ECE 205 “Electrical and Electronics Circuits”

Spring 2024 – LECTURE 25

MWF – 12:00pm

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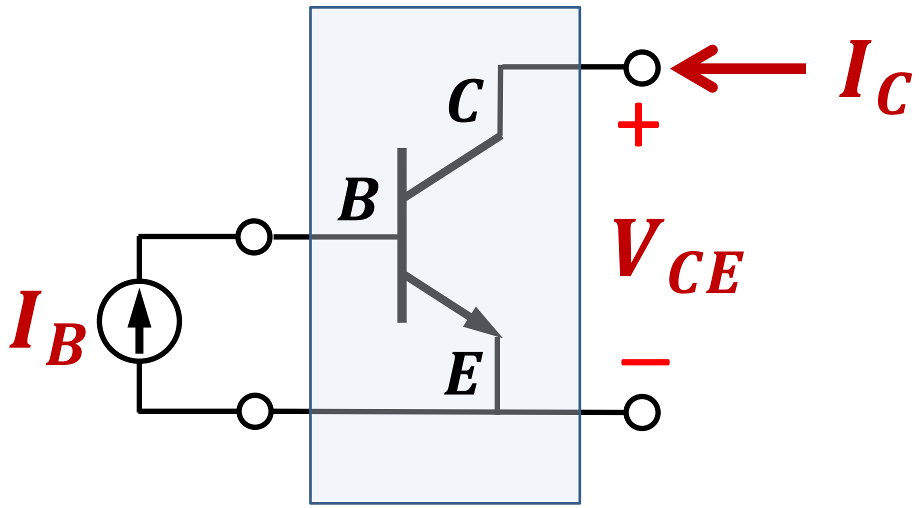
2062 ECE Building

Lecture 25 – Summary

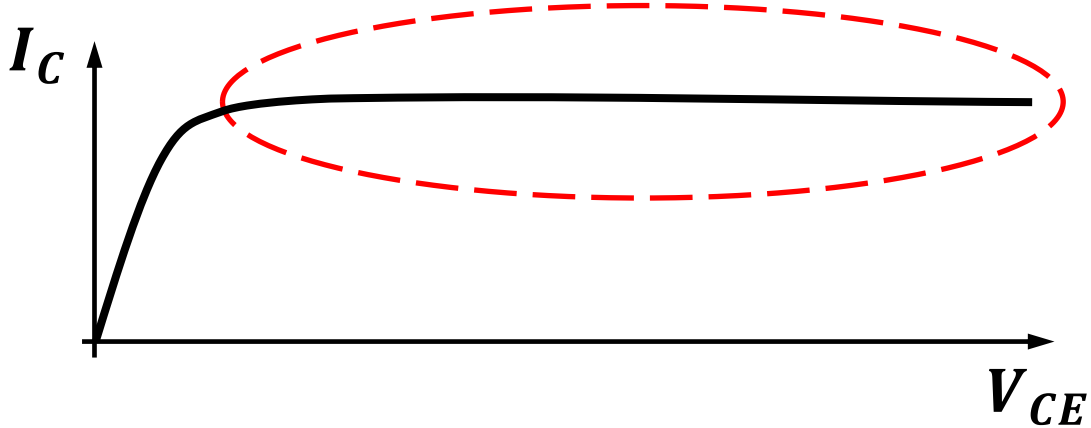
Learning Objectives

1. Solution approaches for BJT circuits

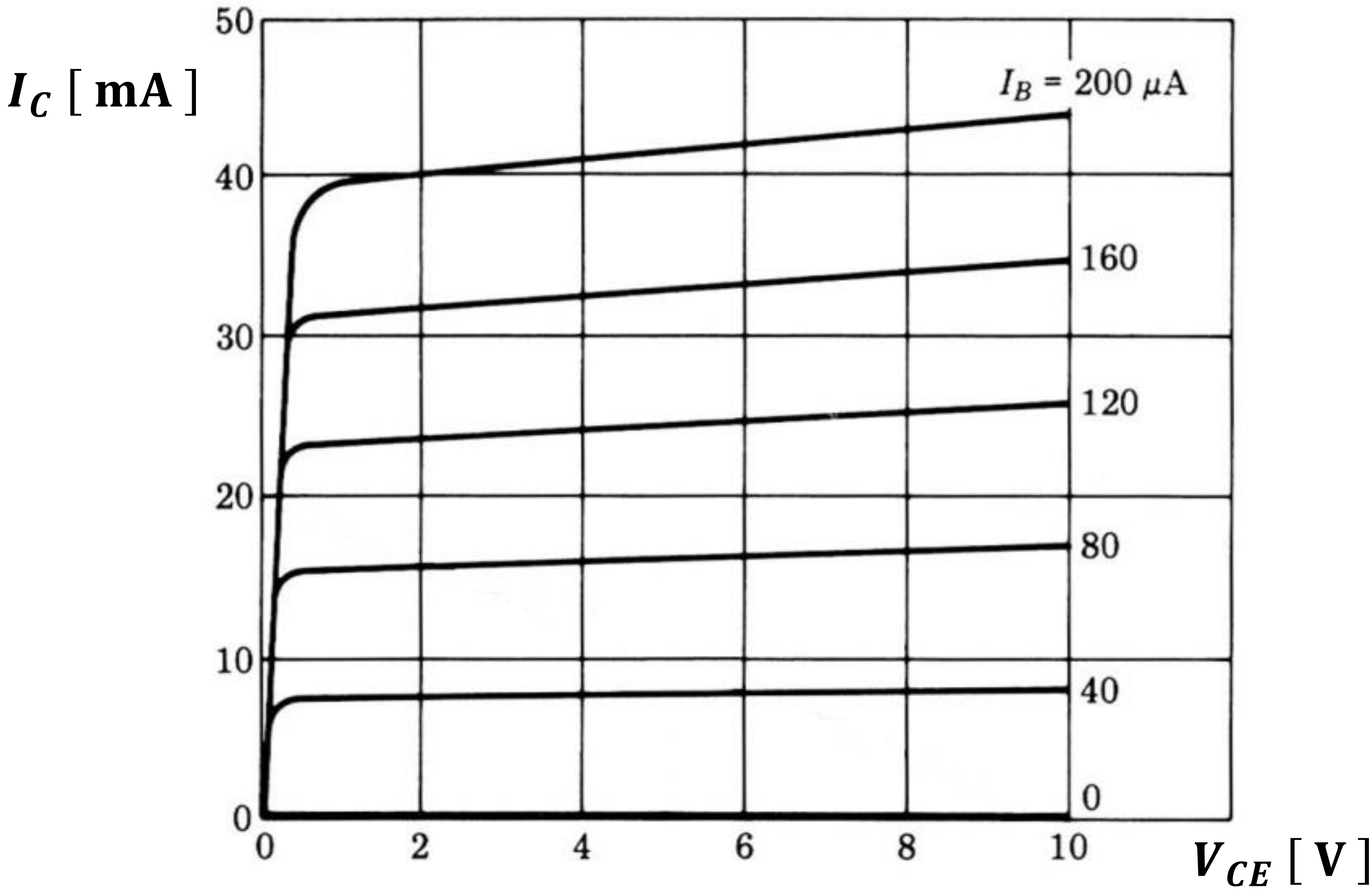
Common Emitter is the most important configuration



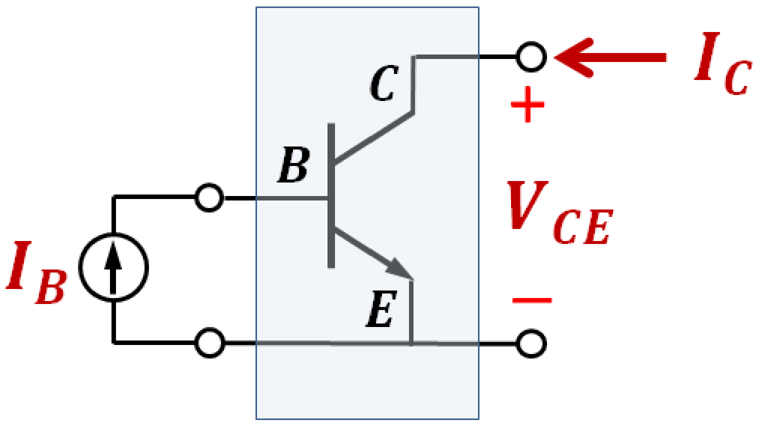
For a given I_B(input) we can measure the resulting I_C and V_{CE} (output)

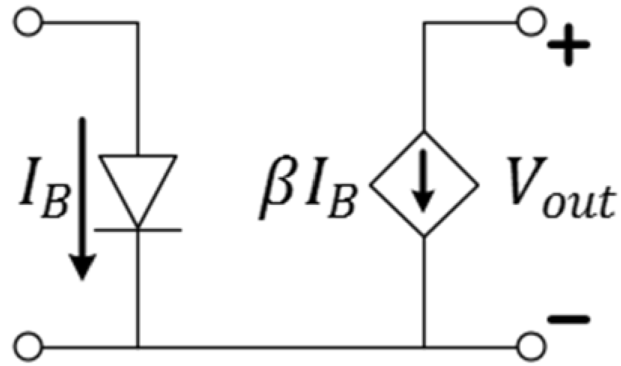


Example of complete I-V curves



BJT common emitter n-p-n circuit model



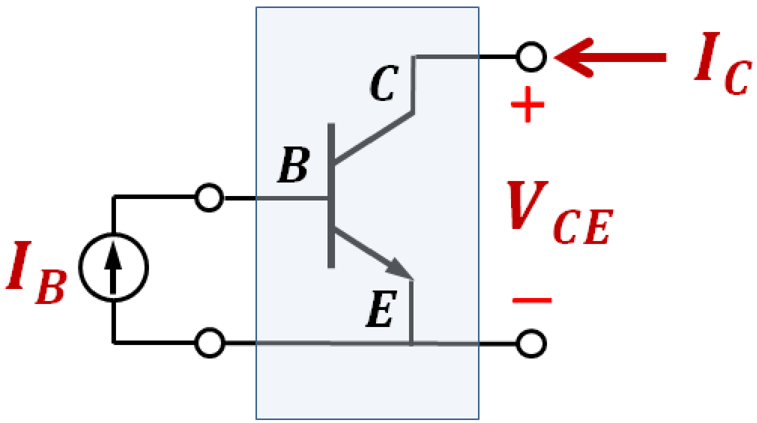


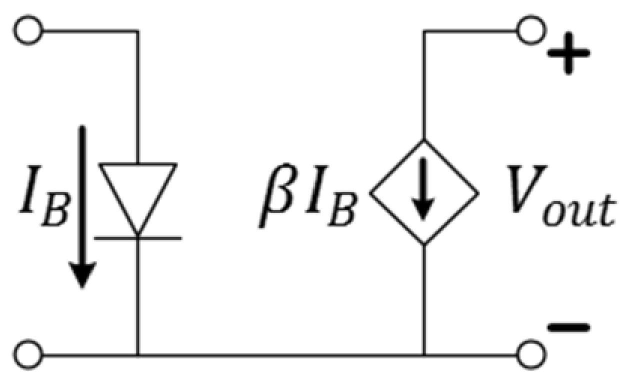
This equivalent circuit model describes the BJT when it behaves as an amplifier (Forward-Active mode)

β is the common emitter current gain factor (typically, between 5 and 100)

Another name used by manufacturers is: h_{FE}

BJT common emitter n-p-n circuit model





NOTE: The transistor has a small DC base current in input and a much larger DC collector current in output.

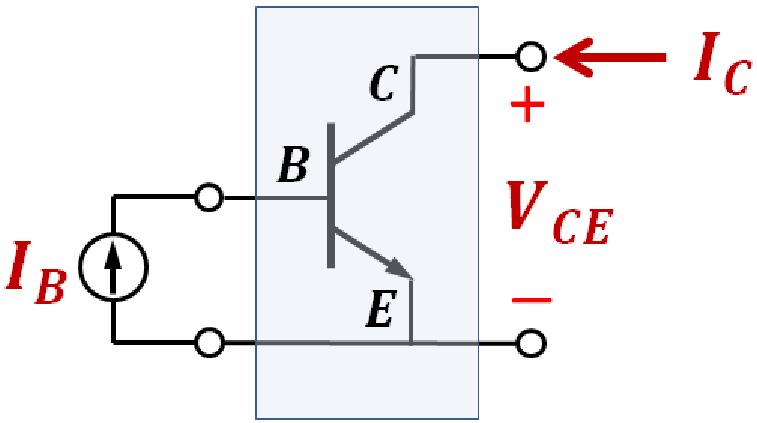
However, it DOES NOT produce power. The power is provided by the DC generators which bias the device.

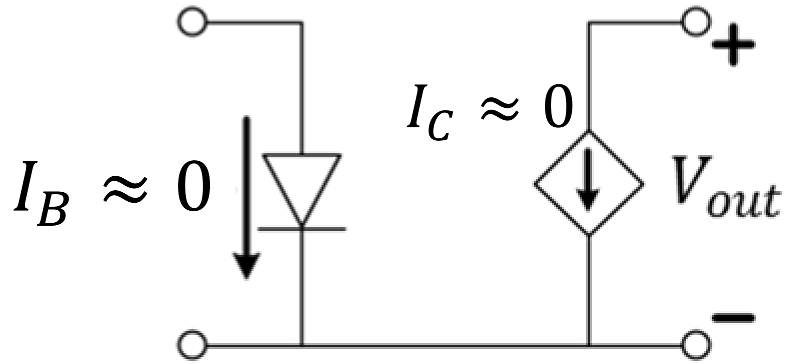
An <u>AC input signal</u> can be amplified and a much larger AC signal is obtained at the output (at the cost of DC power).

There are 3 regimes of operation

1) CUT-OFF MODE
2) FORWARD-ACTIVE MODE
3) SATURATION MODE

States of BJT operation: 1) Cut-off mode



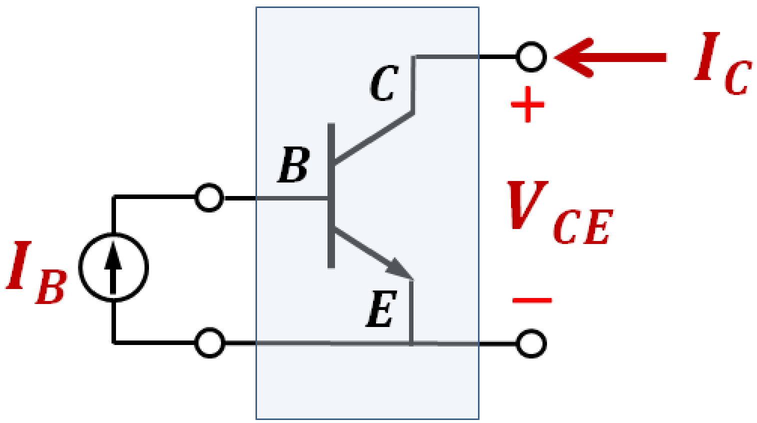


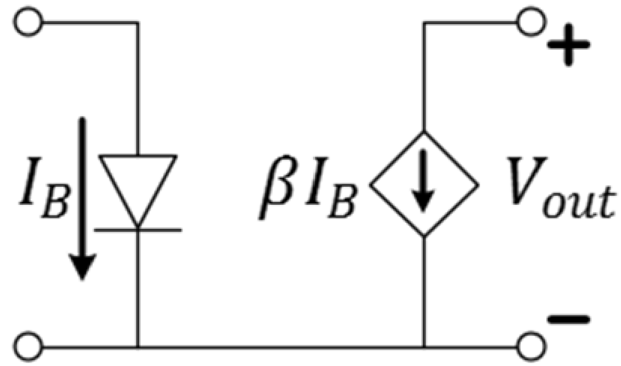
OFF: $V_{BE} < V_{BE}(\mathrm{ON})$

The base-emitter junction is like a *p-n* diode junction. If it is biased below threshold, the base current is negligible and there is no collector current in output. The output voltage V_{CE} is maximum (equal to the DC voltage applied to the collector).

For silicon transistors, typically $V_{BE}(\mathrm{ON}) \approx 0.6\mathrm{V}$ to $0.7\mathrm{V}$

States of BJT operation: 2) Forward Active mode





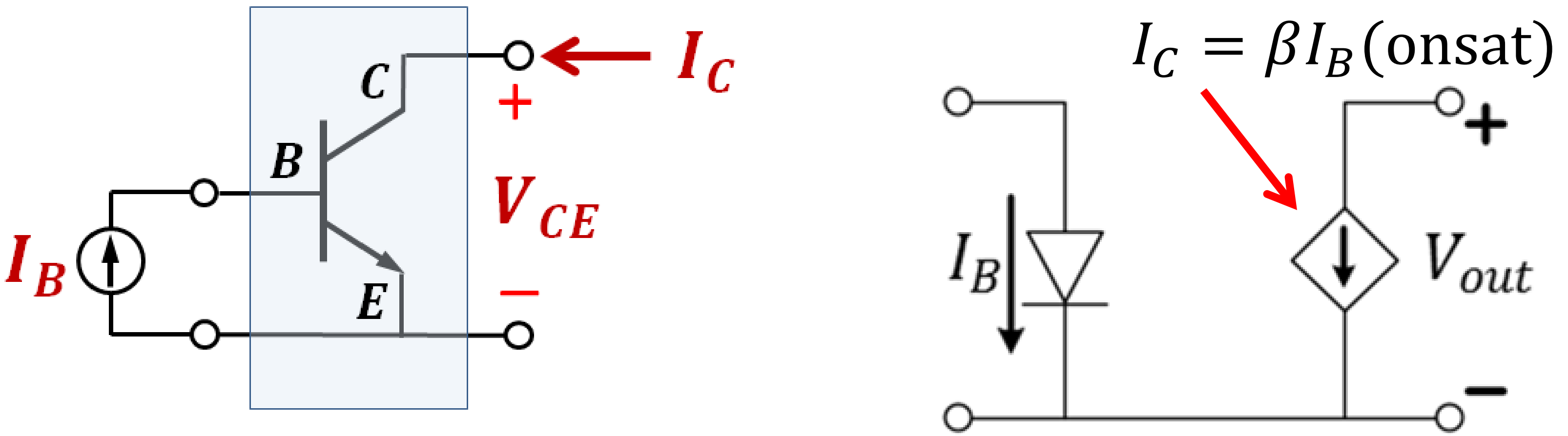
ON: $V_{BE} = V_{BE}(\text{ON})$ & $V_{CE} > V_{CE}(\text{sat})$

The base-emitter junction conducts, with input current I_B. The output voltage V_{CE} is less than the DC bias voltage on the collector.

As long as V_{CE} is larger than a minimum "saturation" value $V_{CE}(\text{sat})$, the transistor is in forward active mode, with collector current βI_B proportional to the base current.

For silicon transistors, typically $V_{CE}(\text{sat}) \approx 0.2\text{V}$

States of BJT operation: 3) Saturation mode



ON: $V_{BE} = V_{BE}(\text{ON})$ & $V_{CE} = V_{CE}(\text{sat})$

When the base current I_B reaches a sufficiently high value, the voltage V_{CE} reaches the minimum saturation value $V_{CE}(\text{sat})$. The collector current saturates and can no longer follow the base current. This starts happening at the "onset of saturation" $I_B = I_B(\text{onsat})$, corresponding to the condition under which $V_{CE} = V_{CE}(\text{sat})$ is first reached, when base current is increased.

$$I_C = I_C(\text{sat}) = \text{constant} \quad \textbf{for} \quad I_B \geq I_B(\text{onsat})$$

THIS IS VALID WHEN THE EMITTER TERMINAL IS GROUNDED.

IMPORTANT FOR PROBLEM SOLUTION

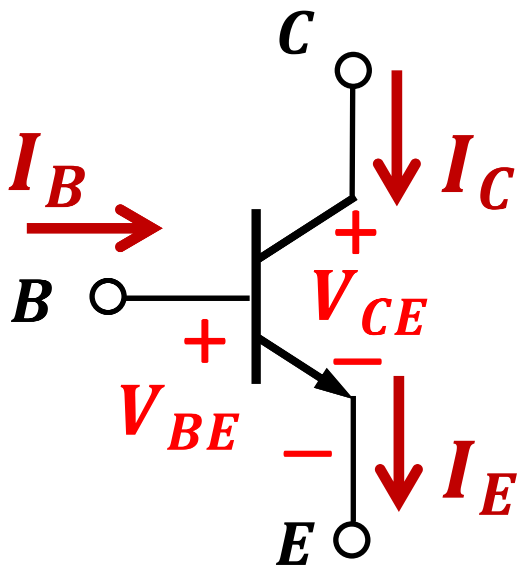
At the onset of saturation point, the Forward-Active and the Saturation conditions coincide.

