Lecture - 18: Applications of Operational Amplifiers

Schmitt Trigger:

If the input to a comparator contains noise, the output may be erractive when v_{in} is near a trip point. For instance, with a zero crossing, the output is low when v_{in} is positive and high when v_{in} is negative. If the input contains a noise voltage with a peak of 1mV or more, then the comparator will detect the zero crossing produced by the noise. Fig. 1, shows the output of zero crossing detection if the input contains noise.

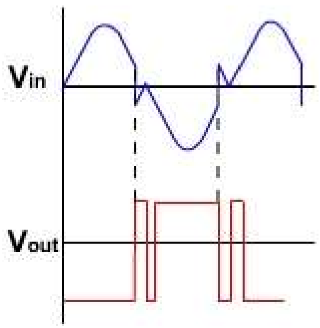

Fig. 1

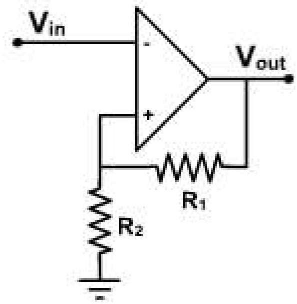

Figure 19.2

This can be avoided by using a Schmitt trigger, circuit which is basically a comparator with positive feedback. Fig. 2, shows an inverting Schmitt trigger circuit using OPAMP.

Because of the voltage divider circuit, there is a positive feedback voltage. When OPAMP is positively saturated, a positive voltage is feedback to the non-inverting input, this positive voltage holds the output in high stage. (v_{in}< v_f). When the output voltage is negatively saturated, a negative voltage feedback to the inverting input, holding the output in low state.

When the output is $+V_{sat}$ then reference voltage V_{ref} is given by

$$V_{ref} = \frac{R_1}{(R_1 + R_2)} * V_{sat} = (+\beta V_{sat})$$

If V_{in} is less than V_{ref} output will remain $+V_{sat}$.

When input v_{in} exceeds $V_{ref} = +V_{sat}$ the output switches from $+V_{sat}$ to $–V_{sat}$. Then the reference voltage is given by

$$V_{ref} = \frac{-R_2}{(R_1 + R_2)} * V_{sat} = (-\beta V_{sat})$$

The output will remain $–V_{sat}$ as long as $v_{in} > V_{ref}$.

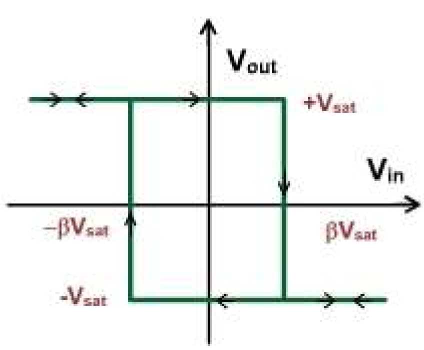

Fig. 3

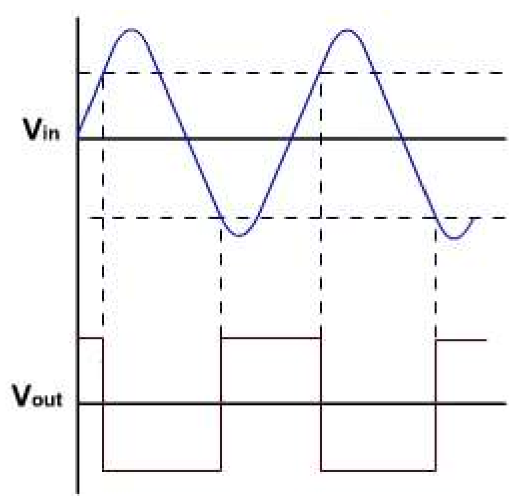

Fig. 4

If $v_{in} < V_{ref}$ i.e. v_{in} becomes more negative than $–V_{sat}$ then again output switches to $+V_{sat}$ and so on. The transfer characteristic of Schmitt trigger circuit is shown in fig. 3. The output is also shown in fig. 4 for a sinusoidal wave. If the input is different than sine even then the output will be determined in a same way.

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Positive feedback has an unusual effect on the circuit. It forces the reference voltage to have the same polarity as the output voltage, The reference. voltage is positive when the output voltage is high ($+v_{sat}$) and negative when the output is low ($-v_{sat}$).

