Lab 2: Current Mirrors

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Lab Day: Monday ○ Tuesday ○ Wednesday ◉ Thursday ○ Friday ○

Lab Time: Mornings ◉ Afternoons: ○

Introduction:

One of the most commonly used circuit structures in analog circuits is the current mirror. A current mirror has a relatively low input resistance and a high output resistance. Provided the output devices are operated in the saturation regime (MOSFETs) or the active regime (BJTs), the output current is a precisely controlled ratio of the input current. This feature makes current mirrors an attractive approach to the design of current sources. Current mirrors are widely used to bias transistors and to transport precise voltages around a chip. For further information, see Chapter 7, sections 8.2 and 8.6 in Microelectronic Circuits, 7th. Ed.

Key parameters for current sources are the output current (I_{OUT}), the output resistance (R_{OUT}) and the compliance range. I_{OUT} is self-evident, while R_{OUT} was defined in Lab 1. The **compliance range** is defined as the range of V_{OUT} over which the current source provides a reasonably constant current. The compliance range has a maximum (V_{OUT_MAX}) and minimum (V_{OUT_MIN}) value. Usually one of these two values is determined by the supply voltage.

Another useful term is Power Supply Rejection. In practical circuits, the supply voltage varies with time. These power supply variations often find their way into the circuit's output. Well designed circuits should reject, or not respond to, variations in the power supply. The ability of a circuit to reject power supply variations is expressed as the **Power Supply Rejection Ratio** or *PSRR*. Since the range of *PSRR*s can be quite large, the *PSRR* is commonly expressed as

$$PSRR = 20\log(v_s/v_{out}) \text{ dB} \quad (1)$$

where v_s is the ac component or "ripple" of the supply voltage while v_{out} is the ac component in the output due to the ripple in the supply voltage.

Preparation:

For this lab, the ALD1106 quad NMOS array and ALD1107 quad PMOS array will be used. As shown in Fig. 1a, the NMOS array contains four devices. The NMOS devices are specified to have V_{tn} = 0.7 V, $\mu_n C_{ox} W/L$ = 0.55 mA /V^2 and V_A = 60 V.

1. If the variable resistance, R_L, in Fig. 1b is set equal to R_1:

   a) Determine I_{IN}, I_{OUT}, V_1 and V_{OUT} and enter them on the schematic.

