Electronics and Measurements Laboratory

Ex. 2
Bipolar Transistor

Section 4:

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Purpose of the exercise

The purpose of this exercise was to test a bipolar transistor – in this case, *BCP54 type transistor*. The purpose of testing the transistor was to get acquainted with its properties and to determine its characteristics:

- Output characteristic
- Transfer characteristic
- Input characteristic
- Reverse characteristic

1 Start of the task – building the circuit.

In accordance with the instruction of the task, we started building the circuit.

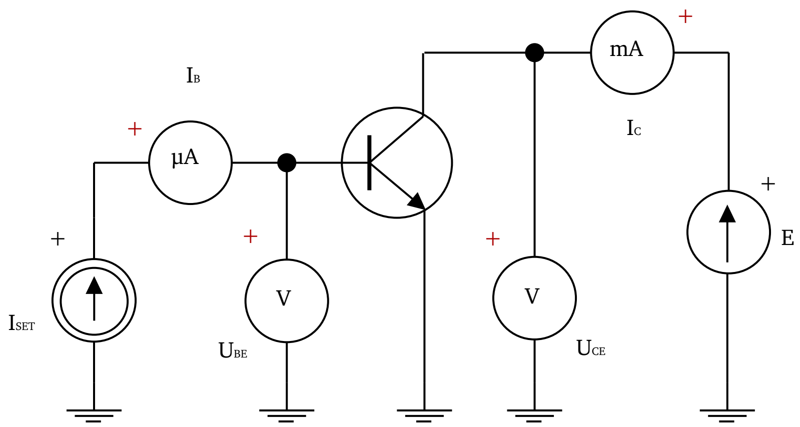


Figure 1: The measurement scheme used to measure characteristics of the bipolar transistor

After building the circuit (see figure 1) we started with measurements related to input and transfer current-voltage characteristics, and the results were recorded in a measurement card. The test consisted of setting the U_{CE} voltage to 0.5V, 4V, and 9V respectively and saving the changes in U_{BE} and I_{CE}.

Additionally, we wrote down the differences in what the I_B ammeter shows and what we pass on to the system as an I_{SET} current source.

1.1 Measurement of input and transfer characteristics of a transistor

While writing the results, we noticed that exceptionally outliers appeared when the current was set to $5 \times n$, where n is the multiplier on the second knob.

		$U_{CE} = U_{CE1}$ = 0.5 V		$U_{CE} = U_{CE2}$ = 4 V		$U_{CE} = U_{CE3}$ = 9 V	
I_{set} [µA]	I_B [µA]	U_{BE} [V]	I_C [mA]	U_{BE} [V]	I_C [mA]	U_{BE} [V]	I_C [mA]
2	2	0.557	0.16	0.557	0.17	0.555	0.17
5	05.07	0.586	0.51	0.585	0.51	0.54	0.52
10	10.17	0.606	1.11	0.606	1.13	0.605	1.14
15	15.15	0.618	1.74	0.617	1.76	0.616	1.78
20	20.4	0.626	2.39	0.625	2.41	0.624	2.44
30	30.5	0.637	3.69	0.636	3.73	0.635	3.78
40	40.6	0.646	05.01	0.644	05.08	0.642	5.15
50	50.7	0.652	6.33	0.65	6.43	0.647	6.53
60	60.7	0.657	7.67	0.655	7.8	0.651	7.93
70	70.8	0.662	09.01	0.658	9.18	0.654	9.35
80	80.9	0.665	10.35	0.662	10.56	0.657	10.79
90	90.9	0.669	11.7	0.665	11.94	0.659	12.23
100	100.9	0.672	13.04	0.667	13.33	0.667	13.69

Table 1: Input and transfer current-voltage characteristic measurements

Warning: The table indicates in red a result that does not match the rest and is the result of an incorrect measurement. It is still included on the chart below (see Fig 2), but this error will not be taken into account when creating the chart in the "Section 2 – Summary".

