University of Michigan
EECS 311: Electronic Circuits
Fall 2008

Lab 1 – Non-Ideal Opamps

Issued 9/8/2008
Pre-Lab Completed 9/15/2008
Lab Due in Lecture 9/22/2008

Introduction

This lab will involve the characterization of an LM741 operational amplifier from Fairchild Semiconductor, with emphasis on the following nonideal properties of opamps: finite gain, bandwidth, offset voltage, and slew rate. A datasheet for this opamp may be found at:

LM741 Datasheet: http://www.eecs.umich.edu/courses/eecs311/f08/labs/lm741.pdf

To adequately prepare you for this lab, a custom model of an opamp has been developed in Cadence that you will characterize in a simulation environment by using the same experiments that will be used in lab to characterize the LM741. The model of the opamp in Cadence is not meant to match the performance of the LM741, but it has similar limitations (finite gain, bandwidth, offset voltage, and slew rate).

Complete all pre-lab exercises before attempting the in-lab exercises. Use the Pre-Lab Report Template and In-Lab Report Template at the end of this assignment to record data and answer questions. Have the GSI sign off on the specified exercises on the check-off sheet at the end of this assignment. Hand in the check-off sheet, both report templates, and the requested plots at the beginning of lecture on the due date.

Pre-Lab Exercises

Complete all of the following exercises before attempting the in-lab exercises. Use Cadence to simulate circuits where requested, using the *lab1_opamp* component in the *EECS311Lib* library for all problems. Refer to the online Cadence tutorial to setup your Cadence environment and for basic information on using Cadence.

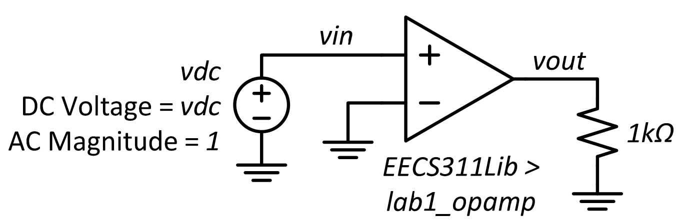


Figure 1. Cadence schematic for exercises P1.1-3.

P1.1 Review the online Cadence tutorial at the following site and refer to this tutorial for guidance in completing any of the following problems. By following the instructions in this tutorial, setup your Cadence environment and then launch Cadence. Create a library called *lab1*. Within your *lab1* library, create a new schematic cell view called *prelab* and build the schematic shown in Figure 1. Make sure you *Check and Save* your schematic.

http://www.eecs.umich.edu/courses/eecs311/f08/tutorials/cadence.html

P1.2 Launch Analog Environment and perform a DC sweep of the variable *vdc* (DC input voltage in Figure 1) from $-5mV$ to $+5mV$ in 10k steps. Plot the output voltage as a function of the swept input voltage. Determine the DC offset voltage of the amplifier by finding the value of V_{in} that results in $V_{OUT} = 0V$. Determine the DC open-loop gain of the amplifier A_0 by measuring the slope of the output voltage, dV_{OUT}/dV_{IN}, around the point $V_{OUT} = 0V$.

P1.3 In Analog Environment, edit the *vdc* variable, giving it the value found from P1.1 that results in $V_{out} = 0$. Perform an AC analysis from $1Hz$ to $1GHz$ with an AC magnitude of $v_{in} = 1V$. Plot the open-loop transfer function $H(s) = 20\log(v_{out}/v_{in})$ and find the DC gain and 3dB bandwidth of the amplifier.

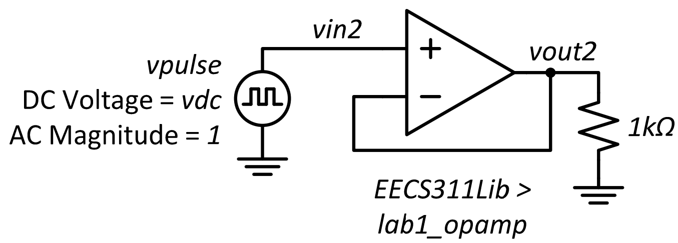


Figure 2. Circuit for exercises P1.4 and P1.5.

