# Circuits and Systems 2CJ4
Lab 2

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**Set 2 Laboratory Experiment**

I. From the background section, explain why we increase or decrease $v_{in}(t)$ such that $V_{th2}$ < $V_{in}(t)$ < $V_{th2}$ the output remains the same.

The output remains unchanged irrespective of whether Vin is increased or decreased, because of the Vgap otherwise known as the hysteresis gap. Vgap is defined as Vthl-Vth2 when Vin(t)<Vth2 or Vin(t) > Vth1 (not corresponding to the stated case in the question). When the output switches from either the positive or negative saturated state, it reinforces the state which makes it less sensitive to small fluctuations in the Vin.When Vgap exceeds the peak-to-peak amplitude of the noise, the output remains unaffected, demonstrating effective noise immunity.

II. Given the circuit from Figure 2 in the example section, fill in the following table using Vref = 0V, 2V, R1 = 4.7 kΩ, 22 kΩ and R2 = 4.7 kΩ (assuming Vsat+ =5V and Vsat_ =-5V). Include one sample calculation for any row.

| Vref, R1,R2 | Vth1 (theoretical) | Vth2 (theoretical) | Vgap (theoretical) |
|---|---|---|---|
| (0V,4.7 kΩ, 4.7 kΩ) | 2.5 | -2.5 | 5 |
| (0V, 22 kΩ, 4.7 kΩ) | 0.88 | -0.88 | 1.76 |
| (2V,4.7 kΩ, 4.7 kΩ) | 3.5 | -1.5 | 5 |
| (2V, 22 kΩ, 4.7 kΩ) | 2.528 | 0.7677 | 1.76 |

*Table 1: Theoretical Values for Vth1, Vth2, Vgap*

Sample Calculations:

For 0V, 4.7kΩ, 4.7kΩ

**Calculation for $V_{th1}$**

$$V_{th1} = V_{sat+}\left(R_2/(R_1+R_2)\right) + \left(V_{ref}R_2/(R_1+R_2)\right)$$

$$V_{th1} = 5\left(4.7/(4.7+4.7)\right) + \left(0V \times 4.7/(4.7+4.7)\right)$$

$$V_{th1} = 2.5 + 0$$

$$V_{th1} = 2.5V$$

**Calculation for $V_{th2}$**

$$V_{th2} = V_{sat-}\left(R_2/(R_1+R_2)\right) + \left(V_{ref}R_2/(R_1+R_2)\right)$$

$$V_{th2} = -5\left(4.7/(4.7+4.7)\right) + \left(0V \times 4.7/(4.7+4.7)\right)$$

$$V_{th2} = -2.5 + 0$$

$$V_{th2} = -2.5V$$

**Calculation for $V_{gap}$**

$$V_{gap} = V_{th1} - V_{th2}$$

$$V_{gap} = 2.5 - (-2.5)$$

$$V_{gap} = 5V$$

*Figure 1: Sample Calculations for 0V, 4.7kΩ, 4,7kΩ*

III. Measure the actual Vth1, Vth2, and Vgap by building the circuits with vi(t) being a sine wave, square wave, or a triangular wave of amplitude 5V with a 0V offset and filling in the values in the following table. Include the resulting waveforms as well as circuits. (Hint: you will need to analyze the circuit if Vref is a value that is not zero)

| Vref, R1,R2 | Vth1 (measured) | Vth2 (measured) | Vgap (measured) |
|---|---|---|---|
| (0V,4.7 kΩ, 4.7 kΩ) | 2.0676 | -2.50328 | 4.57 |
| (0V, 22 kΩ, 4.7 kΩ) | 0.969305 | -1.24733 | 2.216 |
| (2V,4.7 kΩ, 4.7 kΩ) | 3.52911 | -2.076696 | 5.605 |
| (2V, 22 kΩ, 4.7 kΩ) | 2.2857 | -0.5886 | 2.8743 |