The data presented in the table can be presented in two charts of interest to us:

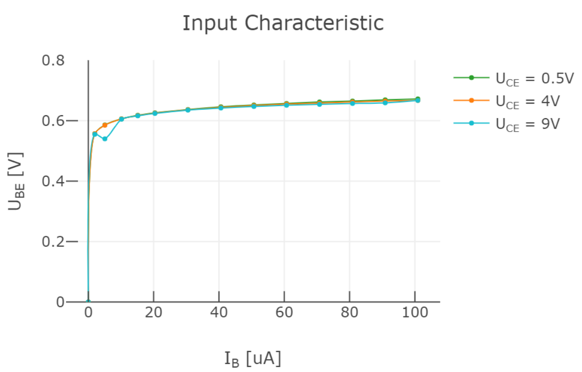


Figure 2: Input characteristic diagram

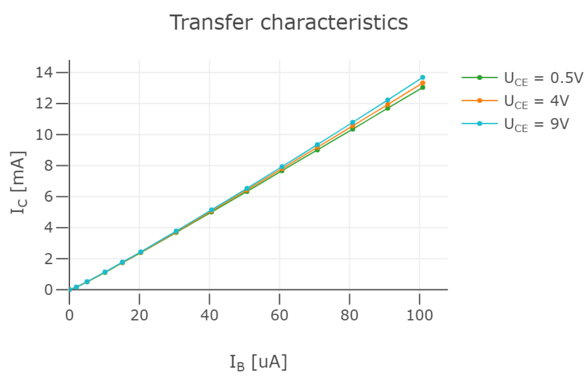


Figure 3: Transfer characteristic diagram

Using data from Table 1 we can determine the small signal parameters h_{11} and h_{21}. To do that, we'll use two equations:

$$h_{11} = \frac{\Delta U_{BE}}{\Delta I_B}\Big|_{\Delta U_{CE}=0} = \frac{u_{be}}{i_b}\Big|_{u_{ce}=0} \tag{1}$$

$$h_{21} = \frac{\Delta I_C}{\Delta I_B}\Big|_{\Delta U_{CE}=0} = \frac{i_c}{i_b}\Big|_{u_{ce}=0} \tag{2}$$

$$h_{12} = \frac{\Delta U_{BE}}{\Delta U_{CE}}\Big|_{\Delta I_B=0} = \frac{u_{be}}{u_{ce}}\Big|_{i_b=0} \tag{3}$$

$$h_{22} = \frac{\Delta I_C}{\Delta U_{CE}}\Big|_{\Delta I_B=0} = \frac{i_c}{u_{ce}}\Big|_{i_b=0} \tag{4}$$

1.1.1 Determining the small signal parameters h_{11} and h_{21}

Having operating points:

- $U_{CE} = 4V$ and I_C corresponding to the $I_B = 15\ \mu A \longrightarrow U_{BE} = 0.617V, I_C = 1.76mA$
- $U_{CE} = 4V$ and I_C corresponding to the $I_B = 30\ \mu A \longrightarrow U_{BE} = 0.636V, I_C = 3.73mA$
- $U_{CE} = 9V$ and I_C corresponding to the $I_B = 15\ \mu A \longrightarrow U_{BE} = 0.616V, I_C = 1.78mA$
- $U_{CE} = 9V$ and I_C corresponding to the $I_B = 30\ \mu A \longrightarrow U_{BE} = 0.635V, I_C = 3.78mA$

Using equations (1), (2), (3) and (4) we calculate:

$$h_{11} = \frac{\Delta U_{BE}}{\Delta I_B}\Big|_{\Delta U_{CE}=0} = \frac{0.636\ -\ 0.617}{0.000030\ -\ 0.000015} = 1266.66\ \Omega$$

$$h_{21} = \frac{\Delta I_C}{\Delta I_B}\Big|_{\Delta U_{CE}=0} = \frac{0.00373\ -\ 0.00176}{0.000030\ -\ 0.000015} = 131.33$$

$$h_{11} = \frac{\Delta U_{BE}}{\Delta I_B}\Big|_{\Delta U_{CE}\equiv 0} = \frac{0.635\ -\ 0.616}{0.000030\ -\ 0.000015} = 1266.66\ \Omega$$

$$h_{21} = \frac{\Delta I_C}{\Delta I_B}\Big|_{\Delta U_{CE}\equiv 0} = \frac{0.00378\ -\ 0.00178}{0.000030\ -\ 0.000015} = 133.33$$

$$h_{12} = \frac{\Delta U_{BE}}{\Delta U_{CE}}\Big|_{\Delta I_B\equiv 0} = \frac{0.616\ -\ 0.617}{9\ -\ 4} = -0.0002$$

$$h_{12} = \frac{\Delta U_{BE}}{\Delta U_{CE}}\Big|_{\Delta I_B\equiv 0} = \frac{0.635\ -\ 0.636}{9\ -\ 4} = -0.0002$$

$$h_{22} = \frac{\Delta I_C}{\Delta U_{CE}}\Big|_{\Delta I_B\equiv 0} = \frac{0.00378\ -\ 0.00373}{9\ -\ 4} = 0.00001\ S$$

