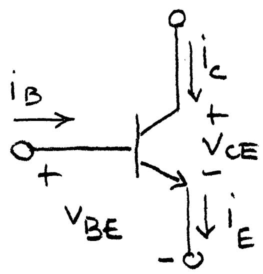
4-3 The Transistor

A transistor is a three terminal device whose i-v characteristics can change as a result of an input

We consider only one type of transistor here — the BJT or bipolar junction transistor



$i_E = i_B + i_c$

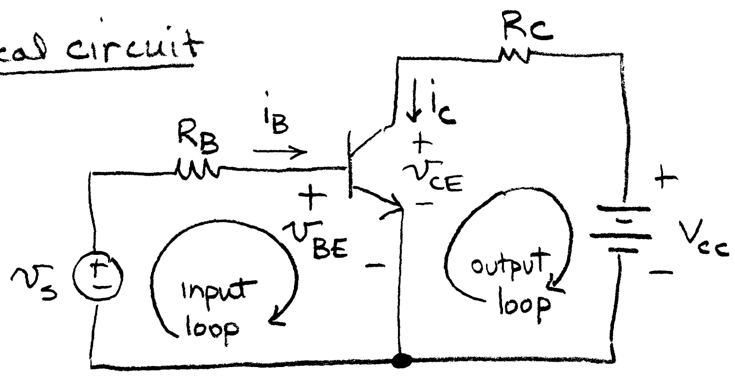
The transistor operates in three modes:

active: $i_c = \beta i_B$ $\quad v_{BE} = V_\gamma$

cutoff (OFF): $i_B = 0$ $\quad i_c = 0$

saturation (ON) $v_{CE} = 0$ $\quad v_{BE} = V_\gamma$

Typical circuit



What are the operating bounds? $\quad 0 \leq i_c \leq i_{sc}$

$$v_{oc} \geq v_{CE} \geq 0$$

1. This means that the current i_c can never be larger than $i_{sc} = \frac{V_{cc}}{R_c}$, i.e. the CE junction is a short.
2. This also means that v_{CE} can never be larger than the open circuit voltage V_{cc} when $i_c = 0$.

Let's assume that the transistor is in the active mode where $v_{BE} = V_\gamma$ and $i_C = \beta i_B$.

KVL around the input loop:

$$-v_S + i_B R_B + v_{BE} = 0$$

($v_{BE} \uparrow V_\gamma$)

Solving for i_B gives $\quad i_B = \dfrac{v_S - V_\gamma}{R_B}$

At the output $\quad i_C = \beta i_B = \beta\left(\dfrac{v_S - V_\gamma}{R_B}\right)$

If $v_S > V_\gamma$ the device is in the active mode

If $v_S < V_\gamma$ the device is cutoff since i_C cannot become negative.

If we stay in the active region we can apply KVL to the output loop

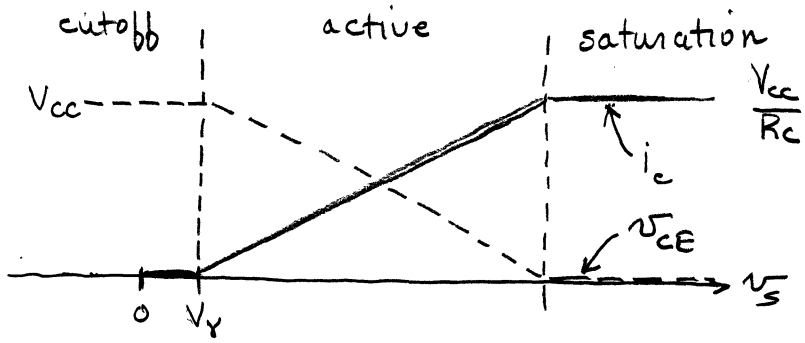
$$-v_{CE} - i_C R_C + V_{CC} = 0$$

Solving for v_{CE}: $\quad v_{CE} = V_{CC} - i_C R_C$

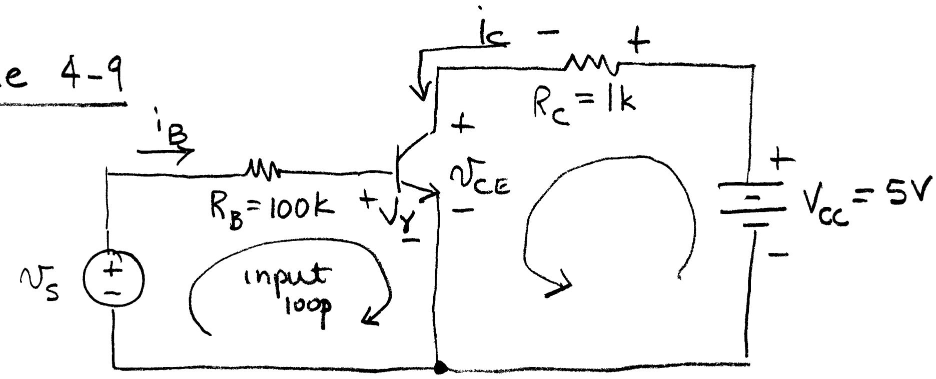
as the result for the active region.

