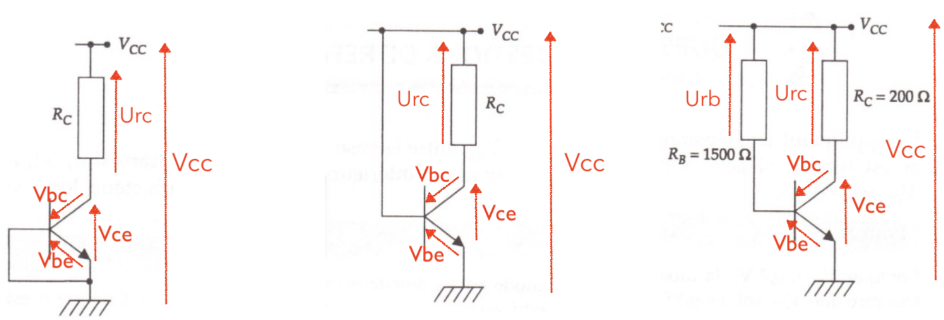
Epita/Info S3 Electronics

TD4 : Bipolar transistors

In this TD, we take $V_{BE} = 0.7V$ if the base-emitter junction is conducting.

Exercise 1

In the following diagrams, the transistor is not biased correctly to operate in the linear mode. Why ? Specify then its operation mode. We will take $V_{CC} = 10V$ and $\beta = 50$.



a. b. c.

Solution 1a

A transistor is in active mode if the BC junction is blocked and the BE junction conducting. This means: $V_{BC} < 0$ and $V_{BE} = 0.7V$. Let's see then if these conditions are satisfied in the present circuit :

In loop 2, KVL gives

$$V_{BE} = 0$$

We are clearly not in active mode, the BE junction being blocked.

In which mode is then this transistor operating ?

In one hand

$$I_E = 0 \text{ since BE is blocked}$$

In the other hand, we know that

$$I_E = I_B + I_C = \beta I_B + I_B = (\beta + 1) I_B \text{ since } I_C = \beta I_B$$

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

Since $I_E = 0$ therefore $I_B = 0$: This is the definition of the cut-off mode : the transistor is fully blocked.

Solution 1b

Here it is clear that $V_{CC} - V_{BE} = 0 \longrightarrow V_{BE} = V_{CC} = 10 >> 0.7V$ is excessively high: the junction (therefore the transistor) is damaged !

Solution 1c

Absurd reasoning: Assume the transistor is in active mode : $V_{BE} = 0.7$, $V_{BC} < 0$ and $I_C = \beta I_B$.
The transistor loop

$$V_{CE} + V_{BC} - V_{BE} = 0 \longrightarrow V_{CE} = V_{BE} - V_{BC} = 0.7 - V_{BC}$$

Since $V_{BC} < 0$, we have therefore

$$-V_{BC} > 0 \longrightarrow 0.7 - V_{BC} > 0.7 \longrightarrow V_{CE} > 0.7 \tag{1}$$

Let's check then if this last condition on V_{CE} is satisfied. Otherwise our active mode assumption is wrong.
Let's determine V_{CE} then:

$$V_{CC} - U_{RC} - V_{CE} = 0 \longrightarrow V_{CE} = V_{CC} - U_{RC} \longrightarrow V_{CE} = V_{CC} - R_C I_C$$

$$V_{CC} - U_{RB} - V_{BE} = 0 \longrightarrow V_{CC} - R_B I_B - V_{BE} = 0 \longrightarrow I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{10 - 0.7}{1500} \simeq 6.2mA.$$

Since

$$I_C = \beta I_B = 50 \times 6.2 = 310mA$$

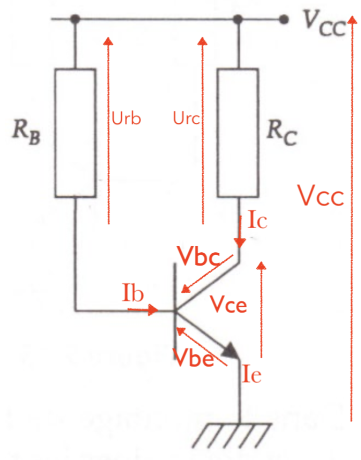
therefore

$$V_{CE} = V_{CC} - R_C I - C \longrightarrow V_{CE} = 10 - 200 \times 0,31 = -5.2V$$

This V_{CE} value is inconsistent with our assumption. Conclusion: we are not in active mode.

