

Esta versión (03 de noviembre de 2021 20:25) fue *aprobada* por Doug Mercer [https://ez.analog.com/members/d Mercer] .
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Actividad: Amplificadores operacionales simples, para ADALM2000

Objetivo:

En esta práctica de laboratorio, presentamos el amplificador operacional (op amp), un circuito activo que está diseñado con ciertas características (alta resistencia de entrada, baja resistencia de salida y una gran ganancia diferencial) que lo convierten en un amplificador casi ideal y un bloque de construcción útil en muchas aplicaciones de circuitos. En esta práctica de laboratorio, aprenderá sobre la polarización de CC para circuitos activos y explorará algunos de los circuitos de amplificadores operacionales funcionales básicos. También utilizaremos este laboratorio para continuar desarrollando habilidades con el hardware del laboratorio.

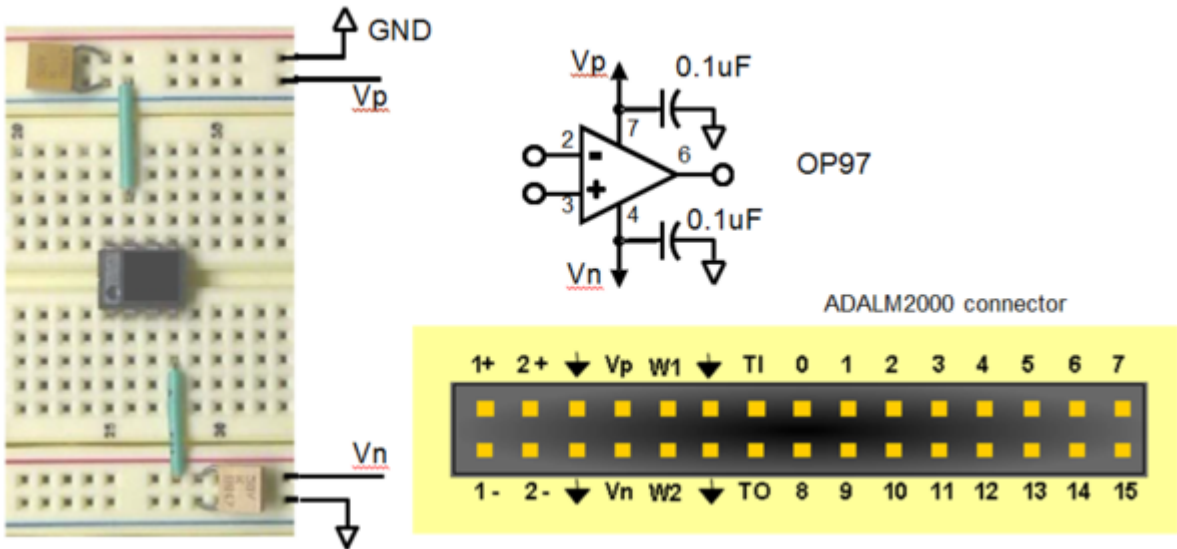
Materiales:

- Módulo de aprendizaje activo ADALM2000 Placa de prueba sin soldadura y juego de cables puente
- 1 Resistencia de 1 kΩ
- 2 Resistencias de 4,7 kΩ
- 2 Resistencias de 10 kΩ
- 2 OP97 (amplificador de baja velocidad de respuesta suministrado con las versiones recientes del kit de piezas analógicas ADALP2000)
- 2 Condensadores de 0,1 uF (cable radial)

1.1 Conceptos básicos del amplificador operacional

Primer paso: Conexión de alimentación de CC:

Los amplificadores operacionales siempre deben recibir alimentación de CC y, por lo tanto, es mejor configurar primero estas conexiones antes de agregar cualquier otro componente del circuito. La Figura 1.1 muestra una posible disposición de energía en su placa de prueba sin soldadura. Usamos dos de los rieles largos para los voltajes de suministro positivo y negativo, y otros dos para cualquier conexión a tierra que pueda ser necesaria. Se incluyen los llamados capacitores de "desacoplamiento de suministro" conectados entre la fuente de alimentación y los rieles de tierra. Es demasiado pronto para discutir en gran detalle el propósito de estos condensadores, pero se utilizan para reducir el ruido en las líneas de suministro y evitar oscilaciones parásitas. Se considera una buena práctica en el diseño de circuitos analógicos incluir siempre pequeños capacitores de derivación cerca de los pines de suministro de cada amplificador operacional en su circuito.



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Figure 1.1 Power connections

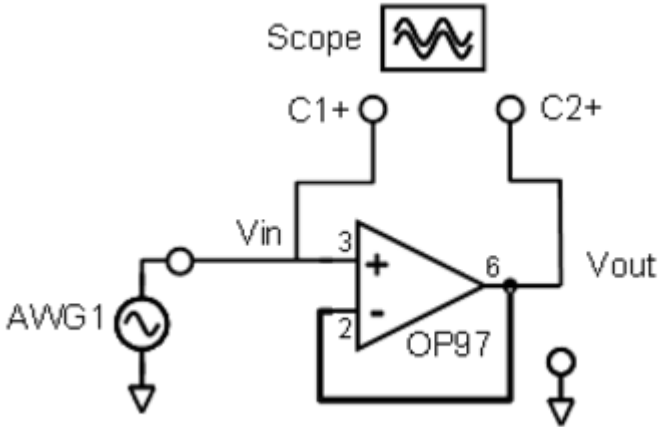
Insert the op amp into your breadboard and add the wires and supply capacitors as shown in figure 1.1. To avoid problems later you may want to attach a small label to the breadboard to indicate which rails correspond to V_p , V_n , and ground. Color coding your wires, red for V_p , black for V_n and green for ground, can also help to keep the connections organized.

