Drexel University
Electrical and Computer Engr. Dept.
Taif Choudhury

Lab Report Structure Guide

READ VERY CAREFULLY!!!

Please also see example report provided below

Cover Page (5%)

Include the cover page as provided in BBLearn page with the information indicated.

Objective (10%)

Please state the purpose of this experiment. A quick and concise overview of what was involved in the lab such as what type of circuits/devices were used and/or what kind of experiments were performed. You may provide some background information on the circuit/components used but be sure to properly cite and sources you used. Do NOT paraphrase your lab procedure/instructions and do NOT put any results or data into this section. I expect this to be one to two paragraphs long.

Results (35%)

Include all tables, graphs and equations obtained from your lab experiment and/or ones obtained from your calculations here. All graphs (since they will be obtained and/or generated by your group) should have your name(s) and date performed on them. Make sure that everything is properly labeled with the appropriate variables AND units. You may describe the graphs/tables/equations in short sentences if it is not clear from the caption alone the significance of it. Length of this will vary depending on the lab.

Explanation (50%)

Be sure to answer all the questions that were asked in your lab instruction. Make comparisons of your results between theoretical, experimental and simulated data where applicable. Note any interesting or significant observations. Reference your graphs, tables and/or calculations here to justify any conclusions you come up with. You may also cite any outside sources if you feel it necessary (include them in the reference page). State any major sources of error and be sure to justify them as well. This should be roughly one to two pages long.

References

You must include all outside sources used in your lab report including websites, journal articles, textbooks, etc. Use proper IEEE formatting as indicated on this page: http://www.york.ac.uk/integrity/ieee.html.

Appendix

Not required but if you feel that there are any additional data or results that should be included, add it to this section.

*Please note that the example below is not meant to serve as THE de facto example; there may be some discrepancies between what is written in the guide and expected. In which case, the guide will supersede what is provided in the example.

THIS IS AN EXAMPLE!

DO NOT USE THIS COVER PAGE!!!

USE THE ONE POSTED ON BBLEARN!

ECEL 301 – Lab Report 6:

OP-AMP Design

To: Suryadevara Basavaiah

From: Taif Choudhury

Team members: Phuc Pham, Riju Singh

Section: 064

Date: April 28, 2011

Objective

The goal of this lab was to learn the operations and applications of an op-amp (operational amplifier), specifically the LM741. This was achieved by first simulating an inverting amplifier and non-inverting amplifier in PSpice and then building/testing the circuits experimentally. The circuits will be designed with a certain desired gain and the output will be analyzed for a range of input voltages by looking at significant points of interests in the output. In addition to its use as amplifiers, op-amps can also be used as differentiators, integrators, filters and comparators [1]. The properties of an op-amp that make it so useful is its very high input impedance and open loop gain, but very low output impedance [2]. However, these properties are restricted by certain limitations due to the capabilities of the op-amp (as well as real-world restrictions) which will be explored in simulation and experimentally.

Results

A gain of -3 and 3 was selected for the inverting and non-inverting amplifier, respectively and used to find the resistor values. In both cases, the input resistor was fixed and chosen to be 5 kΩ with the feedback resistor calculated. The calculations for these are given below in Equations 1-4.

$$G_{inv} = \frac{V_{out}}{V_{in}} = -\frac{R_1}{R_2} \tag{1}$$

$$R_1 = -R_2 G_{inv} = -5000 \cdot -3 = 15\ k\Omega \tag{2}$$

Where R_1 is the feedback resistor given in Ω, R_2 is the input resistor given in Ω, G_{inv} is the gain given in V/V for the inverting amplifier, V_{out} is the input voltage given in V and V_{in} is the input voltage also given in V.

$$G_{non} = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_x} \tag{3}$$

$$R_f = R_x(G_{non} - 1) = 5000 \cdot (3 - 1) = 10\ k\Omega \tag{4}$$

Where R_1 is the feedback resistor given in Ω, R_2 is the input resistor given in Ω, G_{inv} is the gain given in V/V for the inverting amplifier, V_{out} is the input voltage given in V and V_{in} is the input voltage also given in V.

The percent error calculation was used in comparing resistor values (Table 1) and also significant points of interest with the simulated and measured taken as actual values in the calculation (Table 2).

$$Percent\ Error = \frac{|Actual - Expected|}{Expected} * 100 = \frac{|5.06 - 5|}{5} * 100 = 1.2\ \% \tag{5}$$

Table 1. Calculated and actual resistor values with their percent error.

