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XMUT204 Electronic Design

Lecture 3b - BJT – Biasing Circuits

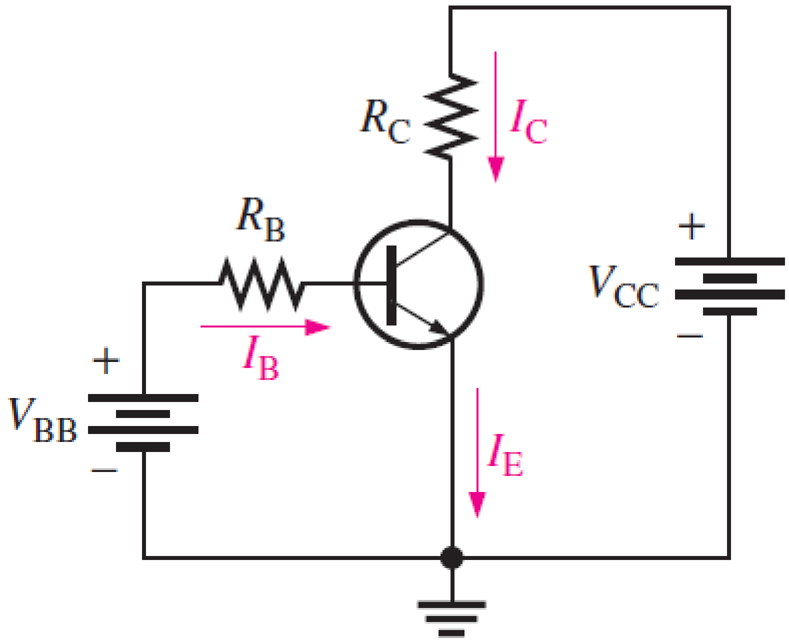
Overview

1. Biasing circuits.
2. Single power supplies with single base resistor.
3. Influence of β and R on the Q-point.
4. Improving device stability.
5. Negative feedback.
6. Voltage divider bias.
7. Loading of voltage divider input.
8. Summary of bias arrangements.

1. (Practical) Biasing Circuits

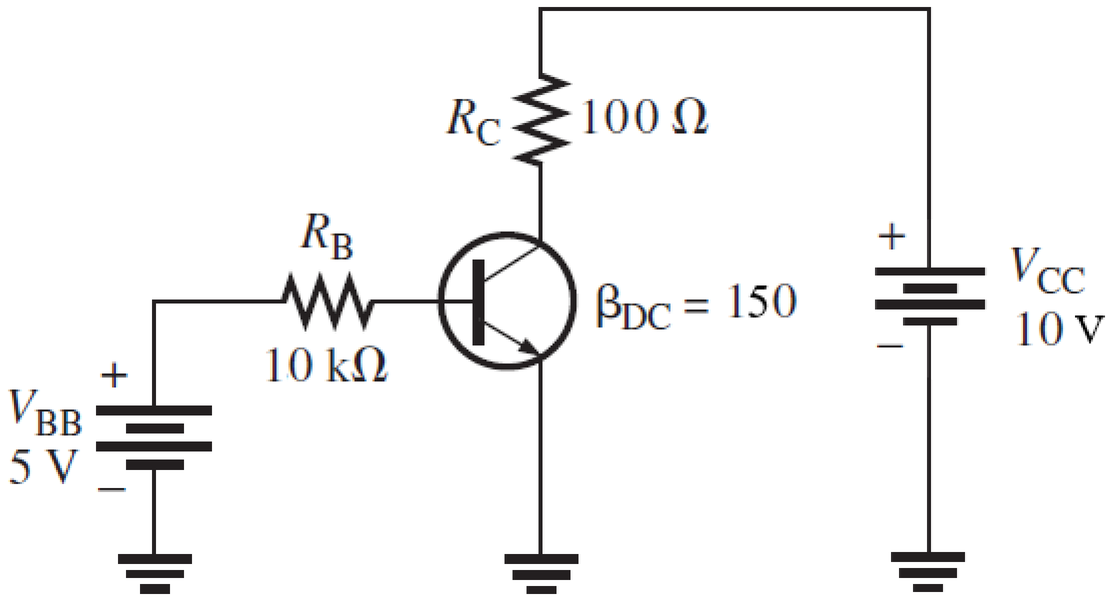
- The common emitter circuits were good for showing principle of operation, but were poor circuits for practical implementation as:
- Required two voltage sources for biasing as shown below.

- Very dependent on the value of β or resistor values.
- The variation in these values -> significant variation in the operating point.
- It is generally poor design to depend on the β value.



Example 1 – BJT Circuit Parameters

Determine emitter current (I_E) and collector-emitter voltage (V_{CE}) in the circuit of given below. The transistor has a β_{DC} = 150. [8 marks]

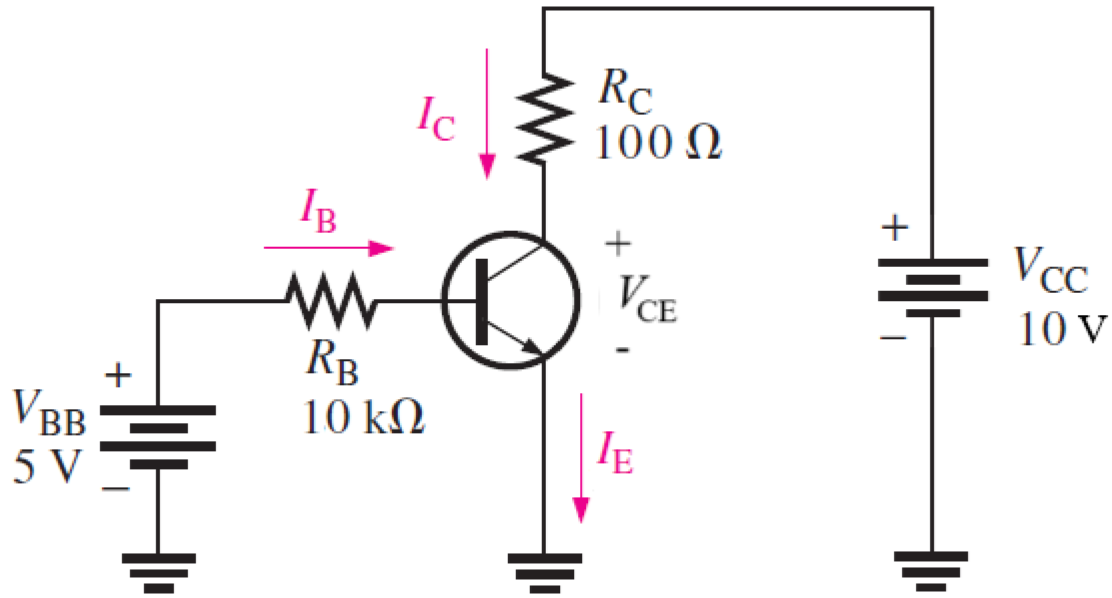


- Assume for a Silicon BJT, $V_{BE} = 0.7\ \text{V}$.
- Using the equations given below, we calculate emitter current as follows:

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

- And

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



- First, calculate the base current:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\ \text{V} - 0.7\ \text{V}}{10\ \text{k}\Omega} = 430\ \mu\text{A}$$

- Thus, calculate the collector current:

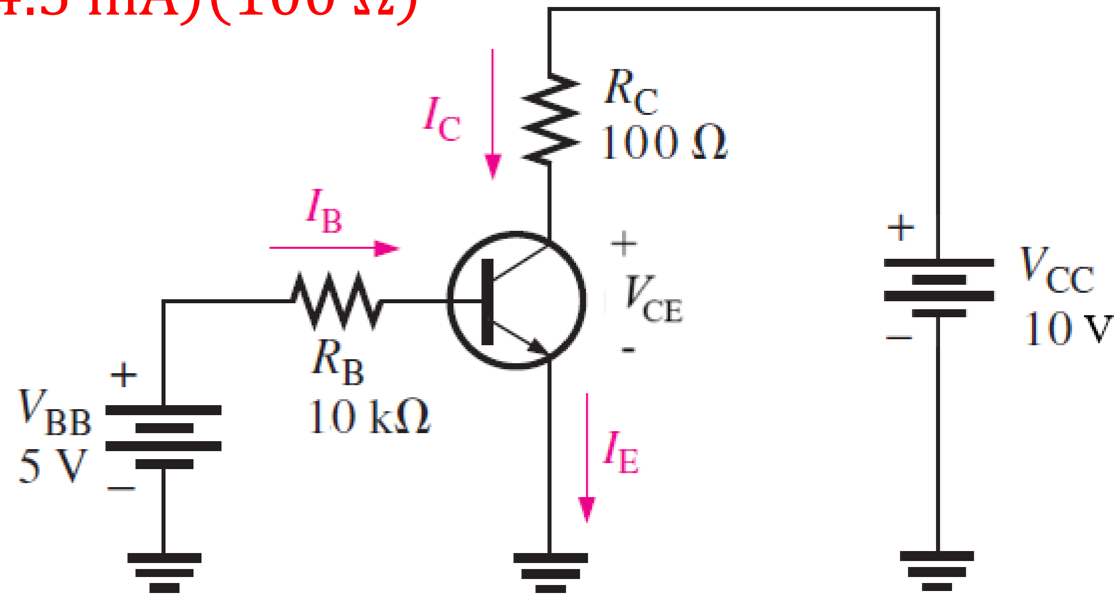
$$I_C = \beta_{DC} I_B = (150)(430\ \mu\text{A}) = 64.5\ \text{mA}$$

- Afterward, calculate the current at the emitter:

$$I_E = I_C + I_B = 64.5\ \text{mA} + 430\ \mu\text{A} = 64.9\ \text{mA}$$

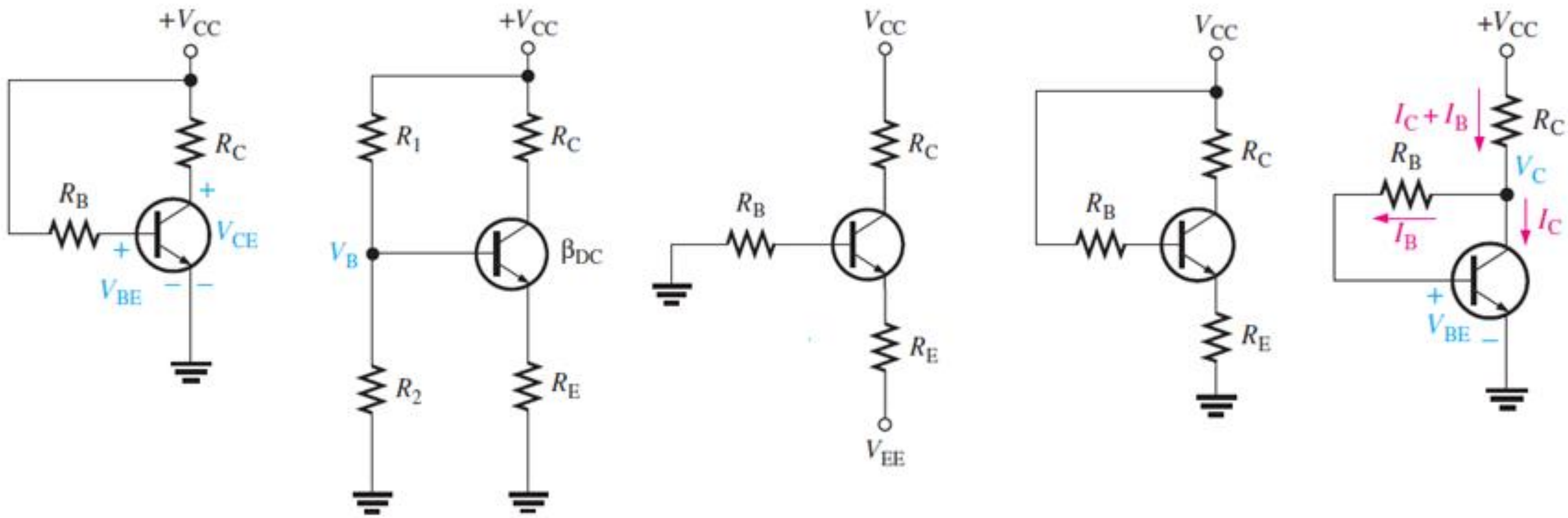
- Finally, solve for V_{CE}:

$$V_{CE} = V_{CC} - I_C R_C$$
$$= 10\ \text{V} - (64.5\ \text{mA})(100\ \Omega)$$
$$= 3.55\ \text{V}$$



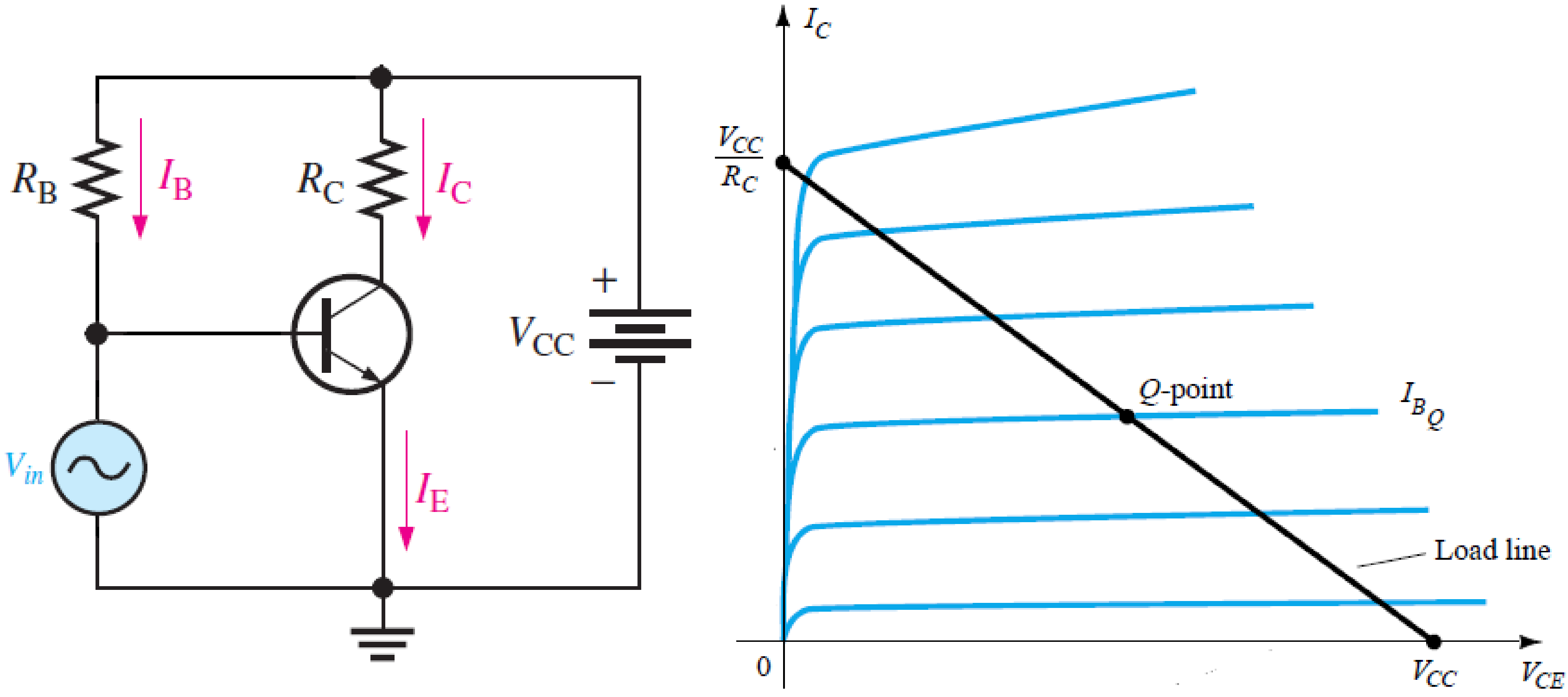
1. Practical Biasing Circuits (Continue …)

- We look at circuits that will be more practical for real implementation.
- There are several biasing circuits for BJT available e.g. base bias, voltage divider bias, emitter bias, emitter feedback bias, collector feedback bias, etc.
- Firstly, we look at circuits that use a single power supply for biasing.



