Lab 5: Operational Amplifiers

Physics 327

Spring 2025

Goals

Gain experience with an important integrated circuit, the operational amplifier. Understand the characteristics and gain of integrated amplifier circuits.

Pre-Laboratory Exercises

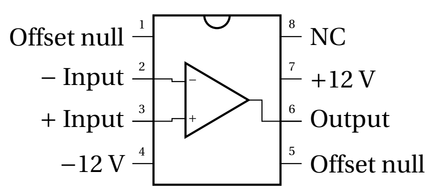
To prepare for this laboratory:

1. Read the **LM741** datasheet and Faissler textbook Chapters 28–31.
2. Construct the circuit shown in Figure 1 in a SPICE simulation program. In `LTspice`, you can use the **OP07** operational amplifier and will need three voltage supplies (±12 V DC for the power connections on the top and bottom of the device, and a sine wave V_{in}). Use the simulation to complete the last part of Section B Part 2, measuring the gain as a function of frequency.
3. Answer Question 1.

Reminder: These steps should be completed *before* your lab meeting.

Introduction

The 741 operational amplifier (op amp) is an integrated circuit containing 24 transistors, 12 resistors, and a capacitor, configured as a high-performance transistor-based amplifier. It is delicate device: if you accidentally hook up a power connection to a signal input pin, large currents will overheat it and make it "pop," i.e. destroy the chip. Please exercise care. The pin diagram is shown in the below, looking down at the device as it would be plugged into your board. The notch indicates which pin is pin #1.



A Offset Null

Ideally, zero input voltage would produce zero output voltage. However, these devices have an offset in the output voltage that typically needs to be corrected. To accomplish this, the chip features two connections labeled "offset null" where you can add a variable resistor (a potentiometer, or pot) with a range from 5–10 kΩ, and adjust as needed. Internally, this is balancing currents through a pair of transistors to achieve a cancellation.

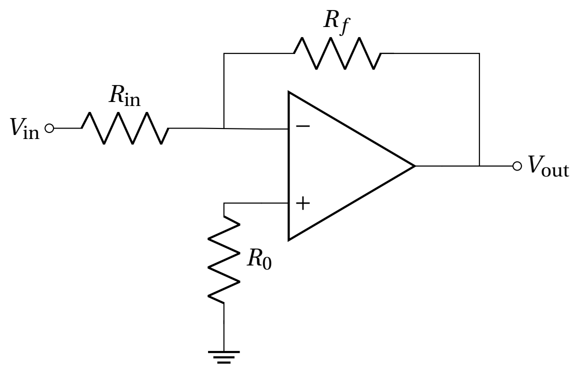


Figure 1: LM741 inverting amplifier schematic. Note that the offset null circuit and power supplies are not shown, but must be present.

Hook up the inverting amplifier circuit shown in Figure 1. Set the input resistor $R_{in} = 1$ kΩ and for now use a feedback resistor $R_f = 100$ kΩ. Set R_0 to be approximately the equivalent of R_{in} and R_f connected in parallel, i.e.

$$R_0 \simeq \frac{R_{in} R_f}{R_{in} + R_f}. \tag{1}$$

Connect the op amp to the ±12 V DC power supplies, without turning power on yet,[1] and connect the input (V_{in}) to the ground. Add a pot, hooking the center lead to the −12 V pin of the op amp and the outer leads between pins 1 and 5 (offset null). Have your instructor check your circuit *before you power it up* the first time, and always turn off (or disconnect) the power and wait for a few seconds before you change the wiring.

Once your wiring has been checked, power up the circuit and adjust the pot as needed to achieve $V_{out} \simeq 0$ with V_{in} grounded. Keep the pot in place, as adjusted, for the subsequent measurements. Include in your report a complete circuit diagram and the voltage offset you were able to achieve.

B Inverting Amplifier

Keeping $R_{in} = 1$ kΩ, choose two different feedback resistors R_f that will provide a gain with magnitude of about 10 and 100 for the inverting amplifier c ircuit. Typically, you cannot set the gain exactly; it is sufficient to be within a factor of two. Be sure the input voltage is small enough that the output voltage will be less than 10 V, which is the maximum allowed output voltage for this op amp. R_0 should always be set according to Eq. 1. Include a complete schematic in your lab report.

> **Question 1:** Qualitatively, what would V_{out} look like on the oscilloscope when V_{in} is a square wave and the power to the LM741 is *off* (this would be equivalent to removing the amplifier from the schematic)? How would this change with the amplifier powered on?

Part 1 DC Gain

For each of the two gains, 10 and 100, complete the following observations. Measure the voltage gain ($G = V_{out}/V_{in}$) for three different input DC voltage levels. To do that, first construct a DC voltage divider using a DC voltage supply connected to four series resistors; each of the points between the resistors can be used as an output. Connect the voltage divider output to the input to the op amp circuit.

> **Question 2:** Based on the inverting op amp gain equation ($V_{out} = G \cdot V_{in}$), what resistors in the DC voltage divider will achieve $V_{out} < 10$ V?

[1] Note that some of the laboratory power supplies do not turn off. Check with a DMM and if this is the case, connect the grounds but leave the supply voltage(s) disconnected.

Now, use either the oscilloscope or digital voltmeter (DMM) to measure the output voltage on your op amp for each V_{in}. Document the measurements in a data table in your report, including the values of R_{in}, R_f, V_{in}, V_{out} and the voltage gain G.

Part 2 AC Gain

After turning off the power to your circuit, disconnect the voltage divider and use the function generator to input a sine wave to the op amp. Ensure the input averages to 0 by looking at the input with DC coupling on the oscilloscope.

Using the resistor your chose for a gain of ~ 100, measure the gain magnitude and phase shift with the oscilloscope by observing the sinusoidal V_{in} and V_{out} traces. Note that you may need to decrease the input amplitude to maintain a sinusoidal output waveform. Take measurements for several input frequencies between 100 Hz and 1 MHz and create a data table recording the input and output amplitudes and the phase shift as a function of frequency. Evaluate the power gain, and plot the power gain in dB and phase shift vs. $\log_{10}(f\ (\text{Hz}))$ together in one figure.

> **Question 3:** Based on your measurements, what is the cutoff frequency (f) for your amplifier circuit, above which the gain starts to fall off? (You can estimate this as the point where the gain drops by 3 dB.)

C Active Differentiator & Integrator

Complete this section during the lab if you have time after finishing the previous measurements. Otherwise, perform these measurements by modifying your simulation and include screenshots in your report.

In Lab 2 Part B.3, you constructed a passive differentiator using an RC circuit. A straightforward modification of your inverting amplifier circuit can be used to build an active differentiator or integrator (an active high-pass or low-pass filter, respectively).

Part 1 Differentiator

Replace the input resistor R_{in} with a capacitor $C_{\text{in}} = 1\ \mu$F and use $R_f = 1$ MΩ, $R_0 = 1$ kΩ, and $V_{\text{in}} \sim 300$ mV. Input a triangle wave and observe the output as a function of input frequency. Describe your observations and how this compares to what you found in Lab 2.

Part 2 Integrator

Finally, build the inverting amplifier circuit but this time using an input resistor $R_{\text{in}} = 10$ kΩ, $R_0 = 1$ kΩ, and a feedback capacitor $C_f = 5000$ pF. Input a square wave and observe the output as a function of input frequency, and how it varies over time.