	Inverting Amplifier		Non-Inverting Amplifier	
	R_1	R_2	R_f	R_x
Calculated (kΩ)	15.00	5.00	10.00	5.00
Measured (kΩ)	14.80	5.06	9.97	5.14
Percent Error (%)	1.33	1.20	.30	2.80

Table 2. Significant points of interest shown for the inverting and non-inverting op-amps (expected, simulated and measured) and percent error as shown in Figure 4.

No. on Graph	Measurement		Inverting Amplifier			Non-Inverting Amplifier		
			Expected	Simulated	Measured	Expected	Simulated	Measured
1	Maximum Output Voltage	Value (V)	15	14.82	14.19	15	14.82	14.19
		Error (%)	-	1.20	5.40	-	1.20	5.40
2	Minimum Input for Linear Amplification	Value (V)	-5	-5.00	-5.00	-5	-5.00	-5.00
		Error (%)	-	0.00	0.00	-	0.00	0.00
3	Maximum Input for Linear Amplification	Value (V)	5	5.00	4.00	5	5.00	6.00
		Error (%)	-	0.00	20.00	-	0.00	20.00
4	Minimum Output Voltage	Value (V)	-15	-14.82	-12.68	-15	-14.82	-13.57
		Error (%)	-	1.20	15.47	-	1.20	9.53
5	Gain	Value (V)	-3	-2.96	-2.99	3	2.84	2.64
		Error (%)	-	1.33	0.33	-	5.33	12.00

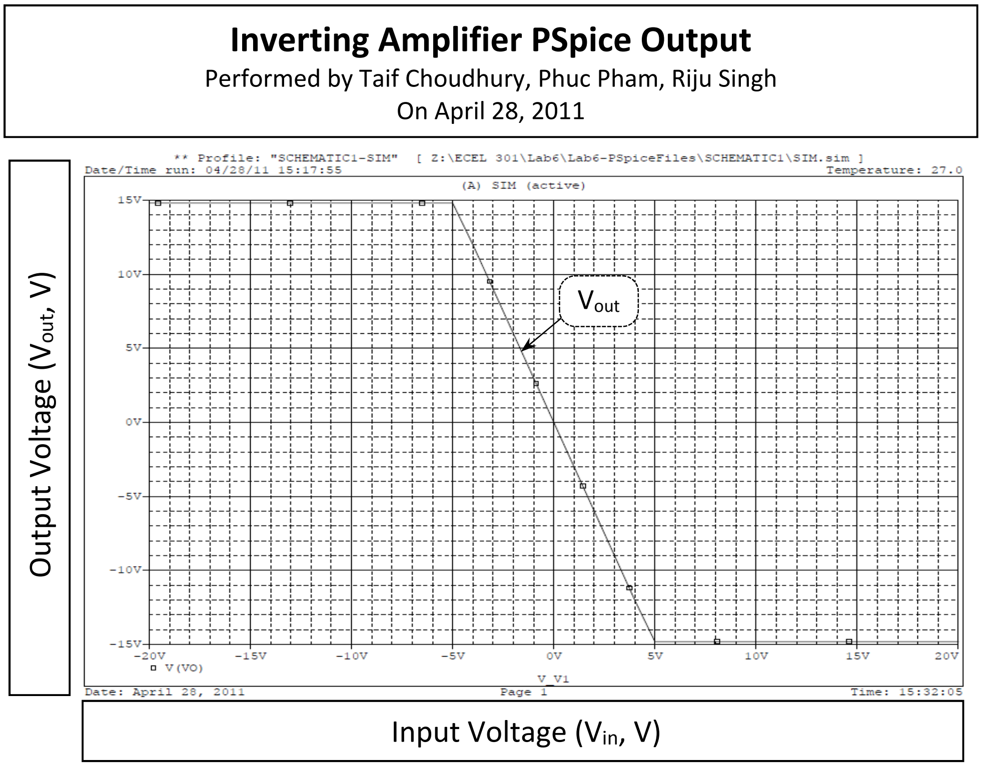

Figure 1. PSpice output of the inverting amplifier designed with a gain of -3.

