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## Experiment A8 Electronics III Procedure

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Deliverables: checked lab notebook, plots

### Overview

Electronics have come a long way in the last century, most especially exemplified by the invention of the *solid-state transistor*. These transistors form the basis of all modern amplifiers and logic circuits. Using state-of-the-art fabrication techniques, engineers can now print billions of transistors onto a piece of silicon the size of a postage stamp. These *integrated circuits* (ICs) have drastically improved nearly every aspect of human civilization, from communications to banking, and have generated a tremendous amount of wealth for many savvy engineers.

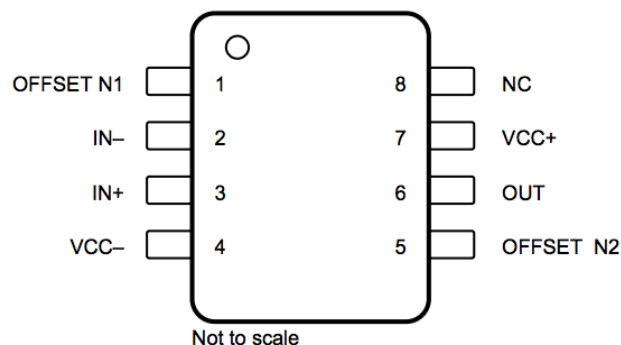
In this lab, you will use an IC chip to amplify signals. Electronic amplification is important for measurements, as it increases the **signal-to-noise ratio**. That is, it allows you to distinguish a signal from any unwanted background noise.

### Part I: Inverting Amplifier Circuit

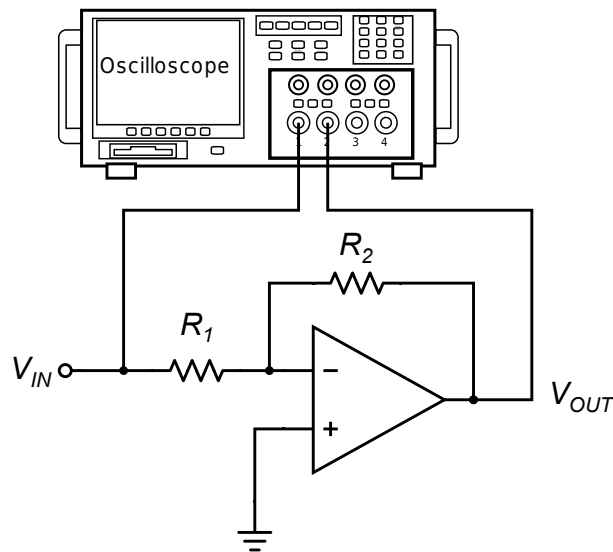
In this laboratory exercise, you will use a bread board to construct an *inverting* amplifier using the TL071 operational amplifier (op-amp) chip. You will construct the op-amp circuit shown in Figure 2 using  $R_1 = 1 \text{ k}\Omega$ . You will then measure the amplitude  $|V_{out}|$  as a function of the other resistor  $R_2$  using the values in Table 1. The gain of the inverting amplifier is given by the equation

$$\frac{|V_{out}|}{|V_{in}|} = -\frac{R_2}{R_1}. \quad (1)$$

The negative sign on the right-hand side simply means that the output sine wave will be flipped upside down.



**Figure 1** - Pin-out for the TL071 op-amp chip.



**Figure 2** – A schematic of the inverting amplifier with input and output connected to the oscilloscope. The input signal  $V_{IN}$  comes from the function generator. (Note that the +15V and –15V power inputs have been omitted in this drawing, but they are still necessary.)

You will now construct the circuit shown above using  $R_1 = 1\text{ k}\Omega$ .

1. Copy the pin-out shown in Fig. 1 into your lab notebook.
2. Copy the circuit diagram shown in Fig. 2 into your lab notebook.
3. Turn on the breadboard. Set the adjustable – and + 15V power supplies to -10V and +10V by turning the knobs. Then, turn off the breadboard.
4. Insert the TL071 into the breadboard so that it is straddling one of the vertical trenches running down the breadboard.
5. Connect the ground, 0 - 15V terminals at the top of the breadboard to the various red and blue vertical columns. You should have a column to the right of the IC at +10V, a column on the left of the IC at -10V, and a third column at ground.
6. Give power to the amplifier IC by connecting the -10V column to the VCC- pin and the +10V column to the VCC+ pin. (Refer to pin-out in Fig. 1.)