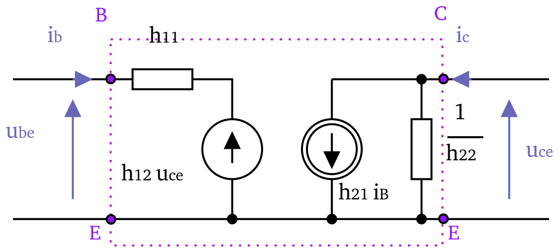
$$h_{22} = \frac{\Delta I_C}{\Delta U_{CE}}\Big|_{\Delta I_B\equiv 0} = \frac{0.00178\ -\ 0.00176}{9\ -\ 4} = 0.000004\ S$$

1.1.2 Drawing the transistor small-signal equivalent circuits

For two operating points:

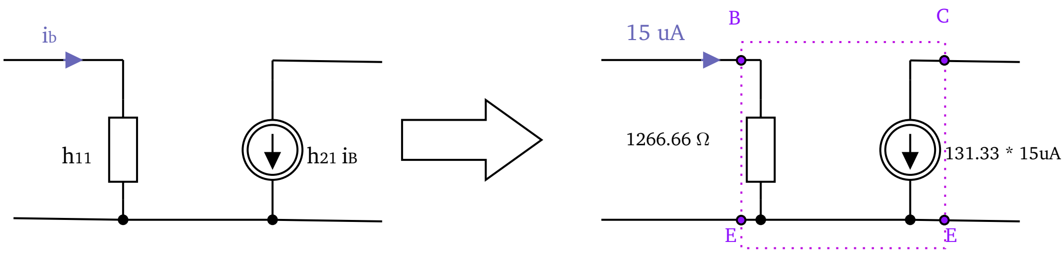
- $U_{CE} = 4V$ and I_C corresponding to the $I_B = 15\ \mu A \longrightarrow U_{BE} = 0.617V, I_C = 1.76mA$
- $U_{CE} = 4V$ and I_C corresponding to the $I_B = 30\ \mu A \longrightarrow U_{BE} = 0.636V, I_C = 3.73mA$

And for the general scheme:



We get:

$$h_{11} = 1266.66\ \Omega \qquad h_{21} = 131.33$$
$$h_{12} \simeq 0 \qquad h_{22} \simeq 0$$
$$i_B = 15\mu A \qquad u_{be} = 0.019V$$

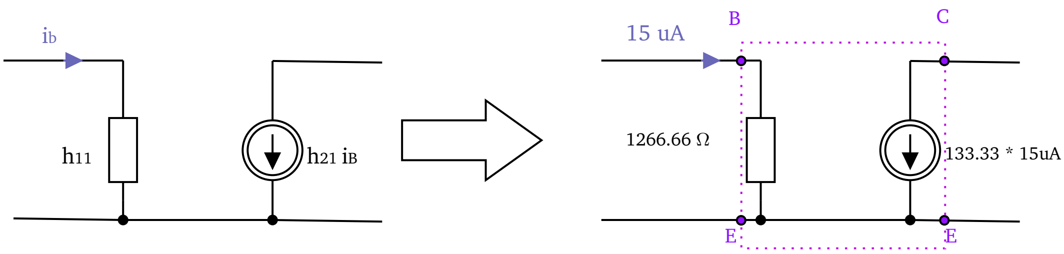


For two another points:

1. $U_{CE} = 9V$ and I_C corresponding to the $I_B = 15\ \mu A \longrightarrow U_{BE} = 0.616V, I_C = 1.78mA$
2. $U_{CE} = 9V$ and I_C corresponding to the $I_B = 30\ \mu A \longrightarrow U_{BE} = 0.635V, I_C = 3.78mA$

