INF3410, fall 2017, mandatory labratory exercise 2: common source amplifier (deadline 17-Oct-2017, 10:00!)

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Abstract

This second lab task is meant to give hands-on experience with a simple single stage, single ended amplifying structure and also some practical experience on ranges of operation and where the ideal small signal behaviour analysis starts to fail. Also a first glimps on frequency dependent behaviour shall be included.

Please refer to lab 1 for **Safty Rules** and general rules of conduct in the lab!

1 Graded Mandatory Group Assignments

Note that this is part of the courses exam and strict rules apply as described in the document http://www.mn.uio.no/ifi/english/studies/admin/mandatory-assignments/index.html. The page explains the significance of mandatory assignments in a course and in particular group assignments. It also specifies your responsibility to not plagiarize anybody else's work and that you are required to conduct and understand your own experiments and obtain your own results, while you are still allowed and encouraged to exchange advice and experiences also between groups.

Each group must deliver a written lab report using the Devilry online submission system **before** the **hard** deadline indicated in the title. Note that you can submitt multiple times and the last submission before the deadline will be graded, so it might be a good idea to plan to submit preliminary versions well before the deadline. The points given for this lab assignment will be weighted as 20% of the total score of the course. Together with the mandatory lab exercise 3 this score will cont 40% towards your final grade.

Each task is labeled with how many points it will contribute towards the score.

2 Requirements for the Lab Report (read carefully!)

You are required to execute the tasks and answer all the questions posed below and to submit a report on your work. The report needs to be explaining clearly what you have done, how you have done it, what the results were and what you conclude from them. Make sure to answer all questions! Supply the report with drawings of the circuits (including the values of the components and parameters you used where appropriate, e.g. bias voltages/currents, component sizes etc.) and measurement setups, and show your measurements in graphs! Use labels in the schematics that you draw, such as M_1, M_2 (M is often used fro labelling CMOS transistors), $opamp_1$, I_1, V_1 etc. You should then use those labels in your text, since it is much easier to write: 'transistor M_1 in figure 1' than 'the transistor third from the top and second from the left in the righthand side circuit in figure 1'. **MANDATORY**: Include a photograph of your circuit into the report!

3 Introduction

Amplification of an electric signal has been an important topic since electric signal were discovered. Stereo amplifiers used in music systems are perhaps the most familiar device around. Disassembling the amplifier we find the amplifier is built from a number of amplifier stages with different properties and characteristics. In the early stages, the signal is small and sensitive to pickup of noise. The output amplifier stage is designed for driving loudspeakers with a considerable amount of watts.

The different amplifier stages are designed for different purposes and must be designed accordingly. The purpose of this lab is to design amplifier stages appropriate for integration in microelectronics. The constraints given by integration in microelectronics strongly affect both circuit solution and achievable performance. One of the major limitations in modern microelectronics is the low power supply voltage because the noise contribution is increasing with lower supply voltages. Also mass production impose constrains on amplifier design since the different components (size and type) varies significantly when produced in large numbers. Amplifier design for integrated circuits is a highly sophisticated skill.

The history of electronic amplifiers has emerged over the last century and has taken different forms depending on available components. Some of the terms used today were introduced with quite different technology. Still the basic concept is the same. We will look at the very basic common source amplifier (earlier common emitter in the days of bipolars) in this lab. These amplifier stages are frequently used in microelectronics usually with refining additions.

In our lab we must be very careful when setting up and carrying out our measurements! Be sure to follow the safety instructions indicated in lab 1!

4 Tools

- **The NI-ELVIS bord and plug-in bread bord**

  Also refer to lab 1!

  It has come to our attention that synchronized measurements with the ELVIS bord are not possible without a full installation of LabView. As a consequence, Thomas has introduced the use of the lab devices connected to the GPIB interface in his lab sessions. We are looking into installing LabView on the machines in the lab, but in the meantime you may also simply use the lab-measurement devices and control them with MATLAB programs.

- **MATLAB**

  We will be using MATLAB for some excersises and it's the best tool for plotting all of your results as nice graphs. Also if tou need to control equipment other than the ELVIS bord via the GPIB interface, you will need to use the correct functions in matlab for this. Thus, you should bring a working knowledge of MATLAB to this course. If you have none, get a crash course from a fellow student who has used it! It is a powerful mathematics tool with a command line interface. One useful function is 'help'. 'help <command_name>' will display an explanation on how to use '<command_name>'. Another help function that helps you find functions that you do not know the exact name of is 'lookfor'. Type 'help lookfor' to learn more.