*Table 2: Measured Values for Vth1, Vth2, Vgap*

**Vref = 0V, R1 = 4.7KΩ and R2 4.7KΩ.**

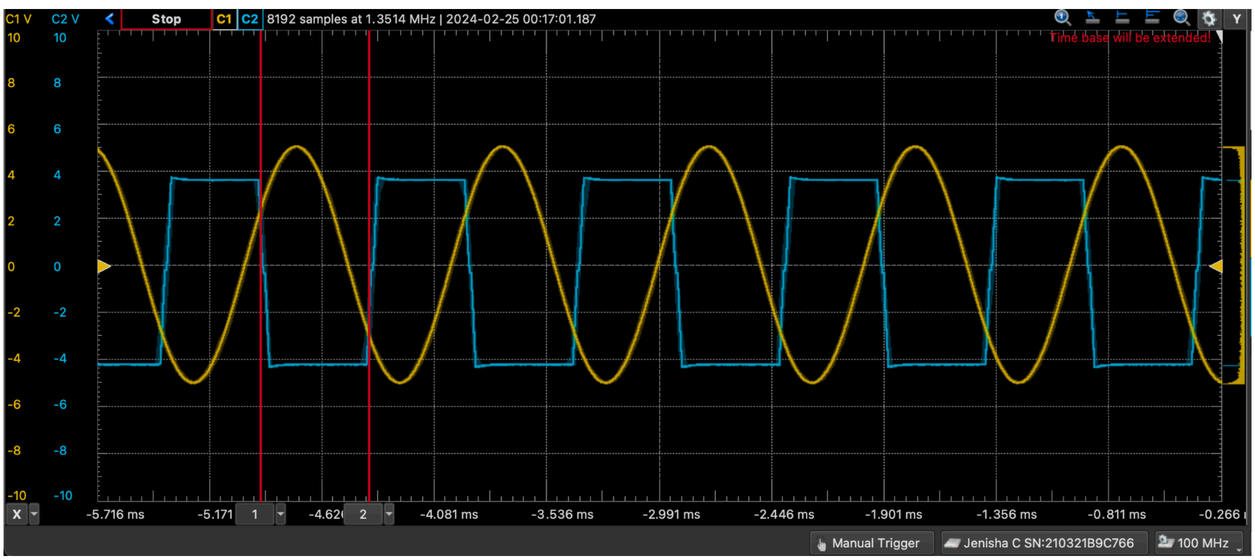



*Figure 2: Waveform for Vref = 0V, R1 = 4.7K and R2 4.7K.*

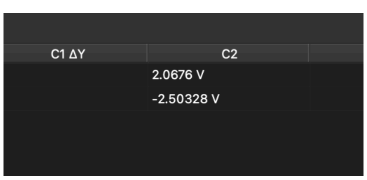



