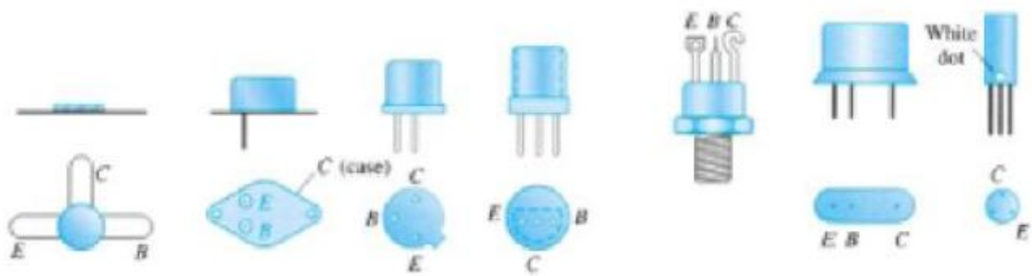
L11 - part2
29/7



ENEE2360 Analog Electronics

T7:
BJT DC Biasing

Instructor : Nasser Ismail

1

Biasing

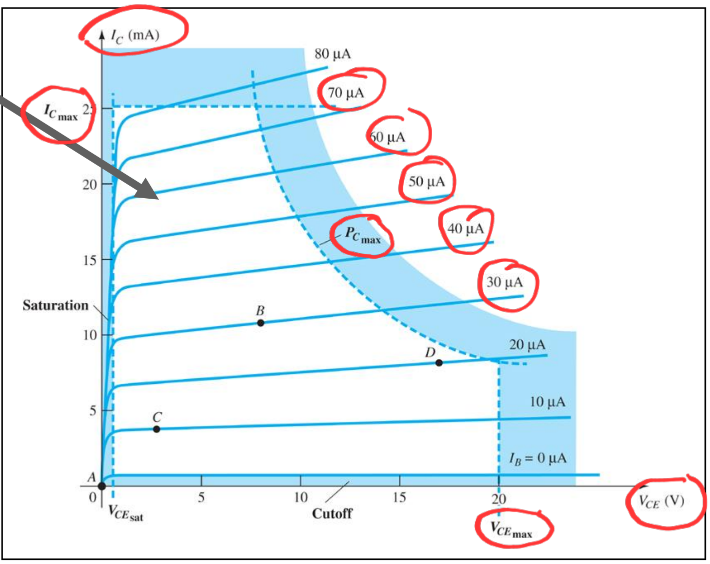
For → active / Linear } mode

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.

Operating Point

Safe Operating Area “SOA”

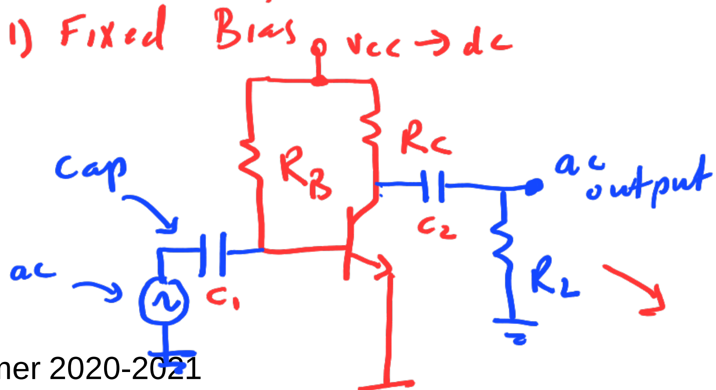
The DC input establishes an operating or *quiescent point* called the ***Q-point***.



DC Biasing Circuits

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

1) Fixed Bias

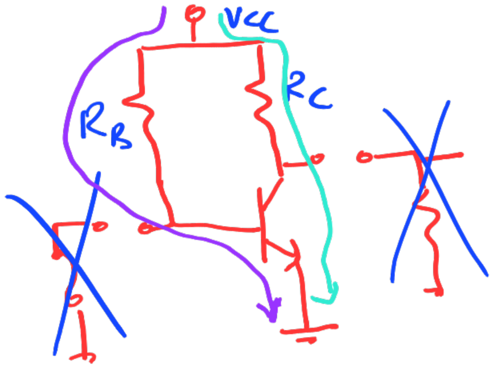


DC analysis → ac sources killed

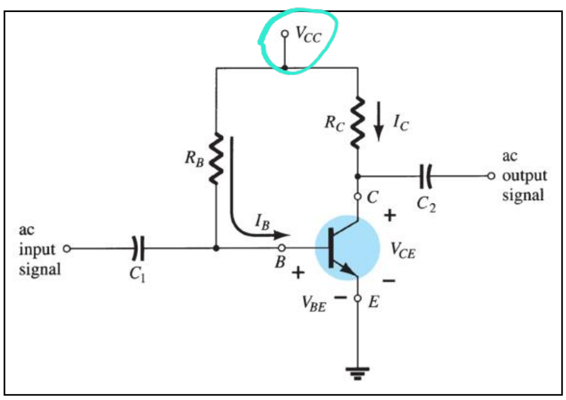
$f = 0$

$X_C = \frac{1}{2\pi f C} \cong \infty$ open

caps treated as open circuit

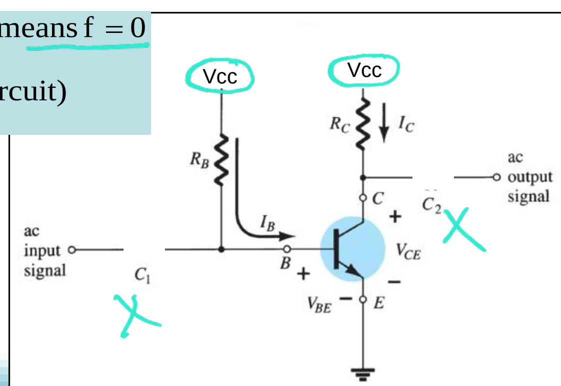


1)Fixed Bias Configuration



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

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



The Base-Emitter Loop

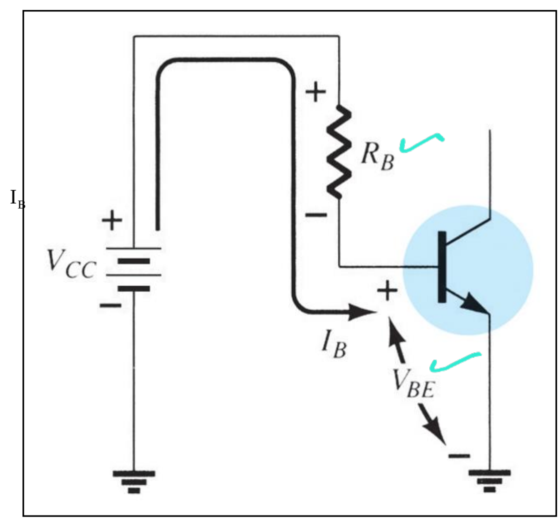
From Kirchhoff's voltage law for Input:

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

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:

