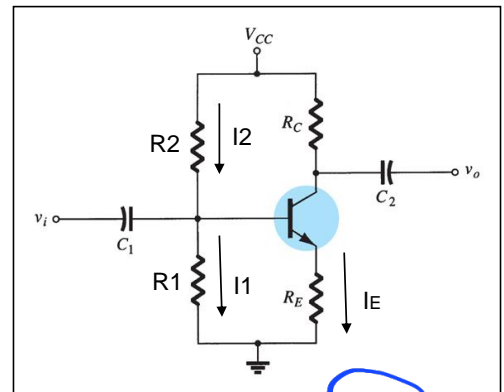
$$\therefore V_{th} = \frac{R_1 V_{CC}}{R_1 + R_2} = I_E \left(\frac{R_{th}}{\beta + 1} + R_E \right) + V_{BE} = 1.72V \dots (1)$$

$$R_{th} = R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2} = 2 \text{ k}\Omega$$

solving (1) & (2) yields:

$$R_1 = 2.42 \text{ k}\Omega$$

$$R_2 = 11.64 \text{ k}\Omega$$



Verify $\frac{I_{C(max)}}{I_{C(min)}} = ?$

Voltage Divider bias Stability

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

$I_C = 0.982 \text{ mA}$

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

$I_C = 1.0069 \text{ mA}$

for

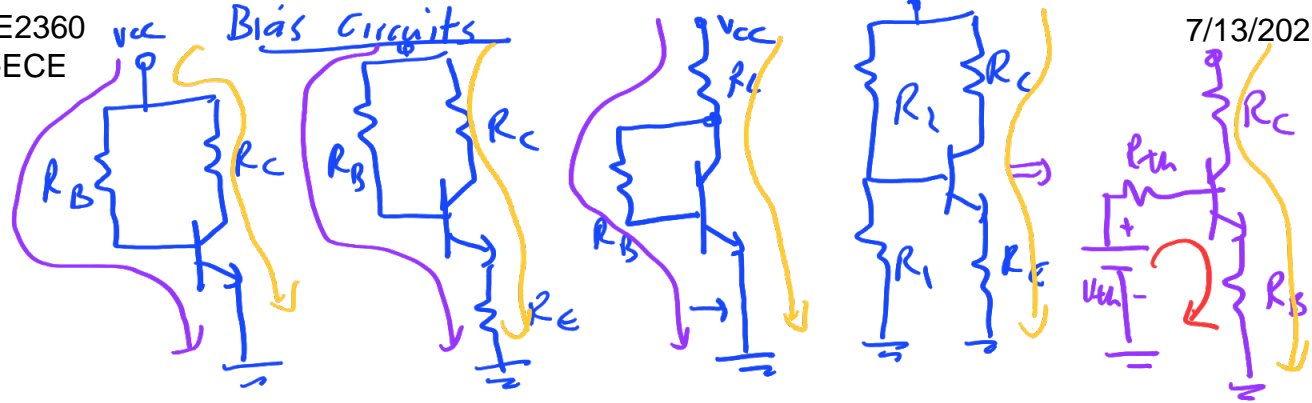
$$50 \leq \beta \leq 150$$

$$0.982 \text{ mA} \leq I_C \leq 1.0067 \text{ mA}$$

$$\therefore \frac{I_{C(max)}}{I_{C(min)}} = \frac{1.0067 \text{ mA}}{0.982 \text{ mA}} \cong 1.0254$$

