ELECENG 2CJ4

Lab 2 Report

Investigating Schmitt Trigger Characteristics

2/12/2025

Jasmine Dosanjh – L03 – dosanj5 – 400531879

Akinniyi Chidiebube – L03 – akinniyc - 400501611

1. Introduction

The Schmitt trigger is an Operational Amplifier circuit that gives a high or low output depending on the voltage value going into the circuit. It differs from the comparator as it uses positive feedback to induce hysteresis in its outputs.

The Schmitt Trigger is a widely used application of the Operational Amplifier, mainly used in analogue to digital conversion and noise reduction. It is one of the operational amplifier circuits that are most commonly used and stands out as it is one of the few op-amps circuits which make use of positive feedback and hysteresis in a practical application.

To better understand the Schmitt trigger's operations under different conditions, a series of experiments were carried out, and the results were documented. This report consists of the results of these experiments with great interest in the effects of changes in the circuit on the hysteresis gap.

2. Operational Principle of the experiment

The theoretical results are included in Table 1, and some sample calculations are included below.

Table 1. Theoretical Values from Figure 2 Circuit

	(V_{ref}, R_1, R_2)	$V_{th1}\ (V)$	$V_{th2}\ (V)$	$V_{gap}\ (V)$
A.	$(0V, 4.7k\Omega, 4.7k\Omega)$	2.5	-2.5	5
B.	$(0V, 22k\Omega, 4.7k\Omega)$	0.8801	-0.8801	1.7603
C.	$(2V, 4.7k\Omega, 4.7k\Omega)$	3.5	-1.5	5
D.	$(2V, 22k\Omega, 4.7k\Omega)$	2.5281	0.7678	1.7603

Sample Calculations:

B. Using Voltage Division:

$$V_{th1} = \frac{R_2}{R_1 + R_2} V_{sat+} = \frac{4.7k\Omega}{22k\Omega + 4.7k\Omega}(5V) = 0.8801\ V$$

$$V_{th2} = \frac{R_2}{R_1 + R_2} V_{sat+} = \frac{4.7k\Omega}{22k\Omega + 4.7k\Omega}(-5V) = -0.8801\ V$$

Finding the gap voltage:

$$V_{gap} = V_{th1} - V_{th2} = 0.8801 - (-0.8801) = 1.7603\ V$$

C. Using Superposition:

$$V_{th1} = V'_{th1} + V''_{th1} = \frac{R_2}{R_1 + R_2} V_{sat+} + \frac{R_1}{R_1 + R_2} V_{ref} = 2.5281\text{ V}$$

$$V_{th2} = V'_{th2} + V''_{th2} = \frac{R_2}{R_1 + R_2} V_{sat-} + \frac{R_1}{R_1 + R_2} V_{ref} = 0.7678\text{ V}$$

Finding the gap voltage:

$$V_{gap} = V_{th1} - V_{th2} = 2.5281 - 0.7678 = 1.7603\ V$$

3. Measurement results

The AD3 measurements results are included in Table 2, and their resulting waveforms and circuits are included below in Figures 1 - 8.

Table 2. Measured Values from AD3

	(V_{ref}, R_1, R_2)	$V_{th1}\ (measured)$/V	$V_{th2}\ (measured)$	$V_{gap}\ (measured)$
A.	$(0V, 4.7k\Omega, 4.7k\Omega)$	2.654	-2.5629	5.2169
B.	$(0V, 22k\Omega, 4.7k\Omega)$	1.007	-1.0984	2.1054
C.	$(2V, 4.7k\Omega, 4.7k\Omega)$	3.799	-1.762	5.561
D.	$(2V, 22k\Omega, 4.7k\Omega)$	2.700	0.526	2.174

A.

