ELEC ENG 2CJ4 Circuits and Systems Lab 2

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Section L01

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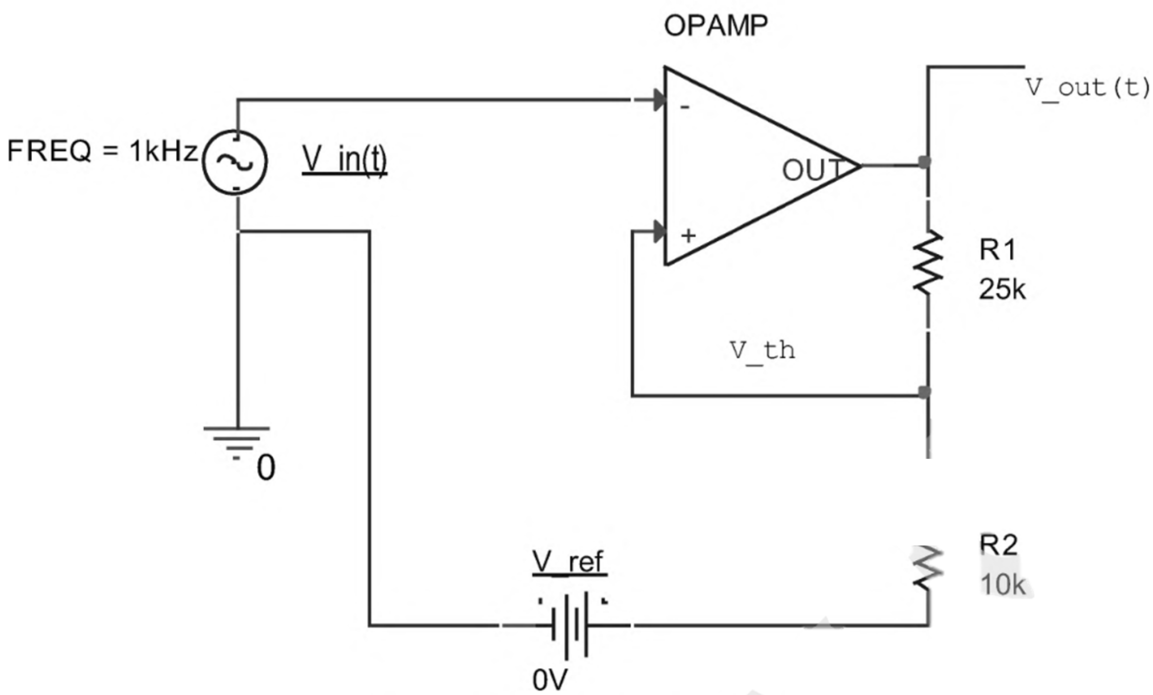
Introduction: This lab investigates the behaviour of the Schmitt trigger circuit including an op-amp with positive feedback. By analyzing different resistor values and references voltages, the thresholds and hysteresis gaps are determined to highlight the Schmitt trigger's role in noise immunity.



1) $V_{ref} = 0V$, $R_1 = R_2 = 4.7k\Omega$

KCL at V_{th} node ($V_{sat+} = 5V$, $V_{sat-} = -5V$):

$$V_{th} = V_{out}\left(\frac{R2}{R1+R2}\right)$$

$$\left(\frac{V_{th}-V_{out}}{R1}\right) + \left(\frac{V_{th}-V_{ref}}{R2}\right) = 0$$

$$V_{th1} = \left(\frac{V_{out}}{R1} + \frac{V_{ref}}{R2}\right)\left(\frac{R1R2}{R1+R2}\right)$$

$$= V_{sat+}\left(\frac{R2}{R1+R2}\right) + V_{ref}\left(\frac{R1}{R1+R2}\right)$$

$$V_{th2} = \left(\frac{V_{out}}{R1} + \frac{V_{ref}}{R2}\right)\left(\frac{R1R2}{R1+R2}\right)$$

$$= V_{sat-}\left(\frac{R2}{R1+R2}\right) + V_{ref}\left(\frac{R1}{R1+R2}\right)$$