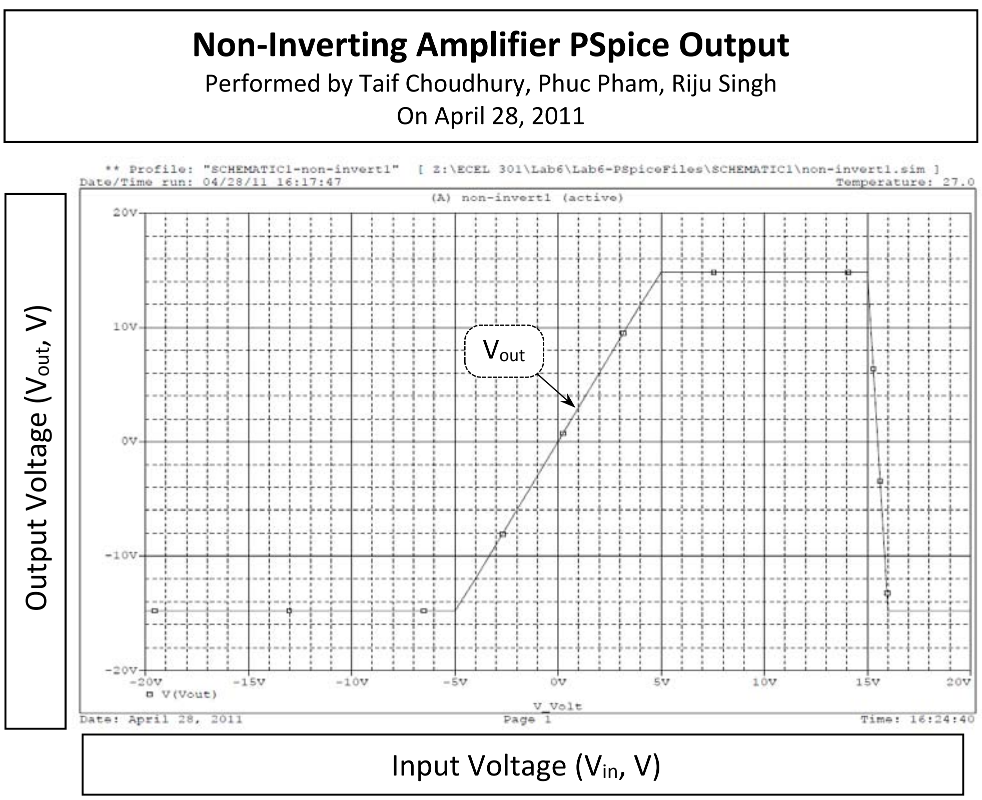

Figure 2. PSpice output of the non-inverting amplifier designed with a gain of 3.

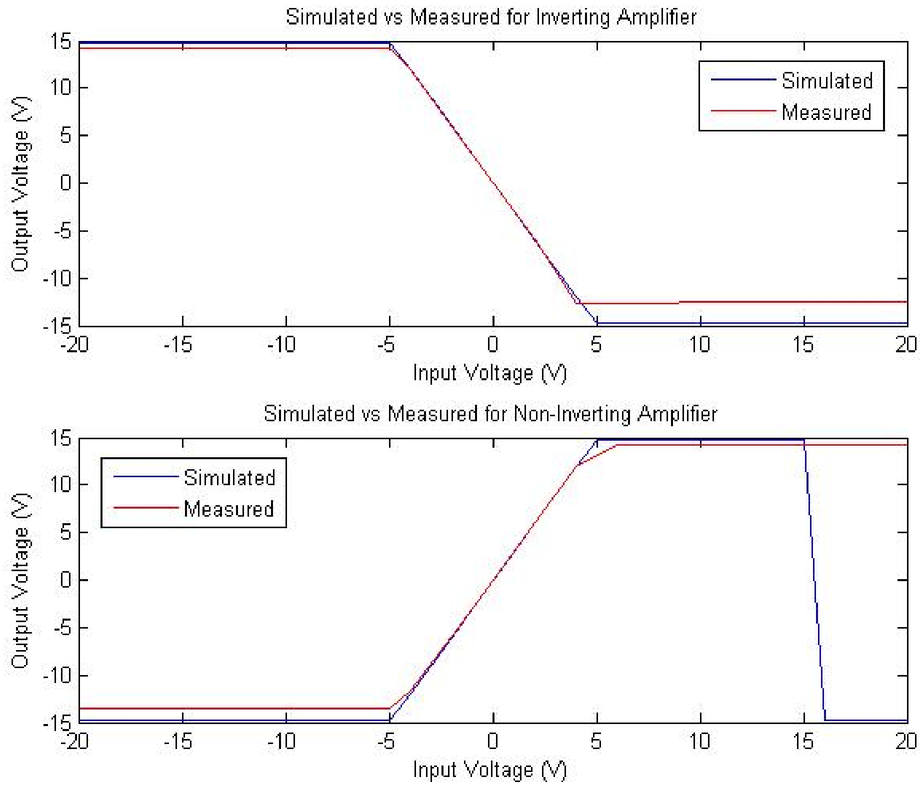

Figure 3. MATLAB plots of the simulated and measured values of the inverting and non-inverting amplifier.

