# *Set 1 - Lab Report*

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ELECENG 2CJ4 - Circuits and Systems

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## Introduction

The purpose of this lab is to analyze Schmitt triggers, specifically their hysteresis behaviors. A Schmitt trigger cleans noisy input signals and outputs a clean square wave. This is done by analyzing $V_{th1}$ and $V_{th2}$, its two threshold voltages, in which there is no voltage change between them. The threshold voltages can be calculated and altered using different resistor and reference voltages in the circuit. This lab aims to understand Schmitt trigger behavior by analyzing how the hysteresis operates with respect to the components in the circuit in addition to how it maintains a stable output.

## Working Principle of the Circuit

The purpose of a Schmitt trigger is to output a clean square wave from a noisy input wave. If the instantaneous input voltage is greater than the upper threshold, the output voltage changes. If the input voltage drops below the lower threshold, the output voltage changes to the lower state. If the input voltage is between these two thresholds, the output voltage stays the same. This is called the Hysteresis effect and it prevents noise from reaching the output. A Schmitt trigger circuit and the threshold and gap voltage values can be calculated using the formulas given below.

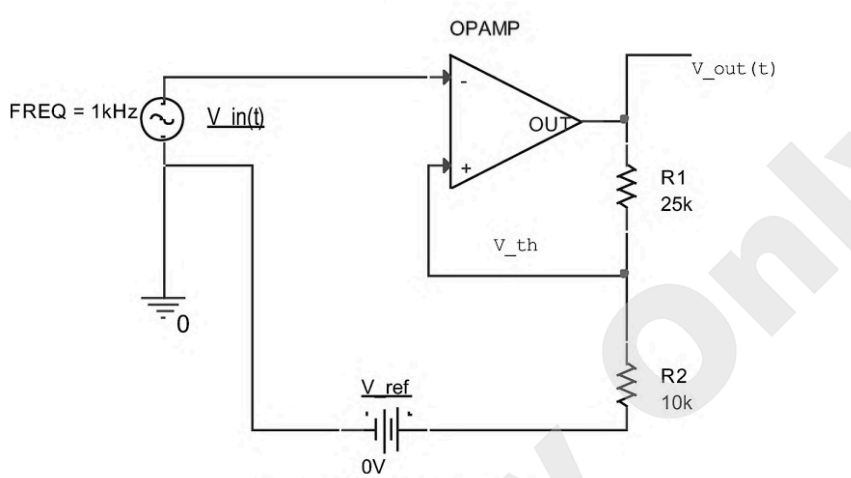


*Figure 1: Schmitt Trigger Circuit*

$$V_{th1} = \frac{R_1}{R_1 + R_2} V_{sat+} \qquad V_{th2} = \frac{R_1}{R_1 + R_2} V_{sat+} \qquad V_{Gap} = V_{th1} - V_{th2}$$

## Experiment

1. From the background section, explain why when we increase or decrease $V_{in}(t)$ such that $V_{th2} < V_{in} < V_{th1}$ the output remains the same.

   A Schmitt trigger converts noisy waves to a square wave. This is done using an upper and lower threshold $V_{th1}$ and $V_{th2}$. The output remains the same because for the voltage levels to change, the input voltage must be greater than the upper threshold or less than the lesser threshold. In this case, it is not beyond these extremities, but rather in between, indicating that there will be no change. This "between" zone is called the hysteresis.

2. Given the circuit from Figure 2 in the example section, fill in the following table using $V_{ref}$ = 0V, 2V, $R_1$= 4.7kΩ, 22kΩ and R2 = 4.7kQ. (assuming $V_{sat+}$ = 5V and $V_{sat-}$ = -5V). Include one sample calculation for any row.

| ($V_{ref}$,$R_1$,$R_2$) | $V_{th1}$ *(Theoretical)* | $V_{th2}$ *(Theoretical)* | $V_{gap}$ *(Theoretical)* |
|---|---|---|---|
| (0V, 4.7kΩ, 4.7kΩ) | 2.5V | -2.5V | 5V |
| (0V, 22kΩ, 4.7kΩ) | 0.88V | -0.88V | 1.76V |
| (2V, 4.7kΩ, kΩ) | 3.5V | -1.5V | 5V |
| (2V, 22kΩ, 4.7kΩ) | 2.53V | 0.77V | 1.76V |

