CG1111 Engineering Principles and Practice I

Op Amp circuits – Comparator and Active low pass filter

(Week 9, Studio 1)

Time	Duration (mins)	Activity
0:00	15	Briefing
0:15	60	Activity #1: Non-inverting comparator (graded lab report)
1:15	70	Activity #2: Active low pass filter (graded lab report - continued)
2:25	15	Final discussions and wrap-up

Introduction:

- An operational amplifier (op-amp) is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output
- The comparator is an electronic decision-making circuit that makes use of an operational amplifier's very high gain in its open-loop state, that is, there is no feedback resistor
- **The comparator is ideal to convert analog signals to digital signals at certain threshold values.**
- The difference between the two inputs is amplified as '*$A(V_+-V_-)$*' at the output. The open loop voltage gain ('*A*') of the op-amp is very high (ideally ∞)
- Even if there is a very small difference between the inputs, the high 'A' will pull the output to either $+V_{sat}$ or $-V_{sat}$
- If $V_+>V_-$ ➔ $V_{out}= +V_{sat}$ or V_{CC} (For ideal op-amp)
- If $V_->V_+$ ➔ $V_{out}= -V_{sat}$ or $-V_{CC}$ (For ideal op-amp)

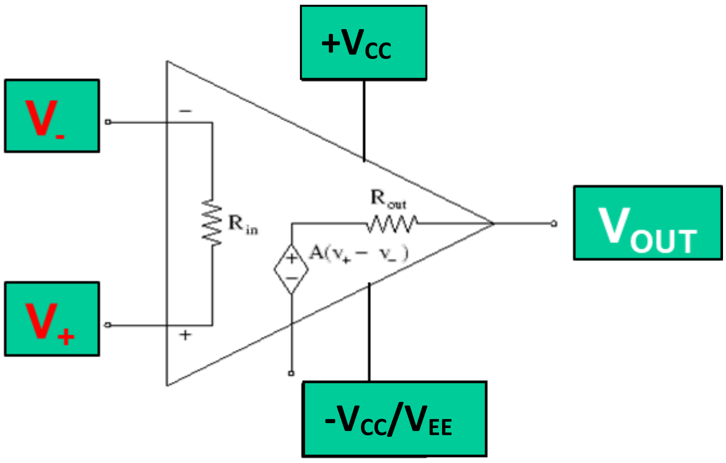

Figure 1: Operational amplifier as a comparator

- A filter is a device or process that removes some unwanted components or features from a signal.
- Frequency response is the quantitative measure of the output spectrum of a system or device in response to a stimulus and is used to characterize the dynamics of the system. It is a

measure of magnitude and phase of the output as a function of frequency, in comparison to the input.

- The Voltage Amplification (Av) or Gain of a voltage amplifier/filter is given by:

$$\boldsymbol{A_v = \frac{V_{out}}{V_{in}}}$$

- To describe a change in output power over the whole frequency range of the amplifier/filter, a response curve, plotted in decibels is used to show variations in output

$$\boldsymbol{Power\ (dB) = 20log_{10}\frac{V_{out}}{V_{in}}}$$

- The cut-off frequency of a low pass filter is given by

$$\boldsymbol{f_c = \frac{1}{2\pi RC}}$$

The pinout diagram of LM358 is given in Figure 2 below.

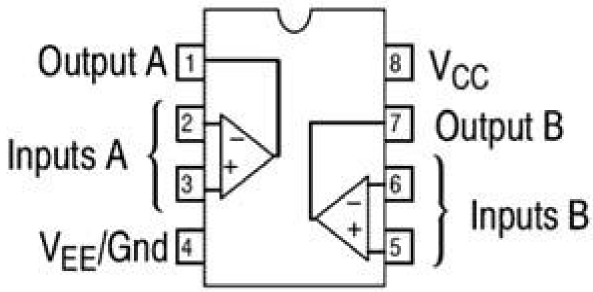

Figure 2: Pinout diagram of LM358

<u>Objectives</u>:

- To learn about the use of a comparator in converting analog signals to digital signals
- To analyse and plot the frequency response of a low-pass filter
- To calculate the cut-off frequency of a low-pass filter
- To understand and infer the frequency vs magnitude plot of a low-pass filter

<u>Materials</u>:

- LM358 Op amp chip
- Breadboard and connecting wires
- Digital multimeter
- Arduino Uno
- Bitscope
- Variable Resistor – 2kΩ
- Resistors
  - 390 kΩ
  - 1 kΩ x2
- 100 pF capacitor (Code - 101)

Setups:

A. Bitscope DSO Setup:

a) Ensure that the "GND" pins of the Bitscope are connected to the common ground terminal of the circuit.
b) In the "Channel Controls (7)" panel, change the voltage per division of "CHA" or "CHB" according to the setup requirements.
c) In the "Timebase Control (6)" panel, change the timebase according to the setup requirements.
d) Change the vertical position for both "CHA" and "CHB" to "Mean".
e) Connect "CHA" and the "AWG" pin to the $\boldsymbol{V_{in}}$ terminal in your circuit.
f) Connect "CHB" to the $\boldsymbol{V_{out}}$ terminal in your circuit. Ensure that you activate "CHB"

B. 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), select the type of waveform by right clicking it and selecting "TONE" (for **sinusoidal** waveform), "RAMP" (for **triangular** waveform) or "STEP" (for **square** waveform)
d) For adjusting the frequency, left click on it and drag its value upward or downward to the desired value.
e) For the peak-to-peak voltage, left click on it and drag its value upward or downward to the desired value.
f) 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.
g) Connect your "AWG" pin to "CHA" and observe the waveform. The "AWG" pin is the output of your waveform generator.

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. **Do not connect the Arduino to the same laptop/PC as the Bitscope and/or the USB breakout Cable**

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 and also your circuit's common ground.

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. Be sure to periodically check and switch on the power bank if needed.

D. 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, click on "CHA"(or "CHB") 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 "CHA" (or "CHB") is now shown in the yellow box directly underneath the dirty-green box.

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

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Activity #1: Non-inverting comparator (60 mins)

In this activity, we will be constructing a non-inverting comparator using the LM358 chip. In this configuration, the input signal is connected to the non-inverting (or positive) input pin and the reference signal is connected to the inverting (or negative) input pin.

Procedure:

1. Fill in the **theoretical** output voltage values for the following combinations of input and reference voltage levels, assuming an ideal op amp. A single power supply of +5V is provided to the op amp.

Table 1

S. No	V_{in}	V_{ref}	V_{out}
1	+2.5 V	0 V	
2	+3.5 V	+3.75 V	
3	+1.25 V	−0.5 V	
4	−3 V	−1 V	
5	−2.5 V	+2.5 V	

2. How would the output voltage values change if a dual power supply of +5V and –5V is provided to the op amp?
3. The input voltage (V_{in}) is generated from Bitscope using the frequency generator. Configure the input voltage (V_{in}) as described in **Setups: B. Waveform Generator Setup** with the following settings:
   - Type: "RAMP" (Triangular Waveform)
   - Frequency: 1 kHz
   - Peak to Peak Voltage: 3.3 V
   - DC Offset: 0 V

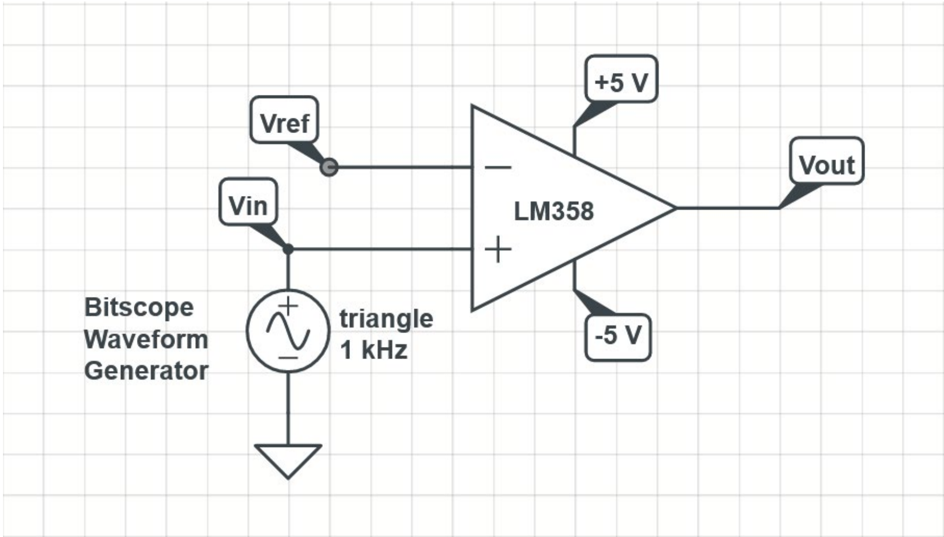


Figure 3: Non-inverting Comparator

4. Construct the circuit given in Figure 3 on the breadboard. Refer to the pinout diagram of the LM358 chip (Figure 2) while making the connections. You can choose to use either one of the op-amps (A or B) for your circuit.
5. Use the dual power setup described above (**Setups: D. 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. The "GND" terminal of the Dual Power Supply Setup is the ground terminal of the circuit
6. Design the reference voltage (**Vref**) to be around 1.6V. You can use a voltage divider circuit as shown in Figure 4. Connect the **Vref** terminal of Figure 4 to the **Vref** terminal of Figure 3. (Hint: Use a variable resistor as R2 to get your desired **Vref**)

