

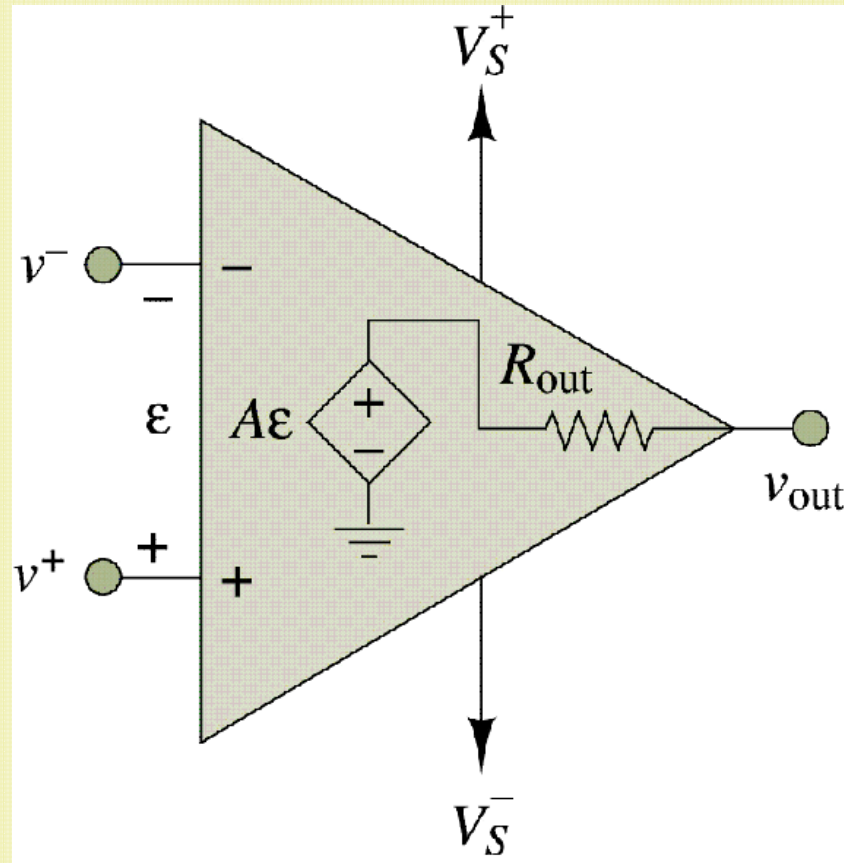
# Comparator and Schmitt Trigger

- Comparator circuits find frequent application in measurement and instrumentation systems.
- Learning Objectives
  - Understand the Op-Amp Comparator with and without an offset and its uses
  - Understand the Schmitt Trigger and its benefits in noise rejection and improved switching speed

## • Op-Amp Comparator

- The prototype of op-amp switching circuits is the op-amp comparator.
- The circuit does not employ feedback.

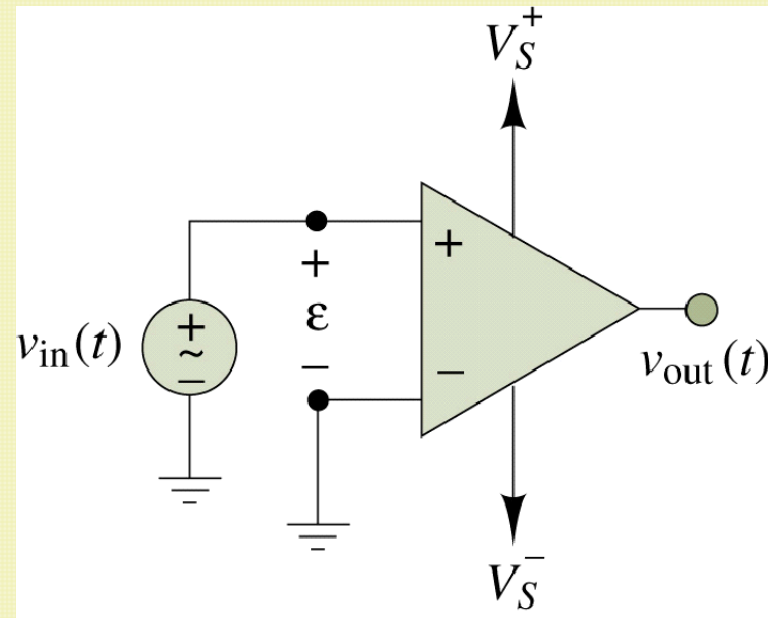
$$V_{\text{out}} = A(V^+ - V^-)$$



- Because of the large gain that characterizes open-loop performance of the op-amp ( $A > 10^5$ ), any small difference between the input voltages will cause large outputs; the op-amp will go into saturation at either extreme, according to the voltage supply values and the polarity of the voltage difference.
- One can take advantage of this property to generate **switching waveforms**.
- Consider the following.

