CG1111 Engineering Principles and Practice I

Basic Operational Amplifier Circuits

(Week 8, Studio 2)

Time	Duration (mins)	Activity
0:00	20	Briefing
0:20	50	Activity #1: Non-inverting Amplifier with dual power supply
1:20	70	Activity #2: Inverting Amplifier with dual power supply
2:20	10	Final discussions and wrap-up

Introduction:

- The Operational Amplifier, commonly referred as op amp, is a fundamental building block of most analog circuits. An amplifier takes an input signal and outputs a larger version of the input signal. This action is known as amplification.
- Op Amps are available in the form of Integrated Chips (ICs) and they are used in a large number of applications apart from their common use as amplifiers, such as in filters, buffers, adders, subtractors, integrators, instrumentation, etc.
- Op Amp is represented using the following symbol. There are two input terminals and one output terminal.

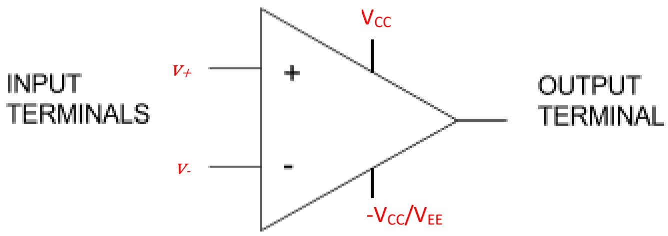


Figure 1: Op Amp symbolic representation

The fundamental characteristics of an op amp are as follows:

- $v_o = A(v_+ - v_-)$, *where* v_+ *and* v_- are the voltages at the input terminals marked with + (non-inverting) and – (inverting) symbols respectively, v_o is output voltage and A is the open-loop voltage gain.
- In an ideal op amp, A is very high, in the order of $10^5 - 10^8$.
    - The input impedance is very high and it can be assumed to be infinite, thereby resulting in no current into the op amp at the input terminals.
    - The output impedance is very low and can usually assumed to be 0 Ω.
- All op amps require an external power supply to operate. This is represented by the vertical power lines leading from the op amp signal (see Figure 2), but in most circuit diagrams it is implicitly understood and not explicitly drawn. In this studio, we will be using single as well as dual power supplies. Figure 2 represents the dual power supply configuration.

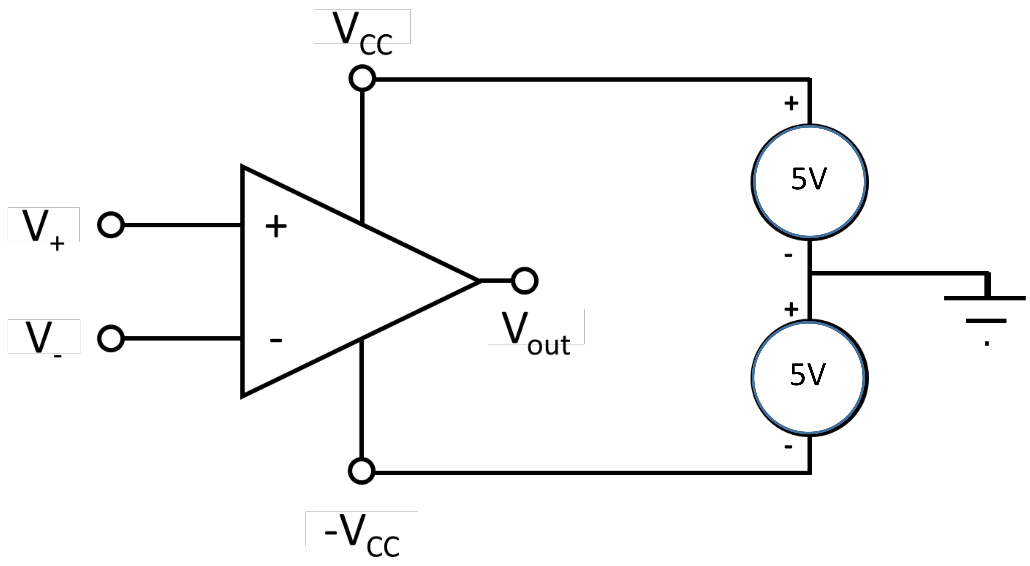


Figure 2: Op Amp with Dual Power supply connection shown

- The input-output characteristics of an op amp are as shown in Figure 3 below. When the differential input voltage level is within the linear region where the slope is given by A, the output is given by the differential input multiplied by A. Otherwise, the output is saturated at $\pm V_{sat}$. The saturation voltage, V_{sat} is determined by the power supply voltage. V_{sat} is usually 1V lower than V_{CC}.