Sample Calculation for Row 1(0V, 4.7kΩ, 4.7kΩ)

$$V_{th1} = \frac{R_1}{R_1 + R_2} V_{sat+}$$
$$V_{th1} = \frac{4.7k\Omega}{4.7k\Omega + 4.7k\Omega} \times 5V$$
$$V_{th1} = 2.5V$$

$$V_{th2} = \frac{R_1}{R_1 + R_2} V_{sat+}$$
$$V_{th2} = \frac{4.7k\Omega}{4.7k\Omega + 4.7k\Omega} \times (-5V)$$
$$V_{th2} = -2.5V$$

$$V_{Gap} = V_{th1} - V_{th2}$$
$$V_{Gap} = 2.5 - (-2.5)$$
$$V_{Gap} = 5V$$

3. Measure the actual $V_{th1}$, $V_{th2}$, and $V_{gap}$ by building the circuits with $v_i(t)$ 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 wella s circuit. (Hint: you will need to analyze the circuit if $V_{ref}$ is a value that is not zero). **Note: As recommended by Dr. Elamain, the LMC662CN op-amp was used in this experiment**

| ($V_{ref}$,$R_1$,$R_2$) | $V_{th1}$ *(Experimental)* | $V_{th2}$ *(Experimental)* | $V_{gap}$ *(Experimental)* |
|---|---|---|---|
| (0V, 4.7kΩ, 4.7kΩ) | 2.534V | -2.461V | 4.991V |
| (0V, 22kΩ, 4.7kΩ) | 0.894V | -0.867V | 1.761V |
| (2V, 4.7kΩ, 4.7kΩ) | 3.585V | -1.503V | 5.088V |
| (2V, 22kΩ, 4.7kΩ) | 2.551V | 0.780V | 1.771V |

