

ECE4902 C2013 - Lab 5
MOSFET Common Source Amplifier with Active Load
Bandwidth of MOSFET Common Source Amplifier:
Resistive Load / Active Load

PURPOSE:

The primary purpose of this lab is to measure the performance of the common source amplifier with active (current source) load. Additionally, you will measure the bandwidth of the common source amplifier with both active (current source) and passive (resistor) loads.

The common source amplifier is an important topology to be familiar with for high gain applications - in single-ended signal situations, the common-source amplifier offers high gain and high input resistance. It will also be relevant in differential signal situations - when the differential amplifier is analyzed with half-circuit techniques, the result of the symmetry split is two common-source amplifiers.

Upon completion of this lab you should be able to:

- Recognize the increased gain available with active loads, and the associated difficulty (and importance) of setting the correct input DC bias level when using high gain circuits.
- Recognize the gain-bandwidth tradeoff
- Using sine wave inputs, make detailed measurement of magnitude and phase response to construct a Bode plot
- Using a small square wave input, use the $BW \times t_r = 0.35$ relationship to quickly measure the bandwidth $BW (f_{3dB})$

NOTE: This lab involves construction and measurement of circuits with high gains (≈ 100). It is extremely important to use bypass capacitors on the supply rail(s) to keep the power supply voltages clean.

LAB PROCEDURE

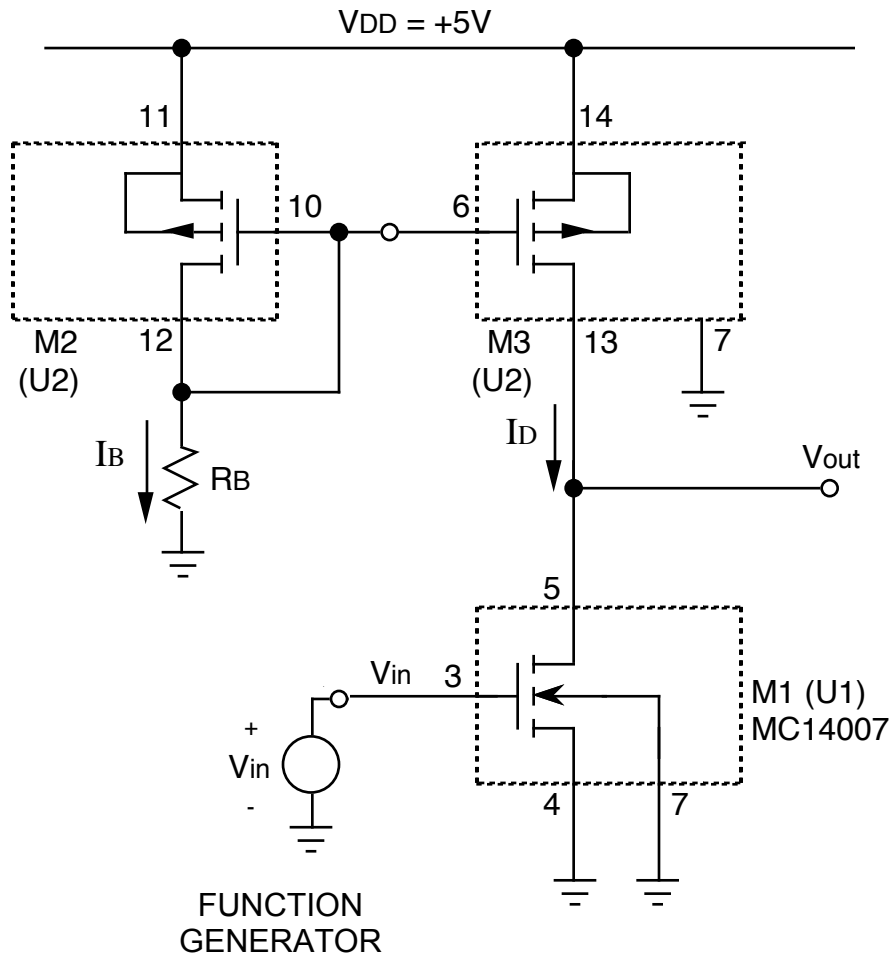


Figure L5-1.

MOSFET COMMON SOURCE AMPLIFIER WITH ACTIVE LOAD

L5-1. Construct the circuit shown in Figure L5-1. In this case, the load is the current source formed by M2 and M3. Choose $R_B=100k\Omega$ for a DC drain current of $I_D \approx 30\mu A$. Use the oscilloscope to monitor input and output voltage signals; also consider use of the DVM when more precise measurements are necessary.