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

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

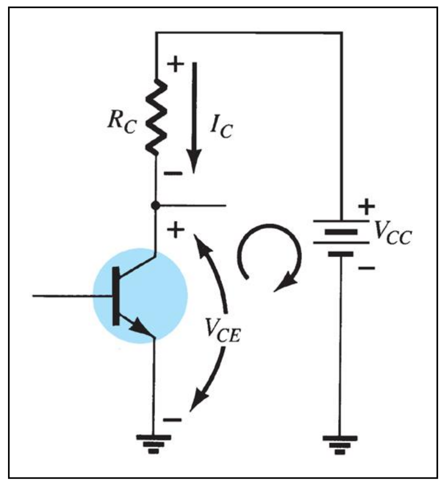
$$\text{Since } V_E = 0 \Rightarrow \therefore V_{CE} = V_C$$

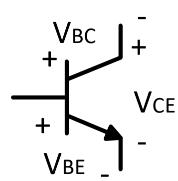
$$V_{CE} = V_{CC} - I_C R_C$$

Also

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

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





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

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

?

	min	nom	max
β	50	100	150

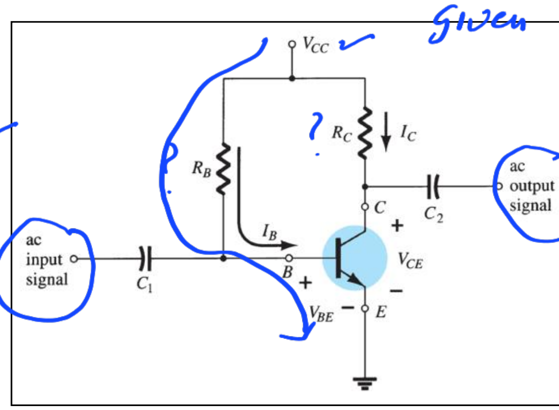
Design of Fixed Bias Circuit

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

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

dc only ? ?

Given



Solution

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

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

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

$$= 930\,k\Omega$$

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

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

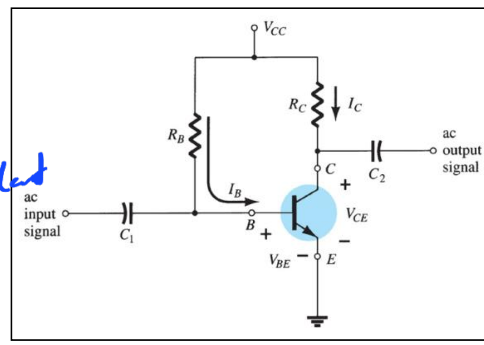
$$\therefore R_C = \frac{5}{1\,mA} = 5\,k\Omega$$

Fixed bias Stability

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

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

Solution – continued



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

$I_B = 10\,\mu A$

$I_B = \frac{V_{CC} - V_{BE}}{R_B}$ → independent of β

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

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

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

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

$I_B = 10\,\mu A$

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

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

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

for

$50 \le \beta \le 150$

$I_B = 10\,\mu A$ fixed

$0.5\,mA \le I_C \le 1.5\,mA$

$7.5\,V \ge V_{CE} \ge 2.5\,V$

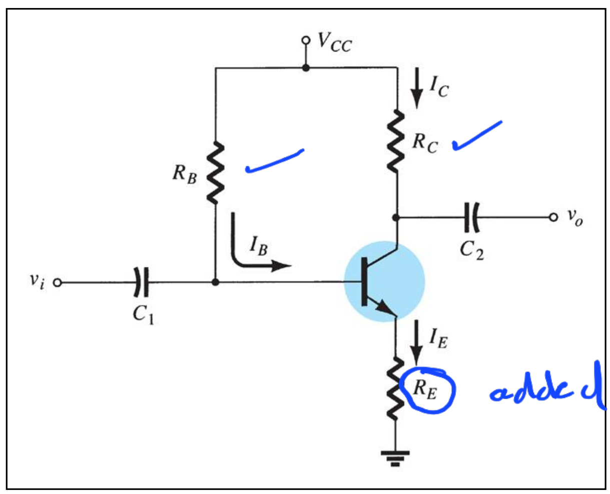
$\therefore \frac{I_{C(max)}}{I_{C(min)}} = \frac{1.5\,mA}{0.5\,mA} = 3$

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:

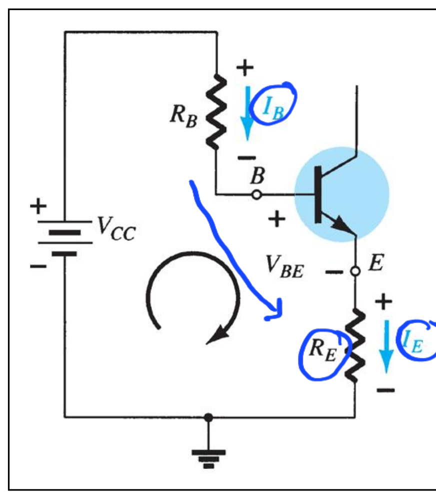
$$+V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

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:

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



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

Base-Emitter Loop

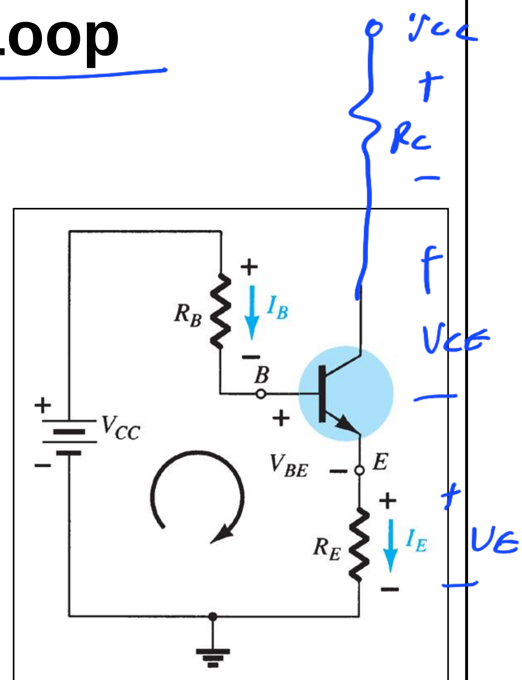
Solving for I_E:

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

In order to get IE almost independant of β 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 $0.1\,V_{CC} \le V_E < 0.2V_{CC}$

Collector-Emitter Loop

From Kirchhoff's voltage law:

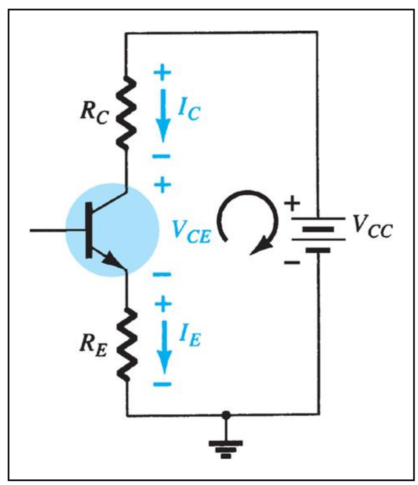
$$I_E R_E + V_{CE} + I_C R_C - V_{CC} = 0$$