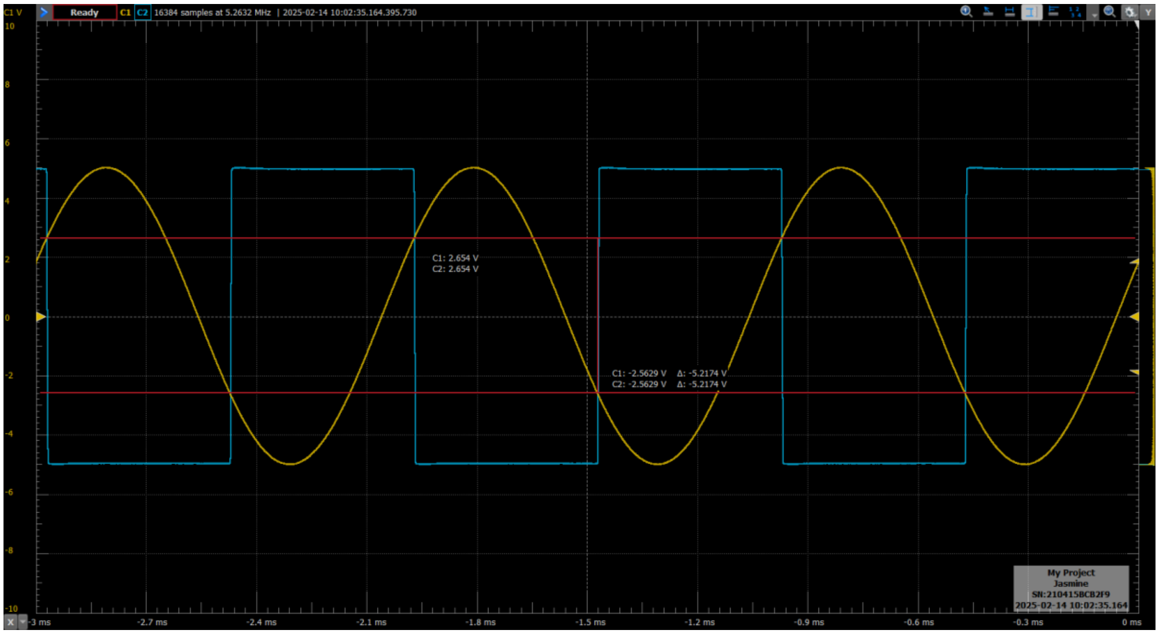

Figure 1. Waveform for A

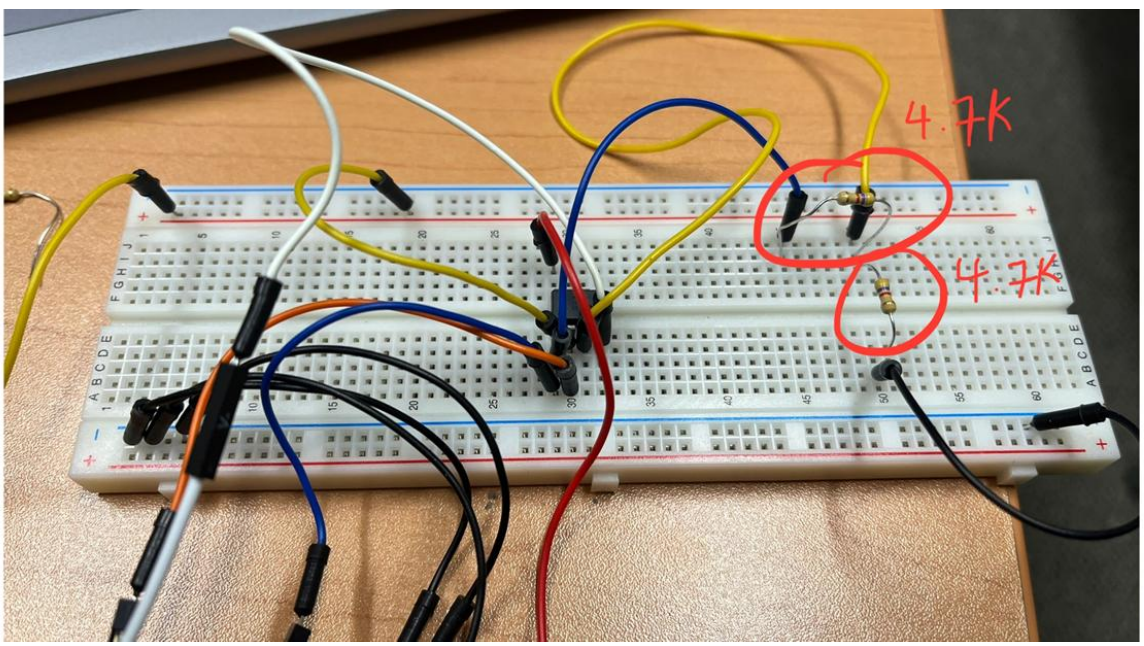

Figure 2. Physical circuit for A

B.