Next, attach the supply and GND connections from the ADALM2000 board to the terminals on your breadboard. Use jumper wires to power the rails as shown. Remember, the power-supply GND terminal will be our circuit “ground” reference. Once you have your supply connections you may want to use a DMM to probe the IC pins directly to insure that pin 7 is at +5V and pin 4 is at -5V. Remember you must have the Scopy software running and have turned on the power supplies before measuring the voltages with the voltmeter.

Unity-Gain Amplifier (Voltage Follower):

Background:

Our first op-amp circuit is a simple one, shown in figure 1.2. This is called a unity-gain buffer, or sometimes just a voltage follower, defined by the transfer function $V_{out} = V_{in}$. At first glance it may seem like a useless device, but as we will show later it finds use because of its high input resistance and low output resistance.

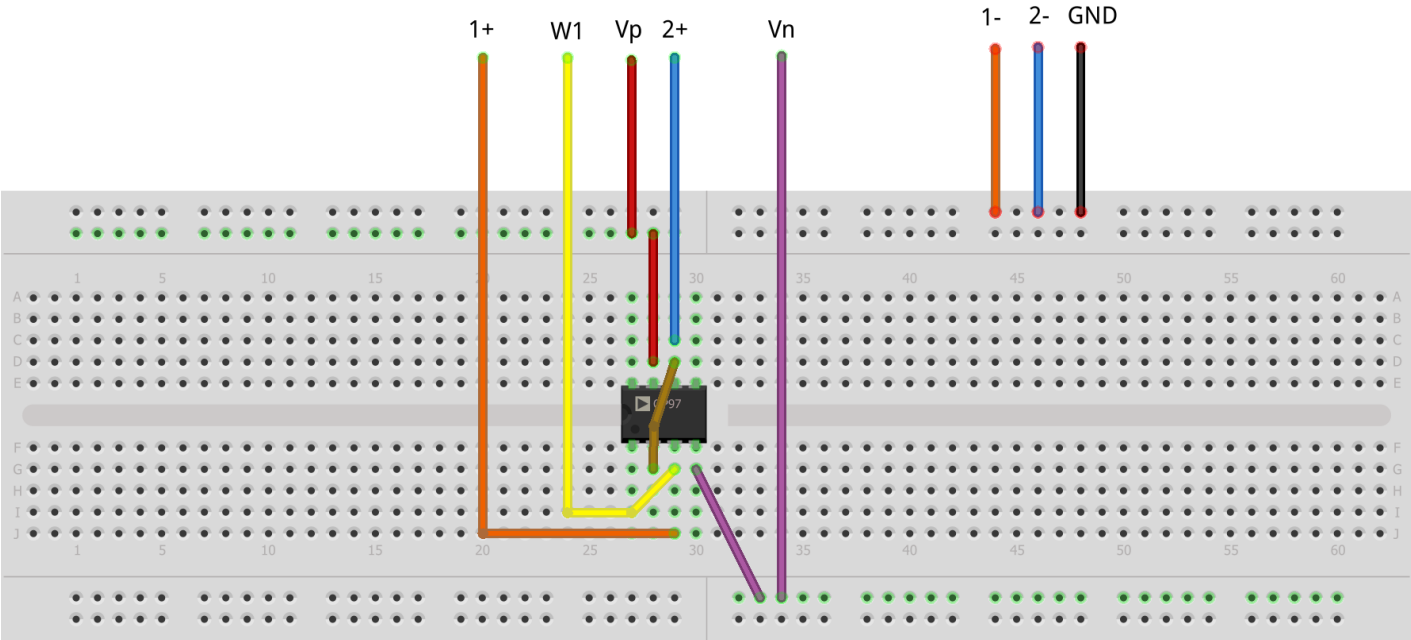


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Figure 1.2 Unity Gain Follower

Hardware Setup:

Using your breadboard and the ADALM2000 power supplies, construct the circuit shown in figure 1.3. Note that the power connections have not been explicitly shown here; it is assumed that those connections must be made in any real circuit (as you did in the previous step), so it is unnecessary to show them in the schematic from this point on. Use jumper wires to connect input and output to the waveform generator and oscilloscope leads. Don’t forget to ground the scope negative input leads C1- and C2- (ground connections are not shown in the schematic).