So, as the base current increases, this is the last point at which the amplification relation

$$I_C = \beta I_B = \beta I_B(\text{onsat})$$

is still formally valid, after which amplification control is lost by the BJT and the collector current stops growing.

When the transistor is ON



$$V_{BE} = V_{BE}(\text{ON}) \approx 0.6 \text{ to } 0.7\text{V}$$

$$I_B > 0 \qquad I_C > 0 \qquad I_E > 0$$

$$I_E = I_B + I_C$$

$I_C = \beta\, I_B$ **Forward active mode**

$I_C = I_C(\text{sat})$ **Saturation mode** $[V_{CE} = V_{CE}(\text{sat}) \approx 0.2\text{V}]$

Typically

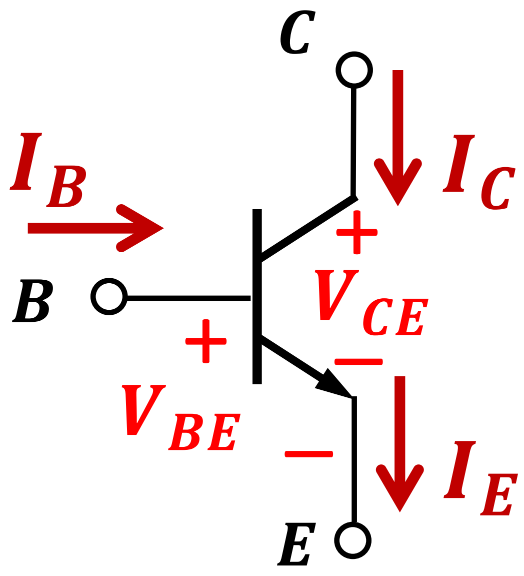
When the transistor is ON

In Forward Active mode

$$I_C = \beta\, I_B$$

KCL $$I_E = I_B + I_C$$

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



$$I_E = \frac{I_C}{\beta} + I_C = \frac{\beta + 1}{\beta} I_C = \frac{1}{\alpha} I_C$$

$$\alpha = \frac{\beta}{\beta + 1} = \frac{I_C}{I_E}$$

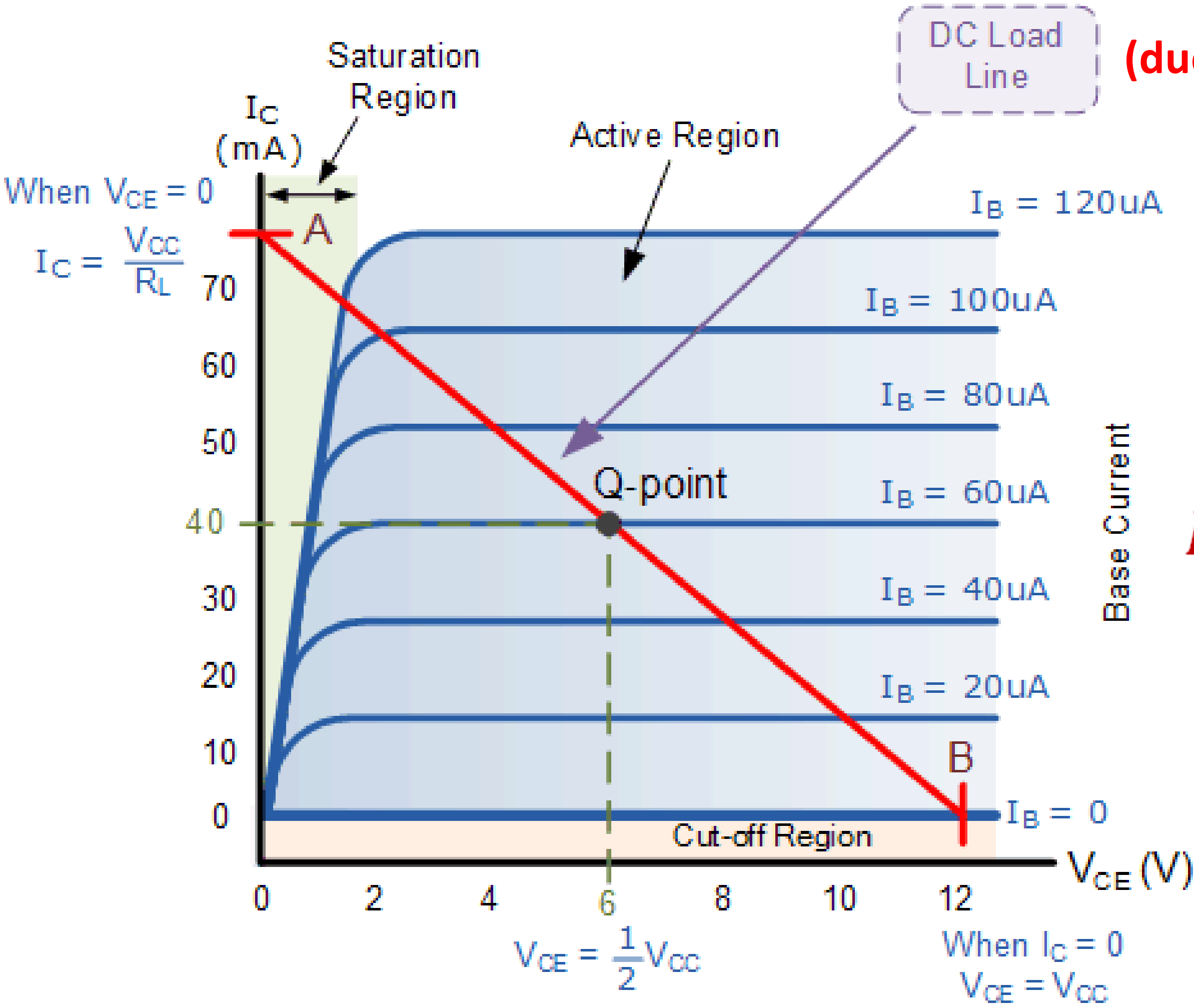
$$I_C = \alpha I_E$$

$$\beta = \frac{\alpha}{1 - \alpha}$$

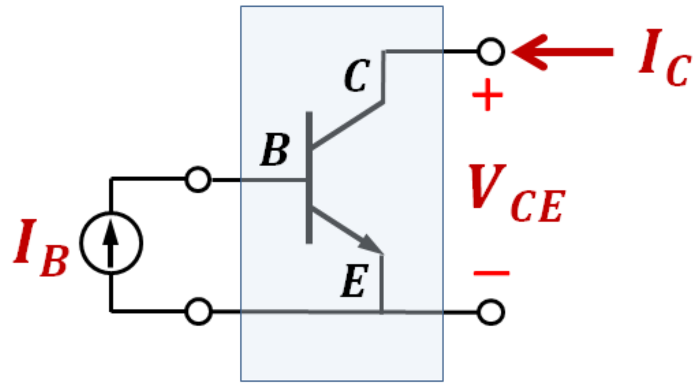
Current transfer ratio

Quantifies the % of electrons (holes in *p-n-p* BJT) originating from the emitter which are able to reach the collector

Common Emitter I-V curves Example



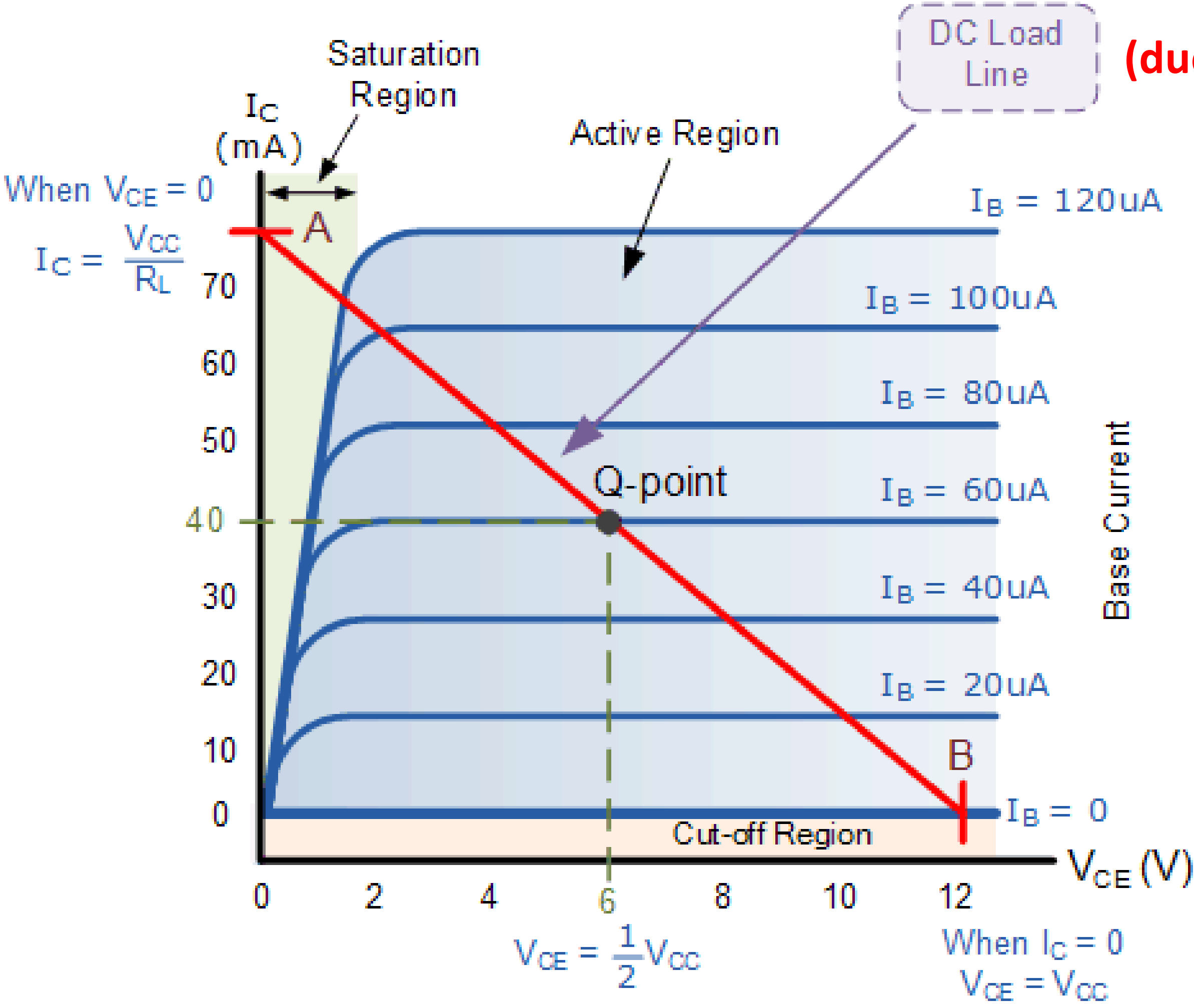
(due to the collector circuit)



V_{CC} = Collector bias voltage

One curve for each value of I_B

BJT as amplifier or as logic switch



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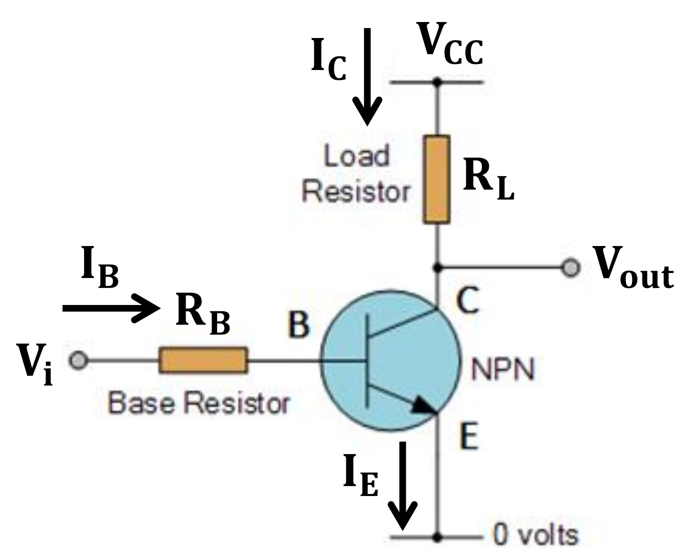
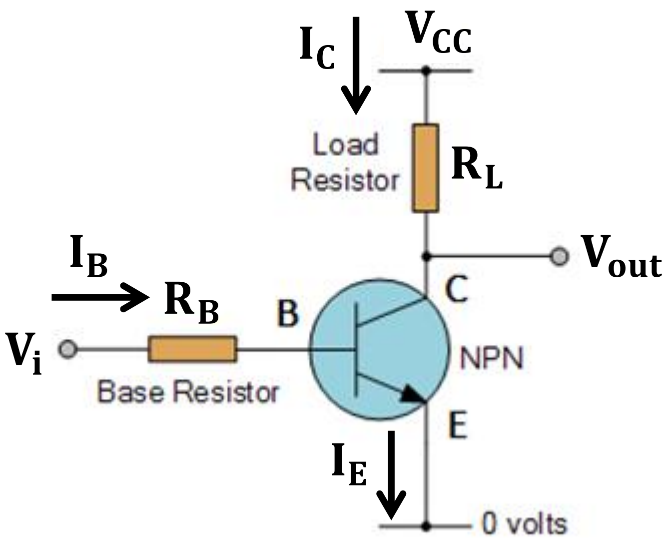


