Rochester Institute of Technology

EEEE 381 - Electronics I
Techical Memorandum

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Date: Performed: 03-20-2015; Due: 04-03-2015
Subject: Lab #3: MOSFET Current Sources

Abstract

The purpose of this exercise was to learn more about the use of MOSFETs as current sources in order to supplement theory learned in class. MOSFET Current sources are used extensively in amplifier circuits to provide bias current. Two amplifier circuits were created and analyzed under varying loads, in order to characterize their responses. The data was analyzed and found to be mostly close between the simulation and calculation, and the measured results. The major outlier being the output resistance for the Modified Wilson source, which was incorrect by a large factor.

Theory

A simple current source can be constructed using two transistors, as shown in figure 1. In figure 1, the current source was replaced with a resistor. This eases calculations, once the resister value is calculated. The current through the resistor is equal to the current through the left MOSFET, and this current sets the gate voltage for the two transistors. This makes the current through the right transistor proportional to the value of the resistor.

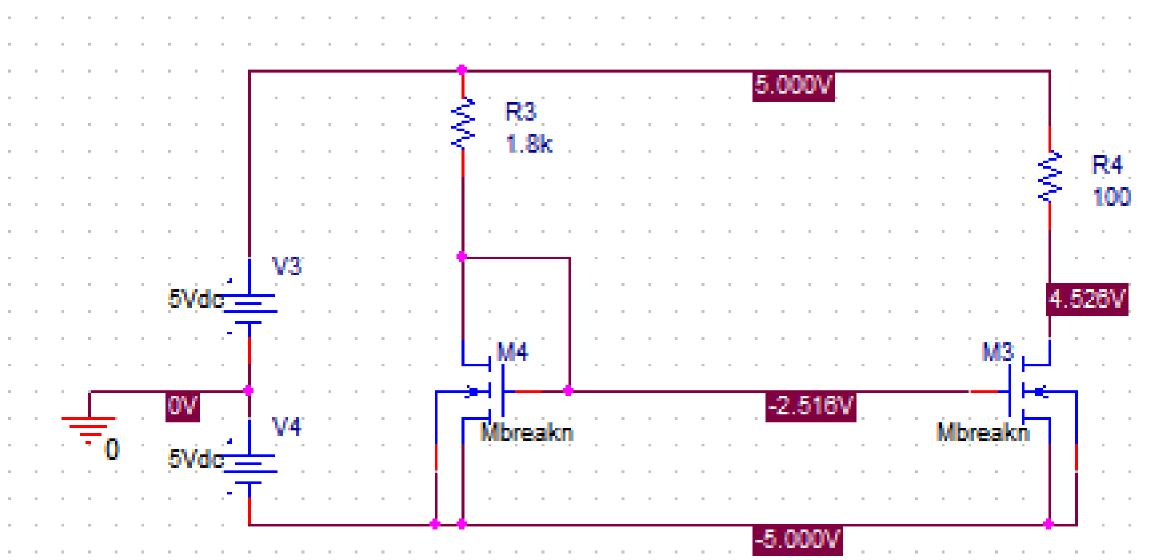

Figure 1: Circuit for the Simple Current Source

The two transistor source is not ideal in the fact that it has a relatively high output impedance, in comparison to another design, the Modified Wilson Current Source. This source is shown in figure 2. Note that in this circuit, the current source has been replaced with a resistor. For both circuits, the current on the right mirrors the current on the left side. This is due to the fact that the MOSFETs on the right and left have the same V_{gs} applied. This is important for designs employing multiple amplifiers with equal performance.

