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# Applications of Operational Amplifiers

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## III. Objectives:

The primary objectives of this experiment are threefold. First, we aim to gain an understanding of how resonant circuits can be utilized to create band-pass and band-reject filters. Second, we seek to develop experience in measuring the frequency response of a simple network, which will enhance our ability to analyze and design filters. Lastly, we intend to familiarize ourselves with the laboratory layout and equipment, ensuring a solid foundation for future experiments in the field of electronics. Through the exploration of active band-pass filters, comparators, and Schmitt triggers, we expect to build a strong foundation in operational amplifier applications, enriching our knowledge and skill set in electronics.

## IV. Equipment Used:

- Breadboard
- Various Electronic Components
- Power supply
- Function generator
- Oscilloscope
- Multi-Meter

## V. Preliminary Calculations:

In the preliminary phase of this experiment, we focused on designing an op-amp band-pass filter using the provided design criteria, which included a center frequency of 2 kHz, a bandwidth of 200 Hz, and a center frequency gain of 10. We began by selecting a non-polarized capacitor with a capacitance value of 4.7 nF. Next, we calculated the required resistor values, obtaining R2 as 338.63 kOhms, R1 as 16.93 kOhms, and R3 as 891.13 Ohms. These calculations ensure that our filter design adheres to the specified criteria and performs as expected during the experiment. The full calculations and design process can be found in **Appendix 1** at the end of the lab report, providing a comprehensive understanding of the steps taken to reach the final component values.

## VI. Procedure/Result/Analysis:

### 01. Procedure:

1. Recalculate the actual center frequency, bandwidth, and gain using the closest available component values in the lab.
2. Breadboard the circuit shown in **Figure 1** using the chosen components, a +12 V supply, and a 741 op-amp.
3. Set RL to 3.3 k and check the op-amp pin assignments with the data sheet or lab instructor.
4. Connect the signal generator and oscilloscope to measure the circuit's center frequency, 3 dB point frequencies (bandwidth), and gain at the center frequency. Compare the measured values with the calculated ones and explain any major differences.
5. Change R3 to lower the center frequency from 2 kHz to 1 kHz, then repeat the measurements from step 4. Compare these results with the calculated values and discuss any differences.
6. Compare the advantages of this band-pass filter with the LC filter designed in Experiment 1 (Resonant Circuits).
7. Breadboard the non-inverting comparator shown in **Figure 4**, setting VREF = 0 (ground) and the power supplies to +12 volts.

8. Connect the signal generator output to the oscilloscope and set the output to a 1 Vp-p and 1 kHz sine wave. Use a BNC Tee connector to display the sine wave on the oscilloscope while applying it to the input of the circuit.
9. Connect the output of the circuit to another channel on the oscilloscope, apply power, and observe the output waveform.
10. Turn off the power, change the circuit to that of **Figure 5**, and observe the output state change using the oscilloscope.
11. Construct the Schmitt trigger circuit of **Figure 6** and observe its clean switching behavior using the input potentiometer.

**02. Experiment:**

a. In Part A of our experiment, we started by constructing the active band-pass filter circuit as shown in **Figure 1**. We used the closest available component values in the lab to build the circuit, and connected it to a +12 V supply and a 741 op-amp. We set RL to 3.3 k and checked the op-amp pin assignments with the data sheet and lab instructor. After completing the circuit assembly, we connected the signal generator and oscilloscope to measure the circuit's center frequency of 1889 Hz, 3 dB point frequencies (bandwidth) of 200 Hz, and gain at the center frequency to be approximately 9.6V. The output waveform can be observed below within **Figure 2**. Next, we changed R3 in the circuit to lower the center frequency from 2 kHz to 1 kHz. We repeated the measurements, the circuit's center frequency of 970 Hz, 3 dB point frequencies (bandwidth) of 100 Hz, and gain at the center frequency to be approximately 10V, this output is shown in **Figure 3** below.