NOTE: the “U1” and “U2” designations in the schematics indicate that M2 and M3 are MOSFETs from a different physical package than M1. Although this isn’t necessary for this circuit, it does make it easier for substituting a resistive load later in the lab.

DC BIAS LEVEL

Note: *Be sure to set the function generator output menu to Hi-Z mode so the voltage readings on the function generator are correct.*

L5-2. Set the DC bias level at the input by setting the function generator to produce a DC only output. Adjusting the DC level at the function generator output until you observe the correct DC bias level ($\approx +2.5V$, midway between the supply rails) at the output of the common source amplifier.

Measure the voltage drop across R_B to determine the DC bias current in the mirror, which should be approximately equal to the DC bias current in the common source amplifier. Also, for MOSFET M1, measure the DC value of V_{GS1} at the operating point. The DC operating current should be around $30\mu A$.

SMALL SIGNAL GAIN

L5-3. Set the function generator to produce a small (20 to 30mV pk-pk) triangle wave at v_{in} , riding on the DC level you determined from L5-2. Adjust the function generator amplitude until the signal swing at the amplifier output is about 2V peak-to-peak. You want an output amplitude large enough to measure easily, but not so large that the output waveform is distorted. Measure and record the input and output peak-to-peak amplitudes, and calculate the small signal gain from input to output.

Is this amplifier inverting or noninverting?

LARGE SIGNAL OUTPUT LIMIT

L5-4. Increase the amplitude on the input until you observe clipping at the output. Measure and record the positive and negative voltage swing limits, and the corresponding input voltages.

LAB PROCEDURE: ACTIVE LOAD BANDWIDTH MEASUREMENT

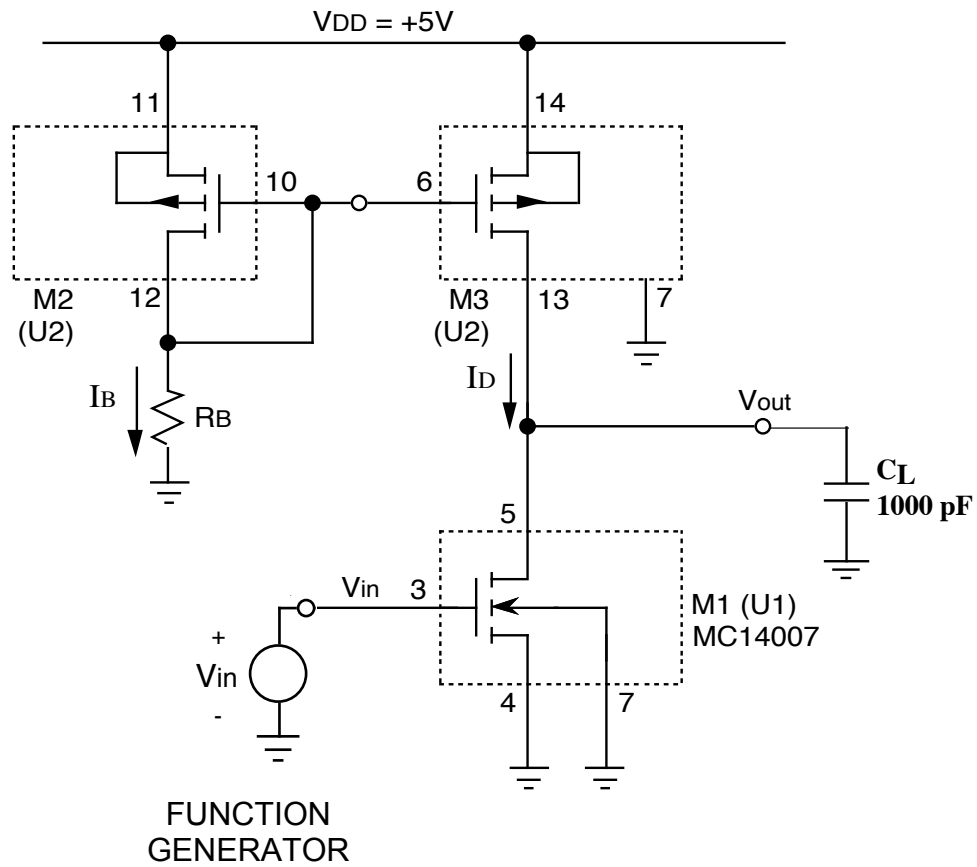


Figure L5-2.