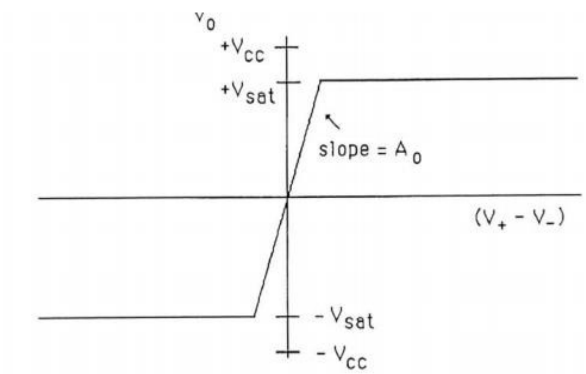


Figure 3: Input-output characteristics of an ideal op amp

- In this studio, we will be using the LM358 IC, which consists of two independent, high-gain operational amplifiers designed to operate from a single supply or split supply over a wide range of voltages.
- The pinout for the IC is as given in Figure 4. As can be seen by the connections symbolically shown within the IC's top view, there are 2 op amps, one on each side. V_{CC} and V_{EE} are the connections to be made from the external power supply. We will be using V_{CC} as the +5V supply line, and V_{EE} as the -5V supply line.

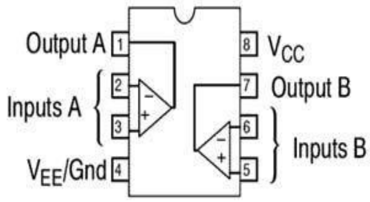


Figure 4: LM358 Pinout diagram

Objectives:

- To understand the ideal characteristics of op amp
- To construct basic op amp circuits and calculate the gain of the op amp using circuit principles
- To understand the importance of the dual power supply and cut-off/saturation
- To appreciate the inverting and non-inverting amplification actions of op amp

Materials:

- LM358 Op amp chip
- Breadboard and connecting wires
- Digital multimeter
- BitScope
- USB breakout cable + your own USB charger
- Arduino Uno (to provide second DC voltage source)
- Resistor
  - 100 Ω
  - 10 kΩ
  - 2 kΩ variable resistor (It says 202 on the variable resistor body)

Setups:

A. Waveform Generator Setup:

a) Run BitScope DSO on your computer.
b) Turn on the power to your BitScope, and turn on its waveform generator by clicking on "WAVE" in the "Scope Selectors (2)" panel (see Appendix for its position).
c) In the "FUNCTION GENERATOR" panel (top left), right-click on the frequency and select **1 kHz**.
d) For the peak-to-peak voltage, left-click it and drag its value downward to 200 mV.
e) For the DC offset (i.e., the box beside the peak-to-peak voltage setting), left-click it and drag its value downward to 0 V. The waveform will still have some DC offset.
f) Connect your "AWG" pin to "CHA" and observe the waveform.
g) In the "Channel Controls (7)" panel, change the voltage per division of CHA to 100 mV/Div.

B. Measurements using Bitscope:

a) Click on "TRACE" in the "Timebase Control (6)" panel to freeze the waveforms.
b) Turn on "CURSOR" in the "Scope Selectors (2)" panel.
c) To measure the peak-to-peak voltage of V_{in}, click on "CHA" in the "Channel Controls (7)" panel, then right-click on the brown voltage box in the "Cursor Measurements (5)" panel to select "MAX".
d) Right-click on the dirty-green box directly underneath the brown box and select "MIN".
e) The peak-to-peak voltage of V_{in} is now shown in the yellow box directly underneath the dirty-green box.
f) To measure the average voltage V_{Avg}, click on "CHA" in the "Channel Controls (7)" panel, then right-click on the brown voltage box in the "Cursor Measurements (5)" panel to select "MEAN".

