Measurements on Operational Amplifiers

Introduction

The purpose of this laboratory work is:

- To become familiar with the operational amplifier characteristics and parameters
- Check the operation of a voltage follower amplifier
- Measure the bandwidth and phase shift for a voltage follower and a high gain amplifier
- Measure the slew rate of the operational amplifier in voltage follower and a high gain amplifier
- Check the minimization of the output errors due to the operational amplifier input currents
- Check the output errors due to the operational amplifier offset voltage
- Measure the offset and bias currents of the operational amplifier

Specifications

- Use a dual voltage supply, $V_{DD} = \pm 15$ V
- Do not use ammeters for any measurement

Materials and Instruments

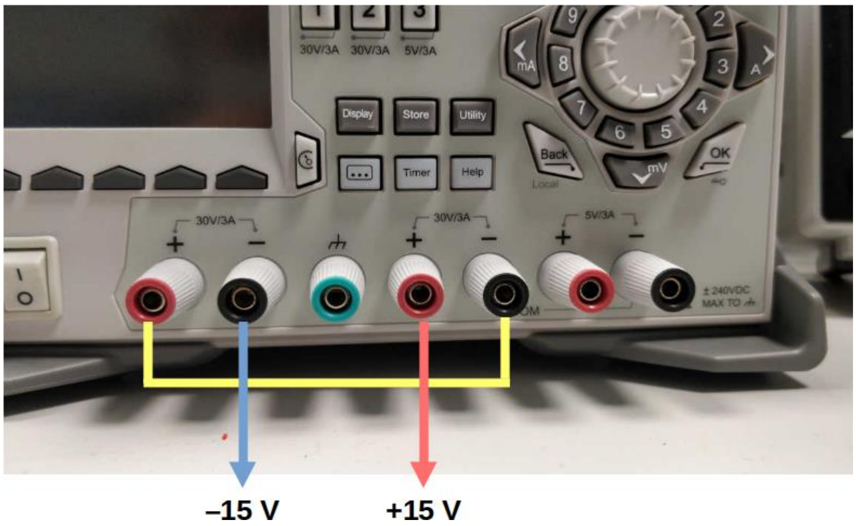
- Dual voltage supply
- Waveform generator
- Voltmeter (do *not* use an ammeter)
- Oscilloscope
- Solderless breadboard
- Low-performance operational amplifier: 1 x LM741 or µA741 (avoid LM324, LM748, or the TLxx)
- Resistors: E12 series, 5% tolerance
- Wires
- Banana terminated cables

Notes

- The user manuals of the bench instruments are on the LED web site.
- Use only the cursors for measurements with the oscilloscope (no auto-setup or measurements)
- The component data sheets are on the LED website.
- Check the type and value of the components (do not rely on the labels of the boxes, as they may have been misplaced, and always place them in the right box).
- Set and measure the supply voltages **before** connecting them to the circuit.
- An integrated circuit must never receive a voltage outside the power supply range:
  - For the analog circuits in this assignment: –15 V…+15 V.
- Do not change the circuit when the power supply is connected. Always follow these steps:
  a. Disconnect any external signals (e.g., waveforms, clock);
  b. Turn off or disconnect the power supply;
  c. Make the desired changes to the circuit;
  d. Turn on or reconnect the power supply;
  e. Reconnect the external signals (e.g., waveform, clock).

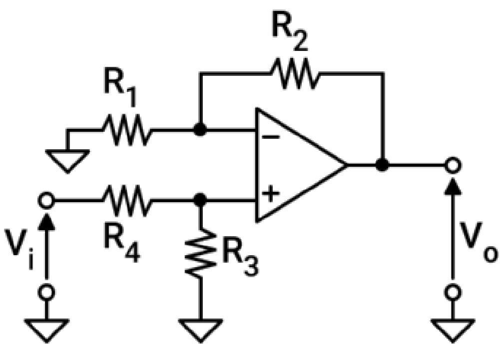
Circuit Design, Mounting, and Measurements

Mount a **voltage follower** circuit with a dual power supply of +15 V and –15 V (see in the figure below how to connect the outputs of the power supply on the LED benches).



If you must use the LM324 operational amplifier, which can operate with a single supply, connect the –15 V of the dual voltage supply to the GND of the LM324 circuit. Check carefully with the voltmeter the supply voltages and their polarity **before** connecting them to your circuit.

1. Program the signal generator to output a sine wave with 0 V average (why?), 1.5 V_{pp} amplitude (why?), and frequency of 1.5 kHz (why?). Connect it to the input of your amplifier circuit and check the correct operation of the amplifier circuit using the oscilloscope (how?) with compensated probes (channel 1 on the input and channel 2 on the output).
2. Reduce the amplitude of the signal to the minimum that is still clearly visible on the oscilloscope (why?). Increase the frequency of the signal and find the frequency at which the output is attenuated by -3 dB, which is the upper limit of the bandwidth (why?). Plot the output amplitude at least four octaves before and after the bandwidth frequency using logarithmic scale for frequency. Measure the input-output phase shift at this frequency (how?). Compare it with the theoretical value and discuss the difference.
3. Set the peak-to-peak sine wave signal amplitude to 15 V (why?) and measure the maximum operating frequency for which there are no noticeable distortions (describe the distortions that appear at higher frequencies). Which parameter of the operational amplifier determines the distortions? Compare your result with the data from the operational amplifier datasheet and discuss the differences.
4. Program the signal generator to output a square wave and measure the slew rate at the amplifier output (how?). Compare your result with the data from the operational amplifier datasheet and discuss the differences.
5. Using the schematic shown in the figure below, mount a non-inverting amplifier with a gain of 683 between the non-inverting input and the output (why?). Then dimension the resistances R_4 and R_3 to obtain a unity gain between V_i and V_o (why?). Select the resistance values to minimize the error contribution of the bias currents on the output (how?).



6. Verify proper operation with a low frequency sinusoidal signal (how?). The signal frequency must be less than the operational amplifier bandwidth (why, how much less?) and its amplitude should be easily visible on the oscilloscope. Remove the input signal and replace it with a short circuit to ground (why?), leaving R_4 and R_3 mounted (why?). Measure with a multimeter the dc output voltage and calculate the offset voltage (how?). If the output is too close to $+V_{DD}$ or $-V_{DD}$, reduce the gain of the amplifier and repeat the experiment.
7. Replace R_3 with a direct connection to the ground (why?) and measure again the output voltage. Explain the results.
8. Reconnect R_3 between the non-inverting input and the ground (remove the previous direct connections to the ground), reconnect the signal generator to R_4 and repeat the bandwidth, phase shift at the bandwidth frequency, and the slew rate measurements. Compare the results with those obtained using the voltage follower configuration and explain the differences.
9. Remove R_3 (why?). Replace the other feedback resistances, R_1, R_2, and R_4, such way to obtain a low voltage gain (for instance, a gain of 2), compensate the effect of the input bias current, but have a contribution of the input offset current to the output far larger than the one due to offset voltage (how?). Determine the value of the input offset current by measuring the output voltage with the input shorted to ground (how is determined the input offset current?). Short circuit R_4 and determine the value of the input bias current (why and how can it be measured this way?).
10. Calculate the gain-bandwidth (GBW) product of the operational amplifier for two distinct gains used in the experiments.

Lab Report

Prepare the report according to the instructions that you can find in the materials of the course portal.