**Q1:** When comparing our measured values with our calculated values, we found some minor differences. The center frequency was slightly lower than expected (1,889 Hz instead of 2 kHz), and the gain at the center frequency was slightly less than calculated (9.6 V instead of 10 V). These differences can be attributed to the tolerances of the components used, as well as possible non-idealities in the op-amp.
**Q2:** After changing R3 to lower the center frequency to 1 kHz, our measurements showed a center frequency of 970 Hz, a bandwidth of 100 Hz, and a gain at the center frequency of approximately 10 V. These values are close to our calculated values, again considering component tolerances and op-amp non-idealities.
**Q3:** The advantages of the active band-pass filter compared to the LC filter, as designed in Experiment 1 (Resonant Circuits), include the ability to adjust the center frequency and gain by changing only resistor values, rather than needing to change inductor or capacitor values. Additionally, active filters can provide gain, whereas passive LC filters can only attenuate signals. Active filters also tend to have better stability and control over the filter characteristics compared to passive filters. However, it is important to note that active filters require a power supply and can introduce noise and distortion due to the op-amp, while passive filters do not have these drawbacks.

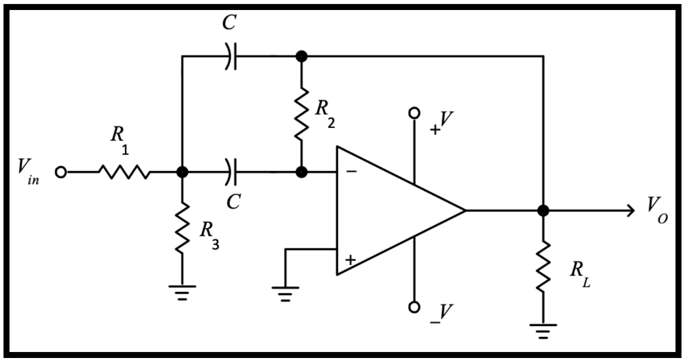


***Figure 1: Active Band-Pass Filter Circuit***

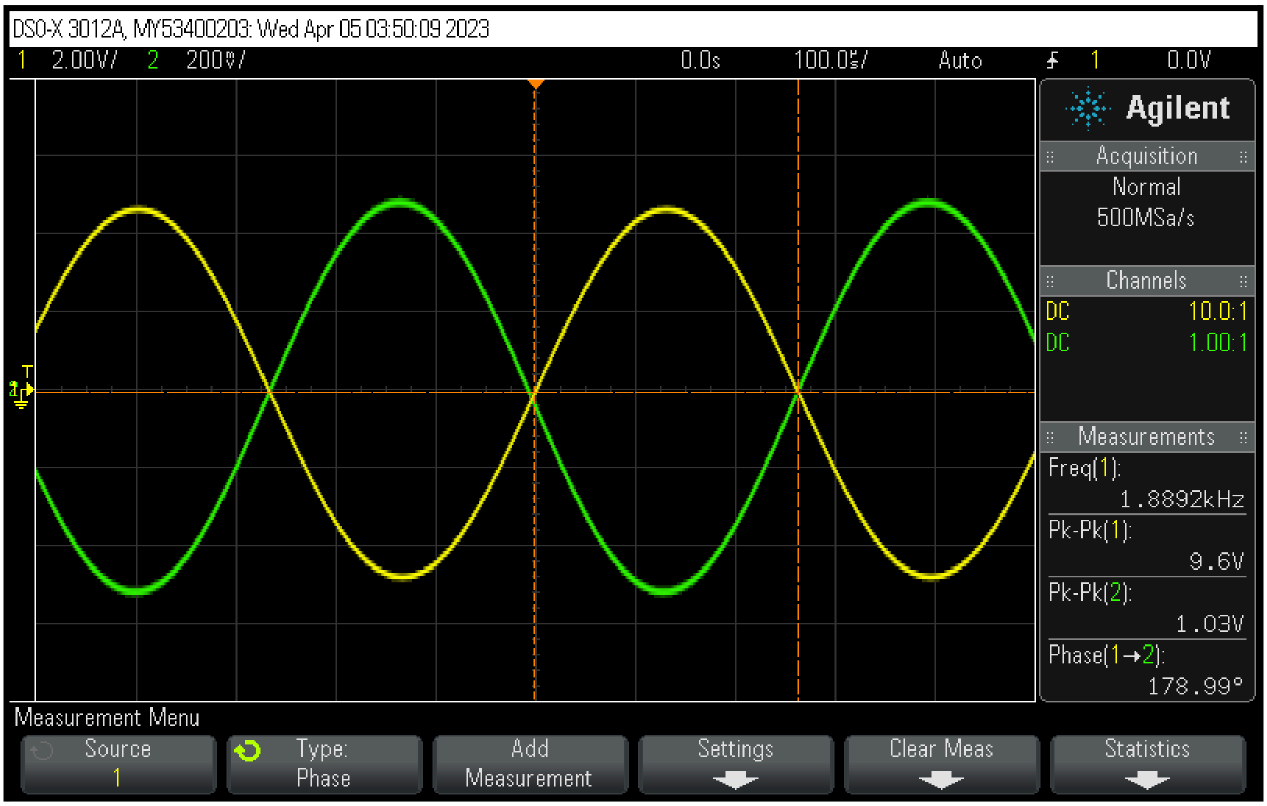


***Figure 2: f0=2000 Hz output***

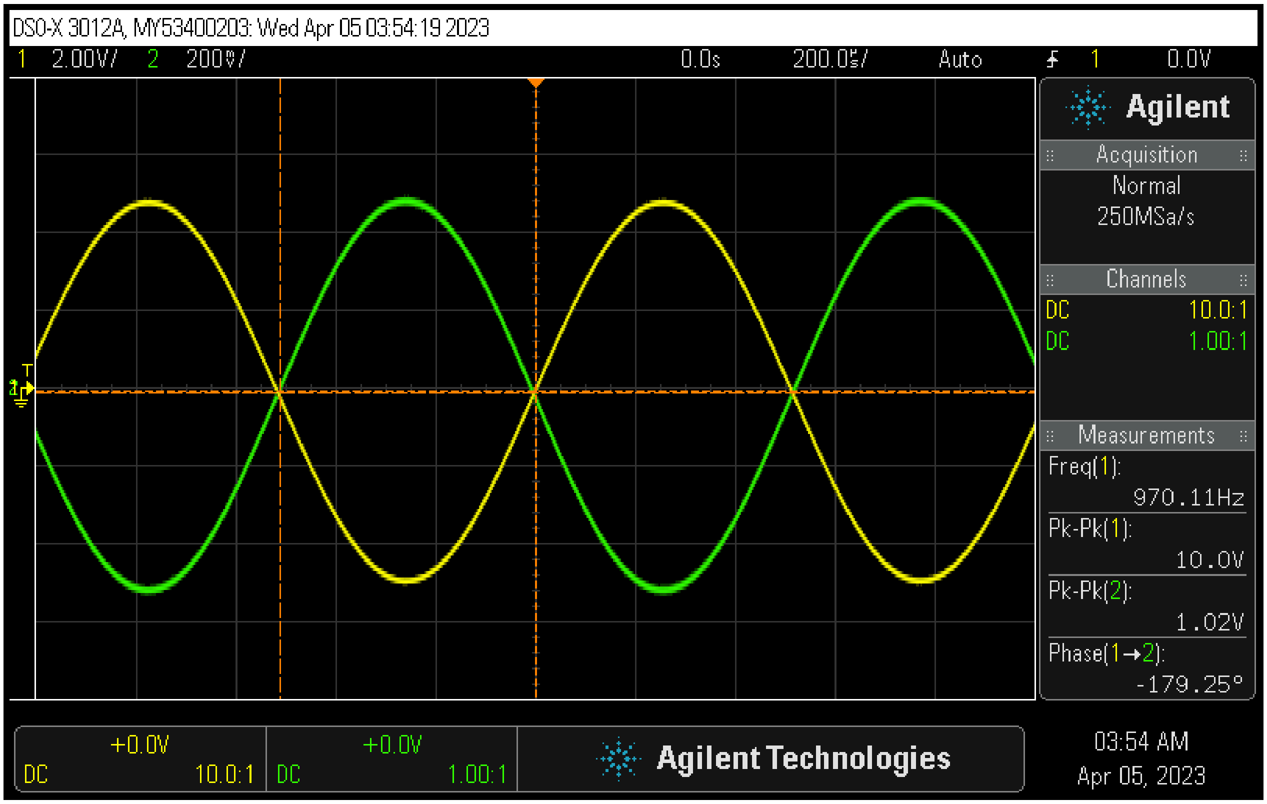


*Figure 3: f0=1000 Hz output*