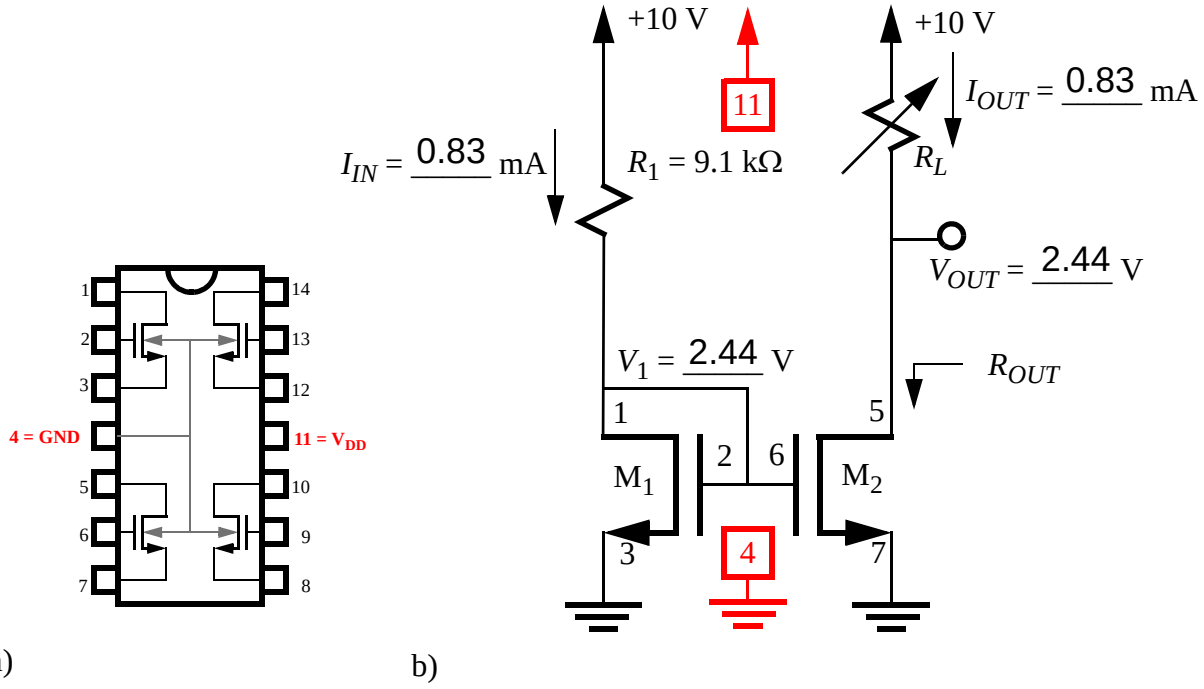

Figure 1) a) Pin diagram for the ALD1106. b) A simple current mirror.

   b) Determine the minimum output voltage, V_{OUT_MIN} for which M_2 remains in saturation.

   V_{OUT_MIN} = 1.74 V

   c) Determine the mirror's output resistance, R_{OUT}.

   R_{OUT} = 72.20 kΩ

   d) Pre-wire the circuit shown in Fig. 1b. Pin 4 must be connected to ground and pin 11 must be connected to +10 V. The variable resistor will be connected into your circuit in the lab.

Preparation Continued,

2. The circuit shown in Fig. 2, contains multiple current mirrors.

   a) Determine the voltage at each node, the indicated currents and the output resistance of the PMOS current mirror (R_{OUT}). The NMOS devices have the same parameters as before. For the PMOS devices, assume $|V_{tp}|$ = 0.7 V, $\mu_p C_{ox} W/L$ = 0.18 mA/V^2 and $|V_A|$ = 30 V. Enter your voltage, current and resistance values on the diagram.
   b) Determine pin numbers for all NMOS and PMOS devices and enter them on the diagram.
   c) Pre-wire the indicated portion of the circuit to one side of the circuit board so that it can be added quickly in the lab.