MOSFET COMMON SOURCE AMPLIFIER WITH ACTIVE LOAD

L5-5. Construct the circuit shown in Figure L5-2 by adding the load capacitor $C_L = 1000\text{pF}$ to the circuit of Figure L5-1.

DC BIAS LEVEL

L5-6. Reduce the signal amplitude to zero and recheck the DC bias condition - it should be the same as from part L5-2. Be sure you have the correct DC bias level at the output ($\approx +2.5\text{V}$, midway between the supply rails), the same DC value of V_{GS1} , and a DC operating current of around $30\mu\text{A}$. If necessary, repeat the procedure from part L5-2 to set the DC bias level.

SMALL SIGNAL GAIN

L5-7. Repeat the procedure from L5-3 to check that you have the same small signal gain from input to output. *Be sure to use an amplitude that does not exceed small signal operation!*

TRANSFER FUNCTION MEASUREMENT: SINE WAVE RESPONSE VS. FREQUENCY

L5-8. Switch the function generator to produce a sine wave output. Starting at 100Hz , measure the input and output amplitudes, and the input-to-output time delay, to fill in Table L5-1. You will repeat these measurements at logarithmically spaced points in frequency to measure the magnitude and phase of the transfer function from input to output.

In your lab notebook, plot the magnitude and phase in Bode plot fashion and verify that the measured data looks like a single pole transfer function. Estimate the 3-dB frequency $f_{3\text{dB}}$.

UNITY GAIN FREQUENCY / GAIN-BANDWIDTH PRODUCT

L5-9. From your plot estimate the unity gain frequency f_T . Verify that this frequency is approximately equal to the product of the low frequency gain and the bandwidth $f_{3\text{dB}}$.

SHORTCUT TO BANDWIDTH MEASUREMENT USING RISE TIME

To verify the entire transfer function, acquiring the full set of sine wave data points is the most reliable method. However, if all you need is a quick estimate of the 3-dB frequency, the risetime method provides a convenient shortcut with just one measurement.

L5-10. Switch to a square wave. Using the rise time measurement procedure (see <http://ece.wpi.edu/~mcneill/handouts/RiseTimeMeasurement.pdf>), measure the rise time t_R . From the risetime use the $\text{BW} \times t_R = 0.35$ relationship to estimate the bandwidth BW, also known as the 3dB frequency or $f_{3\text{dB}}$. Compare this estimate to the $f_{3\text{dB}}$ from part L5-8.

Table L5-1. Frequency Response Measurements, Active Load.

MEASURED				CALCULATED			
FREQ	AMPLITUDE		DELAY	GAIN	GAIN (dB)	PERIOD	PHASE
f	v _{in}	v _{out}	t _d	$\frac{v_{out}}{v_{in}}$	$20 \cdot \log\left(\frac{v_{out}}{v_{in}}\right)$	$T = \frac{1}{f}$	$-360^\circ \cdot \left(\frac{t_d}{T}\right)$
100 Hz							
200 Hz							
500 Hz							
1 kHz							
2 kHz							
5 kHz							
10 kHz							
20 kHz							
50 kHz							
100 kHz							