*Figure 3: Cursor values for Vref = 0V, R1 = 4.7K and R2 4.7K.*

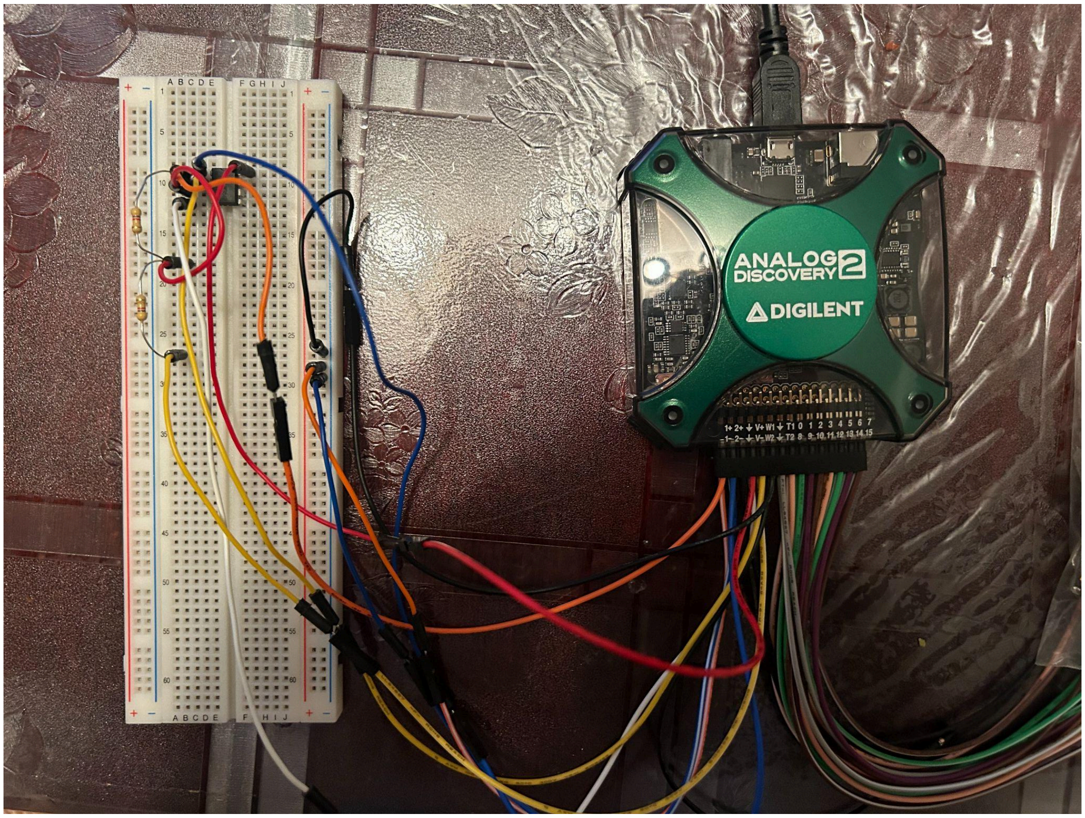



*Figure 4: Circuit Configuration for Vref = 0V, R1 = 4.7K and R2 4.7K.*

## Vref = 0V, R1 = 22KΩ and R2 4.7KΩ.

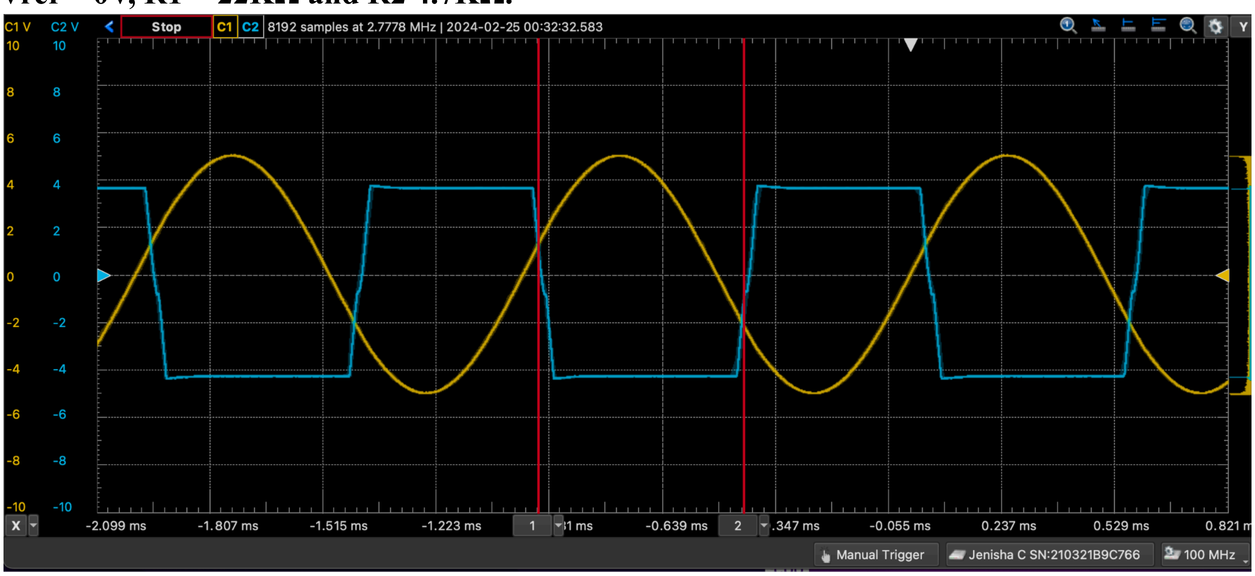