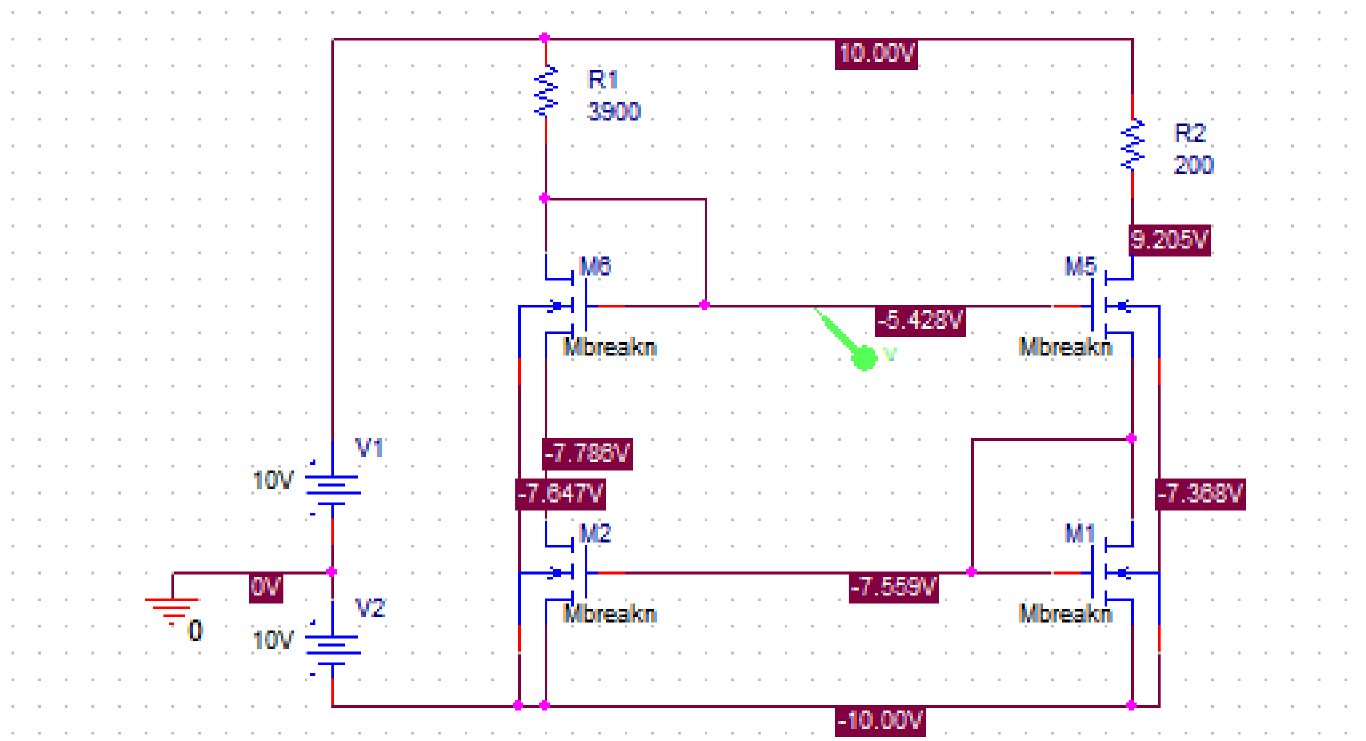

Figure 2: Circuit for the Simple Current Source

An important parameter when analyzing the performance of current sources is the output resistance, R_{out}. For the simple current source, the output resistance of the circuit is simply the value of r_o for the transistor on the right. This is shown in equation 1. The output resistance for the Modified Wilson source is shown in equation 2. Note that the output resistance for the Modified Wilson Source is approximate. This is due to the fact that the other terms in the derivation are minor in comparison to the $(g_m r_o)r_o$ term.

$$R_{out} = r_o \tag{1}$$

Equation 1: Output Resistance for the Simple Current Source

$$R_{out} \approx (g_m r_o)r_o = g_m r_o^2 \tag{2}$$

Equation 2: Output Resistance for the Modified Wilson Current Source

In order to calculate r_o for the two circuits, equation 3 is used. To calculate g_m, equation 4 is used.

$$r_o = \frac{1}{\lambda I_d} \tag{3}$$

Equation 3: r_o Calculation Equation

$$g_m = \frac{2I_d}{V_{ov}} \tag{4}$$

Equation 4: g_m Calculation Equation

Using the standard MOSFET current equation, neglecting channel length modulation, V_{gs} of the left MOSFET in the simple current source can be calculated using the given desired current. This was found to be 2.49V. Once V_{gs} is known, the value of R needed to result in the appropriate amount of current con be found through the simple application of Ohm's law. This resistor was found to be 1817.79Ω. The equations used to calculate V_{gs} and R are shown in equation 5

$$4mA = \frac{5 - V_{gs}}{R} = \frac{1}{2}K(V_{gs} - V_t) \tag{5}$$

Equation 5: Equation for the calculation of V_{gs} and R

Similarly, the resistor for the Modified Wilson Source can be calculated in the same way. This is shown in equation 6. V_{gs} was calculated to be 2.49V and R was found to be 3755.53Ω.

