Background

The objective of this lab is to familiarize ourselves with the behavior of a MOSFET in the triode and saturation operation modes, analyze this behavior using the I-V characteristic of a MOSFET, and understand the behavior of a current mirror circuit. To observe MOSFET behavior, we built a simple MOSFET circuit containing one MOSFET and one resistor connected in series. The voltage at the ends of the resistor were measured and used to obtain the current flowing through the MOSFET, as well as the drain-source voltage at those points. To understand the current mirror, we built a circuit consisting of two MOSFETs, with their gate voltages connected to each other. This report will show the I-V characteristics of the NMOS and PMOS transistors swept at various gate-source voltages and mathematically analyze the behavior of a current mirror.

Procedure – Transistor Characteristics

MOSFETs operate in three distinct operation modes: cutoff, triode, and saturation.

In the cutoff region, the MOSFET does not operate, since the gate-source voltage is lower than the threshold voltage of the MOSFET. This causes the current through the MOSFET to be zero.

In the triode region, the current through the MOSFET is parabolic with respect to the drain-source voltage. The triode region applies only when the drain-source voltage is less than the difference between the gate-source voltage.

In the saturation region, the MOSFET is said to be "saturated" because the current through the MOSFET is no longer heavily dependent on the drain-source voltage. As a result, the MOSFET acts as a current source in this region, outputting the same current if a certain drain-source voltage is reached.

The criteria for each of the three regions and their currents are shown in the table below:

Table 1: Operation Criteria and Drain-Source Current for Various MOSFET Operation Modes

Operation Region	Operation Criteria	MOSFET Drain-Source Current
Cutoff	$V_{GS} < V_T$ (1)	$i_{DS} = 0$ (2)
Triode	$V_{GS} \geq V_T, V_{DS} < V_{GS} - V_T$ (3)	$i_{DS} = k\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}{}^2}{2}\right]$ (4)
Saturation	$V_{GS} \geq V_T, V_{DS} \geq V_{GS} - V_T$ (5)	$i_{DS} = \frac{k}{2}(V_{GS} - V_T)^2$ (6)

We will attempt to confirm the above characteristics by analyzing the I-V characteristics for both the NMOS and PMOS transistors. We can measure the voltage at the node between the MOSFET drain and the resistor in both cases (labeled V_B in Figure 1 and V_A in Figure 2). However, due to the limitations of the Digilent Discovery 2 device, we are unable to measure the current through the MOSFET. Because of this, we will attach a resistor with known value in series with the MOSFET and measure the voltage drop across it. Then, using Ohm's law,

$$V = IR \qquad (7)$$

we can calculate the current across the resistor, which will match the drain-source current of the MOSFET due to the series connection. Figures 1 and 2 below show the circuits used to analyze the NMOS and PMOS transistor behaviors, respectively.