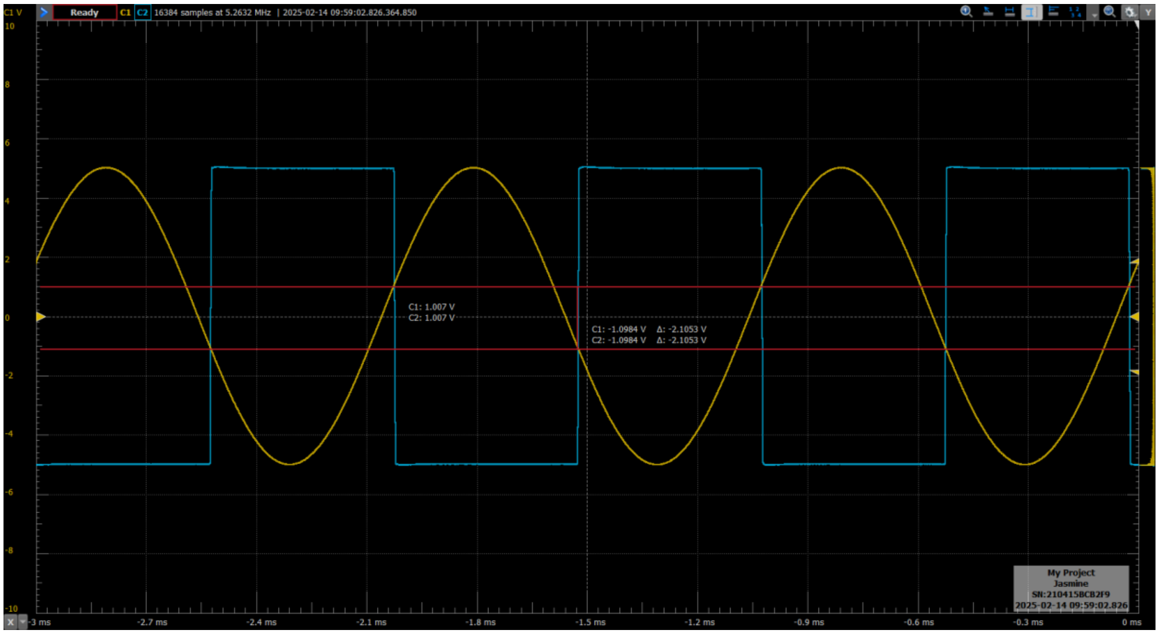

Figure 3. Waveform for B

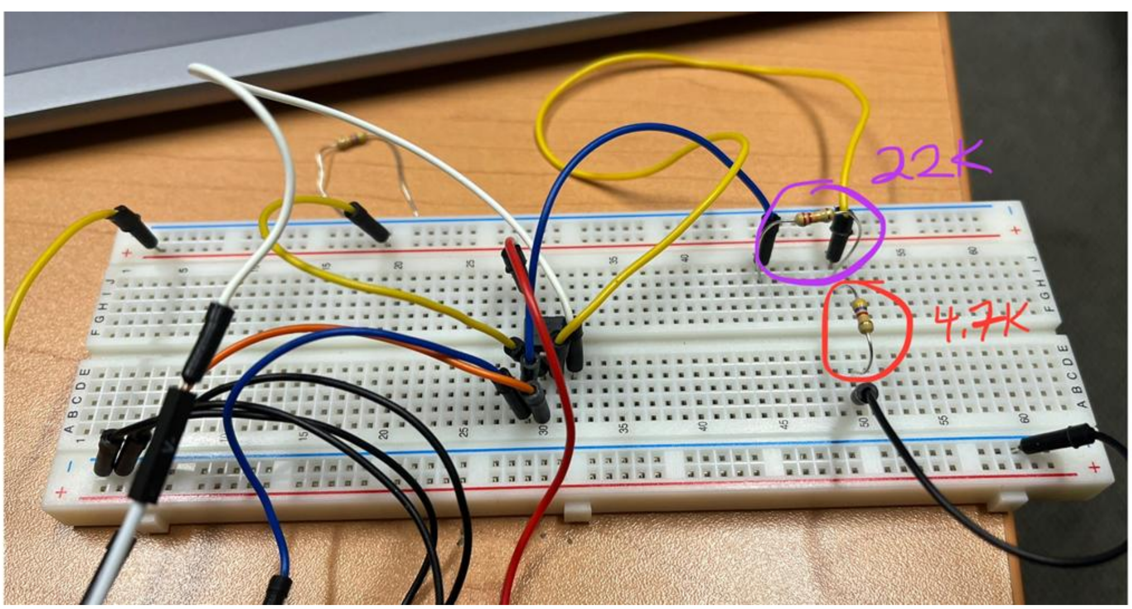

Figure 4. Physical circuit for B

C.