2. Single Power Supply with a Single Base Resistor

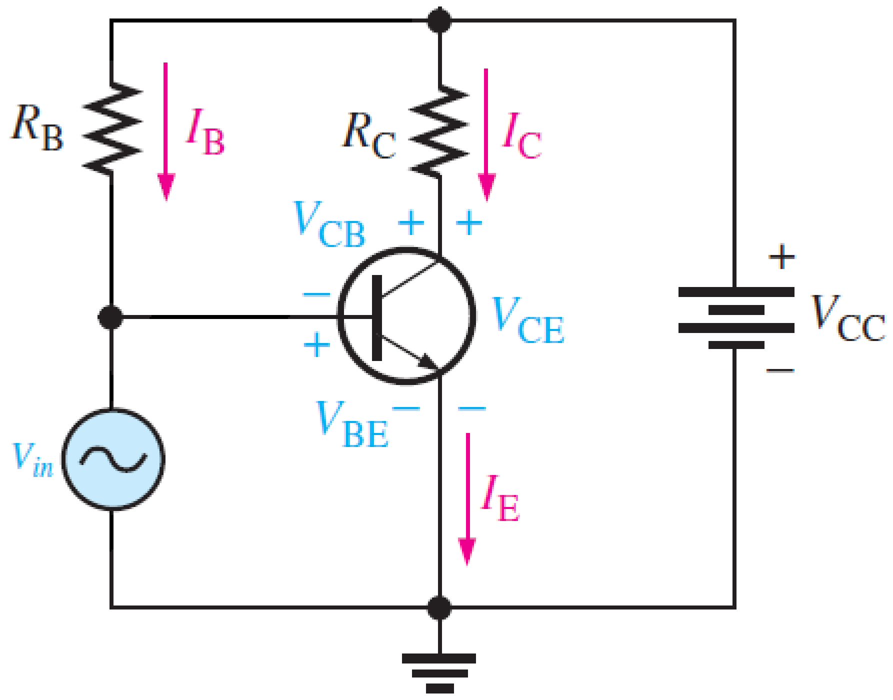
- Given a single-supply biasing circuit as shown below:



- The circuit represents an alternative base bias circuit for a BJT amplifier.
- It uses only a single base resistor and a single power supply.

Example 2 – Basic BJT Biasing Circuit

Given a biasing circuit as shown below, assume that V_{CC} = 12 V, β = 100 and design circuit so that I_{CQ} = 1 mA and V_{CEQ} = 6 V. [6 marks]



- Redraw circuit to present only the DC part.
- As desired I_{CQ} is specified at 1 mA, thus, base current is:

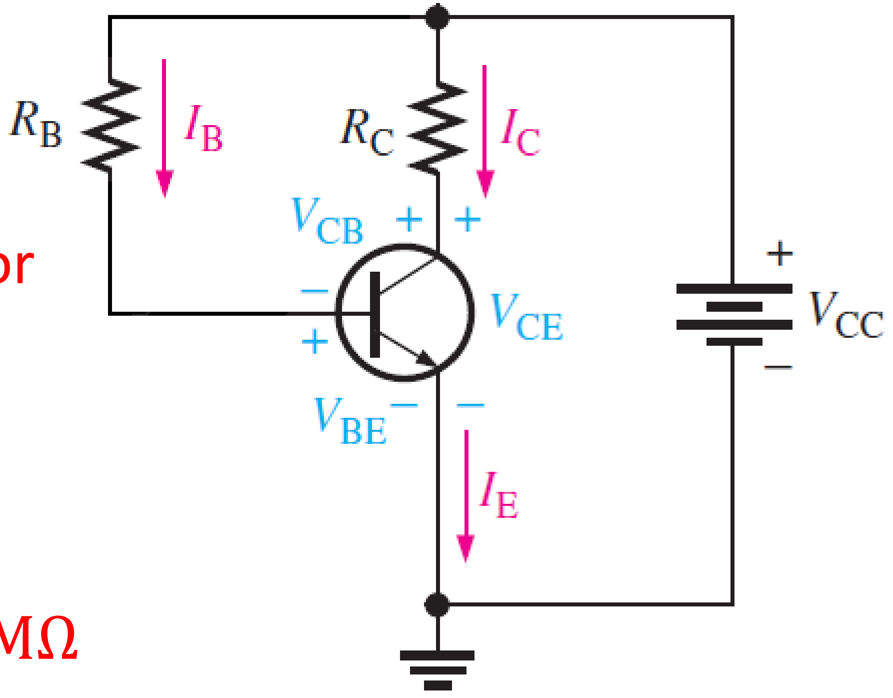
$$I_B = \frac{I_C}{\beta} = \frac{1\text{ mA}}{100} = 10\ \mu\text{A}$$

- For BE loop, apply KVL around the loop:

$$V_{CC} - I_{BQ}R_B - V_{BE} = 0$$

- Thus, the value of the resistor at the base is:

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



- For CE loop, apply KVL around the loop:

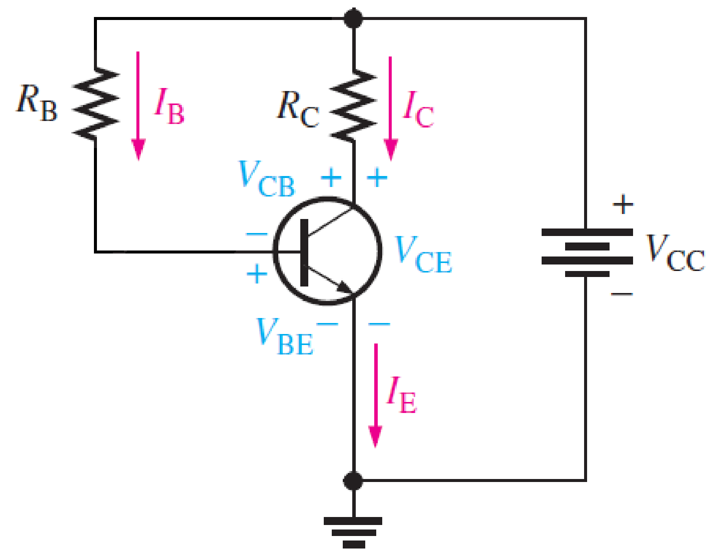
$$V_{CC} - I_{CQ}R_C - V_{CEQ} = 0$$

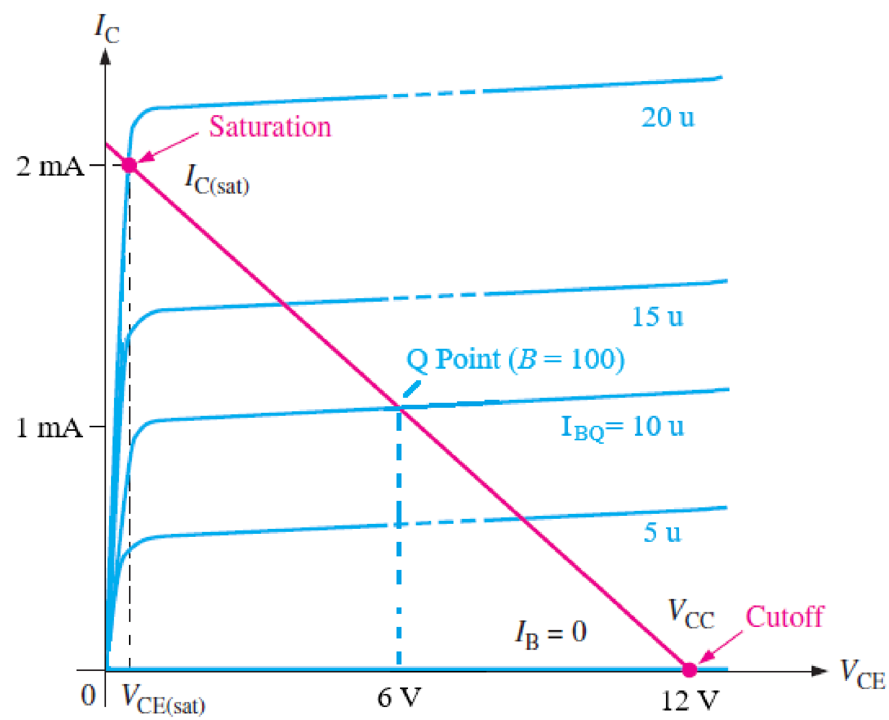
- Thus, the value of the resistor at the collector is:

$$R_C = \frac{V_{CC} - V_{CEQ}}{I_{CQ}}$$

$$= \frac{12\text{ V} - 6\text{ V}}{1\text{ mA}} = 6\text{ k}\Omega$$

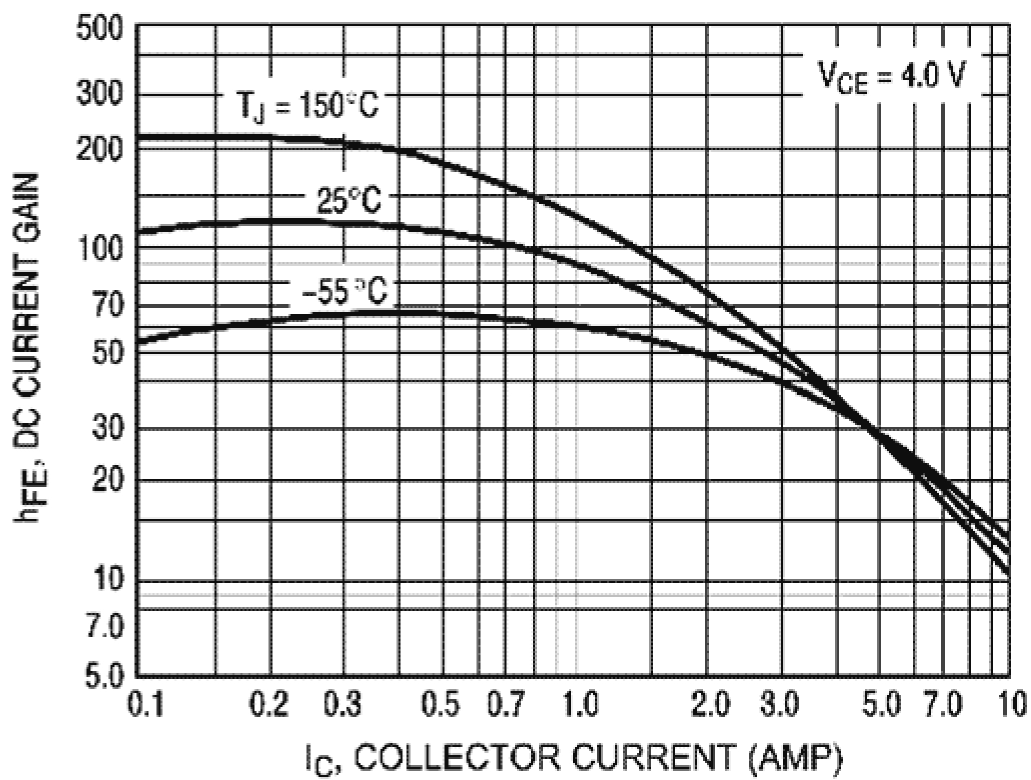
- Finally, the values R_B = 1.13 MΩ and R_C = 6 kΩ will place operation at the desired Q point.





3. Influence of Variations in β and R on the Q Point

- β values can be notoriously variable between the same transistors, and it is also non-linear as shown below.
- We can re-do the previous calculations for the case where we have a transistor that has a lower value of β rather than higher value β.



- Reducing the value of β results in a lower collector current condition for the BJT.
- Desirable for low power losses in the circuit but reduce voltage swing.

3. Influence of Variations in β and R on the Q Point (cont..)

- Notice that for operating condition beyond the stated normal operating temperature of BJT (e.g. 25° C), we need to derate (downgrade) its dissipating power.
- The derating dissipating power is calculated from (with Δ_p as the derating factor):

$$P_D(\text{max}) = P_{D(\text{at } 25°\text{C})} \pm \Delta_p(T_2 - T_1)$$

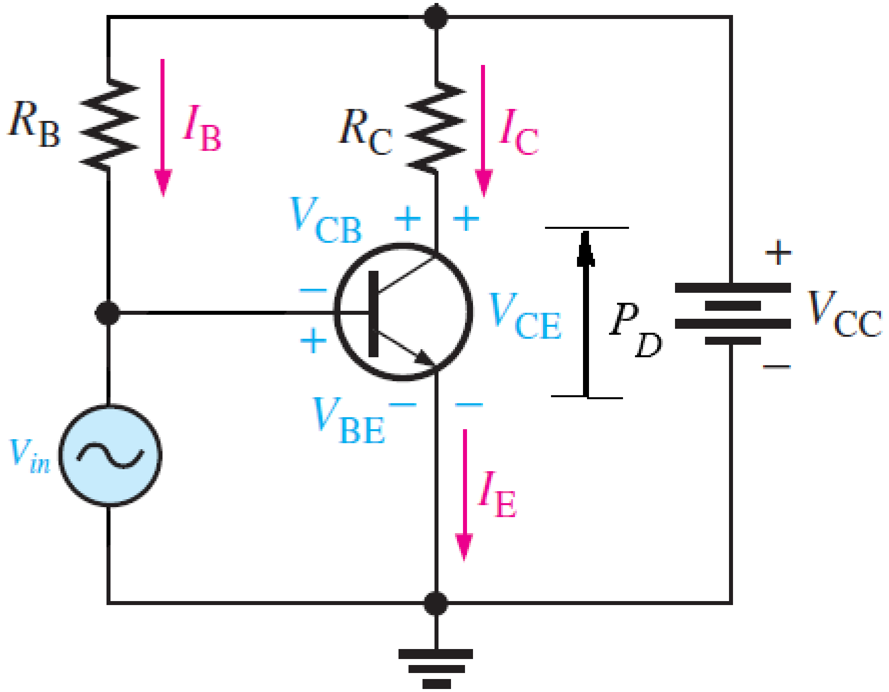
- For increase operating temperature, we need to reduce the dissipating power of the BJT.
- On the other hand, if we operate the BJT below its stated operating temperature, we can afford the maximum dissipating power of the BJT to be higher than stated operating temperature.

3. Influence of Variations in β and R on the Q Point (cont..)

- In practice, most of the power dissipated (as heat) in the BJT occurs at the collector-emitter junction.

- This is due to the resistance across the collector-emitter junction, R_{DS}.
- As a result, the maximum dissipating power of the BJT is calculated from:

$$P_{\mathrm{D(max)}} = V_{CE(\mathrm{max})} I_{C(\mathrm{max})}$$



Example 3 – Further BJT Biasing Circuit

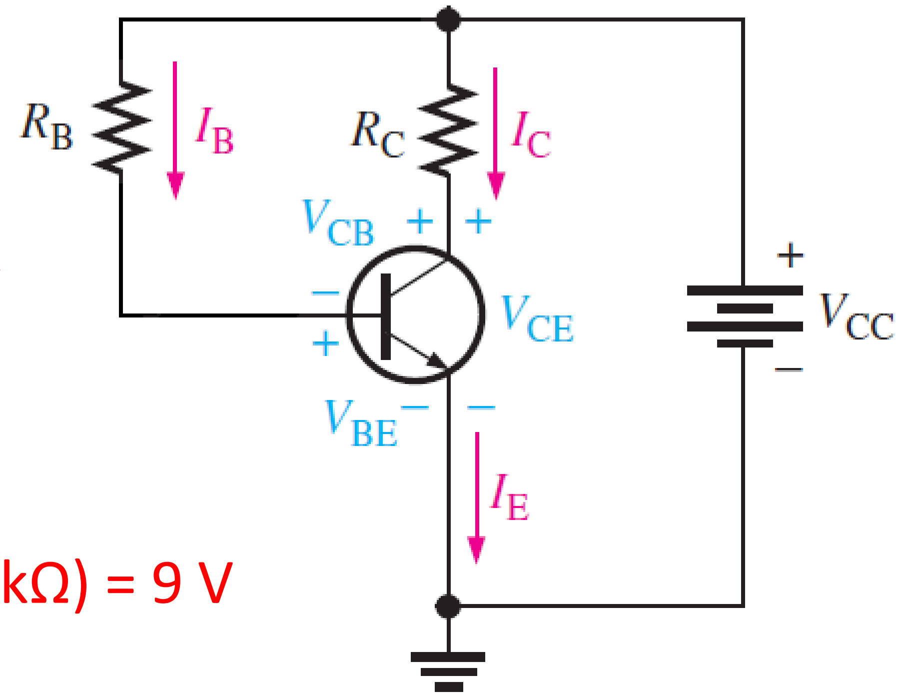
Redo the previous Example 2 for a transistor that has a β = 50 rather than the β = 100 as specified by the manufacturer.