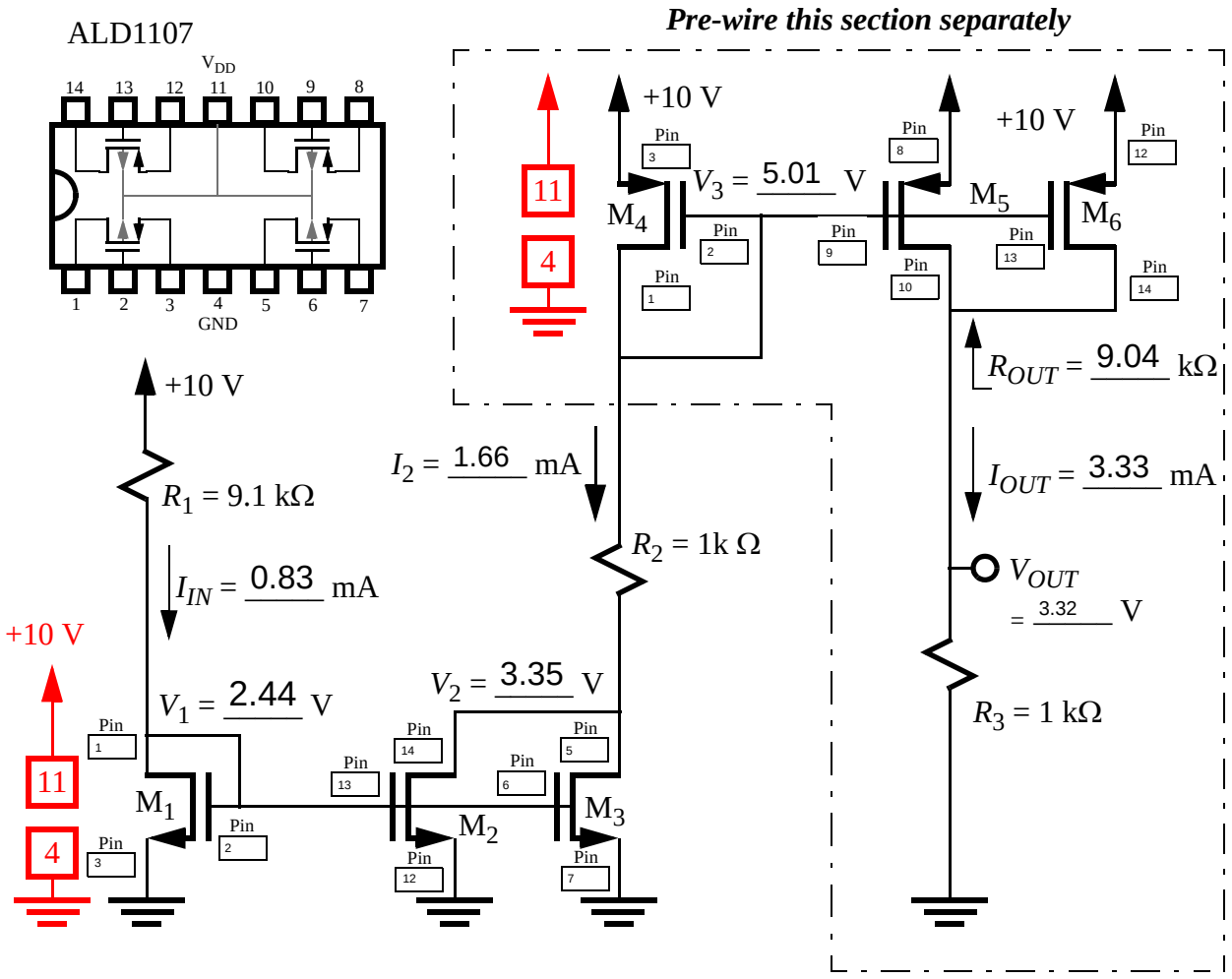

Figure 2) Multiple current mirrors.

Preparation Continued,

3. If R_L, in Fig. 3 equals R_1:

   a) Determine I_{IN}, I_{OUT}, V_1, V_2, V_3 and V_{OUT}. Then, enter them on the schematic. For these calculations, you can ignore the transistors' finite output resistances.