Exercise 2

Consider the diagram opposite. We have: $R_B = 10k\Omega$, $R_C = 50\Omega$, $V_{CC} = 10V$, $V_{CC} = 10V$, $V_{BE} = 0.7V$ and $\beta = 100$. Determine the transistor bias point.



Solution 2

Assume the transistor in active mode (BC blocked, BE conducting).
Determining the bias point consists in determining I_C, I_B, I_E, V_{BE}, V_{BC} and V_{CE}.
I_B can be obtained using KVL in the external loop:

$$V_{CC} - U_{RB} - V_{BE} = 0 \Longrightarrow V_{CC} - R_B I_B - V_{BE} = 0 \Longrightarrow R_B I_B = V_{CC} - V_{BE} \tag{2}$$

From this, we obtain I_B expression :

$$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{10 - 0.7}{10 \times 10^3} = 0.93 \quad mA} \tag{3}$$

I_C is obtained using current gain relation:

$$\boxed{I_C = \beta I_B = 93 \quad mA} \tag{4}$$

KCL at the transistor node gives :

$$\boxed{I_E = I_B + I_C = 93.93 \quad mA} \tag{5}$$

KVL in the left loop gives

$$\boxed{V_{BC} - U_{RC} - U_{RB} = 0 \Longrightarrow V_{BC} = R_C I_C - R_B I_B = -4.65V} \tag{6}$$

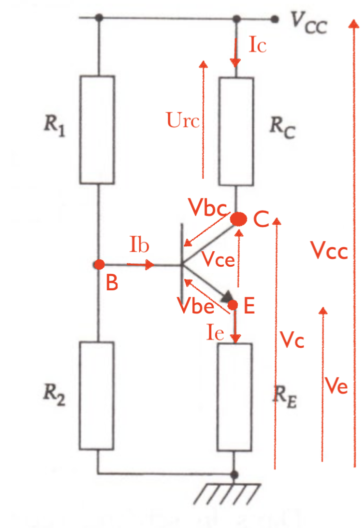
KVL around the transistor

$$\boxed{V_{CE} + V_{BC} - V_{BE} = 0 \Longrightarrow V_{CE} = V_{BE} - V_{BC} = 5.35V} \tag{7}$$

All the values obtained are consistent with the active mode.

Exercise 3

Consider the diagram opposite, in which $R = 10k\Omega$. Calculate the values of resistors R_1 , R_C and R_E so that the bias point is characterized by the potentials $V_E = 2V$, $V_C = 6V$ with a base current $I_B = 100\mu A$. We have $V_{CC} = 10V$ and $\beta = 100$.



Solution 3

$I_B \neq 0$: we are not in cut-off mode.

$V_{CE} = V_C - V_E = 4V > 0$: We are not in saturated mode.

We are therefore in active mode.