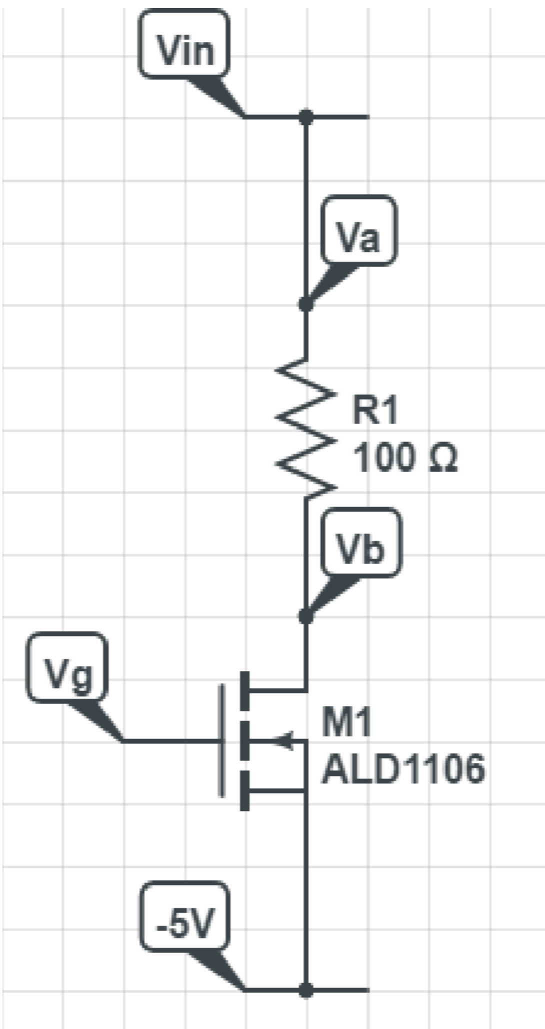

Figure 1: Schematic for NMOS Circuit

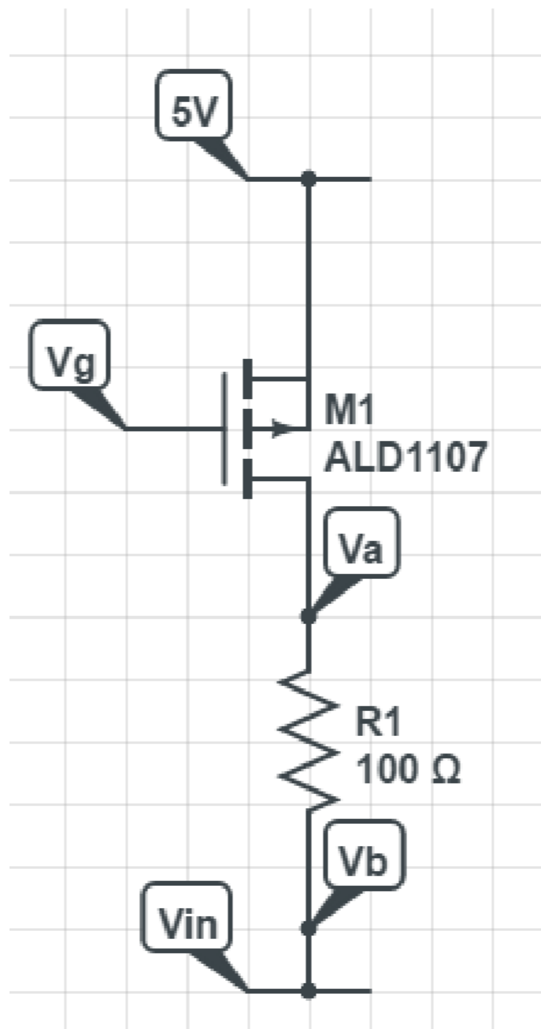

Figure 2: Schematic for PMOS Circuit

To observe all three operation modes for each MOSFET, we need to sweep the input voltage through a range of 10.6 volts. However, the Digilent is only capable of supplying ±5 volts, so we will sweep the input voltage from -5 volts to +5 volts, giving us a total sweep of 10 volts. In addition, we would like to see the effect of increasing V_{GS} on the output I-V characteristic. To achieve this, we will be sweeping the input range once for V_{GS} = 0 V to V_{GS} = 8 V in 2 V intervals, and from V_{GS} = 0 V to V_{GS} = 2 V in 0.2 V intervals.

We can then determine the drain-source voltage by taking the drain voltage of the transistor (labeled V_B in Figure 1 and V_A in Figure 2) and subtracting the fixed source voltage from it (labeled -5V in Figure 1 and 5V in Figure 2). We can also determine the drain-source current using the voltage drop across a fixed-value resistor, as explained earlier. Finally, we can plot the drain-source current against the drain-source voltage to obtain our desired I-V characteristic.

Procedure – Current Mirror

A current mirror is a circuit consisting of at least two MOSFETs that is designed to replicate the current through one branch into another branch. The current mirror consists of two MOSFETs with their gates connected to the drain of the MOSFET with the current that is being replicated. Because the MOSFET is diode-connected (the drain is connected to the gate), we know that the MOSFET must operate in the saturation region. As a result, we know from equation 6 that the current through the MOSFETs must equal:

$$i_{DS} = \frac{k}{2}(V_{GS} - V_T)^2 \quad (6)$$

In this lab, we will be using NMOS transistors to construct our current mirror. Since the two gates are connected, we know that V_{GS} is the same for both MOSFETs. If the K_n values and V_{TH} for both MOSFETs equal, we can equate the drain-source currents to obtain an expression for the output current in terms of the input current and the length and width of both MOSFETs:

$$i_{OUT} = i_{REF}\left(\frac{L_1 W_2}{L_2 W_1}\right) \quad (8)$$

where I_{OUT} is the new replicated current, I_{REF} is the original current, L_1 and W_1 are the length and width of the source MOSFET, and L_2 and W_2 are the length and width of the output MOSFET.