V_{CC} = Collector bias voltage

Q bias point – Amplifier

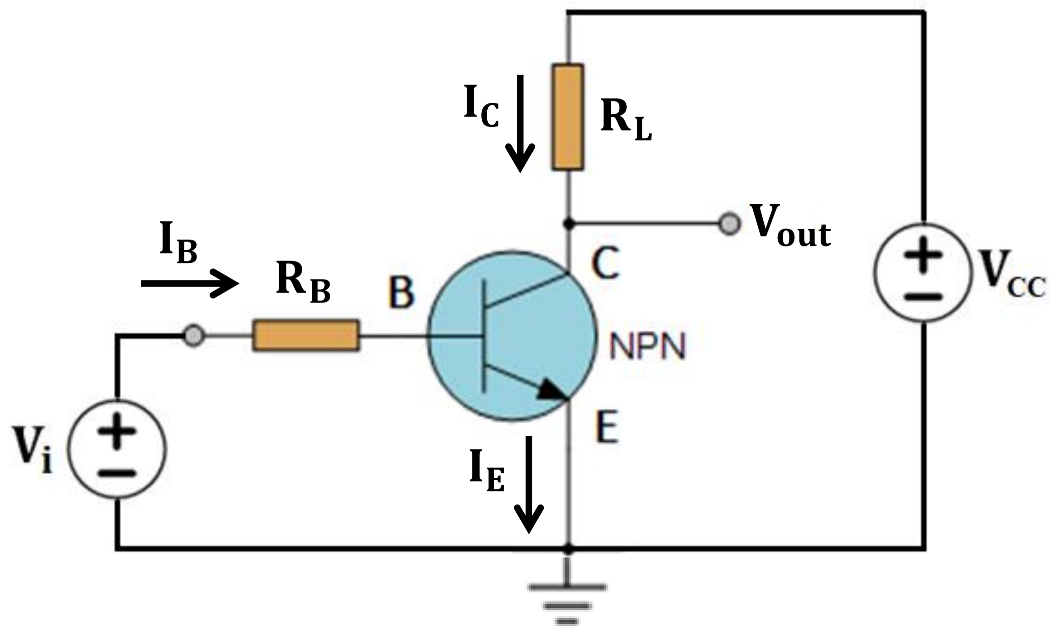
A and B points – Logic Inverter

BJT Circuit Representations



Common BJT circuit representation in technical schematics

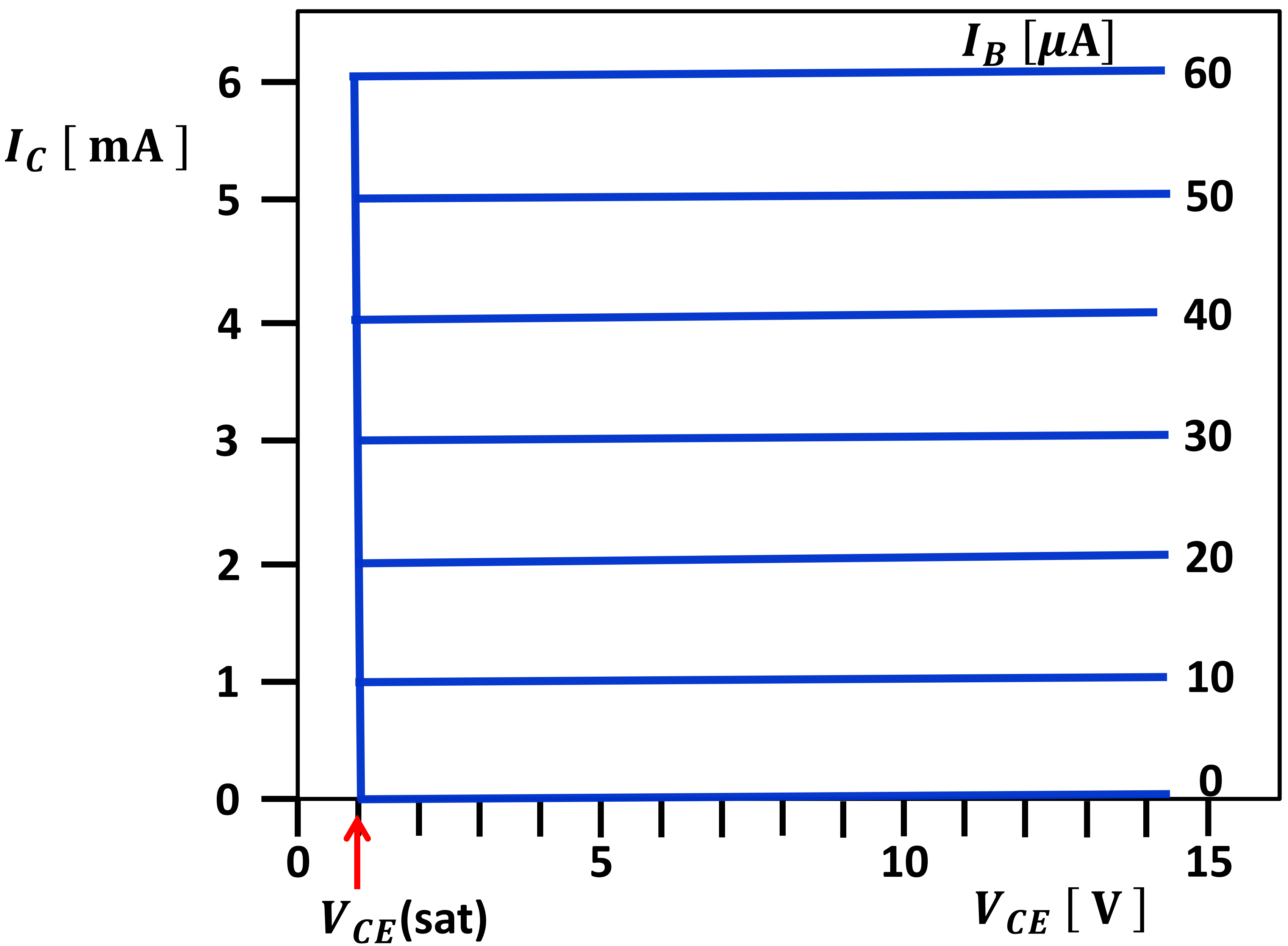
Equivalent to this circuit



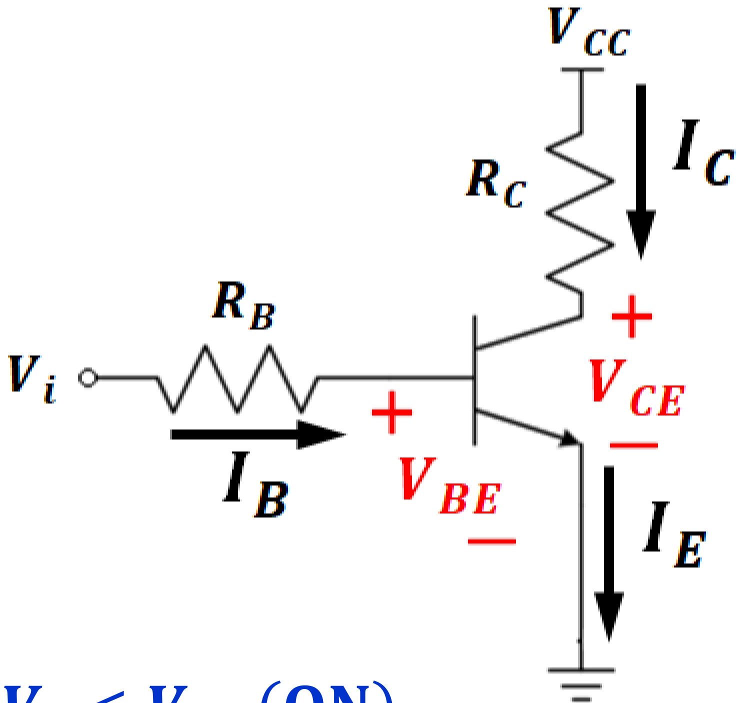
Conventional $V_{CE}(\text{sat})$

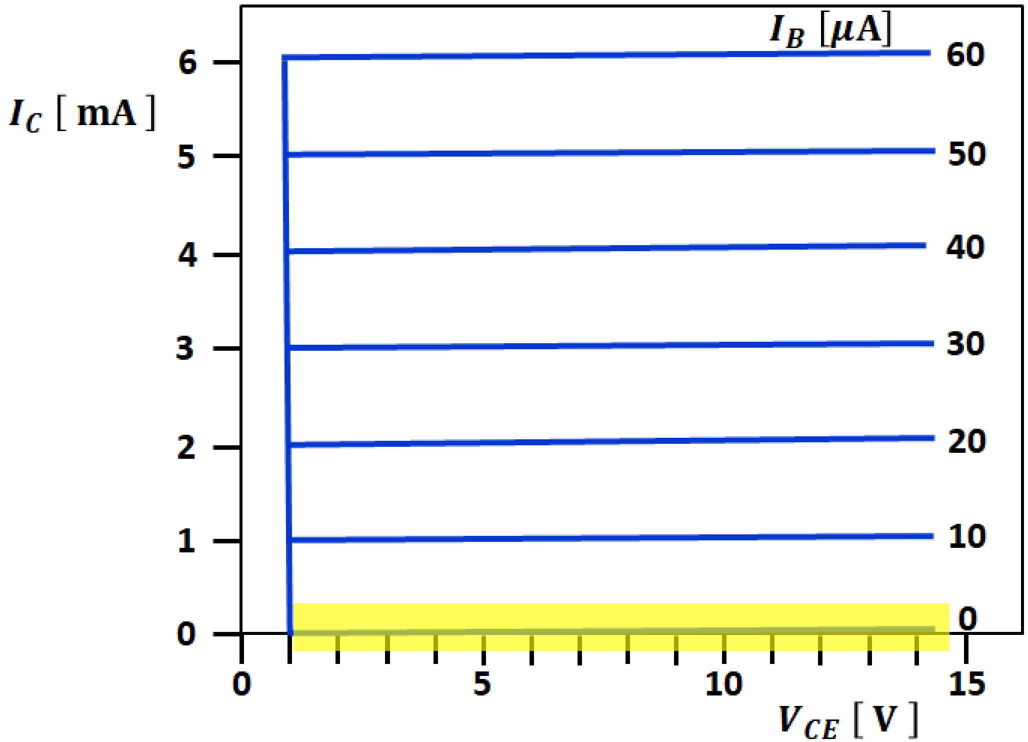
- **Manufacturers provide device specs, with an "average" measured value for $V_{CE}(\text{sat})$.**
- **Simple models assume that for any base current, this specific average $V_{CE}(\text{sat})$ value is established in all practical application.**
- **Of course, this is a model approximation, but usually a very acceptable one.**

Simplified I-V curves corresponding to the approximate BJT model



Emitter connected to ground (Common emitter configuration)





$V_i < V_{BE}(\text{ON})$

$V_{CE} = V_{CC}$

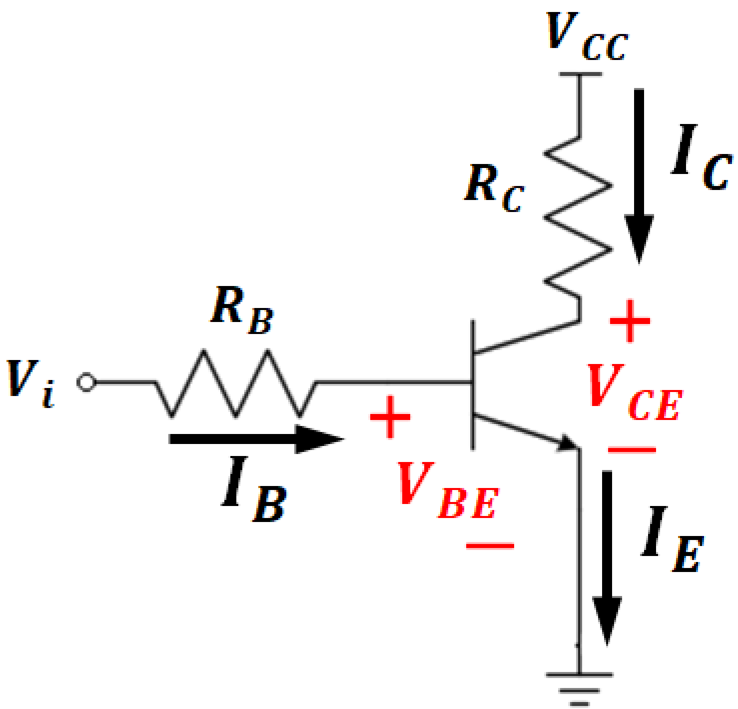
$I_B = I_C = 0$

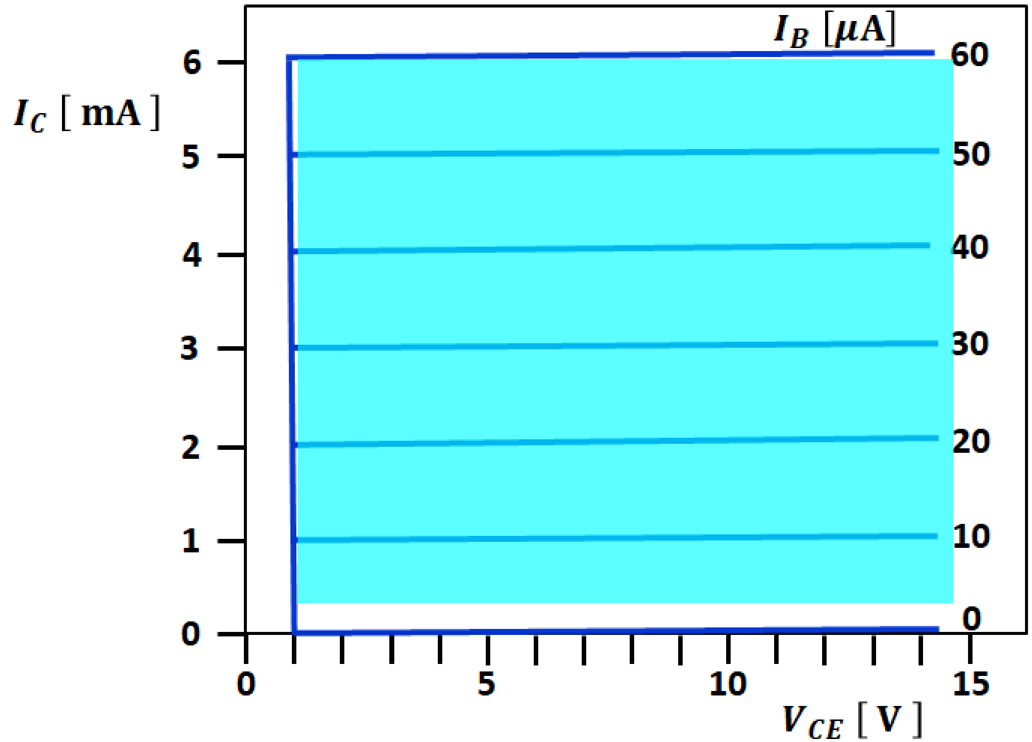
$\longrightarrow V_i$

$V_{BE} < V_{BE}(\text{ON})$	$V_{BE} \geq V_{BE}(\text{ON})$	$V_{BE} \geq V_{BE}(\text{ON})$
	$V_{CE} \geq V_{CE}(\text{sat})$	$V_{CE} < V_{CE}(\text{sat})$

CUT-OFF

Emitter connected to ground (Common emitter configuration)





$V_i > V_{BE}(\mathrm{ON})$

$I_C = \beta I_B$

V_i

$V_{BE} < V_{BE}(\mathrm{ON})$

$V_{BE} \geq V_{BE}(\mathrm{ON})$

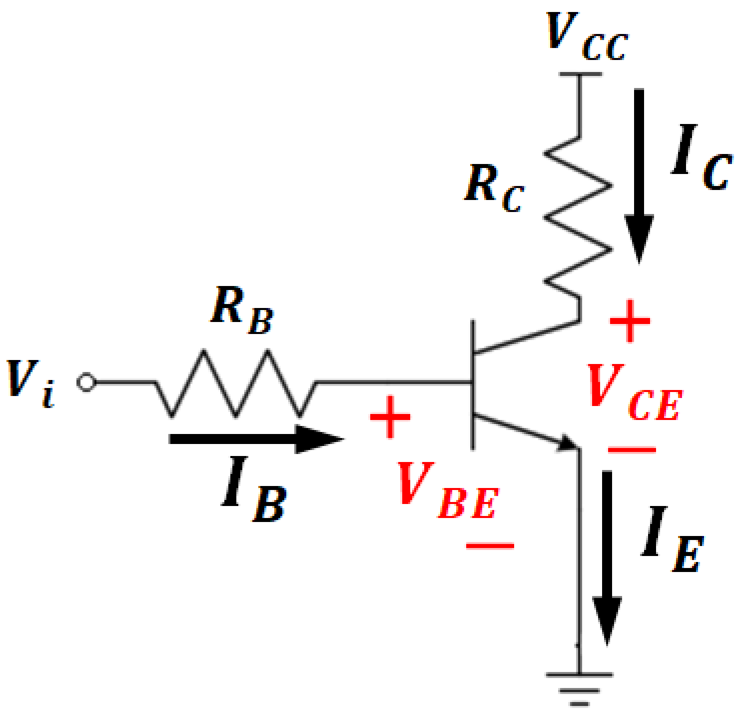
$V_{CE} \geq V_{CE}(\mathrm{sat})$

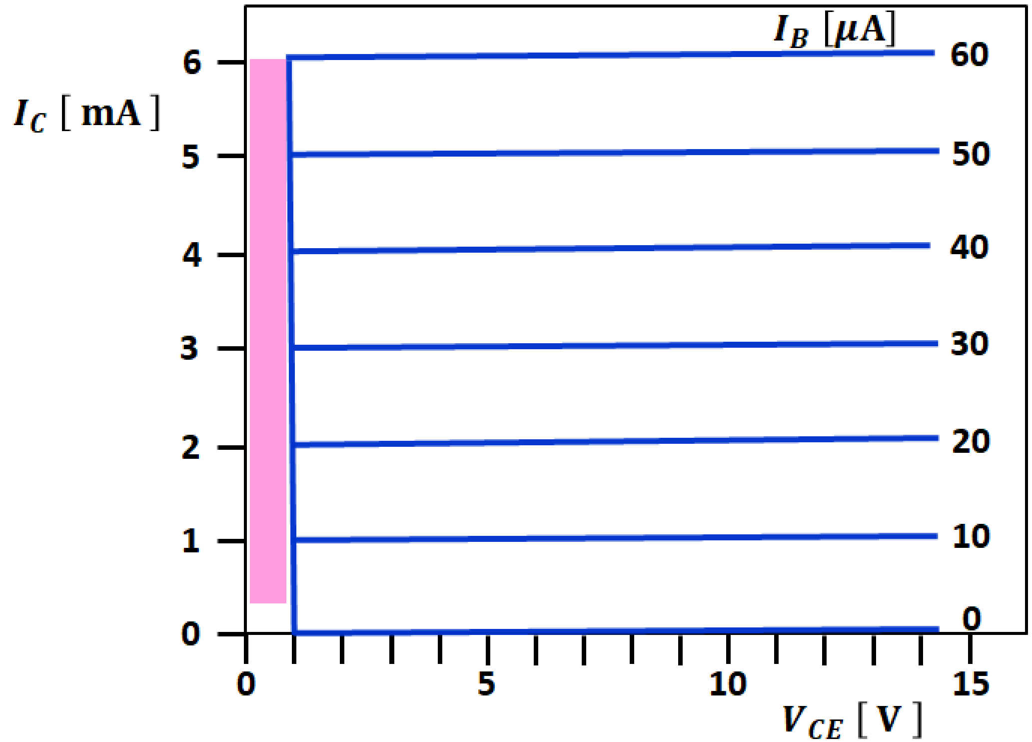
FORWARD-ACTIVE

$V_{BE} \geq V_{BE}(\mathrm{ON})$

$V_{CE} < V_{CE}(\mathrm{sat})$

Emitter connected to ground (Common emitter configuration)





$V_i > V_{BE}(\text{ON})$

$I_C = I_C(\text{sat})$

V_i

$V_{BE} < V_{BE}(\text{ON})$

$V_{BE} \geq V_{BE}(\text{ON})$

$V_{CE} \geq V_{CE}(\text{sat})$

$V_{BE} \geq V_{BE}(\text{ON})$

$V_{CE} < V_{CE}(\text{sat})$

SATURATION

BJT solution strategy – SUMMARY on single slide

STEP 1 – Check if the BJT is ON

The voltage applied in input must turn on the *p-n* junction (diode) between base and emitter so that $V_{BE} = V_{BE}(\text{on})$ $I_B \neq 0$

If BJT is OFF $\rightarrow$ STOP here. If BJT is ON $\rightarrow$ PROCEED to STEP 2

STEP 2 – Assume that the BJT is in Forward Active state

$V_{BE} = V_{BE}(\text{on})$ $I_C = \beta I_B$

If circuit analysis shows that $V_{CE} > V_{CE}(\text{sat})$ **the assumption is verified.**

If assumption is verified $\rightarrow$ STOP here. If not $\rightarrow$ PROCEED to STEP 3

STEP 3 – Select Saturation state

If the result from circuit analysis at STEP 2 is that $V_{CE} < V_{CE}(\text{sat})$ **then the calculated collector current is excessive.**

Set $V_{CE} = V_{CE}(\text{sat})$ **and calculate the corresponding** $I_C = I_C(\text{sat})$

BJT solution strategy

STEP 1 – Check if the BJT is ON

The voltage applied in input must turn on the *p-n* junction (diode) between base and emitter so that

$$\boldsymbol{V_{BE} = V_{BE}(\text{on})} \qquad \boldsymbol{I_B \neq 0}$$

If BJT is OFF $\rightarrow$ STOP here.

If BJT is ON $\rightarrow$ PROCEED to STEP 2

BJT solution strategy

STEP 2 – Assume BJT is in Forward Active state

$$V_{BE} = V_{BE}(\text{on})$$

$$I_C = \beta\, I_B$$

If circuit analysis shows that $V_{CE} > V_{CE}(\text{sat})$ the assumption is verified.

If assumption is verified→ STOP here.

If not → PROCEED to STEP 3

BJT solution strategy

STEP 3 – Select Saturation state

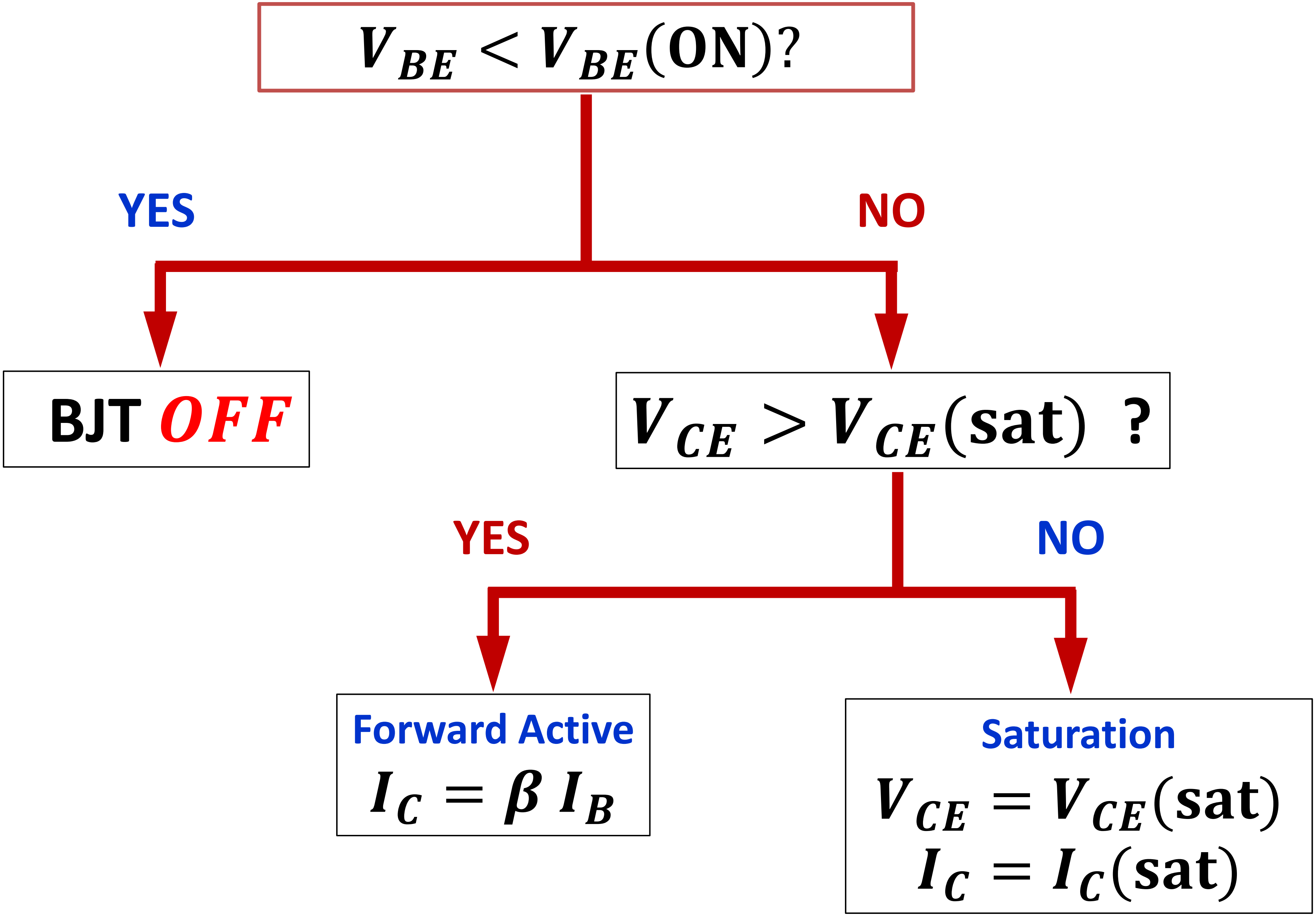
If the result from circuit analysis at STEP 2 is that

$$\boxed{V_{CE} < V_{CE}(\mathrm{sat})}$$

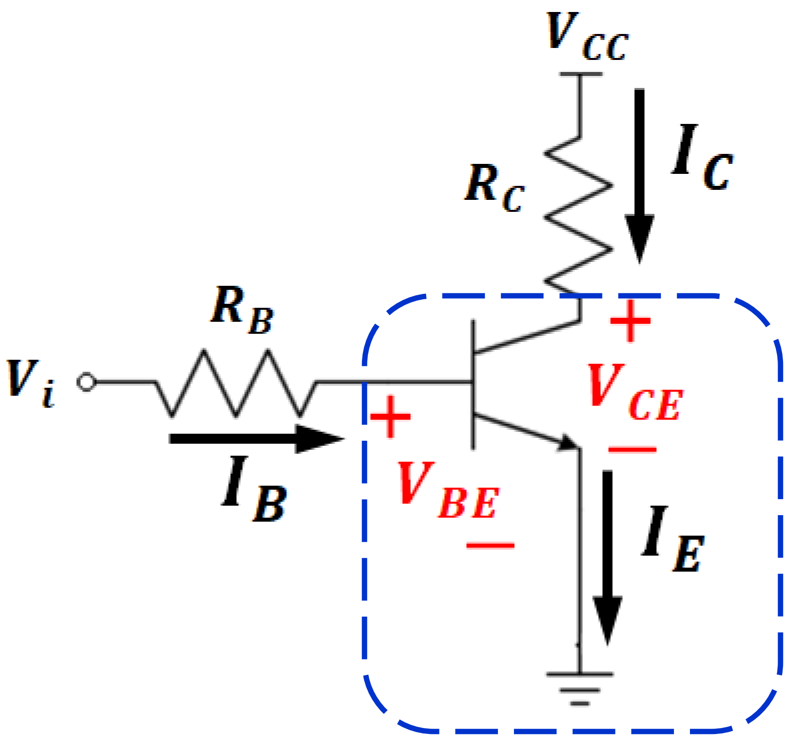
then the calculated collector current is excessive.