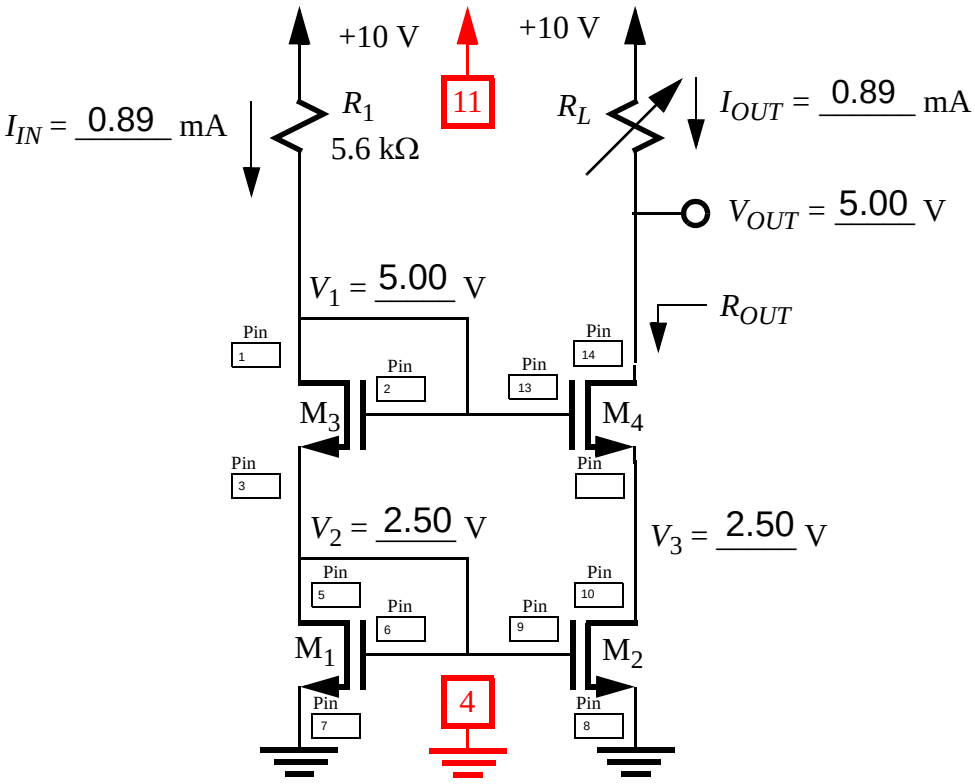

Figure 3) A cascode current mirror.

   b) Determine the current mirror's expected R_{OUT} and the minimum output voltage, V_{OUT_MIN}, for which the current mirror maintains a high output resistance.

   R_{OUT} = 4,650.00 kΩ V_{OUT_MIN} = 4.30 V

   c) Determine pin numbers for the NMOS devices and enter them on the schematic of Fig. 3.

4. Download (from the class website) the workbook entitled *Lab 2.xlsx*. Then, review the laboratory instructions to determine which spreadsheets or tables would be helpful to have prepared in advance of the lab and prepare them. Be sure to submit them with your preparation.

Laboratory:

The Basic Current Mirror

1. Verify that your circuit analysis and the pre-wiring done in part 1 of the preparation are correct by applying 10 V and ground to your pre-wired circuit and measuring the node voltages. Record the measured voltages on Fig. 4 (lab version of Fig. 1).