### Non-inverting Op-Amp Comparator

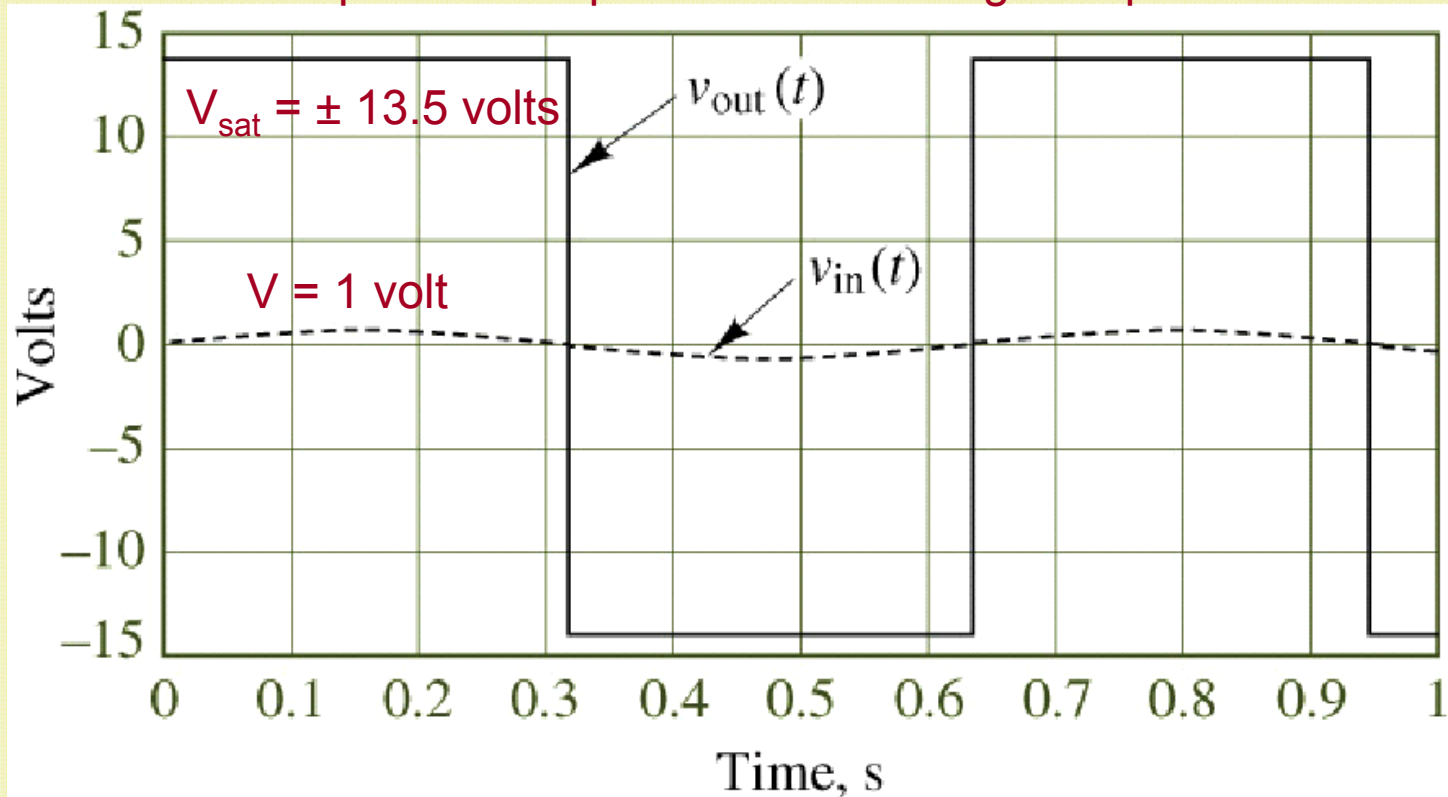
$$\varepsilon = V \cos(\omega t)$$





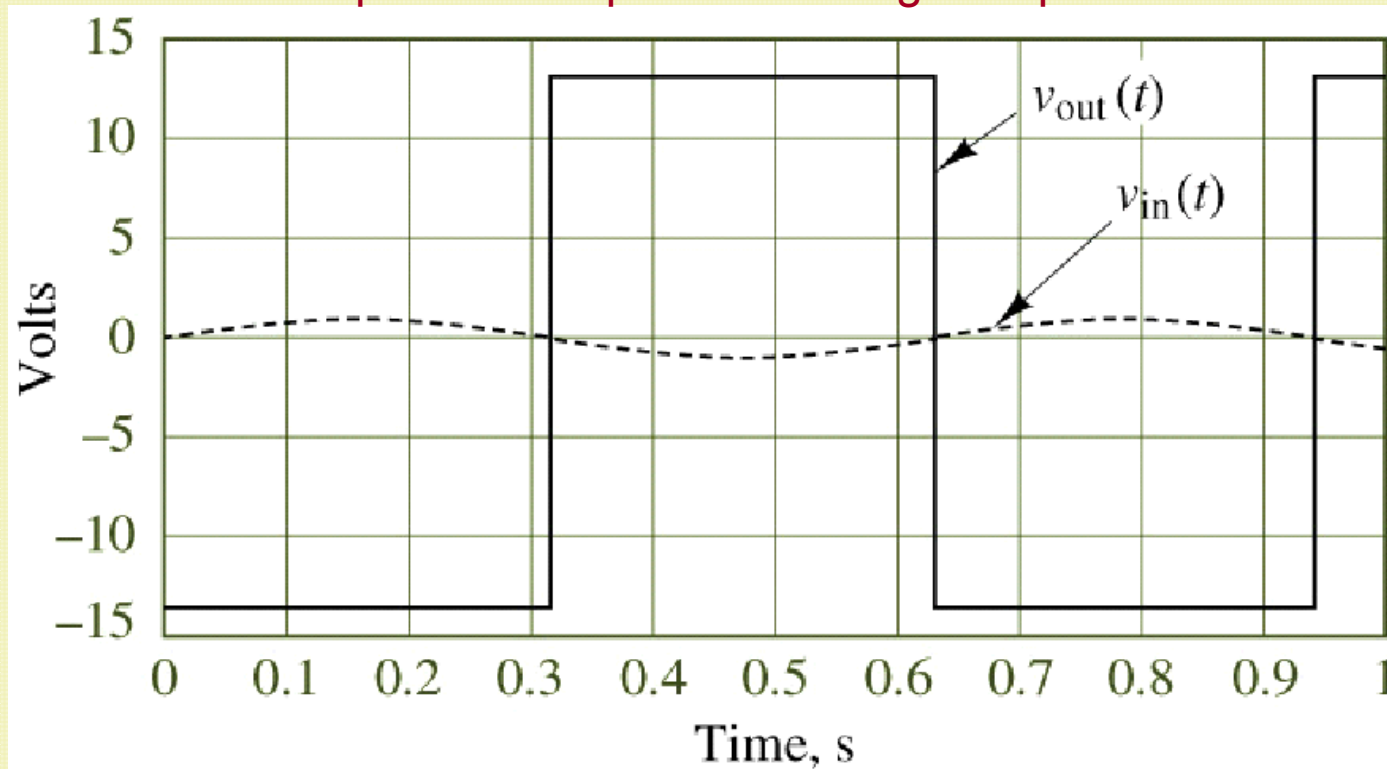
- The comparator is perhaps the simplest form on an analog-to-digital converter, i.e., a circuit that converts a continuous waveform to discrete values. The comparator output consists of only two discrete levels.