- Finding R_C

  KVL :

$$V_{CC} - U_{RC} - V_C = 0 \Longrightarrow U_{RC} = V_{CC} - V_C \Longrightarrow R_C I_C = V_{CC} - V_C$$

$$R_C = \frac{V_{CC} - V_C}{I_C} = \frac{V_{CC} - V_C}{\beta I_B} = 400\Omega$$

- Finding R_E

  Ohm's law :

$$V_E = R_E I_E \Longrightarrow R_E = \frac{V_E}{I_E}$$

  We knox that $I_E = I_C + I_B = \beta I_B + I_B = (\beta + 1) I_B$

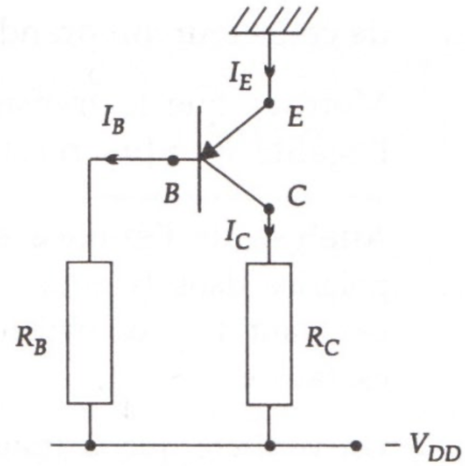
$$R_E = \frac{V_E}{(\beta + 1) I_B} = 198,02\Omega \simeq 200\Omega$$

- Finding R_1 and R_2

  All the attempts to find R_1 and R_2 distinctly have failed; simply because the two resistances can not be determined separately in this exercise.

Exercise 4

Consider the diagram opposite, where $R_B = 10k\Omega$, $R_C = 50k\Omega$, $V_{DD} = 10V$, $V_{BE} = 0.7V$ and $\beta = 100$. Determine the transistor bias point.



Solution 4

Notice that in this exercise, we are dealing with a PNP transistor. You conserve exactly the same orientation of voltages. The only thing to change is to take $V_{BE} = -0.7$ when BE is conducting. As a consequence, in a PNP active mode, V_{BC} is positive, V_{CE} is negative and V_{BE} negative. This is the simply the inverse of what we know from NPN active mode.

For your information, PNP transistor is not included in the exam. If you run out of time, move to the next exercise for your exam preparation.

Assume the transistor in active mode (BC blocked, BE conducting).

KVL in the external loop:

$$U_{RB} - V_{BE} - V_{DD} = 0 \Longrightarrow R_B I_B = V_{DD} + V_{BE} \tag{8}$$

From this we have

$$\boxed{I_B = \frac{V_{DD} + V_{BE}}{R_B} = 0.93 \quad mA} \tag{9}$$

$$\boxed{I_C = \beta I_B \Longrightarrow I_C = \frac{\beta(V_{DD} + V_{BE})}{R_B} = 93 \quad mA} \tag{10}$$

$$\boxed{I_E = I_C + I_B = (\beta + 1)I_B = \frac{(\beta + 1)(V_{DD} + V_{BE})}{R_B} = 93,93 \quad mA} \tag{11}$$

KVL in the right loop gives

$$V_{DD} - V_{CE} - U_{RC} = 0 \Longrightarrow V_{CE} = V_{DD} - R_C I_C \tag{12}$$

KVL in the left loop gives

$$U_{RB} - V_{BC} - U_{RC} = 0 \Longrightarrow V_{BC} = U_{RB} - U_{RC} = R_B I_B - R_C I_C \tag{13}$$

The values in the expression above are known. The calculation gives :

$$\boxed{V_{BC} = 4.6V}$$

The transistor loop gives :

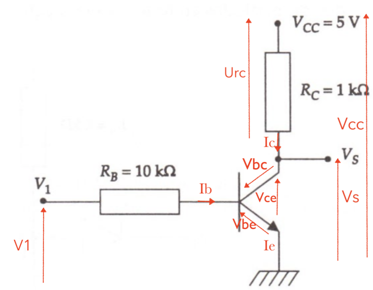
$$V_{BC} - V_{BE} - V_{CE} = 0 \Longrightarrow V_{CE} = V_{BC} - V_{BE}$$

After calculation :

$$\boxed{V_{CE} = -5.4V}$$

Exercise 5

Consider the diagram opposite. Calculate the voltage V_S if $V_1 = 0V$ and $V_1 = 5V$. We have $\beta = 100$.