$$4mA = \frac{10 - V_{gs}}{R} = \frac{1}{2}K(V_{gs} - V_t) \tag{6}$$

Equation 6: Equation for the calculation of V_{gs} and R for the Modified Wilson Source

Using standard resistors for the two sources yields 1.8KΩ and 3.9KΩ. If the resistances were to decrease, all of the mirrored currents would increase as a result.
As the load increases in resistance, there is more of a voltage drop across in, reducing V_{ds}. This can progress far enough to drop the MOSFET(s) out of saturation. The maximum resistor can be found by setting the V_{ds} equal to V_{ov} and using the remaining voltage and the current and Ohm's law. For the simple current source, the maximum load was calculated to be 2052.78Ω. The Modified Wilson Current source has a maximum load of 3755.55Ω. This takes into account the voltage drop across the two transistors, each of which are on the edge of saturation. The equations used to calculate the maximum loads are shown in equations 7 and 8.

$$R_{LMax} = \frac{10V - V_{DS}}{I_d} \tag{7}$$

Equation 7: Calculation of the Maximum Load for the Simple Current Source

$$R_{LMax} = \frac{20V - 2 * V_{DS}}{I_d} \tag{8}$$

Equation 8: Calculation of the Maximum Load for the Modified Wilson Current Source

Once the maximum load was calculated, various resistances were used and the output current and voltage measured. This is shown in figures 1 and 2.

$\mathbf{R_L}$	$\mathbf{V_{gs}}$	$\mathbf{I_{REF}}$	$\mathbf{V_{OUT}}$	$\mathbf{I_{OUT}}$
2000	-2.5500	4.1944×10^{-3}	-2.9800	3.9900×10^{-3}
1500	-2.5200	4.1778×10^{-3}	-1.4000	4.2667×10^{-3}
1000	-2.5200	4.1778×10^{-3}	578.20×10^{-3}	4.4218×10^{-3}
500	-2.5200	4.1778×10^{-3}	2.7050	4.5900×10^{-3}
470	-2.5200	4.1778×10^{-3}	2.8370	4.6021×10^{-3}
200	-2.5200	4.1778×10^{-3}	4.0600	4.7000×10^{-3}
100	-2.5200	4.1778×10^{-3}	4.5260	4.7400×10^{-3}

Table 1: Output Current and Voltage for the Simple Current Source

$\mathbf{R_L}$	$\mathbf{V_{gs}}$	$\mathbf{I_{REF}}$	$\mathbf{V_{OUT}}$	$\mathbf{I_{OUT}}$
3000	-5.2870	3.9197×10^{-3}	-1.7740	3.9247×10^{-3}
2000	-5.3420	3.9338×10^{-3}	2.1130	3.9435×10^{-3}
1100	-5.3870	3.9454×10^{-3}	5.6450	3.9591×10^{-3}
1000	-5.3920	3.9467×10^{-3}	6.0390	3.9610×10^{-3}
500	-5.4140	3.9523×10^{-3}	8.0160	3.9680×10^{-3}
470	-5.4160	3.9528×10^{-3}	8.1350	3.9681×10^{-3}
300	-5.4230	3.9546×10^{-3}	8.8090	3.9700×10^{-3}
200	-5.4280	3.9559×10^{-3}	9.2050	3.9750×10^{-3}
100	-5.4320	3.9569×10^{-3}	9.6030	3.9700×10^{-3}

Table 2: Output Current and Voltage for the Modified Wilson Current Source

Note that at near the maximum load, the V_{gs} value of the transistor closest to the output changes more rapidly. This confirms that the largest resistors used are close to the maximum supported.

Results

Once the simple current source was constructed, its performance was measured in terms of the output current and the reference voltage for various resistors. This data is shown in table 3. The reference resistor was measured to be 1785.4Ω.

