

Experiment 2

Basic Operational Amplifier Circuits

Systems and Signals Laboratory

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- Lab activities: Experimentation with practical operational amplifier (op amp) circuits: Comparator, voltage follower, inverting amplifier, inverting adder, and RC relaxation oscillator.
- Post-lab
- Links to resources and data sheets (access it from lab web site):
 - [Understanding operational amplifier specifications](#)
 - [The LM741 op amp data sheet](#)
 - [The LF351 op amp data sheet](#)
 - [The OPA277 op amp data sheet](#)

Electronic components required for this experiment

- LM741 standard operational amplifier
- LF351 wideband operational amplifier
- $10k\Omega$ (1/4 Watt, 5%) resistor (3)
- $20k\Omega$ (1/4 Watt, 5%) resistor
- $1k\Omega$ (1/4 Watt, 5%) resistor
- $1nF$ ($0.001\mu F$, Polypropylene, 1%) capacitor
- $100\mu F$ (electrolytic) capacitor
- Red LED

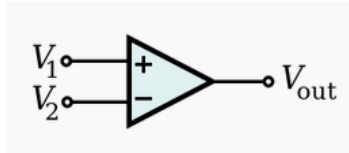
1. Pre-lab

Write a brief report that documents your answers to the following questions. Submit your report to the lab instructor at the beginning of the next lab session.

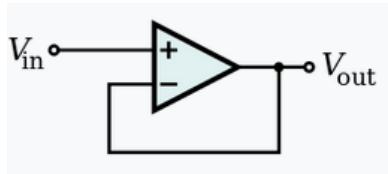
- a. Read the document entitled “Understanding Operational Amplifier Specifications” and provide definitions for the following operational amplifier specifications/parameters: Supply voltage range, input offset voltage (typical and max), input bias current (max), output short-circuit current, gain and bandwidth.
- b. List the properties of an ideal operational amplifier that are relevant in circuit analysis.
- c. Include in your report a table that lists the values of all specifications in Part a for the following two operational amplifiers: LM741, LF351 and OPA277.

- d. Determine the equation relating the output voltage to the input voltage for the following ten operational amplifier circuits and provide a brief description of the operation of each circuit (you may use your circuit analysis textbook and/or Google):

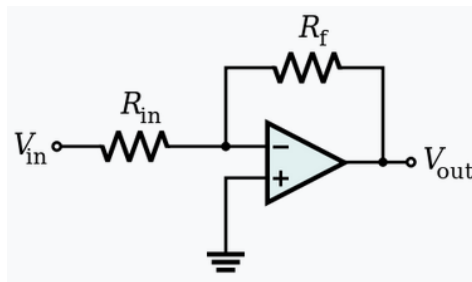
- Comparator:



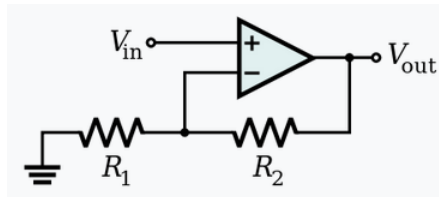
- Voltage follower (buffer):



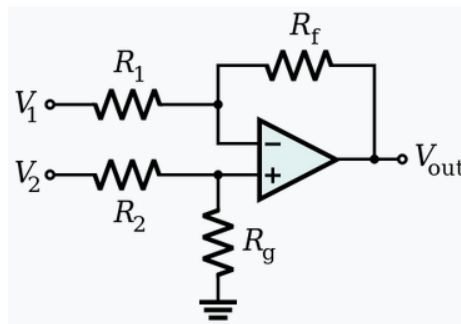
- Inverting amplifier:



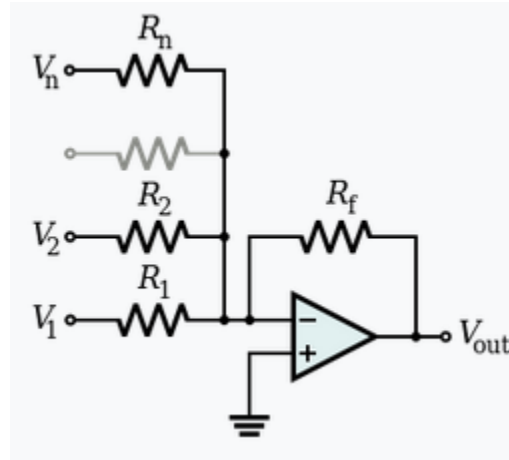
- Non-inverting amplifier:



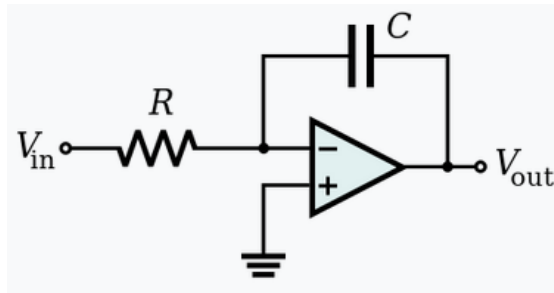
- Differential amplifier:



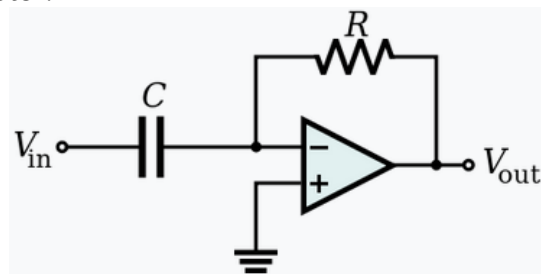
- (Inverting) Summing amplifier:



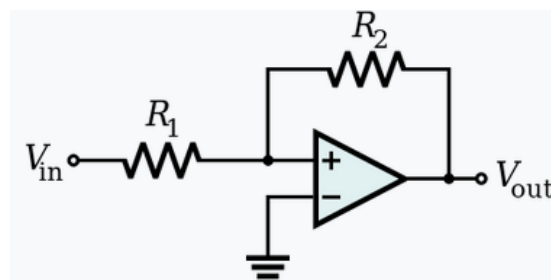
- Inverting Integrator:



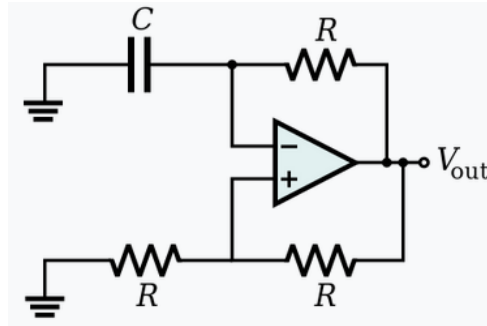
- Inverting differentiator:



- Schmitt trigger (note the positive feedback connection):



- Relaxation oscillator (sketch the periodic output signal and provide an expression for its oscillation frequency as a function of R and C):

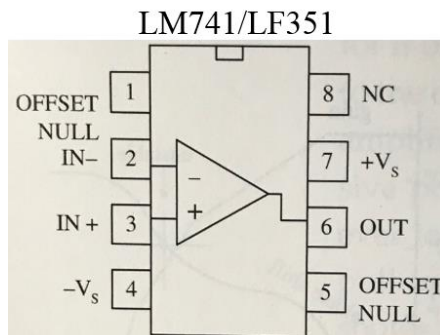
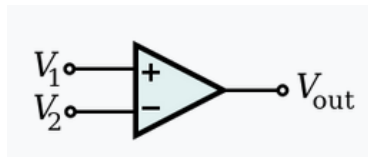


2. Lab activity

In this experiment you will build and test various basic circuits that incorporate operational amplifiers. You will test such circuits and refine them in order to make them useful in practice. Some of these circuits will be used as building blocks for future lab circuits and be applied to solve ordinary differential equations, implement analog filters and design PID controllers.

Make actual measurements of all resistor and capacitor values that you use in the following circuits and use them in your post-lab to report relative errors between the ideal circuit output and the actual circuit. Make sure to take photographs of all circuits that you build in this lab session. Also, you are to save all scope traces. You will be using these photos/images in your lab report.

