

EE105 Lab Experiments

Experiment 1: Non-Ideal Op-Amps

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1 Introduction

In this lab, you will characterize a LM741C operational amplifier. In particular, you will be measuring the following non-ideal properties of op-amps: input offset voltage, slew rate, and finite gain and bandwidth. Linked are the datasheet and SPICE model for the LM741C op-amp, which you should find helpful while doing the lab and pre-lab.

Make sure to download and print out the Pre-Lab Worksheet and the Lab Worksheet. Make sure to complete the Pre-Lab Worksheet before coming to lab. Your lab GSI will check that you have completed the Pre-Lab Worksheet at the beginning of your lab section. Fill out the Lab Worksheet while doing the lab and turn it in with supporting traces and plots to your GSI at the beginning of the lab section for Lab 2.

2 Pre-Lab

For the pre-lab, you primarily will be doing SPICE simulations of the measurements that you will be doing in your lab section to help prepare you for the lab. Since you will be using the LM741 circuit model, make sure to download the LM741.MOD file into the same directory as your *.sp file. Include a .include LM741.MOD statement in your *.sp file so that the subcircuit definition in LM741.MOD can be included in your *.sp file. To instantiate the op-amp subcircuit in your *.sp file, use the following syntax:

```
x<name> <non-inv input> <inv input> <+ supply> <- supply> <output> LM741/NS
```

2.1 DC Open Loop Transfer Characteristic

Simulate the circuit in Figure 1, sweeping V_{in} from -5 mV to $+5$ mV. Plot V_{out} as a function of V_{in} and determine the open loop gain of the op-amp and input offset voltage.

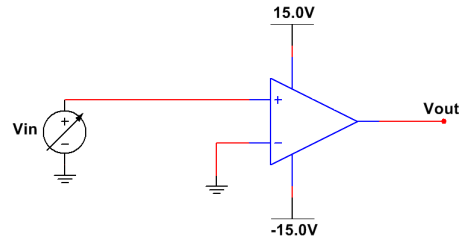


Figure 1: Circuit for Problem 2.1

2.2 Nulling the Offset Voltage

Null the offset voltage by adding a DC component V_{shift} to the input voltage source to cancel the offset. While this works in simulation, in the lab you will use the offset null terminal pins on the op-amp to null the offset voltage. Check the datasheet for the circuit used to null the offset voltage and draw the circuit connected to the pinout diagram for the LM741 on your pre-lab worksheet. Why do we use a potentiometer to null the offset voltage?

2.3 Slew Rate Measurement in Unity Gain Configuration

Simulate the circuit in Figure 2 to look at the transient response of V_{out} to the square wave voltage source V_{in} . Set V_{in} to have the following characteristics: an amplitude of ± 10 V, a $1 \mu\text{s}$ delay, 100 ns rise and fall times, and a pulsewidth and period of $100 \mu\text{s}$ and $200 \mu\text{s}$. In your `.tran` statement, set the timestep to be 100 ns and make sure to simulate one period of the square wave. Plot V_{out} and V_{in} versus time and determine the slew rate (remember: the slew rate has units of $\frac{\text{V}}{\mu\text{s}}$) from the plot. Is the slew rate different for rising and falling voltages?

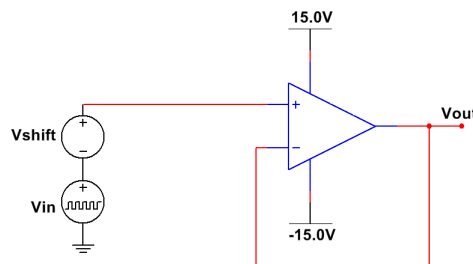


Figure 2: Circuit for Problem 2.3

2.4 Gain and Bandwidth in Unity Gain Configuration

Simulate the circuit in Figure 3, performing an AC analysis from 1 Hz to 1 GHz. Remember to set the magnitude of V_{in} to 1 V to get the proper value of voltage gain and to plot enough points to get a smooth curve. Plot the magnitude response $20 \log \left| \frac{V_{out}}{V_{in}} \right|$, and find the gain and 3 dB bandwidth of the amplifier.