We will attempt to confirm this relationship by constructing a current mirror using equivalent MOSFETs and first determining if the output current is equal to the input current. We will then attempt to double the output current by changing the output MOSFET to a parallel combination of two equivalent MOSFETs, effectively doubling the width.

Figure 3 below shows the complete current mirror circuit used for this lab.

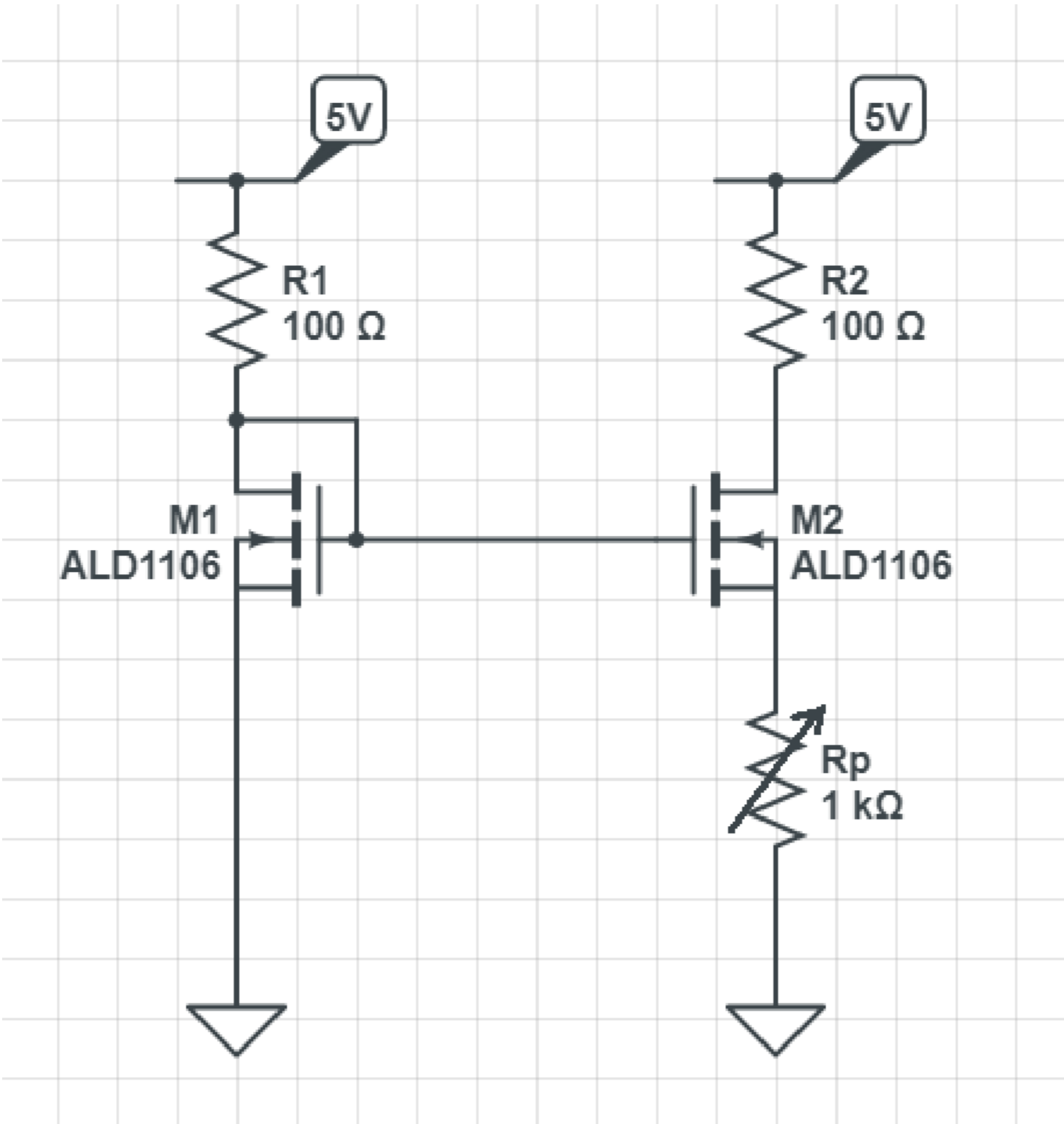

Figure 3: Schematic for Current Mirror Circuit