Since $I_E \cong I_C$:

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

Also:

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



* assumption to be used in design problems
$0.1 V_{CC} \leq V_E \leq 0.2 V_{CC}$ only if R_E is unknown

Design: Emitter Stabilization bias

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

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

→ two equations
→ 3 unknowns

Solution

– let $\boxed{V_E = 0.1\,V_{CC}}$

$V_E = 1V$

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

KVL1

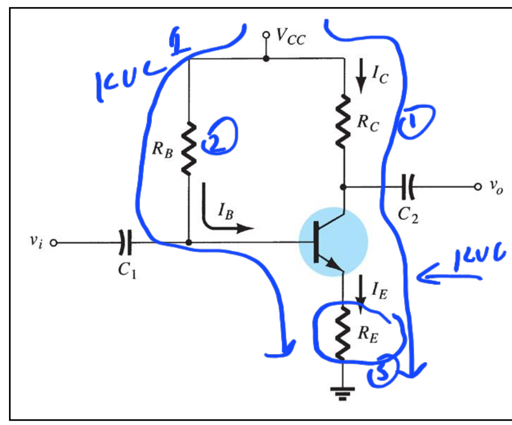
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} \Rightarrow$$

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

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

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

$$= 829\,k\Omega$$



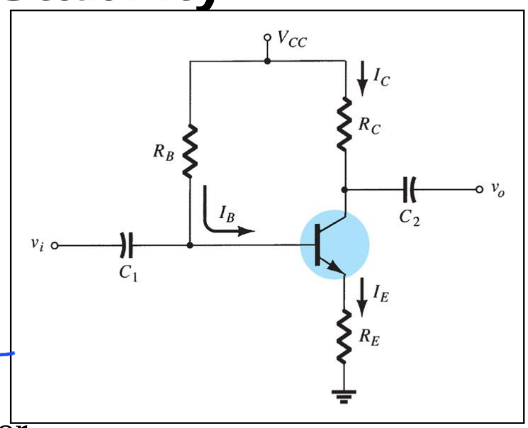
KVL 2 ? $I_E R_E$

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

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

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

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

$$50 \le \beta \le 150$$

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

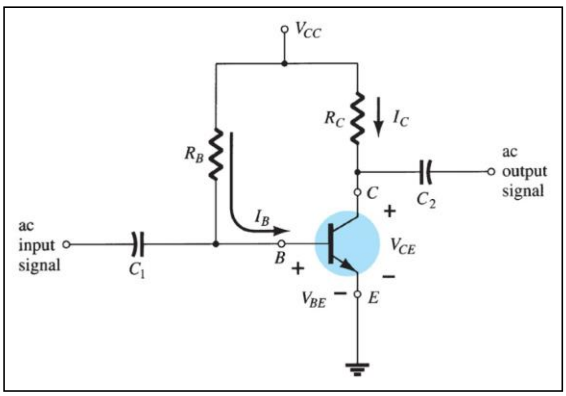
$$\boxed{0.528\,mA \le I_C \le 1.423\,mA}$$

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

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

Improved, but not very stable

Fixed bias



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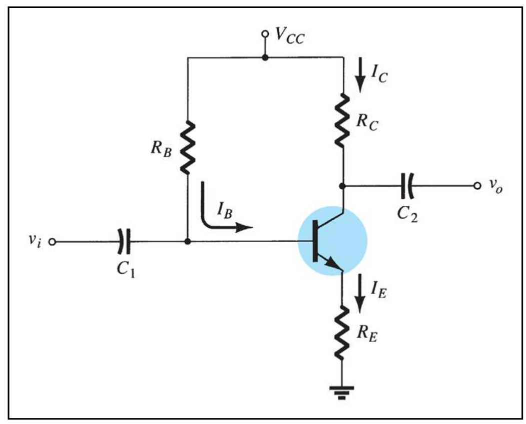
Emitter Stabilization bias



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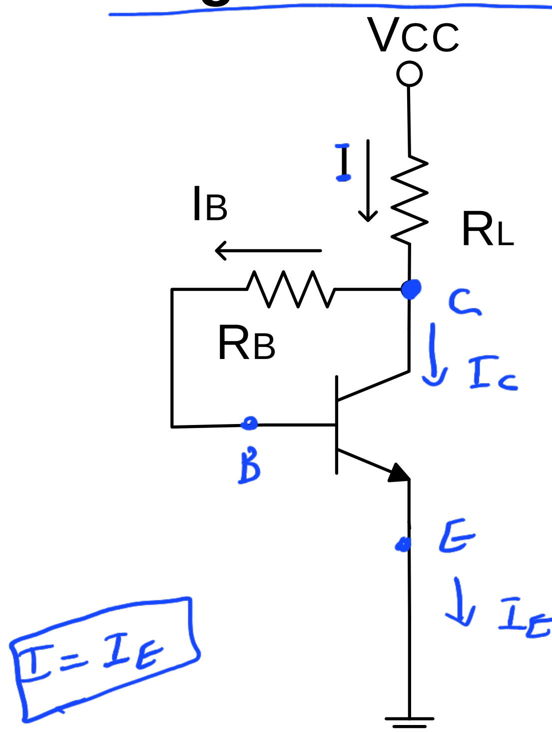
3) DC Bias With Voltage Feedback

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

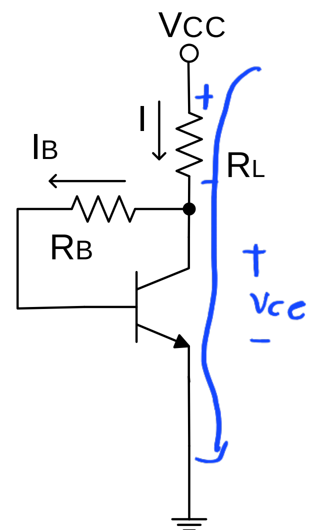
From Kirchhoff's voltage law:

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

Solving for I_B:

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

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



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

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

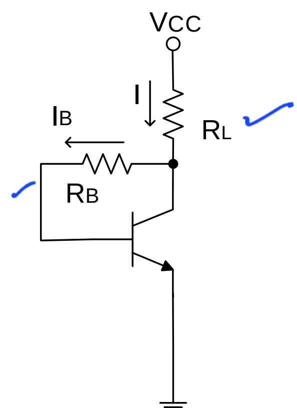
$$= 4.95\,k\Omega$$

KVL output

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

KVL input

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



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

$I_B = 0.013627\,mA$

$I_C = 0.68\,mA$

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

1) $\downarrow$ 3

2) 2.7

3) 1.75

4) $\downarrow$ target

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

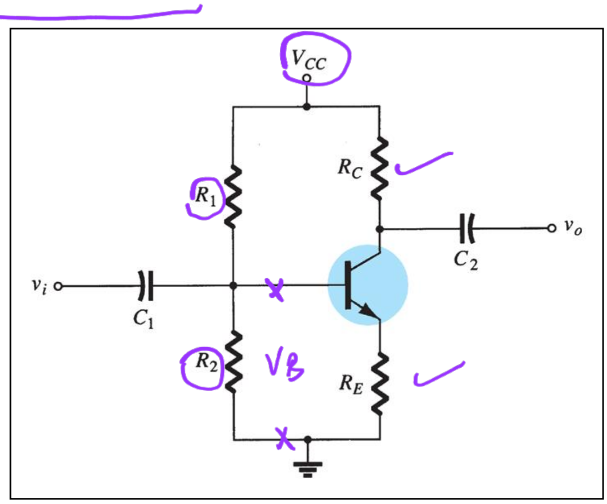
End of L 11
End of Quiz Material
Monday 2/8