**Pro-tip:** Try to avoid having long loops of wire in your circuit. Long loops of wire will pick up electromagnetic noise and make you circuit difficult to see.

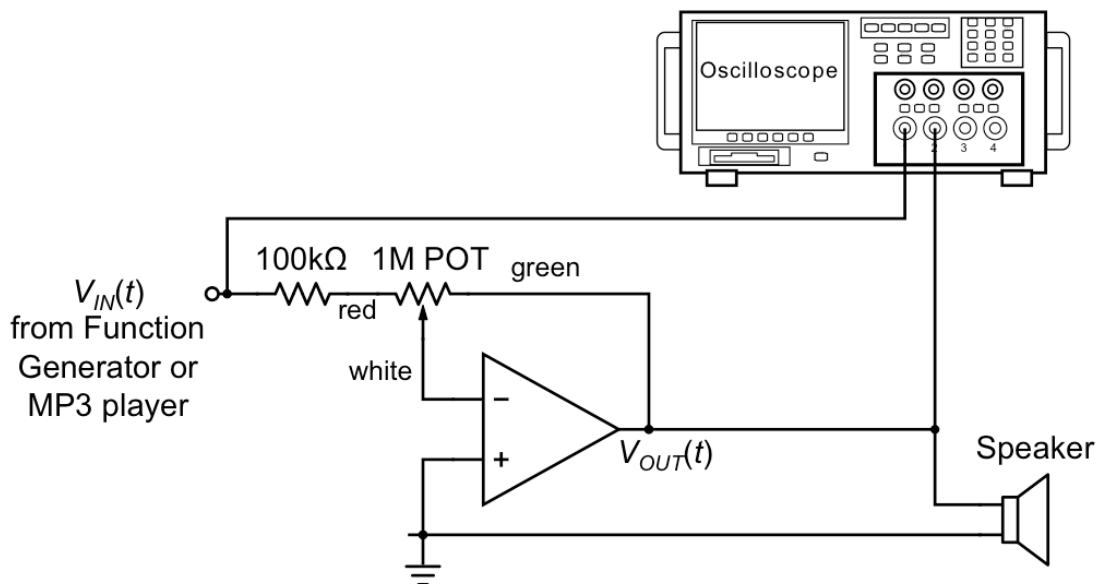
7. Ground the non-inverting input (pin 3) of the amplifier.
8. Copy Table 1 into you lab notebook with a column for  $R_2$  and a columns for the amplitudes  $|V_{out}|$  and  $|V_{in}|$ .
9. Pick a  $1\text{ k}\Omega$  resistor from the resistor set. Using the Extech handheld DMM, measure its resistance and record the value in your lab notebook. This resistor will be used for  $R_1$  in the op-amp circuit. Carefully, insert it into the breadboard in the correct position. One end should be connected to inverting input (pin 2), the other end will be connected to the function generator via the red minigrabber.

Table 1			
$R_2(\Omega)$	Actual $R_2(\Omega)$	$ V_{out} $ (V)	$ V_{in} $ (V)
1k			
2k			
4.7k			
5.6k			
10k			
15k			

10. Take a 1k $\Omega$  resistor from the set. Measure its resistance and record the value in the table in your lab notebook. Insert this resistor into proto board as  $R_2$  to form the circuit shown in Fig. 2. One end should be connected to the inverting input (pin 2) and the other end connected to the op-amp output (pin 6).
11. Turn on the function generator. Press the “sine” button, then “output menu”, then “load impedance”, then “High Z”, then press “Top Menu” to exit to the main menu.
12. Connect the output ‘T’ on the function generator to CH1 of the oscilloscope.
13. Connect the other side of ‘T’ to a BNC cable with minigrabbers on the other end. Use the minigrabbers to connect the output of the function generator to input of the op-amp circuit, through  $R_I$ . Remember, the red minigrabber carries the signal, and the black mini-grabber should always be connected to ground.
14. Connect CH2 of the oscilloscope to the *output* of the circuit  $V_{OUT}$  using a different BNC-to-minigrabber cable.
15. Compare the circuit on your breadboard to the circuit in Figures 1 and 2. Check to make sure that it is
16. Turn on the breadboard.
17. Set the output of the function generator to be a 1 kHz sine wave with a peak-to-peak amplitude of 1V<sub>pp</sub>, and press the “Output ON” button.
18. Press the “auto set” button on the right hand side of the oscilloscope. You should see a sine wave appear. Measure the amplitude of CH1 and CH2 on the scope and these values in the table next to the value of  $R_I$ .
19. Measure the peak-to-peak amplitude  $|V_{out}|$  and  $|V_{in}|$  as a function of  $R_2$  by swapping out the resistor until you have completely cycled through the resistors in the Table 1.
20. Turn off the breadboard and disconnect the minigrabbers from your circuit.