RESISTIVE LOAD BANDWIDTH MEASUREMENT

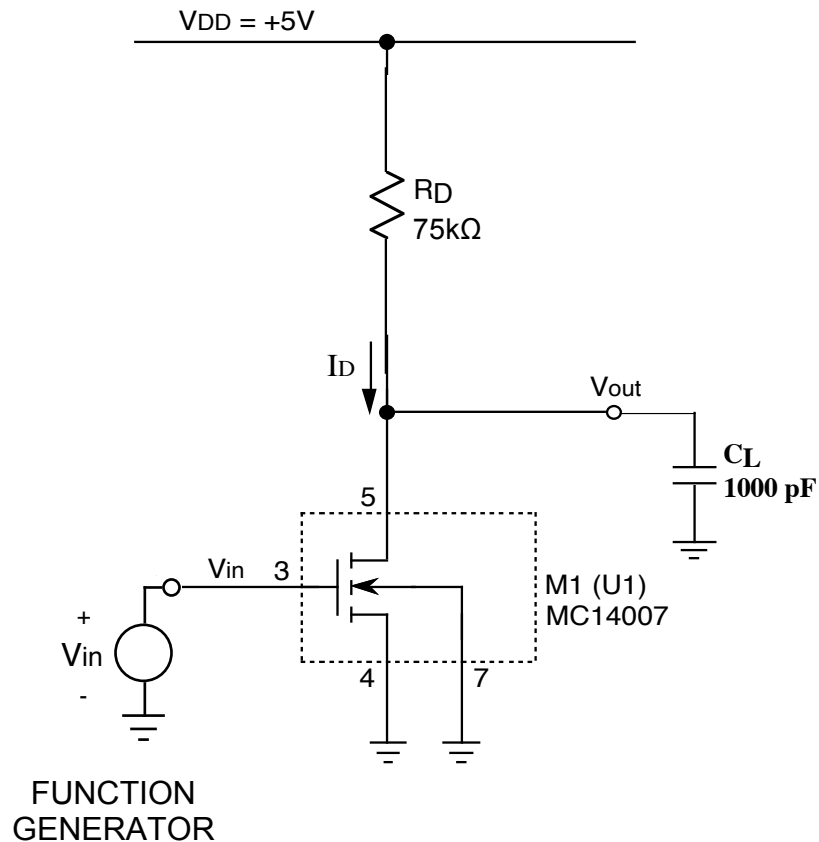


Figure L5-3.

MOSFET COMMON SOURCE AMPLIFIER WITH RESISTIVE LOAD

L5-11. Starting with the circuit you have from Figure L5-2, you can construct the circuit shown in Figure L5-3 by simply disconnecting the drain of M1 (pin 5) from the active load, and connecting it to V_{DD} through a $75k\Omega$ resistor. This resistor value should give approximately the same DC output level of $+2.5V$.

Keep the same DC bias level at the input! DO NOT adjust the function generator offset from what you had for the previous circuit. This ensures that the common source MOSFET M1 is operating at the same DC bias condition (and therefore the same transconductance g_m).

Be sure the 1000pF capacitor is still connected to the v_{out} node. Note that this circuit is similar to the resistive load circuit of Lab 4, with the addition of the load capacitor $C_L = 1000\text{pF}$.

DC BIAS LEVEL

L5-12. *Keep the same DC bias level at the input! DO NOT adjust the function generator offset from what you had for the previous circuit.* This will keep the common source MOSFET M1 at the same operating point: same DC drain current I_D , same transconductance g_m . The output operating point will not be exactly at midscale, but it should be in the linear range of the amplifier.

Measure the voltage drop across R_D to determine the DC bias current in the common source amplifier. Also, for MOSFET M1, measure the DC value of V_{GS1} at the operating point. The DC operating current should be approximately the same as what you measured in lab part L5-6. There may be a small change due to thermal drift; if the operating point has changed significantly, readjust the input offset until you get the same I_D and V_{GS} for M1 that you measured in part L5-6.

SMALL SIGNAL GAIN

L5-13. With a moderately sized triangle wave at a frequency of 100Hz for v_{in} , measure the input and output peak-to-peak amplitudes, and calculate the small signal gain from input to output. Since the gain of the resistive load amplifier is smaller, you will need to increase the function generator amplitude until the signal swing at the amplifier output is about 1V peak-to-peak. As in part L5-3, you want an amplitude large enough to measure easily, but not so large that the output waveform is distorted.

SINE WAVE RESPONSE AT DIFFERENT FREQUENCIES

L5-14. Switch the function generator from triangle wave to sine wave. Starting at 100Hz, measure the input and output amplitudes, and the input-to-output time delay, to fill in Table L5-2. You will repeat these measurements at logarithmically spaced points in frequency.

In your lab notebook, plot the magnitude and phase in Bode plot fashion and verify that the measured data looks like a single pole transfer function. Estimate the 3-dB frequency f_{3dB} .

UNITY GAIN FREQUENCY / GAIN-BANDWIDTH PRODUCT

L5-15. From your plot estimate the unity gain frequency f_T . Verify that this frequency is approximately equal to the product of the low frequency gain and the bandwidth f_{3dB} .

Also verify that the unity gain frequency is approximately equal to the f_T from the active load amplifier measured in L5-9.

SHORTCUT TO BANDWIDTH MEASUREMENT USING RISE TIME

L5-16. Switch the function generator to a square wave. Repeat the procedure from L5-10 to measure the rise time t_r . From the risetime use the $BW \times t_r = 0.35$ relationship to estimate the 3dB bandwidth frequency f_{3dB} . Compare this estimate to the f_{3dB} from part L5-14.