$$V_{th1} = \frac{(5)(4.7k)}{(2)(4.7k)} = 2.5V$$

$$V_{th2} = \frac{(-5)(4.7k)}{(2)(4.7k)} = -2.5V$$

2) $V_{ref} = 0V$, $R1 = 22k\Omega$, $R2 = 4.7k\Omega$

$$V_{th1} = \frac{(5)(4.7k)}{22k + 4.7k} = 0.880V$$

$$V_{th2} = \frac{(-5)(4.7k)}{22k + 4.7k} = -0.880V$$

3) $V_{ref} = 2V$, $R_1 = R_2 = 4.7\ k\Omega$

$$V_{th1} = \frac{(5)(4.7k)}{(2)(4.7k)} + \frac{(2)(4.7k)}{(2)(4.7k)} = 3.50V$$

$$V_{th2} = \frac{(-5)(4.7k)}{(2)(4.7k)} + \frac{(2)(4.7k)}{(2)(4.7k)} = -1.50V$$

4) $V_{ref} = 2V$, $R_1 = 22k\Omega$, $R_2 = 4.7k\Omega$

$$V_{th1} = \frac{(5)(4.7k)}{22k + 4.7k} + \frac{(2)(22k)}{22k + 4.7k} = 2.53V$$

$$V_{th2} = \frac{(-5)(4.7k)}{22k + 4.7k} + \frac{(2)(22k)}{22k + 4.7k} = 0.77V$$

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

No matter whether the value of $V_{in}(t)$ is increased or decreased the output will remain the same due to the hysteresis gap (V_{gap}). Due to positive feedback, two threshold voltages are created. When the input is below V_{th2}, the output is at the positive saturation voltage V_{sat+}, and when the input exceeds V_{th1}, the output switches to the negative saturation voltage. However, between the hysteresis gap where $V_{gap} = V_{th1} – V_{th2}$, the output does not change. This ensures noise stability within the circuit. As long as the input remains within the gap, the output will remain in its previous state, either V_{sat+} or V_{sat-}.

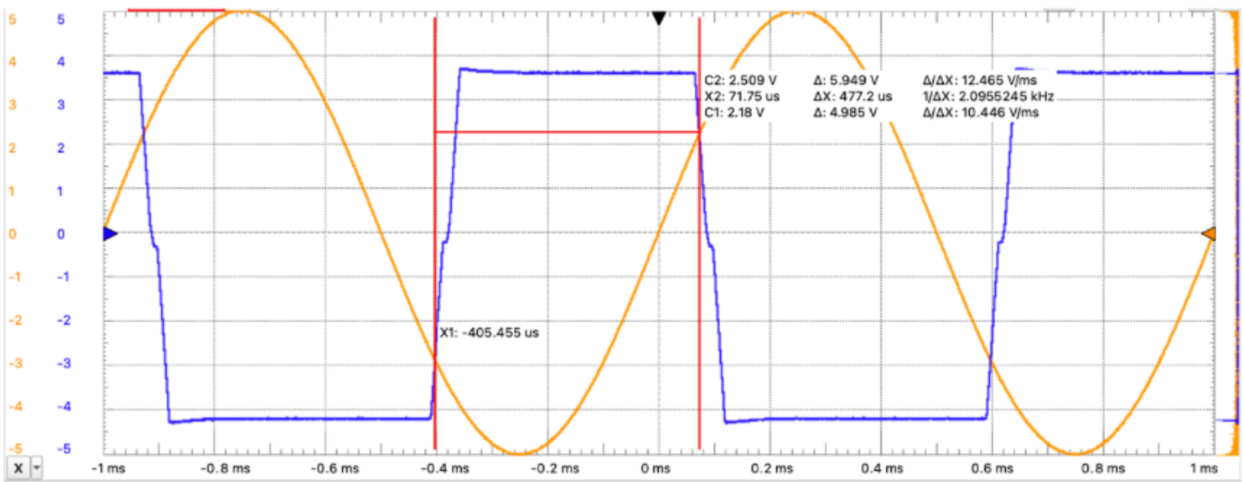
ii. Given the circuit from Figure 2 in the example section, fill in the following table using V_{ref} = 0V, 2V, R_1= 4.7kΩ, 22kΩ and R2 = 4.7kQ (assuming V_{sat+} = 5V and V_{sat-} = -5V). Include one sample calculation for any row.