$\frac{I_{C(max)}}{I_{C(min)}} = 1$ ← 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 للتوضيح

exact

للامتحان فقط
نستخدم

تقريبي

Approximate Analysis

$I_2 = I_1 + I_B$

$I_B << I_1$

$I_2 \approx I_1$

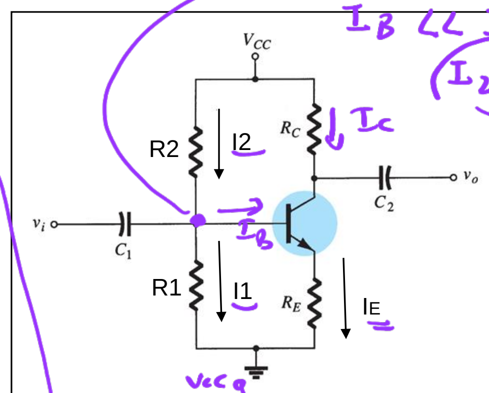
Where $I_B << I_1$ and $I_1 \cong I_2$:

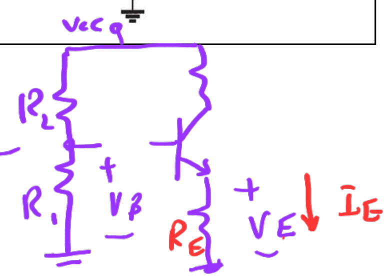
$$V_B = \frac{R_1 V_{CC}}{R_1 + R_2}$$

$V_{BE} = V_B - V_E$

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

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





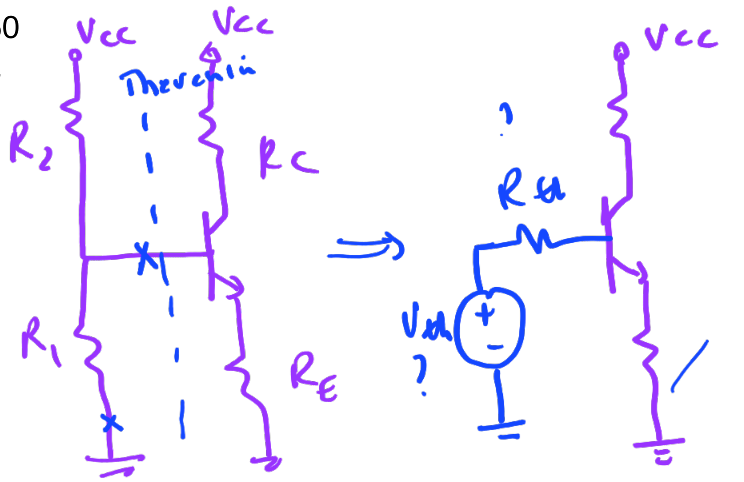
From Kirchhoff's voltage law:

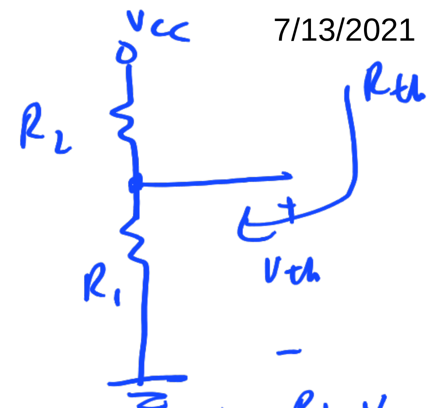
$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

$I_E \cong I_C$ $\qquad$ $I_E = I_c + I_B$

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

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





$R_{th} = R_1 // R_2 \, ; \; V_{th} = \frac{R_1}{R_1+R_2} V_{cc}$

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

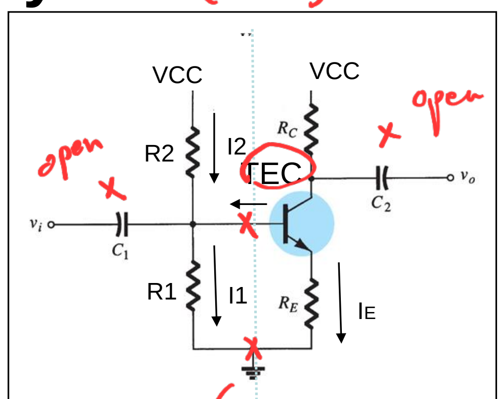
$$V_{th} = \frac{R_1 V_{CC}}{R_1 + R_2}$$

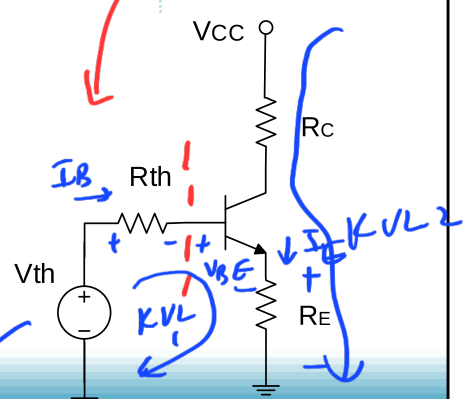
$$R_{th} = R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

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

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

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





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

ليش ؟

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

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

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

$R_E >> \frac{R_{th}}{\beta+1}$

اكبر بكثير

اكبر منها ب ١٠ مرات

$R_E \geq 10 \frac{R_{th}}{\beta+1} \Rightarrow$

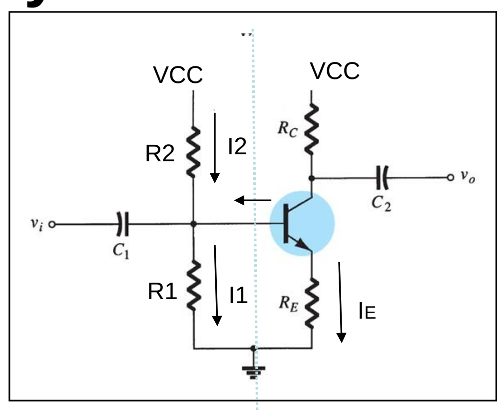
$* \quad R_{th} \leq \frac{(\beta+1) R_E}{10}$ can be >10

