Laboratory 3: The Schmitt Trigger

ELEC ENG 2CJ4: Circuits and Systems
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1 Objective

The objective of this lab is to help you to investigate the characteristics of the Schmitt trigger. You will be asked to build a Schmitt trigger circuit by using the operational amplifier (Op-Amp). You will also learn the input-output transition function of the Schmitt trigger.

2 Euqipment

The following equipments are used in this laboratory:

- DC voltage source with positive and negative output(±9V); Oscilloscope; Function signal generator
- Op-Amp LM358
- Resistors: 10kΩ × 2, 25kΩ × 1

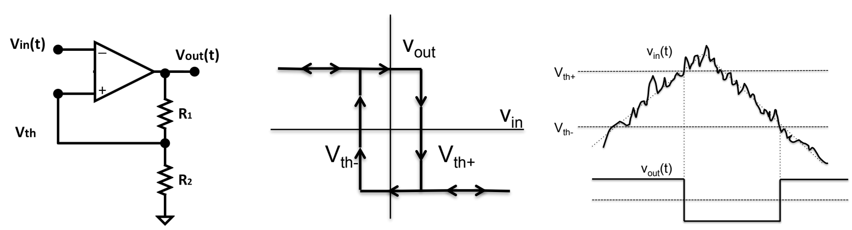

Figure 1: The Schmitt trigger, Rice (2015)

3 Introduction of the Schmitt trigger

The Schmitt trigger uses positive feedback to add hysteresis to the input-output transition threshold. It was invented by Otto Schmitt in 1934[1].

[1] "Otto Herbert Schmitt (April 6, 1913-January 6, 1998) was an American inventor, engineer, and biophysicist known for his scientific contributions to biophysics and for establishing

The main characteristics of the Schmitt trigger are summarized as follows:

- Consider the circuit as illustrated in Fig. 1. Given the DC input $v_{in}(t)$, v_{out} would be either positively saturated or negatively saturated in practice (Can you explain why?)[2]. Denote the positive saturation output voltage and the negative saturation output voltage as V_{sat+} and V_{sat-} ($V_{sat+} > V_{sat-}$), respectively. (If the power supply of Op-Amp is $\pm V_{cc}$, e.g., ± 9V, what is the range of V_{sat+}, V_{sat-}? Please observe it carefully in the following experiment). Given the DC input, V_{th} also takes two possible values, which are denoted by V_{th+} and V_{th-} ($V_{th+} > V_{th-}$).

- If $v_{in}(t) < \min\{V_{th+}, V_{th-}\} = V_{th-}$, we can find that $v_{out}(t) = V_{sat+}$ and hence $V_{th+} = \frac{R_2}{R_1+R_2} V_{sat+}$. If $v_{in}(t) > \max\{V_{th+}, V_{th-}\} = V_{th+}$, we can find that $v_{out}(t) = V_{sat-}$ and hence $V_{th-} = \frac{R_2}{R_1+R_2} V_{sat-}$.

- Now suppose that $V_{min} = \min_t v_{in}(t) < V_{th-}$ and $V_{max} = \max_t v_{in}(t) > V_{th+}$. Increase $v_{in}(t)$ gradually from V_{min} to V_{max}.

  - When $v_{in}(t) < V_{th-}$, we have $v_{out} = V_{sat+}$ and $V_{th} = V_{th+}$. Now increase $v_{in}(t)$ such that $V_{th-} < v_{in}(t) < V_{th+}$; the output remains the same (Why?). If we further increase $v_{in}(t)$ such that $v_{in}(t) > V_{th+}$, the output transition occurs and we have $v_{out} = V_{sat-}$ and $V_{th} = V_{th-}$.
  - Likewise, when $v_{in}(t) > V_{th+}$, we have $v_{out} = V_{sat-}$ and $V_{th} = V_{th-}$. Now decrease $v_{in}(t)$ such that $V_{th-} < v_{in}(t) < V_{th+}$; again the output remains the same (Please explain). If we further decrease $v_{in}(t)$. such that $v_{in}(t) < V_{th-}$, the output transition occurs and we have $v_{out} = V_{sat+}$ and $V_{th} = V_{th+}$.
  - The *hysteresis gap* is denoted by $V_{gap} = V_{th+} - V_{th-}$. Consider the case where $v_{in}(t)$ is corrupted by noise. For $v_{in}(t) < V_{th-}$ or $v_{in}(t) > V_{th+}$, if $V_{gap} >$ *noise peak-peak amplitude*, then the output is unaffected. This characteristic is called noise immunity, which is very useful in practice, e.g, when you want to measure the frequency of a waveform or counting the number of pulses in a noisy enviroment. For the above circuit, we have $V_{gap} = V_{th+} - V_{th-} = \frac{R_2}{R_1+R_2}(V_{sat+} - V_{sat-}) \approx \frac{R_2}{R_1+R_2} V_{pp}$, where $V_{pp} = 2V_{cc}$ is the range of the DC power supply.

- We define the center of the threshold as $\bar{V}_{th} = \frac{1}{2}(V_{th+} + V_{th-})$. Now consider the circuit in Fig. 2. In your lab report, please prove that the hysteresis gap V_{gap} remains the same if we change V_{ref} from zero to some non-zero values such that $V_{sat-} < V_{ref} < V_{sat+}$. Also show that that for Fig. 2, $\bar{V}_{th} = \frac{R_1}{R_1+R_2} V_{ref}$.

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the field of biomedical engineering."- https://en.wikipedia.org/wiki/Otto_Schmitt

[2]Consider noise and impairments arising at the input pin as well as the high open-loop gain of Op-Amp.