Solution 5

Assume the transistor in active mode (BC blocked and BE blocked).

KVL in the right loop gives:

$$V_{CC} - U_{RC} - V_S = 0 \Longrightarrow V_S = V_{CC} - U_{RC} \tag{14}$$

$$V_S = V_{CC} - R_C I_C \tag{15}$$

I_C value is not given We need to find its expression. KVL in the left loop gives:

$$V_1 - R_B I_B - V_{BE} = 0 \tag{16}$$

$$I_B = \frac{V_1 - V_{BE}}{R_B} \tag{17}$$

Current gain gives

$$I_C = \beta I_B = \frac{\beta(V_1 - V_{BE})}{R_B} \tag{18}$$

I_C expression injected in expression 15 allows to find V_S final expression

$$\boxed{V_S = V_{CC} - \beta\frac{R_C}{R_B}(V_1 - V_{BE})} \tag{19}$$

We can now calculate V_S for different values of V_1, as asked:

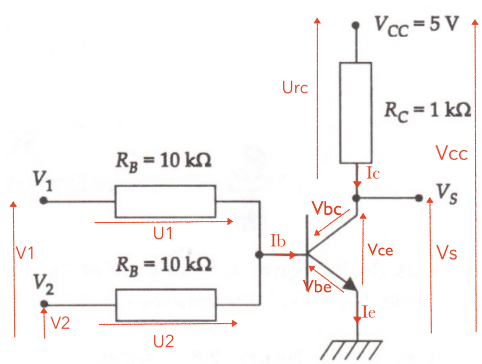
$$\text{if} \quad V_1 = 0V \Longrightarrow V_S = 12V$$

$$\text{if} \quad V_1 = 5V \Longrightarrow V_S = -38V$$

Exercise 6

Consider the circuit opposite. Calculate V_S in the following cases :

- $V_1 = V_2 = 0V$
- $V_1 = 5V$ and $V_2 = 0V$
- $V_1 = 0$ and $V_2 = 5V$
- $V_1 = V_2 = 5V$



With $\beta = 100$

Solution 6

The left loop provides :

$$V_{CC} - U_{RC} - V_S = 0 \tag{20}$$

$$V_S = V_{CC} - U_{RC} \tag{21}$$

$$V_S = V_{CC} - R_C I_C \tag{22}$$

I_C value is not given We need to find its expression in terms of known quantities. KVL in the left loop gives:

$$U_2 = V_2 - V_{BE} \longrightarrow R_B I_2 = V_2 - V_{BE} \longrightarrow I_2 = \frac{V_2 - V_{BE}}{R_B} \tag{23}$$

$$U_1 = V_1 - V_{BE} \longrightarrow R_B I_1 = V_1 - V_{BE} \longrightarrow I_1 = \frac{V_1 - V_{BE}}{R_B} \tag{24}$$

$$I_B = I_1 + I_2 \tag{25}$$

$$I_B = \frac{V_2 - V_{BE}}{R_B} + \frac{V_1 - V_{BE}}{R_B} = \frac{V_2 + V_1 - 2V_{BE}}{R_B} \tag{26}$$

$$I_C = \beta I_B = \frac{\beta}{R_B}(V_1 + V_2 - 2V_{BE}) \tag{27}$$

I_C expression injected in expression 22 allows to find V_S final expression

$$V_S = V_{CC} - \beta \frac{R_C}{R_B}(V_1 + V_2 - 2V_{BE}) \tag{28}$$

We can now calculate V_S for different values of V_1 and V_2, as asked:

- $V_1 = V_2 = 0V \longrightarrow V_S = 19V$
- $V_1 = 5V$ and $V_2 = 0V \longrightarrow V_S = -31V$
- $V_1 = 0V$ and $V_2 = 5V \longrightarrow V_S = -31V$
- $V_1 = V_2 = 5V \longrightarrow V_S = -81V$