[6 marks]

- When β = 50, for the calculated value of I_{BQ} = 10 µA, the value of I_{CQ} will be:

$$I_{CQ} = \beta I_{BQ}$$

= (50)(10 µA) = 0.5 mA

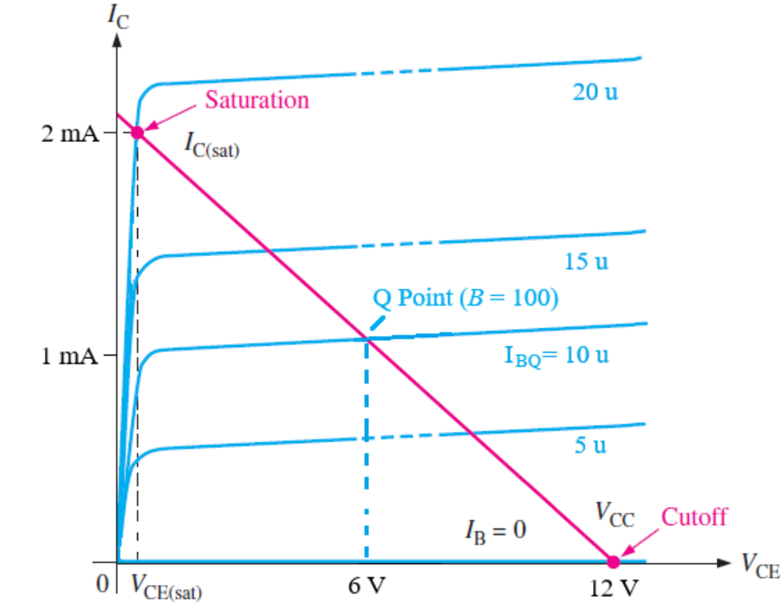


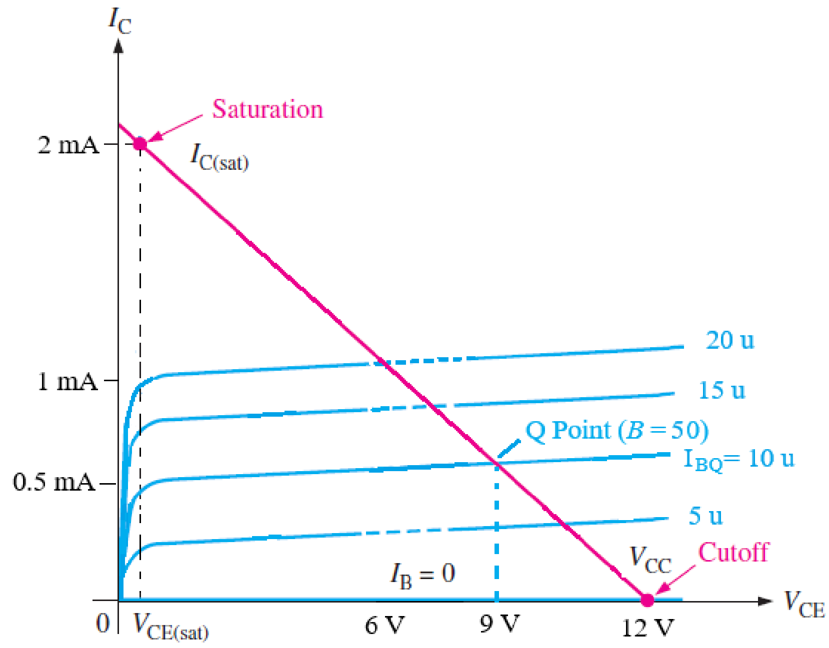
- And the value of V_{CEQ} will be:

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

= 12 V – (0.5 mA)(6 kΩ) = 9 V

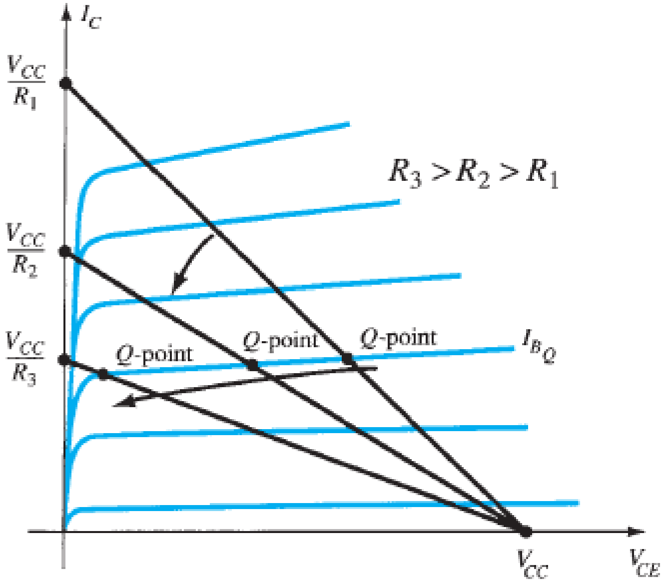
- The Q point has then shifted dramatically when compared to the assumed value of β.
- It is changed e.g. I_{CQ} is from 1 mA to 0.5 mA and V_{CEQ} is from 6 V to 9 V).
- Need alternative for avoiding this fluctuation in the Q-point.



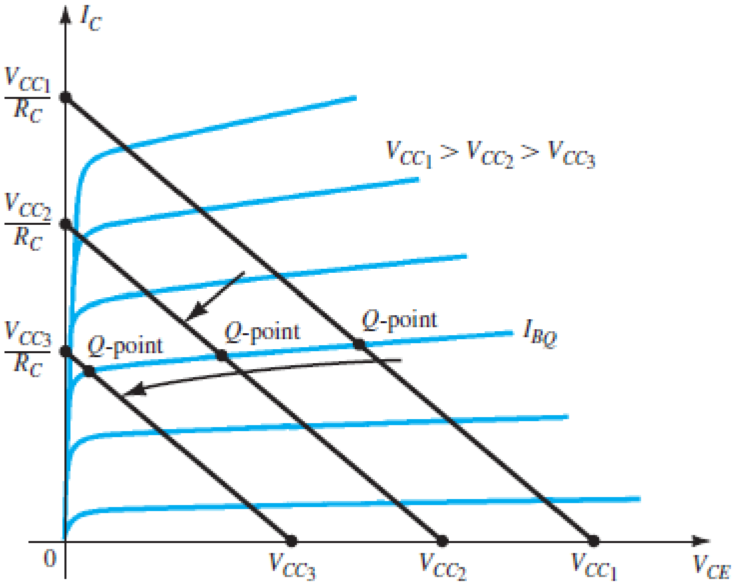


3. Influence of Variations in β and R on the Q Point (cont.)

- Similarly, the Q point will also vary strongly with variations in the resistance values i.e. $I_{CQ} = V_{CC}/R_C$.
- A variation of 5 - 10 % in nominal resistor value will lead to significant changes in Q-point.
- Reducing the supply voltage also changes the Q-points.



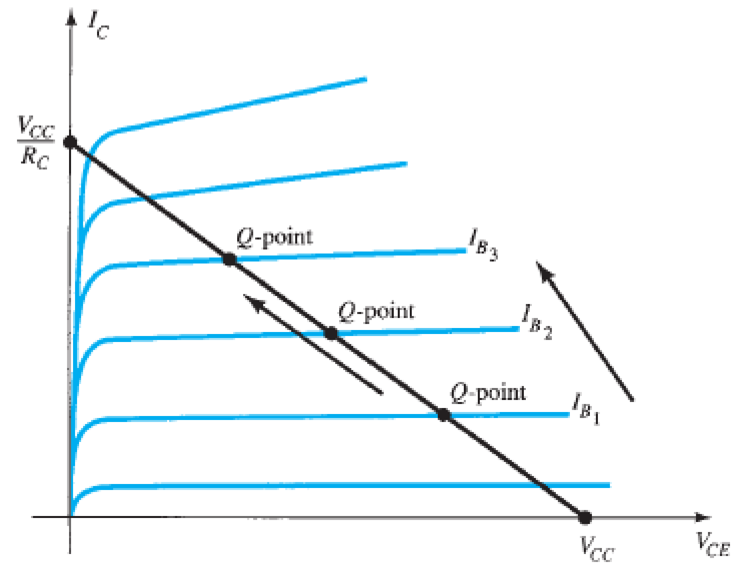
Effect of increasing load resistance on load line and operating points



Effect of reducing supply voltage on load line and operating points

3. Influence of Variations in β and R on the Q Point (cont.)

- As shown before the shift in Q-point from where it is expected with a β value of 100 to where it will occur with an actual β value of 50.
- Shift in Q-point causes the collector current to vary from 1 mA to 0.5 mA.
- This dependence of I_C on the actual value of β_{DC} can be countered using negative feedback.



Effect of increasing base current on load line and operating points

- Must then find a more stable biasing arrangement i.e. voltage divider networks and negative feedback.

4. Improving Device Stability

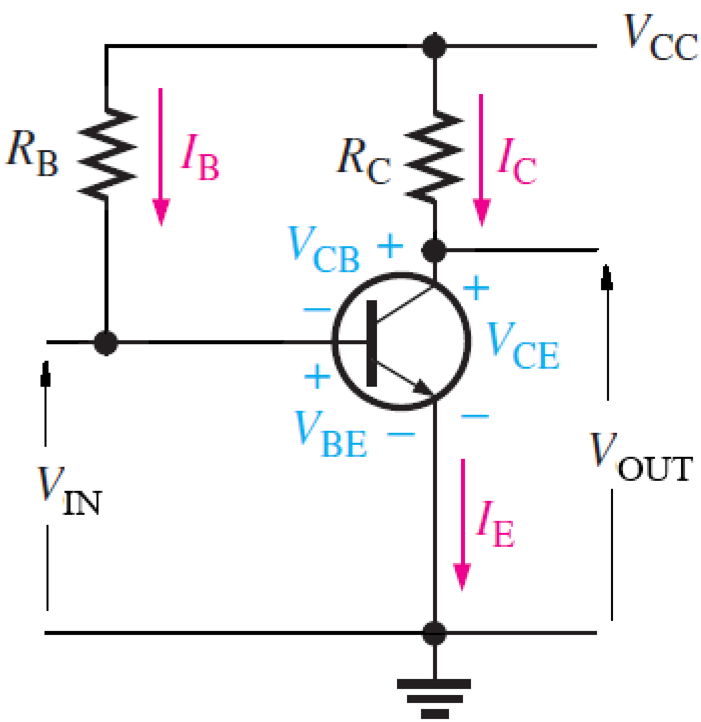
- The previous discussions clearly showed the problem of device instability.
- The fact that we will have large shifts in I_C if the value of β is different from what was initially assumed.
- The extent of this can be seen from an expression for the output voltage V_o in the standard configuration:

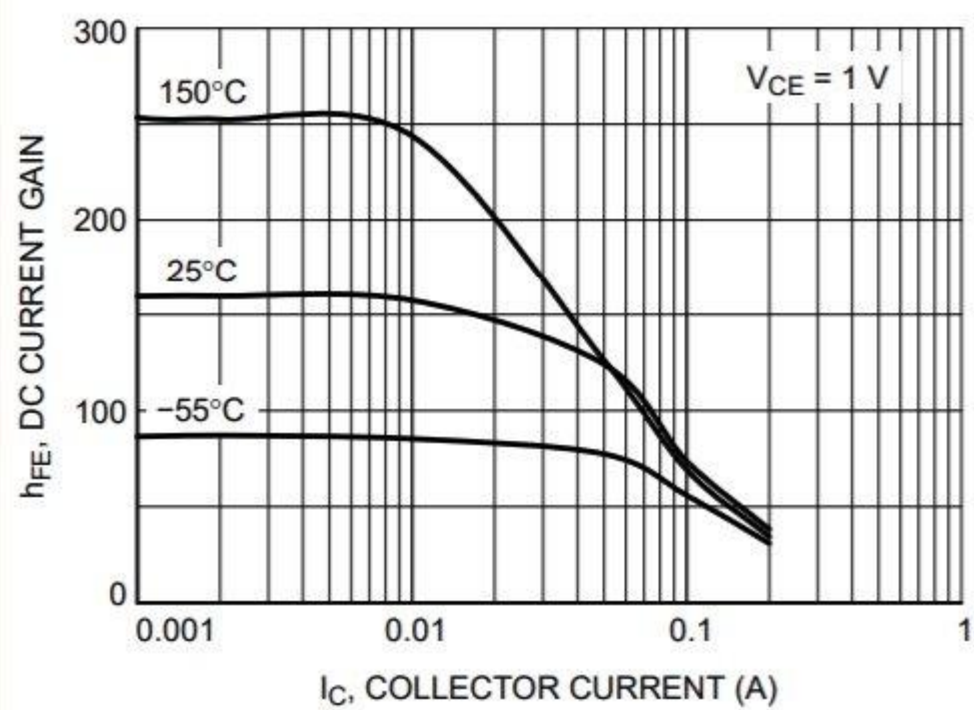
$$V_o = V_{CC} - I_C R_C$$

- Any variation in β will produce a variation in I_C from $I_C = \beta I_B$, and lead to a variation in V_o.

4. Improving Device Stability (cont.)

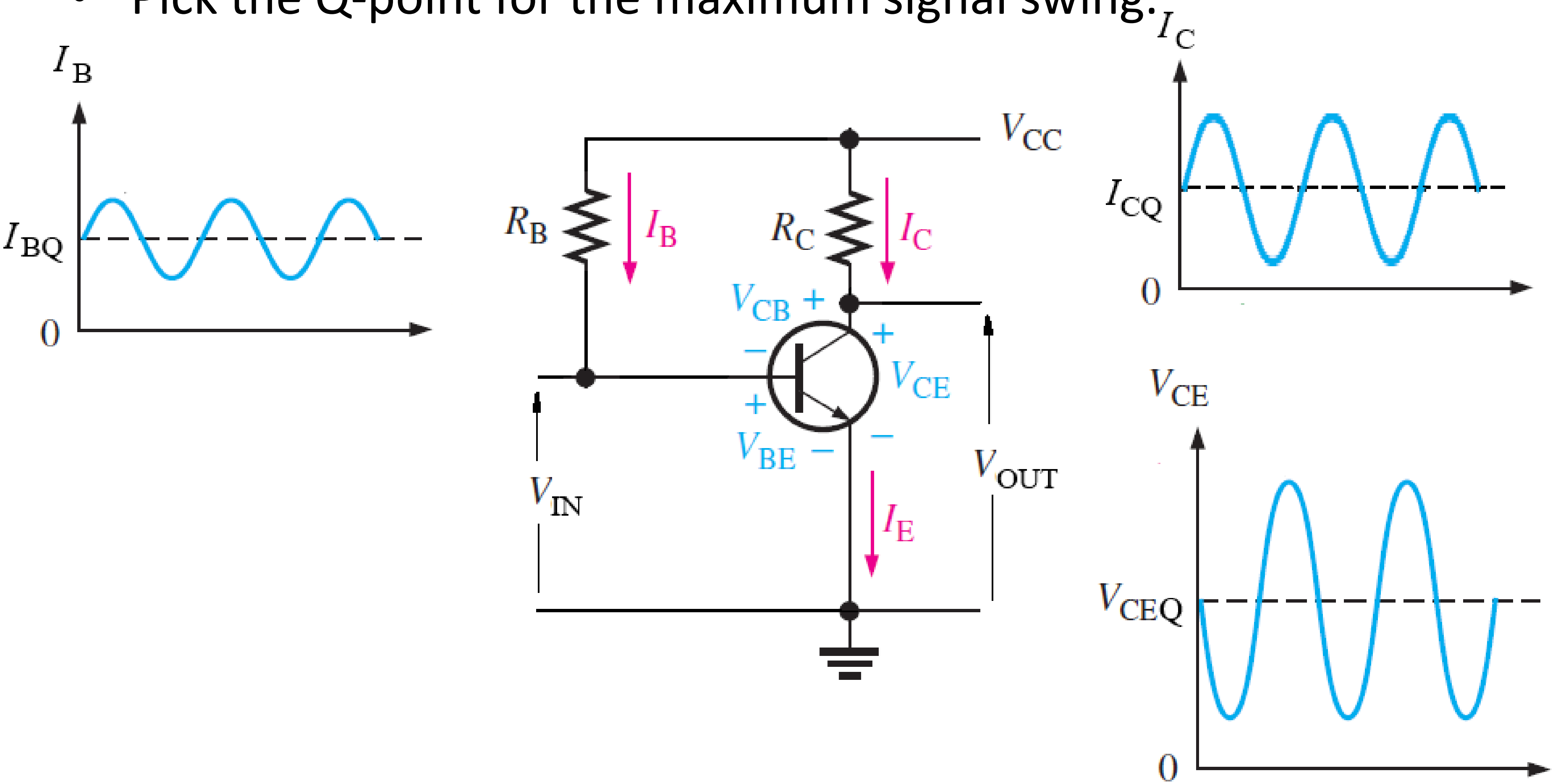
- As shown in the graph given below, due to operating temperature fluctuation, DC current gain (β) varies.
- The variation of the DC current gain (β) of the biasing circuit can lead to variation in the collector current I_C (and hence variation in the output voltage V_o).