P1.4 On the same schematic, without altering the circuit used for P1.2 and P1.3, add a second opamp configured for unity-gain as shown in Figure 2. Use different net names to label the wires – Cadence treats separate wires with the same net name as shorted together. Using Analog Environment, perform an AC analysis from $1Hz$ to $1GHz$ with an AC magnitude of $v_{in} = 1V$. Plot the transfer function $H(s) = 20\log(v_{out}/v_{in})$ and find the DC gain and 3dB bandwidth of the amplifier. Append a plot of the open-loop transfer function to the unity-gain response. At approximately what frequency and gain to the asymptotes of the plots join?

P1.5 Perform a transient analysis for $40\mu s$ of the unity gain amplifier, check the *conservative* option in the transient analysis window. Use the *vpulse* source in the *analogLib* library for the square wave input source. Give the *vpulse* a period of $10\mu s$, pulse width of $20\mu s$, $1ps$ rise/fall time, and Voltage 1 & 2 values of $\pm 1mV$. Plot the output voltage and measure the time constant of the step response. Increase the values of Voltage 1 & 2 to $\pm 10V$ and re-simulate the transient response. Determine the region in which the output of the amplifier is slew rate limited, and measure the slew rate.

Note: slew rate is defined as the maximum rate of change of the output voltage (dv_{out}/dt) of the opamp. An opamp cannot change its output voltage faster than the slew rate limit.

In-Lab Exercises

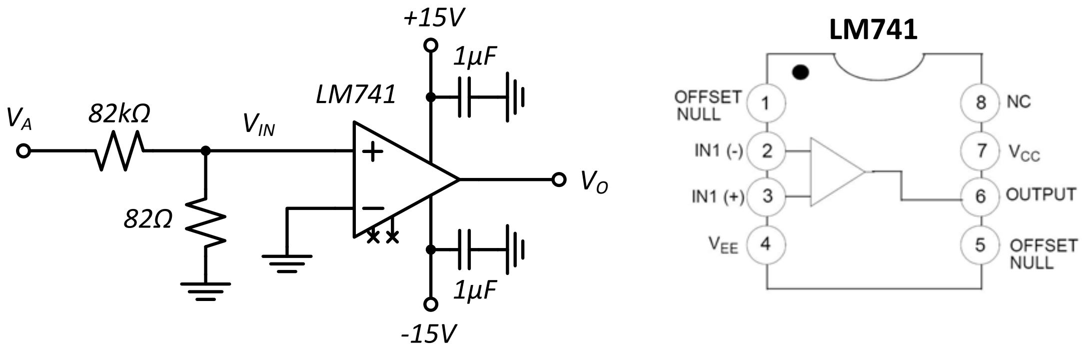


Figure 3. Circuit for exercises L1.1 and pinout of LM741.

L1.1 This part of the lab will use the HP4155 Semiconductor Parameter Analyzer to measure the open-loop characteristics of a 741 opamp. Construct the circuit shown in Figure 3.

Before inserting the resistors on the board, measure the values of R_1 and R_2 using a multimeter. Use these measurements to accurately compute the ratio of V_A to V_{IN}.

Connect your circuit to the HP4155 using the connections below by using the colored wires on the HP4155:

Circuit Net	HP4155 Connection
V_a	$VSU1$ (Voltage Source 1)
Ground	GND
V_o	$VMU1$ (Voltage Monitor 1)

Load and execute the program *P741* on the HP4155, which performs a DC sweep of the voltage V_a from -10V to +10V while recording the output voltage. Refer to the online HP4155 tutorial for instructions on how to load a program:

http://www.eecs.umich.edu/courses/eecs311/f08/tutorials/hp4155.html

Measure the offset voltage V_{off} and open-loop DC gain A_0 of the amplifier the same way you did in P1.2. Make sure you take into account the scaling factor of the resistive divider in your circuit when calculating V_{off} and A_0. You may need to modify the settings in the HP4155 to reduce the step size of the input voltage to accurately capture the output voltage swing.

Important: You must take into account the scaling factor of the resistive divider in your circuit when calculating V_{off} and A_0. The HP4155 will report values relative to the swept voltage V_A, not V_{IN}.

L1.2 Using the same opamp you used in L1.1, build a unity gain buffer on your proto-board following the schematic in Figure 4. Connect the input voltage V_{IN} to ground and measure the output offset voltage at V_O with a multimeter set to the mV scale.