Table 5-2. Frequency Response Measurements, Resistive Load.

MEASURED				CALCULATED			
FREQ	AMPLITUDE		DELAY	GAIN	GAIN (dB)	PERIOD	PHASE
f	v _{in}	v _{out}	t _d	$\frac{v_{out}}{v_{in}}$	$20 \cdot \log\left(\frac{v_{out}}{v_{in}}\right)$	$T = \frac{1}{f}$	$-360^\circ \cdot \left(\frac{t_d}{T}\right)$
100 Hz							
200 Hz							
500 Hz							
1 kHz							
2 kHz							
5 kHz							
10 kHz							
20 kHz							
50 kHz							
100 kHz							

Lab Writeup

The purpose of these labs is to help "close the loop" in your understanding of the complete integrated circuit design process. In terms of this lab, we can approach these circuits at three different levels: hand analysis, simulation, and the measurements of actual circuits. (Since we're working with the CD4007, we don't have the dimension of MOSFET geometry control available that we would have in actual IC design). In your writeup, compare the measured results, the calculated results from hand analysis, and the results of circuit simulation. Note that errors of 20% or so are not unusual! As gains get higher, it is difficult both to predict and to measure gain accurately. Fortunately, when an op-amp is used in negative feedback, we don't care about the value of the op-amp's open loop gain being accurate as long as the gain is high.

COMMON SOURCE AMPLIFIER WITH ACTIVE LOAD

W5-1. For the circuit of Figure L5-1, calculate the expected:

- DC operating point (input voltage corresponding to $V_{OUT}=+2.5V$)
- small signal gain (slope of the plot at the operating point)
- large signal output limits

For the small signal gain, you will need a value of λ for both the n-channel and p-channel MOSFETs. Use your λ_p and λ_n results from your V_{DS} - I_D measurements in Lab 3.

W5-2. Compare the measured values from lab parts L5-2, L5-3, and L5-4, to the calculated values in W5-1.

GAIN IMPROVEMENT WITH ACTIVE LOAD

W5-3. Compare the measured small-signal gain for the active load circuit with that of the resistive load circuit from Lab 4.

FREQUENCY RESPONSE

W5-4. For your measurements from each of the circuits of Figure L5-2 and Figure L5-3, plot the magnitude and phase Bode plots. Your plots should show the measured data points, and the superimposed asymptotes corresponding to "best fit" values of low frequency gain a_v and 3-dB bandwidth frequency f_{3dB} . Also show the unity gain frequency f_T . Indicate on your plot and in your writeup the values of a_v , f_{3dB} , and f_T in each case.

UNITY GAIN FREQUENCY / GAIN-BANDWIDTH PRODUCT

W5-5. In your writeup, calculate the gain-bandwidth product $a_v \times f_{3dB}$, and comment on how well it agrees with the unity gain frequency f_T in each case.

SMALL SIGNAL CALCULATIONS

W5-6. In your writeup, show the small signal models for each circuit and calculate the expected:

- low frequency gain a_v
- bandwidth f_{3dB}
- unity gain frequency f_T

Comment on how well the measured values from lab in W5-4 agree with the calculated values in this part.

SHORTCUT TO BANDWIDTH MEASUREMENT USING RISE TIME

W5-7. For both circuits, compare the f_{3dB} from the Bode plot to the f_{3dB} from the rise time measurement. In your lab writeup, comment on the accuracy and ease of each measurement technique.

GAIN-BANDWIDTH TRADEOFF

W5-8. Plot both magnitude Bode plots (from the data in Tables L5-1 and L5-2) on the same axes. The plot should show a tradeoff between gain and 3-dB frequency, with approximately the same unity gain frequency in both cases.

Simulation

AC SIMULATION: BODE PLOT

S5-1. With help from the Lab 5 simulation page

<http://ece.wpi.edu/~mcneill/4902/labs/lab5/Lab5.html>

perform a DC simulation to find the correct input operating point (one that corresponds to an output operating point of $V_{OUT} = +2.5V$). Then, using that operating point, perform an AC simulation to plot the magnitude and gain of the small signal gain v_{out}/v_{in} . Compare the results to what you measured in the lab.

Include a plot of the DC and AC simulation results in the lab writeup you hand in.