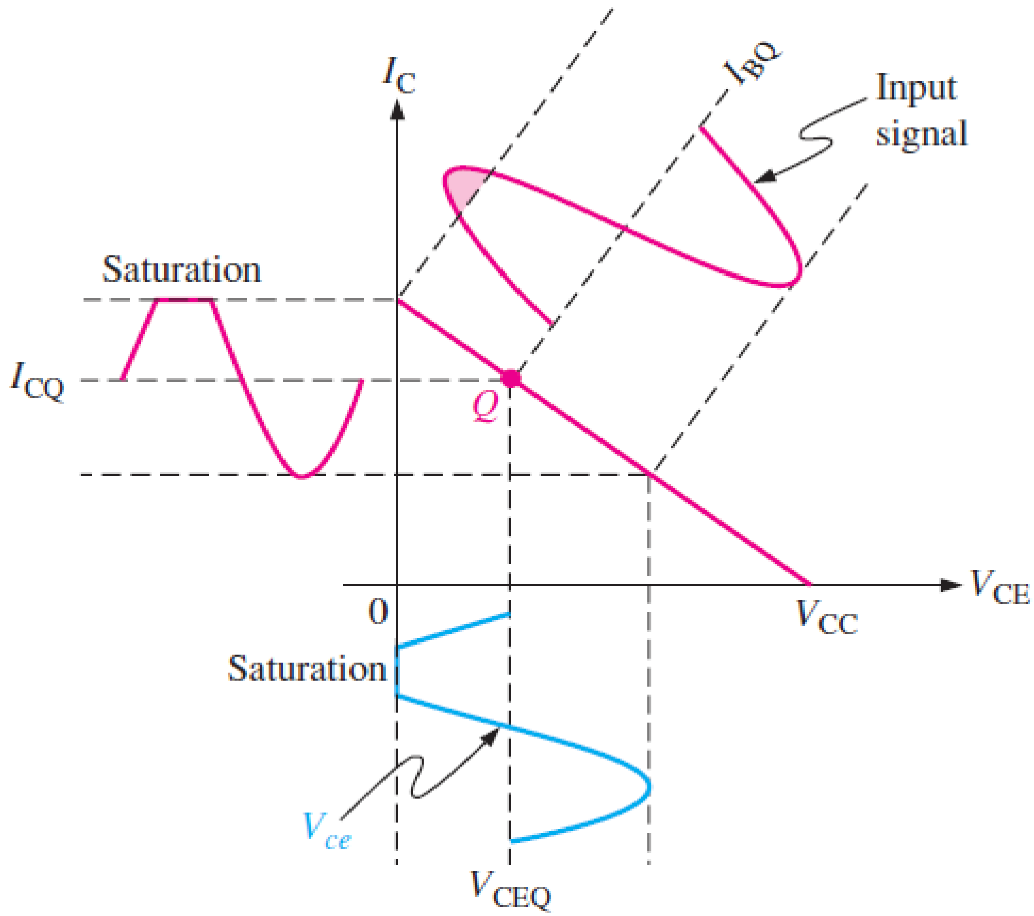


4. Improving Device Stability (cont.)

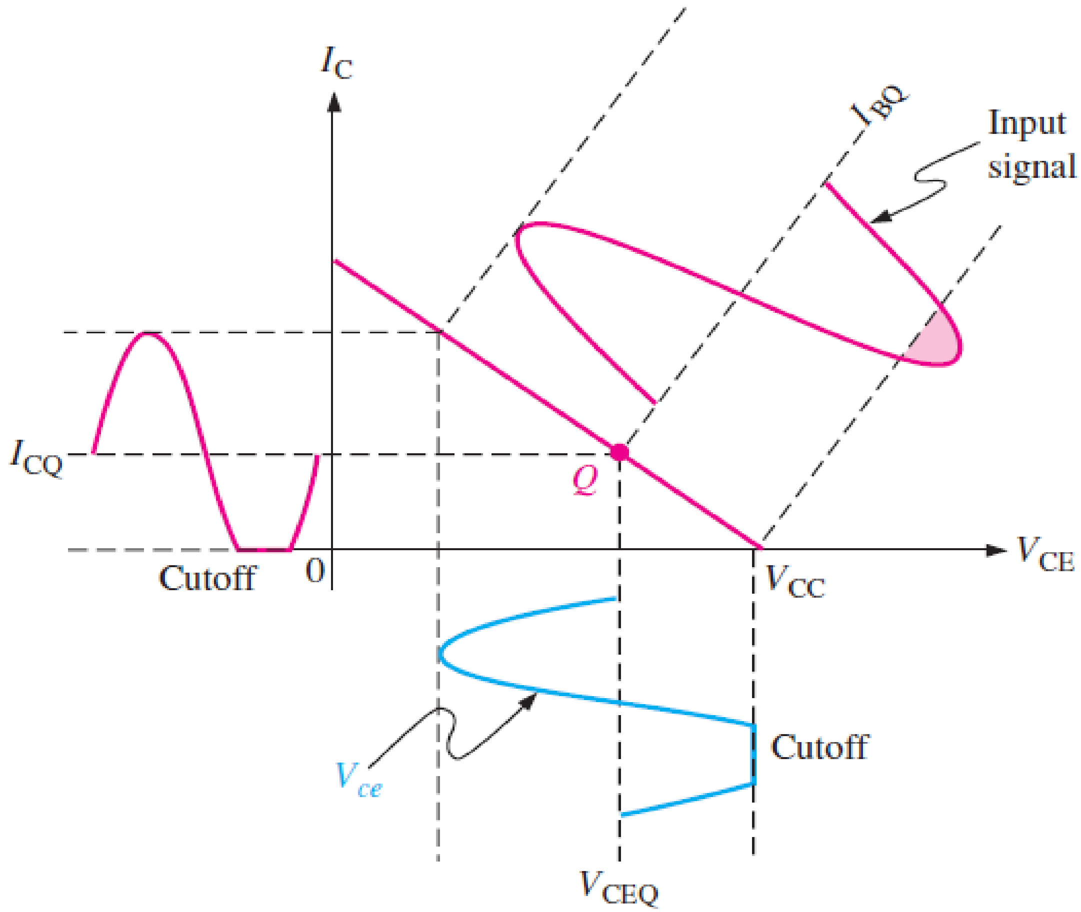
- As shown in the figure given below, we could evaluate various locations of the Q-point in the loadline of the BJT.
- Pick the Q-point for the maximum signal swing.



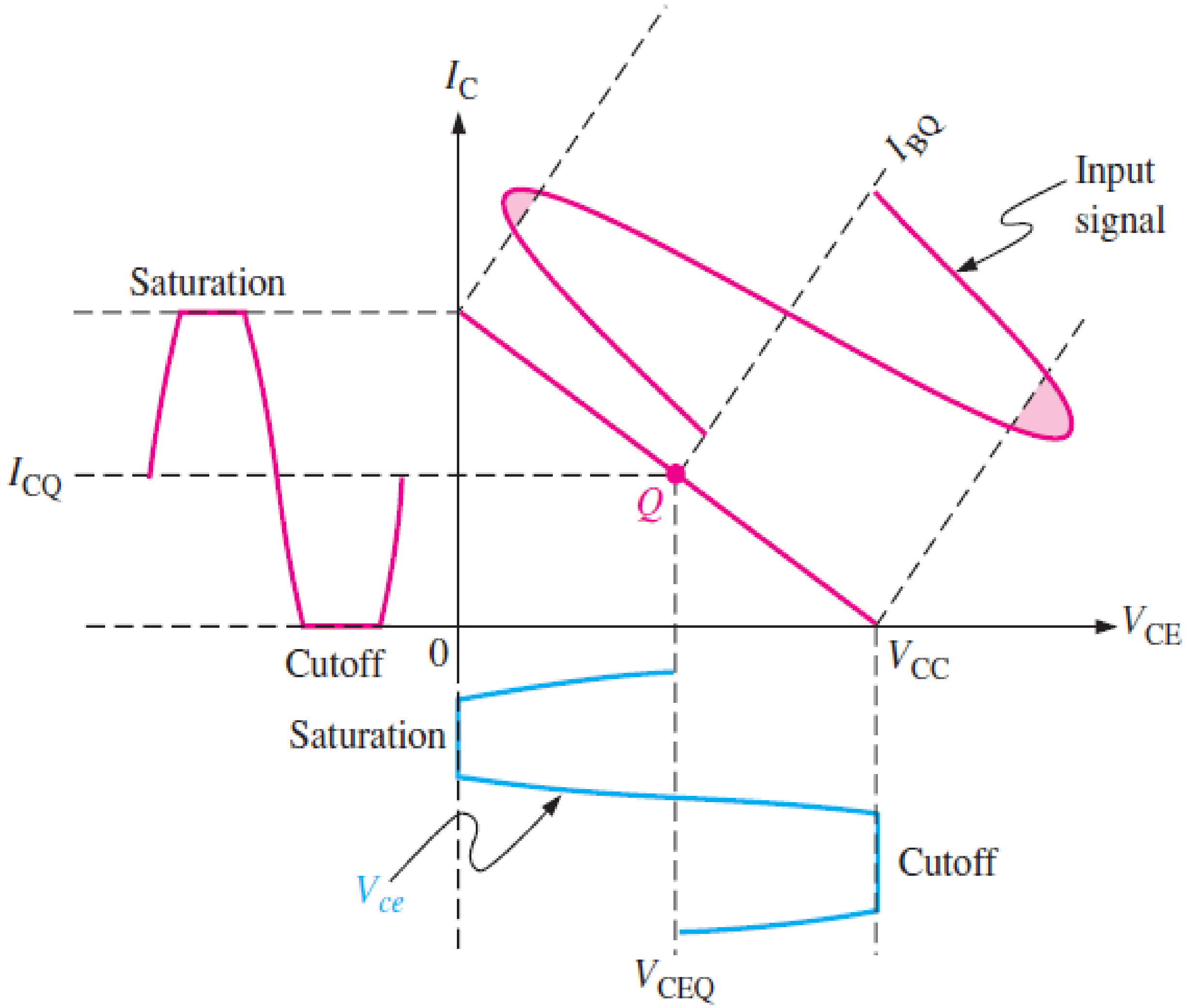
- In the figure given below, the BJT is driven into saturation because the Q-point is too close to saturation for the given input signal.



- As shown in the figure below, the BJT is driven into cut-off because the Q-point is too close to cut-off for the given input signal.

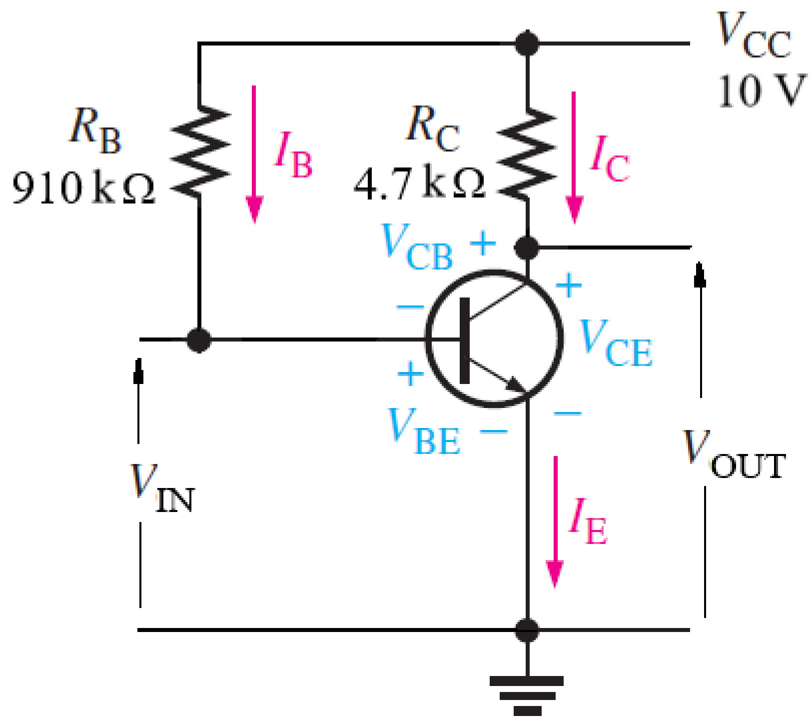


- By referring to the figure below, the BJT is driven into both saturation and cut-off because the input signal is too large.



Example 4 – Output in BJT Biasing Circuit

For a BJT circuit based on base bias given below, perform the following tasks.