Note: Always verify the V_{in} peak-to-peak using the cursor measurement before going ahead with the activity

C. Dual Power Supply Setup:

a) The USB breakout cable provides the primary DC voltage source while the Arduino Uno provides the second DC voltage source
b) Connect your Arduino Uno (using the USB cable that came with it) to another USB power adapter that is isolated from the one powering your USB breakout cable. This can be another USB power bank or adapter.

Note:It is very important that the second power source is isolated from the first. If they are from the same device (e.g., two USB ports on the same power bank or laptop), their grounds (i.e., negative terminals) are connected internally and you will get wrong results!

c) Notice that the Arduino Uno has a pin that is labelled as "5V". This serves as the "+" terminal of your second 5 V source. There are also two ground pins beside it that are labelled as "GND". Either one of this can be used as the "–" terminal of your second Arduino 5V DC source.
d) Connect the '-' of the USB breakout cable to the '+' from the Arduino 5V DC source. This becomes the new GND terminal of the Dual Power Supply setup.
e) Measure the voltage at the '+' of the USB breakout cable with respect to the GND terminal using the digital multimeter and ensure that it is around **+5V**.
f) Measure the voltage at the '-' of the Arduino 5V DC source with respect to the GND terminal using the digital multimeter and ensure that it is around **-5V**.

Note: If you are using a power bank to power up either the Arduino or the USB breakout cable, it may switch off after some time because of low current drawn from the circuit. Ensure to periodically check and switch on the power bank if needed.

Activity #1: Non-inverting amplifier with dual power supply (50 mins)

- First, we will be building a simple circuit using the LM358 chip to perform non-inverting amplification. The schematic of a non-inverting amplifier is given in Figure 5.
- The gain relationship for a non-inverting amplifier is given by, $V_{out} = \left(1 + \frac{R_f}{R_{in}}\right) V_{in}$
- In this activity, we follow up the non-inverting amplifier from Activity 1 with a dual power supply.
- Pin 8 is connected to +5V, while Pin 4 is connected to -5V.

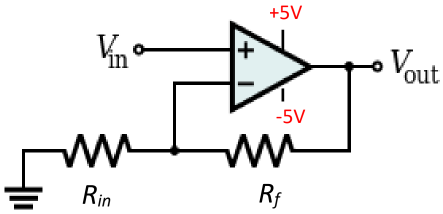


Figure 5: Schematic of Non-inverting amplifier with dual power supply

1. Find the gain relationship relating the output voltage to the input voltage for the non-inverting amplifier. Hint: Use the basic equation governing the op amp, ideal characteristics of an op amp relating to the current at the input terminal and the voltage divider principle.
2. Compute the gain for the different combinations of the resistors (in Table 1) using the input output gain relationship.
3. Use the dual power setup described above (**Setups: C. Dual Power Supply Setup**) to power up the op-amp. Pin 4 of the Op-Amp should be at -5V and Pin 8 should be at +5V. Pay attention to the polarity of the voltage supply. Refer to Figure 5. The GND terminal of the Dual Power Supply Setup is the new ground terminal of the circuit.
4. Connect the V_{in} as described in **Setups: A. Waveform Generator Setup** to the circuit in Figure 5.

   Note: Always verify the V_{in} peak-to-peak using the cursor measurement before going ahead with the activity.

5. Connect "CHA" and "AWG" from the Bitscope to the V_{in} and "CHB" to the V_{out} in Figure 5. Remember to connect the GND terminals of CHA and CHB to the GND terminal of the circuit.Measure the peak-to-peak voltage for "CHB" as described in **Setups B. Measurements using Bitscope** and note down V_{PP} and the V_{Avg} in the output voltage column of Table 1.

   NOTE: You may need to change the vertical scale of "CHB" to ensure that the full waveform is within the oscilloscope screen.

