EE 3101 ELECTRONICS I LABORATORY

EXPERIMENT 7 LAB MANUAL

MOSFET AMPLIFIER DESIGN AND ANALYSIS

OBJECTIVES

In this experiment you will
- Learn procedures for working with static-sensitive devices.
- Construct constant-current sources, active loads and amplifiers using only enhancement-mode MOSFETS.
- Begin learning how to "scale" parameter values from data sheet conditions to circuit conditions.

LAB NOTEBOOKS

The format of lab notebooks should be such that the information can be used to reproduce the lab, including what values were used in a circuit, why the values were used, how the values were determined, and any results and observations made. This lab manual will be used as a guide for what calculations need to be made, what values need to be recorded, and various other questions. The lab notebook does not need to repeat everything from the manual verbatim, but it does need to include enough information for a 3rd party to be able to use the notebook to obtain the same observations and answers. In the following numbered sections there are **bolded words and/or lines**. These bolded words and/or lines are statements and/or questions that the lab TA will be looking for an answer either in the lab preliminary, or lab notebook.

INTRODUCTION

Today's MOSFET technologies make it possible to design very complex low-voltage, low-power analog and digital integrated circuits. As learned in lecture class, most of the circuit elements within the IC are formed with MOSFETs since resistors and capacitors take up too much room in integrated form. In this experiment, matched sets of NMOS and PMOS transistors will be used to explore the design of active loads, constant-current sources and MOSFET amplifiers. Read over this entire experiment before beginning.

ELECTROSTATIC DISCHARGE AND MOSFETS

MOSFETs are extremely vulnerable to discharges of static electricity. They can be destroyed instantly if proper handling procedures are not followed. Industrial labs and manufacturing facilities use static-controlled workstations to prevent damage from electrostatic discharge (ESD). Workers may be required to wear special anti-static shoes, stand on special mats or wear a grounding strap attached to their wrists. To ensure the best chance of success in working with these devices, use the following procedure:

1. As much as possible, bring the parts, leads and probes to the work site before start beginning. Wire up the breadboard for the first circuit. Carefully study the pin connections for the IC chip. Connect any unused pins of the NMOS transistors to ground. Connect any of the unused pins of the PMOS transistors to V_{DD}.

2. The TA will deliver two ALD1103 ICs in their anti-static packaging. Before touching them, both the student and the TA should first touch the metal faceplate (or screw) of the outlet box. (It should be connected to ground.) It is important that the student, the TA and the circuit be at the same potential.

3. Touching the circuit, carefully insert the IC(s) into the breadboard. Have a lab partner check over the circuit connections.

4. Remember: Be sure the power is OFF before connecting or disconnecting the MOSFETs.

5. Keep in mind that just walking a few steps to get a lead or a component can be enough to accumulate significant static charge. *If you must leave the workstation, be sure to ground yourself again before touching the circuit.*

6. Upon completing the last experiment, have the TA come over, ground himself out and return the ICs to their anti-static packaging.

THE ALD1103 MOS TRANSISTOR ARRAY

The ALD1103 MOSFET array contains matched sets of PMOS and NMOS transistors. A data sheet is attached. Note, that while some interesting applications use the substrate terminal, generally, *the substrate of each NMOS transistor is connected to the most-negative voltage in the circuit. The substrate of each PMOS transistor is connected to the most-positive voltage in the circuit.* For this reason, the manufacturer has supplied pins for +V and –V on the chip. In our case, this will correspond to V_{DD} and ground, respectively. After wiring the circuit, check the pin diagram carefully. These are low-voltage circuits that can be easily damaged.

PRELIMINARY

1. Using the formula shown in Figure 1**, calculate the value needed for R_{SET} to obtain a constant current of approximately 10 mA**.

EXPERIMENT

Part 1

1. First, construct the basic current mirror constant-current source shown in Figure 1. Use the nearest standard value for R_{SET} that you have.

2. Place a decade box, with initial value of 0 ohms, in series with the multi-meter in the mA position between V_{DD} and the output of the current source (the drain of Q2). Turn the power on, and observe the current. If it is not close to 10 mA, turn off the power and change R_{SET} in order to get at least within 2 mA of 10 mA. **Record the value of R_{SET} used.**

3. **Now, vary the resistance of the decade box from 0 ohms to 2 k and record the current for each resistive load value (every 100 Ω).** From this data you will later be able to determine an approximation for the output resistance of the current source, and you will also estimate the range that R can be for the circuit to work as a constant-current source.