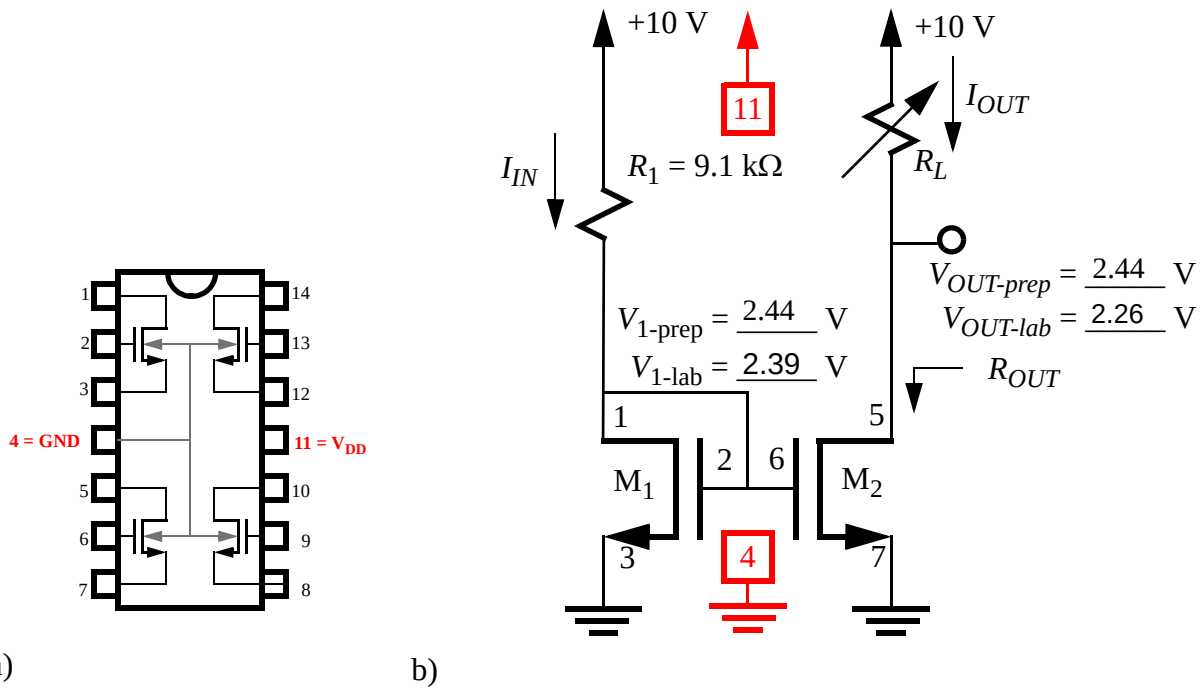

Figure 4) Lab version of Fig. 1, a) Pin diagram for the ALD1106. b) A simple current mirror.

2. Gather data to determine the mirror's output resistance. To do this, download (from the class website) the workbook entitled *Lab 2.xlsx*. On the sheet labeled "Basic Current Mirror", prepare a spreadsheet for finding output resistance, similar to those used in Lab 1. In this case, you will be finding the current through R_L ($i_O = (V_{DD} - V_{OUT})/R_L$). Consequently, you will need to measure and record $\boldsymbol{V_{DD} - V_{OUT}}$ for values of R_L similar to those used in Lab 1. Record at least three significant figures.

Multiple Current Mirrors

1. Construct a multiple current mirror circuit and verify its dc operating point. To do this, power down your circuit. Then, add an NMOS device (M_3) and the pre-wired PMOS mirror to your circuit, as shown in Fig. 5 (lab version of Fig. 2). Re-apply 10 V to the circuit. Verify that the circuit is operating properly by measuring its node voltages[1], recording them on Fig. 5 and comparing the voltages to the preparation values.