6. Repeat the above steps for the remaining combinations of resistors. Use the variable resistor (2kΩ) as the feedback resistor to obtain the different values for Rf during the experiment.

Note: You can adjust the variable resistor to ±5% of the value in the table. Please ensure that you **do not** change the variable resistor value while it is connected in the circuit.

7. Is the output voltage measured from the oscilloscope like what you have computed from the derived gain relationship of the op amp from Step 1? Explain your observations.
8. Is the output voltage in-phase with the input voltage signal?
9. What can you observe about the 5th combination of resistances? Why do you think this occurs?

- $\boldsymbol{V_{in}}$= _____________ mV (peak to peak voltage)
- Average Value of $\boldsymbol{V_{in}}$= _________

Table 1

S. No	R_f	R_{in}	Gain = $\frac{V_{out}}{V_{in}}$	$V_{out}(V_{pp})$ (measured from DSO)	$V_{out}(V_{Avg})$ (measured from DSO)
1	100 Ω	100 Ω			
2	300 Ω	100 Ω			
3	1 kΩ	100 Ω			
4	2 kΩ	100 Ω			
5	10 kΩ	100 Ω			

Activity #2: Inverting Amplifier with dual power supply (70 mins)

- In this activity, we will build another circuit configuration which results in inverted amplification.
- The schematic and circuit diagram of an inverting amplifier is as follows. **The input signal from the function generator is provided to the negative input terminal, also known as the inverting input.** The positive input terminal is connected to ground.
- Pin 8 is connected to +5V, while Pin 4 is connected to -5V.

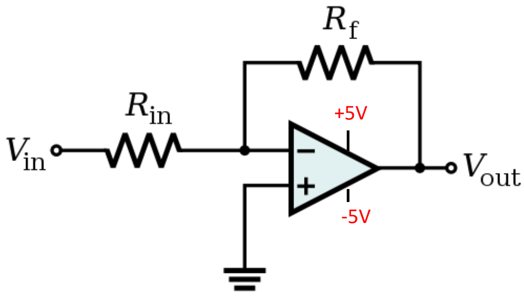


Figure 6: Schematic of Inverting amplifier with dual power supply

The gain relationship for an inverting amplifier is given by, $V_{out} = -\frac{R_f}{R_{in}} V_{in}$

1. Compute the gain for the different combinations of the resistors (in Table 2) using the input output gain relationship.
2. Use the dual power setup described above (**Setups: C. Dual Power Supply Setup**) to power up the op-amp. Pin 4 of the Op-Amp should be at -5V and Pin 8 should be at +5V. Pay attention to the polarity of the voltage supply. Refer to Figure 6. The GND terminal of the Dual Power Supply Setup is the new ground terminal of the circuit.
3. Connect the $\boldsymbol{V_{in}}$ as described in **Setups: A. Waveform Generator Setup** to the circuit in Figure 6.

   Note: Always verify the V_{in} peak-to-peak using the cursor measurement before going ahead with the activity. For this Activity, the V_{in} may get distorted when you switch on the circuit. Readjust the V_{in} such that it is at least 120 -130mV peak to peak.

4. Connect "CHA" and "AWG" from the Bitscope to $\boldsymbol{V_{in}}$ and "CHB" to the $\boldsymbol{V_{out}}$ in Figure 6. Remember to connect the GND terminals of CHA and CHB to the GND terminal of the circuit. Measure the peak-to-peak voltage for "CHB" as described in **Setups B. Measurements using Bitscope** and note down V_{PP} and the V_{Avg} in the output voltage column of Table 2.

   NOTE: You may need to change the vertical scale of "CHB" to ensure that the full waveform is within the oscilloscope screen.

5. Repeat the above steps for the remaining combinations of resistors. Use the variable resistor (2kΩ) as the feedback resistor to obtain the different values for Rf during the experiment.

Note: You can adjust the variable resistor to ±5% of the value in the table. Please ensure that you **do not** change the variable resistor value while it is connected in the circuit.

6. Is the output voltage measured from the oscilloscope like what you have computed from the derived gain relationship of the op amp from Step 1? Explain your observations.
7. Is the output voltage in-phase with the input voltage signal?
8. What can you observe about the 5th combination of resistances? Why do you think this occurs?