Q1. **How does this value compare with the data sheet value: $r_o = 1/G_{OS}$?**

4. Turn the power off. Remove the multi-meter from the circuit and change the test leads on the meter so that you can measure DC voltage. **Turn the power back on and measure the V_{GS} value of the transistors. (Later, consider this voltage and why the first calculation for Rset was off. Try to explain this. Hint: Look at the test conditions for Vth in the data sheet.)**
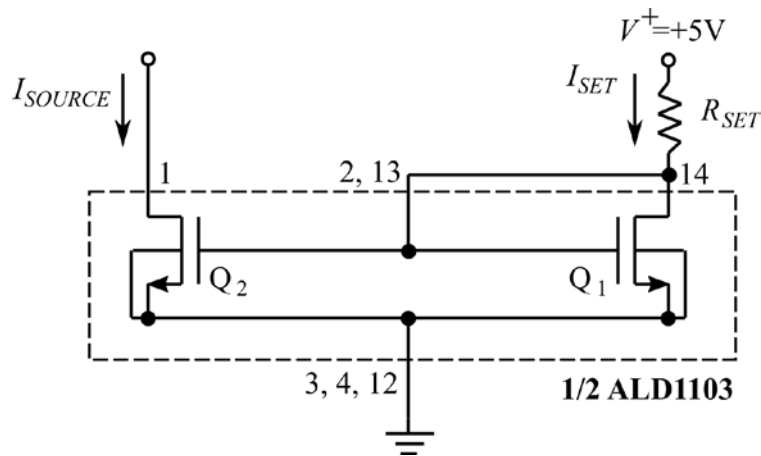
$$I_{SOURCE} = I_{SET} = \frac{V^+ - Vt}{R_{SET}} \equiv \frac{V^+ - 1.0}{R_{SET}} \equiv \frac{4}{R_{SET}}$$

Figure 1: Basic Constant-Current Source built with NMOS.

5. Next, construct the cascode current source shown in Figure 2, using two NMOS pairs. **Repeat the measurement of the output current as you vary the load.**

Q2. **How does the apparent output resistance of the circuit seem to compare with that of the simple current source?**

Q3. **Use equation (10.57) in the EE 3301 text book ("Microelectronics Circuit Analysis and Design", D.A. Neamen) to calculate this new output resistance. The cascode arrangement should increase the output resistance dramatically.**
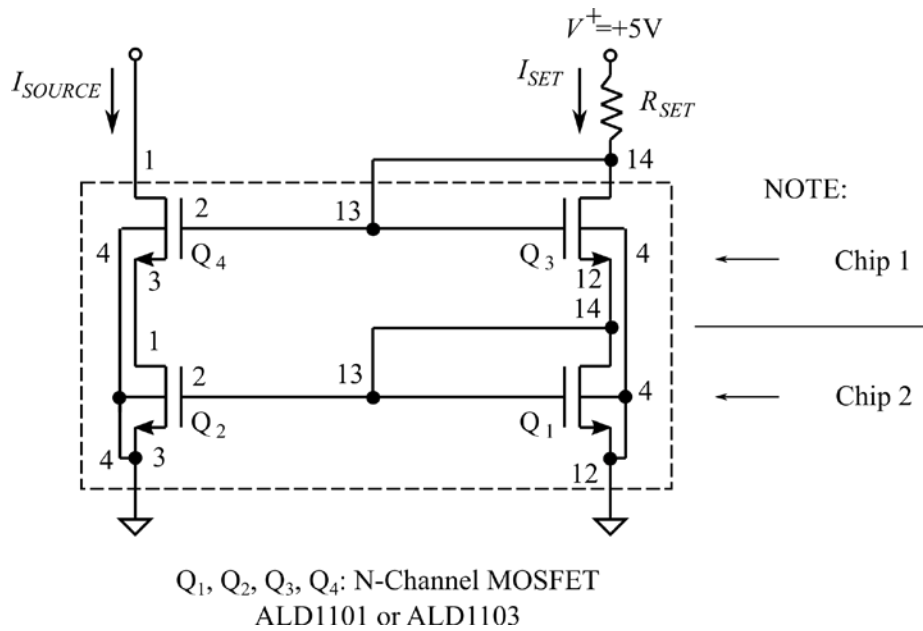
Q4. **How do they compare?**

Figure 2: A Cascode Current Source built with NMOS transistors.