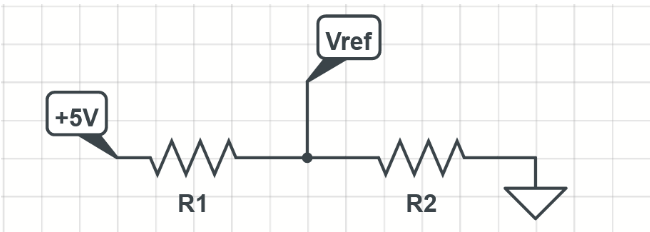


Figure 4: A Voltage Divider Circuit

7. Connect "CHA" and "AWG" from the Bitscope to the V_{in} and "CHB" to the V_{out} in Figure 3. Remember to connect the "GND" terminals of "CHA" and "CHB" to the "GND" terminal of the circuit.
8. Configure "CHA" and "CHB" as described in **Setups: A. Bitscope DSO Setup** with the following settings:
   - Voltage Per Division ("CHA" and "CHB"): 1 V/div
   - Timebase: 500 µs/div
9. What type of waveform do you observe at the output? Does it tally with your expectation for the output? Explain.
10. Observe the output for reference voltages of "0.7V" and "2.5V". Save the screenshots for all three configurations (that are **Vref** = 1.6V, 0.7V, 2.5V).
11. How does the output waveform vary with the change in the reference voltage?

Activity #2: Active low pass filter (70 mins)

In this activity, we will be building an active low pass filter that uses an RC network and test it. The circuit diagram is given below in Figure 5.

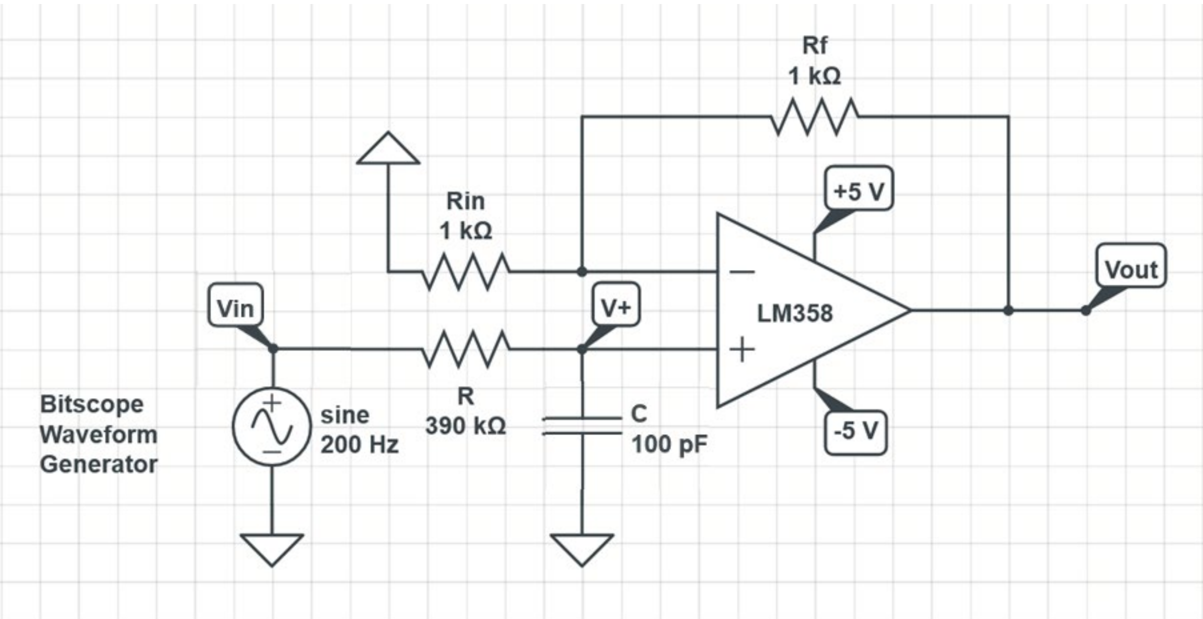


Figure 5: Active Low Pass Filter

Procedure:

1. What is the voltage gain expression (V_{out}/V_{+}) for this op amp circuit? Calculate the value of the gain given the resistance values.
2. Construct the circuit given in Figure 5 on the breadboard. Refer to the pinout diagram of the LM358 chip (Figure 2) while making the connections. You can choose to use either one of the op-amps (A or B) for your circuit.
3. Use the dual power setup described above (**Setups: D. 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. The "GND" terminal of the Dual Power Supply Setup is the ground terminal of the circuit

4. The input voltage (V_{in}) is generated from Bitscope using the frequency generator. Configure the input voltage (V_{in}) as described in **Setups: B. Waveform Generator Setup** with the following settings:
    - Type: "TONE" (Sinusoidal Waveform)
    - Frequency: 200 Hz (The frequency will be varied according to Table 2)
    - Peak to Peak Voltage: 1.6 V
    - DC Offset: 0 V