Exact Analysis

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

if we compare to approximate solution

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



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

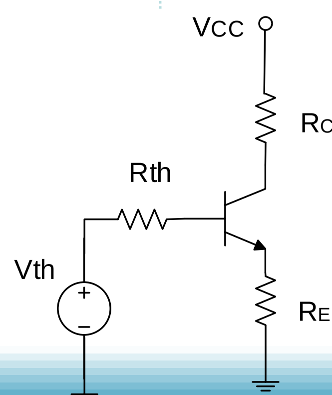
Here we got Ic independent of β

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

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

or

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

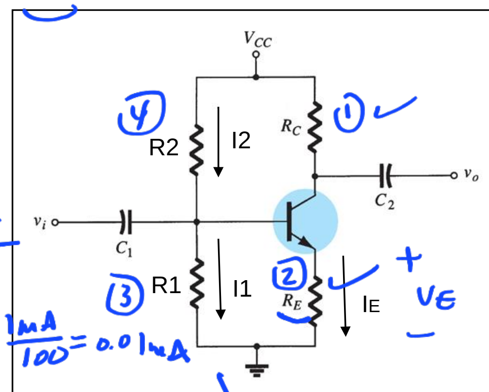


1k ± 5%
10%
1%

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 $\boxed{V_E = 0.1\,V_{CC}}$

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

$V_E = 1V$

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

0.99k

$1mA + 0.01mA$

$I_E = I_C + I_B$

$= 1mA + \frac{I_C}{\beta}$

$\frac{1mA}{100} = 0.01mA$

2) let $Rth \le \dfrac{R_E(\beta_{nominal}+1)}{50} = \dfrac{1\,k\Omega.100}{50} = 2\,k\Omega$

$R_1 // R_2$

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

$V_{CEQ} = 5$

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

$$\underbrace{V_{th}}_{?} - \underbrace{I_B}_{\checkmark}\underbrace{R_{th}}_{2k} - \underbrace{V_{BE}}_{0.7} - \underbrace{I_E R_E}_{V_E = 1V} = 0 \Longrightarrow$$

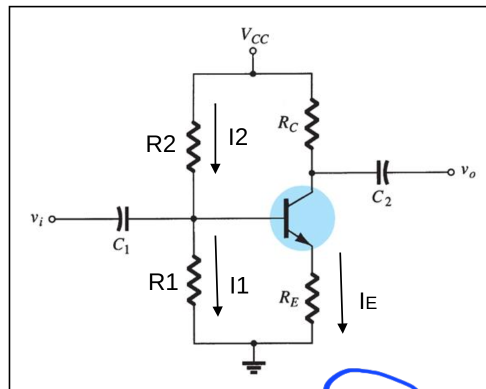
$$V_{th} = 1.72 = \frac{R_1}{R_1+R_2}\cdot 10$$

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 – continued



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

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

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

solving (1) & (2) yields:

$R_1 = 2.42\ k\Omega$ ✓

$R_2 = 11.64\ k\Omega$ ✓

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

Voltage Divider bias Stability

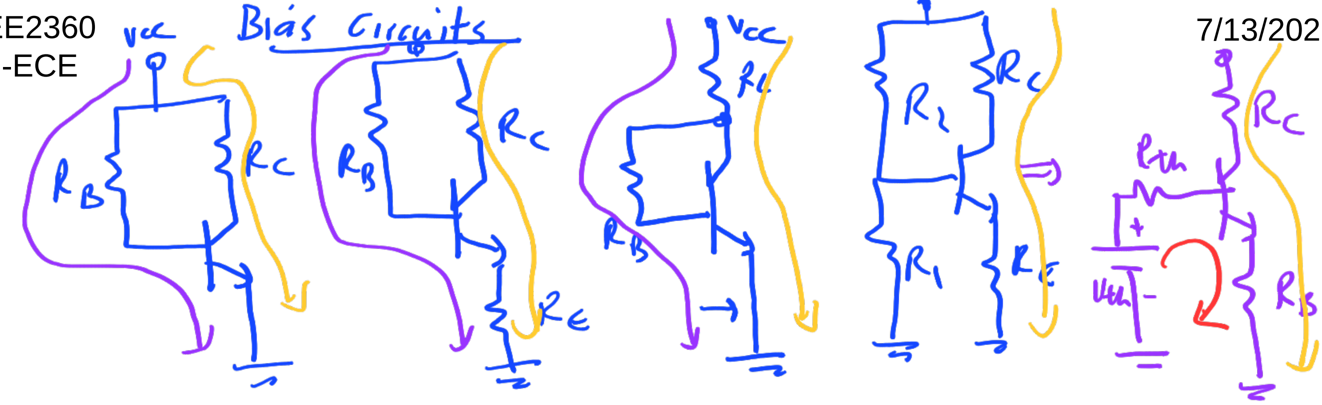
$$\text{If } \beta = \beta_{min} = 50$$
$$I_C = 0.982\text{ mA}$$
$$\text{If } \beta = \beta_{max} = 150$$
$$I_C = 1.0069\text{ mA}$$

for

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

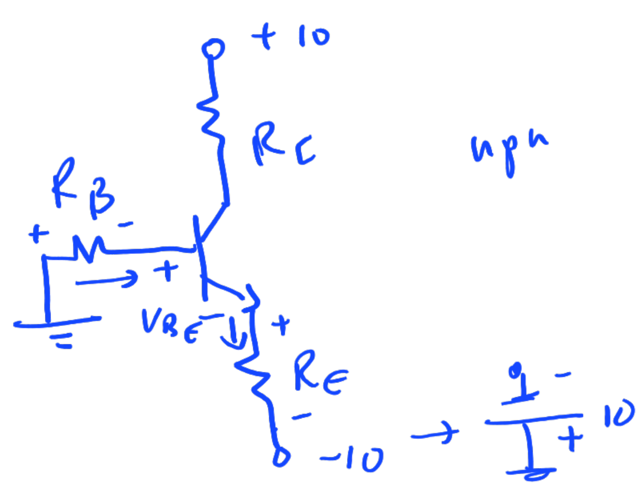
Very good Q-point stability

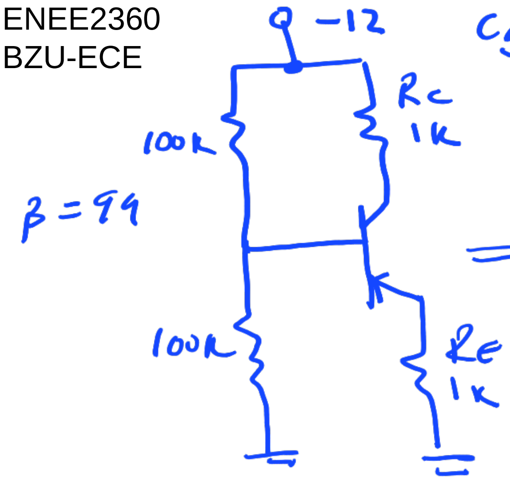
I_C almost independent of β



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.





Calculate V_{EC}, I_C? assume active mode

analysis

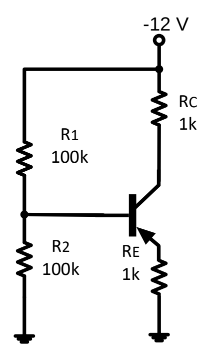
$0.1V_{CC} \le V_E \le 0.2V_{CC}$

$R_{th} \le \frac{(\beta+1)R_E}{10}$

X 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.



