Example: A BJT Circuit in Saturation

Determine all currents for the BJT in the circuit below.

Hey! I remember this circuit, it's just like a previous example. The BJT is in active mode!

Let's see if you are correct! Assume it is in active mode and enforce $V_{CE} = 0.7\ V$ and $i_C = \beta \cdot i_B$.

The B-E KVL is therefore:

$$5.7 - 10 \cdot i_B - 0.7 - 2(99+1) \cdot i_B = 0$$

Therefore $i_B = 23.8\ \mu A$
See! Base current $i_B = 23.8 \mu A$, just like before. Therefore collector current and emitter current are again $i_C = 99i_B = 2.356 \ mA$ and $i_E = 100i_B = 2.380 \ mA$. Right?! 

Well maybe, but we still need to CHECK to see if our assumption is correct!

We know that $i_B = 23.8 \mu A > 0 \checkmark$, but what about $V_{CE}$?

From collector-emitter KVL we get:

$$10.7 - 10i_C - V_{CE} - 2i_E = 0$$

Therefore,

$$V_{CE} = 10.7 - 10(2.36) - 2(2.38) = -17.66 \ V < 0.7 \ V \ X$$

Our assumption is wrong! The BJT is not in active mode.

In the previous example, the collector resistor was 1K, whereas in this example the collector resistor is 10K. Thus, there is 10X the voltage drop across the collector resistor, which lowers the collector voltage so much that the BJT cannot remain in the active mode.
Q: So what do we do now?

A: Go to Step 5; change the assumption and try it again!

Lets ASSUME instead that the BJT is in saturation. Thus, we ENFORCE the conditions:

\[ V_{CE} = 0.2 \text{ V} \quad V_{BE} = 0.7 \text{ V} \quad V_{CB} = -0.5 \text{ V} \]

Now lets ANALYZE the circuit!

Note that we cannot directly determine the currents, as we do not know the base voltage, emitter voltage, or collector voltage.

But, we do know the differences in these voltages!

For example, we know that the collector voltage is 0.2 V higher than the emitter voltage, but we do not know what the collector or emitter voltages are!
Q: So, how the heck do we ANALYZE this circuit!?

A: Often, circuits with BJTs in saturation are somewhat more difficult to ANALYZE than circuits with active BJTs. There are often many approaches, but all result from a logical, systematic application of Kirchoff's Laws!

ANALYSIS EXAMPLE 1 - Start with KCL

We know that \( i_B + i_C = i_E \) (KCL)

But, what are \( i_B, i_C, \) and \( i_E \) ??

Well, from Ohm’s Law:

\[
\begin{align*}
i_B &= \frac{5.7 - V_B}{10} \\
i_C &= \frac{10.7 - V_C}{10} \\
i_E &= \frac{V_E - 0}{10}
\end{align*}
\]

Therefore, combining with KCL:

\[
\frac{5.7 - V_B}{10} + \frac{10.7 - V_C}{10} = \frac{V_E}{10}
\]

Look what we have, 1 equation and 3 unknowns.

We need 2 more independent equations involving \( V_B, V_C, \) and \( V_E \)!
Q: Two more independent equations!? It looks to me as if we have written all that we can about the circuit using Kirchoff’s Laws.

A: True! There are no more independent circuit equations that we can write using KVL or KCL! But, recall the hint sheet:

"Make sure you are using all available information".

There is more information available to us - the ENFORCED conditions!

\[ V_{CE} = V_C - V_E = 0.2 \quad \Rightarrow \quad V_C = V_E + 0.2 \]

\[ V_{BE} = V_B - V_E = 0.7 \quad \Rightarrow \quad V_B = V_E + 0.7 \]

Two more independent equations! Combining with the earlier equation:

\[
\frac{5.7 - (0.7 + V_E)}{10} + \frac{10.7 - (0.2 + V_E)}{10} = \frac{V_E}{10}
\]

One equation and one unknown! Solving, we get \( V_E = 2.2 \) V.

Inserting this answer into the above equations, we get:

\[ V_B = 2.9 \text{ V} \quad V_C = 2.4 \text{ V} \]

\[ i_C = 0.83 \text{ mA} \quad i_B = 0.28 \text{ mA} \quad i_E = 1.11 \text{ mA} \]
ANALYSIS EXAMPLE 2 – Start with KVL

We can write the KVL equation for any two circuit legs:

B-E KVL:
\[ 5.7 - 10 i_B - 0.7 - 2 i_E = 0.0 \]

C-E KVL:
\[ 10.7 - 10 i_C - 0.2 - 2 i_E = 0.0 \]

Note the ENFORCED conditions are included in these KVL equations.

Simplifying, we get these 2 equations with 3 unknowns:

\[ 5.0 = 10 i_B + 2 i_E \]
\[ 10.5 = 10 i_C + 2 i_E \]

We need one more independent equation involving \( i_B \), \( i_C \), and \( i_E \).
Try KCL!\[ \text{i}_\text{B} + \text{i}_\text{C} = \text{i}_\text{E} \]

**Inserting** the KCL equation into the 2 KVL equations, we get:
\[
\begin{align*}
5.0 &= 12 \text{i}_\text{B} + 2 \text{i}_\text{C} \\
10.5 &= 2 \text{i}_\text{B} + 12 \text{i}_\text{C}
\end{align*}
\]

Solving, we get the **same answers** as in analysis example 1.

**Lesson:** There are **multiple** strategies for analyzing these circuits; use the ones that you feel most **comfortable** with!

However you **ANALYZE** the circuit, you **must** in the end also **CHECK** your results.

First **CHECK** to see that all currents are **positive**:
\[
\begin{align*}
\text{i}_\text{C} &= 0.83 \text{ mA} > 0 \checkmark \\
\text{i}_\text{B} &= 0.28 \text{ mA} > 0 \checkmark \\
\text{i}_\text{E} &= 1.11 \text{ mA} > 0 \checkmark
\end{align*}
\]

Also **CHECK** **collector current**:
\[
\text{i}_\text{C} = 0.83 \text{ mA} < \beta \text{i}_\text{B} = 27.7 \text{ mA} \checkmark
\]

Our solution is **correct** !!!