*Figure 5: Waveform for Vref = 0V, R1 = 22K and R2 4.7K.*


*Figure 6: Cursor values for Vref = 0V, R1 = 22K and R2 4.7K.*

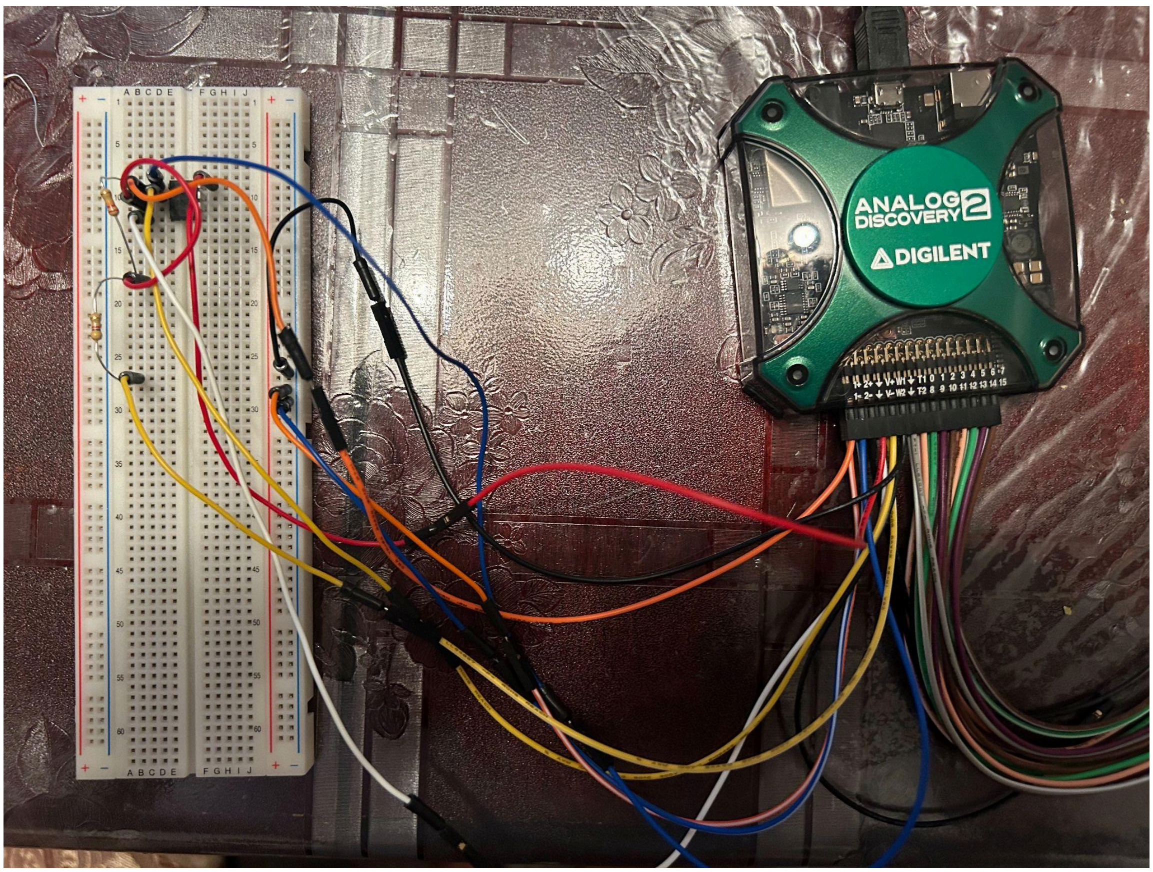


*Figure 7: Circuit Configuration for Vref = 0V, R1 = 22K and R2 4.7K.*