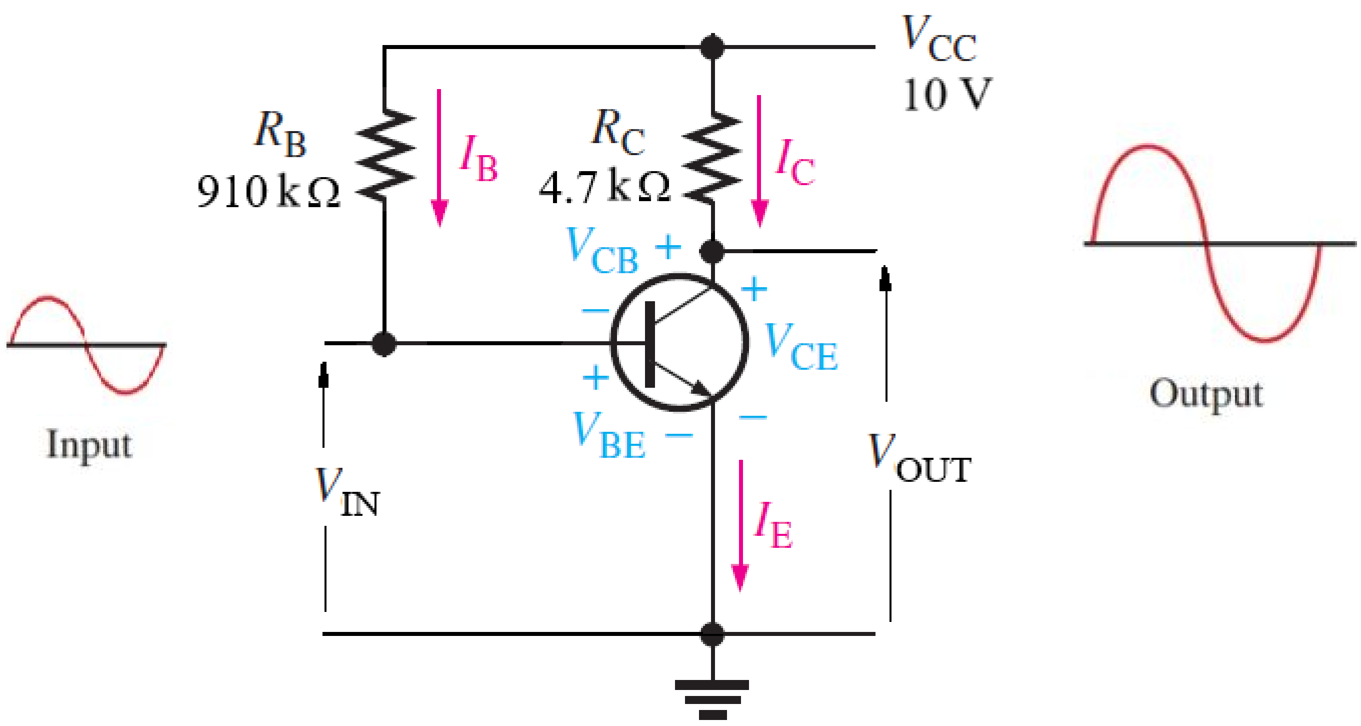
a. Calculate the maximum swing available in the output voltage. [6 marks]

b. Determine the fluctuation of the amplified output signal from its input signal. [6 marks]

Answer

a. For β = 100 in this circuit, the current at the base is:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{10\text{ V} - 0.7\text{ V}}{910\text{ k}\Omega} = 10.2\ \mu\text{A}$$



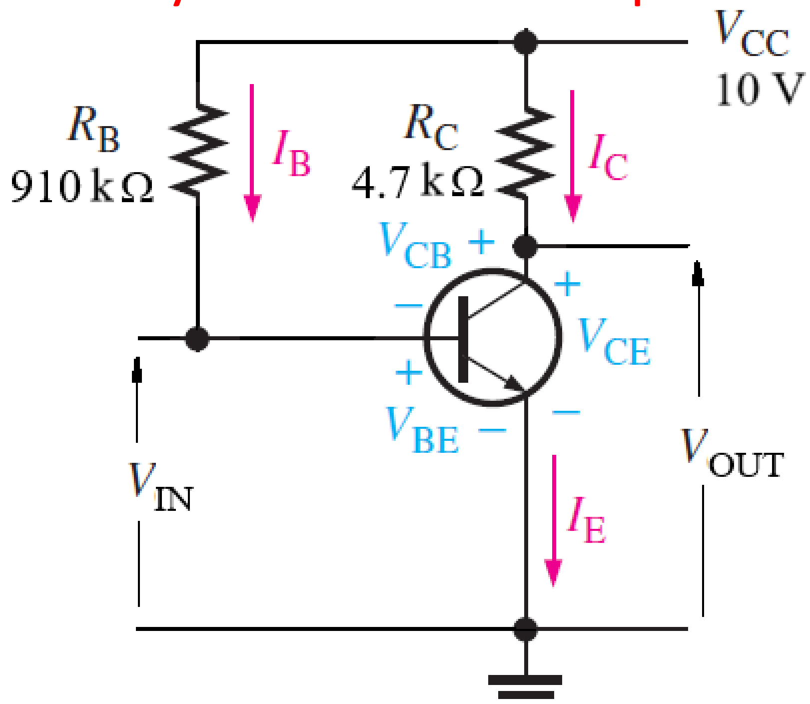
- This I_B = 10.2 μA results in the current at the collector:

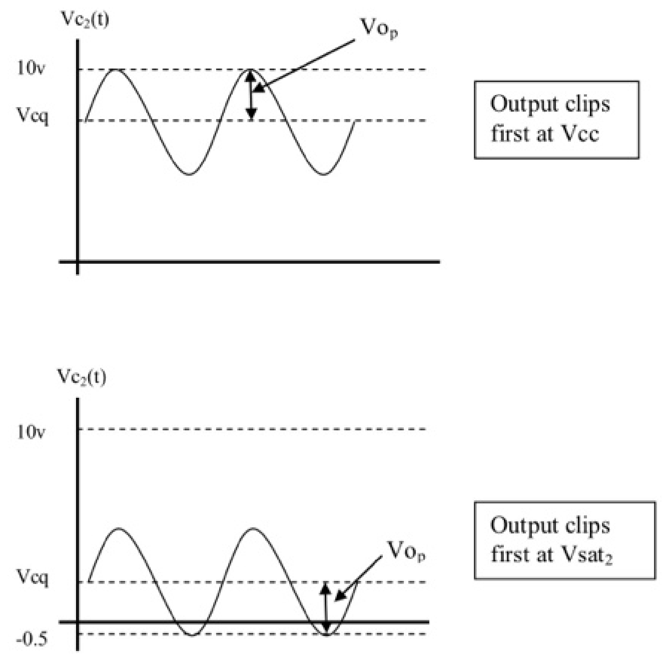
$$I_C = \beta I_B = (10.2\ \mu A)(100) = 1.02\ mA$$

- The voltage observed at the output is:

$$V_o = V_{CC} - R_C I_C = 10\ V - (4.7\ k\Omega)(1.02\ mA) = 5.2\ V$$

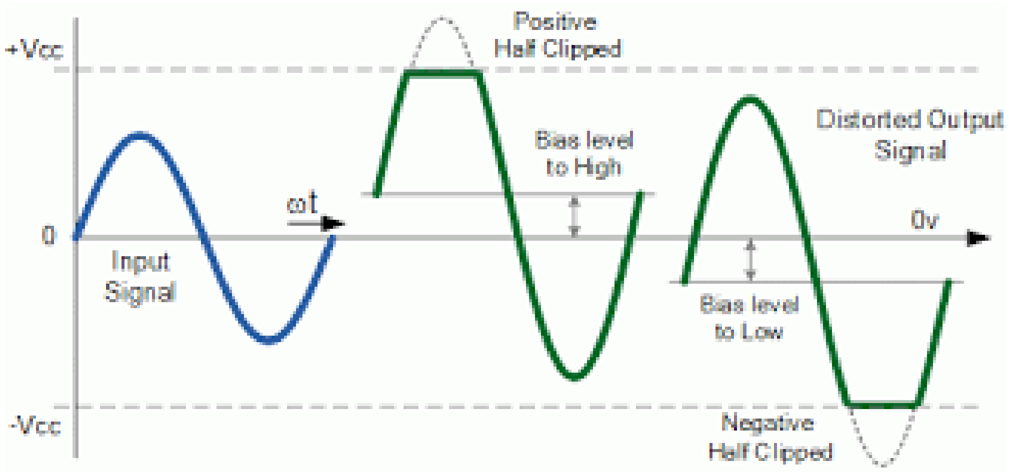
- For the given biasing configuration, output voltage can swing nearly ± 5 V from the operating point (e.g. from 10 V to 0 V).





b. The fluctuations in the output voltage are determined as:

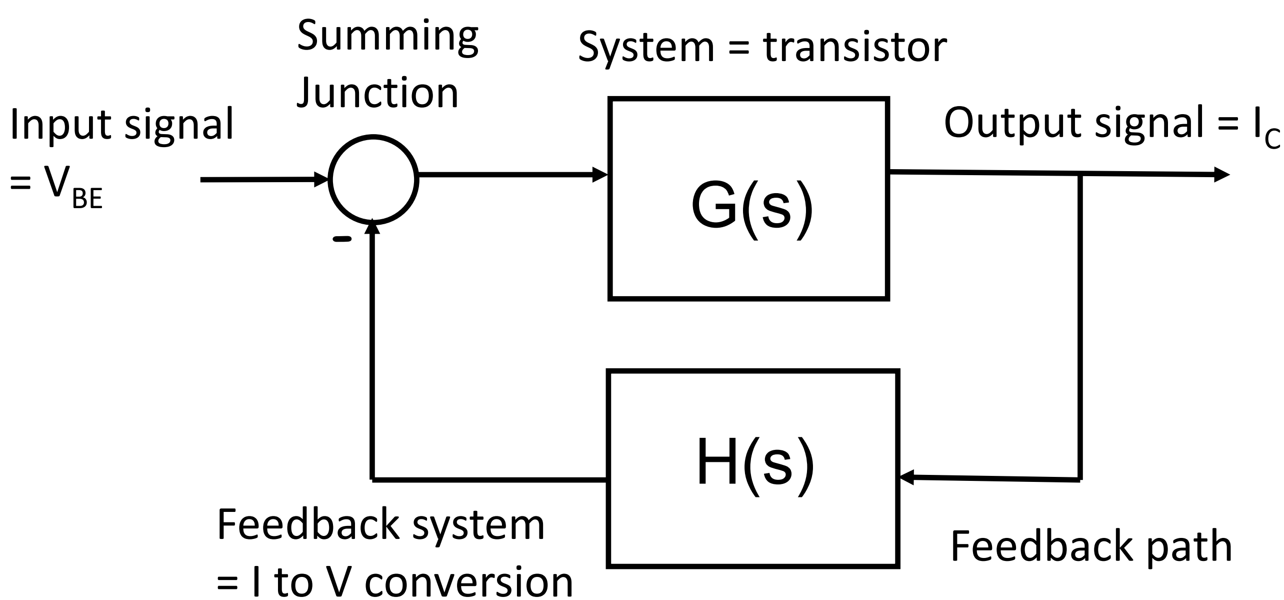
- For β = 80 in this circuit: V_o = 6.2 V and maximum swing +3.8 V.
- For β = 150 in this circuit: V_o = 2.5 V and maximum swing is -2.5 V (e.g. clipping of output voltage waveform).
- For β = 200 in this circuit: V_o = 0.4 V and maximum swing is -0.4 V (e.g. clipping of the output voltage waveform).



- So, as a result, use feedback for enhanced stability.

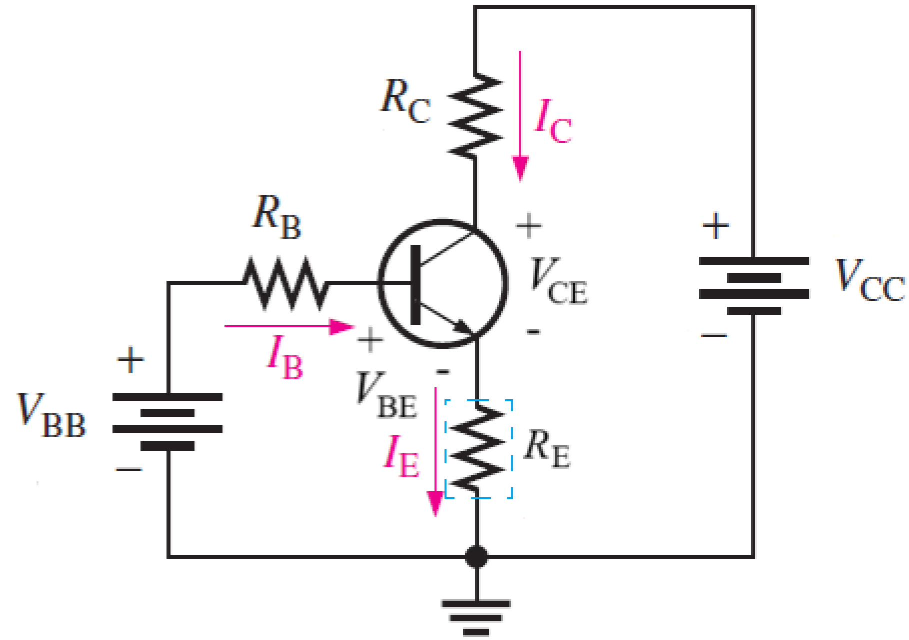
5. Negative Feedback

- It is commonly used in biology, finance, engineering, etc. to stabilise the output of a system against sudden changes.
- It consists of taking the output state of a system and feeding it back to the input.
- The output is then subtracted from the actual input signal, so that the difference signal is actual used for system input.



6. Use of Negative Feedback for Enhanced Stability

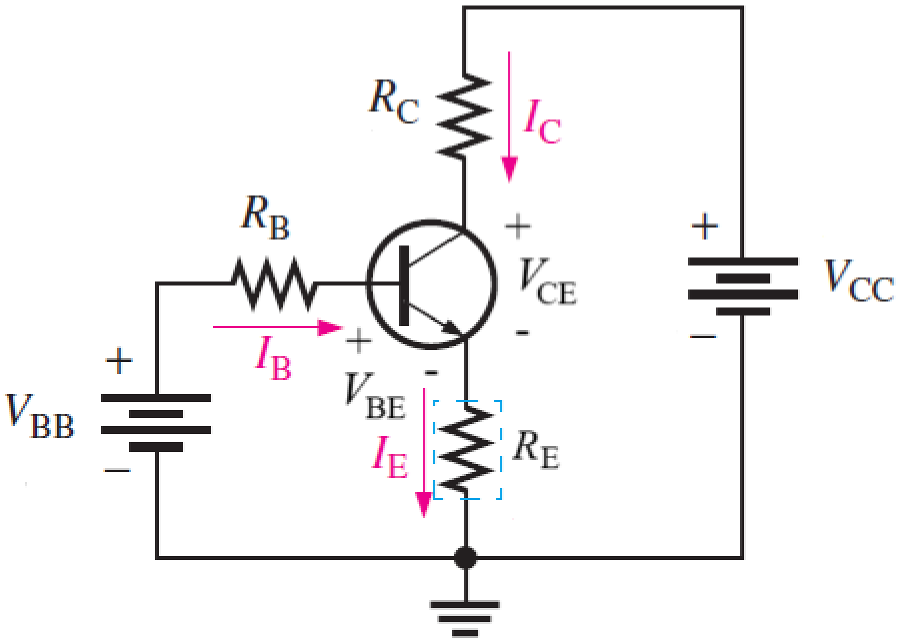
- The use of an emitter resistor can be seen as equivalent to the use of negative feedback.
- The voltage V_{BE} is now not the same as what would be measured between base and ground (V_B).



- The V_{BE} is now determined by the voltage drop that will be over R_E, as that determines the voltage at the emitter.
- This the voltage across R_E is proportional to the emitter current ($\approx I_C$).

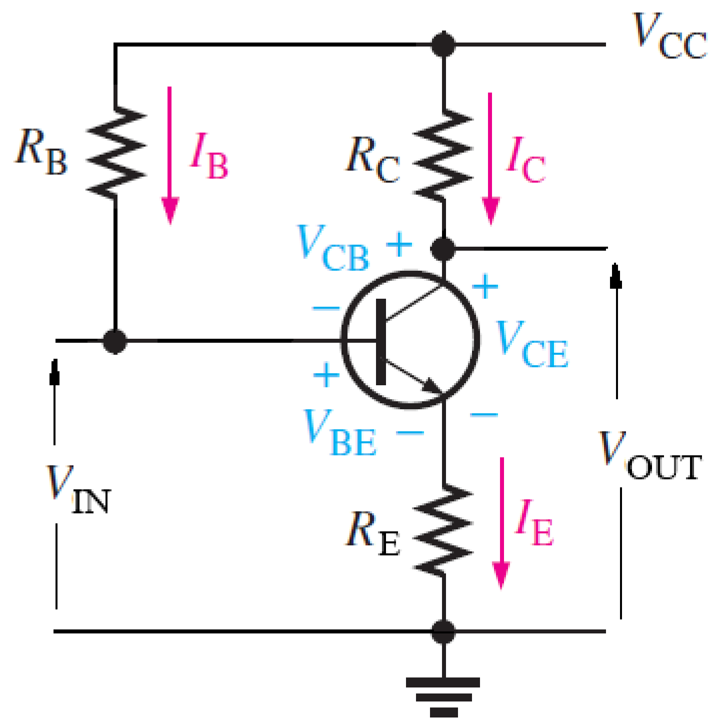
6. Use of Negative Feedback for Enhanced Stability (cont.)