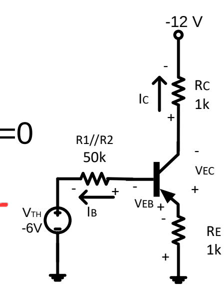
$V_{TH}+I_B*50k+V_{EB}+I_E*1k=0$

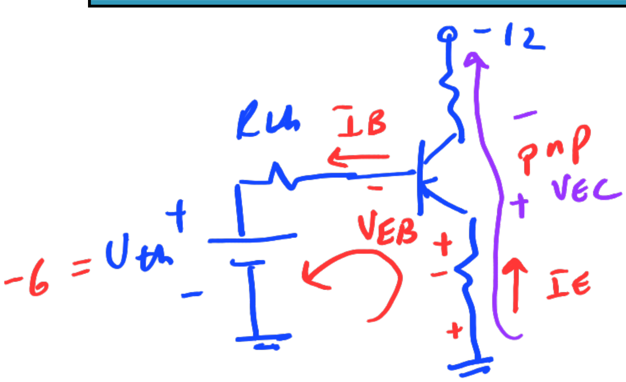
$-6+I_B*50k+0.7+I_E*1k=0$

$I_B= 6-0.7 /(50k+100k)$
$=35.3\ uA$

$I_C=3.49\ mA$ $= 99 \times 35.3\ uA$

$V_{EC}=12-(3.49mA*2k)=5.02\ V$





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

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

$V_{EB} = 0.7$

$I_E R_E + \overset{0.7}{\cancel{V_{EB}}} + I_B R_{th} - 6 = 0$

$I_E = (\beta+1) I_B$

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

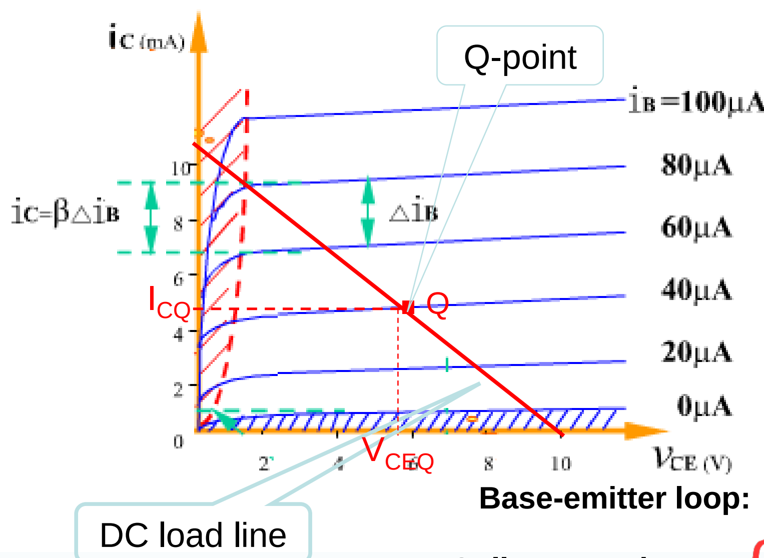
$I_E R_E + V_{EC} + I_C R_C - 12 = 0$

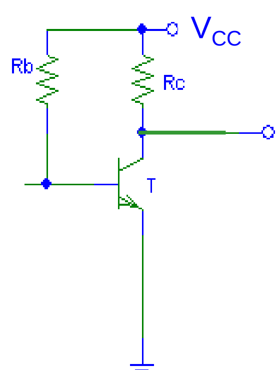
$\therefore V_{EC} = 12 - I_C(R_C + R_E)$

Next → ac analysis

Basic BJT Amplifiers Circuits

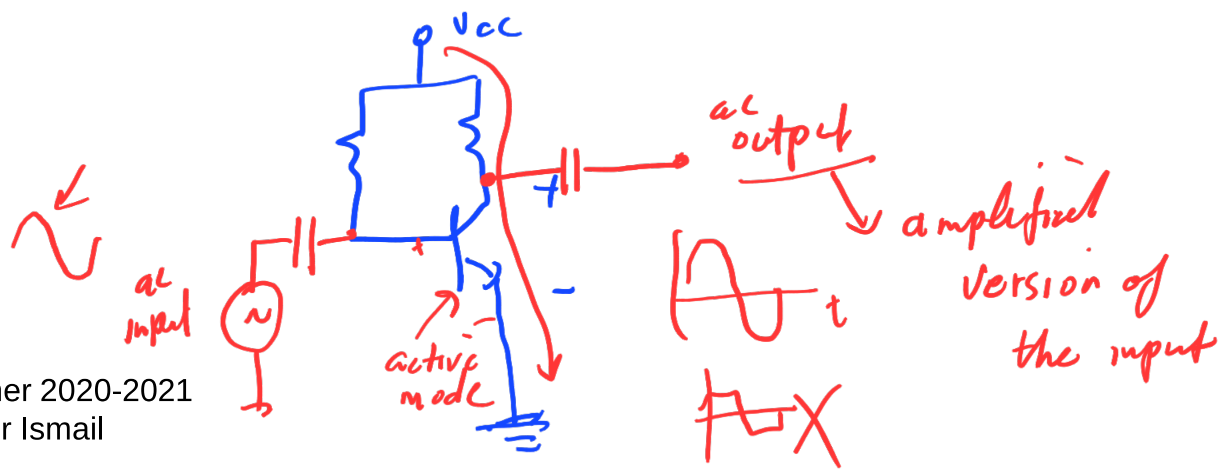
DC Load Line and Quiescent Operation Point



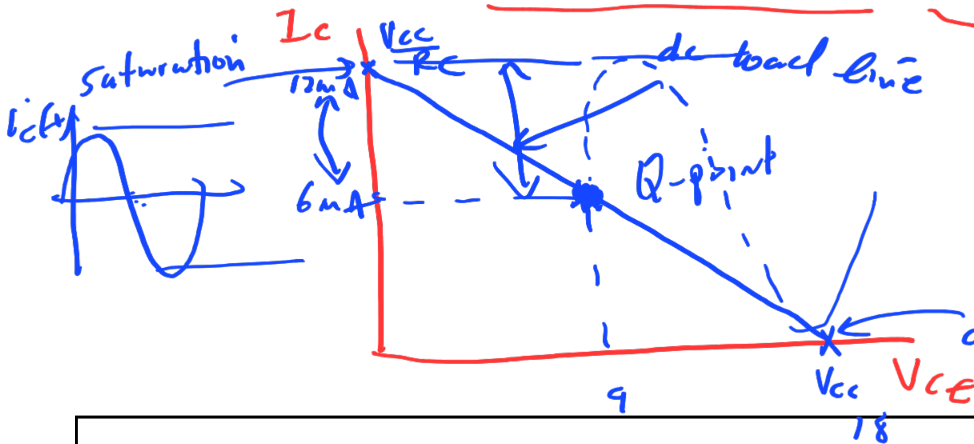


Base-emitter loop: $I_B = \frac{V_{CC} - V_{BE}}{R_b} \approx \frac{V_{CC}}{R_b} = 40(\mu A)$