**Vref = 2V, R1 = 4.7KΩ and R2 4.7KΩ.**

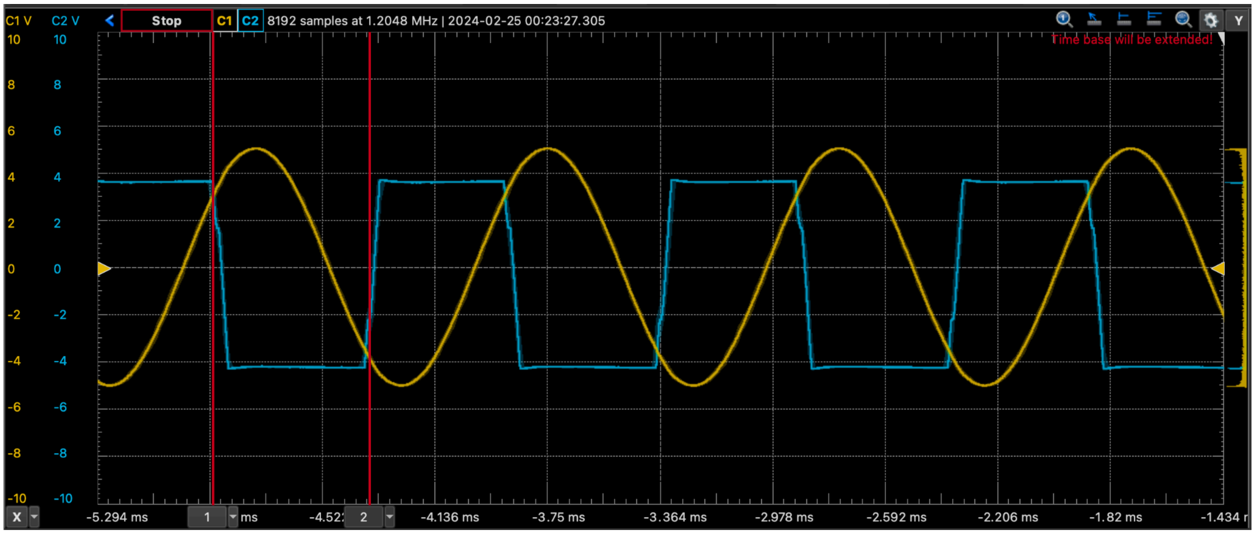



*Figure 8: Waveform for Vref = 2V, R1 = 4.7K and R2 4.7K.*

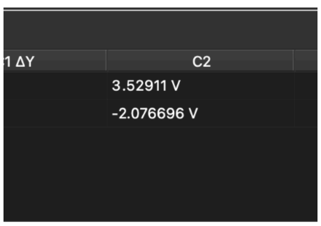



*Figure 9: Cursor values for Vref = 2V, R1 = 4.7K and R2 4.7K.*