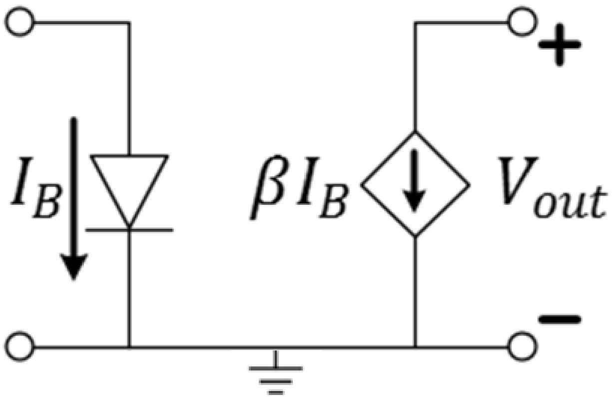
Set $$\boxed{V_{CE} = V_{CE}(\mathrm{sat})}$$

and calculate the corresponding $$\boxed{I_C = I_C(\mathrm{sat})}$$


$V_{BE} < V_{BE}(\mathrm{ON})$?
YES
NO
BJT *OFF*
$V_{CE} > V_{CE}(\mathrm{sat})$?
YES
NO
Forward Active
$I_C = \beta\, I_B$
Saturation
$V_{CE} = V_{CE}(\mathrm{sat})$
$I_C = I_C(\mathrm{sat})$

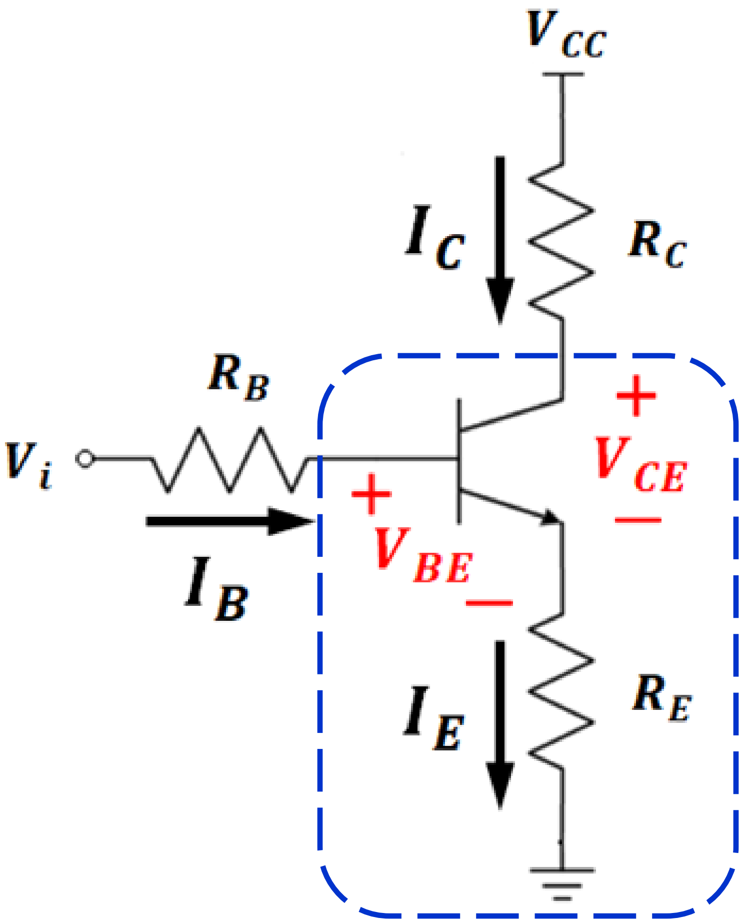
Emitter connected to ground (Common emitter configuration)

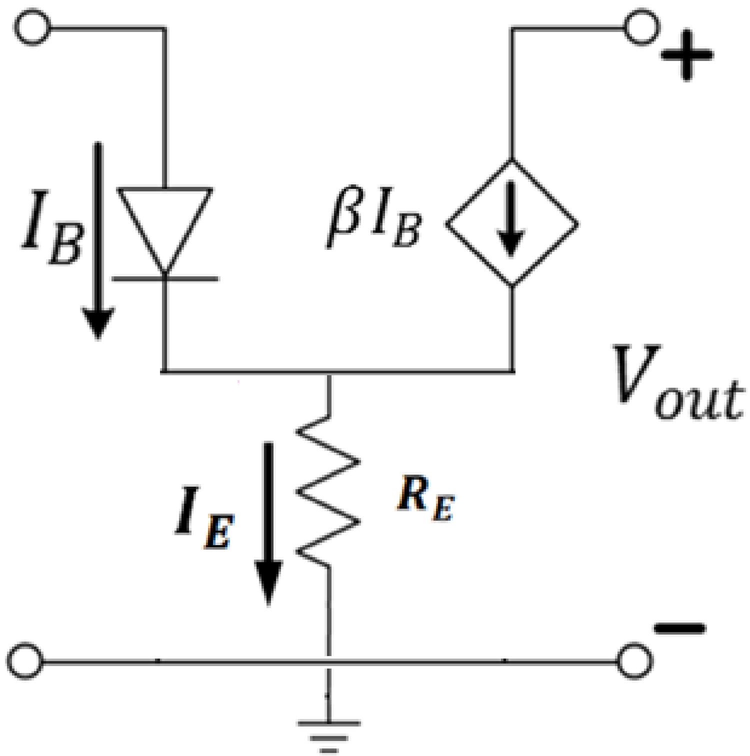




The left and right portions of the circuit are only coupled by the amplification factor β which controls the collector current controlled current source in output.

Addition of a resistor between emitter and ground





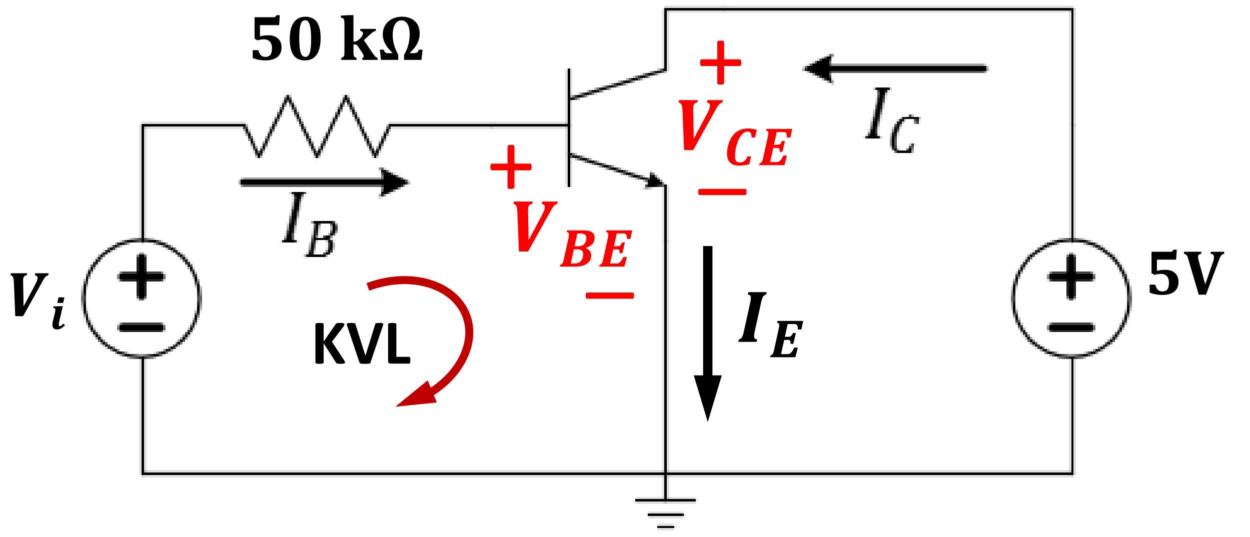
The emitter resistor R_E introduces also a coupling feedback between left and right, since the potential drop on R_E is shared by the KVL's. In saturation conditions, I_C is not constant, as a consequence.

Example 1: Find the BJT mode of operation

$V_{BE}(\text{on}) = 0.6\text{V}$

$V_{CE}(\text{sat}) = 0.2\text{V}$

$\beta = 100$



$(a)\ V_i = 0.5\ \text{V}$

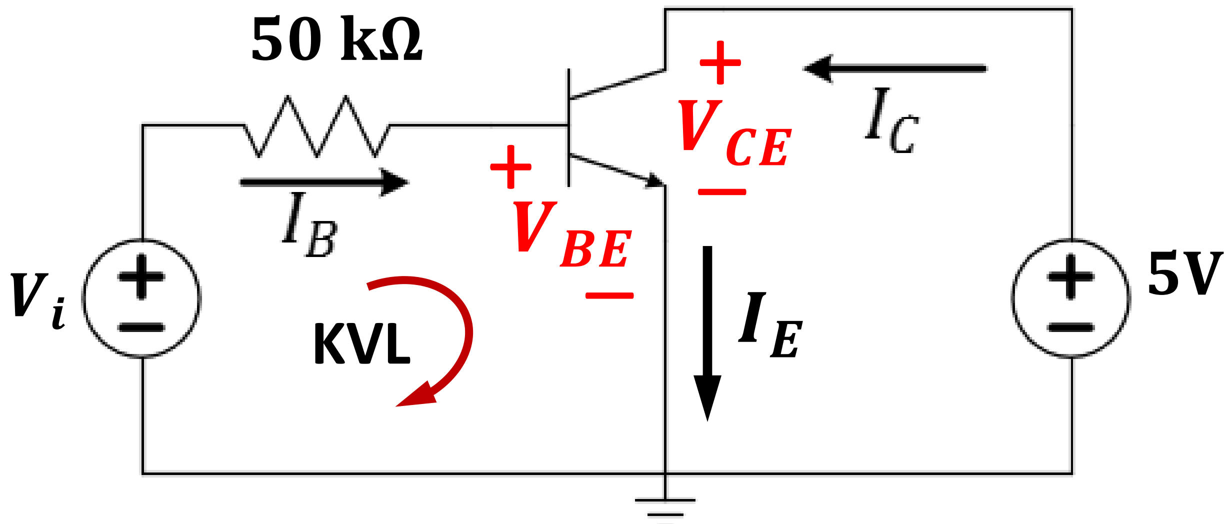
$(b)\ V_i = 2.0\text{V}$

Example 1: Find the BJT mode of operation

$V_{BE}(\mathrm{on}) = 0.6\mathrm{V}$

$V_{CE}(\mathrm{sat}) = 0.2\mathrm{V}$

$\beta = 100$



$(a)\ V_i = 0.5\ \mathrm{V}$

BJT is OFF since

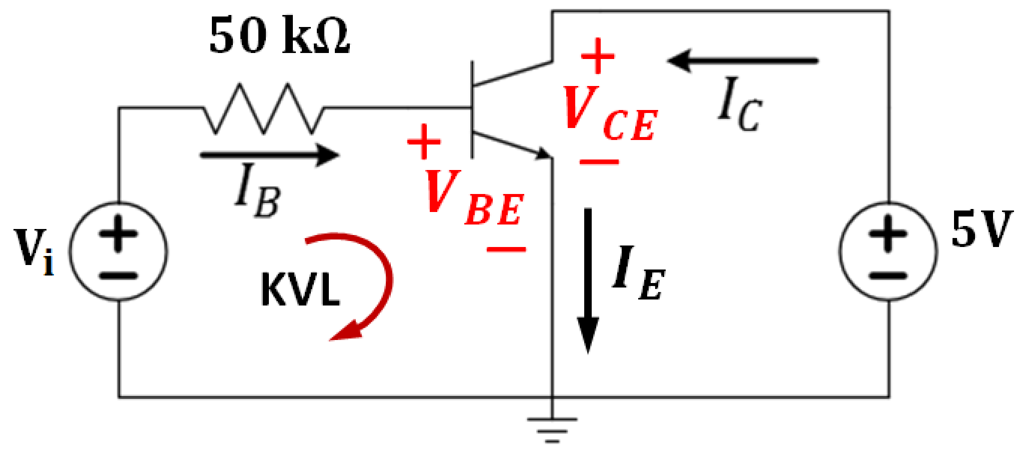
$$V_i < V_{BE}(\mathrm{on})$$

Cut-off mode

$V_{BE}(\text{on}) = 0.6\text{V}$

$V_{CE}(\text{sat}) = 0.2\text{V}$

$\beta = 100$



$(b)\ V_i = 2.0\text{V}$

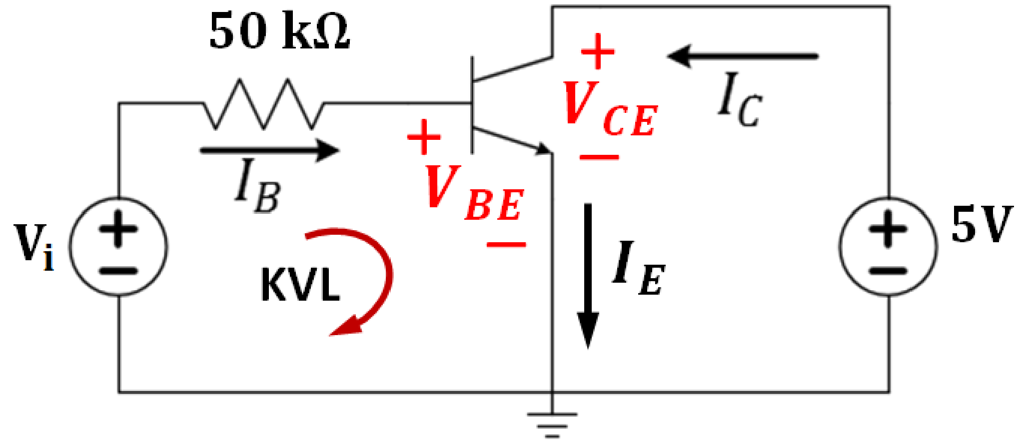
BJT is ON since $V_i > V_{BE}(\text{on})$ **Assume Forward Active mode**

$$V_{CE} = 5\text{V} > V_{CE}(\text{sat})$$

$V_{BE}(\text{on}) = 0.6\text{V}$

$V_{CE}(\text{sat}) = 0.2\text{V}$

$\beta = 100$



$(b)\ V_i = 2.0\text{V}$

BJT is ON since $V_i > V_{BE}(\text{on})$

Assume Forward Active mode

$$V_{CE} = 5\text{V} > V_{CE}(\text{sat})$$

$$-V_i + I_B R_B + V_{BE}(\text{on}) = 0$$

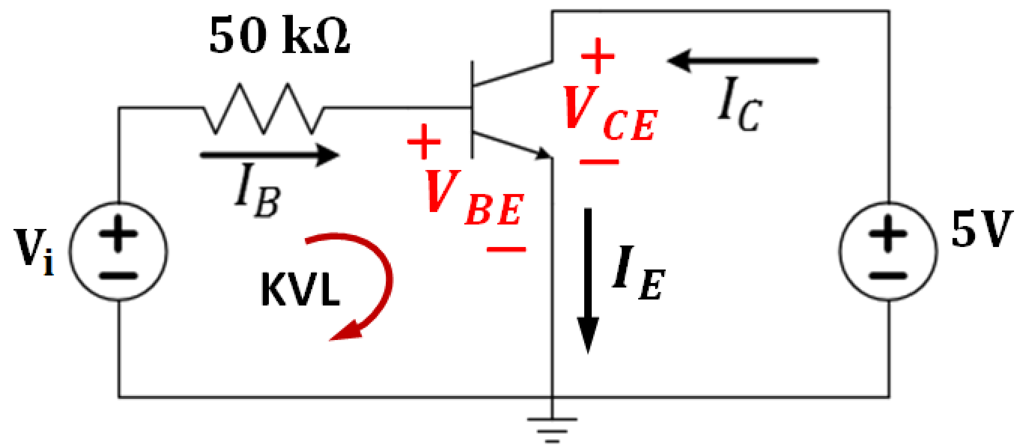
$$-2 + I_B \times 50\text{k}\Omega + 0.6 = 0$$

$$I_B = \frac{1.4}{50\text{k}} = 0.028\text{mA}$$

$V_{BE}(\text{on}) = 0.6\text{V}$

$V_{CE}(\text{sat}) = 0.2\text{V}$

$\beta = 100$



(b) $V_i = 2.0\text{V}$

BJT is ON since $V_i > V_{BE}(\text{on})$

Assume Forward Active mode

$$V_{CE} = 5\text{V} > V_{CE}(\text{sat})$$

$$-V_i + I_B R_B + V_{BE}(\text{on}) = 0$$

$$-2 + I_B \times 50\text{k}\Omega + 0.6 = 0$$

$$I_B = \frac{1.4}{50\text{k}} = 0.028\text{mA}$$

Let's check collector and emitter currents

$$I_C = \beta I_B = 100 \times 0.028 = 2.8\text{mA}$$

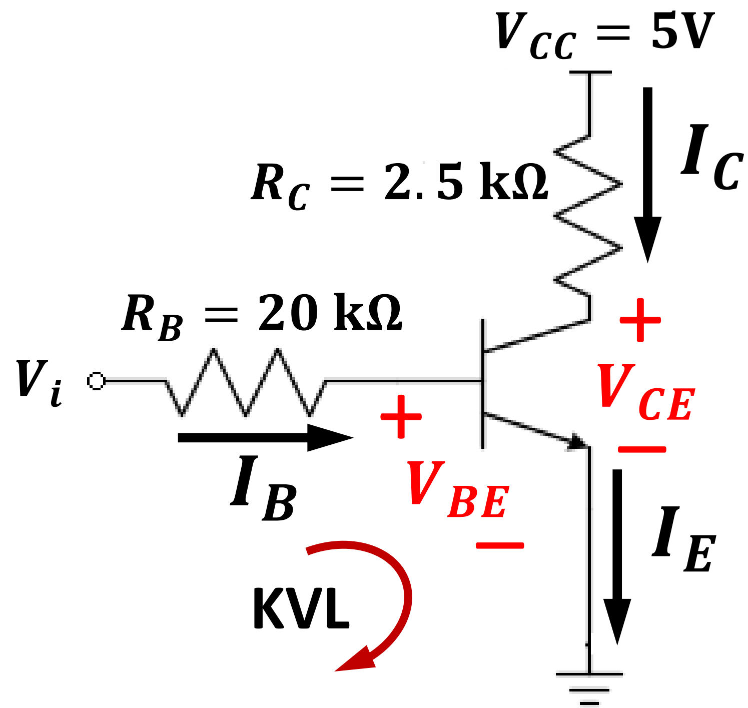
$$I_E = I_B + I_C = 2.8 + 0.028 = \frac{\beta + 1}{\beta} I_C = 2.828\text{mA}$$