- **GPIB interface**

  If you have to use lab equipment *other than the ELVIS bord and its built-in instruments*, GPIB is a bus system that allows your computer (MATLAB) to control this equipment automatically and to transfer data from or to the various devices. To make matlab work with the GPIB interface you must first follow the steps on the following webpage:
  http://nano.wiki.ifi.uio.no/GPIB

  Sometimes the GPIB system fails. If this happens you may have to restart MATLAB and switch off and on the Lab equipment before continuing.

- **Voltage sources**

  Also this instrument you may have become acquainted with during lab 1 already, despite the fact that we neglected to mention it in the description. Also, here it might not be necessary but feel free to take your pick between integrated instruments in the ELVIS bord and discrete lab-bench instruments.

  A GPIB controlled voltage source is the 'Agilent E3631'. You may use the E3631 as both a power supply and to set a constant input voltage. It is preferable to use the +25V Channel to set the power supply voltage, and the 6V channel to set an input voltage because it has a finer resolution.

Example session to initialize GPIB interface to HPE3631 and set its output voltage through MATLAB:

```
>> HPE3631_Init;
>> HPE3631_SetILimit(1,0.1);
>> HPE3631_SetVolt(1,1);
>> HPE3631_Operate;
```

This should set the HPE3631 6V channel to 1 Volts. The `HPE3631_SetILimit()` command sets a current limit of 0.1 Ampere.

- **Multimeters**

  Keithley 6512/617 and Agilent 34401A are a multi-meters that you can use to measure currents and voltages and also to verify that constant voltages are where they are supposed to be. Remember to turn off the "zero check" on the Keithley before use.

- **Oscilloscope HP54622D**

  A manual can be found in the lab. DO NOT REMOVE IT! Only consult it in the lab. Traces can be loaded to the computer via the GPIB interface in Matlab. Again: make sure that you have followed all the steps on http://nano.wiki.ifi.uio.no/GPIB before attempting to use the GPIB interface functions in matlab. Then try:

```
>> % Get traces from the oscilloscope:
>> [time,chan] = HP54622_GetData2;
>> % Plot the results:
>> plot(time,chan(1,:),'g',time,chan(2,:),'r');
>> xlabel('Time [s]'); ylabel('Voltage [V]');
```

- **An Agilent 33250A wave form generator**
  Its use is quite intuitive. When you have set a waveform type, a frequency, offset, and amplitude, you also need to activate the 'output'. For GBIB control (that you will need for this exercise) talk to the lab assistent!

- **CMOS transistors**
  The IC that contains a set of individual transistors is labeled 'MC14007UBCP'. A data sheet will be available in the lab or through the course pages that shows which pins are to be used as bulk, source, drain, and gate.

- **Potentiometer operated as tweakable voltage source**
  If the Keithley, the HP, or ELVIS bord voltage sources are to cumbersome to use as a voltage sources, or if there are too few of them you may also just use potentiometers as resistive voltage dividers between Vdd and Gnd.

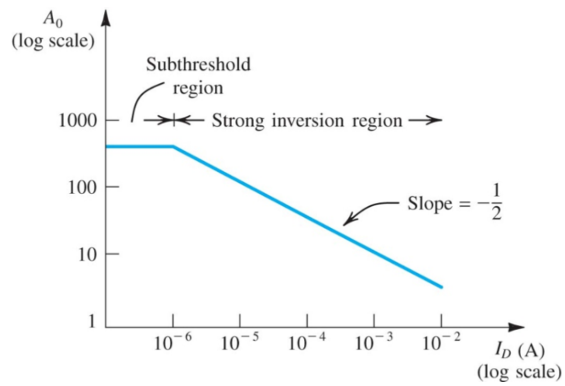

Figure 1: Intrinsic gain in dependence of drain current of a MOSFET.

Always clean up the lab after your time slot, such that the next group can use the equipment!

5 General Advice

- Draw a schematic before you start assembling components on the PCB! Label pins on the PCB and in the schematics (!) clearly in order to keep your overview. Debuging will be much, *much* easier that way!
- Come to the lab with a work plan: Read the entire lab task beforehand and make a plan how to proceed. Put yourself a goal for a lab session. Read the relevant book chapters in order to understand the entire lab. Be ready with questions already before the lab if there are still things unclear.

6 Preparation

The task of this lab is to recreate the figure 7.14 in the book (here figure 1) with real measurements. We shall not plot the intrinsic gain of a single transistor, but the gain of a common source amplifier A_V with a 'active load', i.e. a transistor with fixed bias gate voltage, as depicted in figure 2.