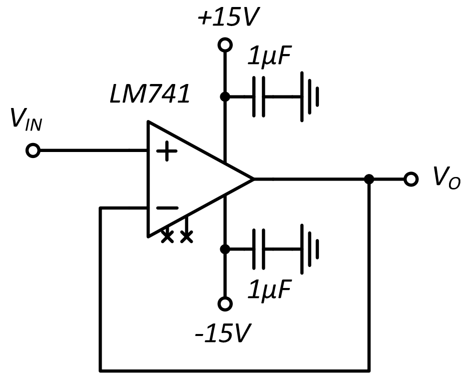
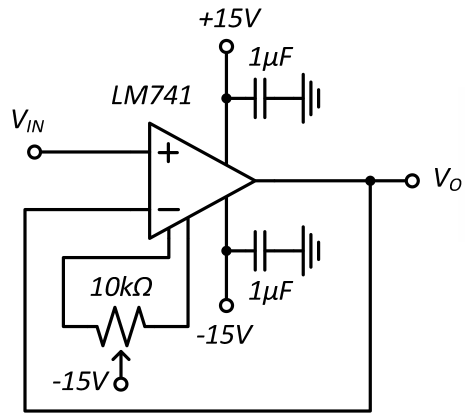


Figure 4. Circuit for exercises L1.2-6.



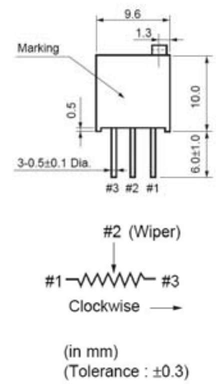


Figure 5. Circuit for exercise L1.2 with offset null.

L1.3 Connect a $10k\Omega$ potentiometer across the offset null pins of the LM741 (pins 1 and 5), with the wiper connected to $-15V$ as shown in Figure 5. Connect the input of the amplifier to ground. While measuring the output voltage with a multimeter set to the mV scale, tune the potentiometer until you see 0V. Then remove the potentiometer and measure the values of resistances between the #1 and #3 pins and the wiper (#2). Keep the potentiometer out for the remainder of the experiments. Show your offset compensated amplifier to the GSI and be prepared to answer questions.

L1.4 Connect the input of the amplifier to the function generator configured as a square wave, 10Vppk, and high-Z mode. Identify the region of the output signal over which the opamp is slew-rate limited. Measure the slew rate for both a positive slope and negative slope.

L1.5 Configure the function generator as a sine wave in high-Z mode. The maximum dV_o/dt of a sine wave is $\omega \cdot V_{oppk}/2$. Choose the input amplitude such that the maximum dV_o/dt of the *output* sine wave never exceeds the slew rate measured in L1.4 for each frequency setting. Using both channels on the oscilloscope, simultaneously measure the input and output voltages. Record the input and output amplitudes from 1kHz to 10MHz in logarithmic steps of 3 points per decade. That is, use multiples of 1, 2, and 5 for each decade: 1kHz, 2kHz, 5kHz, 10kHz, 20kHz, … Additionally measure the 3dB frequency and approximate the phase shift from input to output at that frequency.

L1.6 Configure the function generator as a square wave in high-Z mode. The maximum dV_o/dt of a first-order step response is $V_{step}/\tau = V_{oppk}\omega_{3dB}$. Using the measured 3dB frequency from L1.5, and the slew rate from L1.4, choose an input amplitude to keep the output step response from being slew-rate limited with the function generator configured as a square wave in high-Z mode. Measure the 10%-90% rise-time of the output waveform. Show your step response to the GSI and be prepared to answer questions.

L1.7 Using the same opamp as in the previous exercises, reconnect the amplifier in an inverting configuration with a gain of -10 using the schematic shown in Figure 6. Determine the appropriate values for R_1 and R_2, and measure their values before inserting them into the circuit. Choose the input amplitude for the function generator such that the maximum dV_o/dt of the *output* sine wave never exceeds the slew rate measured in L1.4 for each frequency setting. Record the input and output amplitudes from 1kHz to 10MHz in logarithmic steps of 3 points per decade. Additionally, measure the 3dB frequency and approximate the phase shift from input to output at that frequency.

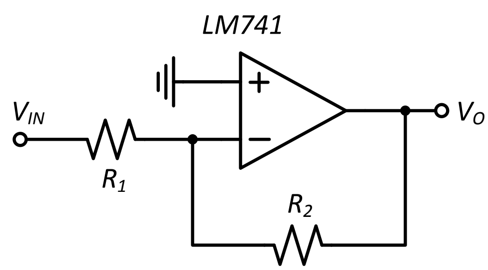


Figure 6. Circuit for exercises L1.6-7. Decoupling capacitors and offset compensation are not shown.

