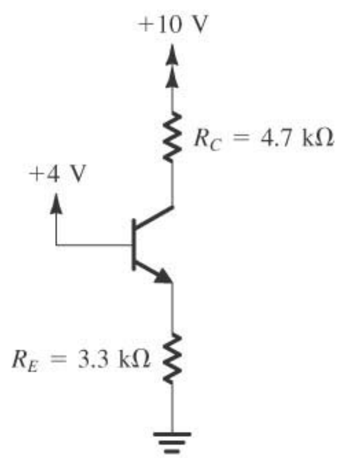
Lecture 12: DC Analysis of BJT Circuits.

In this lecture we will consider a number of BJT circuits and perform the DC circuit analysis. For those circuits with an active mode BJT, we'll assume that $V_{BE} = 0.7$ V (*npn*) or $V_{EB} = 0.7$ V (*pnp*) regardless of the collector current.

Example N12.1 (text Example 6.4). Compute the node voltages and currents in the circuit below assuming $\beta = 100$.



(Fig. 6.23a)

We'll assume the device is operating in the active mode, then we'll check this assumption at the end of the problem by calculating the bias of the EBJ and CBJ.

If the BJT is in the active mode, $V_{BE} = 0.7$ V then

$$V_E = 4 - V_{BE} = 3.3 \text{ V} \quad \text{and} \quad I_E = \frac{V_E}{R_E} = \frac{3.3}{3.3 \times 10^3} = 1 \text{ mA}.$$

With $I_C = \alpha I_E$ then

$$I_C = \frac{\beta}{\beta+1} \cdot 1 \text{ mA} = 0.99 \text{ mA}$$

Consequently, using KVL

$$V_C = 10 - I_C R_C = 10 - 0.99\times 10^{-3} \cdot 4.7\times 10^{3} = 5.3 \text{ V}$$

Finally, using KCL $I_B + I_C = I_E$, or

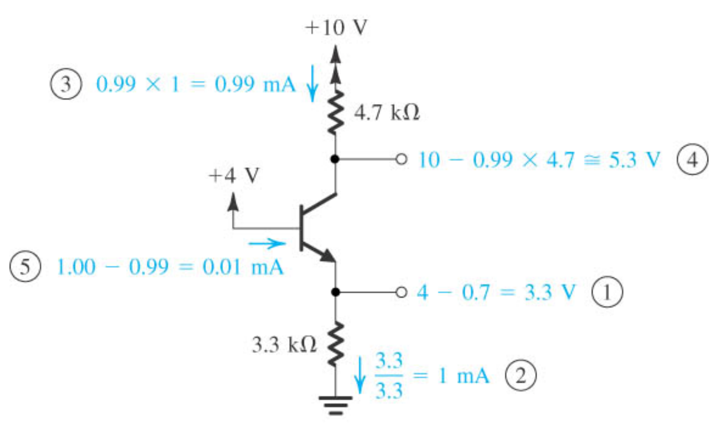
$$I_B = I_E - I_C = 1 - 0.99 = 0.01 \text{ mA}$$

Now we'll check to see if these values mean the BJT is in the active mode (as assumed).

- $V_{CB} = 5.3 - 4 = 1.3$ V. This is greater than zero, which means the CBJ is reversed biased.
- $V_{BE} = 0.7$ V. This is greater than zero, which means the EBJ is forward biased.

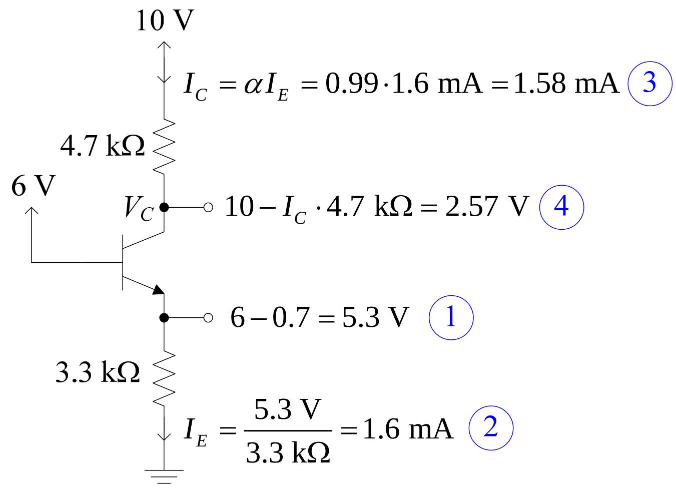
Because the CBJ is reversed biased and the EBJ is forward biased, the BJT is operating in the active mode.

Note that in the text, they show a technique for analyzing such circuits right on the circuit diagram in Fig. 6.23c. Very useful.