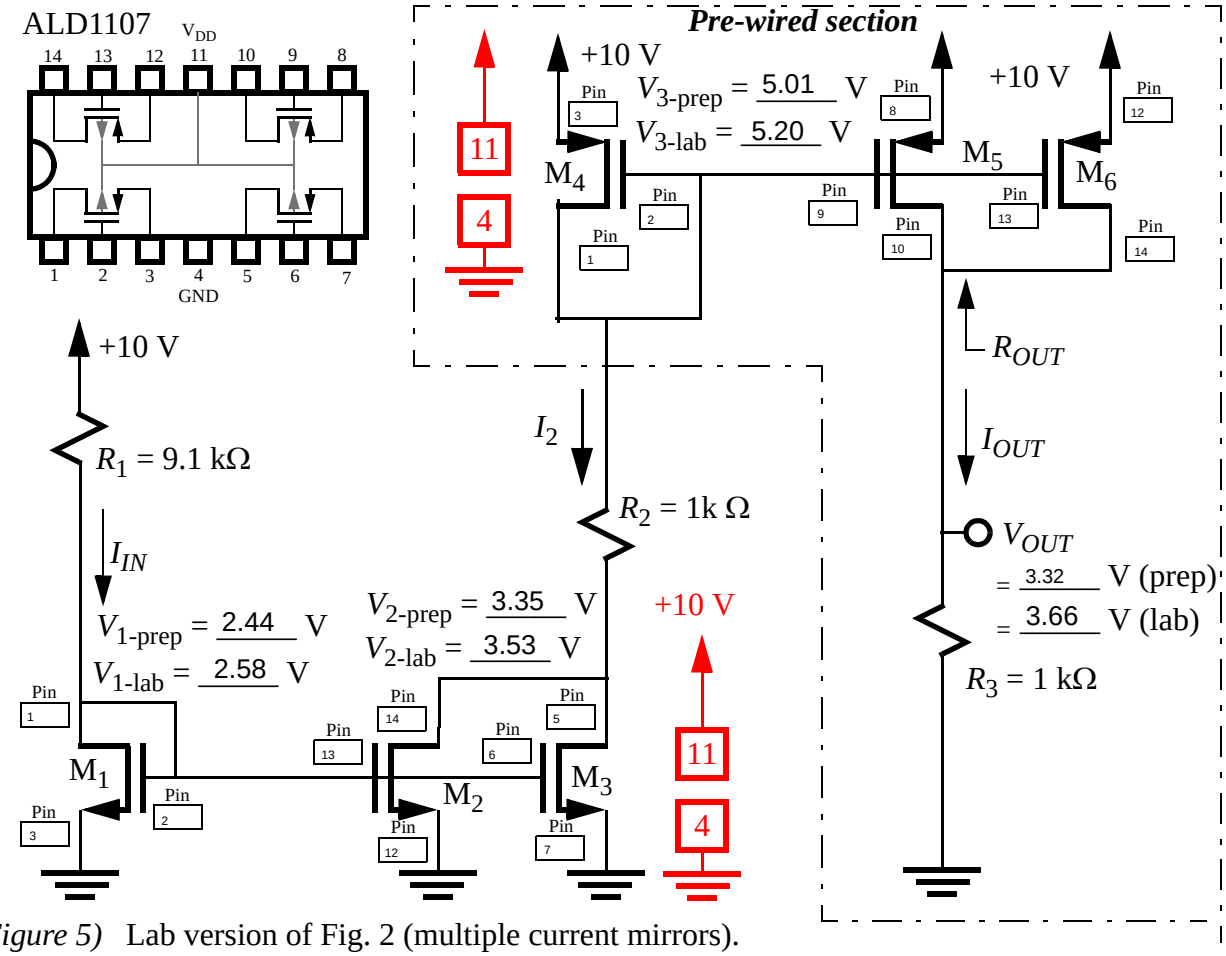

Figure 5) Lab version of Fig. 2 (multiple current mirrors).

2. Determine the current ratios of the NMOS and PMOS current mirrors from the currents through R_1, R_2 and R_3. $\frac{I_2}{I_{IN}}$ = 2.02 $\frac{I_{OUT}}{I_2}$ = 2.08

3. Gather data to determine the mirror's output resistance. To do this, replace R_3 with the decade resistor (R_L). Then, by using a procedure similar to that used in part 2 of *The Basic Mirror*, record, in *Lab 2.xlsx*, on the sheet labeled "Multiple Current Mirrors", sufficient data to determine the range over which the PMOS current mirror's output current is reasonably constant (*i.e.* the compliance range).

1. Note that V_{OUT} will only be close to the expected value if the MOSFETs are all perfectly matched.

4. Investigate power supply rejection. To do this, connect the sources of the PMOS mirror to a 1 V_p, 1 kHz sine wave in series with a 9 V_{DC} source, as shown in Fig. 6. Display v_s and v_{OUT} on the oscilloscope and record them using a scope capture in a file labeled PSRR.png (save the file as a portable network graphics file or ".png" file). Determine the amplitude of the 1 kHz sine wave on both v_s and v_{out}. These signals are known as the **supply ripple** and the **output ripple** respectively.