2.5 Gain and Bandwidth in Non-Inverting Amplifier Configuration

Simulate the circuit in Figure 4 with $R = 100 \text{ k}\Omega$ and $R = 10 \text{ k}\Omega$, performing AC analyses from 1 Hz to 1 GHz. Plot the magnitude response of both circuits in dB on the same plot as Problem 2.4, and find the gain and 3 dB bandwidth of both amplifiers. At approximately what frequency and gain do the three curves intersect on the plot? What does this mean? If you are unsure, compute the product of A_0 and f_{3dB} for the three amplifiers.

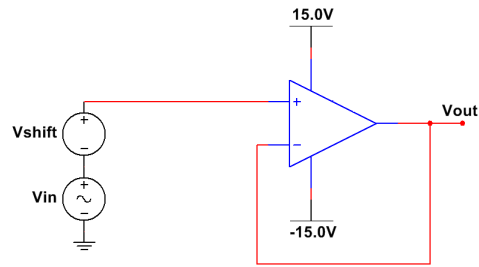


Figure 3: Circuit for Problem 2.4

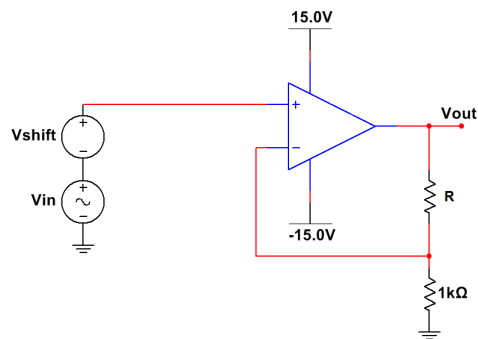


Figure 4: Circuit for Problem 2.5

3 Lab

3.1 DC Open Loop Transfer Characteristic

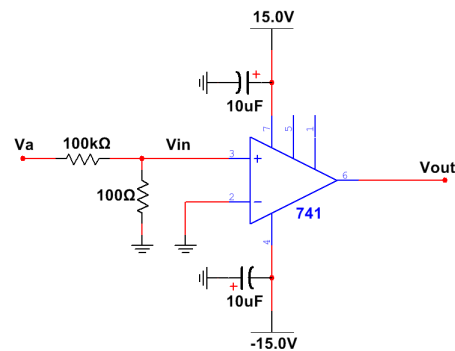


Figure 5: Circuit for Problem 3.1

Because the gain of the op-amp is so high, (the output voltage can swing from $-$ rail to $+$ rail when sweeping the input voltage by 1 mV, the smallest voltage step on the parameter analyzers) the direct gain measurement of the op-amp using the parameter analyzers is not feasible. We first must attenuate the input voltage before feeding it into the input of the op-amp. Before wiring up the circuit in Figure 5, measure the resistance of the two resistors in the voltage divider circuit using the multimeter and write the resistance values in your Lab Worksheet.

Connect V_a and V_{out} to two SMUs of the parameter analyzer. You may need to connect the “COM” ground terminal of the power supply to the ground connection in the back of the parameter analyzer to ensure that your circuit is properly grounded. Ask your lab GSI if you need help with this. Configure the

parameter analyzer to sweep V_a and to measure V_{out} . A useful trick for configuring a SMU to only measure voltage is to program it as a current source with $I = 0$. Ask your lab GSI if you need help with configuring the parameter analyzer.