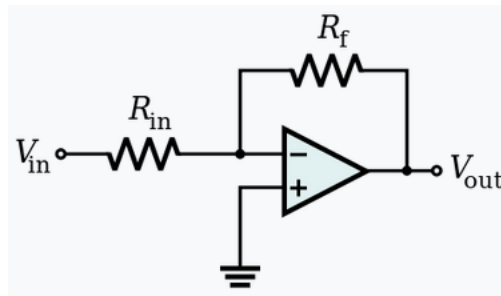
- Use an LM741 op amp to build the following comparator circuit. Set the supply voltages to $\pm V_s = \pm 10\text{V}$.



Connect V_2 (pin 2) to ground (zero volt) and set V_1 (pin 3) to a 100Hz 2Vpp sine wave. Display V_1 and the comparator's output (pin 6) on CH1 (set to 1V/div) and CH2 (set to 5V/div) of the scope, respectively. Configure the scope so that both traces share the same reference voltage, and set the time/div so that about two cycles of the waves are

displayed. Save the scope's trace image. Record the voltages of the upper level and lower level of the generated square wave.

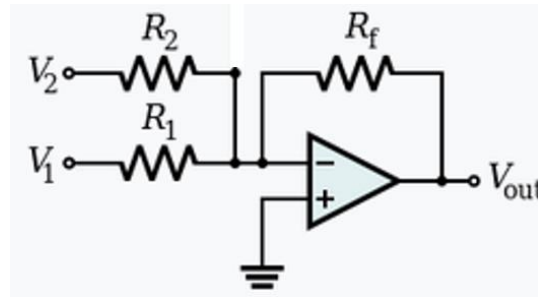
- b. Increase the frequency of the input sine wave to 10kHz. Adjust the time/division so that about three full cycles are displayed. Save the scope's trace image. Repeat for the sine wave frequencies of 16kHz and 20kHz.
- c. Disconnect the input signal and switch off the supply voltage to the op amp. Replace the LM741 with the higher bandwidth LF351 op amp. (Note: These two ICs have the same pin configuration. Be very gentle as you pull out the IC; consult with your lab instructor for the safest way to do that). Switch on the supply voltages and then apply the sine input. Repeat Parts a, b and c. Make sure you save the scope's trace images. Comment in your journal about the frequency characteristics of the two op amps.
- d. Keep the LF351. Remove the input signal and switch the supply voltages off. Add two $10\text{k}\Omega$ resistors to the circuit so that you obtain the inverting amplifier shown below. Be sure that the +ve input (pin 3) of the operational amplifier is grounded. Measure and record the actual value of R_{in} and R_f .



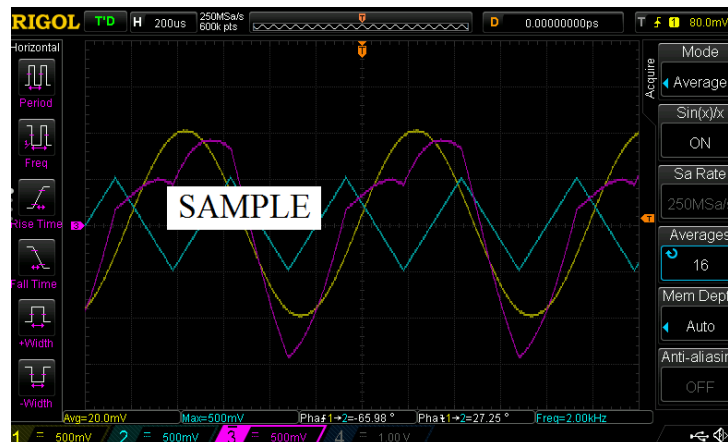
Switch on the power supply to the op amp and apply a 10kHz 2Vpp sine wave, as shown in the above figure. Display the input and output waves on CH1 and CH2 of the scope, respectively. Set the scope to 500mV/div (for both channels) and $20\mu\text{sec}/\text{div}$ for the time axis. Save the scope's traces. Record V_{min} and V_{max} of the output waveform. Also, use the scope to measure the phase difference (in degrees) between the input and the output.