Input and Output of Non-Inverting Comparator



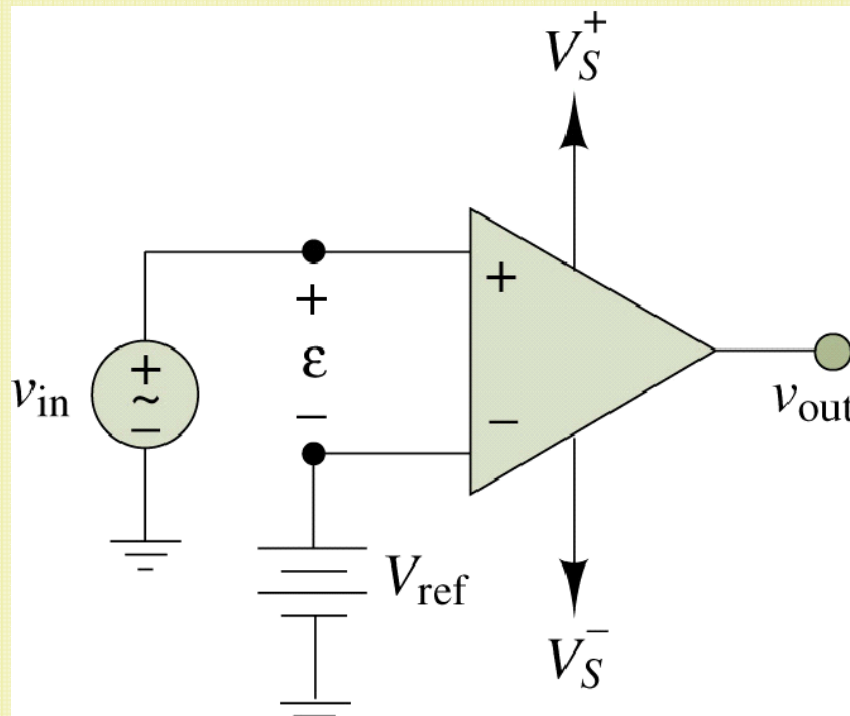
- It is possible to construct an inverting comparator by connecting the non-inverting terminal to ground and connecting the input to the inverting terminal.