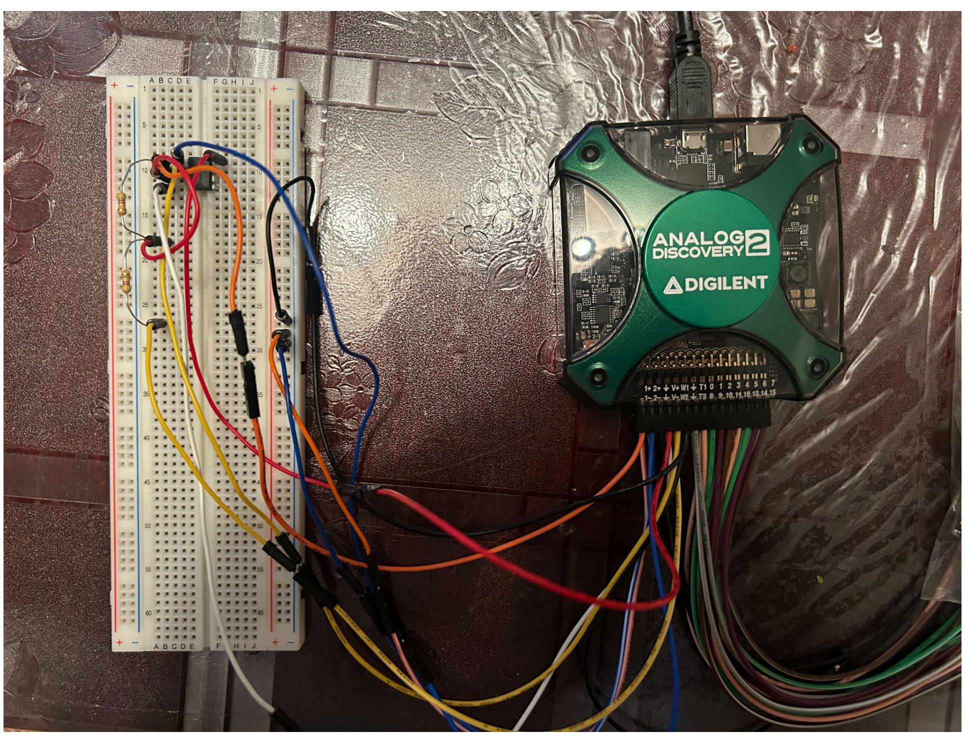


*Figure 10: Circuit Configuration for Vref = 2V, R1 = 4.7K and R2 4.7K.*

**Vref = 2V, R1 = 22KΩ and R2 4.7KΩ.**

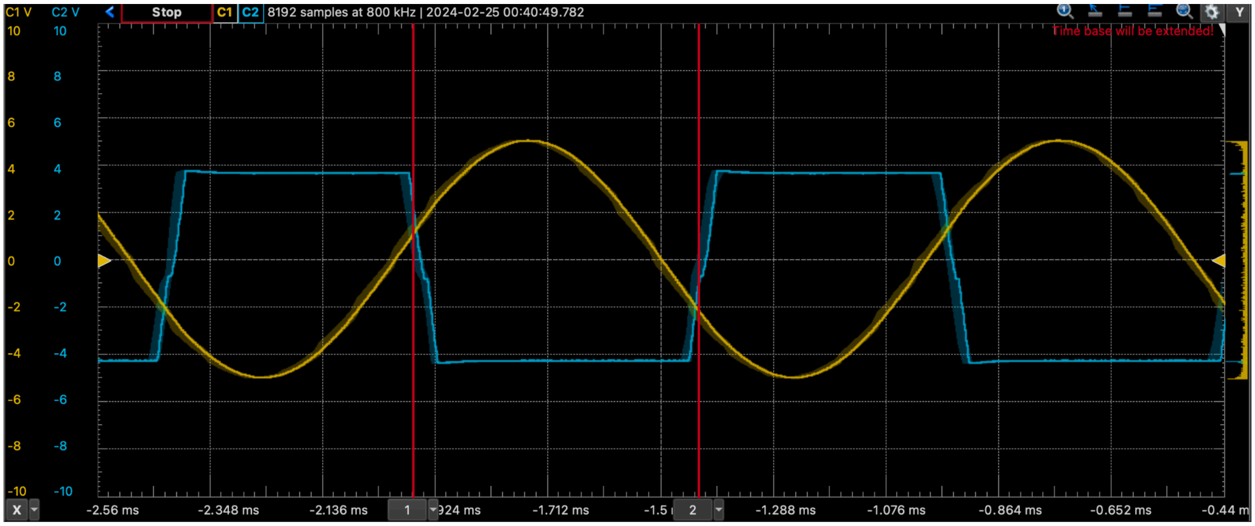
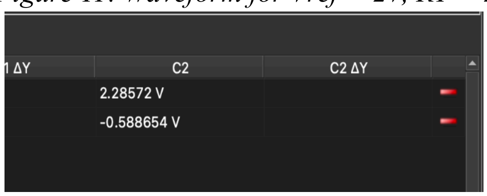