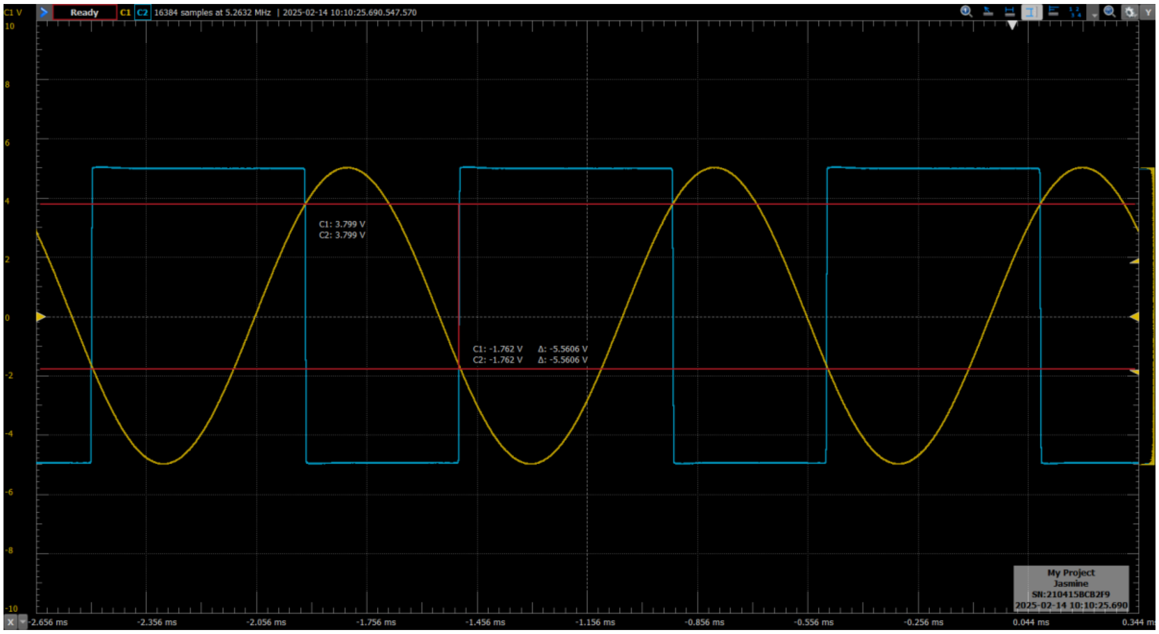

Figure 5. Waveform for C

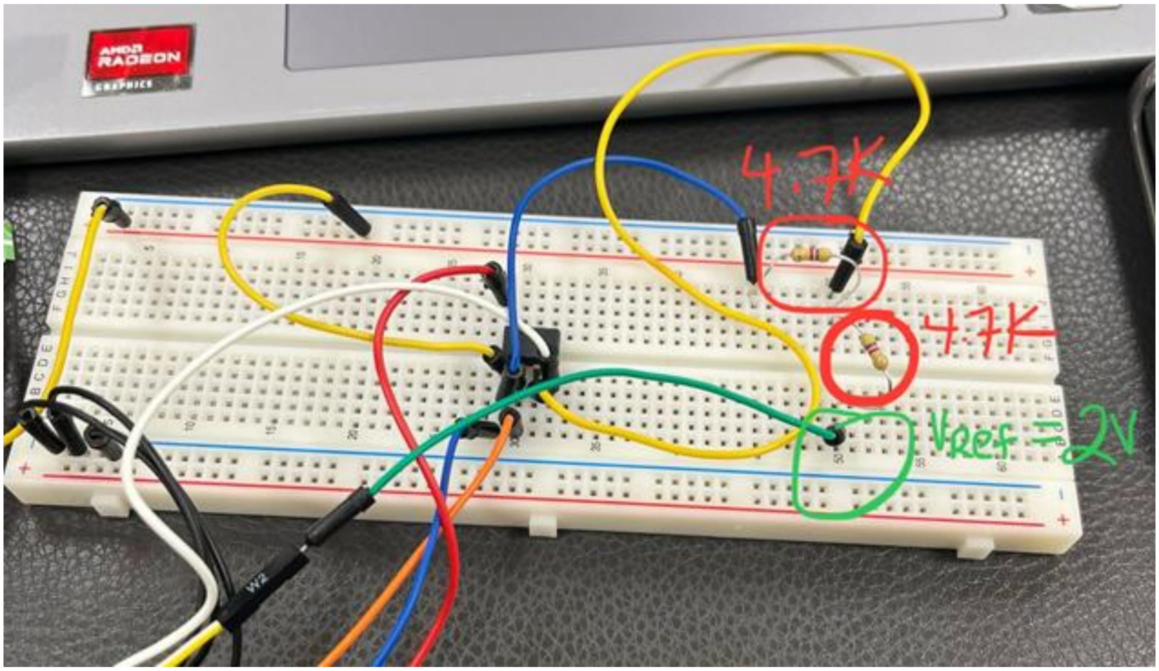

Figure 6. Physical Circuit for C

D.