- $\boldsymbol{V_{in}}$= _____________ mV (V_{pp})
- Average Value of $\boldsymbol{V_{in}}$= _________ (V_{Avg})

Table 2

S. No	R_f	R_{in}	Gain = $\frac{V_{out}}{V_{in}}$	$V_{out}(V_{pp})$ (measured from DSO)	$V_{out}(V_{Avg})$ (measured from DSO)
1	100 Ω	100 Ω			
2	300 Ω	100 Ω			
3	1 kΩ	100 Ω			
4	2 kΩ	100 Ω			
5	10 kΩ	100 Ω			

Please feel free to ask your TA or the Lecturers any questions or doubts you may have.

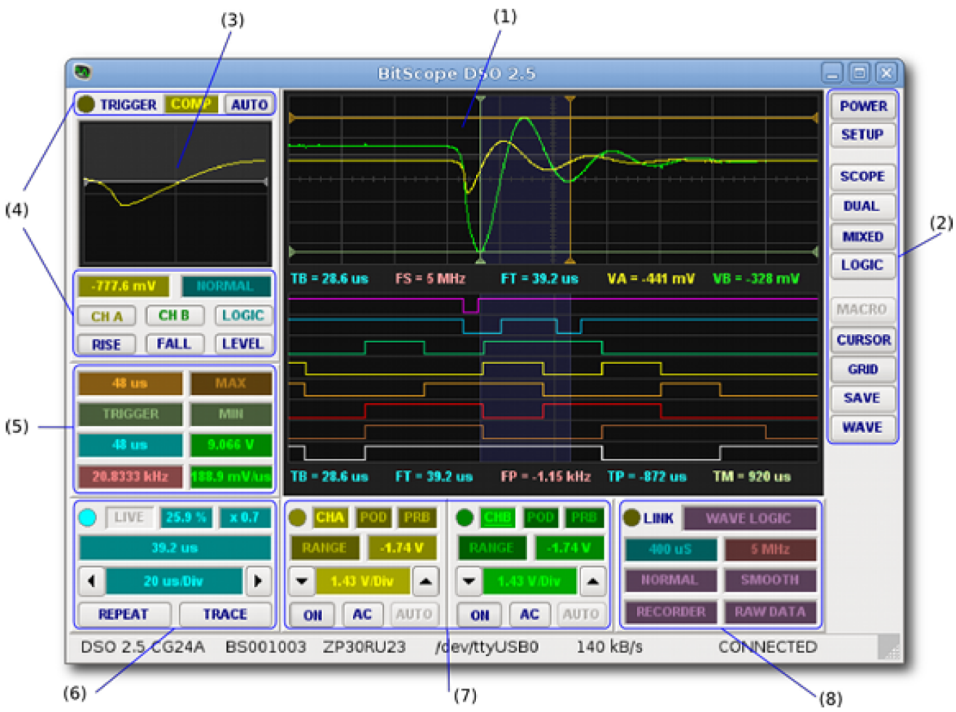
Do get your learning journal endorsed by your TA before the end of the studio session.

END OF STUDIO SESSION

CHALLENGE YOURSELF (Optional)

- Derive the expression for the gain, relating input voltage to the output voltage in an inverting amplifier.

APPENDIX: BITSCOPE DSO'S INTERFACE



ID	FEATURE	DESCRIPTION
(1)	Main Display	Waveform, logic and spectrum displays, measurements and cursors.
(2)	Scope Selectors	Virtual instruments, scope tools, presets, cursors, graticule etc.
(3)	Trigger Windows	Shows trigger levels, analog and logic waveforms at the trigger.
(4)	Trigger Controls	Controls trigger setup and displays trigger waveform and data.
(5)	Cursor Measurements	X and Y cursor values, voltage, time and rate measurements.
(6)	Timebase Control	Timebase, Zoom and Time Focus control parameters.
(7)	Channel Controls	Controls input source, range, vertical position and scaling.
(8)	Capture Control	Capture sample rate, duration, frame rate and display modes.