## Part II: Audio Pre-Amp

You will now use the TL071 to build an amplifier for your favorite music. Please use the step-by-step instructions below to construct the inverting amplifier circuit below.



**Figure 3** – A schematic of the inverting amplifier with input and output connected to audio equipment. Note that the +15V and -15V power inputs have been omitted, but they are still necessary.

**Do NOT get the MP3 player or speaker until the instructor approves your circuit.**

1. Copy the circuit diagram shown in Fig. 3 into your lab notebook.
2. Locate the 1MΩ potentiometer. You may notice that there is something very special about the knob on the potentiometer—it goes all the way up to 11!
3. Connect the Exttech handheld DMM to the leads of the potentiometer and measure its resistance. Turn the knob and see if the resistance changes. Try this with various wiring combinations.
4. Replace the two resistors  $R_1$  and  $R_2$  with the 100kΩ resistor and 1MΩ potentiometer as shown in Figure 3. Return the resistors  $R_1$  and  $R_2$  to the proper bins.
5. Increase the variable DC power supplies on the breadboard to +15V and -15V.
6. Insert a BNC 'T' into the output of the function generator.
7. Connect the output 'T' on the function generator to CH1 of the oscilloscope.
8. Connect the other side of 'T' to a BNC cable with minigrabbers on the other end. Use it to connect the output of the function generator to the input of the circuit  $V_{IN}(t)$ , through the 100kΩ resistor.
9. Insert another BNC 'T' into CH2 on the oscilloscope.

10. Connect the other BNC-to-minigrabber cable to the T on CH2 of the oscilloscope. Use it to connect the output of the Op-Amp  $V_{OUT}(t)$  to CH2 on the scope.
11. Turn on the function generator set it to output a 100 Hz sine wave at  $1V_{pp}$ . Press the “autoset” button on the oscilloscope, and you should see sine waves appear on CH1 and CH2.
12. Turn the knob on the potentiometer. If you built the circuit correctly, you should see the amplitude on CH2 increase or decrease. Demonstrate to the lab instructor, and you will be given a speaker and 3.5mm audio adapters to complete the procedure.
13. Use the 3.5mm audio adapter and another BNC cable to connect the output to the speaker. The amplifier output, the speaker, and the oscilloscope should all be connect via the ‘T’ on CH2.
14. Set the speaker to “AUX mode”. You should hear a sound coming from the speaker.
15. Turn the knob on the potentiometer. You should hear the speaker get louder or softer and see the waveform change size on the oscilloscope.
16. Adjust the frequency on the function generator to play different tones on the speaker.
17. Ask the lab instructor or TA for the MP3 player. Disconnect the BNC cable from the function generator and use another 3.5mm audio adapter to connect it to the mp3 player.

**Caution: If you choose to use your phone instead of the MP3 player, you do so at your own risk!**

18. Pick a song, press play, and crank it up!
19. Demonstrate your circuit to the TA or lab instructor. They must sign off on it before you leave.
20. Finishing Move: Clean up you lab bench and restore it to its initial condition.
  - a. Press the “System Default” button below the screen on the oscilloscope.
  - b. Disconnect all BNC coaxial cables.
  - c. Remove any jumper cables from the breadboard.
  - d. Return all resistors to the proper bins.
  - e. Leave the Op-Amp in the breadboard.

### Data Analysis and Deliverables

Please make the following plots in Matlab, import them into a LaTeX or MS Word document, and give them concise, intelligent captions. Make sure the axes are clearly labeled with units. Plots with multiple data sets on them should have a legend. **Additionally, write a paragraph separate from the caption describing what you did in lab and how it relates to the plot.**