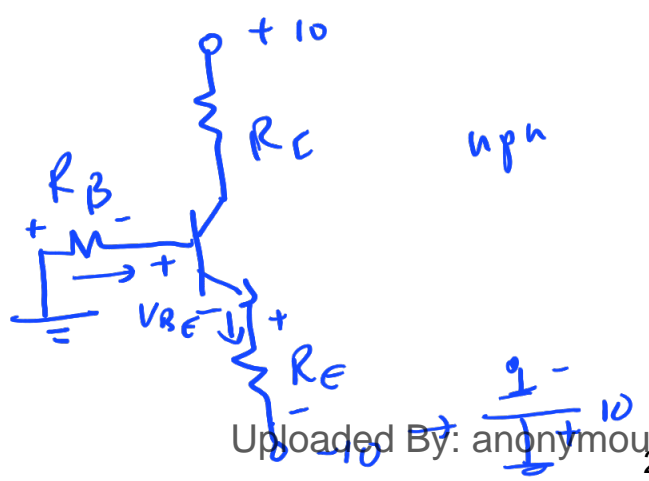
Very good
Q-point
stability

I_C almost
independent
of β



PNP Transistors

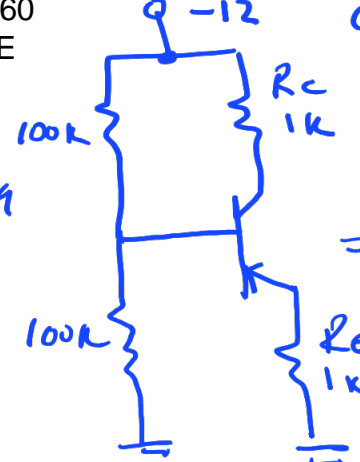
The analysis for *npn* transistor biasing circuits is the same as that for *npn* transistor circuits. The only difference is that the currents are flowing in the opposite direction.



calculate V_{EC}, I_C ? assume active mode

analysis

$\beta = 99$

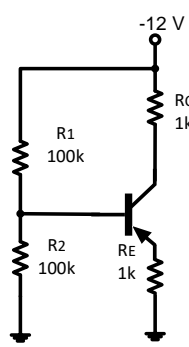


$\Rightarrow 0.1V_{cc} \leq V_E \leq 0.2V_{cc}$
 $R_{th} \leq \frac{(\beta+1)R_E}{10}$

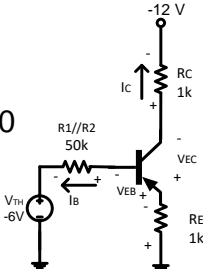
cannot be used since this is not a design problem all resistors are known

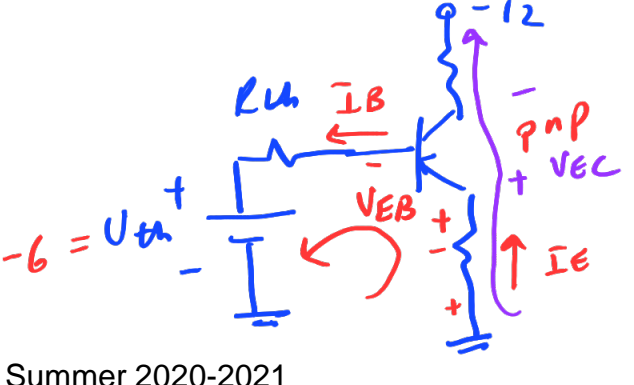
PNP Transistors

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.



$$V_{TH} + I_B \cdot 50k + V_{EB} + I_E \cdot 1k = 0$$
$$-6 + I_B \cdot 50k + 0.7 + I_E \cdot 1k = 0$$
$$I_B = \frac{6 - 0.7}{(50k + 100k)} = 35.3 \mu A$$
$$I_C = 3.49 \text{ mA} = 99 \times 35.3 \mu A$$
$$V_{EC} = 12 - (3.49 \text{ mA} \cdot 2k) = 5.02 \text{ V}$$