L1.8 Reconfigure the inverting amplifier shown in Figure 6 for a gain of -100 and repeat the steps from L1.7. Show your amplifier and results to the GSI and be prepared to answer questions.

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LAB 1 – PRE-LAB REPORT TEMPLATE

NAME: ______________________________________ LAB SECTION: ____________

Pre-Lab Exercises

P1.2 DC Offset Voltage = _____________

DC Open-Loop Gain = _____________

Attach a plot of the DC sweep.

P1.3 DC Open-Loop Gain = _____________

3dB Frequency = _____________

Calculate the gain-bandwidth product = _____________

P1.4 Frequency at which asymptotes join = _____________

Compare this frequency to the gain-bandwidth product from P1.3.

Attach one plot containing the AC sweep results from both amplifiers.

P1.5 Time constant of unity-gain amplifier = _____________

Slew rate = _____________

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LAB 1 – CHECK-OFF SHEET

NAME: ____________________________________ LAB SECTION: ___________

Have the GSI check you off on the following exercises after you have completed them. Be prepared to answer questions about your circuit or the results.

Exercise .... Date Completed

P1.x Prelab Report Template...______________

L1.3 Offset compensated circuit...______________

L1.6 Step response...______________

L1.8 Frequency response...______________

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LAB 1 – REPORT TEMPLATE

NAME: ______________________________________ LAB SECTION: ____________

Use the following lab report template to record your measurements. Use the space provided to answer questions.

Lab Report Template

L1.1 R_1 = ______________

R_2 = ______________

DC Offset Voltage = ______________

DC Open-Loop Gain = ______________

L1.2 DC Offset Voltage of Unity-Gain Amplifier = ______________

Compare the measurements of offset voltage and open-loop gain from L1.1 and L1.2 with the value specified in the Fairchild LM741 datasheet available on the EECS 311 website.

L1.3 Output Offset Voltage after Nulling = ______________

Potentiometer Resistances: $R_{1-to-wiper}$ = ______________

$R_{2-to-wiper}$ = ______________

L1.4 Slew Rate Pos Slope = ______________ Slew Rate Neg Slope = ______________

Compare the measured slew rate with the value specified in the Fairchild LM741 datasheet available on the EECS 311 website.

L1.5 Record values in the table below.

L1.6 Step Response Output Amplitude = _______________

10%-90% Rise-Time = _______________

Compare the measured rise time with the value specified in the Fairchild LM741 datasheet available on the EECS 311 website.

Assuming the step response is first-order, calculate the value of the 3dB frequency.

$\omega_{3dB} = 1/\tau$ = _______________

L1.7,8 Record values in the table below. Then answer the following questions.

Using a graphing tool such as Matlab or Excel, calculate the transfer function in dB and plot the three frequency responses on a single graph. Use a log-scale for the frequency axis. Labele the three curves and the axes. Attach this plot.

Calculate the gain-bandwidth products for the three configurations.

L1.5 = ______________, L1.7 = ______________, L1.8 = ______________

Should these all be equal assuming a first-order opamp? Are they? Explain.

Compare the unity-gain 3dB frequency from L1.5 with the results from L1.6.

What should the phase of a first-order amplifier be at the 3dB frequency? ____________

What do the measurements of phase tell you about the assumption of a first-order amplifier in each configuration?

	L1.5	**L1.7**	**L1.8**
R_1			
R_2			
1kHz (V_{IN} / V_O)	/	/	/
2kHz (V_{IN} / V_O)	/	/	/
5kHz (V_{IN} / V_O)	/	/	/
10kHz (V_{IN} / V_O)	/	/	/
20kHz (V_{IN} / V_O)	/	/	/
50kHz (V_{IN} / V_O)	/	/	/
100kHz (V_{IN} / V_O)	/	/	/
200kHz (V_{IN} / V_O)	/	/	/
500kHz (V_{IN} / V_O)	/	/	/
1MHz (V_{IN} / V_O)	/	/	/
2MHz (V_{IN} / V_O)	/	/	/
5MHz (V_{IN} / V_O)	/	/	/
10MHz (V_{IN} / V_O)	/	/	/
3dB Frequency			
Phase Shift			