Task 1 (1p): How do you expect the gain A_V that you will measure in this particular common source amplifier to be different from the intrinsic gain of the PMOSFET? Hint: assume that r_o is approximately the same for both the PFET and NFET.

You will need your measurement results from lab 1! There you have characterized the NFET and know what V_{GS} corresponds to what I_D for a constant V_{DS}. Use that knowledge to have the NFET supply a range of different I_D.

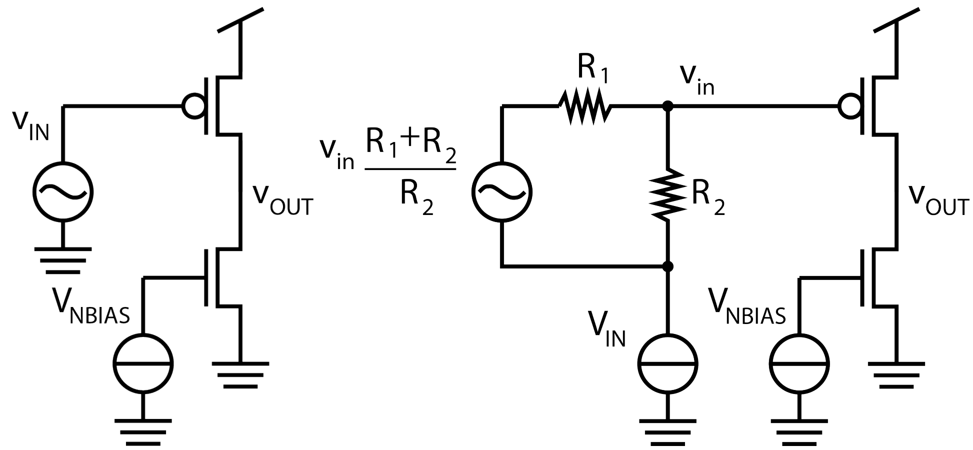

Figure 2: Left: Common source amplifier using a PMOSFET as amplifier and NMOSFET as current source/load. Right: the same circuit but now using a DC voltage source to set the point of operation and a resistive divider to use a coarse variable voltage source to provide more fine grained input to the CS amplifier.

7 Common Source Amp Characterization

Task 2 (4p): Set up the circuit in figure 2 on your breadbord. Choose Vdd according to the datasheet of the transistor IC as a 'normal' supply voltage for the device. For a bias current I_D of near 5μA supplied by the NMOSFET (What gate voltage V_{NBIAS} do you use to achieve this?), sweep the input voltage from Gnd to Vdd and plot the output curve to find a good point of operation. Make sure to use small enouch steps of the input voltage to get several measurement points in the linear region! If necessary, use a resistive divider (see figure 2 Right: two resistors in series between the voltage source you sweep and the voltage source you set to the input's point of operation and using the voltage between the two resistors as input voltage) to generate a plot just around the linear region with smaller voltage steps than the voltage source can provide. Indicate a rough approximation of the linear range of operation in the plot and an good point of operation. How do you read the voltage gain A_V in that point in the graph and what is it? Can you express the gain both as a linear number and in dB?

Task 3 (4p) Measure the gain for a range of biassing conditions, i.e. different I_D. Use at least 10 different I_D and make sure to have several both in strong inversion and weak inversion to get a 'smooth' plot of A_V vs I_D similar to figure 1. Also use a log-log plot. Does the curve indeed look similar to figure 1?

Task 4 (4p) Use the largest (!) weak inversion (!) biassing current I_D setting that you used in task 3 (i.e. a V_{GS} just below the treshold) and apply a small sine wave as input, small enough that the output remains in the linear range, but ideally the output should almost be big enough to be outside the linear range, i.e. almost (!) a full p2p swing between the supply rails (makes it easiest to measure), but be carefull that there is no distortion, i.e. the output should still clearly look like a sine wave. Use a resistive divider again if necessary to get it small enough. Start with a low frequency, e.g. 100Hz. Use the oscilloscope to observe both the input and the output. Show these traces in a plot. Is the output amplitude indeed A_V times bigger than the input? Then increase the frequency and continue to observe the output swing. Use the measurements to make a Bode plot (both magnitude and phase). Can you detect the frequency at which the output starts to become smaller? At what frequency to you observe a -3dB ($A(f_{-3dB}) = \frac{1}{\sqrt{2}} A_{DC}$) decrease of the original output swing? Make a plot of the two traces also at that frequency. What's the phase of the output relative to the input?