v_s = 1.0 V v_{out} = 0.1600 V

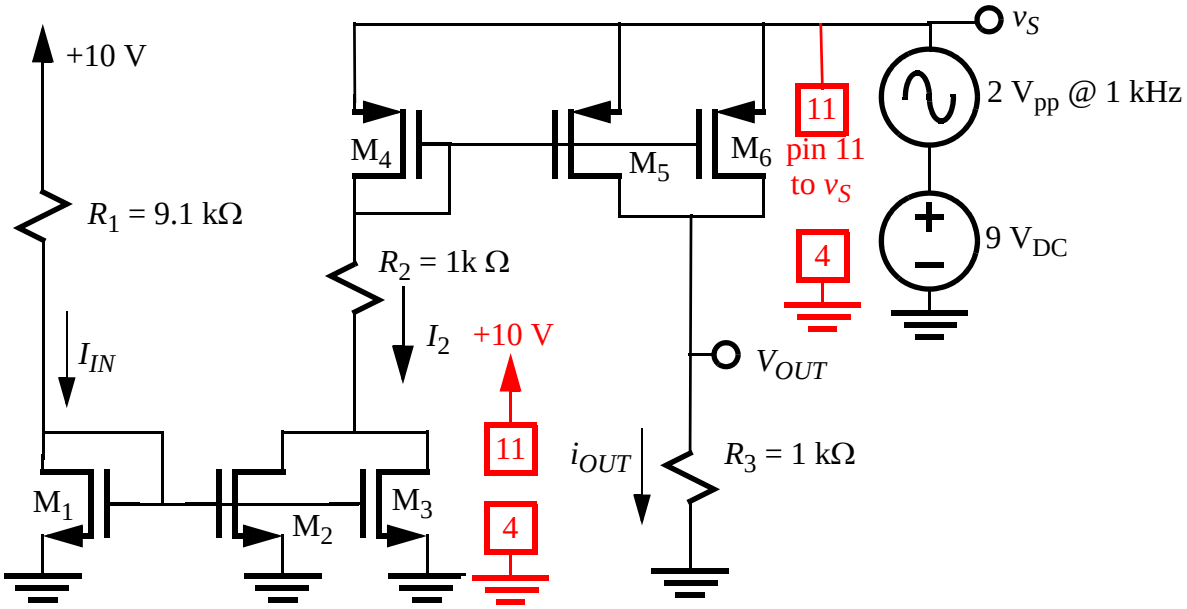

Figure 6) Power supply noise and current source behaviour.

- For the NMOS array, connect pin 11 to +10 V.
- For the PMOS array, connect pin 11 to v_s.
- For both arrays, connect pin 4 to ground.

The Cascode Current Mirror

1. Construct a cascode current mirror and verify its operating point. To do this, power down your circuit. Then, remove the PMOS current mirror. Create a cascode mirror by changing the position of M_3, adding M_4 to your circuit and changing the value of R_1, as shown in Fig. 7. Power up your circuit and verify that your circuit analysis is correct by measuring the node voltages and recording them on Fig. 7.

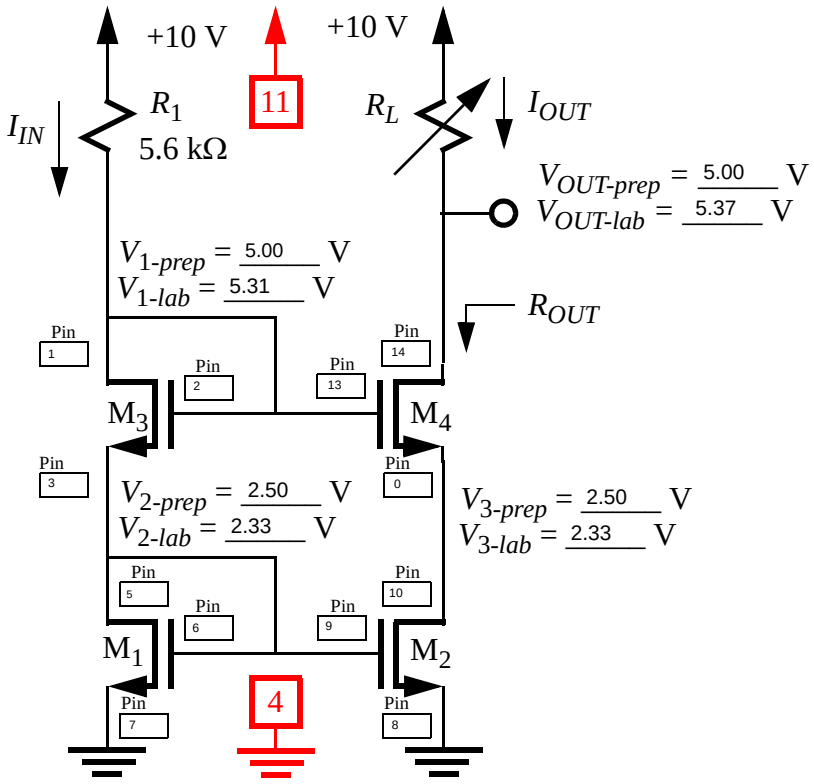

Figure 7) Lab version of Fig. 3 (a cascode current mirror).