$\mathbf{R_L}$	$\mathbf{R_{real}}$	$\mathbf{V_{IREF}}$	$\mathbf{I_{REF}}$	$\mathbf{I_{OUT}}$	$\mathbf{V_{OUT}}$
2000	1984.7	7.9950	4.4780×10^{-3}	4.3497×10^{-3}	-3.8736
1500	1498.3	7.9943	4.4776×10^{-3}	4.5500×10^{-3}	-1.8124
1000	993.45	7.9932	4.4770×10^{-3}	4.6930×10^{-3}	344×10^{-3}
500	495.35	7.9921	4.4764×10^{-3}	4.6960×10^{-3}	2.6060
470	464.9	7.9797	4.4694×10^{-3}	4.8429×10^{-3}	2.7477
200	200.84	7.9901	4.4752×10^{-3}	4.9353×10^{-3}	4.0088
100	99.6	7.9905	4.4755×10^{-3}	5.1205×10^{-3}	4.4900

Table 3: Measured Output for the Simple Current Source

This data was also collected for the Modified Wilson source. This is shown in table 4. The reference resistor was measured to be 3786.5Ω.

$\mathbf{R_L}$	$\mathbf{R_{real}}$	$\mathbf{V_{IREF}}$	$\mathbf{I_{REF}}$	$\mathbf{I_{OUT}}$	$\mathbf{V_{OUT}}$
3000	2974.7	15.698	4.1458×10^{-3}	4.0753×10^{-3}	-2.1228
2000	1985.4	15.647	4.1323×10^{-3}	4.1739×10^{-3}	1.7131
1100	1009.3	16.510	4.3602×10^{-3}	5.8197×10^{-3}	4.1260
1000	993.58	16.600	4.3840×10^{-3}	4.7310×10^{-3}	5.2994
500	496.56	15.530	4.1014×10^{-3}	5.3454×10^{-3}	7.3457
470	465.91	15.470	4.0856×10^{-3}	5.3884×10^{-3}	7.4895
300	299.07	15.737	4.1561×10^{-3}	5.8916×10^{-3}	8.2380
200	199.32	15.736	4.1558×10^{-3}	5.9282×10^{-3}	8.8184
100	99.735	15.330	4.0486×10^{-3}	6.1663×10^{-3}	9.3850

Table 4: Measured Output for the Modified Wilson Source

Plotting V_{out} against I_{out} allows for the calculation of the output resistance from the slope. Plots of the data are shown in figures 3 and 4 for the simple and Modified Wilson sources, respectively. Note that the 3K resistor data was omitted from the Modified Wilson plot. This was because the resistor pulled the source too close or over the edge of saturation. There are still more measurements than were required.