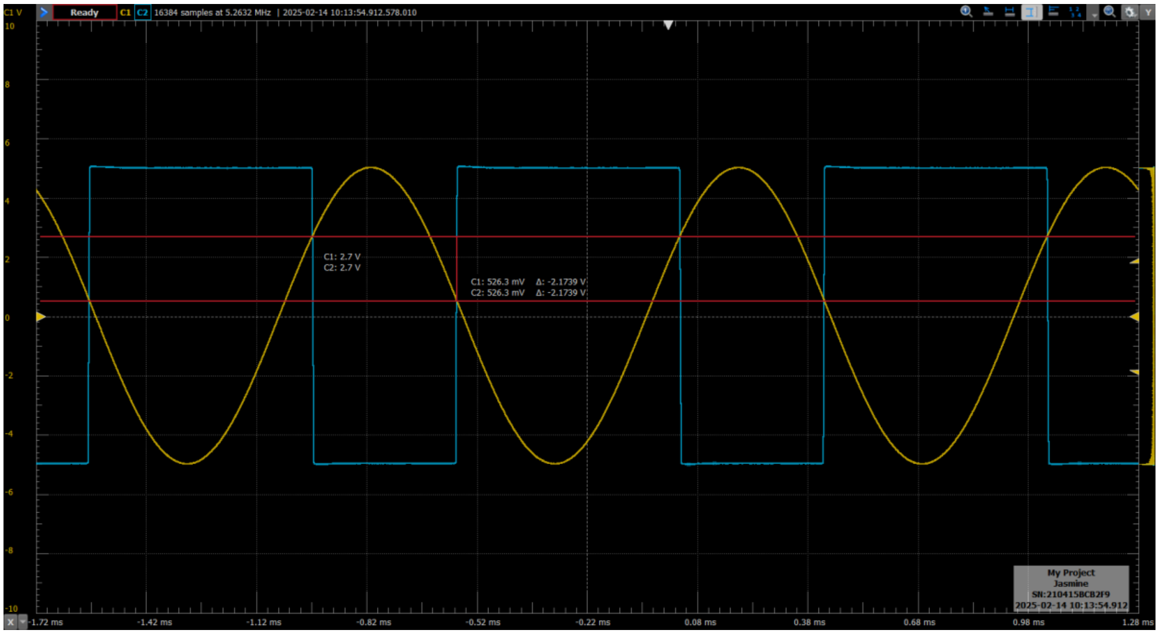

Figure 7. Waveform for D

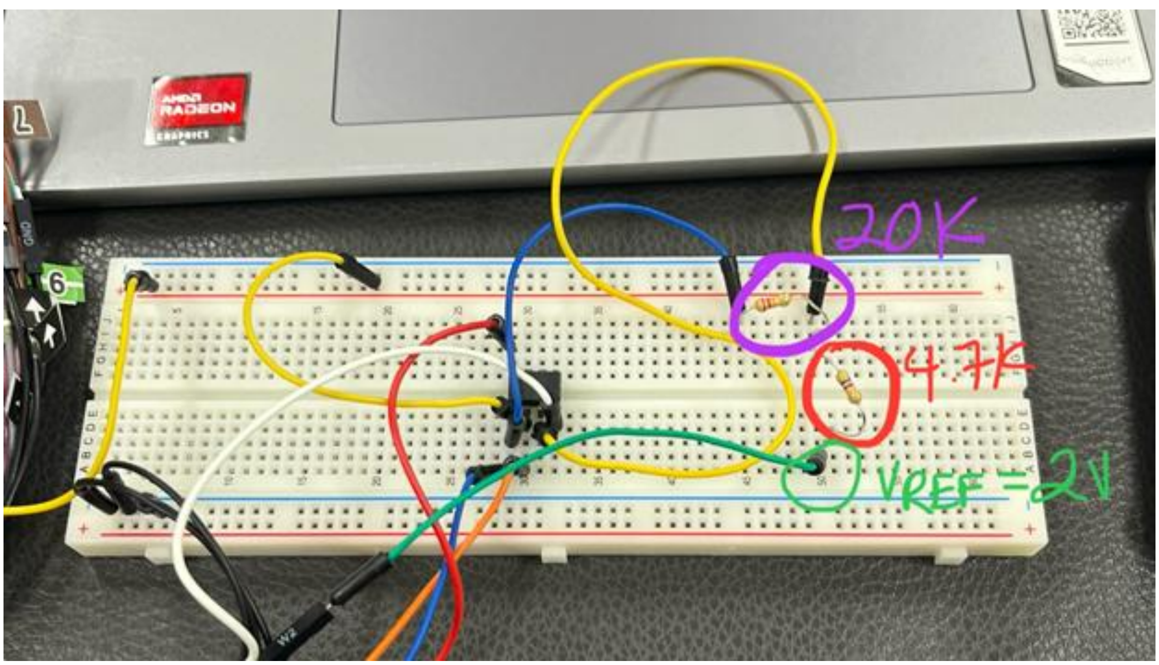

Figure 8. Physical Circuit for D

The percent difference between the calculated C and measured M values of V_{gap} are:

A. $percent\ difference = \frac{|C-M|}{\left(\frac{C+M}{2}\right)} \times 100 = \frac{|5-5.2169|}{\left(\frac{5+5.2169}{2}\right)} \times 100 = 4.24\%$

B. $percent\ difference = \frac{|C-M|}{\left(\frac{C+M}{2}\right)} \times 100 = \frac{|1.7603-2.1054|}{\left(\frac{1.7603+2.1054}{2}\right)} \times 100 = 17.85\%$

C. $percent\ difference = \frac{|C-M|}{\left(\frac{C+M}{2}\right)} \times 100 = \frac{|5-5.561|}{\left(\frac{5+5.561}{2}\right)} \times 100 = 10.62\%$

D. $percent\ difference = \frac{|C-M|}{\left(\frac{C+M}{2}\right)} \times 100 = \frac{|1.7603-2.174|}{\left(\frac{1.7603+2.174}{2}\right)} \times 100 = 21.03\%$

The calculated percent differences, ranging from 4% to 21%, are most likely caused by component tolerances and noise.

4. Discussion

When we increase or decrease the input voltage $v_{in}(t)$ such that $V_{th2} < v_{in}(t) < V_{th1}$, the output remains unchanged due to *hysteresis* in the system. The hysteresis is caused by the presence of positive feedback from saturation, keeping the output voltage at whatever state it was in until the input voltage reaches the threshold voltage for the alternative state.

The experimental results confirmed all theoretical expectations on the behaviour of the Schmitt trigger, as it was observed that the output voltage never changed until the threshold voltage for the alternating stage was reached.