2. Gather data to determine the mirror's output resistance. To do this, use the same resistor values and procedure as used in part 2 of *The Basic Current Mirror*. Record the data in *Lab 2.xlsx*, on the sheet labeled "Basic Current Mirror" by adding any necessary columns to the spreadsheet used in *The Basic Current Mirror*.

Report:

The Basic Current Mirror

1. Using the data recorded in your spreadsheet for the basic current mirror, plot I_{OUT} *versus* V_{OUT} on the sheet entitled "I versus V". See part 1 under *The Cascode Current Mirror* below, before preparing your plot.

2. From the plot and your spreadsheet, determine the current mirror's R_{OUT} and the range of V_{OUT} over which the current mirror provides a reasonably constant current (*i.e.* the compliance range). Be sure to annotate the plot to unambiguously show the compliance range. Compare these values with parts 1b and 1c of the preparation.

   R_{OUT} = _____ kΩ V_{OUT_min} = _____ V V_{OUT_max} = _____ V

3. Using the plot of part 1 above, determine the value of I_{OUT} when $V_{OUT} = V_1$ (see Fig. 1) and determine the value of I_{IN} based on your measured value of V_1. Then, based on these values of I_{OUT} and I_{IN} determine;

   a) The actual current mirror ratio (*i.e.*, I_{OUT}/I_{IN}) for the basic current mirror. $\frac{I_{OUT}}{I_{IN}}$ = _____

   b) If the only source of mismatch is due to W/L variations, what are the relative W/L ratios for M_1 and M_2? $\frac{W_2/L_2}{W_1/L_1}$ = _____

   c) If the only source of mismatch is due to variations in V_t, and M_1 has exactly the V_t given in the preparation, by how much does the V_t of M_2 differ from that of M_1? $V_{t2} - V_{t1}$ = _____ mV

Multiple Current Mirrors

1. Based on your measured results, determine the PMOS current mirror's current ratio by comparing the currents through R_2 and R_3 (this should be the same value found in part 2 of the *Multiple Current Mirrors* section in the Lab. $\frac{I_{OUT}}{I_2}$ = _____

2. Based on your scope capture (from part 4 of the *Multiple Current Mirrors* section of the lab) labeled PSRR.png, determine the amplitude of the 1 kHz sine wave for both v_s and v_{out}. Annotate the PSRR.png to clearly indicate these two signals. These signals are known as the **supply ripple** and the **output ripple** respectively. Then determine the circuit's *PSRR*..[1]

   v_s = _____ V

   v_{out} = _____ V

   $PSRR$ = _____ dB

1. Obviously this is not the circuit's actual *PSRR* as the bias current (through R_1) is also affected by the supply. If interested in more details, do an internet search on "bandgap references".

3. Using the spreadsheet created in part 3 of *Multiple Current Mirrors* (in the lab), determine the PMOS current mirror's R_{OUT} and find the ratio R_{OUT}/R_3 (in dB).

   R_{OUT} = _____ kΩ R_{OUT}/R_3 = _____ dB

4. Compare the *PSRR* found above, to the ratio R_{OUT}/R_3.

The Cascode Current Mirror

1. Using the data recorded in your spreadsheet for the cascode current mirror, plot I_{OUT} *versus* V_{OUT} on the same plot and scale as used in part 2 of *The Basic Current Mirror*.
2. From the plot and your spreadsheet, determine the cascode current mirror's R_{OUT} and compliance range. Compare these values with part 3b of the preparation.

   R_{OUT} = _____ kΩ V_{OUT_min} = _____ V V_{OUT_max} = _____ V

3. Comment on the basic and cascode mirror's output resistances and compliance ranges.