We would get:

$$h_{11} = 1266.66\ \Omega \qquad h_{21} = 133.33$$
$$h_{12} \simeq 0 \qquad h_{22} \simeq 0$$
$$i_B = 15\mu A \qquad u_{be} = 0.019V$$



1.2 Measurement of output and reverse characteristics of a transistor

	$I_B = I_{B1}$ = 15 µA		$I_B = I_{B2}$ = 30 µA		$I_B = I_{B3}$ = 60 µA	
U_{CE} [V]	U_{BE} [V]	I_C [mA]	U_{BE} [V]	I_C [mA]	U_{BE} [V]	I_C [mA]
0	0.542	0	0.563	-0.01	0.583	-0.02
0.05	0.591	0.54	0.611	1.1	0.629	2.27
0.1	0.611	1.28	0.632	2.79	0.65	5.58
0.15	0.618	1.68	0.638	3.52	0.658	7.3
0.2	0.619	1.73	0.639	3.66	0.659	7.6
0.3	0.619	1.74	0.639	3.69	0.659	7.66
0.4	0.619	1.74	0.639	3.69	0.659	7.67
0.5	0.619	1.74	0.639	3.69	0.659	7.67
0.6	0.619	1.75	0.639	3.69	0.659	7.68
0.9	0.619	1.75	0.639	3.7	0.659	7.69
1	0.619	1.75	0.639	3.71	0.659	7.69
2	0.619	1.75	0.639	3.72	0.658	7.72
3	0.619	1.76	0.638	3.72	0.657	7.75
4	0.619	1.76	0.638	3.73	0.657	7.78
5	0.619	1.77	0.638	3.74	0.657	7.81
6	0.618	1.77	0.637	3.75	0.655	7.85
7	0.618	1.77	0.637	3.76	0.654	7.88
8	0.618	1.78	0.636	3.77	0.653	7.91
9	0.617	1.78	0.636	3.78	0.652	7.94
10	0.617	1.78	0.635	3.79	0.651	7.96

Table 2: Output and Reverse current-voltage characteristic measurements

The data presented in the table can be presented in two charts of interest to us:

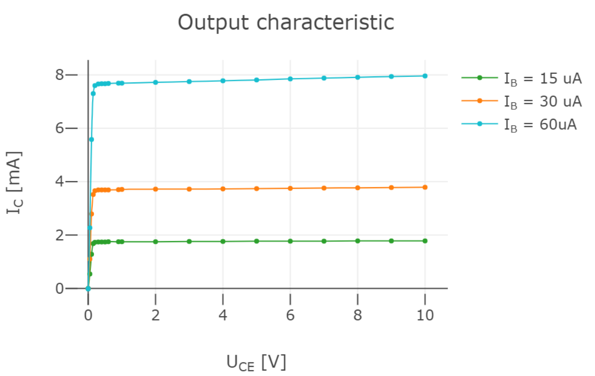


Figure 4: Output characteristic diagram

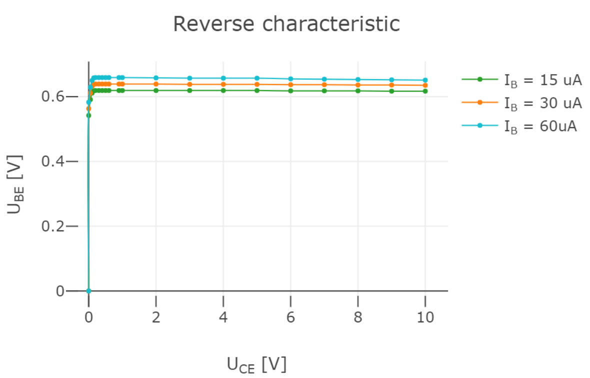
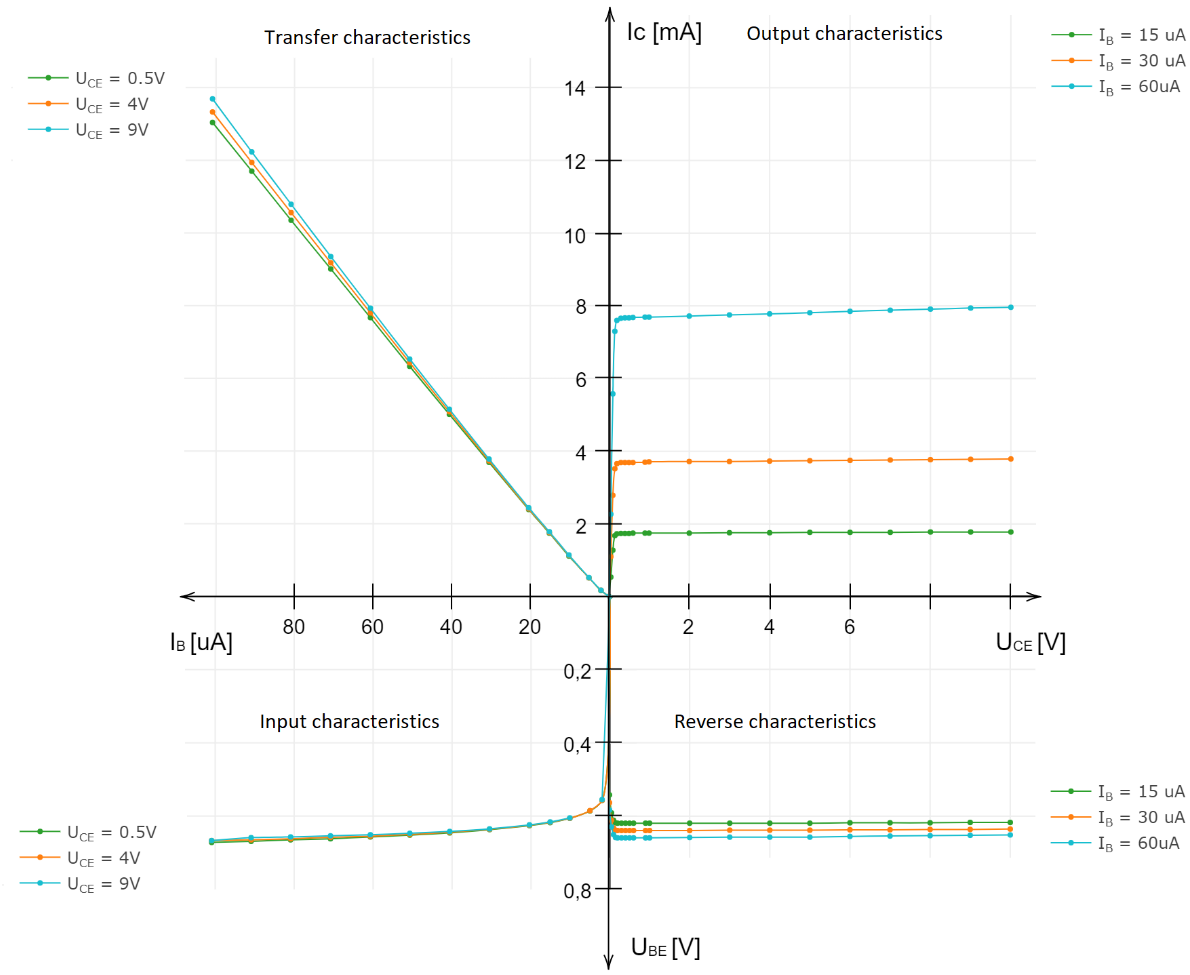


Figure 5: Reverse characteristic diagram

2 Summary

After collecting all the information and processing it into one chart, we get it:



2.1 Conclusions

The characteristics of the transistor are as much in line with what we expected. Although our measurements were not perfect and one mentioned error had to be thrown out of the final chart, but after the obtained characteristics we can make many conclusions.

Thanks to the output characteristics we can see that the transistor can be a kind of current controlled current source (CCCS). We can see that the current of the collector increases proportionally with the value of the base current, which at the same time proves its ability to amplify the current flowing between the base and the emitter.

From the transition characteristics it can be concluded that the collector current depends directly proportionally on the base current (of course in the range of normal transistor operation).

From the reverse characteristics it can be seen that changes in the collector-emiter voltage rather slightly affect the base-emiter voltage.

As I also mentioned before – we had one very wrong measurement, which was thrown out of the final graph. There were more anomalies and different knob combinations for the same values gave us different results. For example, setting the current knobs to 5×2 gave different results than setting them to 1×10. Of course, they were not extremely different, although slightly different.