As long as $i_C < \dfrac{V_{CC}}{R_C}$ $\;v_{CE}$ will be >0

When $i_C \geq \dfrac{V_{CC}}{R_C}$ the device is at its short circuit limit and the transistor is saturated.



Example 4-9



Given that $\beta = 100$ and $V_\gamma = 0.7$ volts find i_c and v_{CE} for $v_s = 2$ Volts and $v_s = 6$ volts.

Assume transistor is active. Then KVL at input and $i_c = \beta i_B$ give

$$-v_s + i_B R_B + V_\gamma = 0$$

$$i_B = \frac{v_s - V_\gamma}{R_B}$$

$$i_c = \beta i_B = \beta\left(\frac{v_s - V_\gamma}{R_B}\right)$$

Substituting values gives ($v_s = 2V$)

$$i_c = 100\left(\frac{2 - 0.7}{100 \times 10^3}\right) = 1.3\,mA$$

This is greater than zero but is it more than available short circuit current?

$$i_{sc} = \frac{V_{cc}}{R_c} = \frac{5}{1 \times 10^3} = 5\,mA \quad \Rightarrow \text{ transistor is active}$$

Since transistor is active do KVL at output loop

$$-v_{CE} - i_c R_c + V_{cc} = 0$$

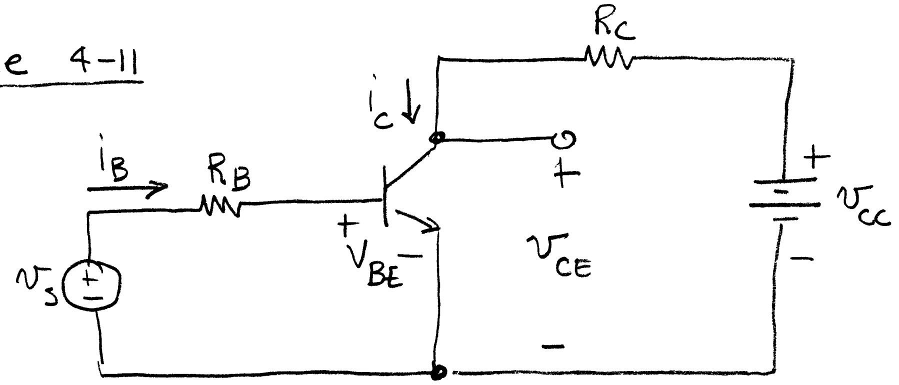
$$v_{CE} = V_{cc} - i_c R_c = 5 - (1.3 \times 10^{-3})(1 \times 10^{3}) = 3.7 \text{ volts.}$$

For $v_s = 6$ volts.

$$i_c = 100\left(\frac{6 - 0.7}{100 \times 10^3}\right) = 5.3\,mA$$

This is MORE than the available short circuit current and the transistor i_c stops at its saturation limits of $i_c = 5mA$, $v_{CE} = 0$ volts.

Example 4-11



$R_C = 1k\Omega$
$V_{CC} = 5$ Volts

Given that $\beta = 100$ and $V_\gamma = 0.7$ volts find R_B such that

1. $v_{CE} = 5$ volts when $v_s = 0$ volts
2. $v_{CE} = 0$ volts when $v_s = 5$ volts.

For condition 1, the transistor must be CUTOFF. This occurs whenever $v_s < V_\gamma$ or $v_s < 0.7$ volts. and is independent of R_B.

For condition 2, the transistor must be saturated.

At input $\quad -v_s + i_B R_B + v_{BE} = 0$

$$i_B = \frac{v_s - v_{BE}}{R_B} = \frac{5 - 0.7}{R_B} = \frac{4.3}{R_B}$$

At output $\quad i_C = \beta i_B = 100\left(\frac{4.3}{R_B}\right)$

For saturation $\quad i_C \geq i_{SC} = \frac{V_{CC}}{R_C} = \frac{5}{1\times10^3} = 5\text{mA}.$

$$\therefore \quad 100\left(\frac{4.3}{R_B}\right) \geq 5\times10^{-3}$$

Solving gives $\quad R_B \leq \frac{100\,(4.3)}{5\times10^{-3}} = 86\,k\Omega$