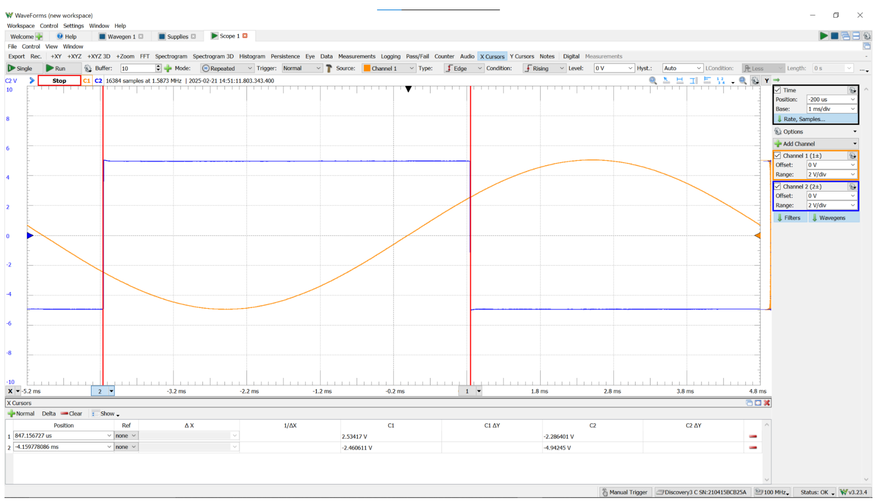

*Figure 2: (0V, 4.7kΩ, 4.7kΩ)*

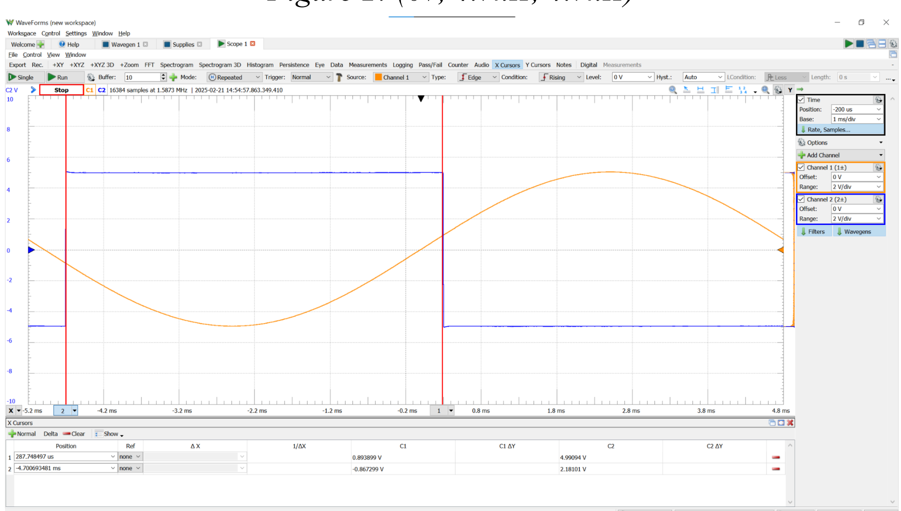

*Figure 3: (0V, 22kΩ, 4.7kΩ)*

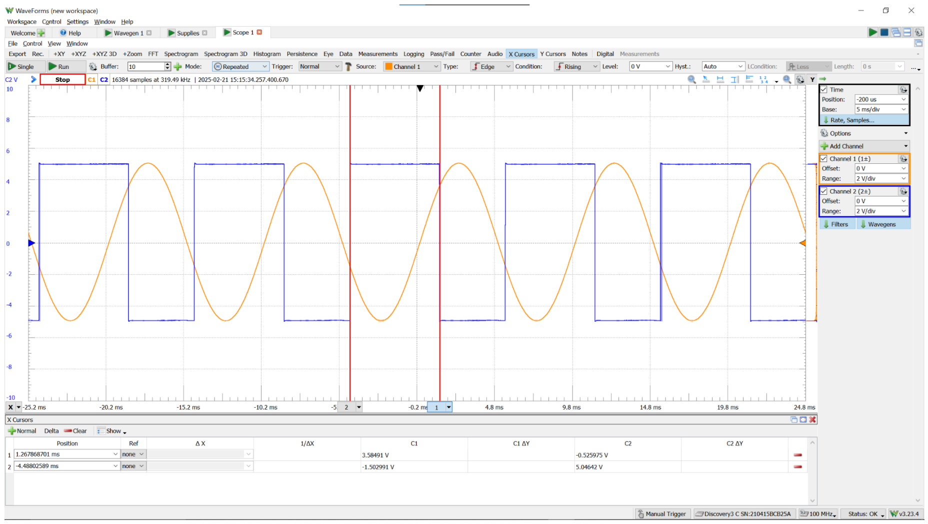

*Figure 4: (2V, 4.7kΩ, 4.7kΩ)*

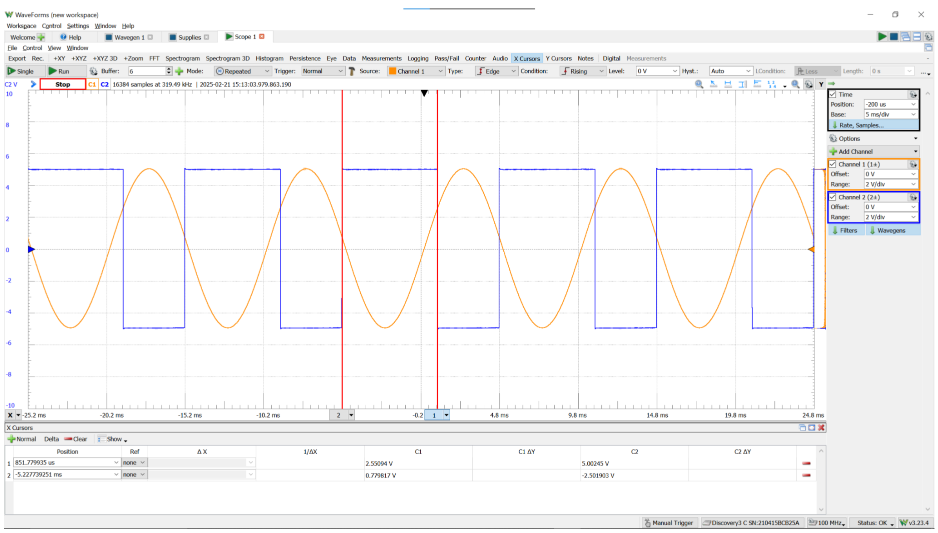

*Figure 5: (2V, 22kΩ, 4.7kΩ)*

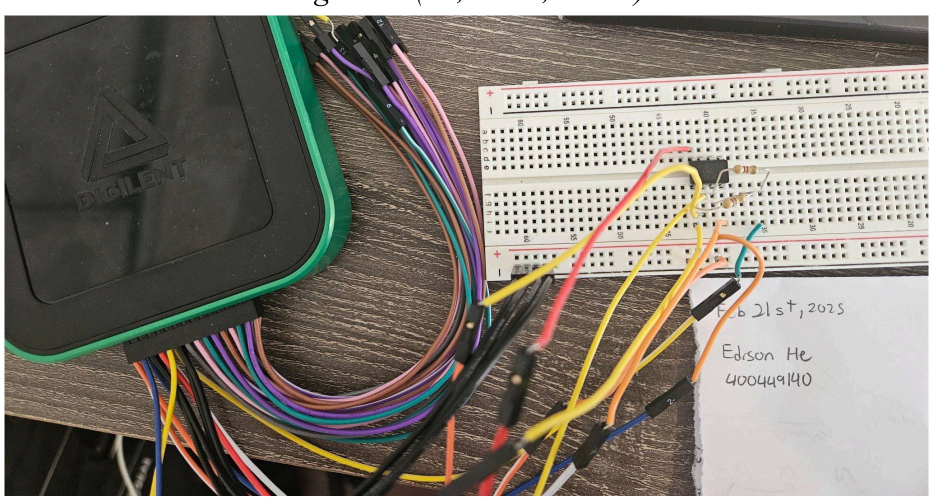


*Figure 6: (0V, 4.7kΩ, 4.7kΩ) circuit*

4. What is the percent difference between the calculated and measured voltages?

| ($V_{ref}$,$R_1$,$R_2$) | $V_{th1}$ | $V_{th2}$ | $V_{gap}$ |
|---|---|---|---|
| (0V, 4.7kΩ, 4.7kΩ) | 1.360% | 1.560% | 0.180% |
| (0V, 22kΩ, 4.7kΩ) | 1.591% | 1.477% | 0.0560% |
| (2V, 4.7kΩ, 4.7kΩ) | 2.429% | 0.200% | 1.706% |
| (2V, 22kΩ, 4.7kΩ) | 0.830% | 1.299% | 0.625% |

Sample Calculation for $V_{th1}$ (2V, 22kΩ, 4.7kΩ)

$$Percent\ Error = |\frac{Theoretical - Experimental}{Theoretical}| \times 100\%$$

$$Percent\ Error = |\frac{2.53 - 2.551}{2.53}| \times 100\%$$

$$Percent\ Error = 0.830\%$$

5. What do you notice about the hysteresis gap $V_{gap}$ if we change $V_{ref}$ from zero to some non-zero value?

   Citing both theoretical and experimental values, I notice that the hysteresis gap does not change when $V_{ref}$ is set to 0, or a non-zero value. The only change in the hysteresis gap is depending on $V_{ref}$, the gap shifts upwards or downwards. This can be seen as the threshold values do change with a change in $V_{ref}$, however, the gap size, or the difference in the thresholds does not.

## Discussion

In this lab, the hysteresis gap of Schmitt triggers were analyzed. This was done by analyzing the resistors, reference voltage, input, and output voltages and how they influence the upper threshold voltage, lower threshold voltage, and the hysteresis gap. It confirmed that the output voltage is stable when the input voltage is between both threshold voltages but changes when beyond the threshold voltages. This can be seen in both the theoretical and experimental results that the hysteresis gap does not depend on the reference voltage. The threshold voltages do change with a change in reference voltage, but the gap does not. This is further proved by the low percent error between the theoretical and experimental values.