(V_{ref}, R_1, R_2)	**V_{th1} (theoretical)**	**V_{th2} (theoretical)**	**V_{gap} (theoretical) ($V_{gap} = V_{th1} – V_{th2}$)**
(0V, 4.7kΩ, 4.7kΩ)	**2.5V**	**-2.5V**	**5V**
(0V, 22kΩ, 4.7kΩ)	**0.880V**	**-0.880V**	**1.76V**
(2V, 4.7kΩ, 4.7kΩ)	**3.50V**	**-1.50V**	**5V**
(2V, 22kΩ, 4.7kΩ)	**2.53V**	**0.77V**	**1.76V**

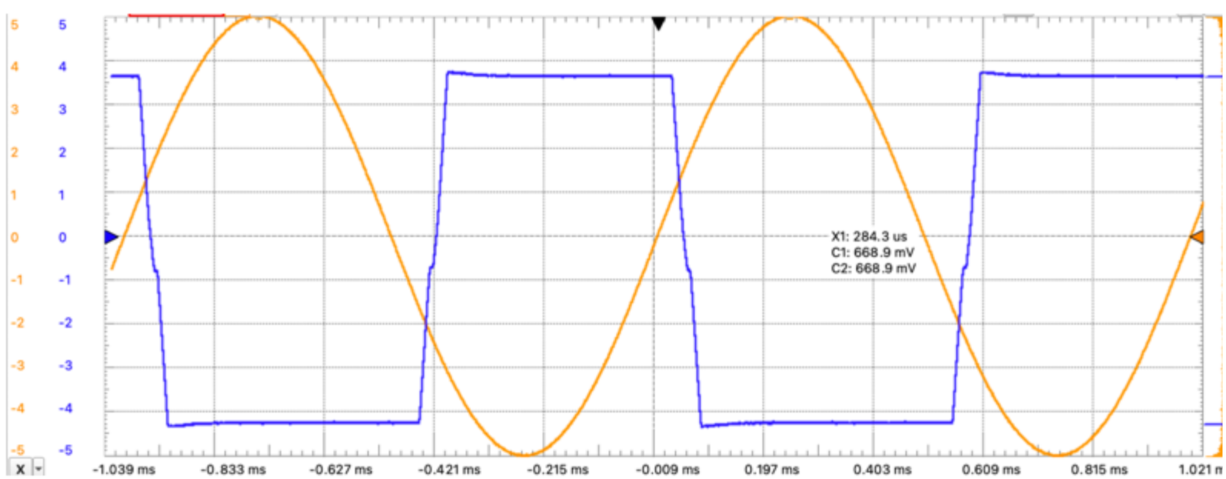
iii. **Measure the actual V_{th1}, V_{th2}, and V_{gap} by building the circuits with $v_i(t)$ being a sine wave, square wave, or a triangular wave of amplitude 5V with a 0V offset and filling in the values in the following table. Include the resulting waveforms as well as circuits. (Hint: you will need to analyze the circuit if V_{ref} is a value that is nonzero).**

(V_{ref}, R_1, R_2)	**V_{th1} (measured)**	**V_{th2} (measured)**	**V_{gap} (measured) ($V_{gap} = V_{th1} – V_{th2}$)**
(0V, 4.7kΩ, 4.7kΩ)	**2.598V**	**-2.381V**	**4.979V**
(0V, 22kΩ, 4.7kΩ)	**0.923V**	**-0.983V**	**1.906V**
(2V, 4.7kΩ, 4.7kΩ)	**2.948V**	**-1.512V**	**4.460V**
(2V, 22kΩ, 4.7kΩ)	**2.451V**	**0.864V**	**1.587V**