Collector-emitter loop: $v_{CE} = V_{CC} - i_C R_C = 10 - i_C \times 4k$



$V_{cc} - V_{ce} - I_c R_c = 0$



$I_c = \frac{-1}{R_c} V_{ce} + \frac{V_{cc}}{R_c}$

$y = mx + b$

for $I_c = 0$
$V_{CE} = V_{cc}$
for $V_{CE} = 0$
$I_c = \frac{V_{cc}}{R_c}$

DC Load Lines

Assume $VCC = 18V, \beta = 100$

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

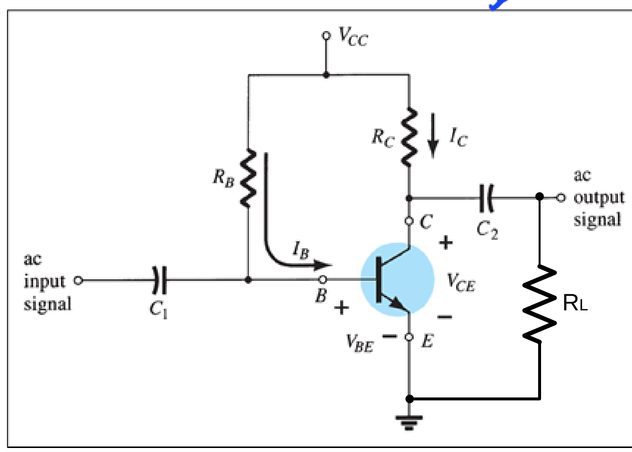
FIRST: DC ANALYSIS

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

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

This is a straight line equation

$$Y = mX + b$$



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

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

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

DC Load Line

I_{Csat}

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

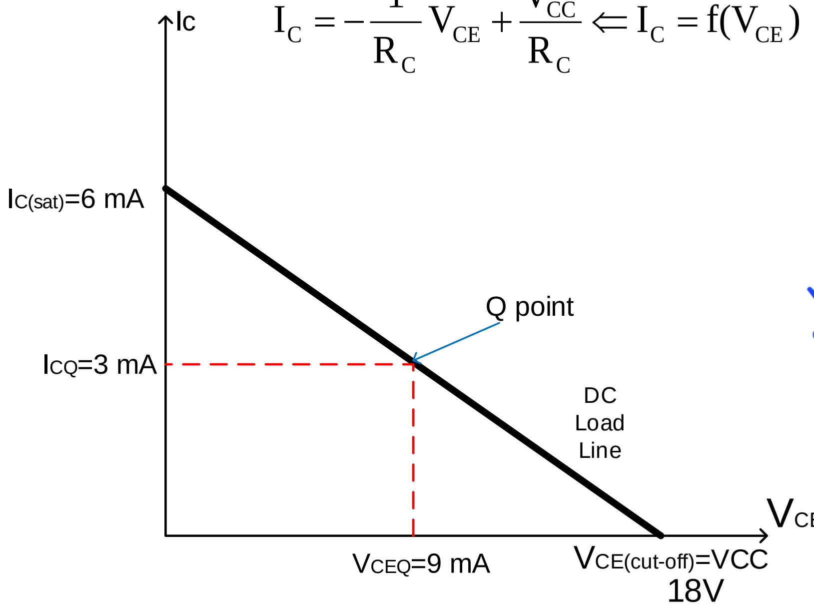
$$V_{CE} = V_{CE(sat)} \cong 0\ V$$

$V_{CEcutoff}$

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

$I_C = 0$ mA

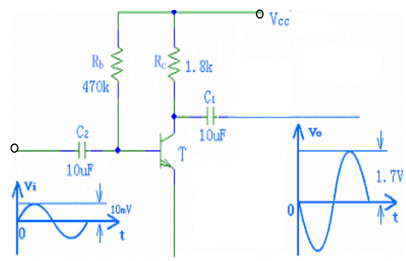
$$\mathrm{I_C} = -\frac{1}{\mathrm{R_C}}\mathrm{V_{CE}} + \frac{\mathrm{V_{CC}}}{\mathrm{R_C}} \Leftarrow \mathrm{I_C} = \mathrm{f(V_{CE})}$$