Input and Output of Inverting Comparator

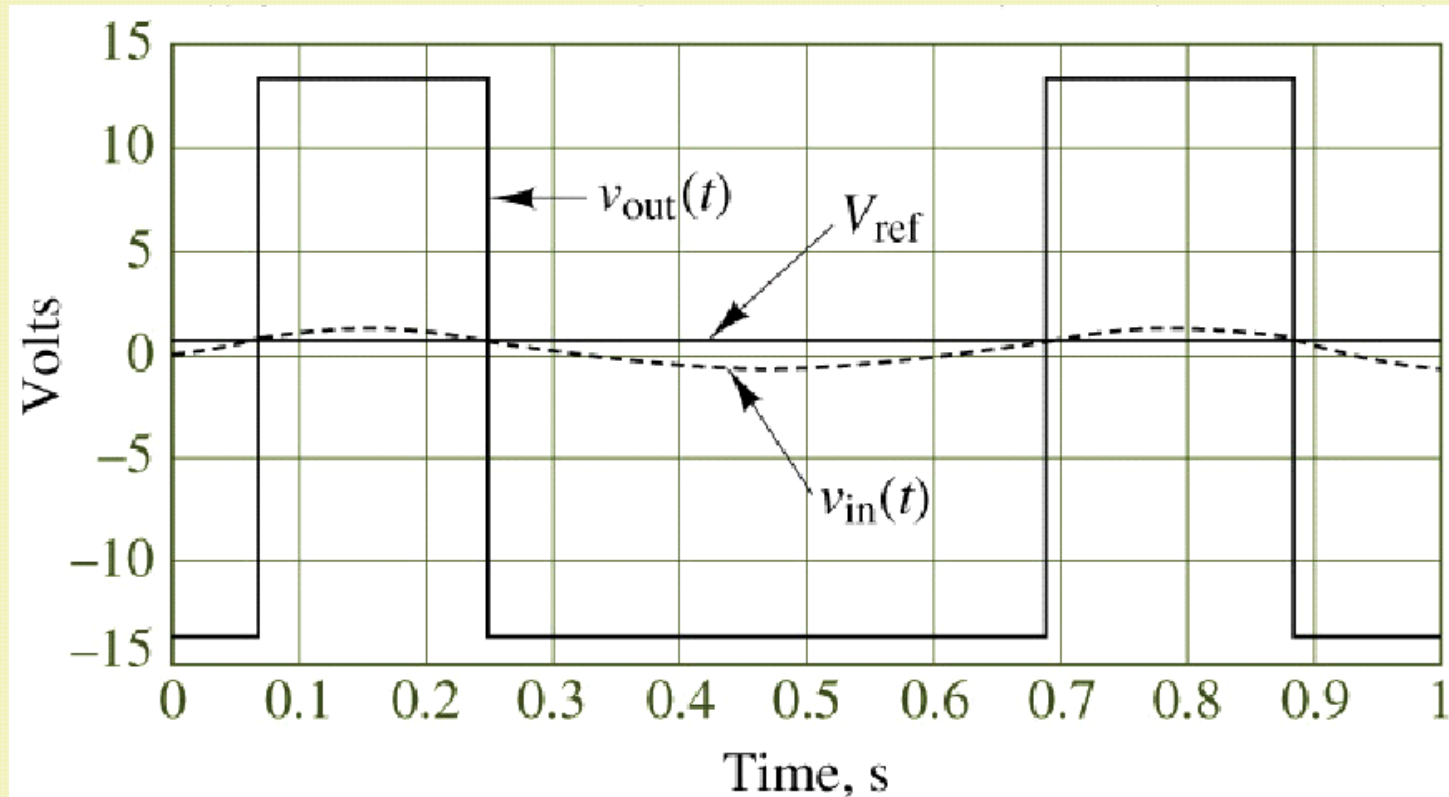


## – Comparator with Offset

- A simple modification of the comparator circuit consists of connecting a fixed reference voltage to one of the input terminals; the effect of the reference voltage is to raise or lower the voltage level at which the comparator will switch from one extreme to the other.



- Below is the waveform of a comparator with a reference voltage of 0.6 V and an input voltage of  $\sin(\omega t)$ .

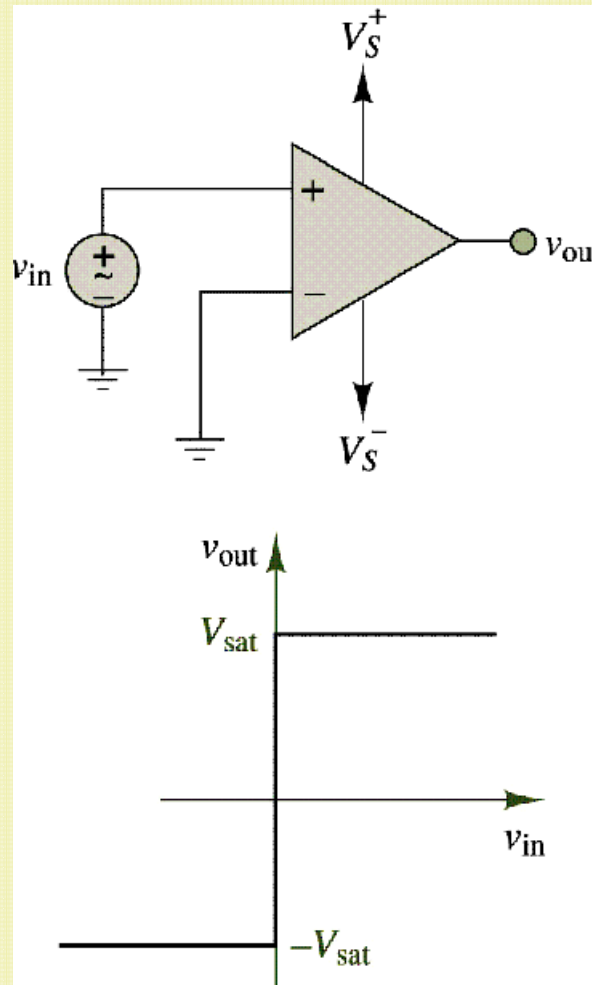


- Note that the comparator output is no longer a symmetric square wave.