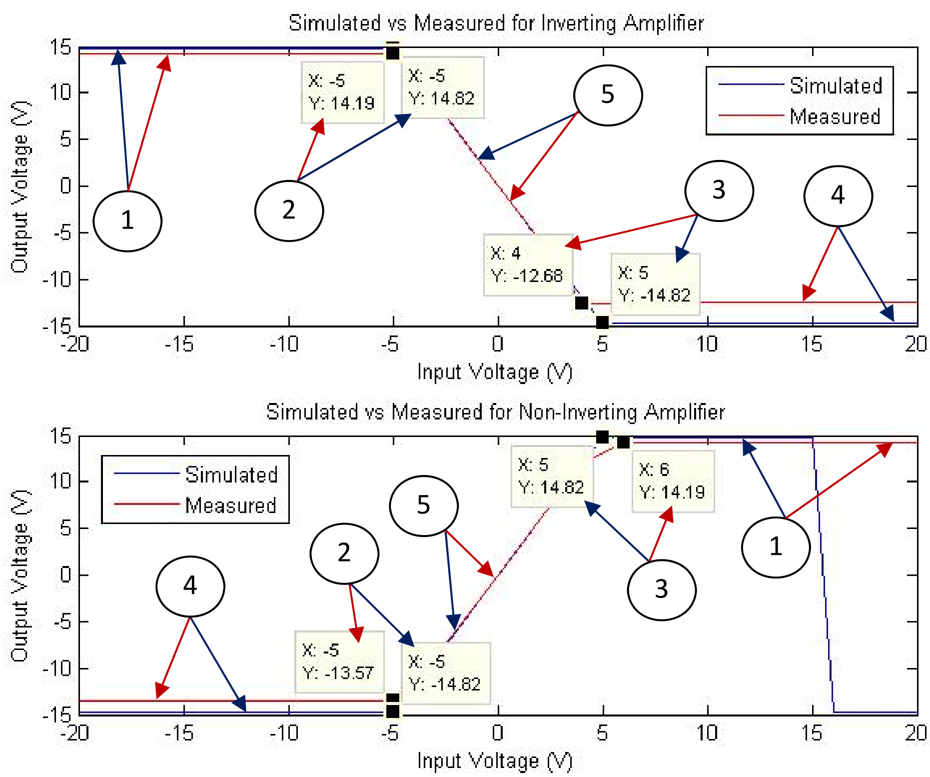

Figure 4. Figure 3 with numbered text bubbles and arrows showing points of significant interest (See Table 2 for details on what each number corresponds to). NOTE: Certain arrows are directed at textboxes that mark and identify the points corresponding to those numbered text bubbles.

Explanation

The plot of the data collected in PSpice and the measurement data seem to follow the same general trend and are close in value (Figure 3). The expectation is that the output voltages would saturate at the supply voltages (-15 V and 15 V). The simulated and measured circuit (for both the inverting and non-inverting amplifier) comes close and saturates near those values. However, it saturates farther from the expected value in the measured results for both amplifiers than it is does for the simulated. This is most likely due to the voltage drop within the op-amp itself which consumes a portion of the supply voltages thus restricting the maximum possible output voltage provided by the supply. Although a linear relationship is expected between input voltages of -5 V and 5 V (since the gain is a constant and experiences no saturation between those points), the measured values for the non-inverting amplifier experiences a discontinuity between 5 V and 6 V. This could be explained by the fact that the voltage was collected in 1 V steps and thus the discontinuity is the result of extrapolation between those two points in MATLAB. This also led to certain errors being 0% (Table 2). This could have been eliminated had the voltage increment been lower and more data points were collected.

The results for the simulated amplifiers, with the highest being 5.33% error was minor and errors within this range was expected (Table 2). PSpice accounts for some physical device characteristics in simulation and as a result will factor in certain losses not accounted for in theory. However, the highest error for the measured circuit, 20%, was significant and unexpected. Although this percent error was observed in both the inverting and non-inverting amplifiers at the maximum input for linear amplification, the value was less (4 instead of the theoretical 5) in the case of the inverting amplifier but more (6 instead of 5) in the case of the non-inverting amplifier. Oddly enough, there were no errors (0%) observed at the opposite end, in the minimum input for linear amplification. This probably indicates that the actual op-amp behaves expectedly in the beginning but fails to perform as ideally the longer it is in operation.