(Fig. 6.23c)

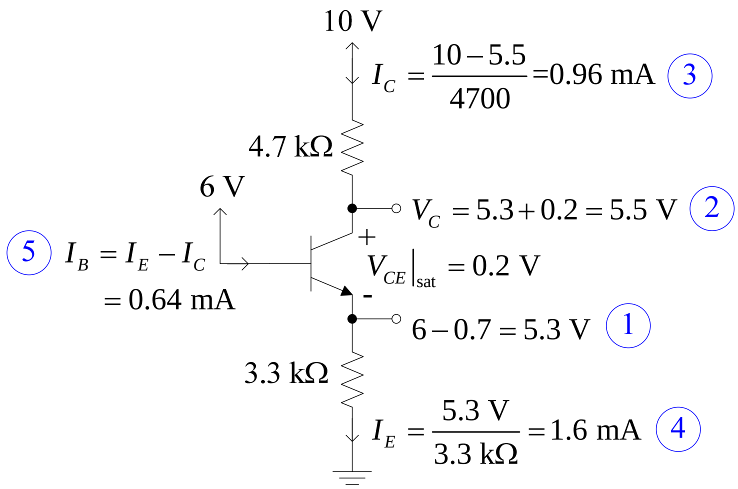
Example N12.2 (text Example 6.5). Repeat the previous example but with $V_B = 6$ V. Assuming the BJT is operating in the active mode:



From the last calculation $V_C = 2.57$ V $\Rightarrow$ $V_{CB} = -3.43$ V. Consequently, the BJT is **not** in the active mode because the CBJ is forward biased.

A better assumption is the transistor is operating in the saturation mode. We'll talk more about this later. For now, suffice it to say that in the saturation mode $V_{CE}\big|_{\text{sat}} \approx 0.2$ V (see Section 6.1.4).

Assuming this and reanalyzing the circuit:

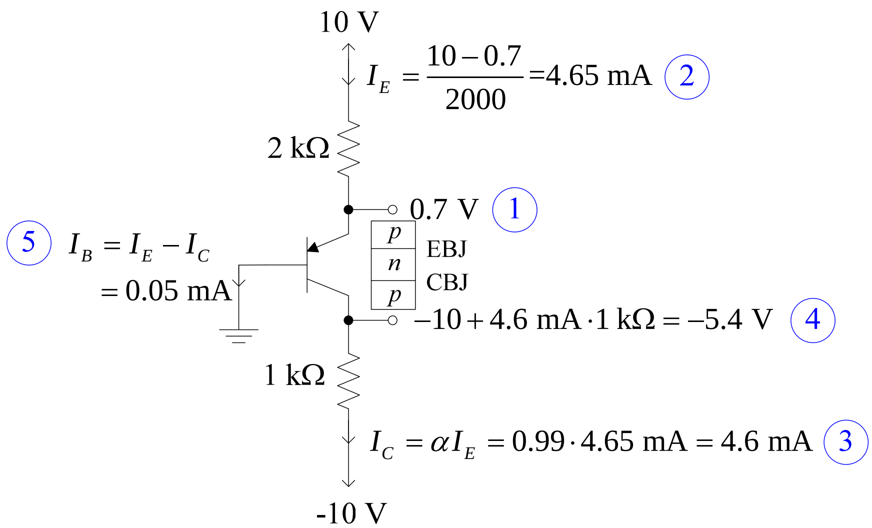


Notice that

$$\frac{I_C}{I_B} = \frac{0.96}{0.64} = 1.5$$

This ratio is often called β_{forced}. Observe that it's not equal to 100, as this ratio would be if the transistor were operating in the active mode (see Section 6.1.4).

Example N12.3 (text Example 6.7). Compute the node voltages and currents in the circuit below assuming β = 100. To begin, we'll assume the *pnp* transistor is operating in the active mode.

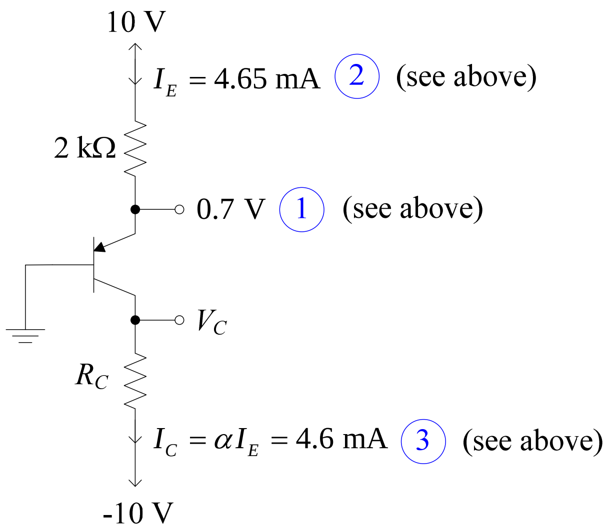


Now check if the BJT is in the active mode:

- EBJ? Forward biased.
- CBJ? Reversed biased.

So the BJT is in the active mode, as originally assumed.

Example N12.4 (text Exercise D6.25). Determine the largest R_C that can be used in the circuit below so that the BJT remains in the active mode. (This circuit is very similar to the one in the previous example.)



We'll begin by assuming the BJT is operating in the active mode. In the active mode, the CBJ needs to be reversed biased. The lowest voltage across this junction for operation in the active mode is $V_{CB} = 0 \Rightarrow V_C = V_B = 0$ V.