Part 2

1. Construct the differential amplifier of Figure 3. The constant-current source shown will be built using the circuit of Figure 1. Check the wiring carefully.
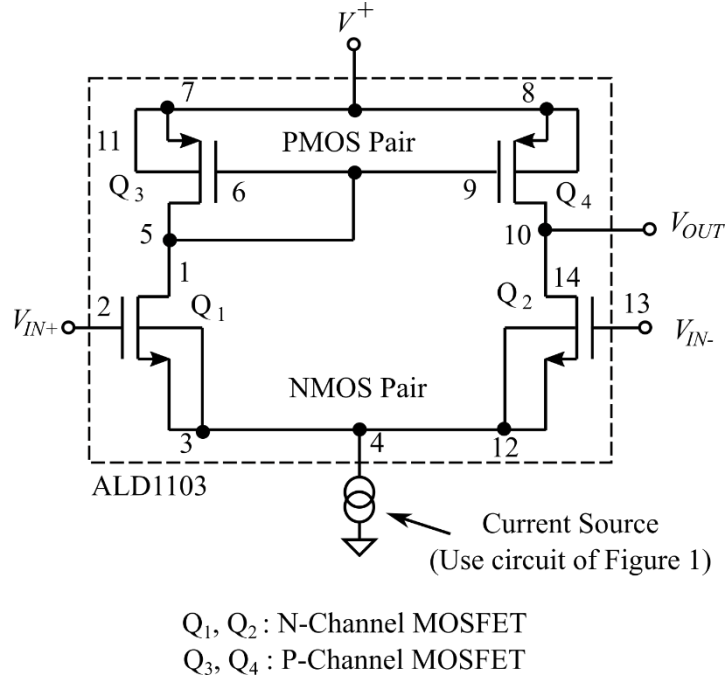

Q_1, Q_2 : N-Channel MOSFET
Q_3, Q_4 : P-Channel MOSFET

Fig. 3. Differential Amplifier with PMOS Active Loads.

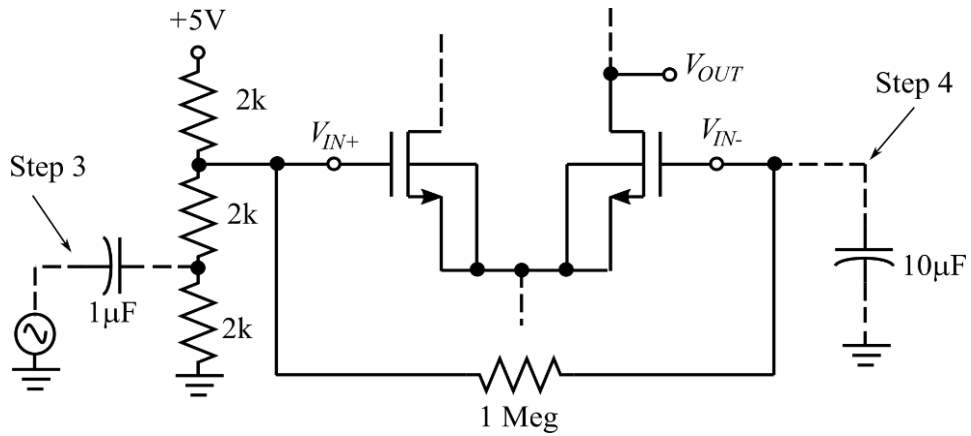Add the resistive bias/attenuator network shown in Figure 4.

Figure 4: Test Set-up for Differential Amplifier Measurements.

2. **Apply power and measure the DC voltages of the circuit. In particular, measure the drain voltages of the differential transistors, which should be around 3 volts**.

3. Add the 1 µF coupling capacitor and generator as shown in Figure 4. Set the generator frequency for 1 kHz. Slowly increase the generator amplitude until the input amplifier's input voltage is about 1 volt peak-to-peak. Look at the voltage waveform at the output (**save the oscilloscope screen for both input and output waveforms**). The amplitude should be very small if the amplifier is working right and rejecting this common-mode signal.

4. Now, add the 10 µF bypass capacitor. **Measure the single-ended gain by setting the generator amplitude so that the amplifier output is as large as possible without distortion.** This should be about 1 volt peak-to-peak. Attach the oscilloscope probe for channel 2 of the oscilloscope to the amplifier input. If the connections are right and the amplifier is working, you should see that the signal is inverted (**save the oscilloscope screen for both input and output waveforms**). **Measure the input and output voltages of the amplifier and calculate the voltage gain.** When finished, turn the power off and let the TA know that he can pick up your MOSFET arrays. Part 3

Use the equations in the textbook to determine what the single-ended gain should be. To obtain the transconductance for the differential transistors, note that they share equal currents of 5 mA (or half of what the current source supplies). This current is different than that of the current-source transistors which is close to 10 mA. Remember that g_m varies with the square root of I_D. So halving the drain current will decrease g_m by 0.707. Similarly, halving the drain current will *double* r_o of the active load transistors. This "scales" the data sheet values to the conditions of the circuit. This is sometimes necessary if the data sheet test conditions are significantly different from those of the desired circuit.

Q5. **Calculate these estimates and see how the calculated gain compares with the measured gain.**

Q6. **Be sure to note that the data sheet parameters for the PMOS and NMOS transistors are different.**

Q7. **Explain any differences found in the calculated and measured gain.**