b. In Part B of our experiment, we began by constructing the non-inverting comparator circuit as shown in **Figure 4**. We set VREF to 0 (ground) and connected the power supplies to +12 volts. We connected the signal generator output to the oscilloscope, setting it to a 1 kHz sine wave with 1 Vp-p amplitude, and used a BNC Tee connector to monitor the sine wave on the oscilloscope while applying it to the input of the circuit. Next, we connected the output of the circuit to another channel on the oscilloscope and powered the circuit. We observed an in-phase quasi-square wave at the output, as shown in **Figure 7**. We then turned off the power and changed the circuit to the non-inverting comparator test circuit presented in **Figure 5**. After turning on the power again, we slowly adjusted the input potentiometer while observing the output state change with the oscilloscope. The outputs of the non-inverting comparator test circuit can be seen in **Figures 8 and 9**. Finally, with the power off, we constructed the inverting Schmitt Trigger test circuit shown in **Figure 6**. We used the input potentiometer to adjust the input voltage while monitoring the output on the oscilloscope. We observed clean switching, as shown in **Figure 10**. This concluded Part B of our experiment, where we explored the behavior of different comparator configurations and the Schmitt Trigger circuit.

**Q4:** Yes, we observed erratic behavior in the non-inverting comparator test circuit when we adjusted the input potentiometer. The output appeared to rapidly swap between positive and negative voltage levels, which can be problematic in certain applications.

**Q5:** After slightly changing the input voltage using the potentiometer in the inverting Schmitt Trigger test circuit, we measured the values of VTT+ and VTT-. These values can be observed in **Figures 8 and 9**, where VTT+ is approximately +10.7 V and VTT- is approximately -10.7 V. This indicates that the hysteresis of the Schmitt Trigger circuit provides a stable switching behavior compared to the non-inverting comparator test circuit.