In a Schmitt trigger, the voltages at which the output switches from $+v_{sat}$ to $-v_{sat}$ or vice versa are called upper trigger point (UTP) and lower trigger point (LTP). the difference between the two trip points is called hysteresis.

$$UTP = \frac{R_2}{R_1+R_2} V_{sat}$$

$$LTP = \frac{R_2}{R_1+R_2}(-V_{sat})$$

$$\begin{aligned} V_{hys} &= UTP - LTP \\ &= \frac{R_2}{R_1+R_2} V_{sat} - \frac{R_2}{R_1+R_2}(-V_{sat}) \\ &= 2\left(\frac{R_2}{R_1+R_2}\right) V_{sat} \\ &= 2\beta V_{sat} \end{aligned}$$

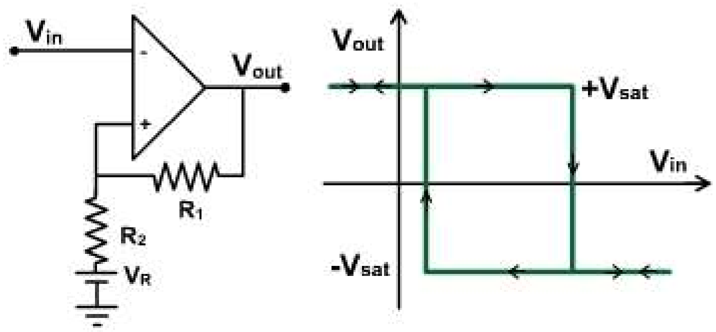

Fig. 5

The hysteresis loop can be shifted to either side of zero point by connecting a voltage source as shown in [fig. 5](#).

When $V_O = +V_{sat}$, the reference. Voltage (UTP) is given by

$$\begin{aligned} UTP &= \frac{(V_{sat} - V_R)R_2}{R_1+R_2} + V_R \\ &= \beta V_{sat} + \frac{R_1 V_R}{R_1+R_2} \end{aligned}$$

When $V_O = -V_{sat}$, the reference. Voltage (UTP) is given by

$$\begin{aligned} LTP &= \frac{(-V_{sat} - V_R)R_2}{R_1+R_2} + V_R \\ &= -\beta V_{sat} + \frac{R_1 V_R}{R_1+R_2} \end{aligned}$$

If V_R is positive the loop is shifted to right side; if V_R is negative, the loop is shifted to left side. The hysteresis voltage V_{hys} remains the same.

Non-inverting Schmitt trigger:

In this case, again the feedback is given at non-inverting terminal. The inverting terminal is grounded and the input voltage is connected to non-inverting input. [Fig. 6](#), shows an non-inverting schmitt trigger circuit.

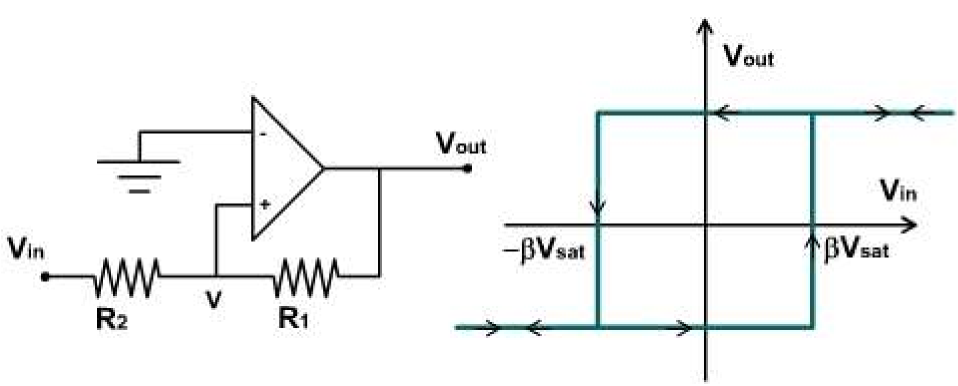

Fig. 6

To analyze the circuit behaviour, let us assume the output is negatively saturated. Then the feedback voltage is also negative ($-V_{sat}$). Then the feedback voltage is also negative. This feedback voltage will hold the output in negative saturation until the input voltage becomes positive enough to make voltage positive.

$$\begin{aligned} V_+ &= \frac{(-V_{sat} - v_{in})}{R_1 + R_2} R_2 + v_{in} \\ &= \frac{-V_{sat} R_2}{R_1 + R_2} + \frac{v_{in} R_1}{R_1 + R_2} \\ &= \frac{R_1}{R_1 + R_2} (-R_2 V_{sat} + R_1 v_{in}) \\ &= \frac{R_1}{R_1 + R_2} \left(-\frac{R_2 V_{sat}}{R_1} + v_{in} \right) \end{aligned}$$

When v_{in} becomes positive and its magnitude is greater than $(R_2 / R_1)\ V_{sat}$, then the output switches to $+V_{sat}$. Therefore, the UTP at which the output switches to $+V_{sat}$, is given by

$$UTP = \left(\frac{R_2 V_{sat}}{R_1} \right)$$

Simillarly, when the output is in positive saturation, feedback voltage is positive. To switch output states, the input voltage has to become negative enough to make. When it happens, the output changes to the negative state from positive saturation to negative saturation voltage negative.