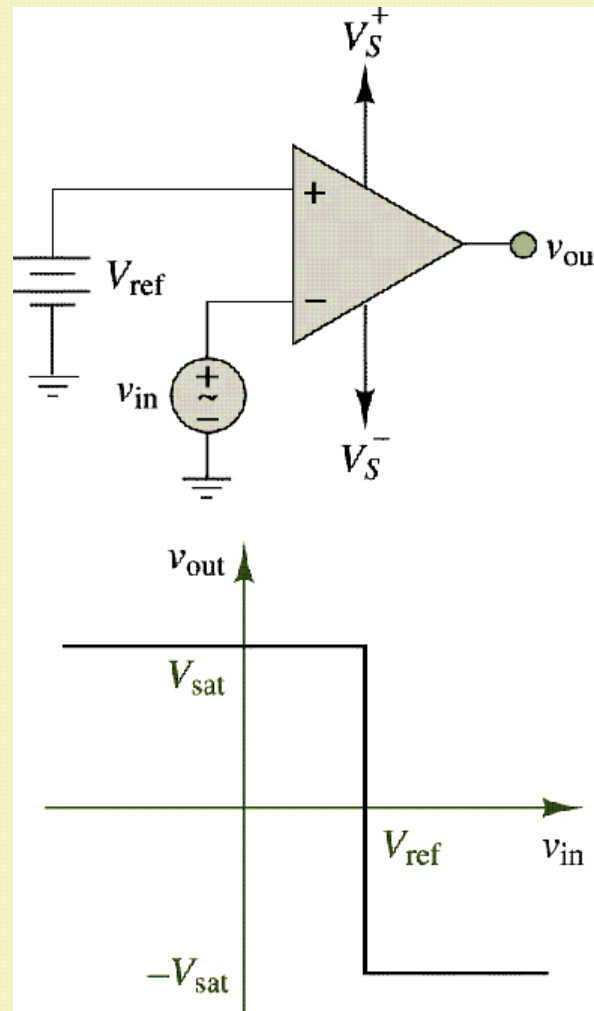
- Another useful interpretation of the op-amp comparator can be obtained by considering its input-output transfer characteristic.

Non-Inverting Zero-Reference  
(no offset) Comparator  
often called a  
zero-crossing comparator





- Shown below is the transfer characteristic for a comparator of the inverting type with a nonzero reference voltage.



- Very often, in converting an analog signal to a binary representation, one would like to use voltage levels other than  $\pm V_{\text{sat}}$ . Commonly used voltage levels in this type of switching circuit are 0 and 5V.
- Special-purpose integrated-circuit packages are available that are specially designed to serve as comparators. These typically can accept relatively large inputs and have provision for selecting the desired reference voltage levels.
- An example is the LM311, which provides an open-collector output. The open-collector output allows the user to connect the output transistor to any supply voltage of choice by means of an external pull-up resistor, thus completing the output circuit.

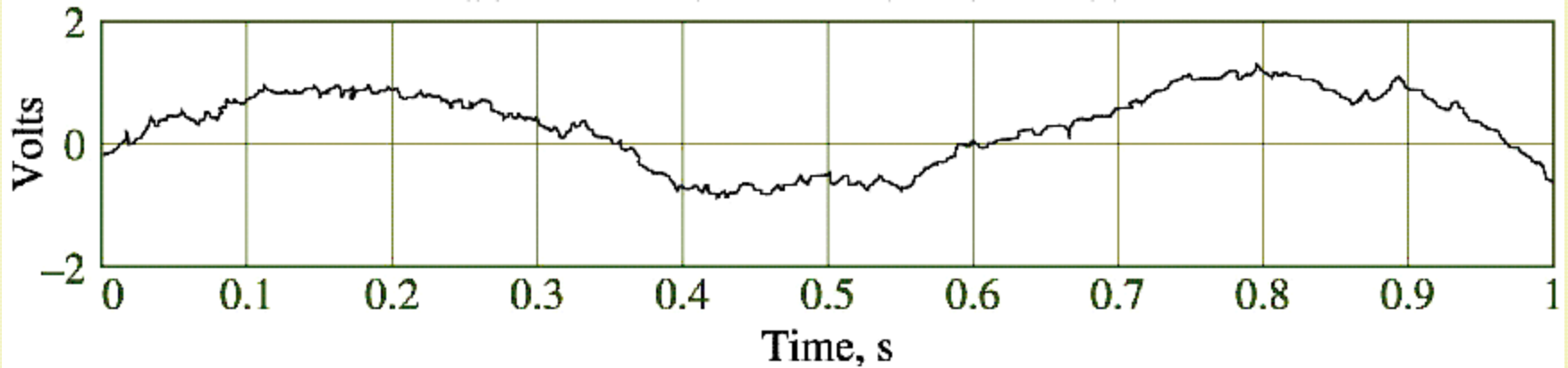
- The actual value of the resistor is not critical, since the transistor is operated in the saturation mode; values between a few hundred and a few thousand ohms are typical.