    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 $\boldsymbol{V_{in}}$ and "CHB" to the $\boldsymbol{V_{out}}$ in Figure 5. Remember to connect the "GND" terminals of "CHA" and "CHB" to the "GND" terminal of the circuit.
6. Configure "CHA" and "CHB" as described in **Setups: A. Bitscope DSO Setup** with the following settings:
    - Voltage Per Division ("CHA" and "CHB"): 500 mV/div
    - Timebase: 2ms/div
    - Note: The Timebase needs to be readjusted as we vary the frequency later according to Table 2.
7. Measure the peak-to-peak voltage for "CHB" as described in **Setups D. Measurements using Bitscope** in the output voltage (V_{out})column of Table 2.
8. Calculate the gain in dB

$$\textbf{Gain in dB} = 20 \log_{10}(V_{out}/V_{in})$$

9. Repeat steps 4 to 8 for the various frequencies listed in Table 2 and tabulate the results.

Table 2

S. No	Frequency (Hz)	V_{in} (V)	V_{out} (V)	Gain (V_{out}/V_{in})	Gain in dB
1	200				
2	500				
3	1000				
4	1500				
5	2000				
6	3000				
7	5000				
8	10k				
9	20k				
10	50k				

10. Plot *gain in dB* vs *frequency* in excel. Set the x-axis scale to be logarithmic, by right clicking on the 'x-axis' values in the plot and choosing the "logarithmic" scale option in the new window.

11. The cut-off frequency is defined as the frequency where the voltage gain (V_{out}/V_{in}) is reduced to 0.707 times the maximum gain (Gain calculated in Step 1). In other words, at the cut-off frequency, the gain is down by 3 dB. Determine the cut-off frequency from your excel plot.
12. Compare it with the theoretical value obtained using

$$f_c = \frac{1}{2\pi RC}$$

13. What value of capacitor would you use if a cut-off frequency of about 2 kHz is required? Assume that R remains unchanged.

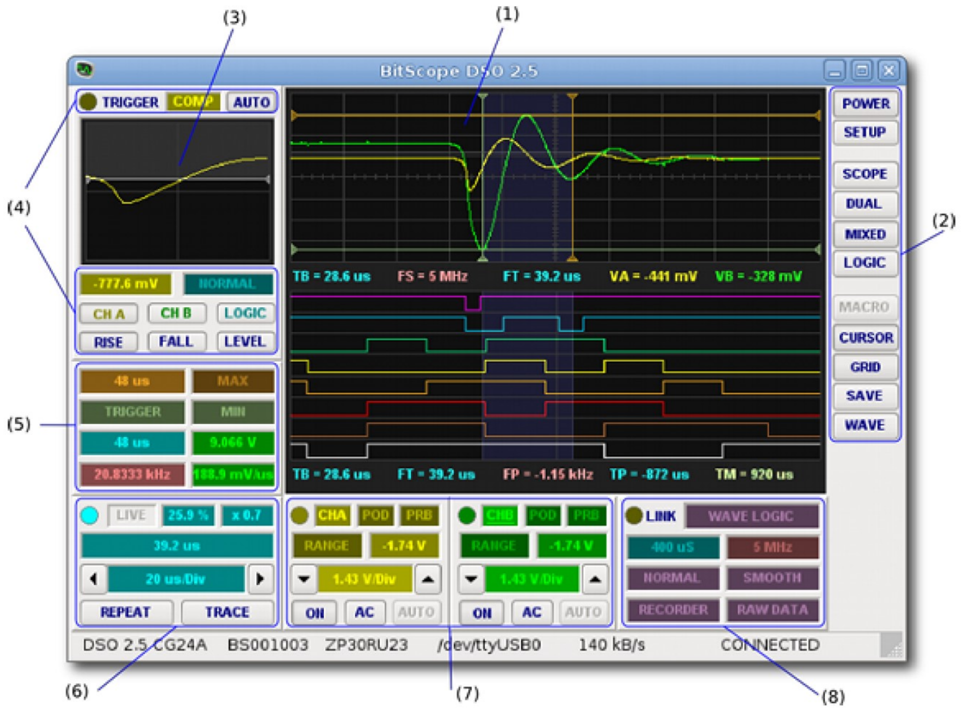
Please feel free to ask your TA or the Instructors any questions or doubts you may have.

END OF STUDIO SESSION

CHALLENGE YOURSELF (Optional)

1. How would the output of an inverting comparator differ from that of a non-inverting comparator?
2. How would you design an active high pass filter using op amp?
3. Derive the gain expression Gain in dB = 20 $\log_{10}$ (V_{out}/V_{in})

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.