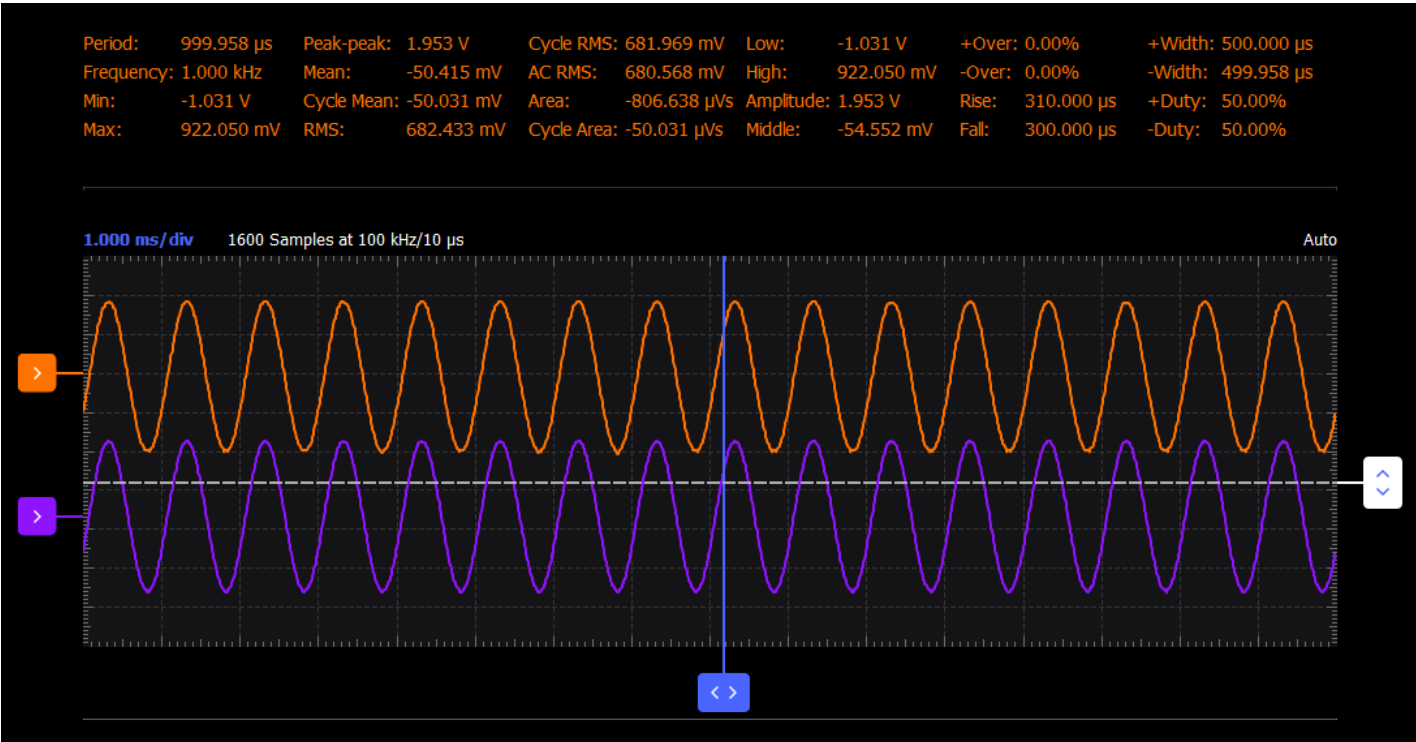
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Figure 1.3. Unity Gain Follower Breadboard Circuit

Procedure:

Use the first waveform generator as source V_{in} to provide a 2V amplitude peak-to-peak, 1 kHz (kilohercio) sine wave excitation to the circuit. Configure the scope so that the input signal is displayed on channel 2 and the output signal is displayed on channel 1. Export a plot of the two resulting waveforms and include it your lab report, noting the parameters of the waveforms (peak values and the fundamental time-period or frequency). Your waveforms should confirm the description of this as a “unity-gain” or “voltage follower” circuit.

A plot example is presented in Figure 1.4.

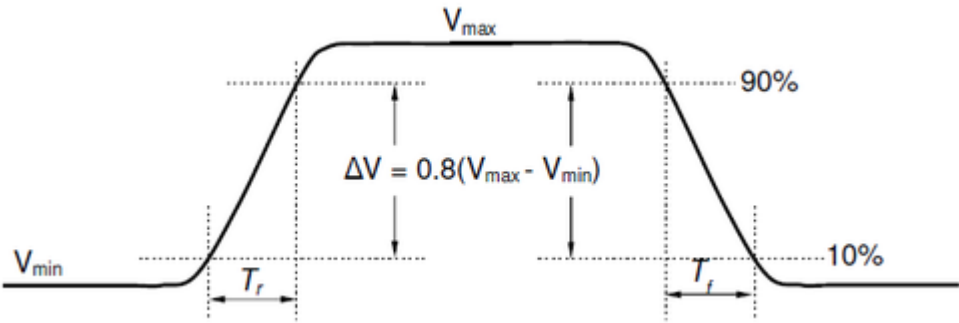


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Figure 1.4. Unity Gain Follower Waveforms

Slew Rate Limitations:

For an ideal op-amp the output will follow the input signal precisely for any input signals, but in a real amplifier the output signal can never respond instantaneously to the input signal. This non-ideality can be observed when the input signal is a rapidly changing function of time. For large-amplitude signals this limitation is quantified by the slew rate, which is the maximum rate-of-change (slope) of the output voltage that the op-amp is capable of delivering. The units of slew-rate are usually expressed as $\frac{V}{\mu s}$ (volt)/μs (microsecond).



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Figure 1.5 Slew Rate

Set the waveform generator to a square wave signal with a 2V amplitude peak-to-peak and increase the frequency until you see a significant departure from ideal behavior, that is, when the output starts looking more like a trapezoid than a square wave. You will likely need to adjust the time scale (Sec/Div) on the scope display to see this. Export a plot of the output waveforms at this point and measure its 10-90% rise time (and 90-10% fall time) as defined in figure 1.5. Also note the peak-to-peak voltage of the output signal. Compute and record the slew rate for both rising and falling outputs according to your measurements. Comment on why the response to rising and falling edges might be different.

A waveform that exemplifies the slew rate is presented in figure 1.6.