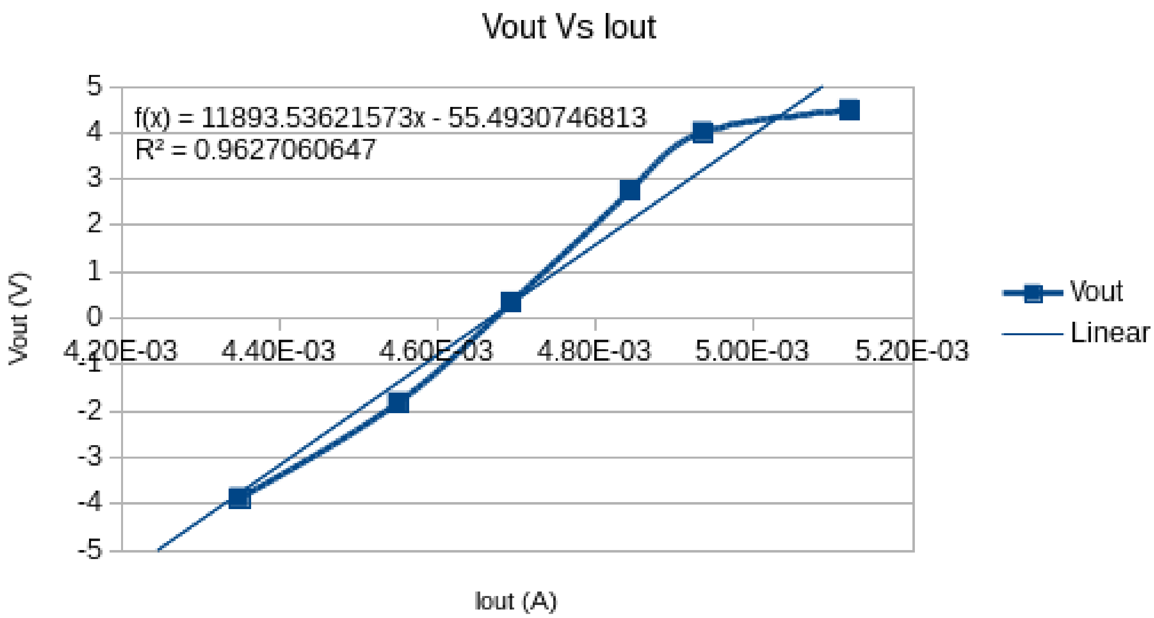

Figure 3: V_{out} vs I_{out} for the Simple Source

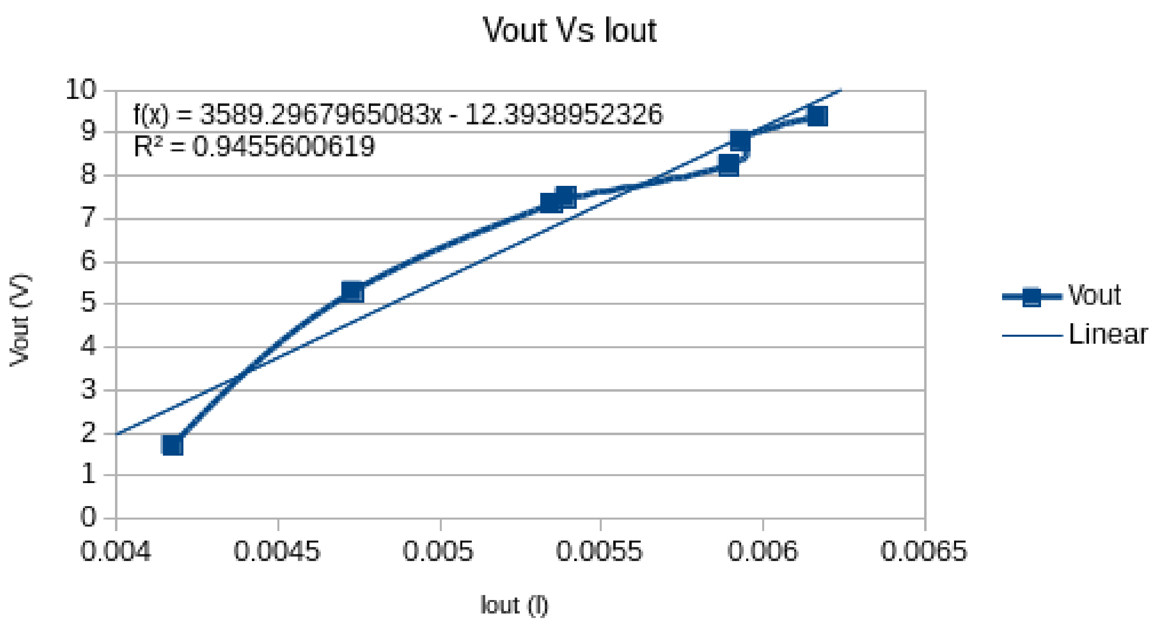

Figure 4: V_{out} vs I_{out} for the Modified Wilson Source

From the plots, the output resistance was calculated. The results for this are shown in table 5.

Circuit	R_{out} Calculated	R_{out} Calculated	%error
Simple Current Source	12500	11893	-0.04856
Modified Wilson	698753	3589.29	-0.9948632922

Table 5: Final Calculated Output Resistance

The results for the simple current source are almost exact. The results for the Modified Wilson are off by a great amount. This is most likely due to errors in measurement. The results are too far away from eachother to be a simple error and most likely were due to the measurements being taken wrong. Another possibility is that the chip was slightly burned. This would lead to consistently wrong results. The chip may have been affected by static, or a high current load.

Conclusion

Current sources are important for amplifying circuits. The more stable the source, the bettor quality of amplification. This exercise reinforced theory learned in class and was valuable in that it taught the use and troubleshooting of important circuits which will be used later in lab. Even though the results for the output resistance were off for the Wilson source, the results were consistent, suggesting a problem with the measurements, or the chip. The results for the simple source were consistent and close to the expected values.