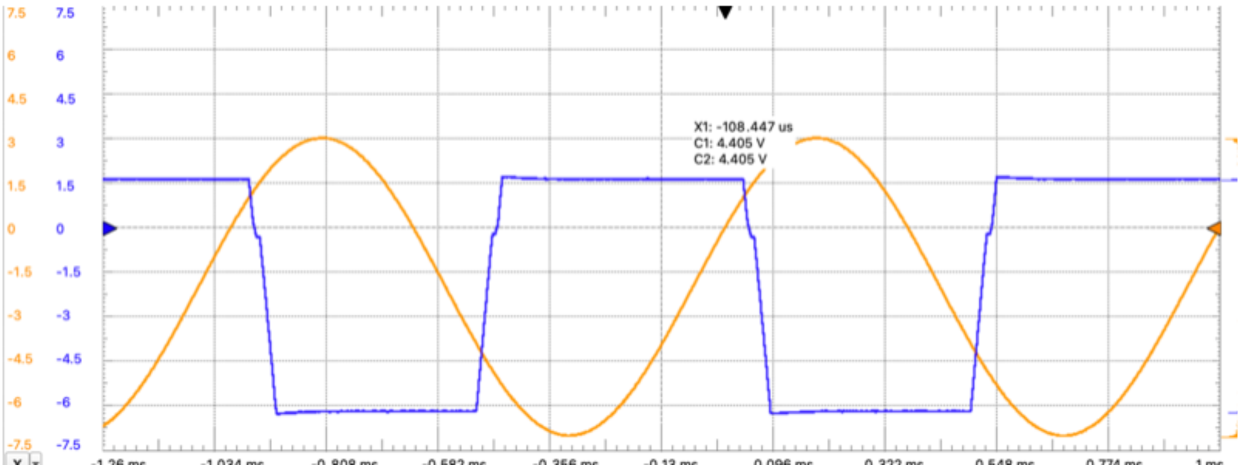
For V_{ref} = 0V, $R_1 = R_2$ = 4.7kΩ:



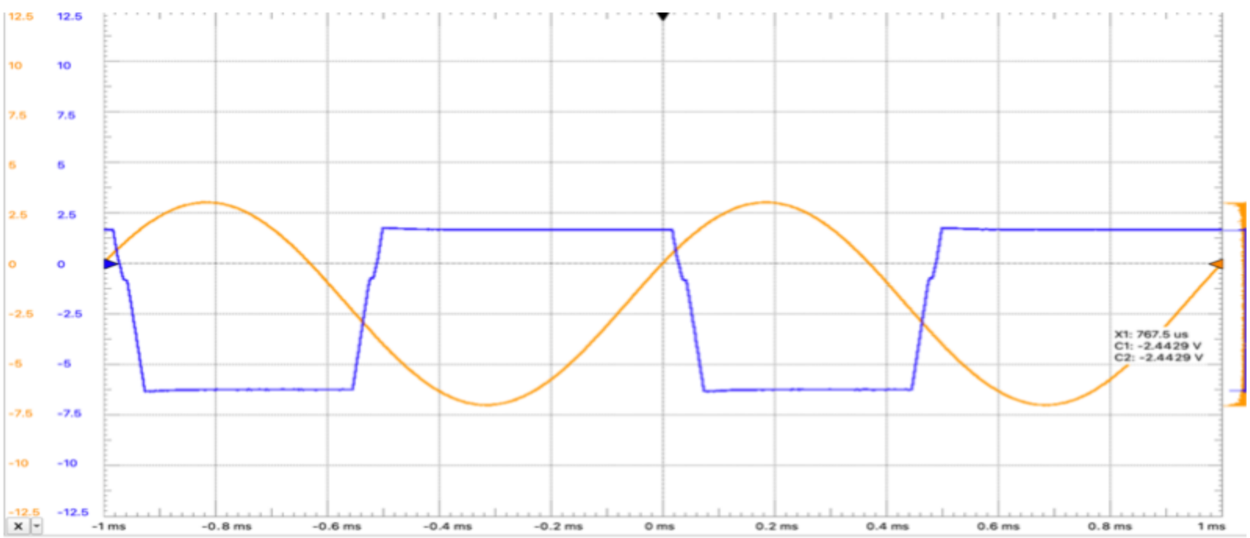
For V_{ref} = 0V, R_1 = 22kΩ, R_2 = 4.7kΩ:



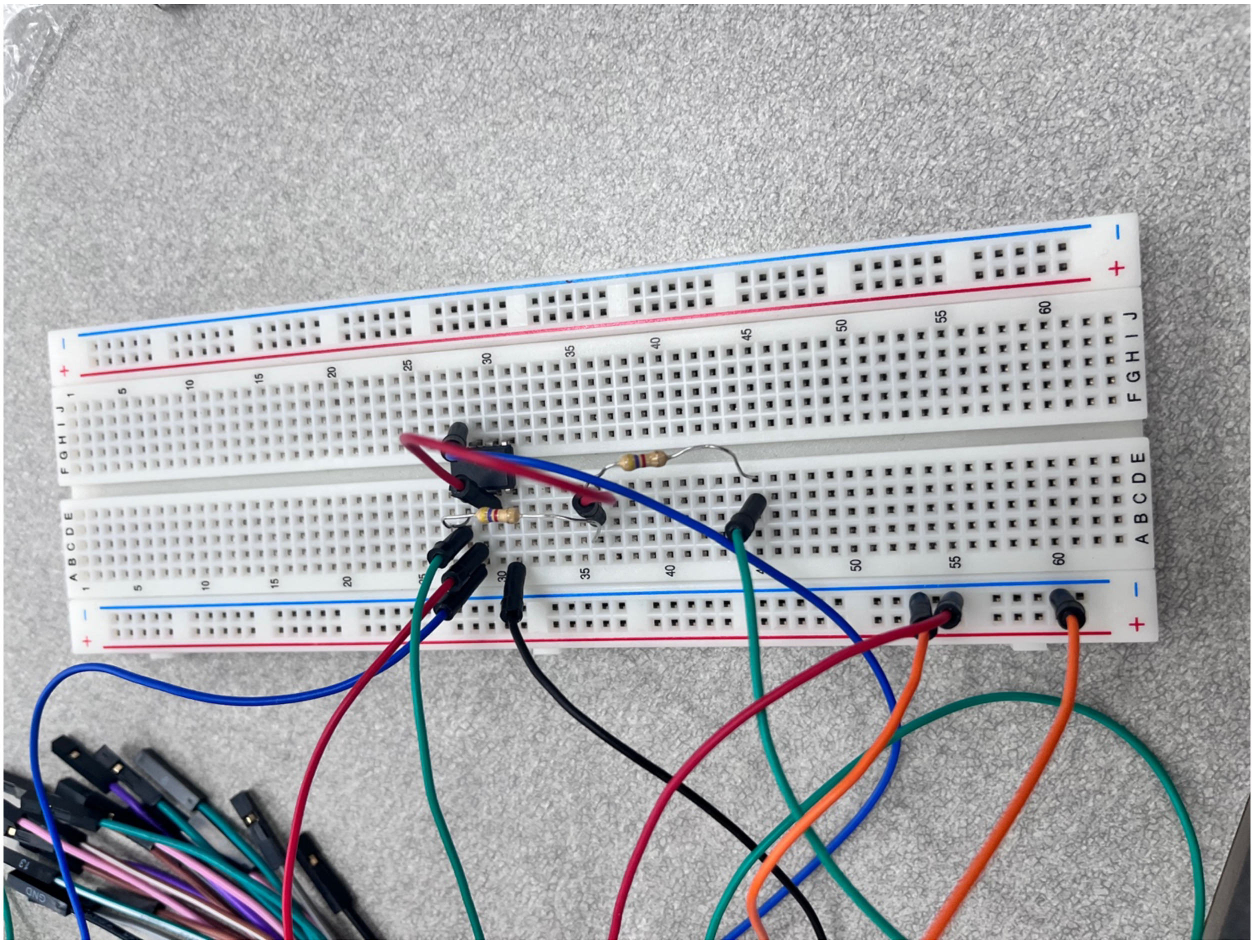
For $V_{ref} = 2V$, $R_1 = 4.7k\Omega$, $R_2 = 4$.



