Laboratory Electronics 2

Task 1: Field Effect Transistor Basics

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Learning Objectives

The main objective of the first lab task is to get familiar with the basic methodology of the lab. For this objective, the basic characteristics of a MOSFET shall be measured and compared to the information in the datasheet. Please be prepared before you come to the lab and upload your prepared files at the Moodle-course. Read this task carefully and plan what you have to do as preparation, in the lab and after the lab in the analysis. The objectives for this lab task are the following:

- Getting familiar with the course of the lab, the lab infrastructure and measurement devices
- Setting up a template for the lab documentation
- Practice the reading and understanding of a technical datasheet
- Understanding the relevancy of the information from datasheets, simulations and measurements

Lab Devices

You will find the following devices in the lab. Please make sure that you have the manuals ready. We also provide a breadboard with all required components and wires to setup your electrical circuit.

- **Digital Multimeter** GOSSEN METRAWATT METRA HIT 26S
- **Oscilloscope** Tektronix MDO3012
- **Differential Probe** EDITEST ELECTRONIC GE 8109
- **Frequency Generator** Agilent 33210A
- **DC Power Supply** Rohde & Schwarz NGT 20

1 MOSFET Transfer Function

MOSFETs are usually used to realize amplifiers or switching circuits. Therefore, it is important to know the characteristic transfer function of them to dimension those systems correctly. One of the two main characteristics is the transfer function of the drain current I_D as a function of the gate-source voltage V_{GS}. It is shown in figure 1. In this lab we use the general purpose n-channel MOSFET BS108.

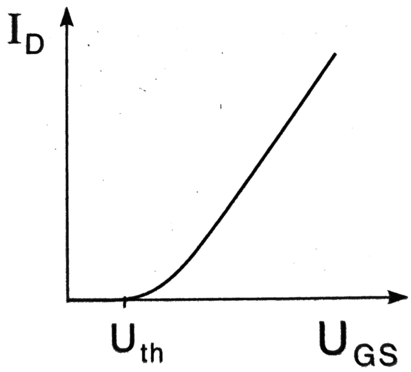

Figure 1: MOSFET transfer function $I_D = f(V_{GS})$ [1]

Theoretically, the function can be approximated by using the equations 1 [1].

$$I_D = \begin{cases} 0 & \text{for } V_{GS} < V_{th} \\ K\, V_{DS} \left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right) & \text{for } V_{GS} \geq V_{th},\ 0 \leq V_{DS} < V_{GS} - V_{th} \\ \frac{K}{2} \left(V_{GS} - V_{th}\right)^2 & \text{for } V_{GS} \geq V_{th},\ V_{DS} \geq V_{GS} - V_{th} \end{cases} \tag{1}$$

The first equation describes the cutoff region, the second the ohmic region and the third the pinch-off region. In this lab task the MOSFET is only operated in the cutoff and pinch-off regions. The coefficient K is called the *transconductance coefficient* and describes the slope of the transfer function. It can be calculated by using equation 2 [1].

$$K = \mu_n\, C'_{ox}\, \frac{W}{L} \tag{2}$$

Here, μ_n is the *mobility of the charge carriers* in the channel, C'_{ox} the *capacity per unit area of the gate oxide*, W the *width* and L the *length* of the gate. These values are usually not part of a MOSFET datasheet. Therefore, the following generic values can be used [1]:

$$\begin{aligned} \mu_n &\approx 0.05...0.07\,\mathrm{m^2\,V^{-1}\,s^{-1}} \\ C'_{ox} &\approx 0.35...0.9 \cdot 10^{-3}\,\mathrm{F\,m^{-2}} \\ W &\approx 10\,\mathrm{mm} \\ L &\approx 1...5\,\mathrm{\mu m} \end{aligned}$$

- Set up a script file (MATLAB Live Script, Jupyter Notebook or similar) which includes the following sections: Preparation, Data import, Data processing, Visualization, Conclusion. This script should be saved as a template for all upcoming lab tasks.
- How should a circuit look like to measure the transfer function $I_D = f(V_{GS})$? Draw a circuit diagram with all sources and measurement devices and include all relevant designators for voltages and currents. A picture of this circuit and a brief description must be included into the preparation section of the script.
- Collect all relevant parameters of the MOSFET. You need the parameters for the calculation of the transfer function (see 1) and the boundary conditions for your measurement (min. and max. voltages or currents). You find these information in the datasheet.
- Calculate and plot the function $I_D = f(V_{GS})$ based on equation 1 with the MOSFET parameters from the datasheet.
- Simulate your previously prepared circuit and export the simulated function $I_D = f(V_{GS})$ as waveform (no image!). Import the waveform in your script and plot it.
- Set up your prepared circuit and measure the transfer function $I_D = f(V_{GS})$. How can it be measured with an oscilloscope?

  Hint: You can use the XY-mode of the oscilloscope to create a graph for the function $V_{ch2} = f(V_{ch1})$. An oscilloscope has the only function to measure the voltage over the time. You will need a shunt resistor to perform an indirect current measurement. Additionally, the usage of the differential probe can be useful for this type of measurement.
- Export the measured function $I_D = f(V_{GS})$ as csv-file and import it to your script. Plot the function.
- Compare the measured transfer function with the calculated function from equation 1 and your simulated one. Plot all three functions in one diagram.
- Analyze the differences between the functions and list possible explanations.

References

[1] U. Tietze, C. Schenk, and E. Gamm, *Electronic Circuits: Handbook for Design and Application* (Electronic Circuits). Springer Berlin Heidelberg, 2015, ISBN: 9783540786559.