Example 2: Find the BJT mode of operation

$V_{BE}(\text{on}) = 0.7\text{V}$

$V_{CE}(\text{sat}) = 0.2\text{V}$

$\beta = 200$



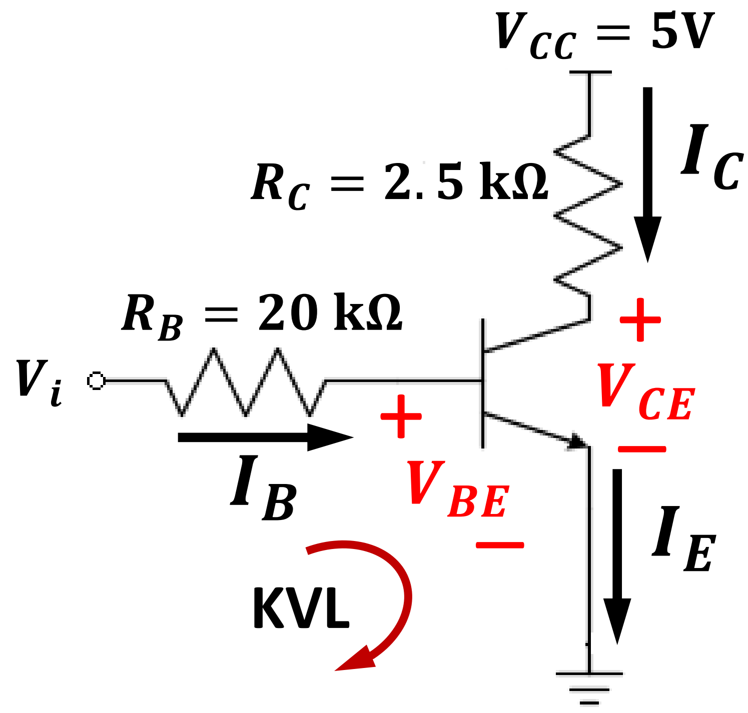
$(a)\ V_i = 0.5\text{V}$

$(b)\ V_i = 3.5\text{V}$

$$V_{BE}(\text{on}) = 0.7\text{V}$$

$$V_{CE}(\text{sat}) = 0.2\text{V}$$

$$\beta = 200$$



$(a)\ V_i = 0.5\text{V}$

BJT is OFF since

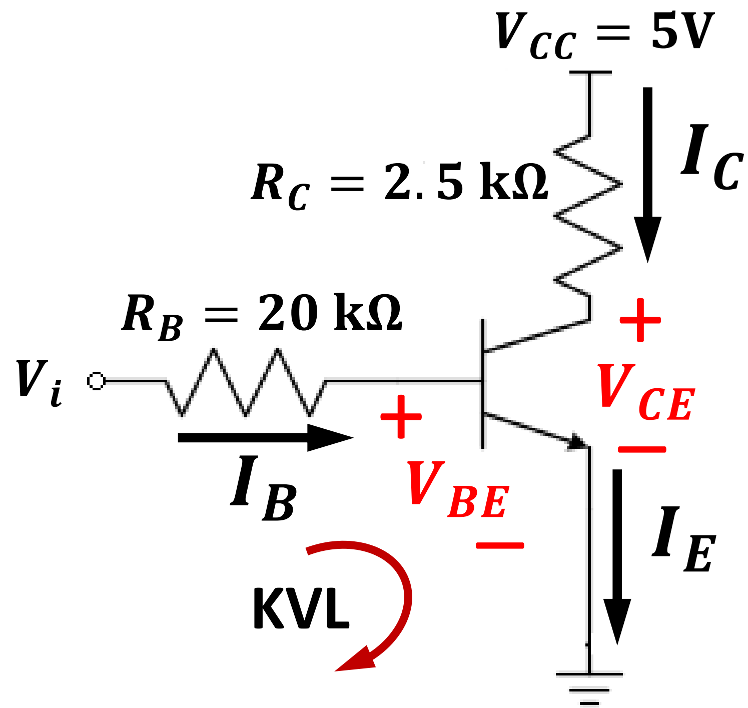
$$V_i < V_{BE}(\text{on})$$

Cut-off mode

$$V_{BE}(\text{on}) = 0.7\text{V}$$

$$V_{CE}(\text{sat}) = 0.2\text{V}$$

$$\beta = 200$$



$(b)\ V_i = 3.5\text{V}$

BJT is ON since $V_i > V_{BE}(\text{on})$

Assume forward active mode and check the collector behavior

KVL $-3.5 + I_B \times 20\text{k}\Omega + 0.7 = 0$

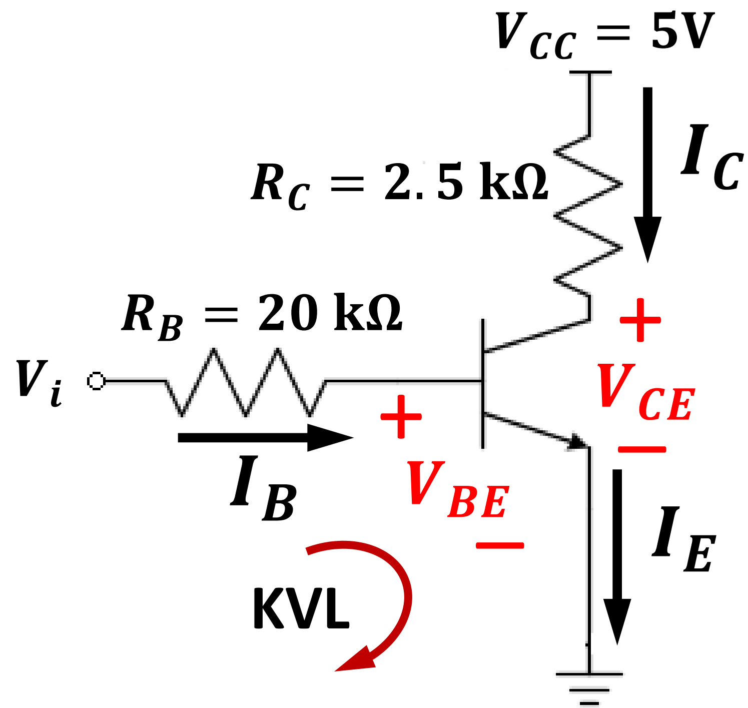
$$I_B = 0.14\text{mA}$$

$$I_C = \beta I_B = 200 \times 0.14 = 28\text{mA}$$

$V_{BE}(\text{on}) = 0.7\text{V}$

$V_{CE}(\text{sat}) = 0.2\text{V}$

$\beta = 200$



$(b)\ V_i = 3.5\text{V}$

BJT is ON since $V_i > V_{BE}(\text{on})$

Assume forward active mode and check the collector behavior

KVL $-3.5 + I_B \times 20\text{k}\Omega + 0.7 = 0$

$I_B = 0.14\text{mA}$

$I_C = \beta I_B = 200 \times 0.14 = 28\text{mA}$

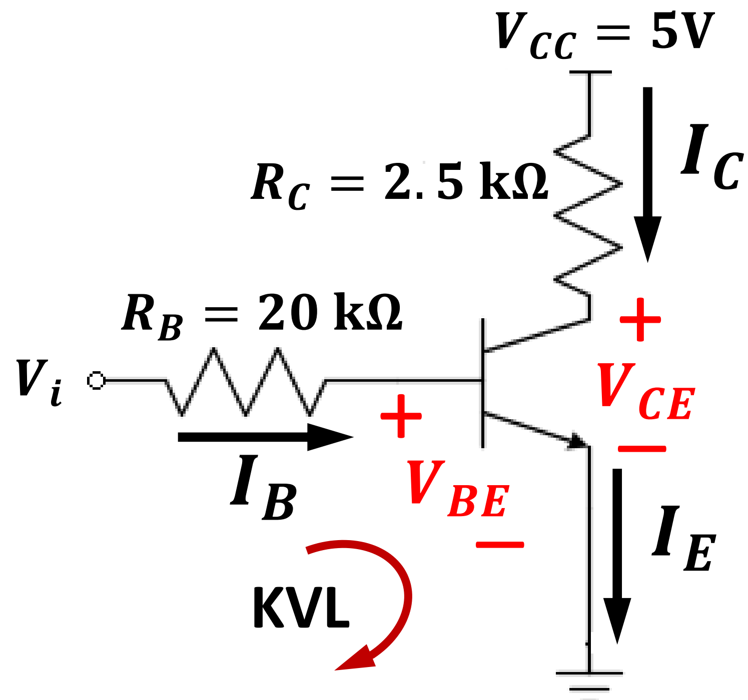
Contradiction

$V_{CE} = V_{CC} - I_C R_C = 5 - 28\text{m} \times 2.5\text{k} = -65\text{V} < 0.2\text{V}$

$V_{BE}(\text{on}) = 0.7\text{V}$

$V_{CE}(\text{sat}) = 0.2\text{V}$

$\beta = 200$



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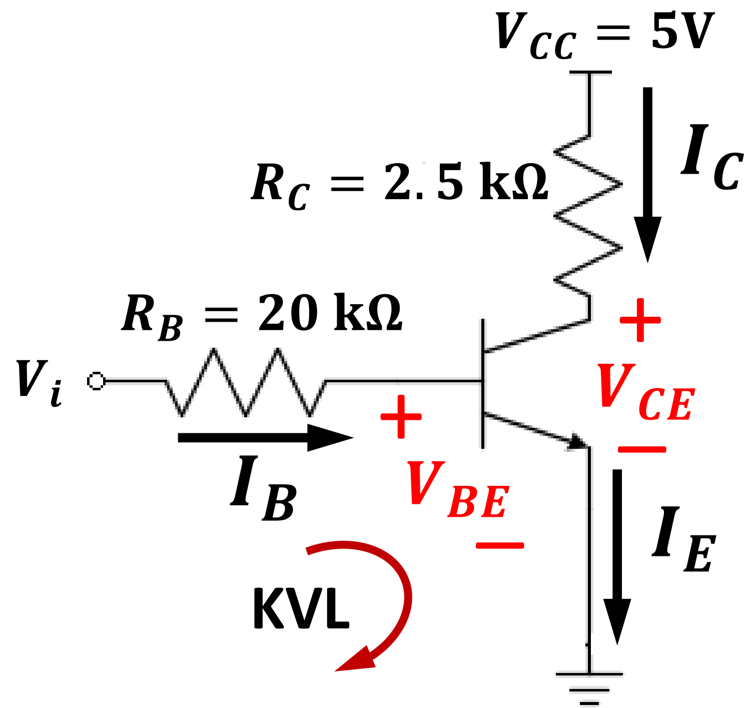
$V_{CE} = V_{CE}(\text{sat}) = 0.2\text{V}$ **Saturation mode**

$$V_{BE}(\text{on}) = 0.7\text{V}$$

$$V_{CE}(\text{sat}) = 0.2\text{V}$$

$$\beta = 200$$



$(b)\ V_i = 3.5\text{V}$

BJT is ON since $V_i > V_{BE}(\text{on})$

Let's find the collector current at onset of saturation

$$I_B = 0.14\text{mA}$$

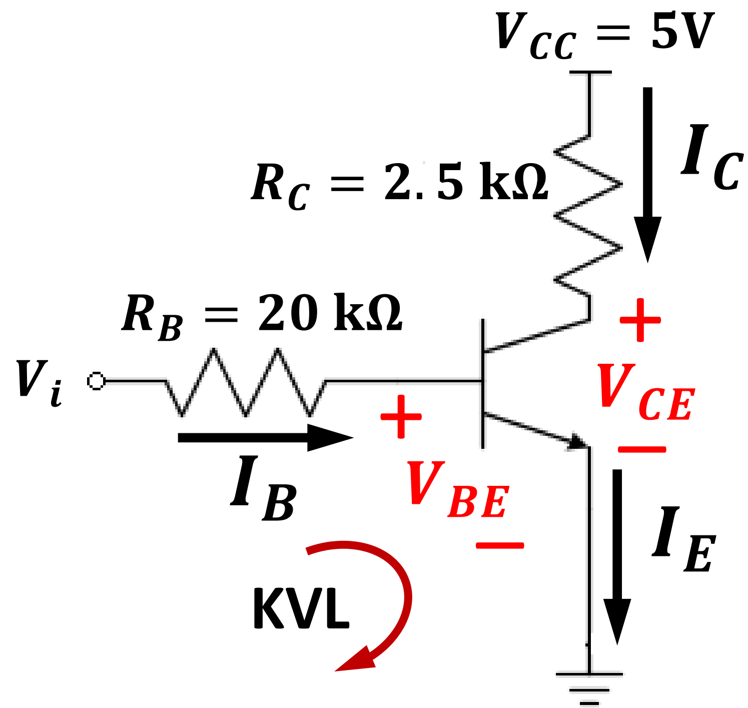
$$I_C = \beta I_B = 28\text{mA}$$

Under Forward-Active assumption

$$V_{BE}(\text{on}) = 0.7\text{V}$$

$$V_{CE}(\text{sat}) = 0.2\text{V}$$

$$\beta = 200$$



$$(b)\ V_i = 3.5\text{V}$$

BJT is ON since $V_i > V_{BE}(\text{on})$

Let's find the collector current at onset of saturation

$$I_B = 0.14\text{mA}$$

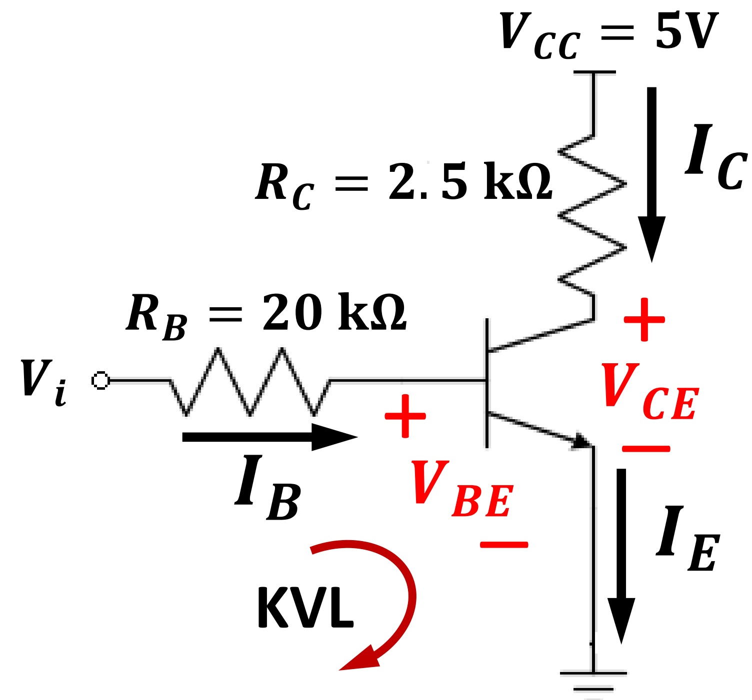
$$I_C = \beta I_B = 28\text{mA}$$

KVL $5 + (-I_C(\text{sat}) \times 2.5\text{k}\Omega) - V_{CE}(\text{sat}) = 0$

$$V_{BE}(\text{on}) = 0.7\text{V}$$

$$V_{CE}(\text{sat}) = 0.2\text{V}$$

$$\beta = 200$$



$(b)\ V_i = 3.5\text{V}$

BJT is ON since $V_i > V_{BE}(\text{on})$

Let's find the collector current at onset of saturation

$$I_B = 0.14\text{mA} \qquad I_C = \beta I_B = 28\text{mA}$$

KVL $5 + (-I_C(\text{sat}) \times 2.5\text{k}\Omega) - V_{CE}(\text{sat}) = 0$

$$I_C(\text{sat}) = 4.8\text{V}/2.5\text{k}\Omega = 1.92\text{mA} \ll \beta I_B$$

$$V_{BE}(\text{on}) = 0.7\text{V}$$

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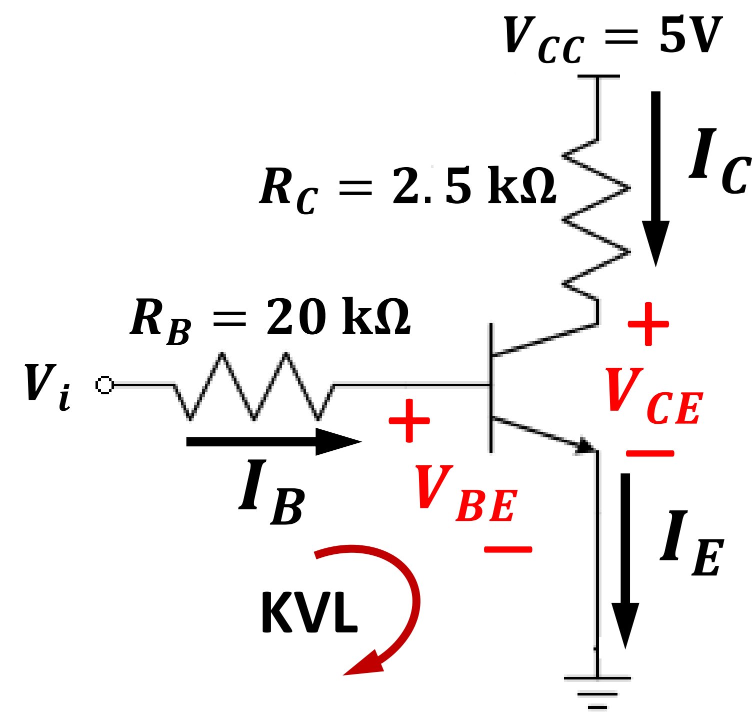
$$\beta = 200$$



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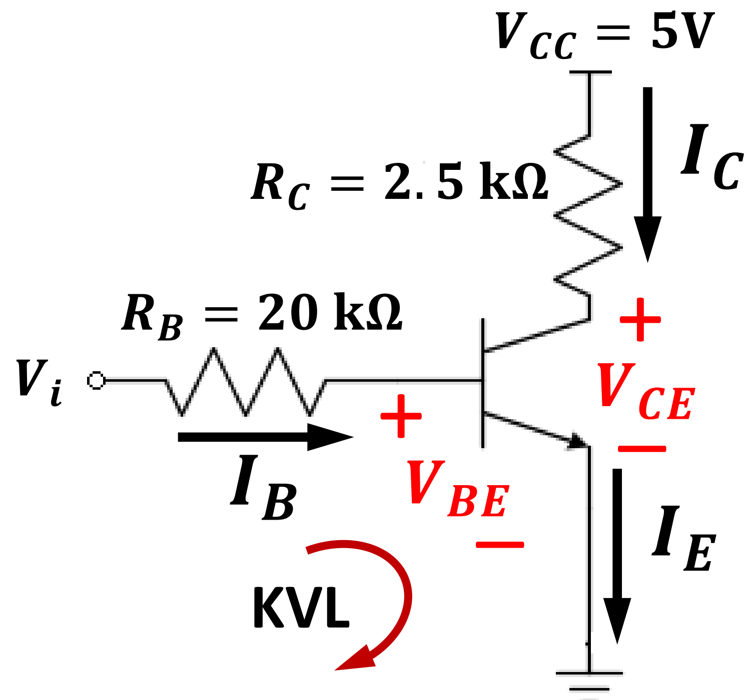
$$I_C(\text{sat}) = 4.8\text{V}/2.5\text{k}\Omega = 1.92\text{mA} \ll \beta I_B$$

$V_{CE} = V_{CE}(\text{sat}) = 0.2\text{V}$ **Saturation mode**

$$V_{BE}(\text{on}) = 0.7\text{V}$$

$$V_{CE}(\text{sat}) = 0.2\text{V}$$

$$\beta = 200$$



(b) $V_i = 3.5\text{V}$

Let's find the base current at onset of saturation

$$I_B(\text{at onset of saturation}) = \frac{I_C(\text{sat})}{\beta} = 9.6\ \mu\text{A}$$

$$V_i(\text{at onset of saturation}) = 9.6\ \mu\text{A} \times 20k\Omega + 0.7 = 0.892\text{V}$$

The base current can be increased further, but the collector current remains at the saturation value $I_C(\text{sat})$.