$-6 = V_{th}$

$R_{th} = 100k // 100k = 50k$

$V_{EB} = 0.7$

$I_E R_E + V_{EB} + I_B R_{th} - 6 = 0$

$I_E = (\beta + 1) I_B$

$\therefore I_B = \frac{6 - 0.7}{50k + 1k(99+1)} = 35.3 \mu A$

$V_{th} = \frac{50k}{50k + 50k} \times -12 = -6$

$R_{th} = 100k // 100k = 50k$

$V_{EB} = 0.7$

$I_E R_E + V_{EB} + I_B R_{th} - 6 = 0$

$I_E = (\beta + 1) I_B$

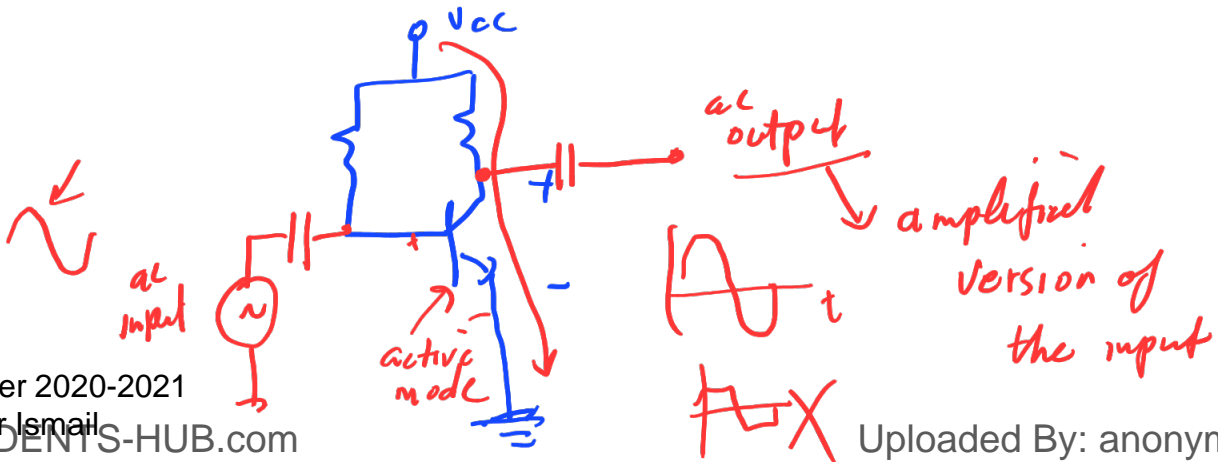
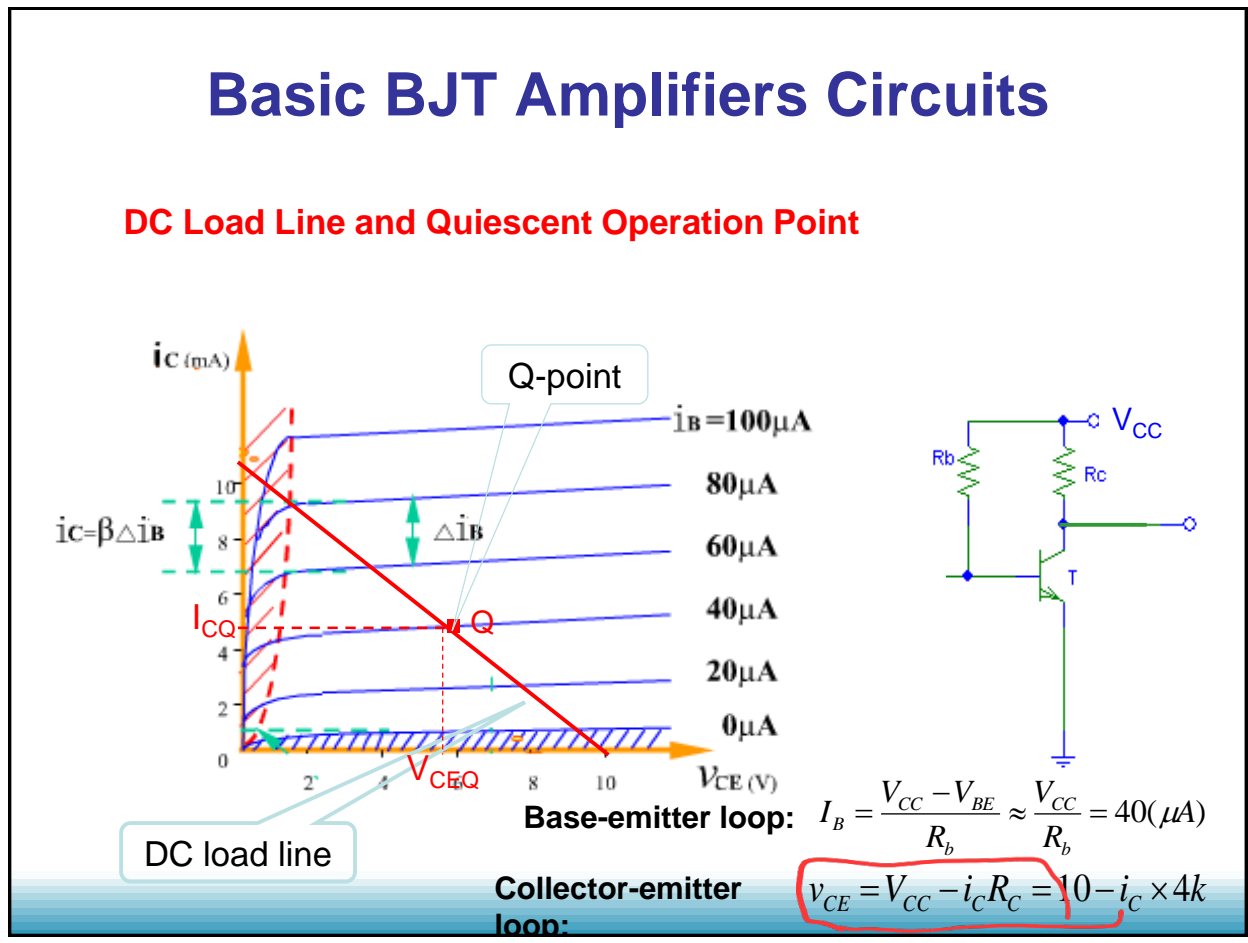
$\therefore I_B = \frac{6 - 0.7}{50k + 1k(99+1)} = 35.3 \mu A$