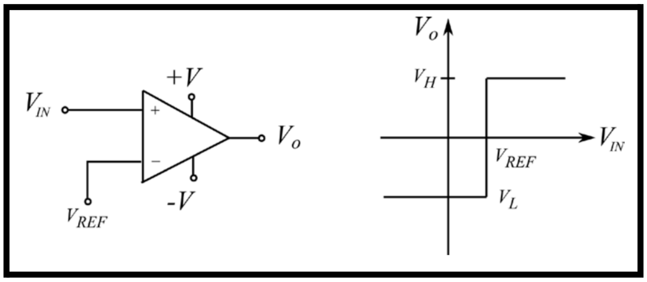


***Figure 4: The non-inverting comparator***

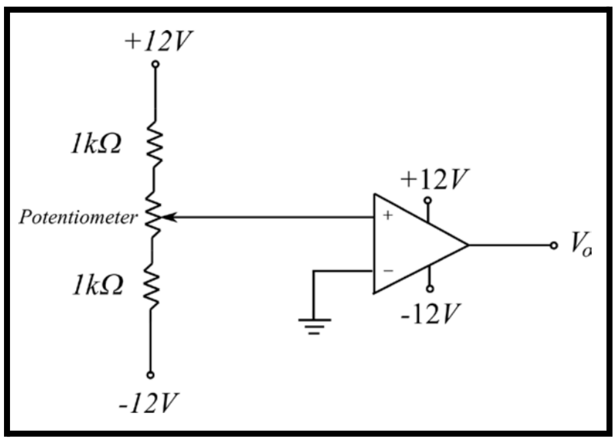


***Figure 5: Non Inverting comparator test circuit***

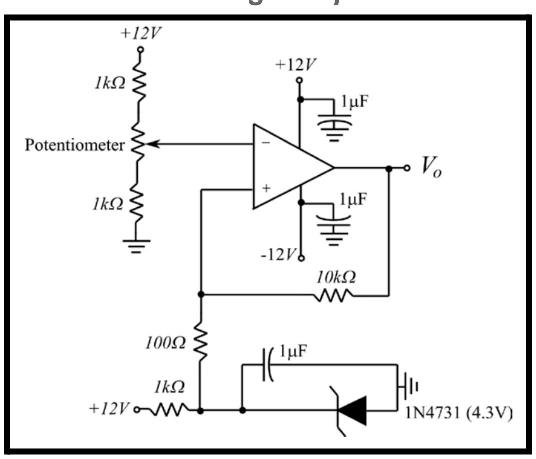


***Figure 6: Inverting Schmitt Trigger test circuit.***

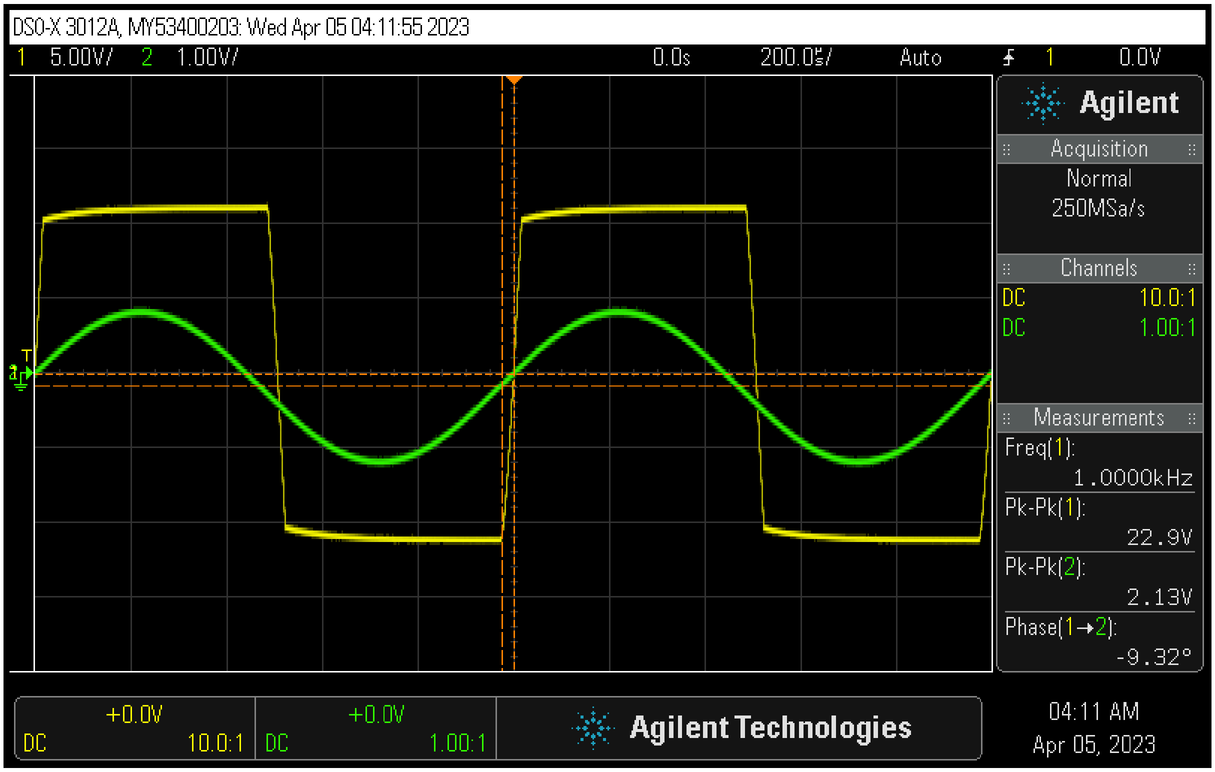


*Figure 7: The non-inverting comparator Output*

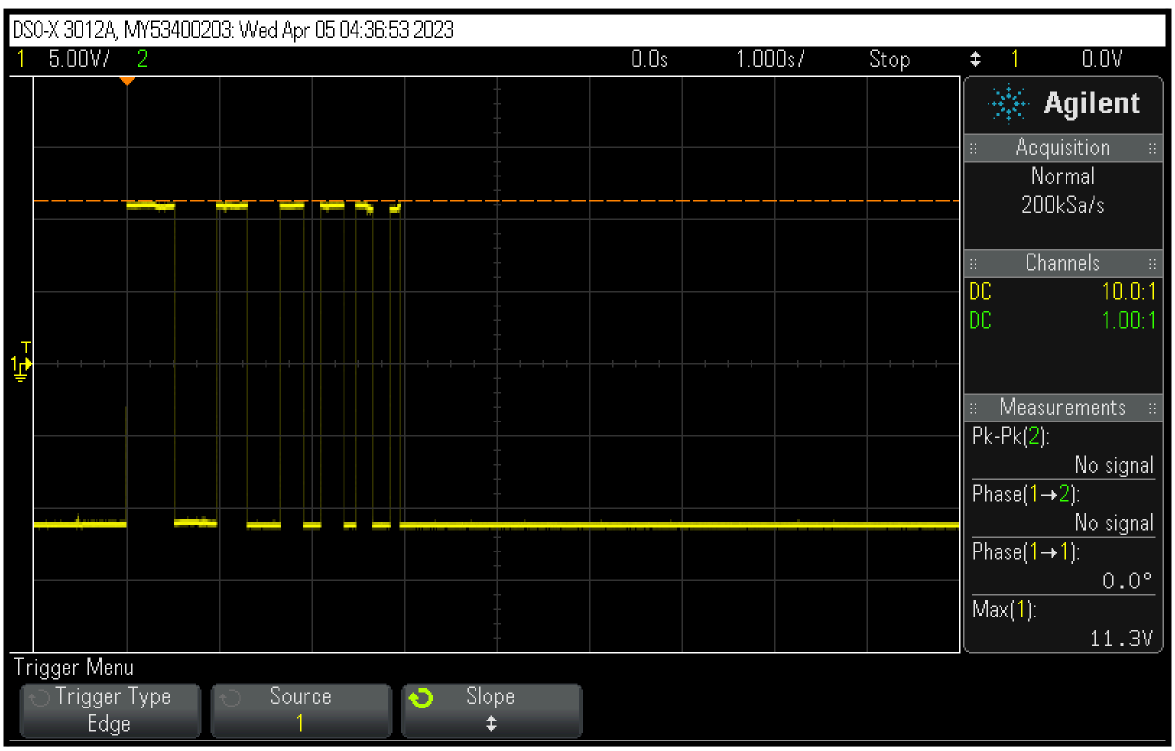


*Figure 8: Non Inverting comparator Output 1*

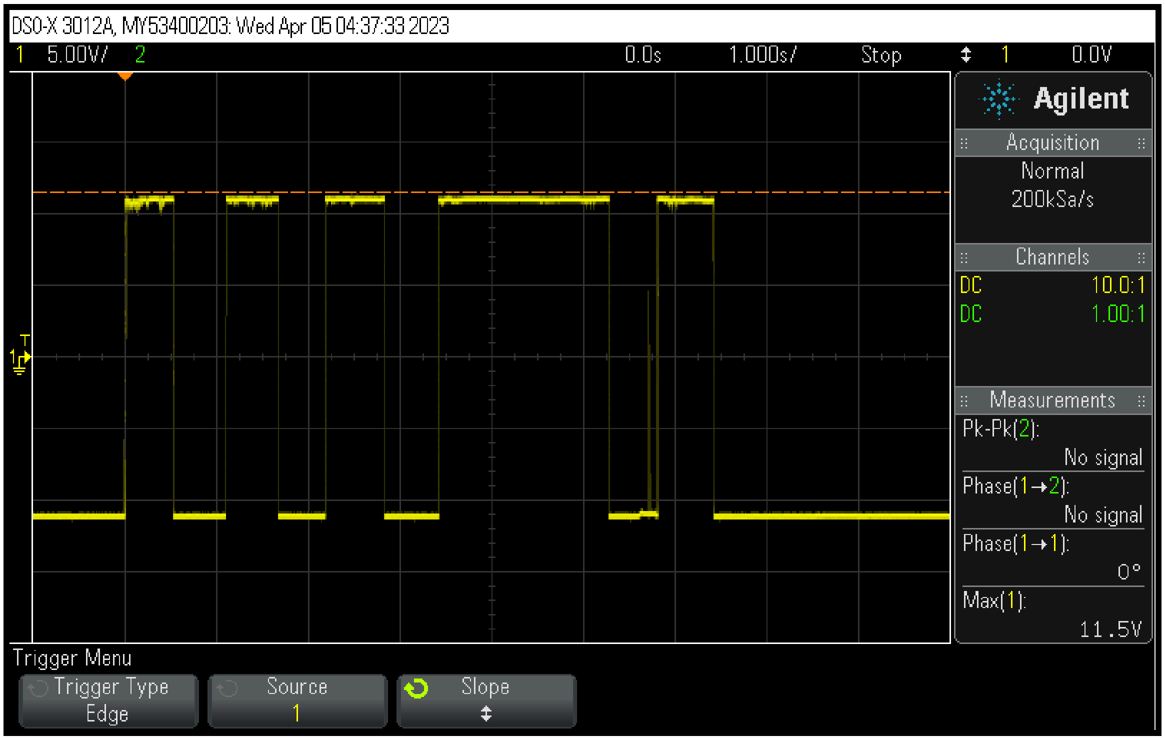