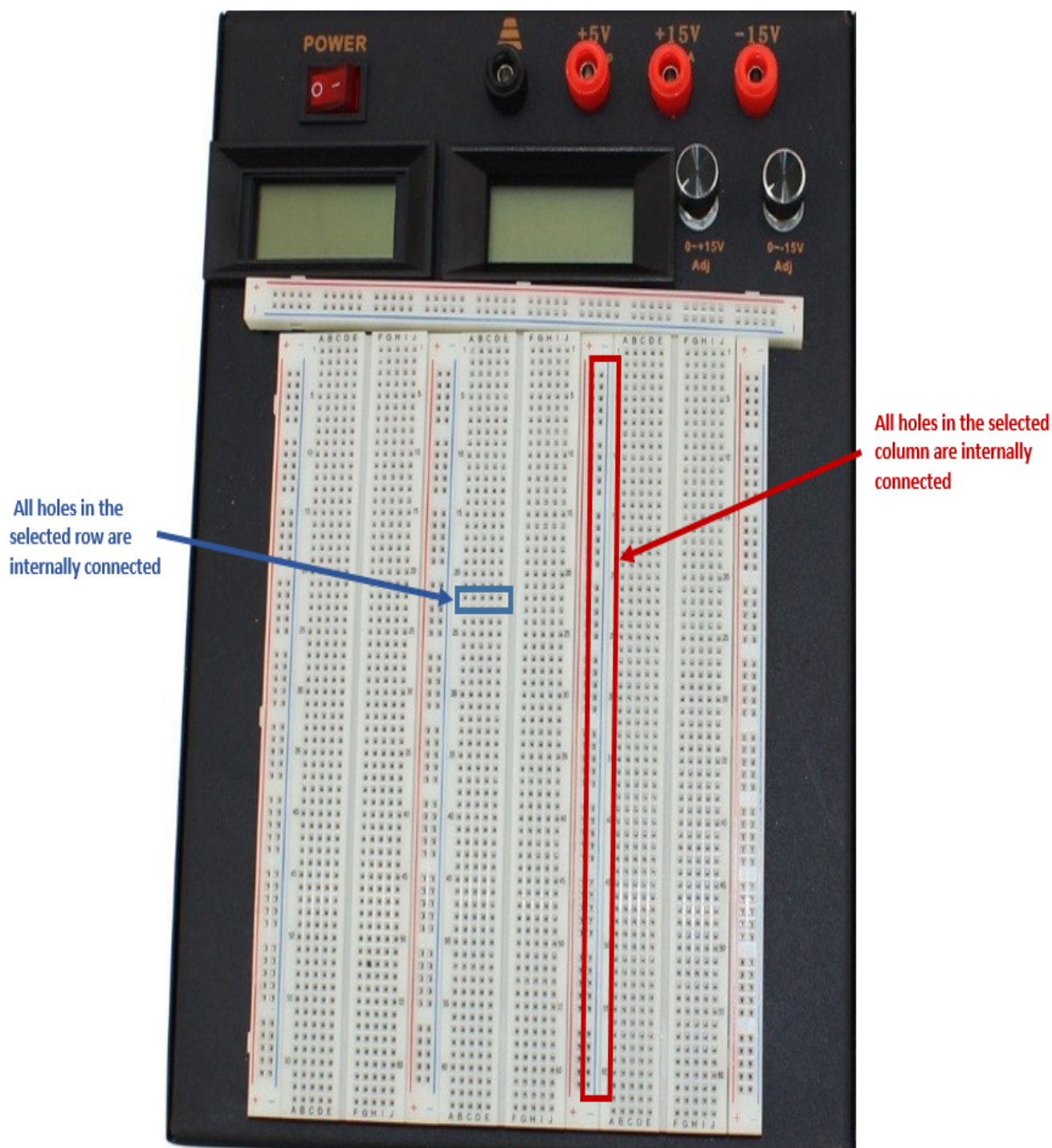
1. For Part I, make a plot of the measured gain  $G$  as a function of  $R_2$  with the theoretical curve on top for the inverting amplifier.

## Appendix A

### Equipment

- Tektronix AFG3021C Function Generator
- Tektronix MDO3012 Digital Oscilloscope
- Extech Handheld DMM
- Powered Breadboard
- Breadboard Solder-less Connectors
- Texas Instruments TL071CP Op-Amp; Digikey # 296-7186-5-ND
- Socket, IC, 08 PIN; MFG# 6100-8-R
- 4x BNC Cables, 3' – 4' in length
- 2x BNC – “T” connector
- 2x BNC to minigrabber adapter
- Resistors
- 33pF Capacitor
- 2x BNC to 3.5mm male audio adapters
- WSA-8612 Wireless Desktop Speak
- AGPTEK Badge-ZOOM MP3 Player

## Appendix B



**Figure 4** – Shown in blue, any 5 holes in a horizontal row are electrically connected, but they are NOT connected to the adjacent row of 5. Shown in red, all 50 holes in any vertical column or “bus bar” are electrically connected.