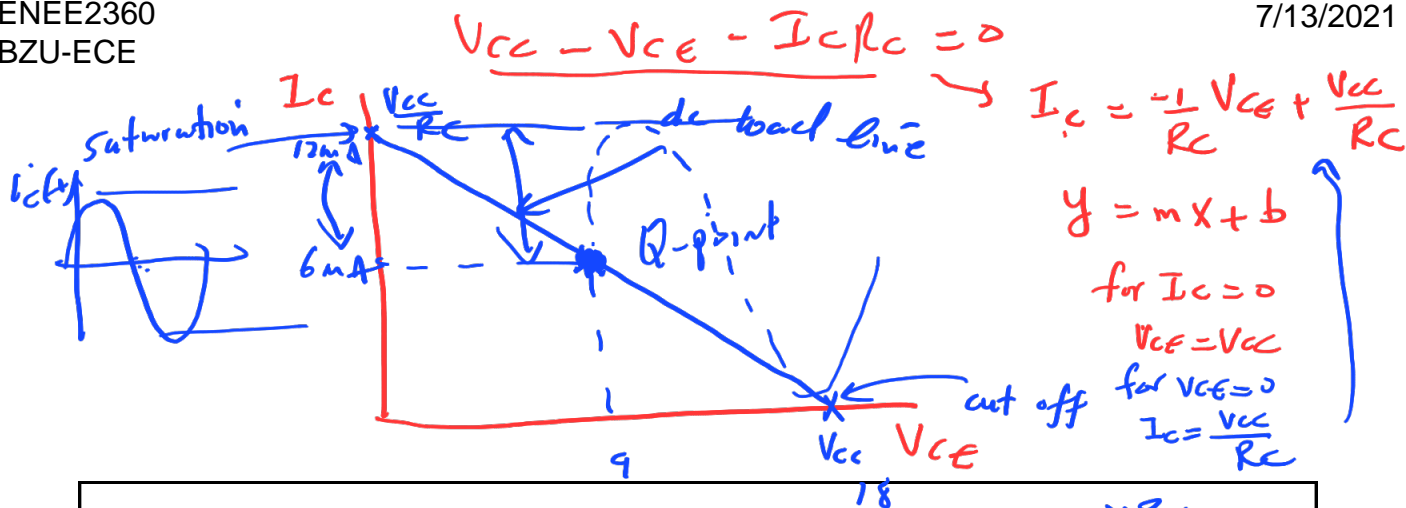
$$I_E R_E + V_{EC} + I_C R_C - 12 = 0$$
$$\therefore V_{EC} = 12 - I_C (R_C + R_E)$$