Example 3: BJT with emitter resistor

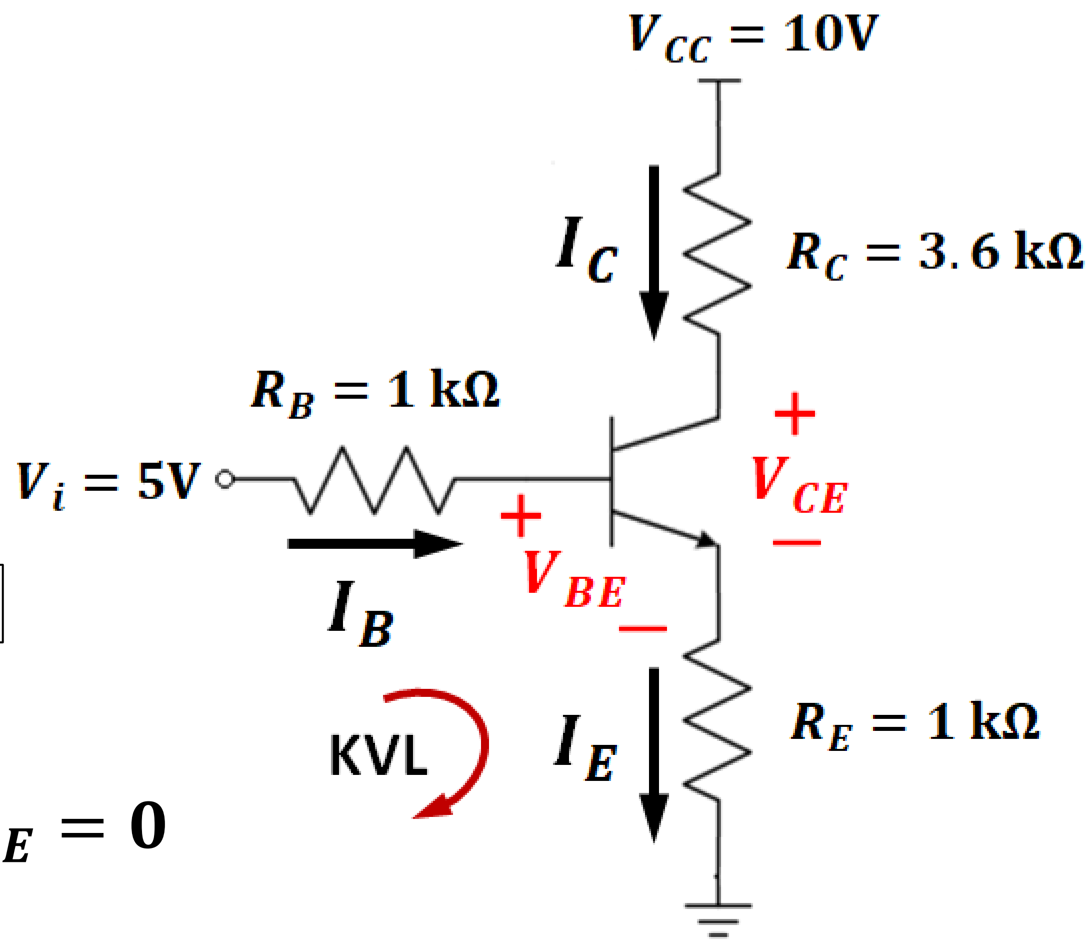
$$V_{BE}(\mathrm{on}) = 0.7\mathrm{V}$$

$$V_{CE}(\mathrm{sat}) = 0.2\mathrm{V}$$

$$\beta = 100$$

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

Assume forward active mode



Base-emitter KVL

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

Example 3: BJT with emitter resistor

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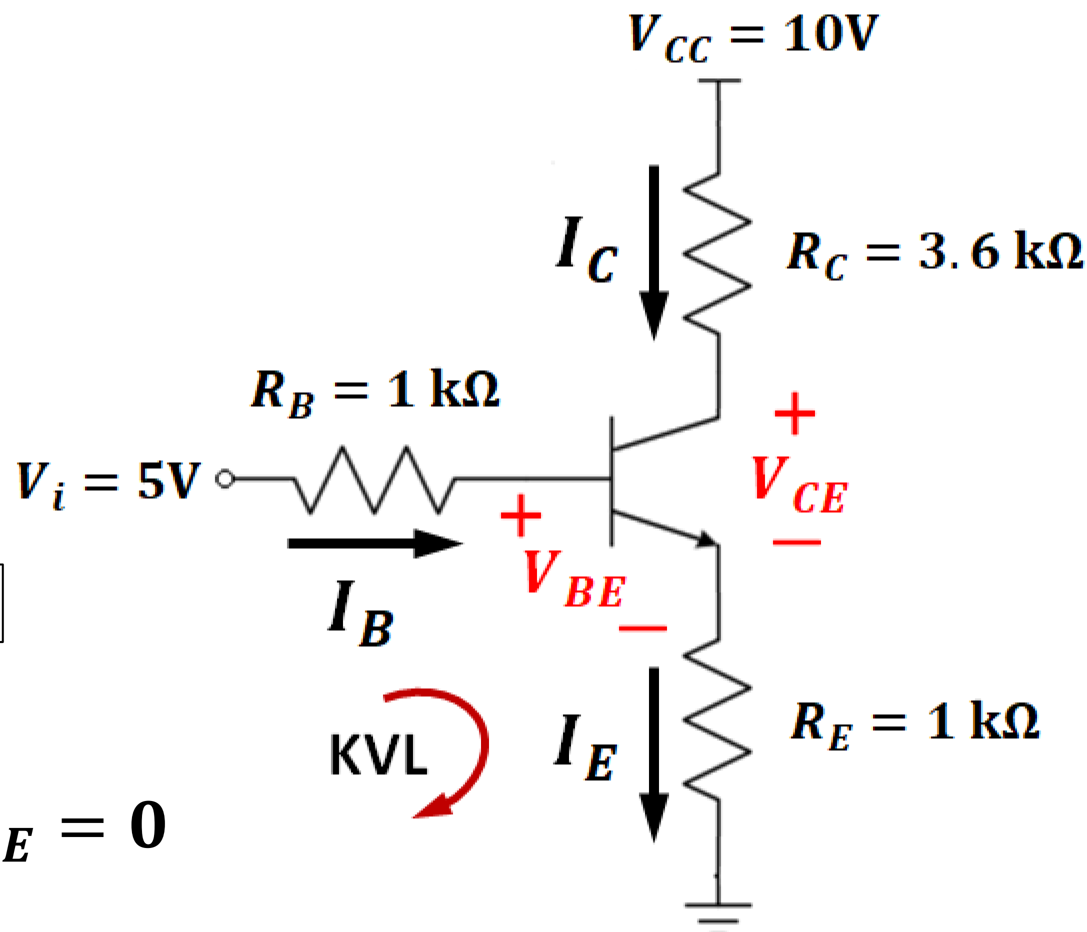


Assume forward active mode

Base-emitter KVL

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

$$-5 + I_B \times 1\text{k} + 0.7 + (\beta + 1) I_B \times 1\text{k} = 0$$

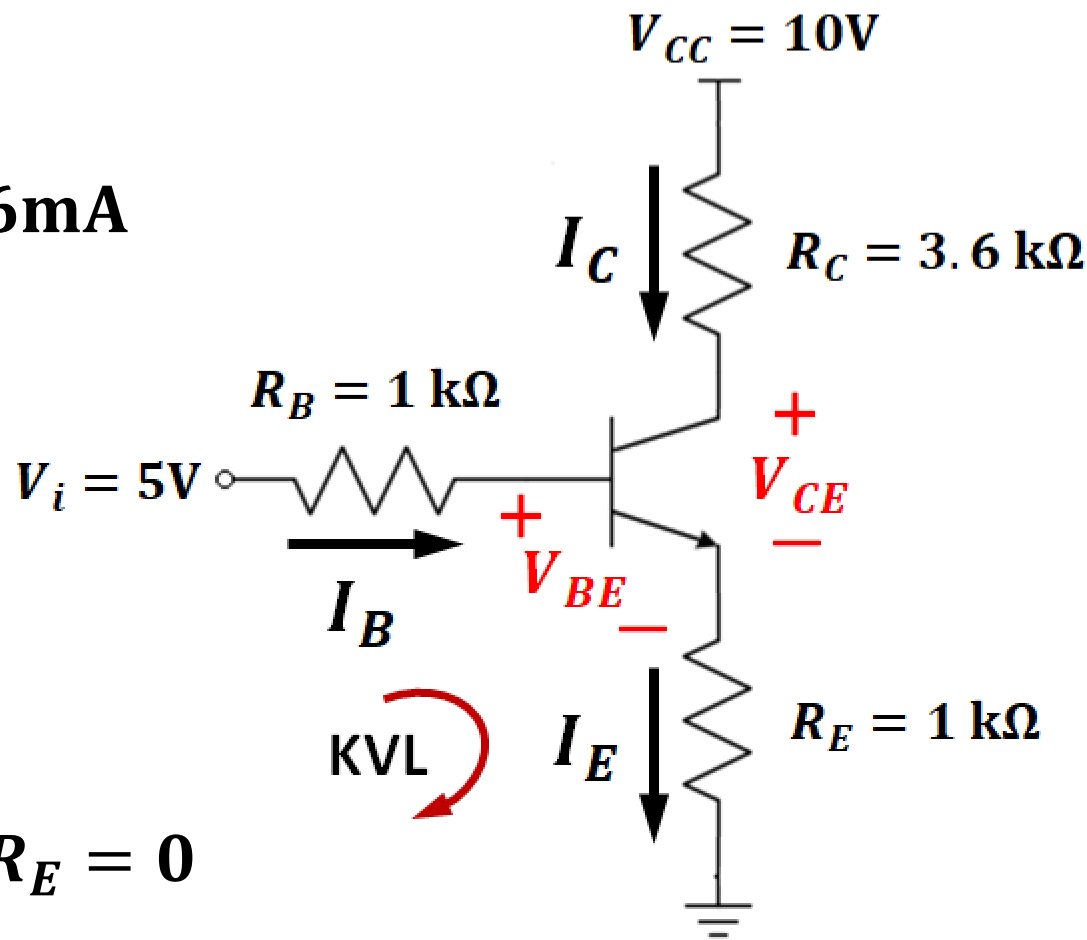
$$I_B = \frac{4.3}{1\text{k} + (\beta + 1)1\text{k}} = \frac{4.3}{102\text{k}} = 0.0422\text{mA} = 42.2\mu\text{A}$$

Example 3: BJT with emitter resistor

$$I_B = 0.0422\text{mA}$$

$$I_E = (\beta + 1)I_B = 4.26\text{mA}$$

$$I_C = \beta I_B = 4.22\text{mA}$$



Now, check for saturation

Collector-emitter KVL

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

Example 3: BJT with emitter resistor

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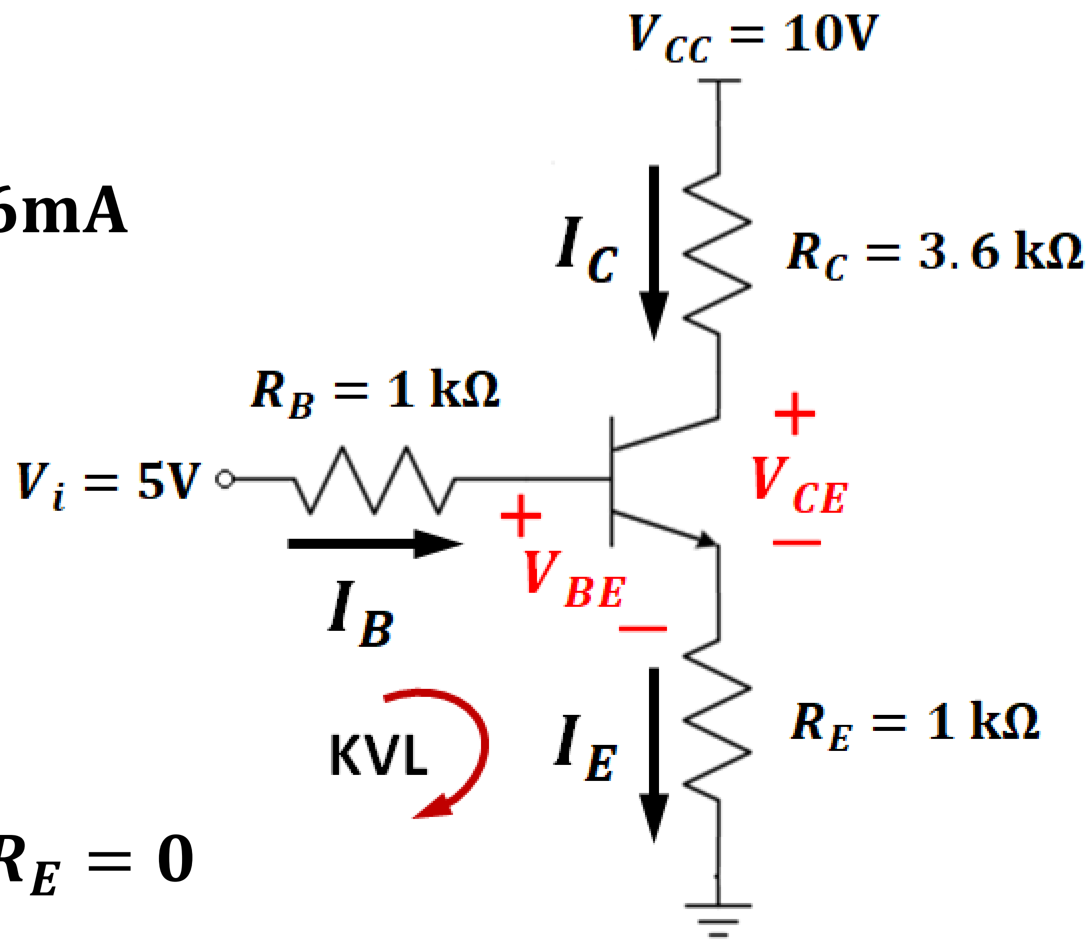

Now, check for saturation

Collector-emitter KVL

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

$$-10 + 4.22\text{m} \times 3.6\text{k} + V_{CE} + 4.26 \times 1\text{k} = 0$$

$$V_{CE} = 10 - 15.192 - 4.26 = -9.452\ \text{V} \ll V_{CE}(\text{sat})$$

Example 3: BJT with emitter resistor

$$I_B = 0.0422\text{mA}$$

$$I_E = (\beta + 1)I_B = 4.26\text{mA}$$

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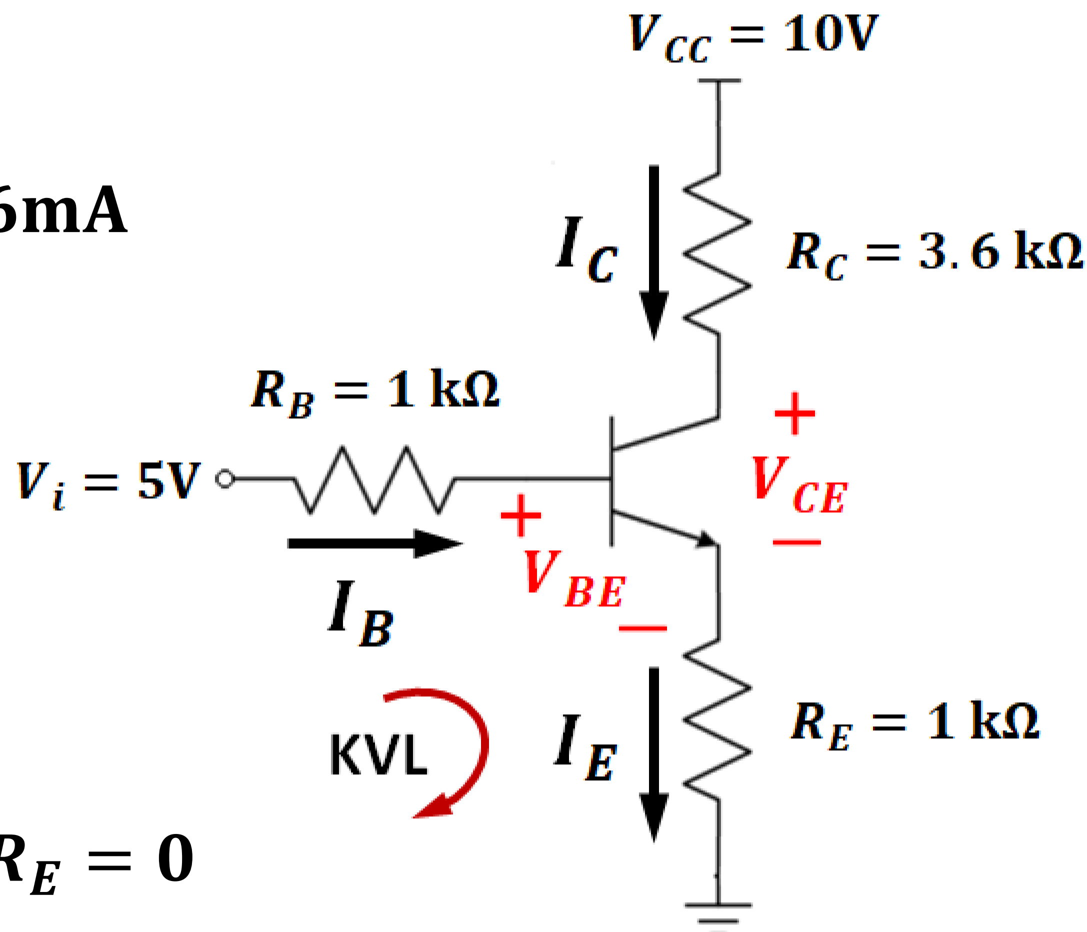


Now, check for saturation

Collector-emitter KVL

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

$$-10 + 4.22\text{m} \times 3.6\text{k} + V_{CE} + 4.26 \times 1\text{k} = 0$$

$$V_{CE} = 10 - 15.192 - 4.26 = -9.452\ \text{V} \ll V_{CE}(\text{sat})$$

Assumption is invalid. ⇨ $V_{CE} = V_{CE}(\text{sat}) = 0.2\ \text{V}$

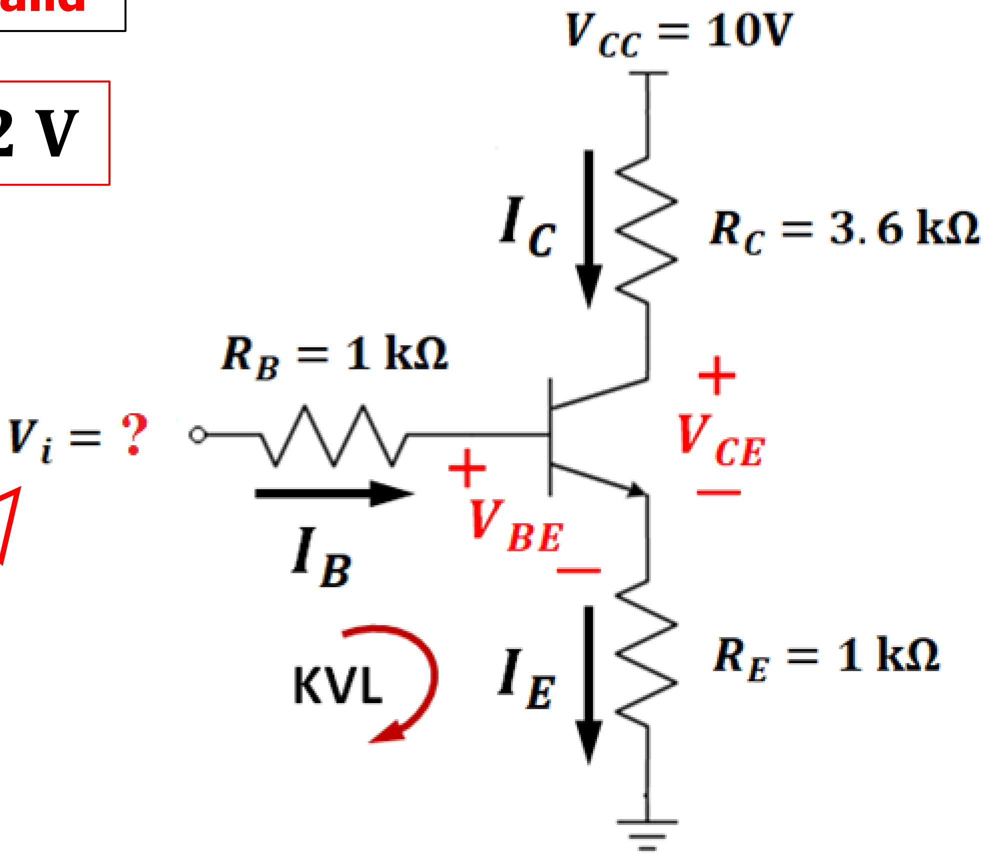
Previous results for currents are invalid

$$\Rightarrow \quad V_{CE} = V_{CE}(\text{sat}) = 0.2\ \text{V}$$

Remember

$$I_E = \frac{\beta + 1}{\beta} I_C = 1.01\ I_C$$

(valid up to onset of saturation)