The rest of the percent errors for the points of significant interests varied considerably, ranging from .33% to 15% (Table 2). It can't be pinpointed exactly where most of these errors could have occurred. For example, the gain for the experimental inverting amplifier had an error of .33% but on the other hand, the non-inverting amplifier gain was 12%. Although overall, the simulation performed better than the measured results, there were some instances of the measured having less percent error than the simulated such as in the case of inverting amplifier gain. Of special note is a bug in PSpice which caused the voltage to almost instantaneous drop to 0 V at 15 V input in the non-inverting amplifier. However, this was not factored into the percent error calculations and the subsequent error analyses.

The biggest source of error in this experiment would probably be in the op-amp itself. It was noted that the actual op-amp wouldn't be too far from ideal, but this was not the case with the highest error being 20%. Specifically, this can probably be attributed to the tolerances of the components inside the op-amp. It was also noted earlier that only a limited number of data points were collected and MATLAB extrapolation could have led to significant errors. Another source of error is the tolerances of the resistors that were used in constructing the circuit, although the effect from this would be minimal, since the highest percent error in the resistors was 2.8% (Table 1). There are also other sources of errors such as the accuracy of the voltage sources/measurement equipment and environmental factors, such as the temperature and humidity. Most of these sources of error would be difficult to eliminate but can be minimized by obtaining higher precision components and/or equipment. Despite the errors and unexpected results, the objective of this lab, to learn the operations, applications and limitations of an op-amp by simulating and building different circuits utilizing it, was achieved.

References

[1] S. Basavaiah.. ECEL 301. Class Lecture, Topic: "Op-Amp." Randell 121, Drexel University, Philadelphia, Pennsylvania, April 27, 2010 and May 5, 2010.

[2] A. Fox. (2008, November 8). *Lecture 6 Inverting and non-inverting amplifiers* [Online]. Available: http://www.learning.drexel.edu.

Appendix

Table A1. Measured outputs collected at different input voltages of inverting and non-inverting op-amps.

Input (V)	Inverting Op-Amp Output (V)	Non-inverting Op-Amp Output (V)
-20	14.155	-13.571
-18	14.159	-13.571
-16	14.163	-13.571
-14	14.167	-13.572
-12	14.171	-13.572
-10	14.176	-13.572
-8	14.180	-13.572
-6	14.185	-13.572
-5	14.188	-13.572
-4	11.923	-11.593
-2	5.958	-5.967
0	0.004	0.003
2	-5.910	5.991
4	-12.679	11.993
6	-12.627	14.19
8	-12.587	14.189
10	-12.548	14.189
12	-12.513	14.189
14	-12.486	14.189
16	-12.472	14.191
18	-12.466	14.191
20	-12.463	14.191

Editor - Z:\ECEL 301\Lab 6\lab6.m*

```matlab
figure(1);

subplot(2,1,1);
plot(data(1:41,10),data(1:41,11));

Minimum_Simulated_Inverting_Output_Voltage  = min(data(1:41,11))
Maximum_Simulated_Inverting_Output_Voltage  = max(data(1:41,11))

Simulated_Inverting_Gain = (-14.82-14.82)/(5-(-5))

hold on;
plot(data(1:22,1),data(1:22,2),'r');

Minimum_Measured_Inverting_Output_Voltage  = min(data(1:22,2))
Maximum_Measured_Inverting_Output_Voltage  = max(data(1:22,2))

Measured_Inverting_Gain = (-12.68-14.19)/(4-(-5))

title('Simulated vs Measured for Inverting Amplifier');
legend('Simulated', 'Measured');

ylabel('Output Voltage (V)');
xlabel('Input Voltage (V)');


subplot(2,1,2);
plot(data(1:41,7),data(1:41,8));

Minimum_Simulated_NonInverting_Output_Voltage  = min(data(1:41,8))
Maximum_Simulated_NonInverting_Output_Voltage  = max(data(1:41,8))

Simulated_NonInverting_Gain = ((14.82-(-13.57))/(5-(-5)))

hold on;
plot(data(1:22,4),data(1:22,5),'r')

Minimum_Measured_NonInverting_Output_Voltage  = min(data(1:22,5))
Maximum_Measured_NonInverting_Output_Voltage  = max(data(1:22,5))

Measured_NonInverting_Gain = (14.19-(-14.82))/(6-(-5))

title('Simulated vs Measured for Non-Inverting Amplifier');
legend('Simulated', 'Measured');

ylabel('Output Voltage (V)');
xlabel('Input Voltage (V)');
```

Figure A1. MATLAB code used to generate plots and calculate values for inverting and non-inverting amplifiers.