Introduction to the Schmitt Trigger

NAT 2019

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1 Introduction

The Schmitt trigger is an application of positive feedback. This circuit is a voltage comparator with hysteresis. A voltage comparator will give as its output one of two voltages:

$$V_{out} = \begin{cases} -15 & V_{in} > V_{th} \\ +15 & V_{in} < V_{th} \end{cases}$$

where V_{th} is a threshold voltage. A voltage comparator with hysteresis will have different V_{th} for rising input voltages than for falling input voltages.

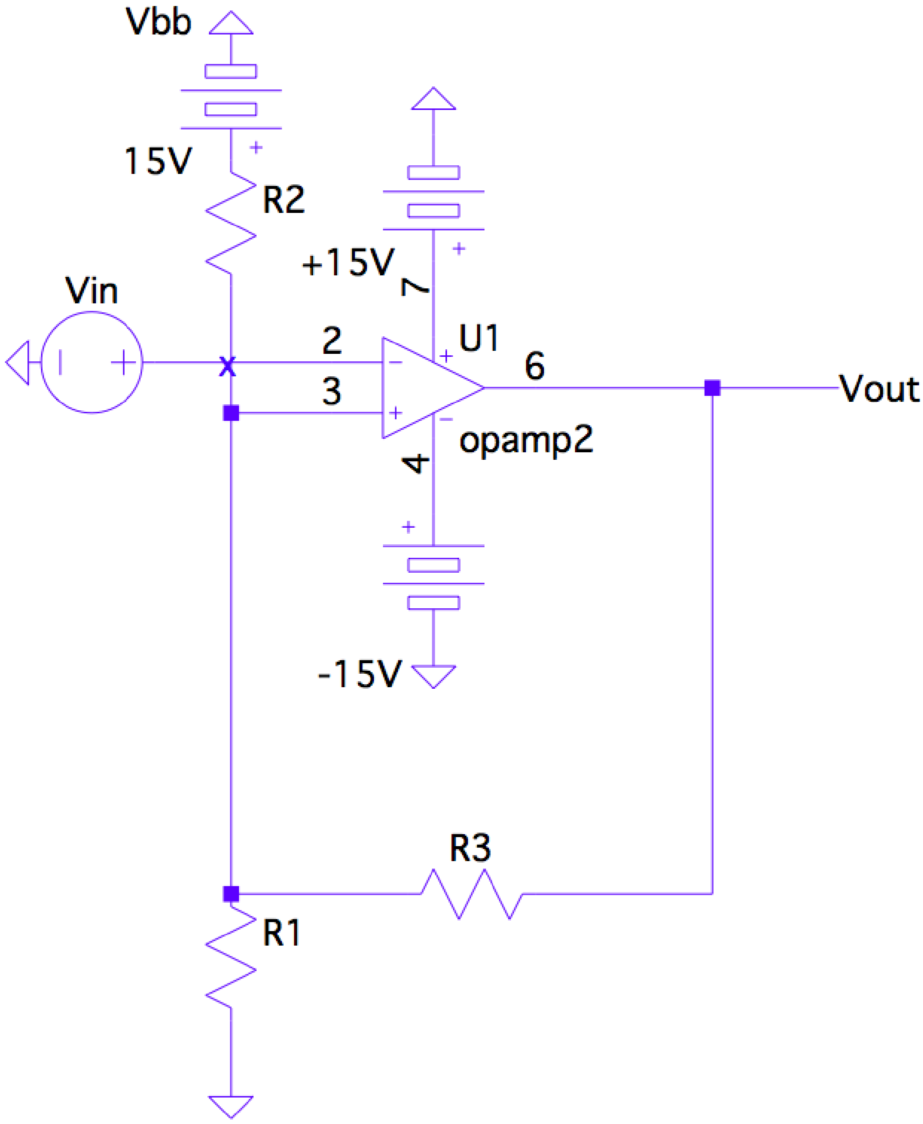
In this lab we will build a Schmitt trigger using the LF411 op amp. Then we will measure V_{th} and verify the circuit's operation as a voltage comparator.

2 Schmitt Trigger

The Schmitt Trigger is shown in the next figure (1). Build this circuit at least twice, each time with a different set of resistors. Some recommended values are

$R_1\,(k\Omega)$	$R_2\,(k\Omega)$	$R_3\,(k\Omega)$
10	10	100
10	10	1,000
10	22	100

Use the variable voltage supply on your breadboard for V_{in} and measure it with the voltmeter. Measure V_{out} with the oscilloscope and note how fast the output switches from +15V to -15V. For each set of resistors, record V_{th} for both positive and negative transitions. See how close they are to the predicted values:



Schmitt trigger circuit

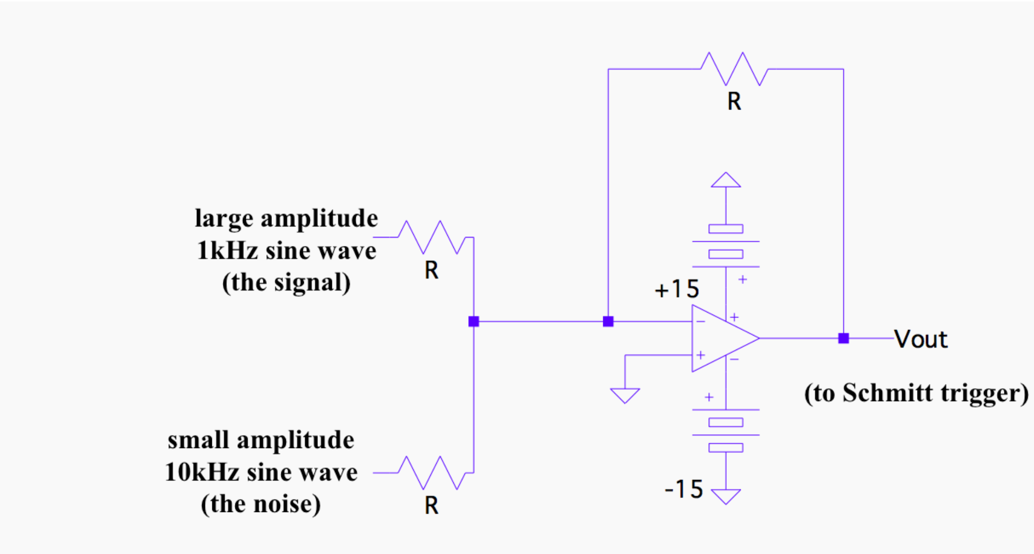
$$V_{th} = \frac{R_1||R_2||R_3}{R_2} V_{bb} + \frac{R_1||R_2||R_3}{R_3} V_{out}$$

Refer to section 4 for the derivation of this expression. Draw the measured voltages on a V_{out} versus V_{in} curve showing the hysteresis loop. (Make a separate drawing for each set of resistors).

Apply a sine wave or a triangle wave to the input and note the output. Compare the transition points to the threshold voltages you measured earlier with the voltmeter.

3 Simulated Noisy Source

To see how a Schmitt trigger might be useful, we will construct a source with some fake noise introduced into it. The following figure shows how to do this using two sine waves and a second op amp, used as a summing amplifier. Build this circuit and use it as the input to your Schmitt trigger. Regard the 1kHz sine wave as the 'signal' and the 10kHz sine wave as the 'noise.' Try to determine approximately how much hysteresis is required to filter out a given amount of noise (2).



Noisy source circuit

4 Schmitt Trigger Derivation

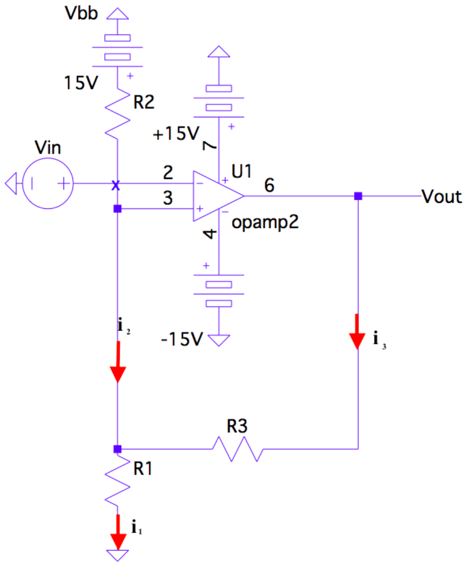
A 2-minute summary of an ideal op amp is given below:

- They are differential amplifiers that amplify the difference between the non-inverting (+) and inverting (-) inputs $[V_{out} = A\,(V_+ - V_-)]$.
- In the ideal case, the gain is infinite ($A = \infty$) so the voltage between the non-inverting and inverting leads is 0.

- The input impedance of the inverting and non-inverting inputs is infinite so there is no current that runs into the op amp
- The output impedance is 0 (no voltage drop at the output of the op amp)

With this in mind, we can solve for the output voltage of the Schmitt trigger by setting up a system of equations and solving for V_{out}.

First, let's set up the following scheme for the nodes of interest:



Schmitt trigger with currents marked

$$i_1 = i_2 + i_3 \tag{1}$$

$$V_{out} = i_3 R_3 + i_1 R_1 \tag{2}$$

$$V_{bb} = i_2 R_2 + i_1 R_1 \tag{3}$$

This produces a system of equations that can be row reduced:

$$\left[\begin{array}{ccc|c} i_1 & i_2 & i3 & \\ \hline 1 & -1 & -1 & 0 \\ R_1 & 0 & R_3 & V_{out} \\ R_1 & R_2 & 0 & V_{bb} \end{array}\right]$$

After row reduction, this becomes:

$$\left[\begin{array}{ccc|c} 1 & 0 & 0 & \frac{R_2 V_{out}+R_3 V_{bb}}{R_1 R_2+R_1 R_3+R_2 R_3} \\ 0 & 1 & 0 & \frac{R_1(V_{bb}-V_{out})+R_3 V_{bb}}{R_1 R_2+R_1 R_3+R_2 R_3} \\ R_1 & R_2 & 0 & \frac{R_1(V_{out}-V_{bb})+R_2 V_{out}}{R_1 R_2+R_1 R_3+R_2 R_3} \end{array}\right]$$

We can now find $V_{in} = V_{th}$:

$$V_{in} = i_1 R_1$$

Then, using our solution above yields

$$V_{in} = \frac{R_2 V_{out} + R_3 V_{bb}}{R_1 R_2 + R_1 R_3 + R_2 R_3} R_1$$

This looks ugly, but we can simplify it using the following definition:

$$R_1 || R_2 || \ldots || R_n = \left(\frac{1}{R_1} + \frac{1}{R_2} \cdots \frac{1}{R_n} \right)$$

For three resistors, this becomes

$$R_1 || R_2 || R_3 = \frac{R_1 R_2 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

Therefore, we can simplify to make our final expression

$$V_{in} = \frac{R_1 || R_2 || R_3}{R_2} V_{bb} + \frac{R_1 || R_2 || R_3}{R_3} V_{out}$$