- e. Measure the cutoff frequency of the amplifier: Determine the frequency of the input sine wave that leads to an output peak voltage of $\sqrt{2}/2 \cong 0.7$. Use the scope to measure the phase difference between the output and input signals at the cutoff frequency. Save the scope trace image.
- f. Repeat Part e using the (lower bandwidth) LM741 op amp.
- g. Replace the LM741 with the LF351 IC, and keep it for the rest of this experiment. Set the sine wave frequency to 1kHz 2Vpp. Replace R_f with a $20\text{k}\Omega$ resistor (measure and record its value). Determine the voltage gain of your amplifier using the scope. Save the scope's trace image.

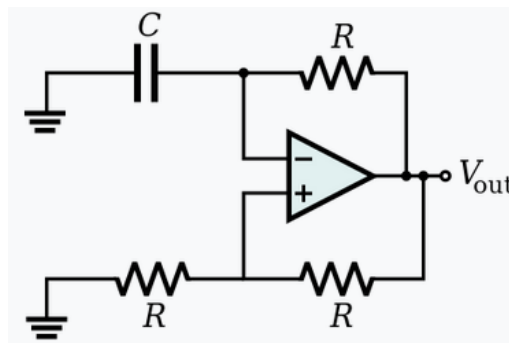
- h. Build the following summing amplifier circuit and use it to add a 1kHz 2Vpp sine wave and a 2kHz 1Vpp triangular wave. Use three 10k Ω resistors. Display the two input waveforms and the output waveform on CH1, CH2 and CH3, respectively. Make sure that the probe setting is 1X for the three channels. Also, since this is an inverting summer, and for convenience, set the scope's CH3 to "Invert: ON" in order to undo the inversion. Save the scope's trace image.



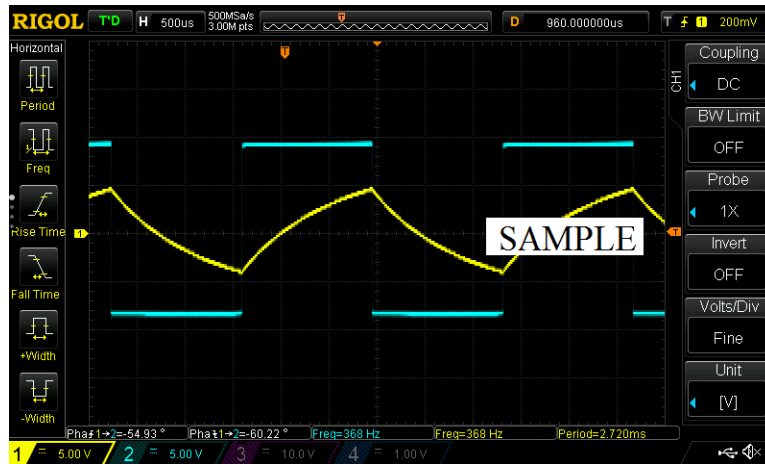
The following figure shows a sample scope output (averaging was used).



- i. Modify the last circuit to build the following (positive feedback) RC relaxation oscillator. Use three 10k Ω resistors and one 1nF (i.e., 0.001 μ F) capacitor (measure and record all component values).



- Connect the 1nF capacitor terminal (connected to pin 2 of the LF351) to CH1 of the scope and connect the output of the op amp to CH2. The scope should be adjusted so that the display looks like the following sample. Save the scope's trace image.



- Measure the frequency in Hz of the square wave and compare it to the theoretical oscillation frequency,

$$f = \frac{1}{2\ln(3)RC}.$$

- Replace the 1nF capacitor with a 100μF electrolytic capacitor. Make sure to connect the capacitor's negative terminal to ground. Record the oscillation frequency of the square wave. Next, adjust the op amp supply voltages $\pm V_s$ such that a ± 4 Volt square wave is displayed. Record the oscillation frequency. Does the supply voltage have an effect on the oscillation frequency?
- Restore the supply voltages to ± 10 V. Connect a red LED in series with a 1kΩ resistor between the op amp's output pin and ground. Observe the flashing pattern of the LED. How does the "ON" time of the LED compare to the half-period,

$$\frac{T_o}{2} = \ln(3) RC?$$

3. Post-lab

Write your lab report according to the required format. Analyze and discuss, in details, all results obtained, from your pre-lab and your lab activity, in your report. Explain the limitations of the circuits that you have built and the sources of imperfections. Also, report the absolute relative errors (in percent) for all experimental measurement whenever the true value is known.