- Assume I_B is constant with V_{BE} = 0.7 V.
- If I_B now increases, I_C should also increase according to $I_C = \beta_{DC} I_B$.
- However, if there is an emitter resistor in place, any increase in I_C (and I_E) will produce an increase in the voltage drop over R_E.
- This will lead to an increase in the voltage at the emitter, so that V_{BE} will decrease, counteracting the original increase in V_{BE}.



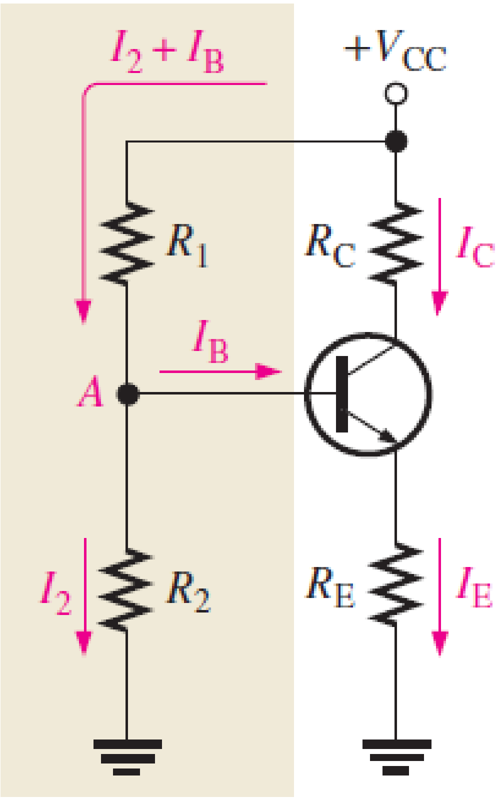
6. Use of Negative Feedback for Enhanced Stability (cont.)

- We thus have *negative feedback with a voltage proportional to the output current being subtracted from the input.*
- The output current is then stabilised by increasing the output resistance, and the voltage amplification is stabilised by increasing the input resistance.
- The voltage gain is then stabilised, making it less susceptible to variations in β.



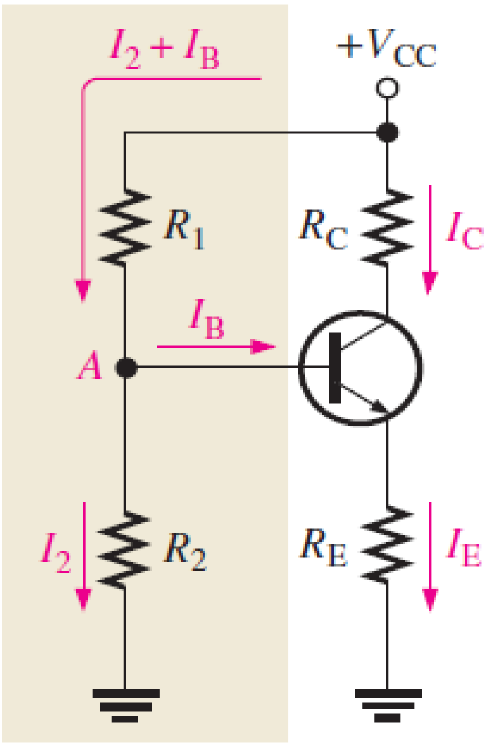
7. Voltage Divider Bias

- Bias from a single voltage source can be achieved by several methods, with the so-called voltage divider bias circuit being the most popular for transistor operation in the linear region.



- This method used a resistor pair R_1 and R_2 to form a voltage divider.
- Two current paths will thus exist: I_B through the BE junction of the transistor and I_2 through R_1.
- Voltage divider is designed so that I_B is much smaller than I_2.
- In this case, we can thus assume that the transistor has little loading on the voltage divider.

7. Voltage Divider Bias (cont..)



- For a circuit in which the transistor does not load the voltage divider, we will have:

$$V_B \approx \left(\frac{R_2}{R_1 + R_2}\right) V_{cc}$$

  Where: V_B which is the voltage at the base.

- The voltage at the emitter should be $V_E = V_B - V_{BE}$, thus the emitter voltage should be approximately 0.7 V lower than the base.

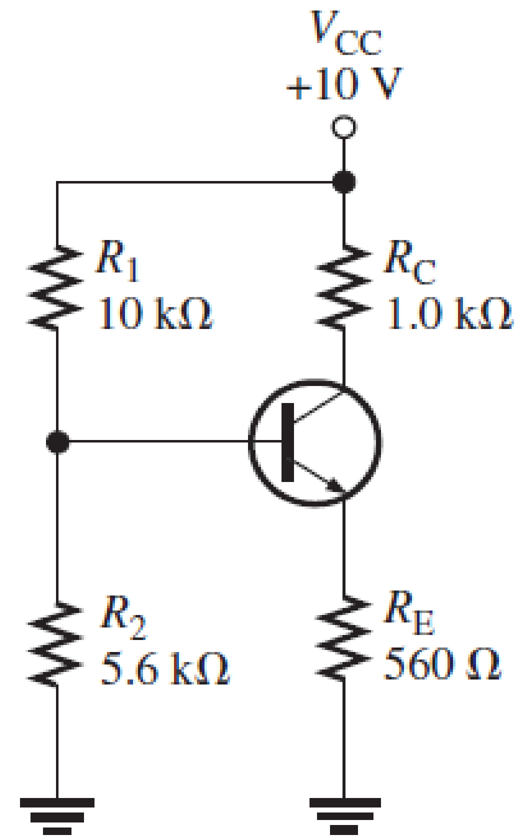
- Also, $I_C \approx I_E = V_E/R_E$ and $V_C = V_{CC} - I_C R_C$
- V_{CE} can then be calculated from the values of V_C and V_E :

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

Example 5 – Potential Divider BJT Biasing

- Determine the operating parameters in the circuit given below. [10 marks]

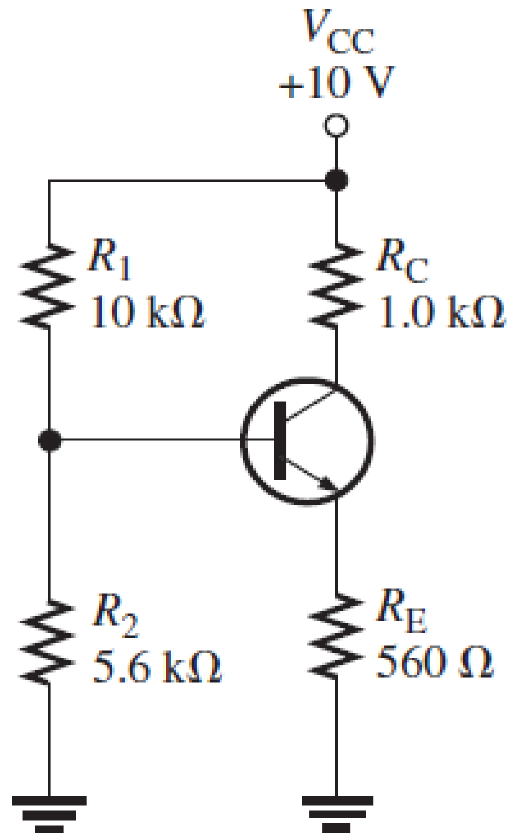
- To perform DC analysis, we assume the following:
  - DC gain, β is large.
  - So, we could neglect I_B, hence $I_C \approx I_E$
  - V_{BE} is constant at ~ 0.7 V



Answer

Calculate the base voltage V_B:

$$V_B \approx V_{CC}\left(\frac{R_2}{R_2 + R_1}\right) = 10\text{ V}\left(\frac{5.6\text{ k}\Omega}{10\text{ k}\Omega + 5.6\text{ k}\Omega}\right) = 3.59\text{ V}$$



Calculate the emitter voltage V_E, we can see that:

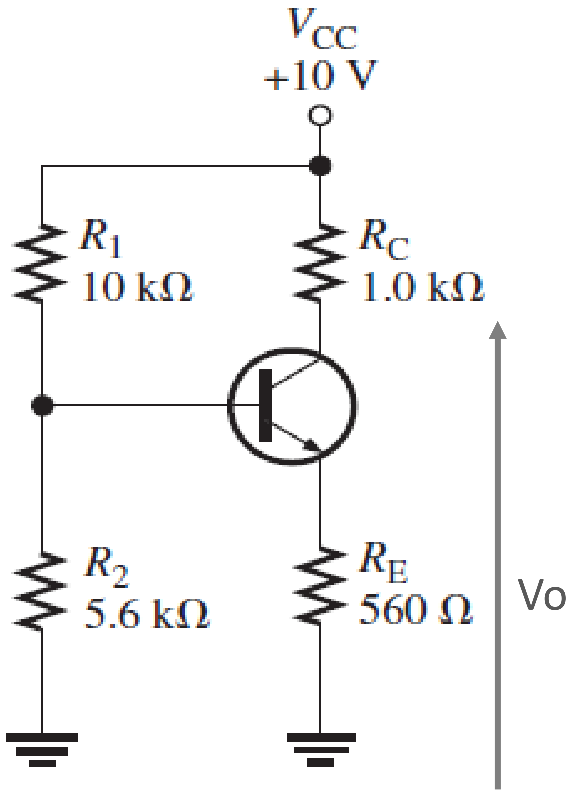
$$V_E = V_B - V_{BE}$$

Assume that $V_E = 0.7\text{ V}$ (= constant), thus:

$$V_E = 3.59\text{ V} - 0.7\text{ V} = 2.89\text{ V}$$

The emitter current I_E:

$$I_E = \frac{V_E}{R_E} = \frac{2.89\ \text{V}}{560\ \Omega} = 5.16\ \text{mA}$$



The collector current I_C:

$$I_C \approx I_E = 5.16\ \text{mA}$$

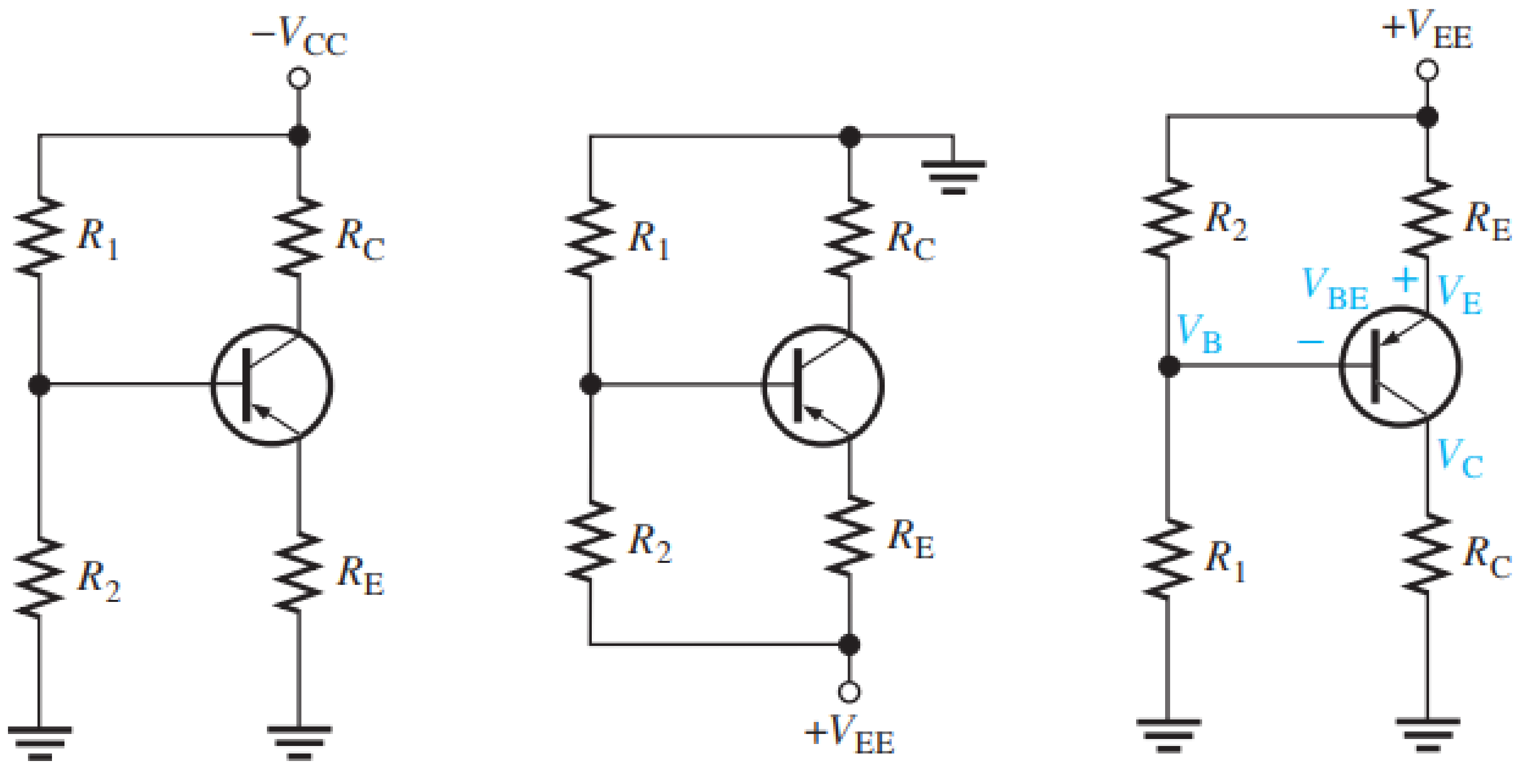
The output voltage V_o:

$$V_o = V_{CC} - I_C R_C = 10\ \text{V} - (5.16\ \text{mA})(1\ \text{k}\Omega) = 4.84\ \text{V}$$

Notice that in this example, we set up the biasing configuration without referring to DC gain of the transistor (β).

8. Transformation of PNP BJT

- For simpler analysis, we could view the PNP BJT circuit as transformed from the NPN BJT circuit to the PNP BJT circuit.
- The PNP is often drawn upside down, like in figure (c), i.e., the supply voltage is at the top and ground at the bottom.



