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Electronics and Measurements Laboratory

Ex. 3
Unipolar Transistor

Section 4:

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Purpose of the exercise

The aim of the task was to get acquainted with the current-voltage characteristics of the n-channel J-FET type BF545B.

1 Start of the task – building the circuit.

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

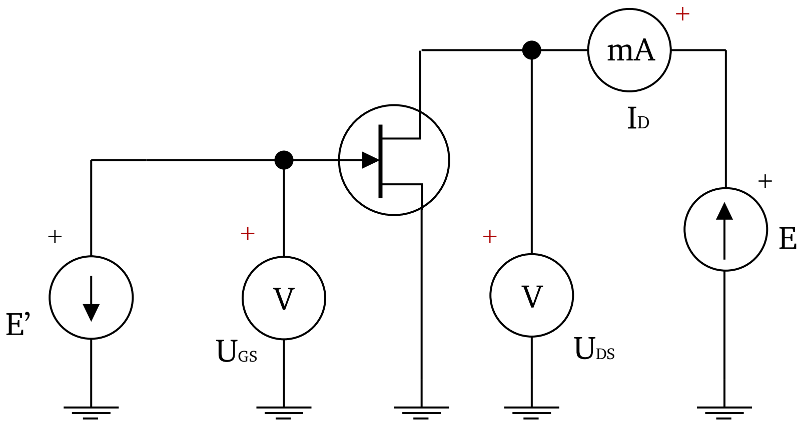

Figure 1: The measurement scheme used to measure characteristics of the unipolar transistor

Compared to the bipolar transistor, which is controlled by the current, here the unipolar transistor is controlled by the voltage (this is the difference of potentials between the gate and the source) – that is why in the diagram we can see the voltage source in comparison to a bipolar transistor, where the current source was present.

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1.1 Measurement of j-FET transfer current-voltage characteristic

After building the circuit, we started researching the transfer characteristics. For this purpose, we filled in the measurement table. Our $U_{GS_{off}}$ value was *-2.68 V*. Then for U_{DS} = 1V, U_{DS} = 4V, U_{DS} = 8V we wrote down the I_D value for $U_{GS_{off}}$ multiplied by the multipliers given in the table, and we have also written down their respective U_{GS} values.

To be more precise, to achieve this we have set I_{SET} at $10 \times 0.5\ mA$. U_{DS} has been set to 8 V and the potentiometer value has been set so that I_D is close to zero. Then we were changing the multiplier I_{SET} accordingly. For example, $I_{SET} = 9 \times 0.5\ mA \longrightarrow 0.9 \times U_{GS_{off}}$. This allowed us to control U_{GS}.

			$U_{DS} = U_{DS1}$ = 1V	$U_{DS} = U_{DS2}$ = 4V	$U_{DS} = U_{DS3}$ = 8V
multiplier		U_{GS} [V]	I_D [mA]	I_D [mA]	I_D [mA]
x10	$1.0 * U_{GS_{off}} =$	-2.68	0.00066	0.00275	0.00577
x9	$0.9 * U_{GS_{off}} =$	-2.4	0.0243	0.0517	0.08
x8	$0.8 * U_{GS_{off}} =$	-2.14	0.1805	0.297	0.386
x7	$0.7 * U_{GS_{off}} =$	-1.87	0.545	0.871	0.932
x6	$0.6 * U_{GS_{off}} =$	-1.6	1.051	1.444	1.649
x5	$0.5 * U_{GS_{off}} =$	-1.34	1.636	2.24	2.5
x4	$0.4 * U_{GS_{off}} =$	-1.07	2.26	3.16	3.45
x3	$0.3 * U_{GS_{off}} =$	-0.8	2.9	4.19	4.51
x2	$0.2 * U_{GS_{off}} =$	-0.54	3.55	5.32	5.67
x1	$0.1 * U_{GS_{off}} =$	-0.27	4.22	6.53	6.91
x0	$0.0 * U_{GS_{off}} =$	0	4.92	7.85	8.24

From the table we get:

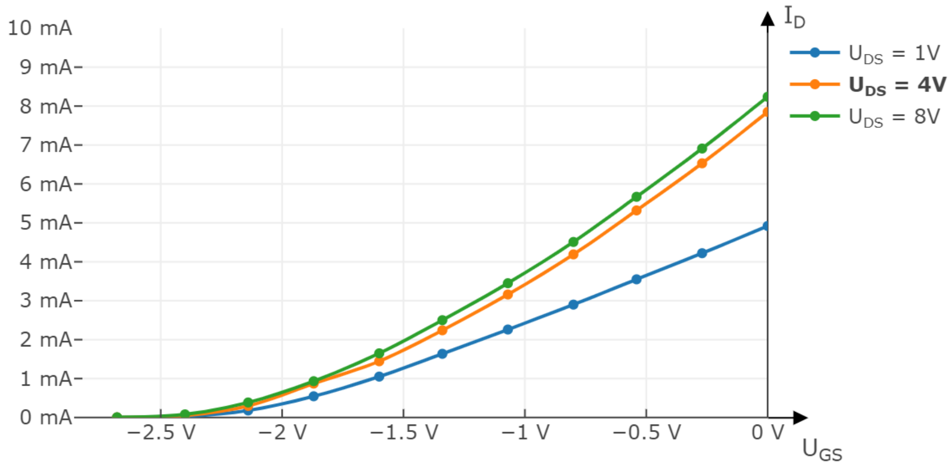


Figure 2: Transfer characteristics of n-channel J-FET

1.2 Measurement of j-FET output current-voltage characteristic

In this part of the task, in order to measure the output characteristics, we set the U_{DS} by changing knob several times and wrote down on the measurement card the I_D measurement for 0.5, 0.3 and 0.0 multiplied by $U_{GS_{off}}$

	$0.5 \times U_{GS_{off}} = -1.34\ V$	$0.3 \times U_{GS_{off}} = -0.8\ V$	$0.0 \times U_{GS_{off}} = 0\ V$
U_{DS} [V]	I_D [mA]	I_D [mA]	I_D [mA]
-0.5	-1.727	-2.42	-0.365
-0.4	-1.332	-1.874	-2.85
-0.3	-0.965	-1.359	-2.08
-0.2	-0.612	-0.892	-1.373
-0.1	-0.284	-0.433	-0.636
0	-0.00235	-0.00041	-0.0004
0.1	0.31	0.464	0.718
0.2	0.566	0.853	1.302
0.3	0.778	1.205	1.88
0.4	0.964	1.537	2.42
0.5	1.139	1.831	2.92
0.6	1.276	2.1	3.37
0.8	1.492	2.55	4.22
1	1.636	2.89	4.91
1.2	1.744	3.16	5.49
1.4	1.82	3.36	5.96
1.7	1.91	3.57	6.49
2	1.98	3.72	6.88
2.5	2.06	3.88	7.29
3	2.13	4	7.54
4	2.23	4.16	7.82
6	2.38	4.36	8.09
8	2.48	4.5	8.23
10	2.57	4.59	8.34

From the table we get:

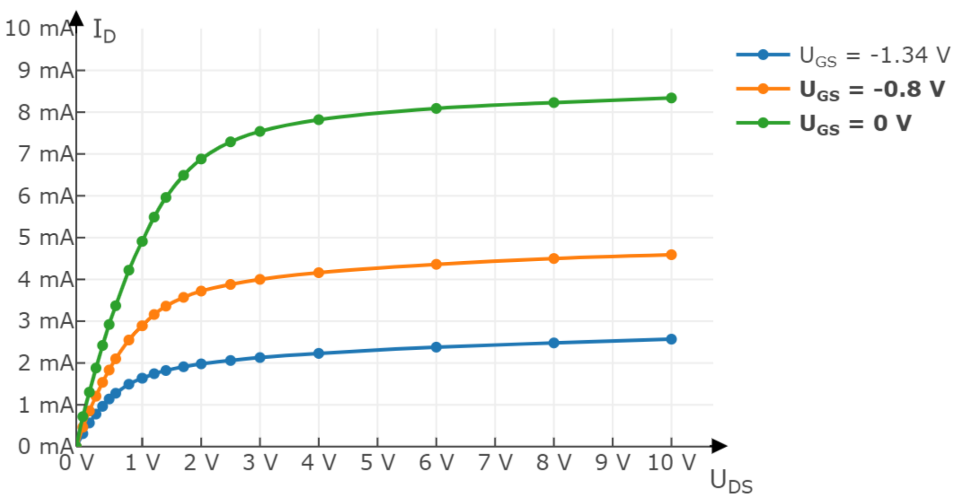


Figure 3: Output characteristics of n-channel J-FET

2 Combining side-by-side transfer and output characteristic

Task 1

Draw side-by-side transfer and output characteristics of the J-FET

By combining the two previous diagrams (see Fig. 2, and Fig. 3) we get:

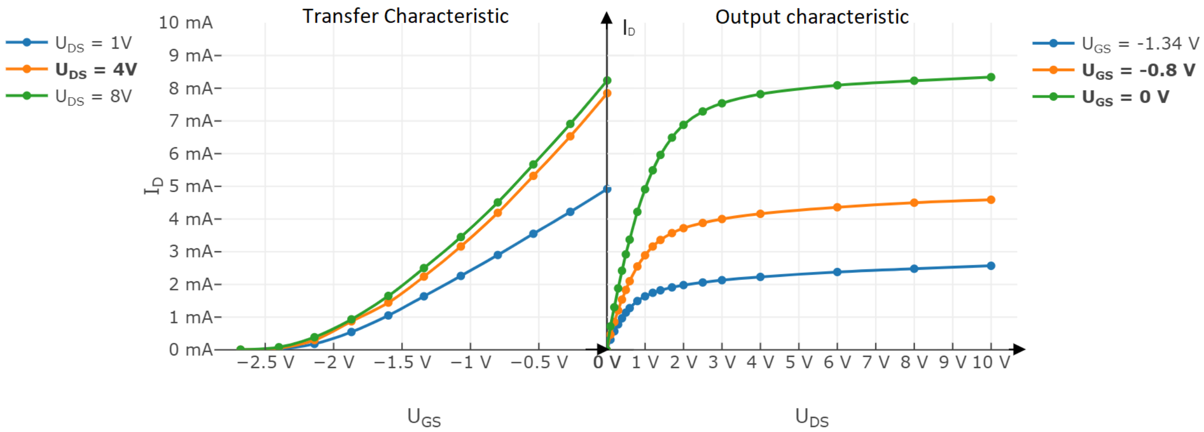


Figure 4: Transfer and output characteristics of the J-FET

3 Calculating drain current for zero bias IDSS, and pinch-off voltage UP parameters

Task 2

Read from the characteristics the values of I_{DSS} and U_P .

From transfer characteristic of n-channel J-FET we can read the values of U_P and I_{DSS}, also known as drain-source saturation current. The voltage U_{GS} for which the drain current becomes zero is called pinch-off voltage.

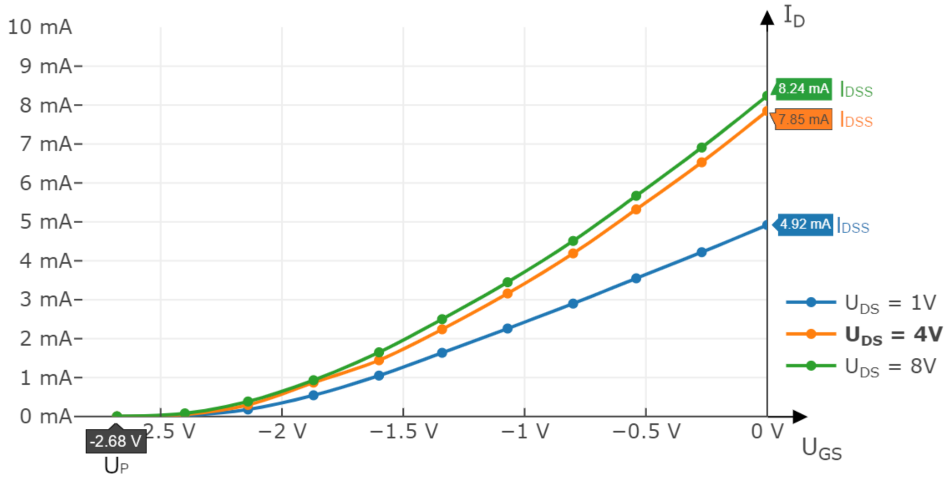
We find our U_p using the I_D values that are closest to zero. In this way, we assume that this is the place from where the I_D value is fading away and converging to zero. From our diagram it can be easily seen that the value of U_P for three independent parameters of
$U_{DS} = 1V = 4V = 8V$ equals:

$$U_P = -2.68V \longrightarrow I_D \approx 0 \; [mA]$$

I_{DSS} is the maximum current that flows through a J-FET transistor, it appears when U_{GS} equals zero. In the diagram we can see three such values:

$$U_{DS} = 1V \longrightarrow I_{DSS} = 8.24 \; [mA]$$
$$U_{DS} = 4V \longrightarrow I_{DSS} = 7.85 \; [mA]$$
$$U_{DS} = 8V \longrightarrow I_{DSS} = 4.92 \; [mA]$$

We can mark these values on a chart:



4 Small signal parameters

Task 3

Calculate the small-signal parameters g_m and g_{ds} of the J-FET for two operating points defined by U_{DS} and I_D:

- U_{DS} = 5V and I_D corresponding to $U_{GS} = 0.5 \times U_P$
- U_{DS} = 5V and I_D corresponding to $U_{GS} = 0.3 \times U_P$

For J-FET transistor we obtained transfer and output characteristics, it means that two small-signal parameters can be derived. These are g_m and g_{ds}, in order to indicate them we use formulas:

The small change in the drain current due to change in gate to source voltage can be determined using transconductance factor. We can derive it from the transfer characteristic as:

$$g_m = \frac{\Delta I_D}{\Delta U_{GS}}\Big|_{\Delta U_{DS}=\,0}$$

From the output characteristic of J-FET transistor we can determine the conductance factor.

$$g_{ds} = \frac{\Delta I_D}{\Delta U_{DS}}\Big|_{\Delta U_{GS}=\,0}$$

In order to calculate these parameters, we must select two points around the given operating point. After choosing them, next step is to calculate its incremental value of the argument.

Below,there are calculations for small signal parameters for the corresponding two operating points:

- U_{DS} = 4V and I_D corresponding to U_{GS} = $0.5 \cdot U_P$

$$g_{m1} = \frac{\Delta I_D}{\Delta U_{GS}} = \frac{3{,}16mA - 1{,}444mA}{-1{,}07V + 1{,}6V} = 3,23\ [mS]$$

$$g_{ds1} = \frac{\Delta I_D}{\Delta U_{DS}} = \frac{2{,}38mA - 2{,}13mA}{6V - 3V} = 0,083\ [mS]$$

- U_{DS} = 4V and I_D corresponding to U_{GS} = $0.3 \cdot U_P$

$$g_{m2} = \frac{\Delta I_D}{\Delta U_{GS}} = \frac{5{,}32mA - 3{,}16mA}{-0{,}54V + 1{,}07V} = 4,07\ [mS]$$

$$g_{ds2} = \frac{\Delta I_D}{\Delta U_{DS}} = \frac{4{,}36mA - 4mA}{6V - 3V} = 0,12\ [mS]$$

5 Conclusions

Looking at the output characteristic we can observe that when the U_{DS} voltage reaches pinch-off voltage, the saturation region occurs. Then J-FET is controlled only by the U_{GS}, while U_{DS} has almost no effect. For small applied Drain-Source voltage the drain current increases linearly until the point when U_P is reached. The J-FET in that region acts like a controlled by voltage resistor.

From the transfer characteristic it is seen that drain current decreases with the increase in negative U_{DS}. We also know that the maximum current that flows through J-FET can be found when the U_{GS} equals zero, this current is called drain-source saturation current I_{DSS}.

Consequently, the characteristics of the JFET unipolar transistor are similar and consistent in terms of theoretical assumptions.