Next \rightarrow ac analysis

Basic BJT Amplifiers Circuits

DC Load Line and Quiescent Operation Point





DC Load Lines

Assume $V_{CC} = 18V$, $\beta = 100$

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

FIRST: DC ANALYSIS

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

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

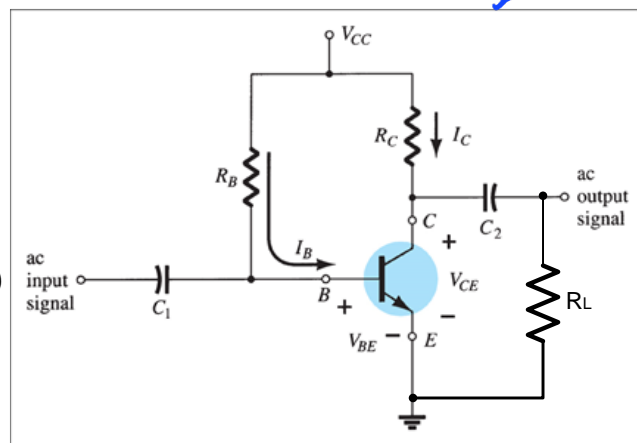
This is a straight line equation

$$Y = mX + b$$

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

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

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



DC Load Line

I_{Csat}

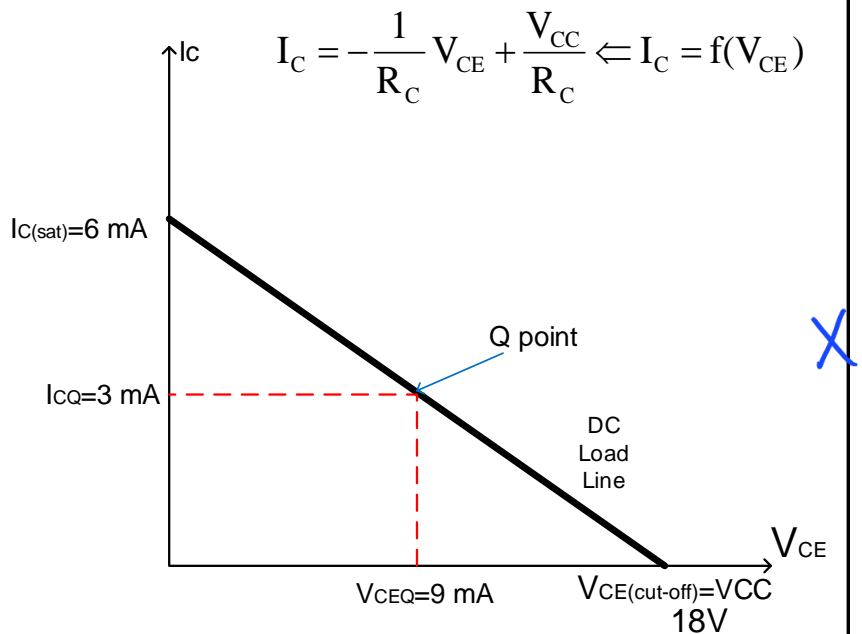
$$I_{Csat} = \frac{V_{CC}}{R_C}$$

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

$V_{CEcutoff}$

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

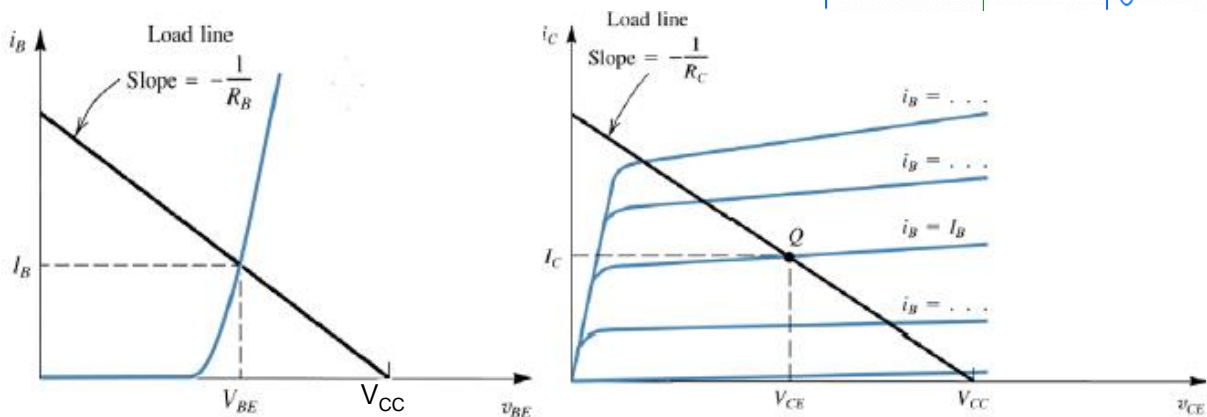
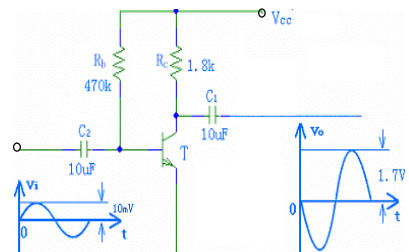
$$I_C = 0 \text{ mA}$$



Basic BJT Amplifiers Circuits

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



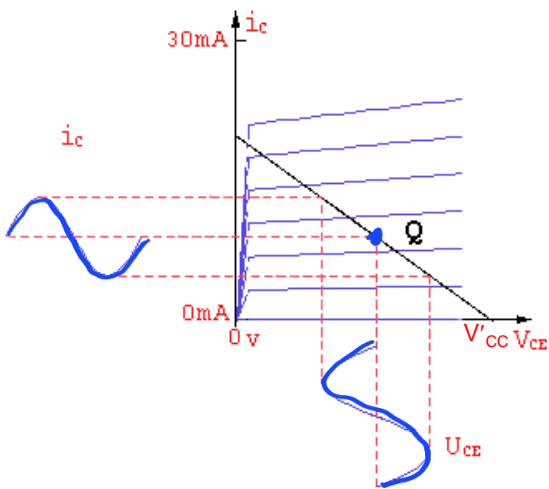
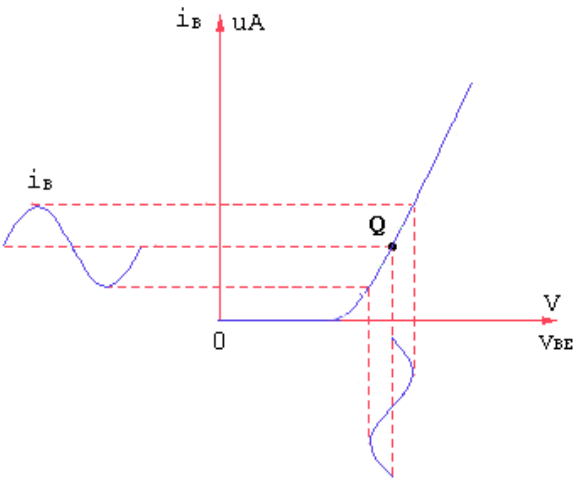
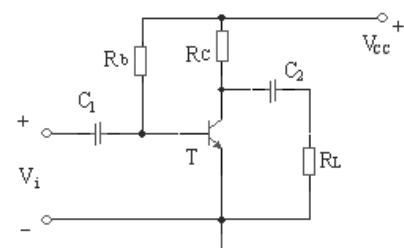
Can get a feel for whether the BJT will stay in active region of operation