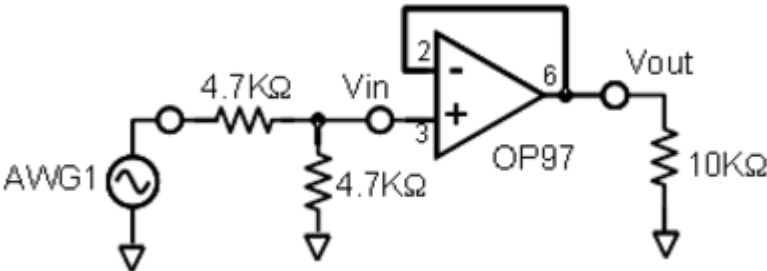


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Figure 1.6 Slew Rate Waveform

Buffering Example:

The high input resistance of the op amp (zero input current) means there is very little loading on the generator; i.e. (in other words), no current is drawn from the source circuit and therefore no voltage drops on any internal (Thevenin) resistance. Thus in this configuration the op amp acts like a “buffer” to shield the source from the loading effects from other parts of the system. From the perspective of the load circuit the buffer transforms a non-ideal voltage source into a nearly ideal source. figure 1.7 describes a simple circuit that we can use to demonstrate this feature of a unity-gain buffer. Here the buffer is inserted between a voltage-divider circuit and some “load” resistance:



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Figure 1.7 Buffer Example

Turn off the power supplies and add the resistors to your circuit as shown in figure 1.7 (note we have not changed the op-amp connections here, we’ve just flipped the op-amp symbol relative to figure 1.2).

Turn on the power supplies and set the waveform generator to a 1 kHz (kilohertz) sine signal with a 4V amplitude peak-to-peak. Use the scope to simultaneously observe Vin and Vout and record the amplitudes in your lab report.

Remove the 10 kΩ load and substitute a 1 kΩ resistor instead. Record the amplitude.

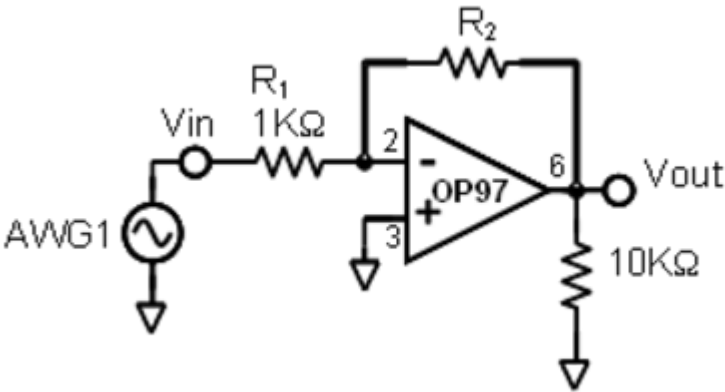
Now move the 1 kΩ load between pin 3 and ground, so that it is in parallel with the 4.7 kΩ resistor. Record how the output amplitude has changed. Can you predict the new output amplitude?

1.2 Simple Amplifier Configurations

Inverting Amplifier:

Background:

Figure 1.8 shows the conventional inverting amplifier configuration with a 10 kΩ “load” resistor at the output.



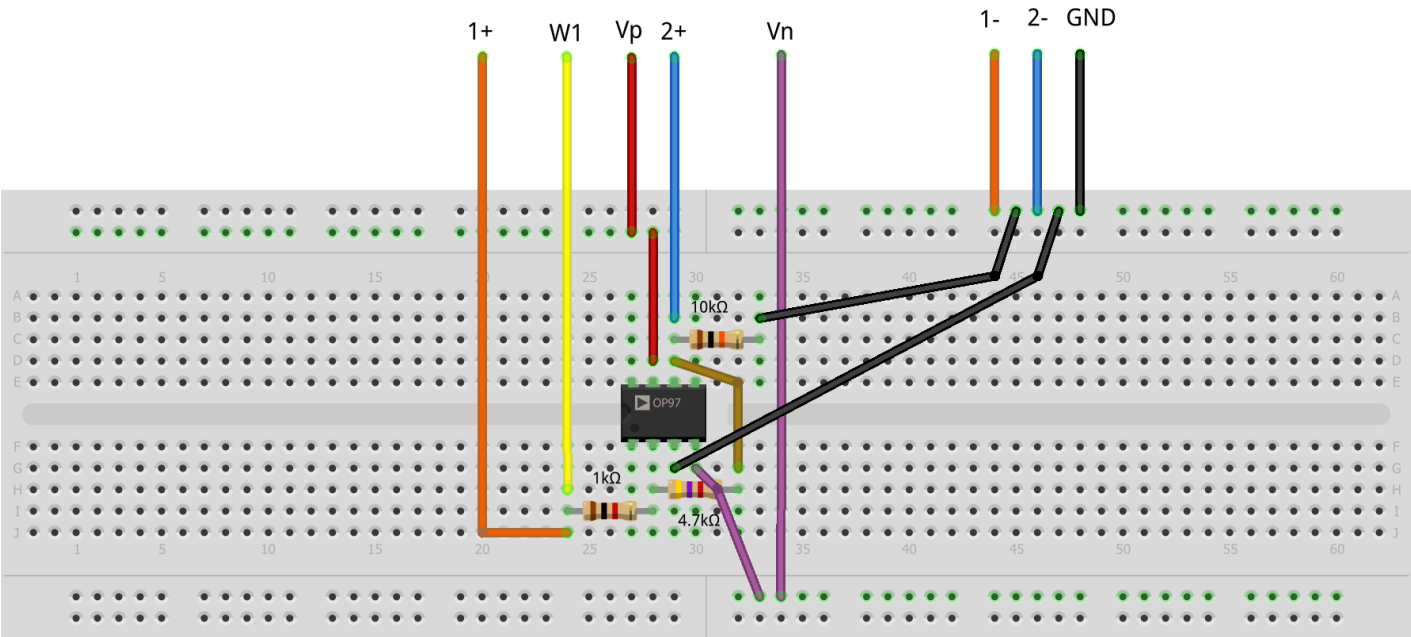
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Figure 1.8 Inverting amplifier configuration

Hardware Setup:

Now assemble the inverting amplifier circuit shown in figure 1.9 using $R_2 = 4.7\text{k}\Omega$. Remember to shut off the power supply before assembling a new circuit. Cut and bend the resistor leads as needed to keep them flat against the board surface, and use the shortest jumper wires for each connection (as in figure 1.1). Remember, the breadboard gives you a lot of flexibility. For example, the leads of resistor R_2 do not necessarily have to bridge over the op amp from pin 2 to pin 6; you could use an intermediate node and a jumper wire to go around the device instead.