- For an Op-Amp which works in the positive feedback mode, when the transition of the output occurs, the change of the output will be fed into the positive input pin which boosts the speed of the transition even if the input signal changes relatively slowly. This phenomenon is commonly referred to as *regenerative feedback*.

4 Experiment

This laboratory consists of two parts: 1) build a Schmitt trigger by using Op-Amp LM358 (see Fig. 2); 2) measure the characteristics of the Schmitt trigger.

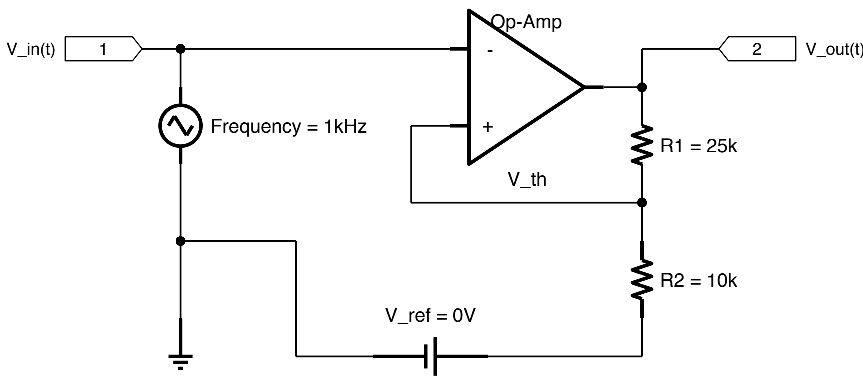

Figure 2: The Schmitt trigger

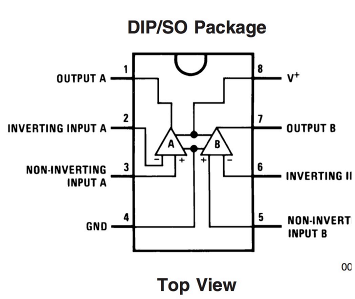

Figure 3: LM358

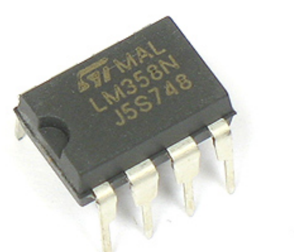

Figure 4: LM358 package

4.1 Preparation:

a. You should explain why the Schmitt trigger is can be used to measure the frequency or the period of a periodic wave form (e.g., sinusoid, square, or triangular) in a noisy environment?

b. Download the Datasheet of LM358 and study it carefully before your lab. Make sure that you are familiar with its connection diagram (the numbering of pins).

c. Estimate $V_{gap}(th), V_{th+}(th), V_{th-}(th)$ in Fig. 2 for $V_{ref} = 0V, 5V$, $R_1 = 10k\Omega, 25k\Omega$, and $R_2 = 10k\Omega$ (assuming $V_{sat+} = 8V$ and $V_{sat-} = -8V$). Later you will measure the actual V_{sat+}, V_{sat-}, and the corresponding $V_{gap}(m), V_{th+}(m), V_{th-}(m)$. Fill out the following table.

(V_{ref}, R_1, R_2)	$V_{th+}(th)$	$V_{th-}(th)$	$V_{gap}(th)$	$V_{th+}(m)$	$V_{th-}(m)$	$V_{gap}(m)$
$(0V, 10k\Omega, 10k\Omega)$						
$(0V, 25k\Omega, 10k\Omega)$						
$(5V, 10k\Omega, 10k\Omega)$						
$(5V, 25k\Omega, 10k\Omega)$						

Table 1: Schmit trigger

4.2 Experiment: Implement your Design by Using the Equipments

a. Build a Schmitt trigger following Fig. 2. **Note that $V_{ref} = 0V$ and the DC power supply is ±9V**. Caution: You should connect the circuit first and make sure that all the hook-up wires are connected correctly before you connect it to the DC power. Also the DC power should be set to the correct value before you make the connection.

b. Use the function generator to generate $1kHz$ sinusoid, square, or triangular input signals with **zero mean** and **amplitude** $3.0V$. Caution: In general, the dynamic range of the input signal should not go beyond the range of DC power source. Otherwise, you may destroy the Op-Amp. Then use the oscilloscope to measure the input and output signals using channel 1 and channel 2 at the same time and sketch the waveform in your lab report.

*You may change the input signal frequency from $1kHz$ to $1MHz$ (using the sinusoid signal) and observe the output signal waveform[3].

*You may change R_1 to $10k\Omega$, and then observe the input and the corresponding output signal.

[3]The steps labelled with "*" are not mandatory.

c. Change the amplitude of input signal to $1.0V$ (using the triangular signal) and measure the input and output signals again.

d. calculate and verify the lock-up range of the input signal for $V_{ref} = 0V, 5.0V$ in Fig. 2 (The lock-up range is the range in which the output voltage is locked to a certain value which does not change with the instantaneous input signal).

5 Results and Conclusions

In your lab report, you should include:

a. An analysis of the input-output relationship of the Schmitt trigger in Fig 2.

b. Calculate V_{th+} and V_{th-} based on the measured values of V_{sat+} and V_{sat-} in Fig. 2, then compare them to the measured values of V_{th+} and V_{th-}.

c. Sketch the measured input-output waveform for sinusoid, square, and triangular input signals with frequency $1kHz$ and amplitude $3.0V$.

References

Rice, F. (2015). *Physics 5/105, Introductory Electronics Laboratory.* Caltech.