$$\begin{aligned} V_+ &= \frac{(V_{sat} - v_{in})}{R_1 + R_2} R_2 + v_{in} \\ &= \frac{V_{sat} R_2}{R_1 + R_2} + \frac{v_{in} R_1}{R_1 + R_2} \\ &= \frac{R_1}{R_1 + R_2} (R_2 V_{sat} + R_1 v_{in}) \\ &= \frac{R_1}{R_1 + R_2} \left(\frac{R_2 V_{sat}}{R_1} + v_{in} \right) \end{aligned}$$

When v_{in} becomes negative and its magnitude is greater than $R_2 / R_1\ v_{sat}$, then the output switches to $-v_{sat}$. Therefore,

$$LTP = \left(-\frac{R_2 V_{sat}}{R_1} \right)$$

The difference of UTP and LTP gives the hysteresis of the Schmitt trigger.

$$\begin{aligned} V_{hys} &= UTP - LTP \\ &= 2\left(\frac{R_2}{R_1} \right) V_{sat} \\ &= 2\beta V_{sat} \end{aligned}$$

In non inverting Schmitt trigger circuit, the β is defined as

$$\beta = \frac{R_2}{R_1}$$

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Example - 1

Design a voltage level detector with noise immunity that indicates when an input signal crosses the nominal threshold of – 2.5 V. The output is to switch from high to low when the signal crosses the threshold in the positive direction, and vice versa. Noise level expected is 0.2 V_{PP}, maximum. Assume the output levels are V_H = 10 V and V_L = 0V.

Solution:

For the triggering action required an inverting configuration is required. Let the hysteresis voltage be 20% larger that the maximum pp noise voltage, that is, V_{hys} = 0.24V.

Thus, the upper and lower trigger level voltages are -2.5 ± 0.12, or

UTP = 2.38 V and LTP = -2.62 V

Since the output levels are V_H and V_L instead of $+V_{sat}$ and $–V_{sat}$, therefore, hysteresis voltage is given by

$$V_{hys} = \frac{R_2}{R_1 + R_2}(V_H - V_L)$$

or $$\frac{V_H - V_L}{V_{hys}} = 1 + \frac{R_1}{R_2}$$

and $$\frac{R_1}{R_2} = \frac{10 - 0}{0.24} - 1 = 40.7$$

The reference voltage V R can be obtained from the expression of LTP.

$$LTP = \beta V_L + \frac{R_1 V_R}{R_1 + R_2}$$

Given that V_L = 0, and LTP= -262, we obtain

$V_R = (1 + R_2 / R_1)$ LTP = (1 + 1 / 40.7) (-2.62) = - 2.68 V

We can select any values for R_2 and R_1 that satisfy the ratio of 40.7. It is a good practice to have more than 100 kΩ for the sum of R_1 and R_2 and 1 kΩ to 3kΩ for the pull up resistor on the output. The circuit shown in fig. 7 shows a possible final design. The potentiometer serves as a fine adjustment for V_R, while the voltage follower makes V_R to appear as an almost ideal voltage source.

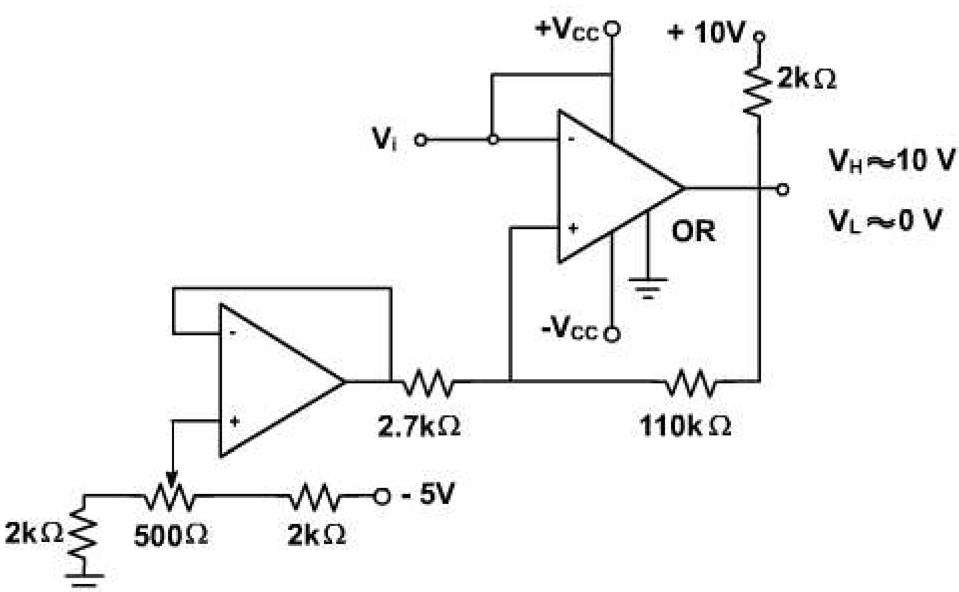

Fig. 7

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