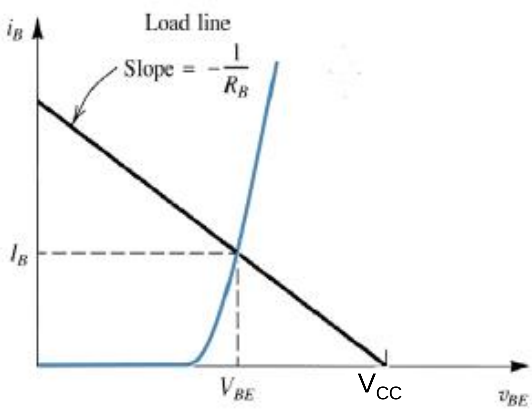


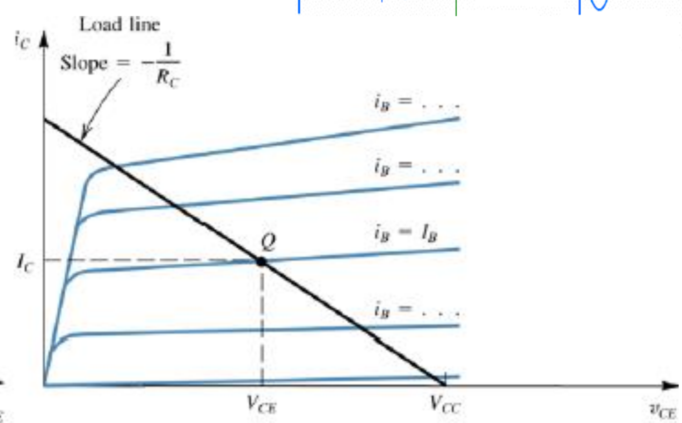
Basic BJT Amplifiers Circuits

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







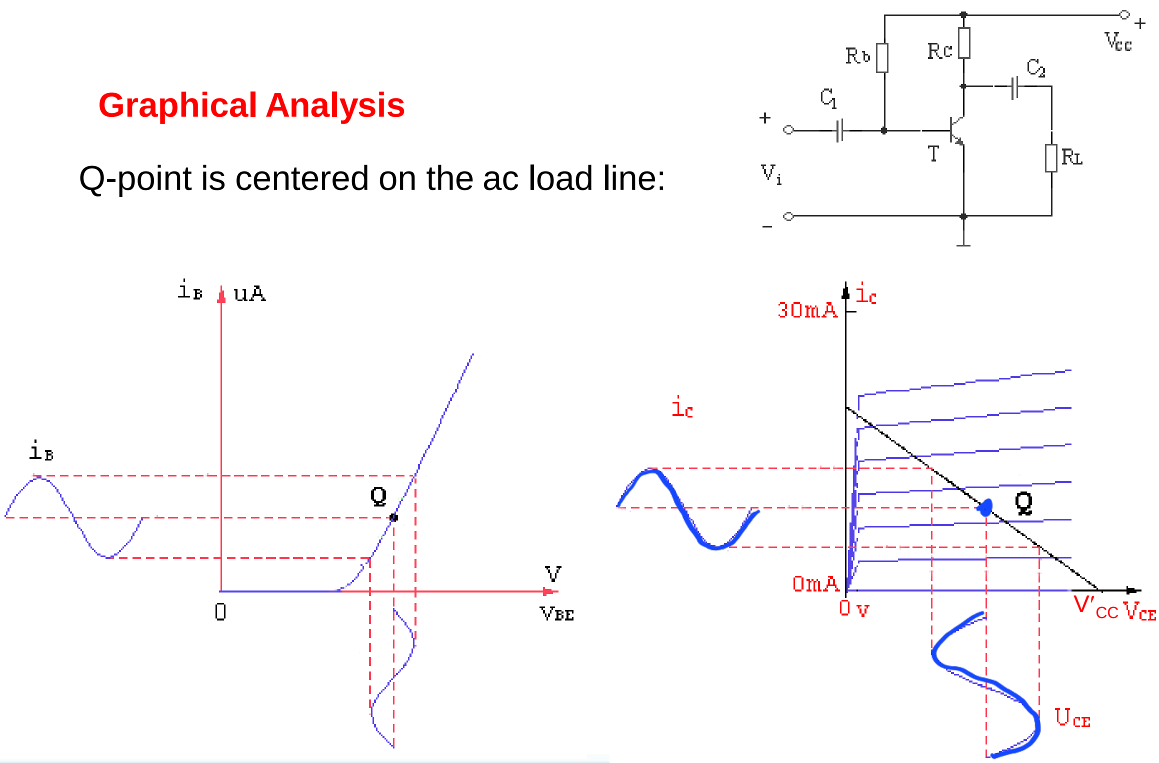
Can get a feel for whether the BJT will stay in active region of operation

– What happens if R_C is larger or smaller?

Basic BJT Amplifiers Circuits

Graphical Analysis

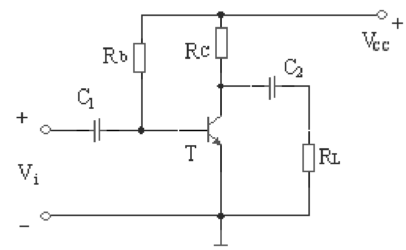
Q-point is centered on the ac load line:

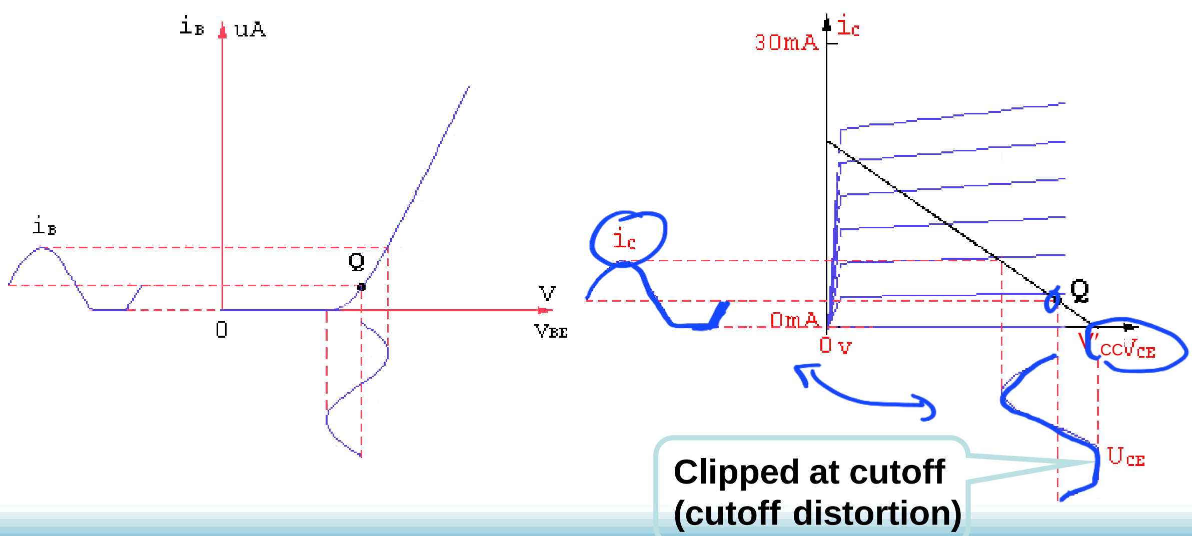


Basic BJT Amplifiers Circuits

Graphical Analysis

Q-point closer to cutoff:

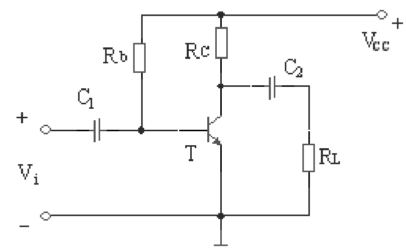


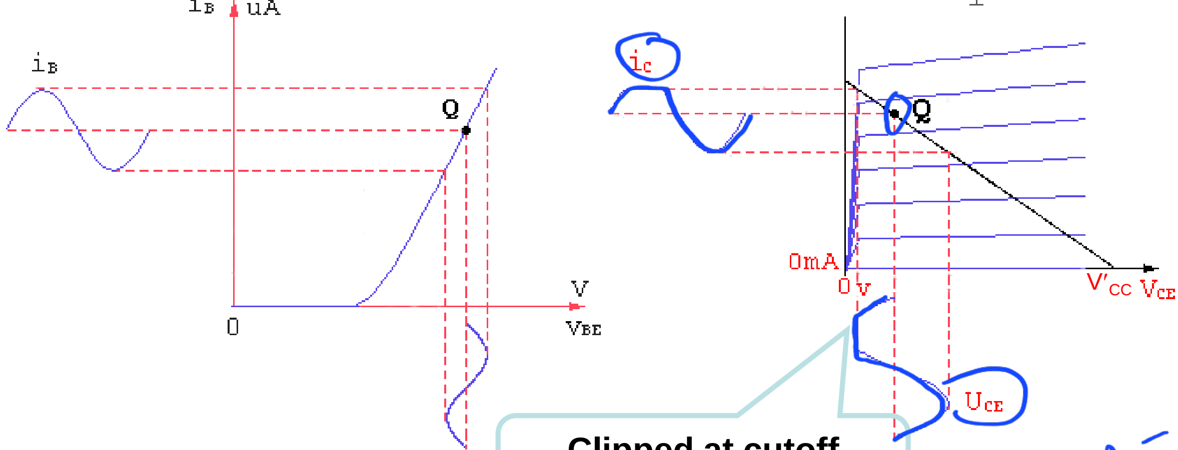


Basic BJT Amplifiers Circuits

Graphical Analysis

Q-point closer to saturation:





Clipped at cutoff (saturation distortion)

تشويه

Basic BJT Amplifiers Circuits

Graphical Analysis