Turn on the power supplies and observe the current draw to be sure there are no accidental shorts. Now adjust the waveform generator to produce a 2 volt amplitude peak-to-peak, 1 kHz (kilohertz) sine wave at the input (Vin), and again display both the input and output on the oscilloscope. Measure and record the voltage gain of this circuit, and compare to the theory that was discussed in class. Export a plot of the input/output waveforms to be included your lab report.



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Figure 1.9. Inverting amplifier Breadboard Circuit

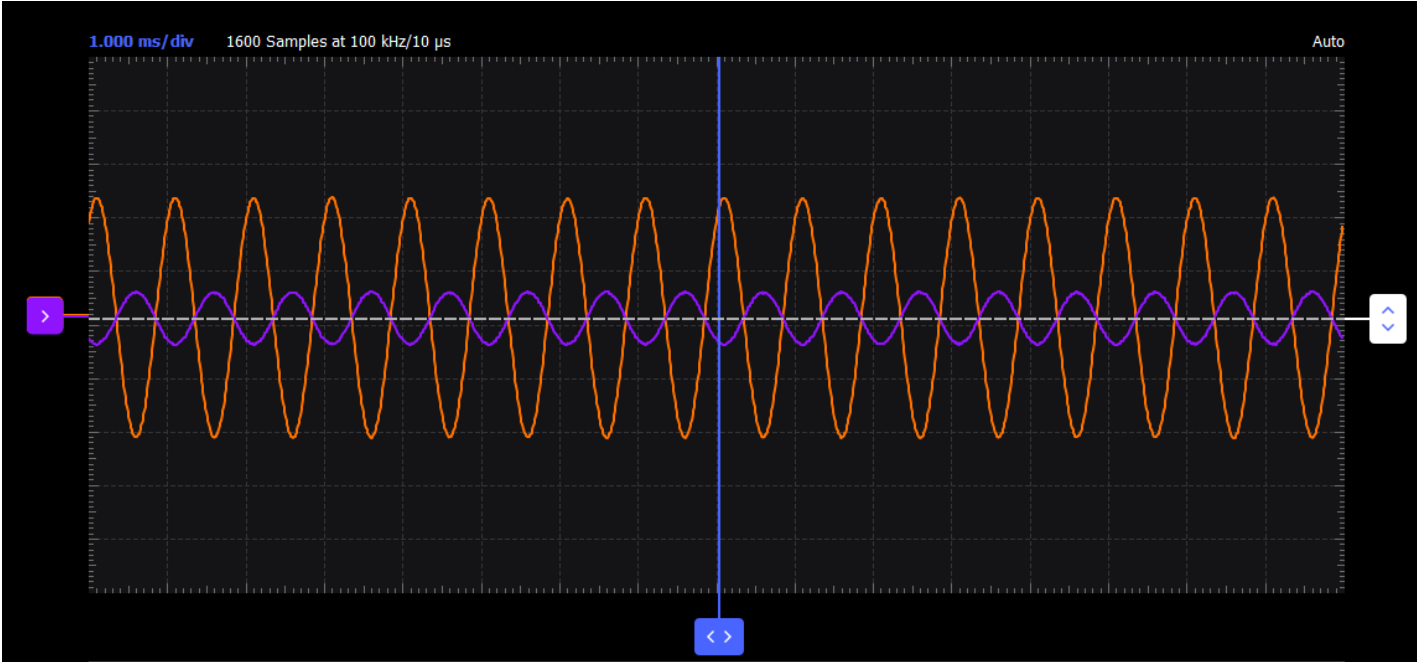
This is a good point to comment on circuit debugging. At some point in this class you are likely to have trouble getting your circuit to work. That is not unexpected, nobody is perfect. However, you should not simply assume that a non-working circuit must imply a malfunctioning part or lab instrument. That is almost never true; 99% of all circuit problems are simple wiring or power supply errors. Even experienced engineers will make mistakes from time to time, and consequently, learning how to

“debug” circuit problems is a very important part of the learning process. It is NOT the TA’s responsibility to diagnose errors for you, and if you find yourself relying on others in this way then you are missing a key point of the lab and you will be unlikely to succeed in later coursework. Unless smoke is issuing from your op amp or there are brown burn marks on your resistors or your capacitor has exploded, your components are probably fine, in fact most of them can tolerate a little abuse before significant damage is done. The best thing to do when things aren’t working is to just turn off the power supplies and look for a simple explanation before blaming parts or equipment. The DMM can be valuable debugging tool in this regard.

Procedure:

Use the first waveform generator as source V_{in} to provide a 2V amplitude peak-to-peak, 1 kHz (kilohertz) sine wave excitation to the circuit. Configure the scope so that the input signal is displayed on channel 2 and the output signal is displayed on channel 1.

A plot example is presented in Figure 1.10.