Therefore, by KVL

$$-10 + R_C I_C = 0$$

or

$$R_C = \frac{10}{I_C} = \frac{10}{4.6 \times 10^{-3}} = 2{,}174 \ \Omega$$

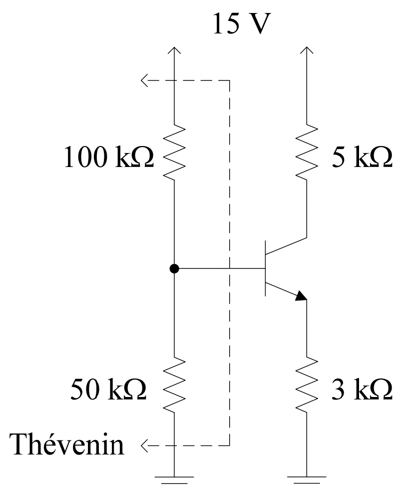
This value of R_C and smaller is required for the BJT to operate in the active mode.

This value of R_C is conservative since we have used the $V_{CB} = 0$ to define of the edge of the active region. The text gives a slightly different value $R_C = 2.26$ kΩ that was derived using a slightly different definition of the edge of the active region. As mentioned in Section 6.2.1, we can refine the edge of the active region to the voltage $V_{CB} \approx 0.4$ V where the CBJ is forward biased but not conducting appreciable current (think of the characteristic curve of a *pn* junction.)

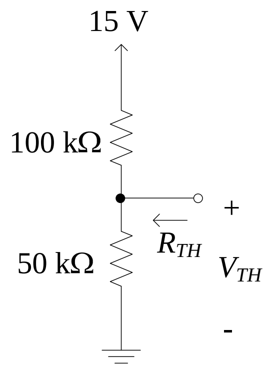
In this case,

$$R_C = \frac{0.4-(-10)}{I_C} = \frac{10.4}{4.6\times10^{-3}} = 2,261\ \Omega$$

Example N12.5 (text Example 6.10). Determine the node voltages and currents in the circuit shown below. Assume the BJT is operating in the active mode with $\beta = 100$.



First, we'll use Thévenin's theorem to simplify the base circuit



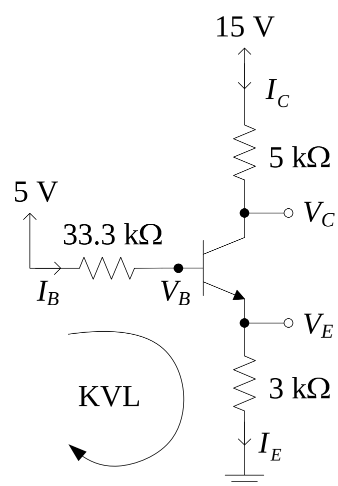
The Thévenin equivalent resistance and voltage are then

$$R_{TH} = 100 \text{ k}\Omega \,||\, 50 \text{ k}\Omega = 33.33 \text{ k}\Omega$$

and

$$V_{TH} = \frac{50}{100+50} 15 = 5 \text{ V}$$

Using this Thévenin equivalent for the base circuit, the overall circuit is then



To find the emitter current, we'll apply KVL over the loop shown giving

$$5 = 33.3\times 10^3 \cdot I_B + 0.7 + 3{,}000 \cdot I_E$$

The quantity of interest is I_B. With $I_C = \beta I_B$ and $I_C = \alpha I_E$ for a BJT in the active mode, we find

$$I_E = \frac{I_C}{\alpha} = \frac{\beta}{\alpha} I_B = \frac{\beta}{\beta/(\beta+1)} I_B$$

or
$$\boxed{I_E = (\beta+1) I_B \quad \text{(active mode)}}$$

Using this in the KVL equation

$$5 - 0.7 = \left[33.3\times10^3 + 3{,}000(\beta+1)\right] I_B$$

With $\beta = 100$ then solving this equation we find

$$I_B = 12.8\ \mu\text{A} \quad \Rightarrow \quad I_E = (\beta+1) I_B = 1.29\ \text{mA}.$$

Next, by KCL

$$I_C = I_E - I_B = 1.29\ \text{mA} - 12.8\ \mu\text{A} = 1.28\ \text{mA}$$

The node voltages are then

$$V_C = 15 - I_C \cdot 5\ \text{k}\Omega = 8.6\ \text{V}$$
$$V_E = I_E \cdot 3\ \text{k}\Omega = 3.87\ \text{V}$$
$$V_B = 5 - I_B \cdot 33.3\ \text{k}\Omega = 4.57\ \text{V}$$

Lastly, let's check if the BJT is operating in the active mode.

- $V_{BE} = V_B - V_E = 4.57 - 3.87 = 0.7$ V. This is 0.7 V originally assumed for a forward biased EBJ.
- $V_{BC} = V_B - V_C = 4.57 - 8.6 = -4.03$ V. This is less than zero, which means the CBJ is reversed biased.

Therefore the BJT is operating in the active mode, as originally assumed.