Previous results for currents are invalid

$$V_{CE} = V_{CE}(\text{sat}) = 0.2\ \text{V}$$

Remember

$$I_E = \frac{\beta + 1}{\beta} I_C = 1.01\ I_C$$

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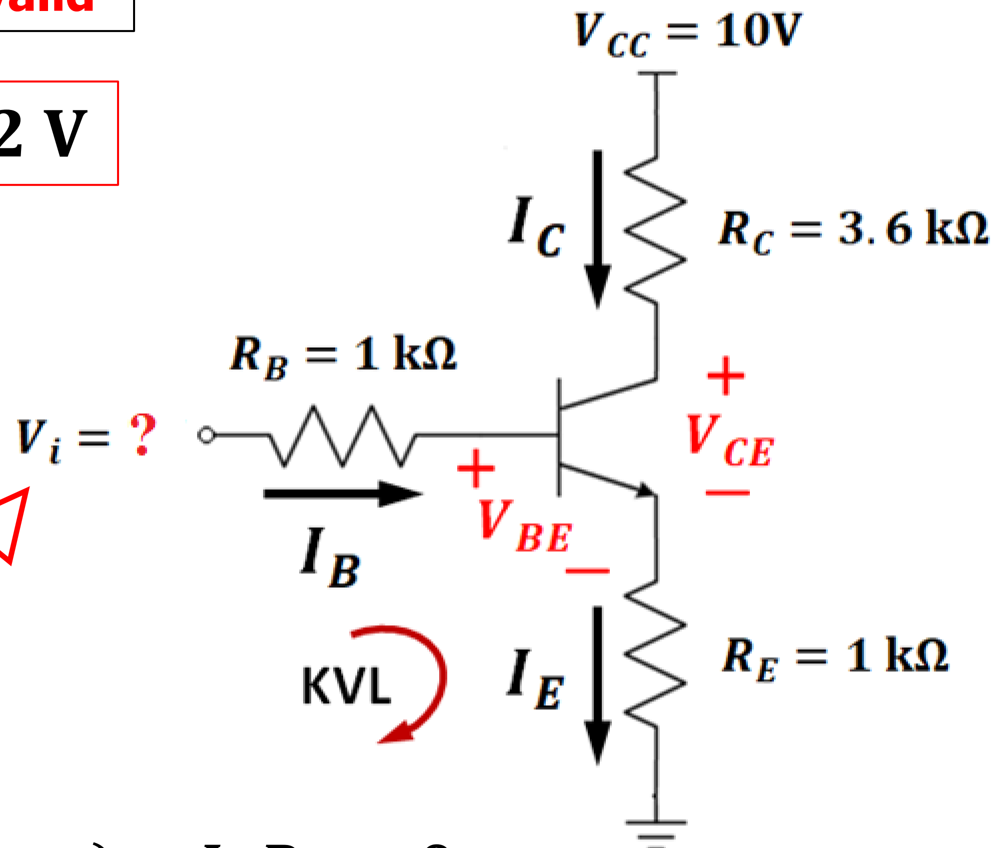


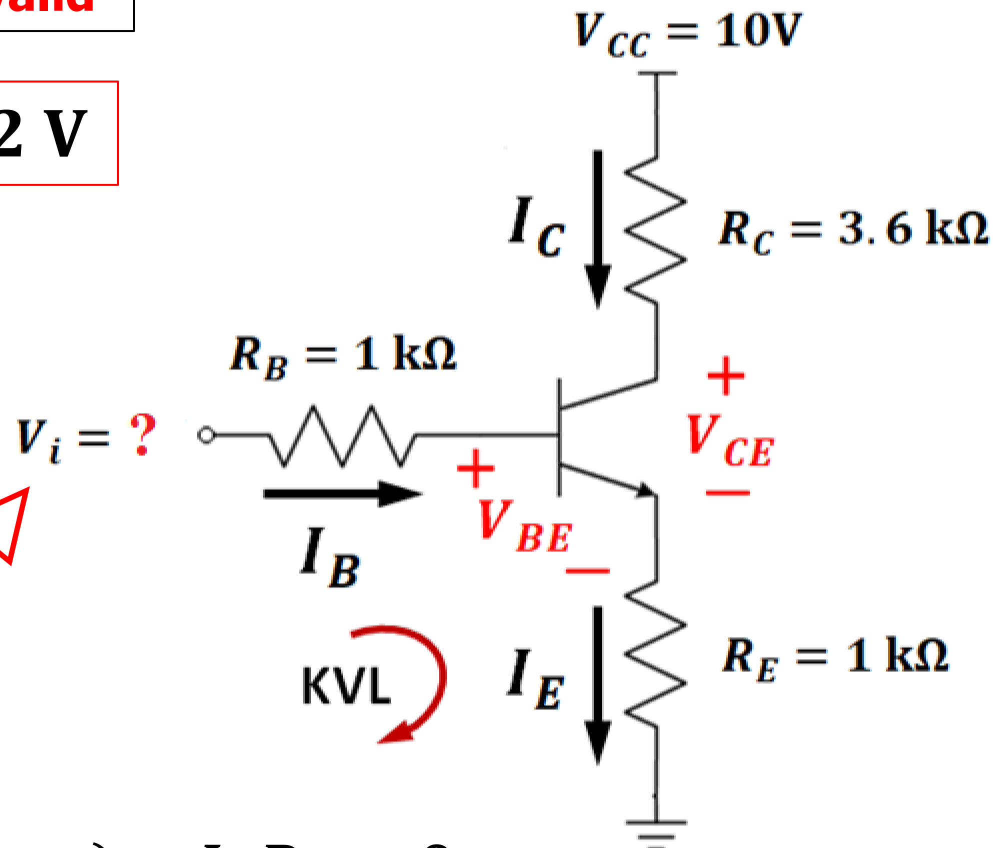
Recalculate collector-emitter KVL

$$-V_{CC} + I_C(\text{onsat})R_C + V_{CE}(\text{onsat}) + I_E R_E = 0$$

$$-10 + I_C(\text{onsat}) \times 3.6\text{k} + 0.2 + 1.01 \times I_C(\text{onsat}) \times 1\text{k} = 0$$

Previous results for currents are invalid

$$V_{CE} = V_{CE}(\text{sat}) = 0.2\text{ V}$$



Remember

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Recalculate collector-emitter KVL

$$-V_{CC} + I_C(\text{onsat})R_C + V_{CE}(\text{onsat}) + I_E R_E = 0$$

$$-10 + I_C(\text{onsat}) \times 3.6\text{k} + 0.2 + 1.01 \times I_C(\text{onsat}) \times 1\text{k} = 0$$

$$I_C(\text{onsat}) = 9.8/4.61\text{k} = 2.13\text{ mA}$$

$$I_E(\text{onsat}) = 1.01\, I_C = 2.15\text{ mA}$$

At onset of saturation

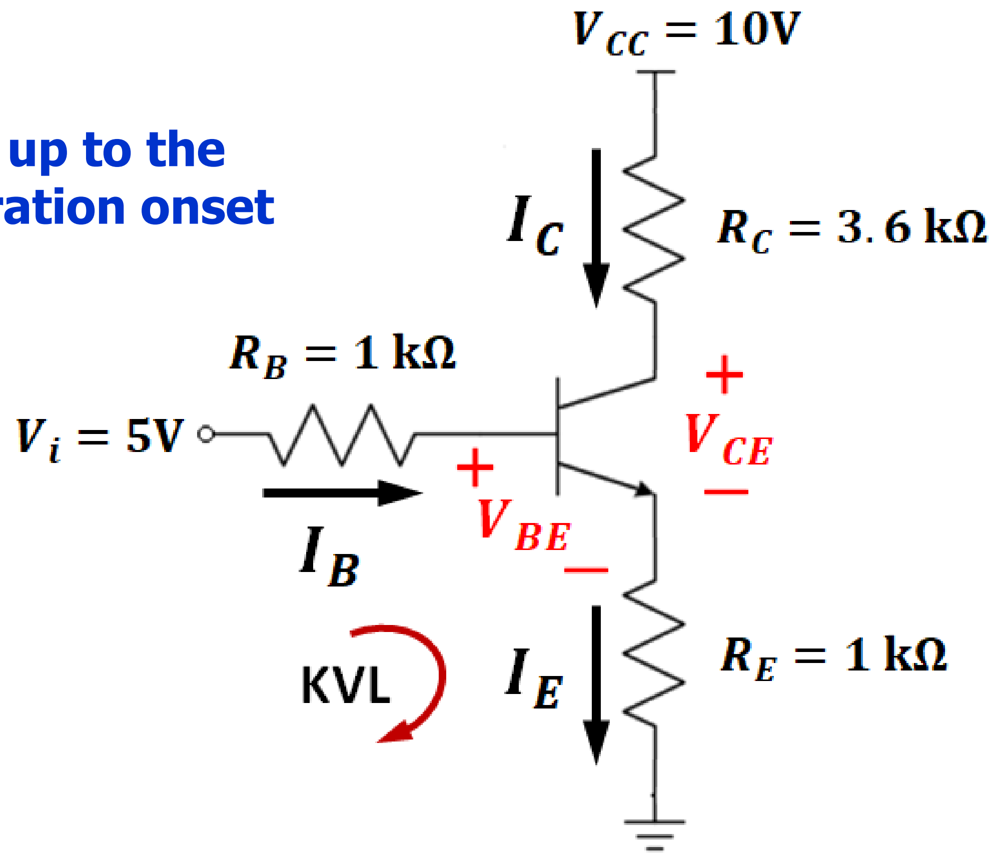
ATTENTION – Relevant for HW10-PL

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

is valid ONLY up to the point of saturation onset

Deeper in saturation one must keep using

$$I_E = I_B + I_C$$



AGAIN: The derivations in the previous slide ARE NOT VALID in deeper saturation but only at the onset point where the device transitions from Forward-Active mode to Saturation mode

When the base current is increased beyond onset, the voltage drop in the emitter resistor changes, since

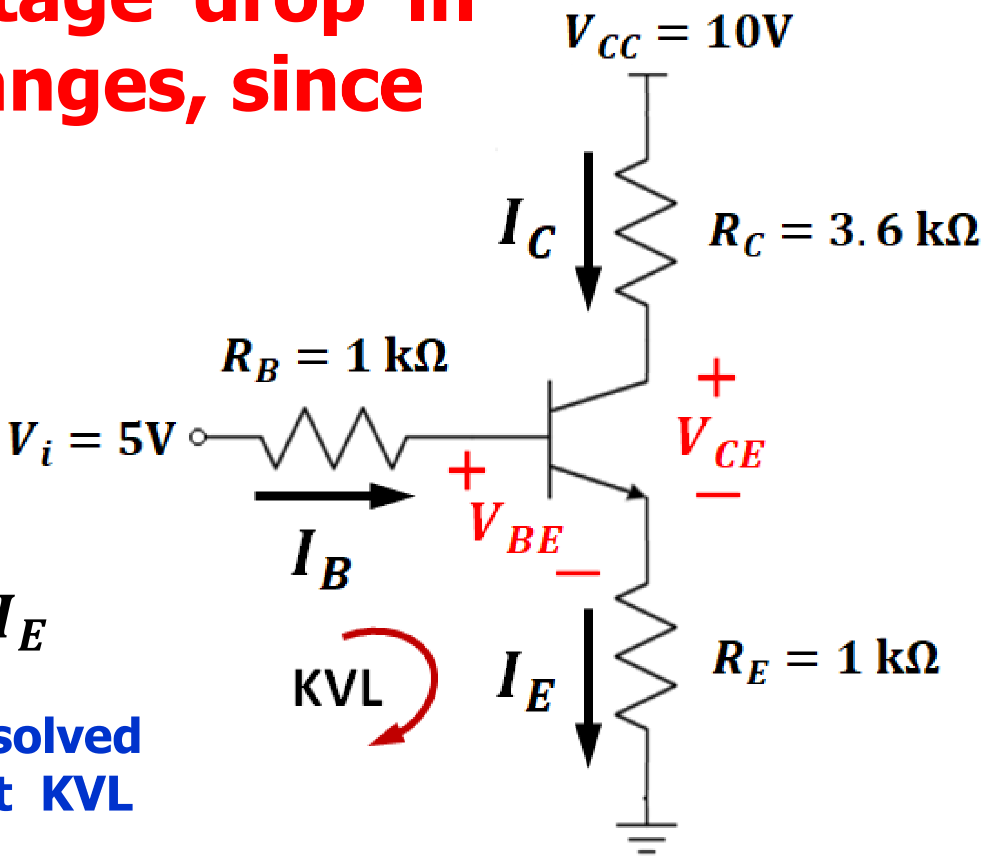
$$I_E = I_B + I_C$$

If we assume that the saturation $V_{CE}(\text{sat})$ remains at the value specified by the manufacturer throughout, in saturation

$$V_{CC} - V_{CE}(\text{sat}) = R_C I_C + R_E I_E$$

This equation has to be solved simultaneously with the base circuit KVL

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

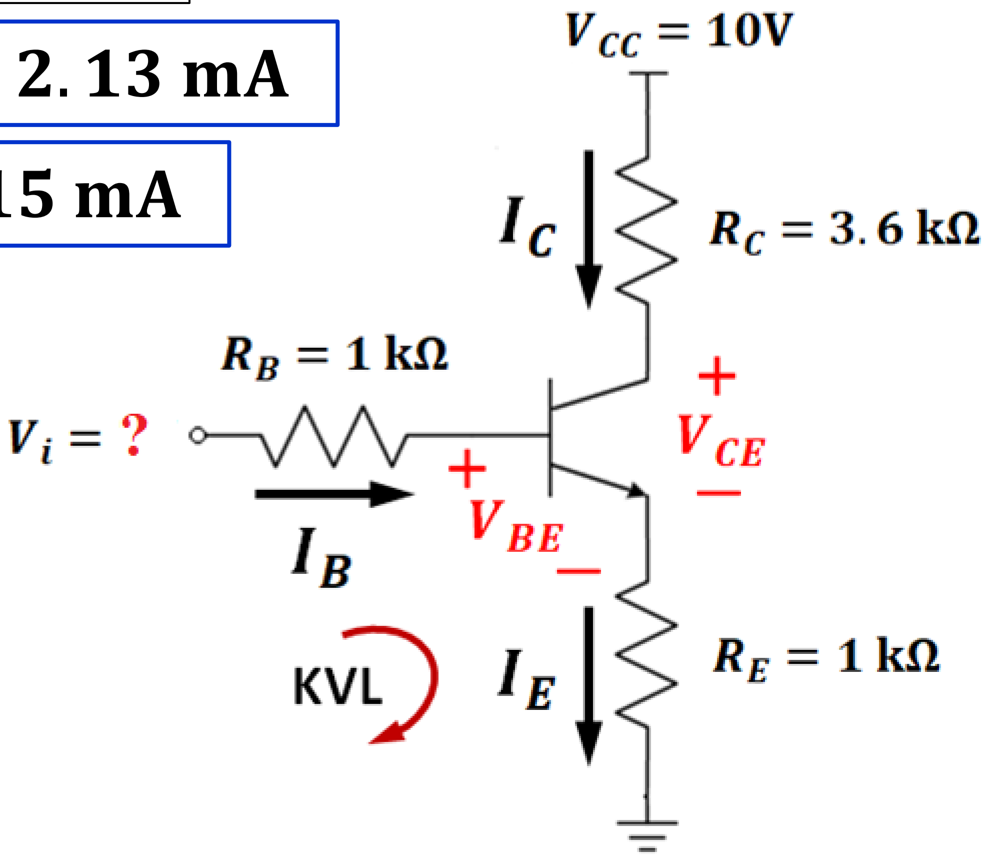


Recalculated currents

$$I_C(\text{onsat}) = 9.8/4.61\text{k} = 2.13\ \text{mA}$$

$$I_E(\text{onsat}) = 1.01\, I_C = 2.15\ \text{mA}$$

Find base voltage at onset of saturation



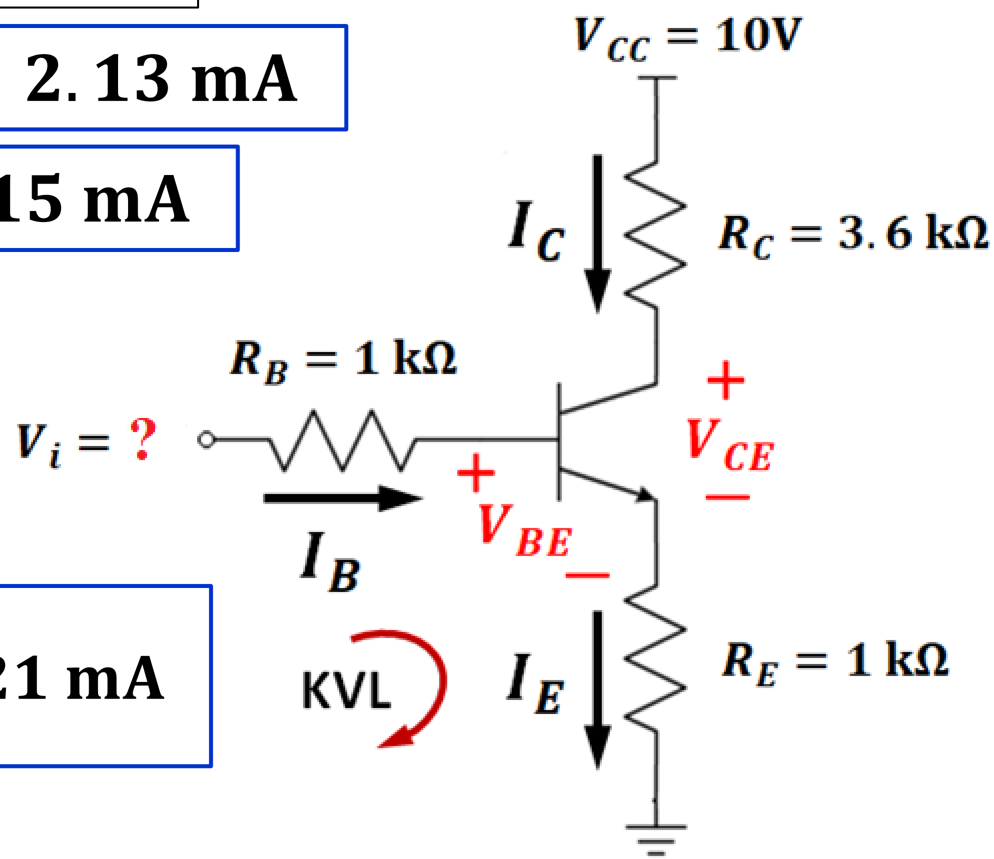
Recalculated currents

$$I_C(\text{onsat}) = 9.8/4.61\text{k} = 2.13\ \text{mA}$$

$$I_E(\text{onsat}) = 1.01\, I_C = 2.15\ \text{mA}$$

Find base voltage at onset of saturation

$$I_B(\text{onsat}) = \frac{I_C(\text{onsat})}{\beta} = 0.021\ \text{mA}$$



Recalculated currents

$$I_C(\text{onsat}) = 9.8/4.61\text{k} = 2.13\text{ mA}$$

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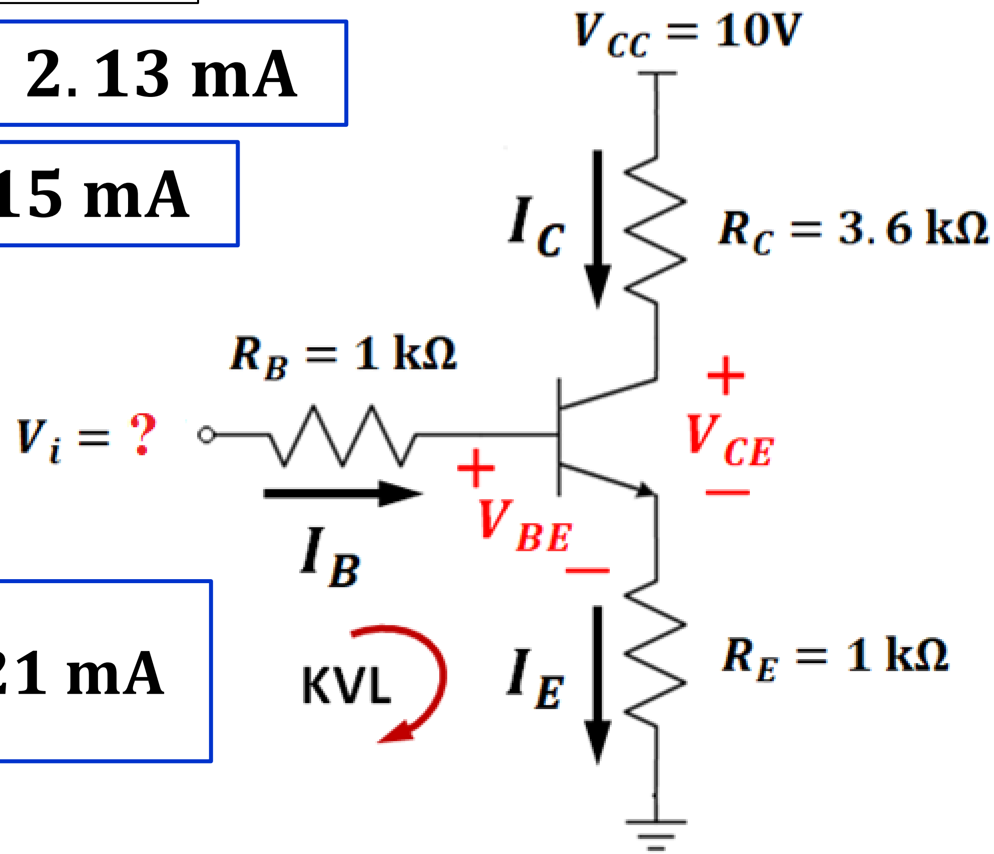
Find base voltage at onset of saturation