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Figure 1.10. Inverting amplifier Waveforms

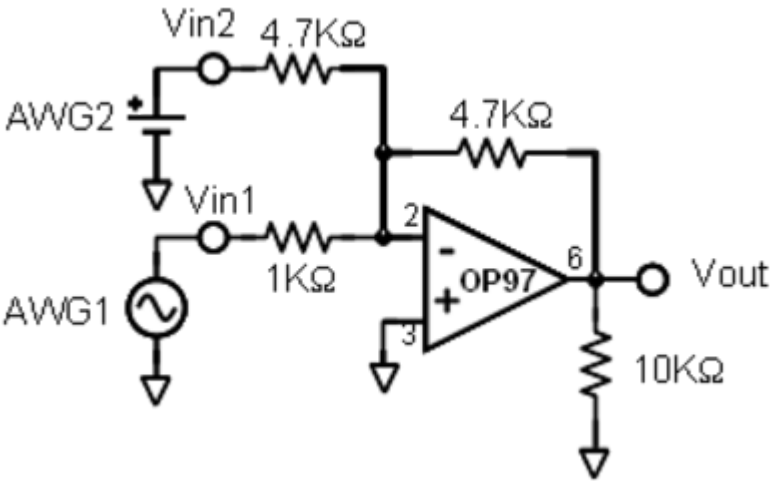
Output Saturation:

Now change the feedback resistor R_2 in figure 1.8 from 4.7 kΩ to 10 kΩ . What is the gain now? Slowly increase the amplitude of the input signal to 2 volts, and export the waveforms into your lab notebook. The output voltage of any op amp is ultimately limited by the supply voltages, and in many cases the actual limits are much smaller than the supply voltages due to internal voltage drops in the circuitry. Quantify the internal voltage drops in the OP97 based on your measurements above.

Summing Amplifier Circuit:

Background:

The circuit of figure 1.11 is a basic inverting amplifier with an additional input, called a “summing” amplifier. Using superposition we can show that V_{out} is a linear sum of V_{in1} and V_{in2} , each with their own unique gain or scale factor.



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Figure 1.11 Summing Amplifier configuration

Hardware Setup:

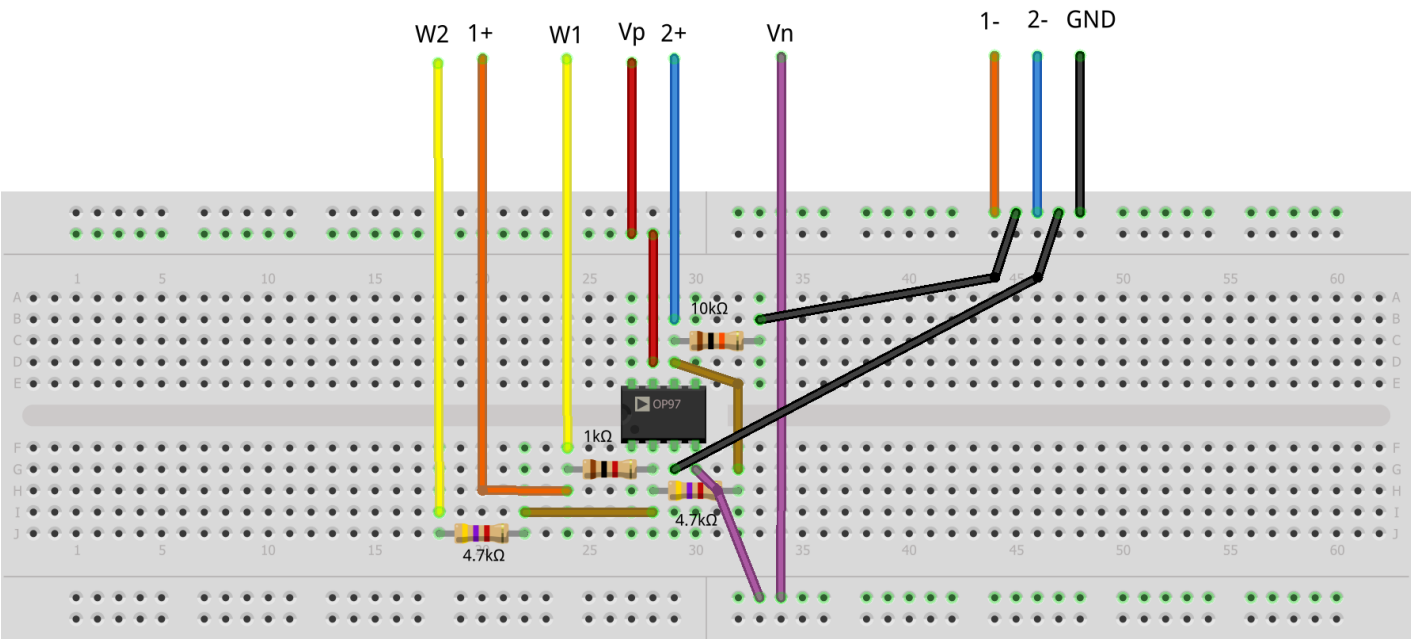
With the power turned off, modify your inverting amplifier circuit as shown in figure 1.12. Use the second waveform generator output for V_{in2} . Turn the amplitude all the way down to zero so that you can adjust up from zero during the experiment.

Now apply a 2 volt amplitude peak-to-peak sine wave for Vin1 and 1 volts DC for Vin2. Observe and record the input/output waveforms on the oscilloscope screen. Pay close attention to the ground signal level of the output channel on the oscilloscope screen. When used in this way, such a circuit could be called a level shifter.

Adjust the DC offset of waveform generator W1 (Vin1) until Vout has zero DC component. Estimate the required DC offset by observing the input waveform on the scope (note: it is not Vin2, be sure to understand why).

Reset the offset of waveform generator W1 to zero. With channel 2 of the scope (the channel connected to the op amp output) set for 2V/div, increase the offset voltage of waveform generator W2, Vin2 slowly. What happens to Vout? Record the DC voltage of the output.

Return the offset voltage of waveform generator W2 to approximately +1V. Set the scope to 1V/div, and adjust the scope offset so you can see the complete Vout waveform. Turn Vin2 back up to the value you increased it to in the previous step. What does the oscilloscope trace for Vout look like? Does the amplifier appear to be amplifying?