You will want to sweep V_a over a large voltage range to start out with and then sweep V_a over a smaller range so you can get enough points to be able to accurately calculate the gain A_0 . Determine A_0 and the input offset voltage V_{off} from the plot of V_{out} versus V_a and write them in your lab worksheet. Remember: the parameter analyzer is plotting V_{out} versus V_a . **Make sure to back-calculate V_{in} from V_a before determining the gain and input offset voltage!**

3.2 Nulling the Offset Voltage

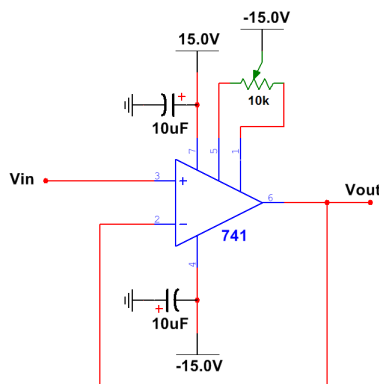


Figure 6: Circuit for Problems 3.2, 3.3, 3.4

Connect the op-amp in the configuration shown in Figure 6. Make sure to connect the middle lead (“the wiper”) of the 10 k Ω potentiometer to the -15 V power supply rail. Ground V_{in} and connect V_{out} to the multimeter and measure the the output voltage of the op-amp. Adjust the potentiometer until the measured output voltage is nulled as best as you can. Measure the resistances between the wiper and the two outside leads of the potentiometer and write them in your lab worksheet.

3.3 Slew Rate Measurement in Unity Gain Configuration

Keep the op-amp in the configuration as shown in Figure 6. Apply a square wave signal to the input of the op-amp by connecting V_{in} to the function generator. Make sure that the function generator is set to “High-Z” mode so that it outputs the proper voltage. See the function generator tutorial if you are confused about how to do this. Monitor V_{in} and V_{out} on the oscilloscope on separate channels. Make sure that the input impedances of the channels of the oscilloscope are set to 1 M Ω so that the oscilloscope doesn’t load your circuit. Ask your lab GSI if you are unsure about how to do this.

Apply a $\pm 10\text{ V}$ amplitude square wave to V_{in} and determine the slew rate for both the rising and falling edge from the oscilloscope trace. Write the slew rates in your lab worksheet, and attach the oscilloscope trace(s) to the end of your lab worksheet. See your lab GSI if you are unsure about how to save an oscilloscope trace.

3.4 Gain and Bandwidth in Unity Gain Configuration

With your op-amp in the same configuration as shown in Figure 6, change the function generator to generate a sine wave signal. Set the amplitude and frequency of the signal high enough so that it is intentionally slewing. This means that your sine wave output needs to have:

$$\frac{dV_{out}}{dt} = 2\pi A \cdot f \geq \text{Slew Rate}$$

Save the oscilloscope trace of the slewing output voltage. Now that you know what a slewing output voltage looks like, reduce the amplitude of the sine wave signal to ensure that it will not produce a slewing output. Measure the magnitude response of the voltage gain of the circuit from 1 Hz to 10 MHz, making sure to plot at least 3 points per frequency decade. If you can measure out to f_{3dB} , write it in your lab worksheet. Also, write the measured gain A_0 in your worksheet.

3.5 Gain and Bandwidth in Non-Inverting Amplifier Configuration

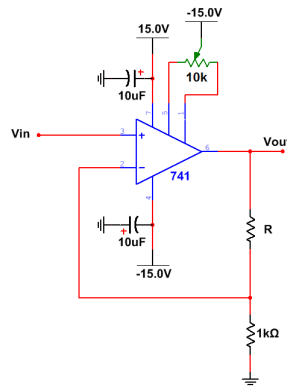


Figure 7: Circuit for Problem 3.5

Now connect your op-amp in the configuration shown in Figure 7. For both $R = 10\text{ k}\Omega$ and $R = 100\text{ k}\Omega$, measure the magnitude response of the voltage gain of the circuit from 1 Hz to 10 MHz, making sure to plot at least 3 points per frequency decade. If you can measure out to f_{3dB} , write it in your lab worksheet. Also, write the measured gain A_0 in your worksheet. Plot the magnitude response of the voltage gain in dB for the two non-inverting amplifier circuits and the circuit from Problem 3.4 on the same plot and attach the plot to the end of your lab worksheet.