$$I_B(\text{onsat}) = \frac{I_C(\text{onsat})}{\beta} = 0.021\text{ mA}$$

Base circuit KVL

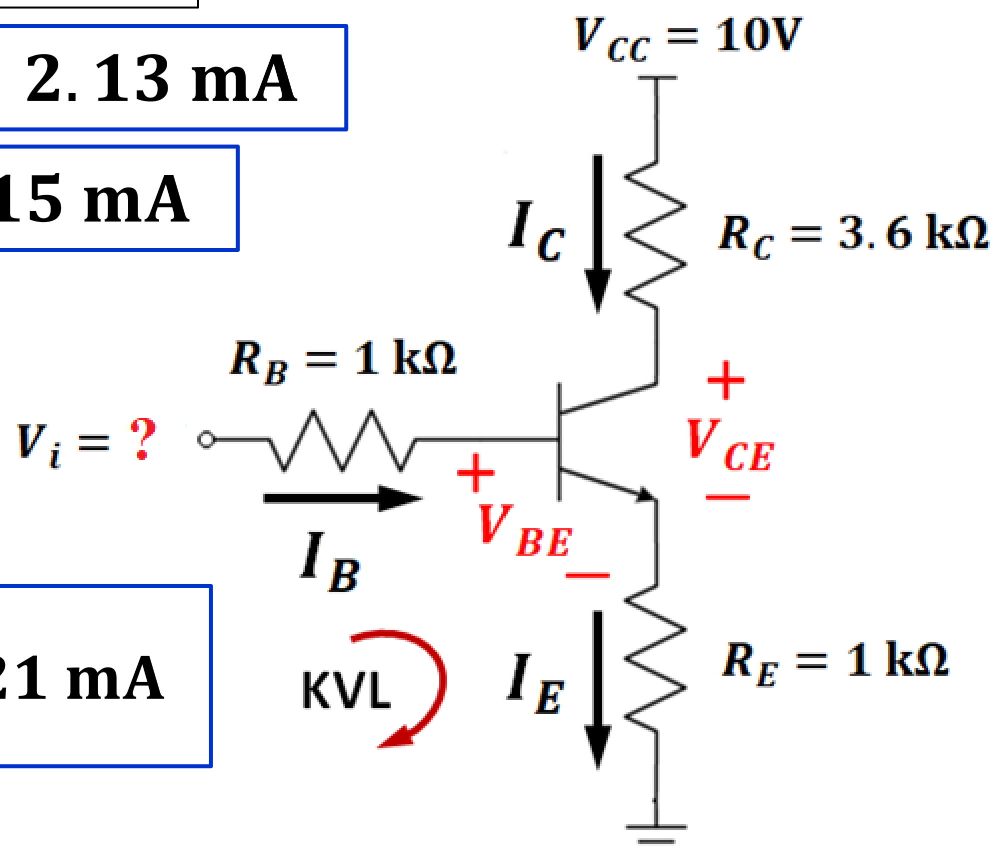
$$-V_i(\text{onsat}) + I_B(\text{onsat})R_B + V_{BE} + I_E(\text{onsat})R_E = 0$$

$$V_i(\text{onsat}) = 0.021\text{m} \times 1\text{k} + 0.7 + 2.15\text{m} \times 1\text{k}$$

Recalculated currents

$$I_C(\text{onsat}) = 9.8/4.61\text{k} = 2.13\ \text{mA}$$

$$I_E(\text{onsat}) = 1.01\, I_C = 2.15\ \text{mA}$$



Find base voltage at onset of saturation

$$I_B(\text{onsat}) = \frac{I_C(\text{onsat})}{\beta} = 0.021\ \text{mA}$$

Base circuit KVL

$$-V_i(\text{onsat}) + I_B(\text{onsat})R_B + V_{BE} + I_E(\text{onsat})R_E = 0$$

$$V_i(\text{onsat}) = 0.021\text{m} \times 1\text{k} + 0.7 + 2.15\text{m} \times 1\text{k}$$

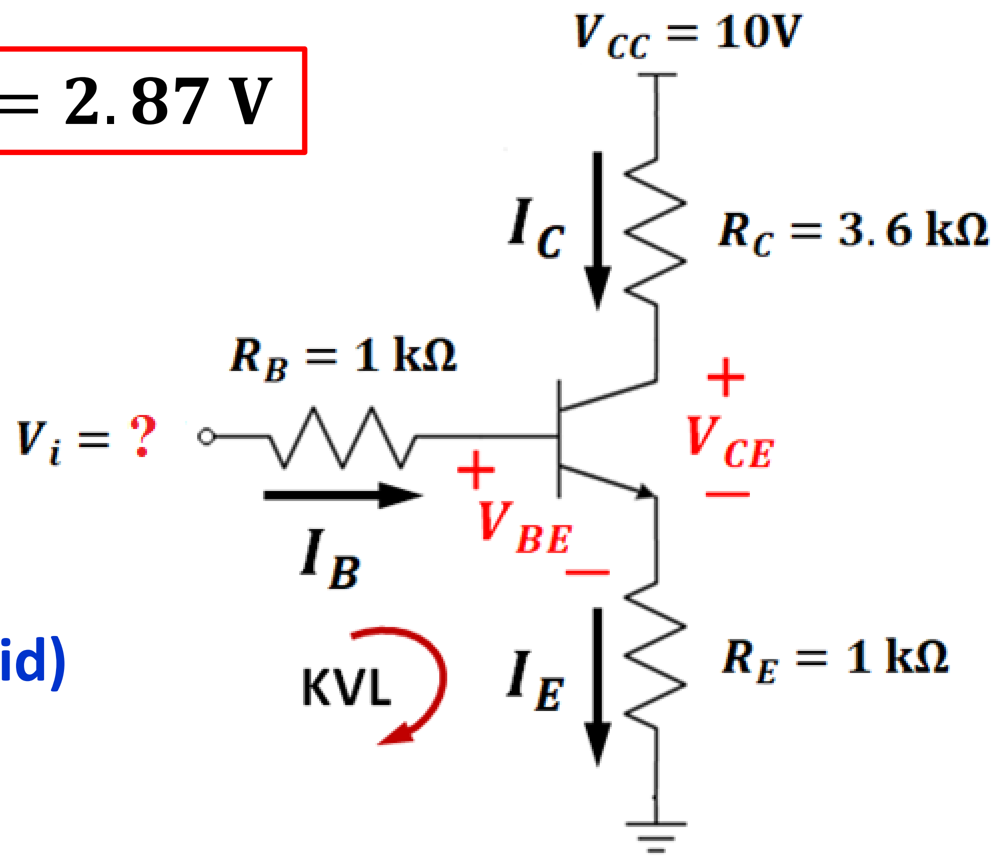
$$V_i(\text{onsat}) = 2.87\ \text{V}$$

At this input voltage on the base resistor, the BJT starts saturating

Resistor on emitter changes the saturation behavior

$$V_{BE}(\text{on}) \le V_B < V_i(\text{onsat}) = 2.87\ \text{V}$$

Forward-Active mode



$$V_B = V_i(\text{onsat}) = 2.87\ \text{V}$$

Onset of saturation

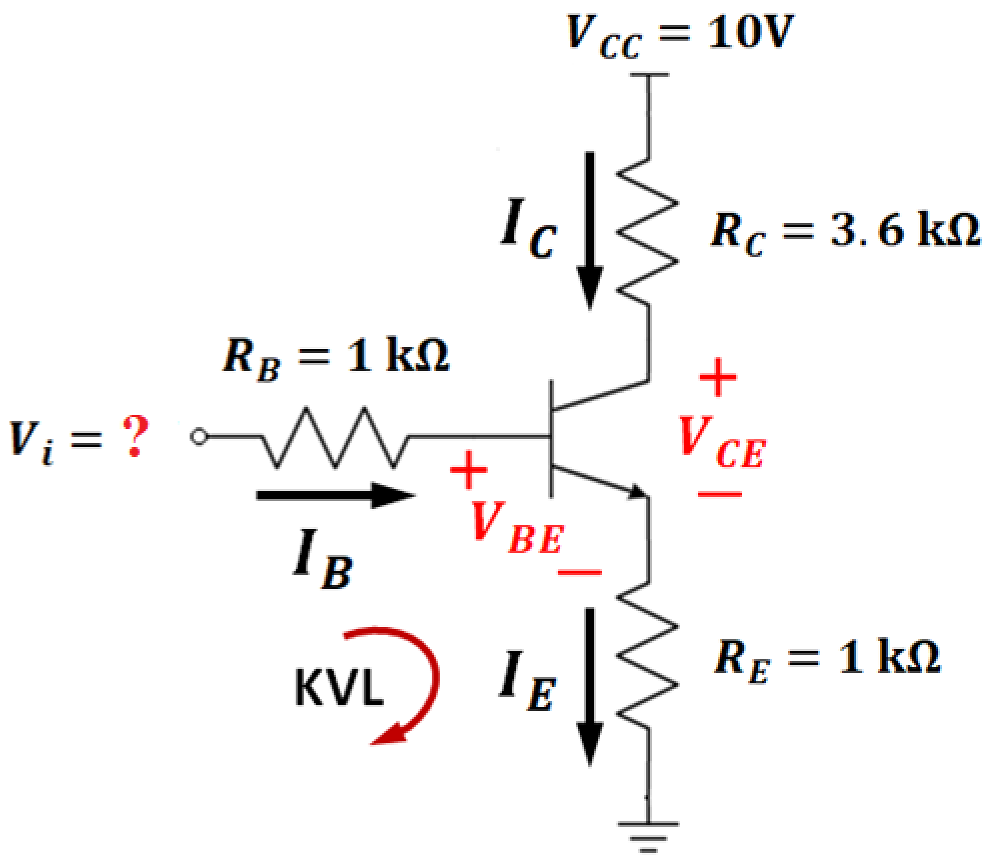
(FA mode equations are still valid)

$$V_B > V_i(\text{onsat}) = 2.87\ \text{V}$$

"*Deeper*" saturation

(FA mode equations are NOT valid)

In deeper saturation, collector current decreases somewhat



$V_{CC} = 10\ \text{V}$

$I_C R_C$

assume constant

$V_{CE} = V_{CE}(\text{sat}) = 0.2\ \text{V}$

$I_E R_E = (I_B + I_C)R_E$

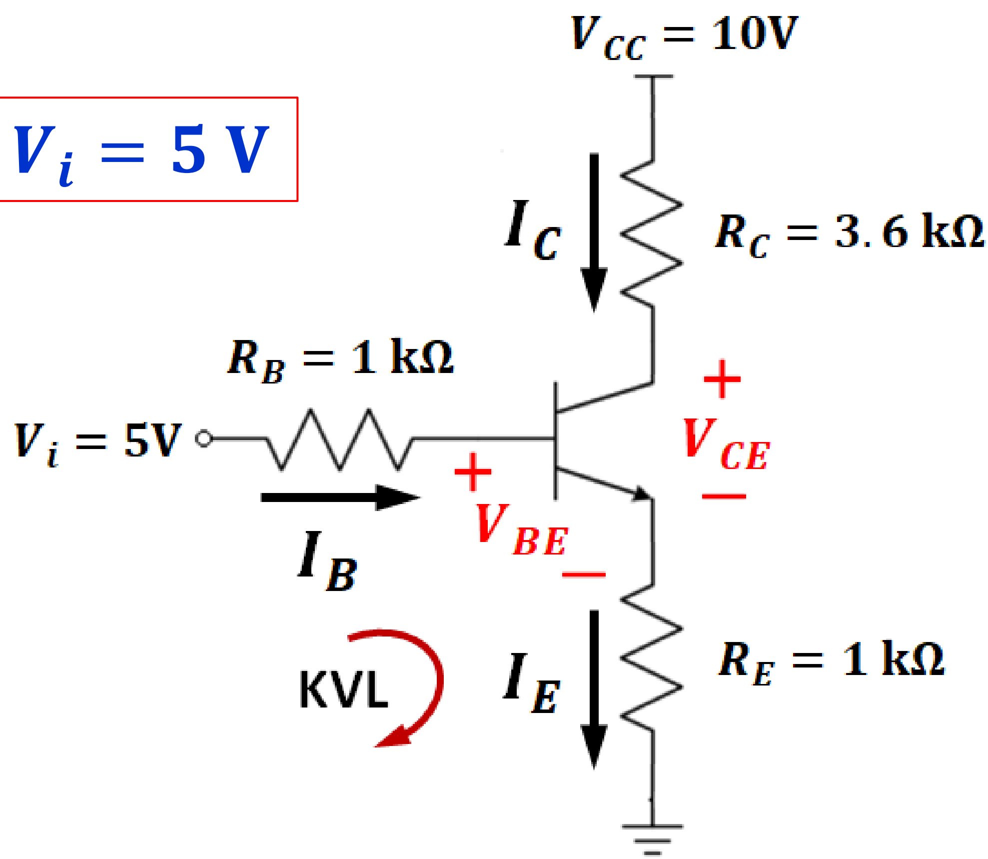
I_B keeps increasing in deeper saturation

$V_B > V_i(\text{onsat}) = 2.87\ \text{V}$

$I_C < I_C(\text{onsat}) = 2.13\ \text{mA}$

MUST SOLVE FOR COUPLED KVL's IN BASE AND COLLECTOR LOOPs

$V_i = 5\ \text{V}$



$V_{CC} = 10\ \text{V}$

$I_C R_C$

assume constant

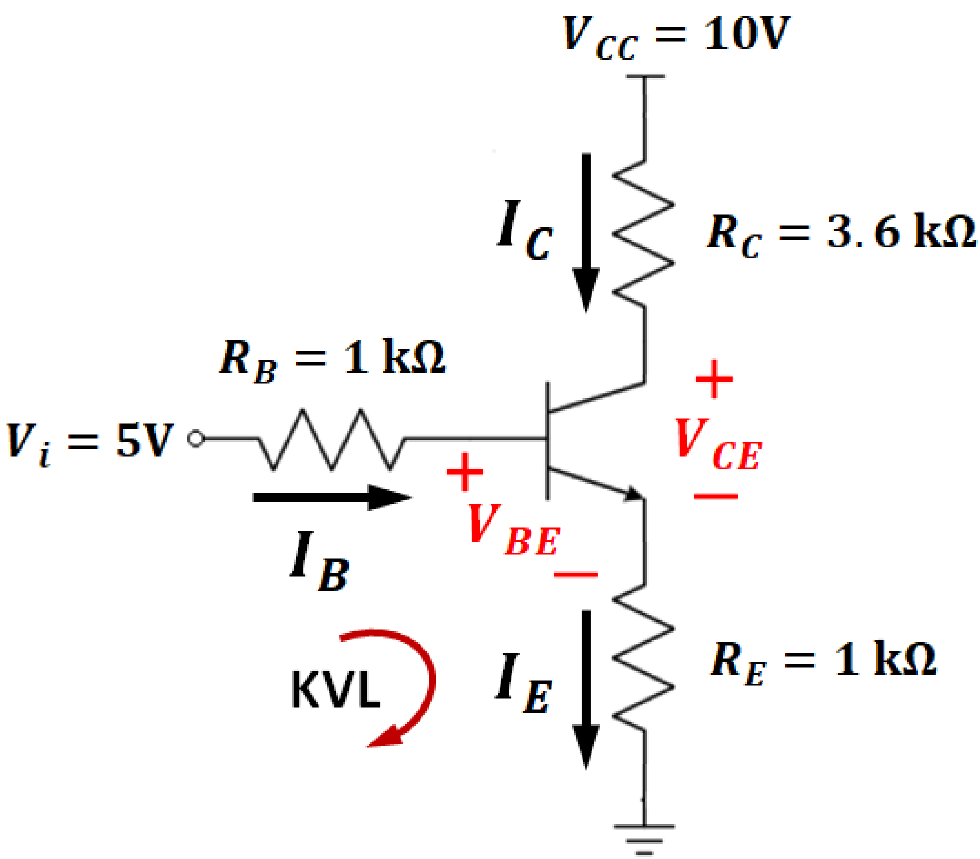
$V_{CE} = V_{CE}(\text{sat}) = 0.2\ \text{V}$

$I_E R_E = (I_B + I_C) R_E$

$$V_i = I_B R_B + V_{BE}\ (\text{on}) + I_E R_E$$

$$V_{CC} = I_C R_C + V_{CE}\ (\text{sat}) + I_E R_E$$

MUST SOLVE FOR COUPLED KVL's IN BASE AND COLLECTOR LOOPs



$$V_{CC} = 10\text{ V}$$

$$I_C R_C$$

assume constant

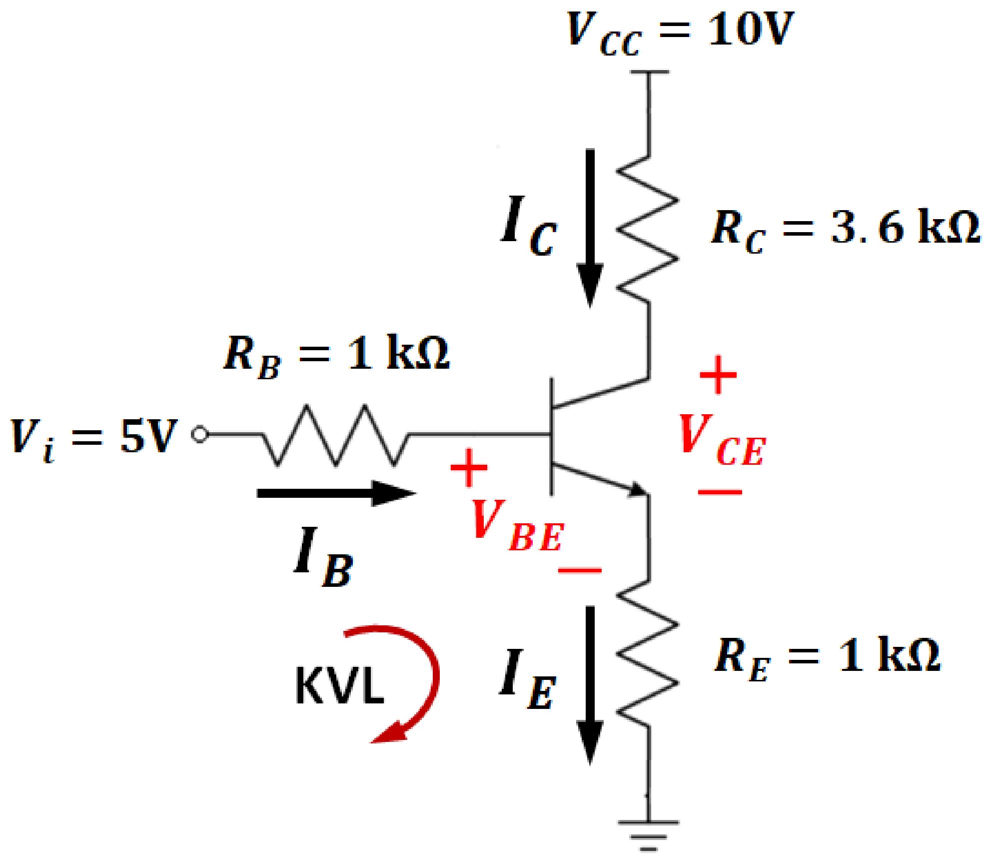
$$V_{CE} = V_{CE}(\text{sat}) = 0.2\text{ V}$$

$$I_E R_E = (I_B + I_C) R_E$$

$$5 = 1\text{k}\, I_B + 0.7 + (I_B + I_C)1\text{k}$$

$$10 = 3.6\text{k}\ \ I_C + 0.2 + (I_B + I_C)1\text{k}$$

MUST SOLVE FOR COUPLED KVL's IN BASE AND COLLECTOR LOOPs



$$V_{CC} = 10\ \text{V}$$

$$I_C R_C = 6.717\ \text{V}$$

assume constant

$$V_{CE} = V_{CE}(\text{sat}) = 0.2\ \text{V}$$

$$I_E R_E = (I_B + I_C)R_E = 3.083\ \text{V}$$

$$2\text{k}\ I_B + 1\text{k}\ I_C = 4.3$$

$$1\text{k}\ I_B + 4.6\text{k}\ \ I_C = 9.8$$

$$I_B = 1.217\ \text{mA}$$

$$I_C = 1.866\ \text{mA}\ < I_C(\text{onsat})$$

$$I_C(\text{onsat}) = 2.13\ \text{mA}$$