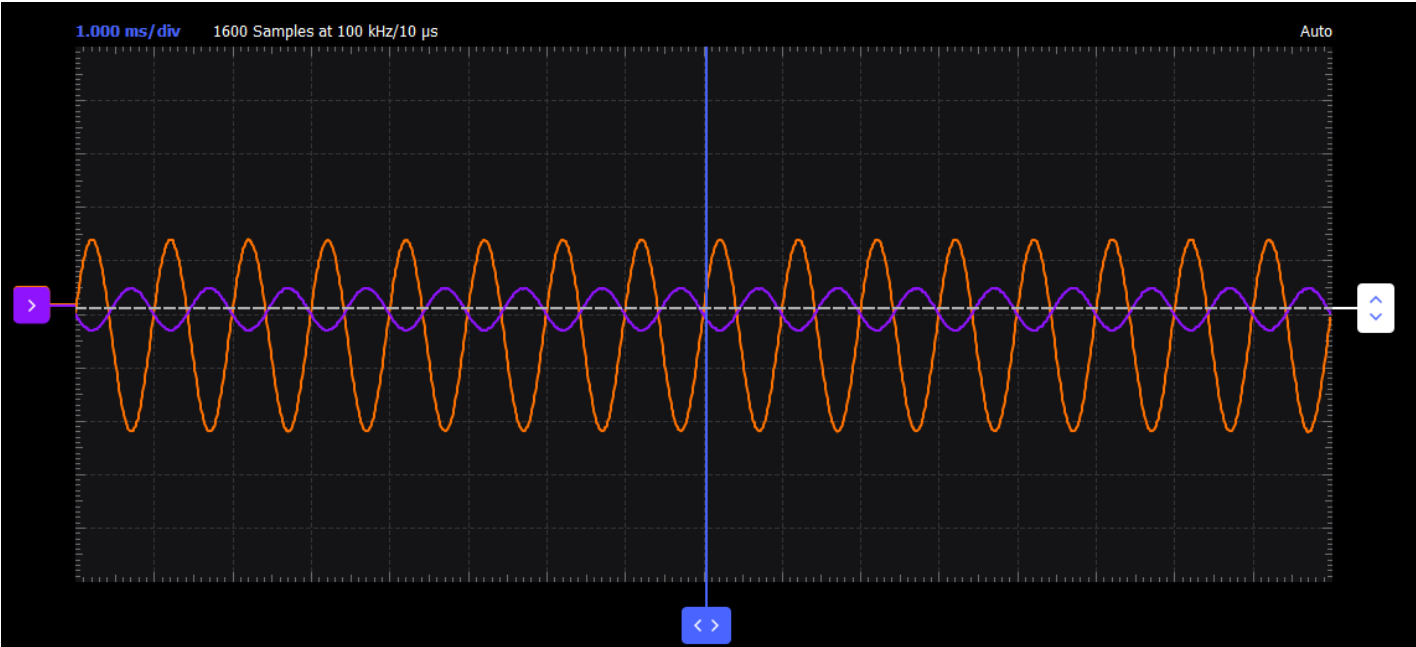
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Figure 1.12. Summing Amplifier Breadboard Circuit

Procedure:

Use the first waveform generator as source Vin to provide a 2V amplitude peak-to-peak, 1 kHz (kilohertz) sine wave excitation to the circuit. The second waveform generator is used to generate 1V constant voltage. Configure the scope so that the input signal is displayed on channel 2 and the output signal is displayed on channel 1.

A plot example is presented in Figure 1.13.



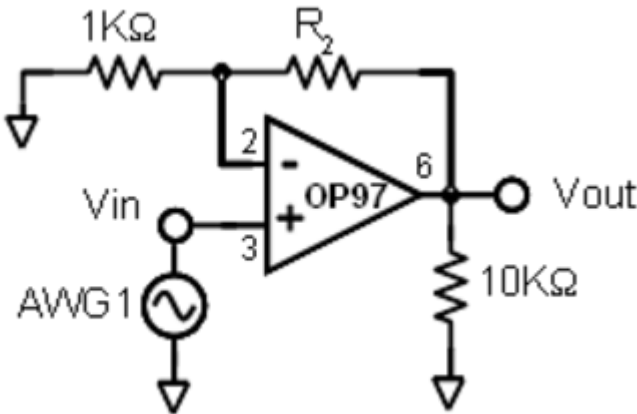
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Figure 1.13. Summing Amplifier Waveforms

Non-Inverting Amplifier:

Background:

The non-inverting amplifier configuration is shown in figure 1.14. Like the unity-gain buffer, this circuit has the (usually) desirable property of high input resistance, so it is useful for buffering non-ideal sources:



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Figure 1.14 Non-inverting Amplifier with gain

Hardware Setup:

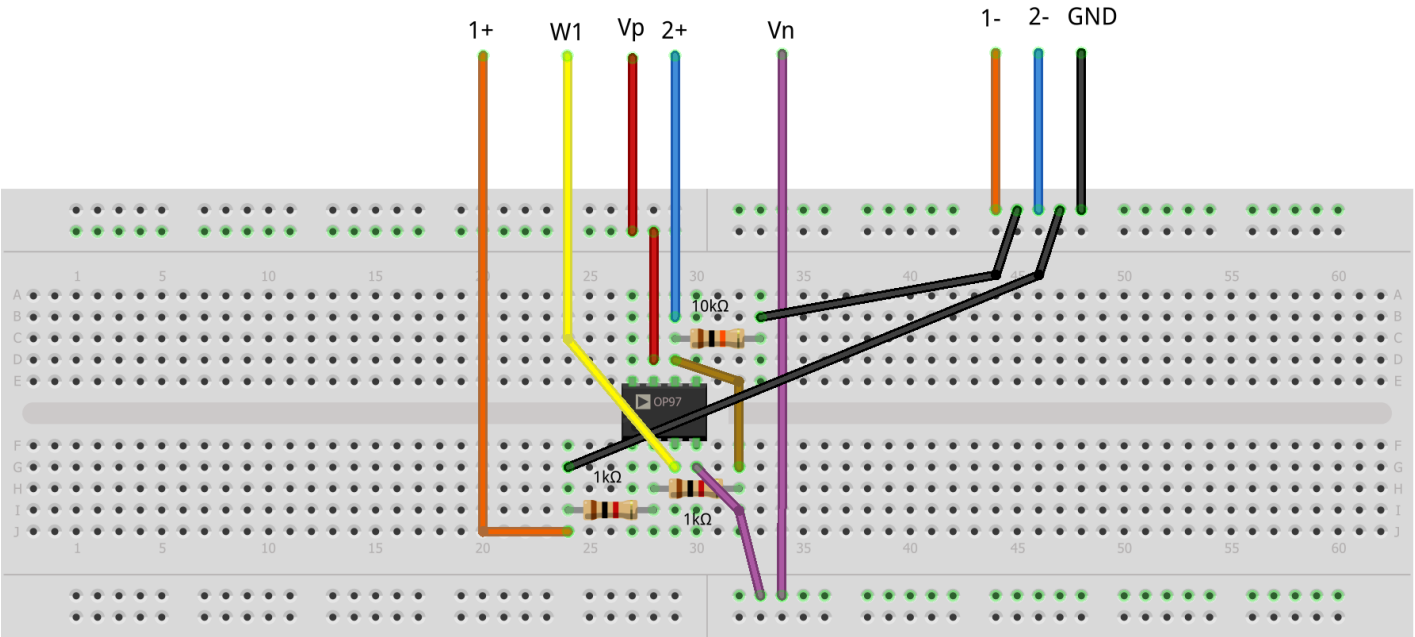
Assemble the non-inverting amplifier circuit shown in figure 1.15. Remember to shut off the power supplies before assembling the new circuit. Start with $R_2 = 1\text{k}\Omega$.

Apply a 2 volt amplitude peak-to-peak, 1 kHz (kilohertz) sine wave at the input, and display both input and output on the scope. Measure the voltage gain of this circuit, and compare to the theory discussed in class. Export a plot of the waveforms and include it in your lab report.

Increase the feedback resistor (R_2) from 1 kΩ to about 5 kΩ. What is the gain now?

Increase the feedback resistance further until the onset of clipping, that is, until the peaks of the output signal begin to be flattened due to output saturation. Record the value of resistance where this happens. Now increase the feedback resistance to 100 kΩ. Describe and draw waveforms in your notebook. What is the theoretical gain at this point? How small would the input signal have to be in order to keep the output level to less than 5V given this gain? Try to adjust the waveform generator to this value. Describe the output achieved.

The last step underscores an important consideration for high-gain amplifiers. High-gain necessarily implies a large output for a small input level. Sometimes this can lead to inadvertent saturation due to the amplification of some low-level noise or interference, for example the amplification of stray 60Hz signals from power-lines that can sometimes be picked up. Amplifiers will amplify any signals at the input terminals...whether you want it or not!



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Figure 1.15. Non-Inverting Amplifier Breadboard Circuit

Procedure:

Use the first waveform generator as source V_{in} to provide a 2V amplitude peak-to-peak, 1 kHz (kilohertz) sine wave excitation to the circuit. Configure the scope so that the input signal is displayed on channel 2 and the output signal is displayed on channel 1.

A plot example is presented in Figure 1.16.



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Figure 1.16. Non-Inverting Amplifier Waveforms

Congratulations! You have now completed Lab Activity 1

As noted in the previous lab: keep all your leftover electrical components!

Specific Discussion Items for Lab Report

Some specific ideas for the report might be as follows:

- Slew rate: discuss how you measured and computed the slew rate in the unity-gain buffer configuration, and compare this with the value listed in the OP97 data sheet.
- Buffering: explain why the buffer amplifier in figure 1.7 allowed the voltage divider circuit to function perfectly with differently load resistances.
- Output saturation: explain your observations of output voltage saturation in the inverting amplifier configuration and your estimate of the internal voltages drops. How close does the output come to the supply rails in this experiment and also later when used as a comparator with different power-supply voltages? Can you guess what the output voltage swing would be for an op-amp that is advertised as a “rail-to-rail” device?
- Summing circuit: using superposition, derive the expected transfer characteristic for the circuit of figure 1.11; that is, find the output voltage in terms of Vin1 and Vin2 . Compare the predictions of the ideal relationship with your data.
- Comparator: discuss your measurements and what would happen if the polarity of Vref is reversed

Resources:

- Fritzing files: opamp_bb [https://analogdevicesinc.github.io/DownGit/#/home?url=https://github.com/analogdevicesinc/education_tools/tree/master/m2k/fritzing/simple_op_amps_bb]
- Archivos LTSpice: opamp_ltspace [https://analogdevicesinc.github.io/DownGit/#/home?url=https://github.com/analogdevicesinc/education_tools/tree/master/m2k/ltspace/opamp_ltspace]

Continúe con la siguiente actividad de laboratorio de amplificador operacional: [amplificador operacional como comparador \(/university/courses/electronics/electronics-lab-opamp-comparator\)](#)

Más sobre los amplificadores operacionales en la configuración de amplificadores: [Amplificadores de ganancia variable \(/university/courses/electronics/electronics-lab-variable-gain-amplifier\)](#)

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