*Figure 9: Non Inverting comparator Output 2*

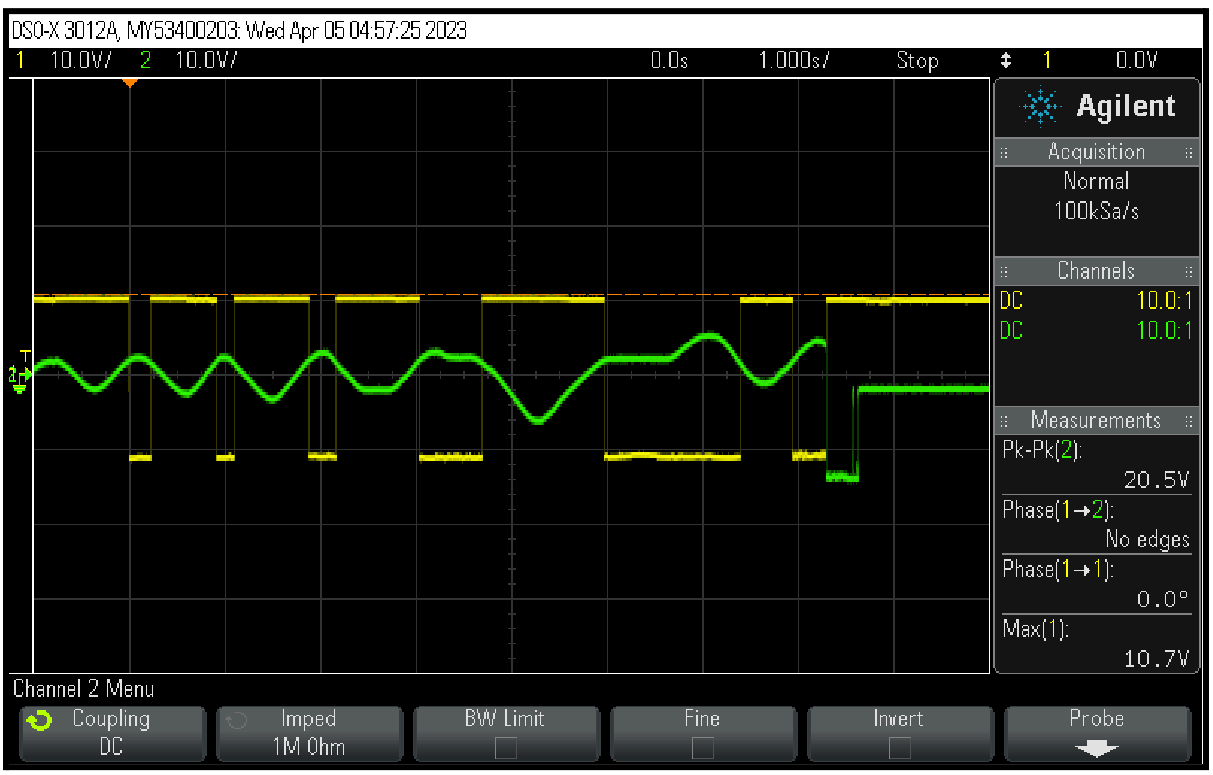


*Figure 10: Inverting Schmitt Trigger Output*

## VII. Conclusion:

In conclusion, throughout this experiment, we explored the applications of operational amplifiers in various circuits, such as active band-pass filters, comparators, and Schmitt triggers. We successfully designed and constructed an op-amp based active band-pass filter and analyzed its performance by measuring the center frequency, bandwidth, and gain. We also investigated the differences between LC filters and op-amp-based active filters, highlighting the advantages of the latter in terms of tunability and simplicity. Furthermore, we built and tested both non-inverting comparator and Schmitt trigger circuits, examining their behavior and comparing their stability under varying input conditions. We observed erratic behavior in the non-inverting comparator test circuit, while the Schmitt trigger circuit exhibited stable switching performance due to the presence of hysteresis. This experiment has provided valuable insights into the practical implementation of operational amplifiers in various applications and allowed us to gain hands-on experience in working with these circuits.

## VIII. References:

Not applicable

## IX. Appendix:

### Appendix 1:

$$BW = \frac{1}{C\pi R_2}$$

$$R_2 = \frac{1}{C\pi BW} = \frac{1}{\pi(4.7E-6)(200)} = 338.63\ K\Omega$$

$$R_1 = \frac{R_2}{2A_V} = \frac{(338.63\ K\Omega)}{2(10)} = 16.93\ K\Omega$$

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{R_1+R_3}{C^2 R_1 R_2 R_3}}$$

$$R_3 = 891.13\ \Omega$$