The addition of a reference voltage was also seen to have shifted the expected threshold values as expected. If V_{ref} is changed from zero to some non-zero value, the hysteresis gap V_{gap} will shift accordingly but remain the same in magnitude. This is because $V_{gap} = V_{th1} - V_{th2}$, and since both threshold voltages shift together, the gap remains unchanged.

→ For $V_{ref} = 0$:

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

→ For $V_{ref} \neq 0$:

$$V_{th1} = \frac{R_2}{R_1+R_2} V_{sat+} + \boldsymbol{\frac{R_1}{R_1+R_2} V_{ref}} \qquad V_{th2} = \frac{R_2}{R_1+R_2} V_{sat+} + \boldsymbol{\frac{R_1}{R_1+R_2} V_{ref}}$$

where $\frac{\boldsymbol{R_1}}{\boldsymbol{R_1+R_2}}\boldsymbol{V_{ref}}$ is the shifting factor.

The final finding was the effects of the feedback resistor on the threshold voltages. Taking R_1 as the feedback resistor and R_2 as the resistor connected to the reference voltage. It was discovered that as the ratio of R_1:R_2 increases, the hysteresis gap seemed to reduce.

We believe that the hysteresis gap width would be inversely proportional to the finite gain of

$$A_0 = 1 + \frac{R_2}{R_1}$$

We attribute the gain to the decrease in the hysteresis gap as the output voltage reaches saturation at a lower input value if the circuit has a higher gain, accounting for the lower threshold values and the smaller hysteresis gap.