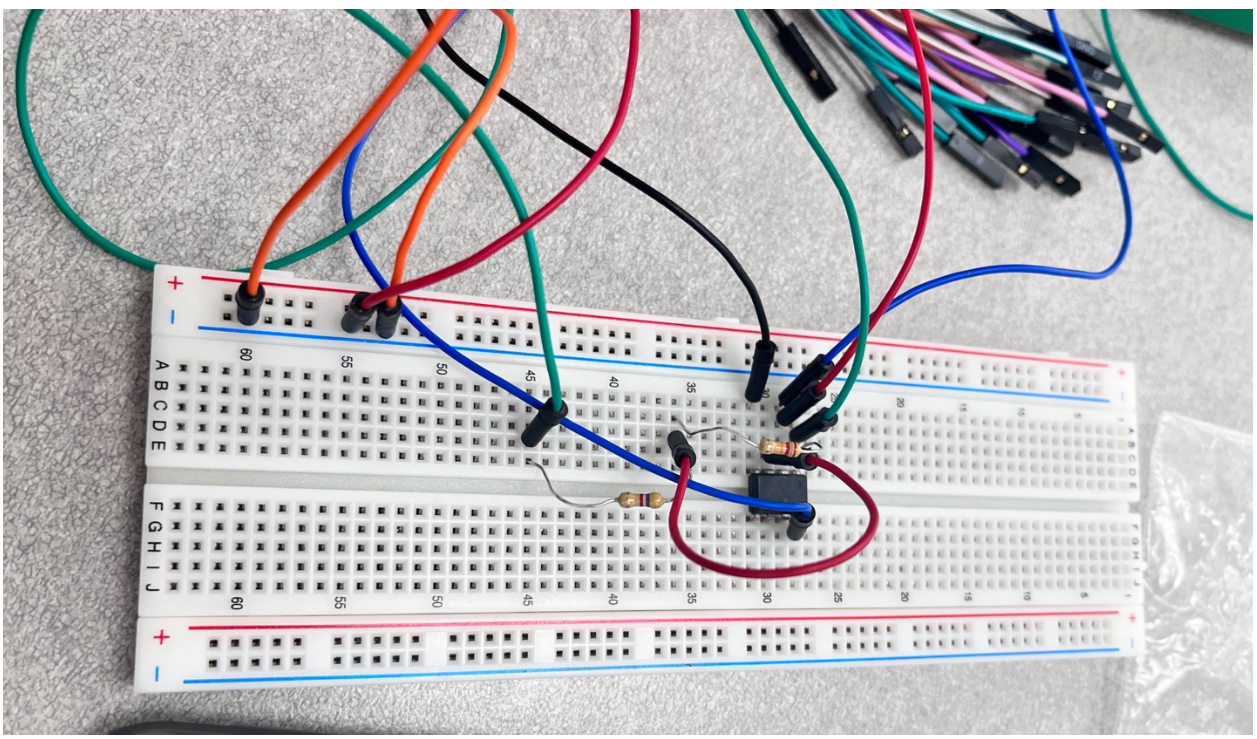
For $V_{ref} = 2V$, $R_1 = 22k\Omega$, $R_2 = 4.7k\Omega$:



Circuit for (0V, 4.7kΩ, 4.7kΩ) and (2V, 4.7kΩ, 4.7kΩ):



Circuit for (0V, 22kΩ, 4.7kΩ) and (2V, 22kΩ, 4.7kΩ):



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

Percentage Error = $\frac{|Theoretical - Measured|}{Theoretical} \times 100\%$

	Percentage Error		
(V_{ref}, R_1, R_2)	**V_{th1}**	**V_{th2}**	**V_{gap}**
(0V, 4.7kΩ, 4.7kΩ)	**3.92%**	**4.76%**	**0.42%**
(0V, 22kΩ, 4.7kΩ)	**4.89%**	**22.88%**	**8.29%**
(2V, 4.7kΩ, 4.7kΩ)	**15.77%**	**0.80%**	**10.80%**
(2V, 22kΩ, 4.7kΩ)	**3.12%**	**10.88%**	**9.83%**

As shown, there are differences between the calculated and measured voltages of V_{th1}, V_{th2}, and V_{gap}. Different factors include internal resistance of the breadboard or wiring, tolerances within resistors which may lead to inaccurate values and constraints of the AD3 equipment itself.

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

It was noticed that the hysteresis gap V_{gap} does not get affected by the value of V_{ref}. As seen in calculations, V_{ref} does not affect V_{gap}, but cause an increase or decrease shift in the graph in the vertical direction by V_{gap} with V_{gap} remaining the same.