– What happens if R_C is larger or smaller?

Basic BJT Amplifiers Circuits

Graphical Analysis

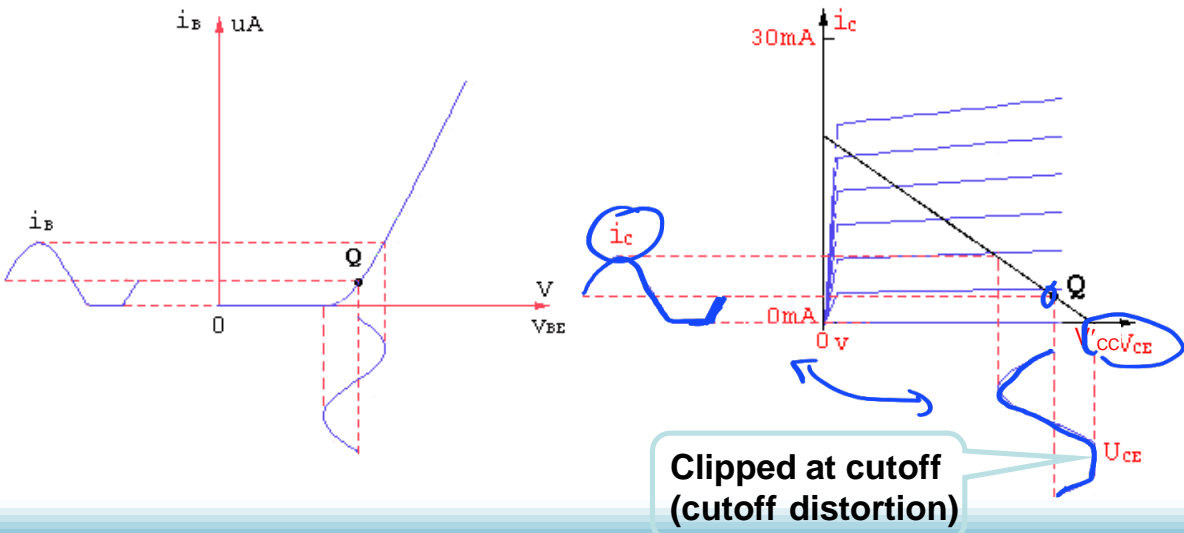
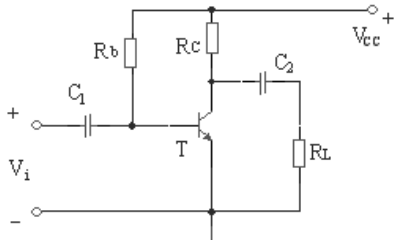
Q-point is centered on the ac load line:



Basic BJT Amplifiers Circuits

Graphical Analysis

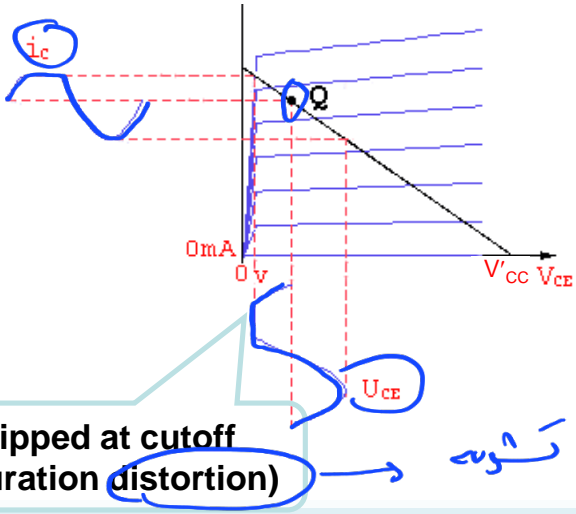
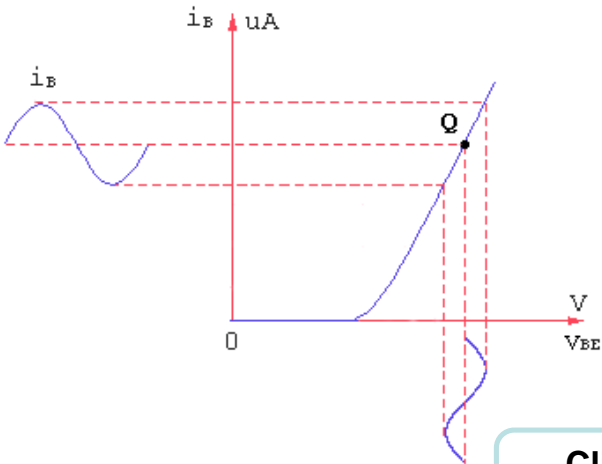
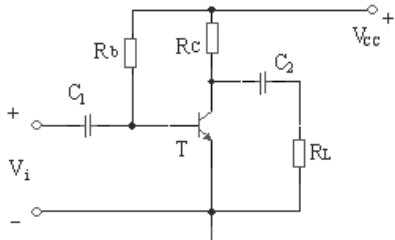
Q-point closer to cutoff:



Basic BJT Amplifiers Circuits

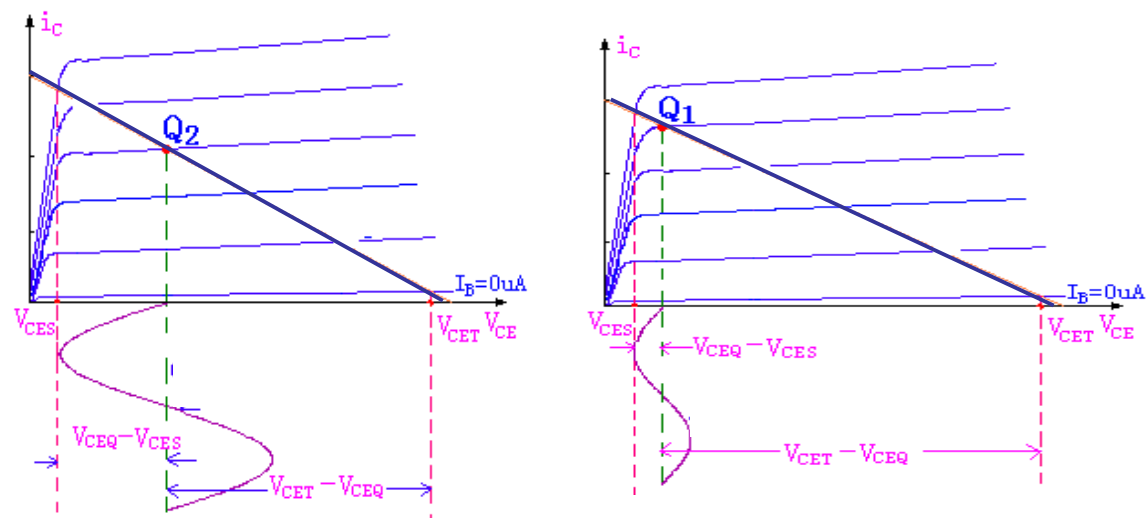
Graphical Analysis

Q-point closer to saturation:



Basic BJT Amplifiers Circuits

Graphical Analysis



X