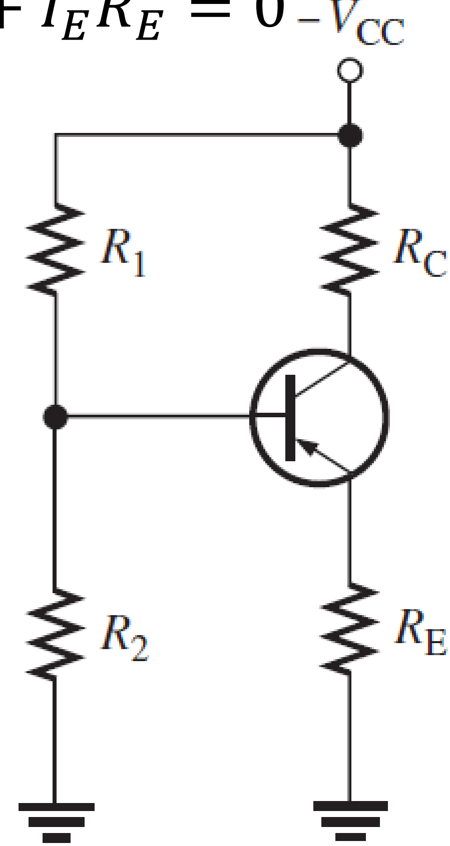
(a) Negative collector supply voltage, V_{CC}

(b) Positive emitter supply voltage, V_{EE}

(c) The circuit in (b) redrawn

- Applying KVL around the base-emitter circuit in figure (a) gives:

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



- By Thevenin's theorem

$$V_{Th} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC}$$

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

- The base current is:

$$I_B = \frac{I_E}{\beta_{DC}}$$

- The equation for I_E is:

$$I_E = \frac{-V_{Th} + V_{BE}}{R_E + \left(\frac{R_{Th}}{\beta_{DC}}\right)}$$

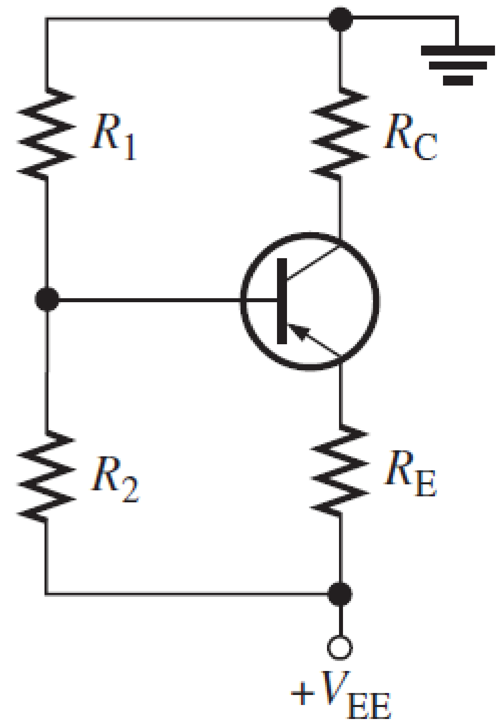
- From figure (b), the analysis is as follows:

$$-V_{Th} + I_B R_{Th} - V_{BE} + I_E R_E - V_{EE} = 0$$

- With

$$V_{Th} = \left(\frac{R_1}{R_1 + R_2}\right) V_{EE}$$

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



- Thus

$$I_B = \frac{I_E}{\beta_{DC}}$$

- The equation for I_E is:

$$I_E = \frac{V_{Th} + V_{BE} - V_{EE}}{R_E + \left(\frac{R_{Th}}{\beta_{DC}}\right)}$$

9. Loading of Voltage Divider Input

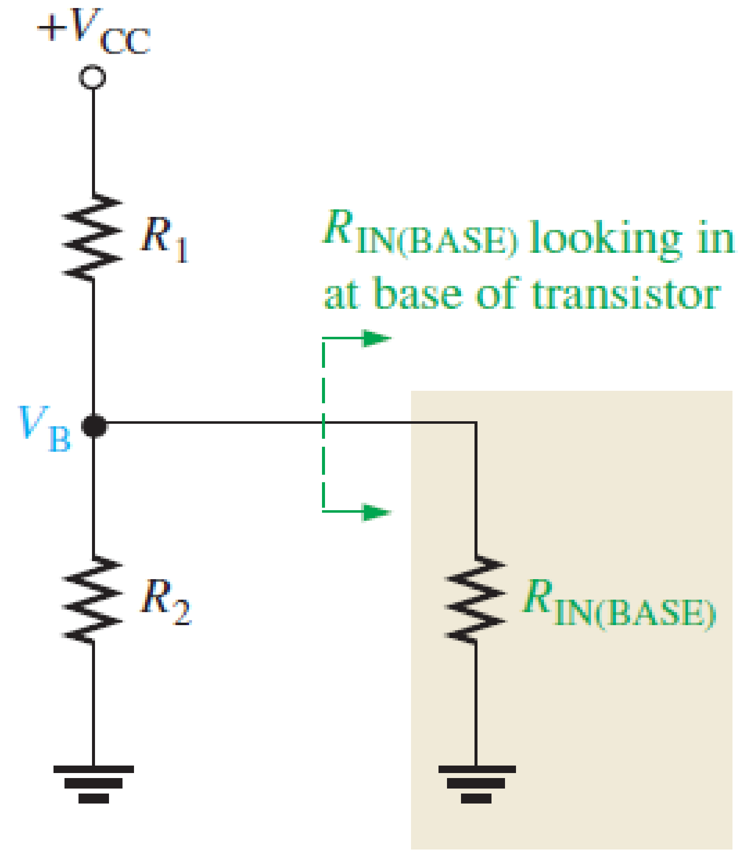
- It is clear the input resistance of the transistor will influence the voltage at the base as it represents a resistance in parallel with R_2.

- In order to ensure that no loading occurs from the transistor (a so-called "stiff" input), we have a rule of thumb:

$$R_{\mathrm{IN(BASE)}} \geq 10R_2$$

- Typical values of $R_{\mathrm{IN(BASE)}}$ is approximately > 100 kΩ

- Thus, limit R_2 to ~ 10 kΩ



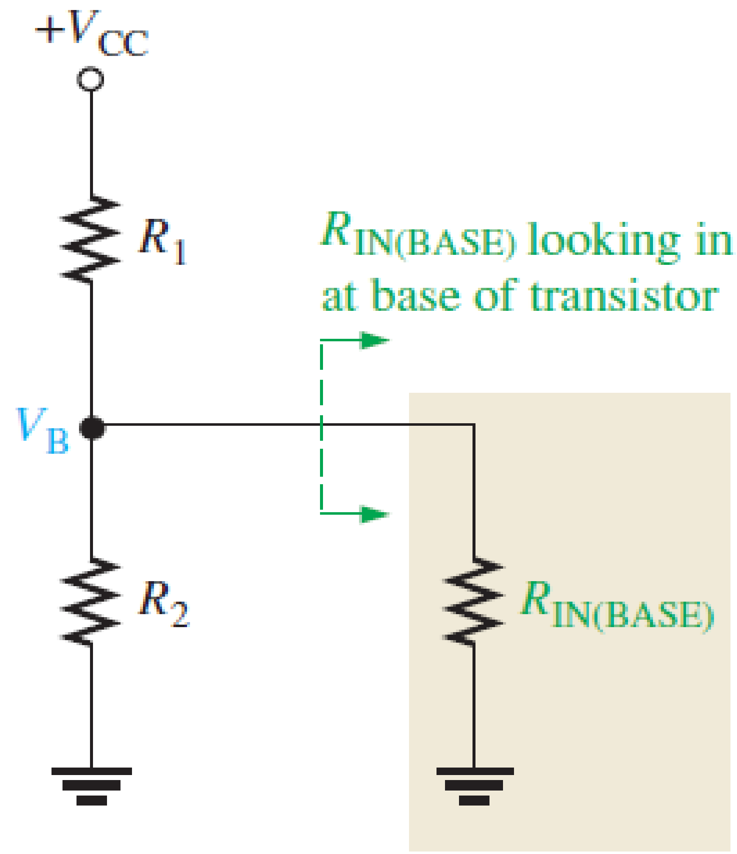
9. Loading of Voltage Divider Input (cont..)

- The input resistance at the base of the BJT amplifier circuit is:

$$R_{IN(\mathrm{BASE})} = \frac{V_B}{I_B} = \frac{V_B}{\left(\frac{I_E}{\beta_{DC}}\right)}$$

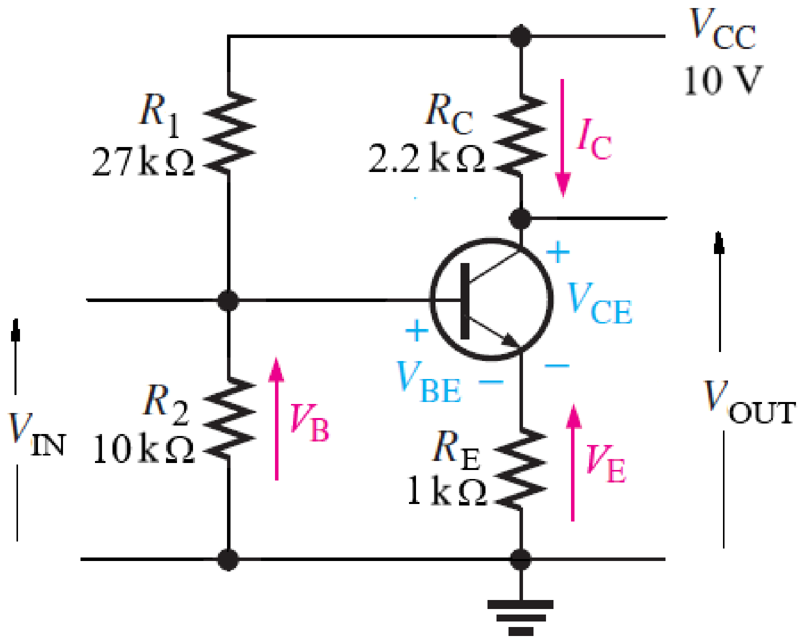
- For the voltage divider biasing circuit, notice that the Thevenin equivalent of these resistors is:

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



- As before, if the value of R_2 is typically designed to be at least 1/10 of the $R_{IN(\mathrm{BASE})}$, this will make current that flows in I_B to be smaller than the current in R_2. So, $I_E \cong I_C$.

Summary: DC analysis of the voltage divider-based CE feedback amplifier configuration at Q-point



To perform DC analysis, we assume:

- DC gain β is large – can neglect I_B so $I_C \approx I_E$
- V_{BE} is constant ~ 0.7 V

1. Calculate the base voltage V_B:

$$V_B \approx V_{CC}\left(\frac{R_2}{R_1 + R_2}\right) = 10\text{ V}\left(\frac{10\text{ k}\Omega}{27\text{ k}\Omega + 10\text{ k}\Omega}\right)$$
$$= 2.7\text{ V}$$

2. Calculate the emitter voltage V_E:
We can see that $V_E = V_B - V_{BE}$ and assume V_{BE} = 0.7 V = constant.
Thus, V_E = 2.7 V – 0.7 V = 2.0 V

3. Calculate the emitter current I_E:

$$I_E = \frac{V_E}{R_E} = \frac{2.0\text{ V}}{1\text{ k}\Omega} = 2\text{ mA}$$

4. Determine the collector current I_C:
$I_C \approx I_E$ = 2 mA

5. Calculate the output voltage V_o:
$V_O = V_{CC} - I_C R_C$
= 10 V – (2 mA)(2.2 kΩ) = 5.6 V

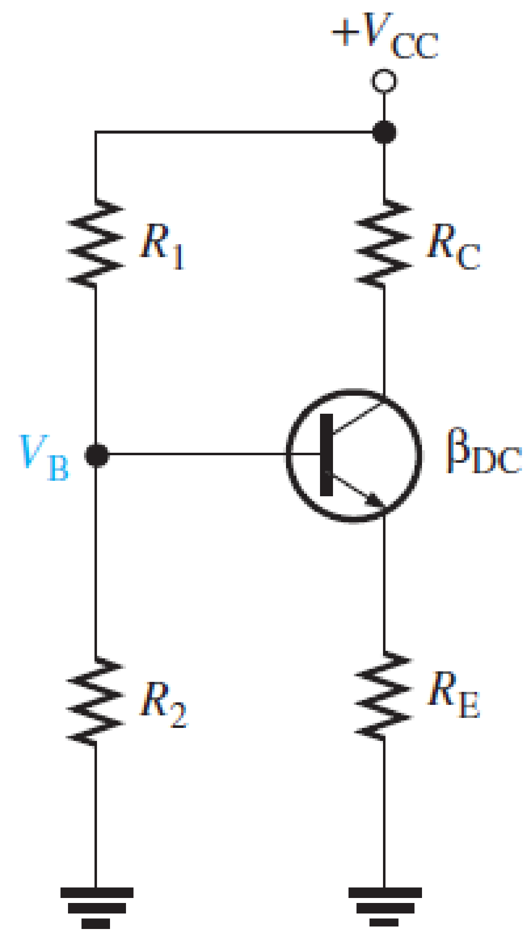
Note: We have calculated the circuit parameters at Q point without knowledge of β! DC operation of circuit now largely independent of β.

10. A Brief Look at Bias Arrangement Circuits for BJT

- Voltage divider bias.
- Base bias.
- Emitter bias.
- Emitter feedback bias.
- Collector feedback bias.

10.1. Voltage Divider Bias

- Use V_{CC} as the single bias source
- Bias by a resistive voltage divider that consists of R_1 and R_2.
- Loading effect of the base current can be ignored.
- Stiff voltage divider as the base voltage is relatively independent of different transistors and temperature fluctuations.
- Base current is much smaller than the current (I_2) through R_2.



- Voltages in the circuit:

$$V_B = V_E + V_{BE} \cong \left(\frac{R_2}{R_1 + R_2}\right) V_{CC}$$

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

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

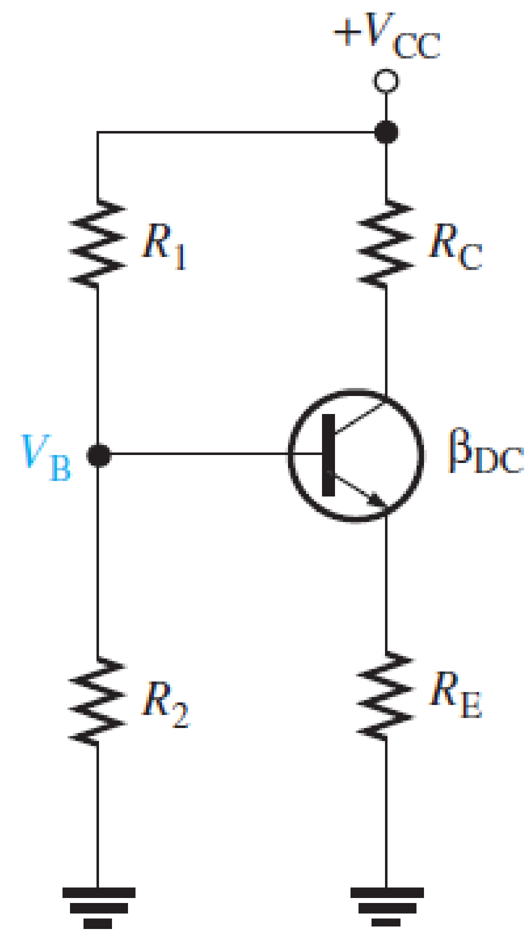
- Once V_C and V_E are known,

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

- Currents in the circuit:

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

$$I_B = \frac{V_B}{R_{IN(\mathrm{BASE})}}$$



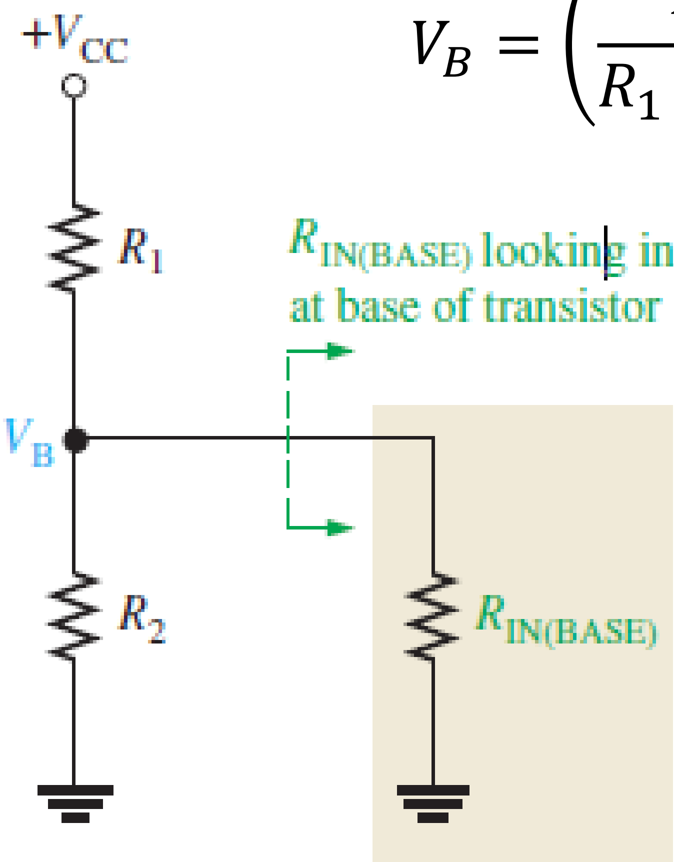
For a voltage divider with load:

- Stiff ($R_{IN(\text{BASE})} \geq 10R_2$):

$$V_B = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC}$$

- Not stiff ($R_{IN(\text{BASE})} < 10R_2$):

$$V_B = \left(\frac{R_2 \parallel R_{IN(\text{BASE})}}{R_1 + R_2 \parallel R_{IN(\text{BASE})}}\right) V_{CC}$$