*Figure 11: Waveform for Vref = 2V, R1 = 22K and R2 4.7K.*



| 1 ΔY | C2 | C2 ΔY |
|---|---|---|
| | 2.28572 V | |
| | -0.588654 V | |

*Figure 12: Cursor values for Vref = 2V, R1 = 22K and R2 4.7K.*

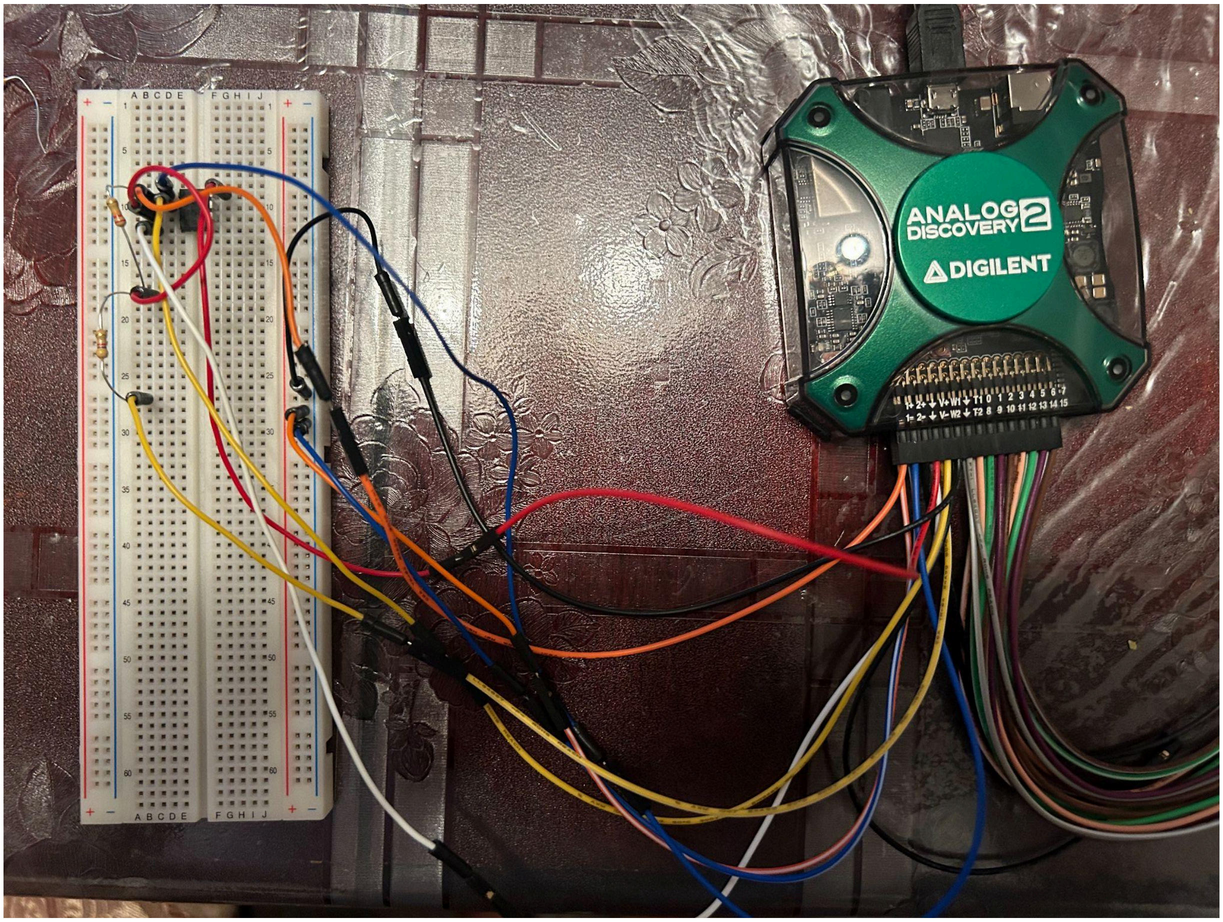



*Figure 13: Circuit Configuration for Vref = 2V, R1 = 22K and R2 4.7K.*

IV. What is the percentage difference between the calculated and measured voltages?

| Vref, R1,R2 | Percent Difference (Theoretical vs Measured Vth1) | Percent Difference (Theoretical vs Measured Vth2) | Percent Difference (Theoretical vs Measured VGap) |
|---|---|---|---|
| (0V,4.7 kΩ, 4.7 kΩ) | 18.9334% | 0.128637% | 8.98642% |
| (0V, 22 kΩ, 4.7 kΩ) | 9.65822% | 34.5344% | 22.9376% |
| (2V,4.7 kΩ, 4.7 kΩ) | 0.82827% | 32.2474% | 11.4097% |
| (2V, 22 kΩ, 4.7 kΩ) | 10.0671% | 26.41% | 47.9482% |

*Table 3: Percent Difference Values for Vth1, Vth2, Vgap*

As seen in Table 3, there is a discrepancy between the calculated and measured values. Multiple factors can lead to significant percentage errors between AD2 waveform simulations, theoretical calculations, and physical experiments. These discrepancies can stem from the internal resistance of the breadboard, loose wiring to the breadboard, and constraints of our measuring equipment. Factors such as background interference, complex behaviors, unintended electrical connections, and errors in the sampling process may contribute to additional inaccuracies. It is crucial to comprehend and tackle these elements to make sense of and reduce errors observed in experimental data. Another major contributor to the discrepancy of values is the internal tolerance of circuit components, where variations in their values can affect overall precision, such as the resistors. Inaccuracies in op-amp properties, such as input offset voltage and gain, also play a role in impacting precision.

V . What do you notice about the hysteresis gap Vgap if we change Vref from zero to some non-zero value?

By adjusting Vref from zero to a non-zero value, the measurements indicated that the Vgap values remained consistent from both the measured values for the AD2 and the theoretical values. The hysteresis gap (Vgap) remains unchanged during the transition of Vref from zero to a non-zero value. As illustrated in Table 1, where identical calculations were conducted with the same resistance and Vsat values but a non-zero Vref, the Vgap value exhibited no variation. The hysteresis gap is primarily determined by the differential between the upper and lower threshold voltages which are independent of the reference voltage. As a result, regardless of the value of Vref, as long as it lies between the positive and negative saturation voltages, the hysteresis gap is constant.