- That is,

$$R_{IN(\text{BASE})} = \frac{V_B}{I_B} = \frac{V_B}{\left(\frac{I_E}{\beta_{DC}}\right)}$$

$$R_{IN(\text{BASE})} = \frac{\beta_{DC} V_B}{I_E}$$

- Thus

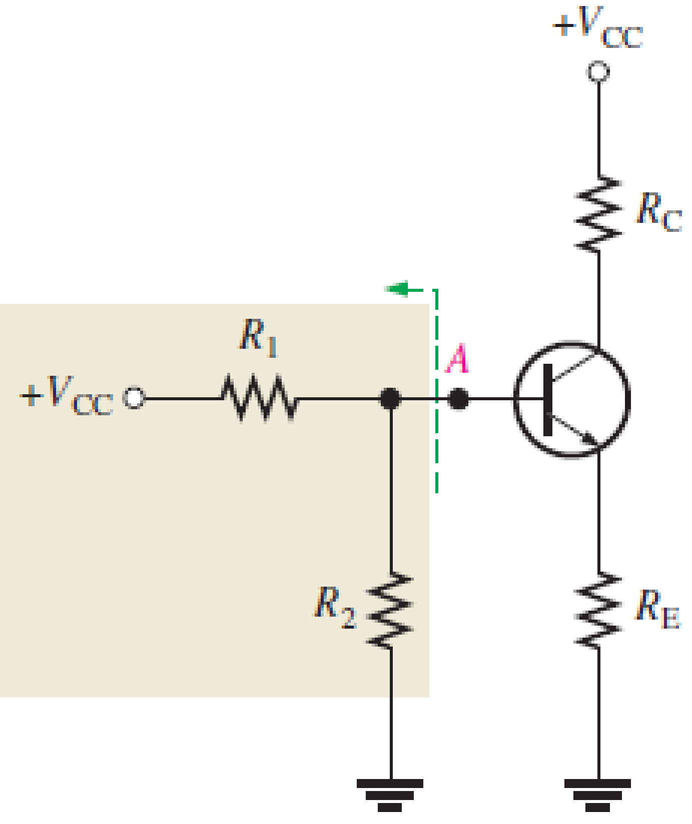
$$I_B = \frac{V_B}{R_{IN(\text{BASE})}}$$

- Referring to the given Thevenin equivalent circuit at the base.
- Applying Thevenin equivalent at A, with V_{CC} is shorted to ground, the voltage at A with respect to the ground is:

$$V_{Th} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC}$$

- And the resistance is:

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



- Applying KVL around the equivalent base-emitter loop gives:

$$V_{Th} - V_{R_{Th}} - V_{BE} - V_{R_E} = 0$$

- Substituting, using Ohm's law, and solving for V_{Th}:

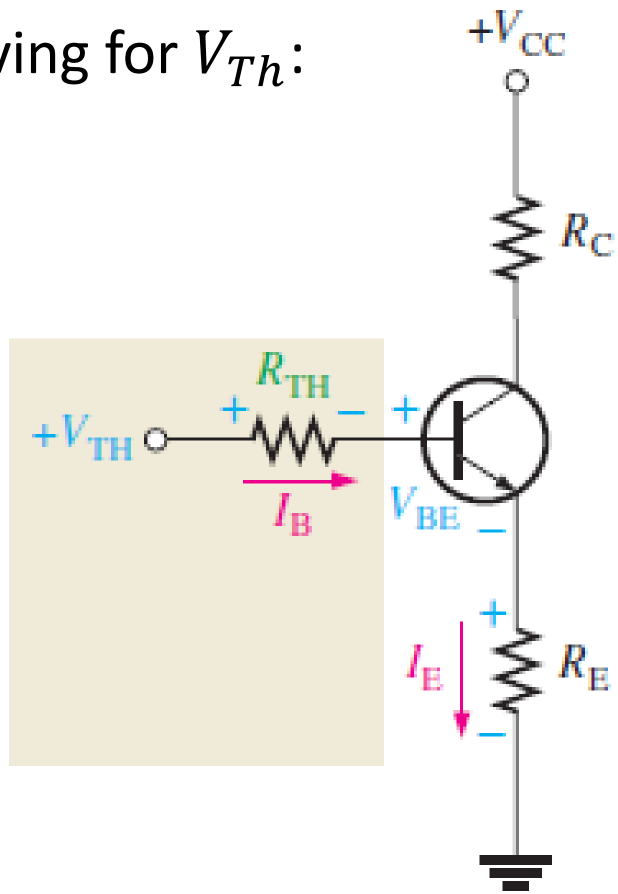
$$V_{Th} = I_B R_{Th} + V_{BE} + I_E R_E$$

- Substituting I_E/β_{DC} for I_B

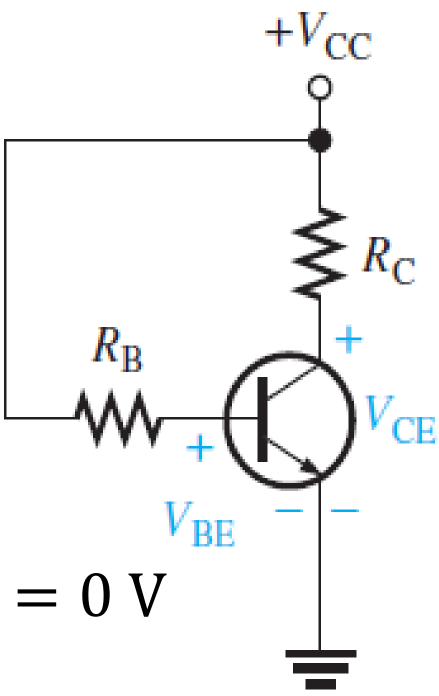
$$V_{Th} = I_E(R_E + R_{Th}/\beta_{DC}) + V_{BE}$$

- Then, solving for I_E,

$$I_E = \frac{V_{Th} - V_{BE}}{R_E + R_{Th}/\beta_{DC}}$$



10.2. Base Bias



- Poor bias for the linear region as the operating point is β dependant.
- Used for switching circuits.
- Voltages in the circuit:

$$V_B = V_{BE} \qquad V_C = V_{CC} - I_C R_C \qquad V_E = 0 \text{ V}$$

- Currents in the circuit:

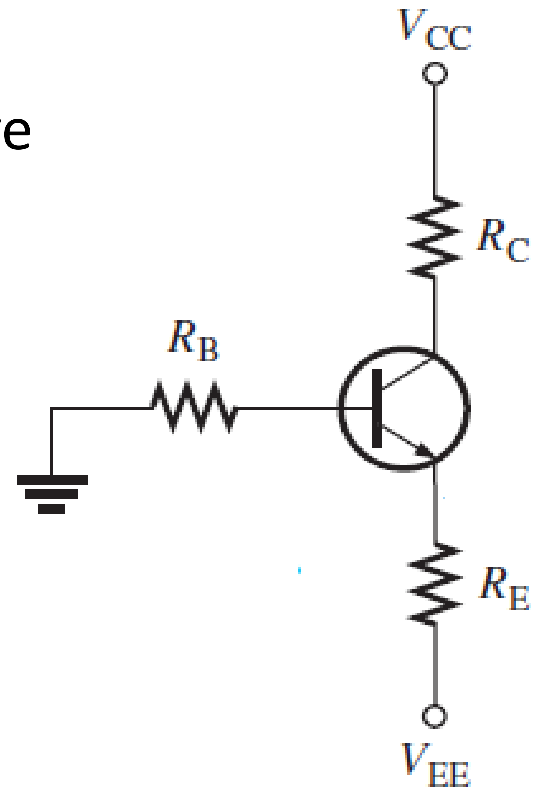
$$I_E \cong I_C \qquad I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

- Knowing $I_C = \beta_{DC} I_B$, thus:

$$I_C = \beta_{DC}\left(\frac{V_{CC} - V_{BE}}{R_B}\right)$$

10.3. Emitter Bias

- Provide good stability to changes in both β and temperature.
- Use both a positive and a negative supply voltage.



- Voltages in the circuit:

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

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

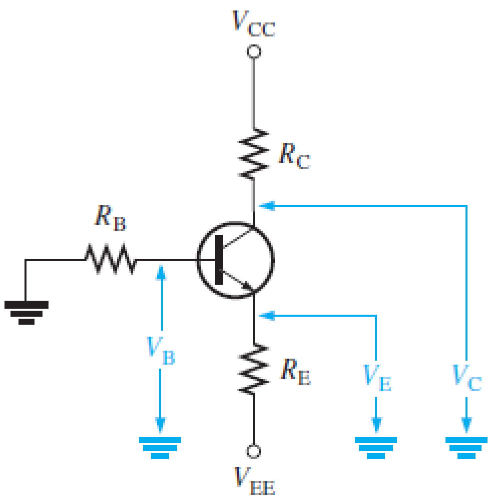
$$V_E = V_{EE} + I_E R_E$$

- Currents in the circuit:

$$I_C \cong I_E \qquad I_B = \frac{V_B}{R_B}$$

- KVL around base-emitter circuit

$$V_{EE} + V_{RB} + V_{BE} + V_{RE} = 0$$



- Substituting, using Ohm's law,

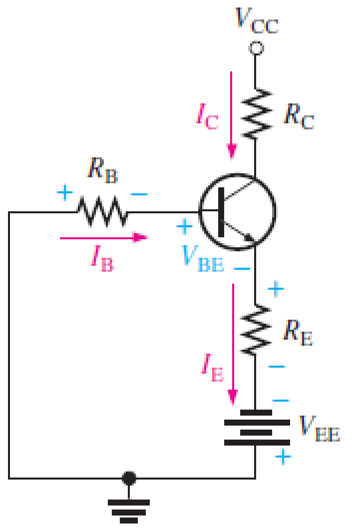
$$V_{EE} + I_B R_B + V_{BE} + I_E R_E = 0$$

- Substituting for $I_B \cong I_E/\beta_{DC}$ and transposing V_{EE},

$$\left(\frac{I_E}{\beta_{DC}}\right) R_B + I_E R_E + V_{BE} = -V_{EE}$$

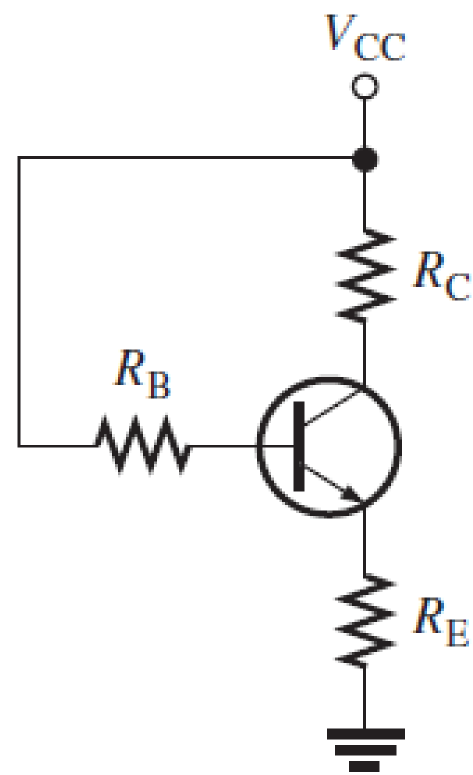
- Currents in the circuit:

$$I_E = \frac{-V_{EE} - V_{BE}}{R_E + \left(\frac{R_B}{\beta_{DC}}\right)}$$



10.4. Emitter Feedback Bias

- Negative feedback at the emitter, which negates any attempted change in collector current with an opposing change in base voltage



- Better for linear circuits than base bias, it is still dependent on DC gain
- Not as predictable as voltage-divider bias.
- Voltages in the circuit:

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

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

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

- Currents in the circuit:

$$I_C \cong I_E$$

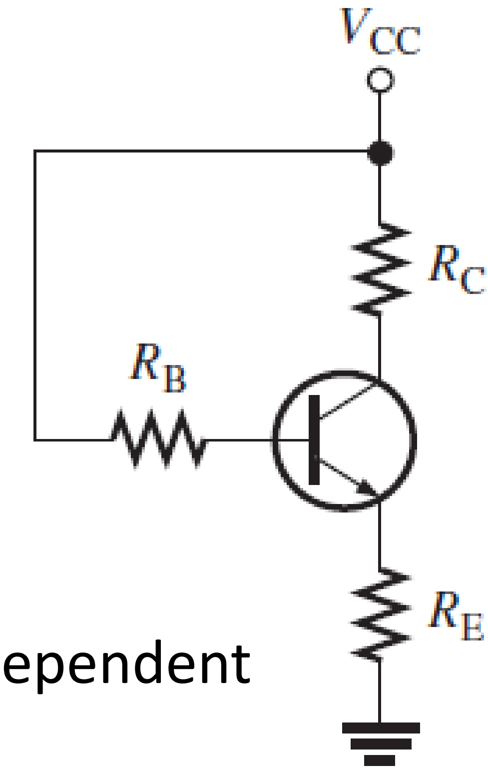
$$I_B = \frac{V_{CC} - V_B}{R_B}$$

- Write KVL around the base:

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

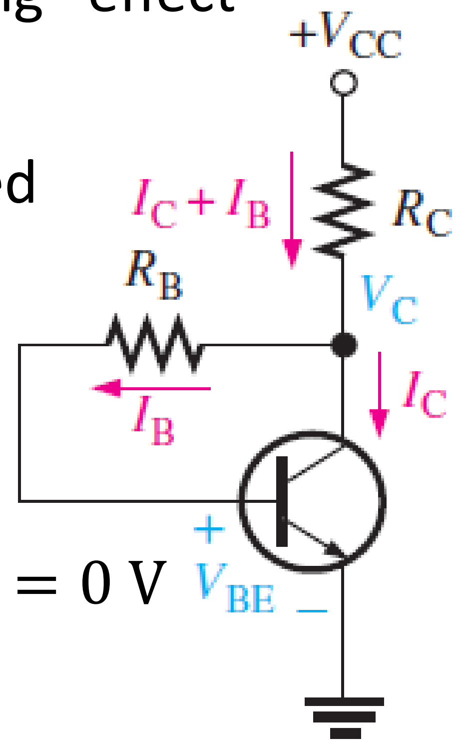
- Substituting I_E/β_{DC} for I_B, thus I_E is still dependent on β_{DC}.

$$I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta_{DC}}$$



10.5. Collector Feedback Bias

- Provide the bias for the base-emitter junction.
- The negative feedback creates an "offsetting" effect that tends to keep the Q-point stable.
- Eliminate the dependency even if the stated conditions are met.
- Maintain a relatively stable Q-point



- Voltages in the circuit:

$$V_B = V_{BE} \qquad V_C = V_{CC} - I_C R_C \qquad V_E = 0\text{ V}$$

- Currents in the circuit:

$$I_E \cong I_C \qquad I_B = \frac{V_C - V_{BE}}{R_B}$$

- Assume $I_C \gg I_B$, the collector voltage is:

$$V_C \cong V_{CC} - I_C R_C$$

- Also

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

- Substituting for V_C in:

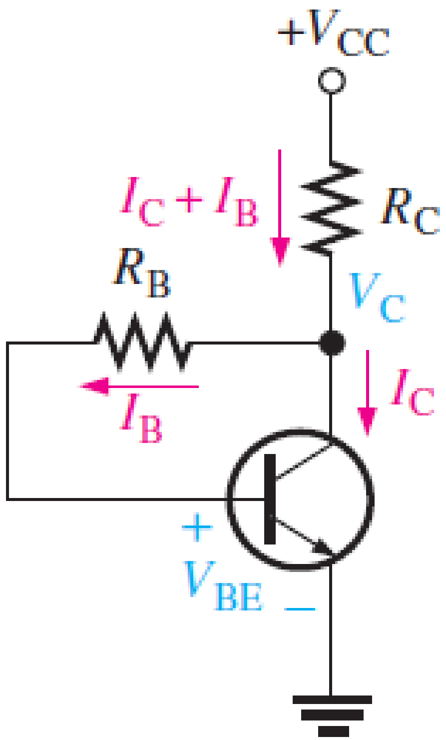
$$I_B = (V_C - V_{BE})/R_B$$

- Thus:

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

- Rearrange the equation above,

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



- Solve for I_C,

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

- Thus

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

- Since emitter is ground $V_{CE} = V_C$,

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