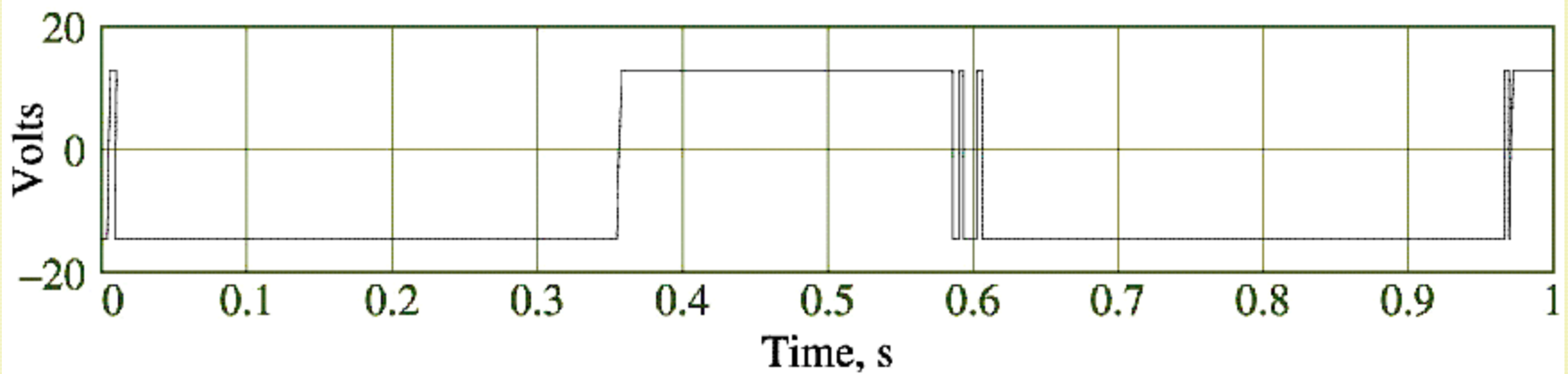
- Schmitt Trigger

- One of the typical applications of the op-amp comparator is in detecting when an input voltage exceeds a present threshold voltage. The desired threshold is then represented by a DC reference  $V_{ref}$  connected to the non-inverting input, and the input voltage source is connected to the inverting input.
- The presence of noise and a finite slew rate of practical op-amps requires special attention.
- Two improvements are discussed:
  - How to improve the switching speed of the comparator.
  - How to design a circuit that can operate correctly even in the presence of noisy signals.

## Comparator Response to Noisy Inputs



Noisy input waveform

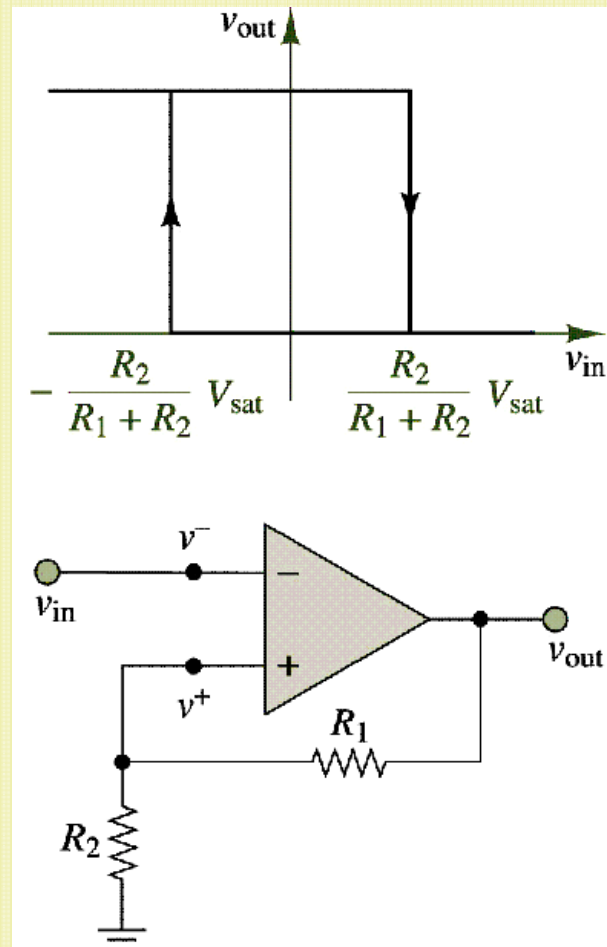


Comparator output waveform

- One very effective way of improving the performance of the comparator is by introducing positive feedback. Positive feedback can increase the switching speed of the comparator and provide noise immunity at the same time.

## Transfer Characteristic of the Schmitt Trigger

Can you explain how this works?





- If it is desired to switch about a voltage other than zero, a reference voltage can also be connected to the non-inverting terminal.

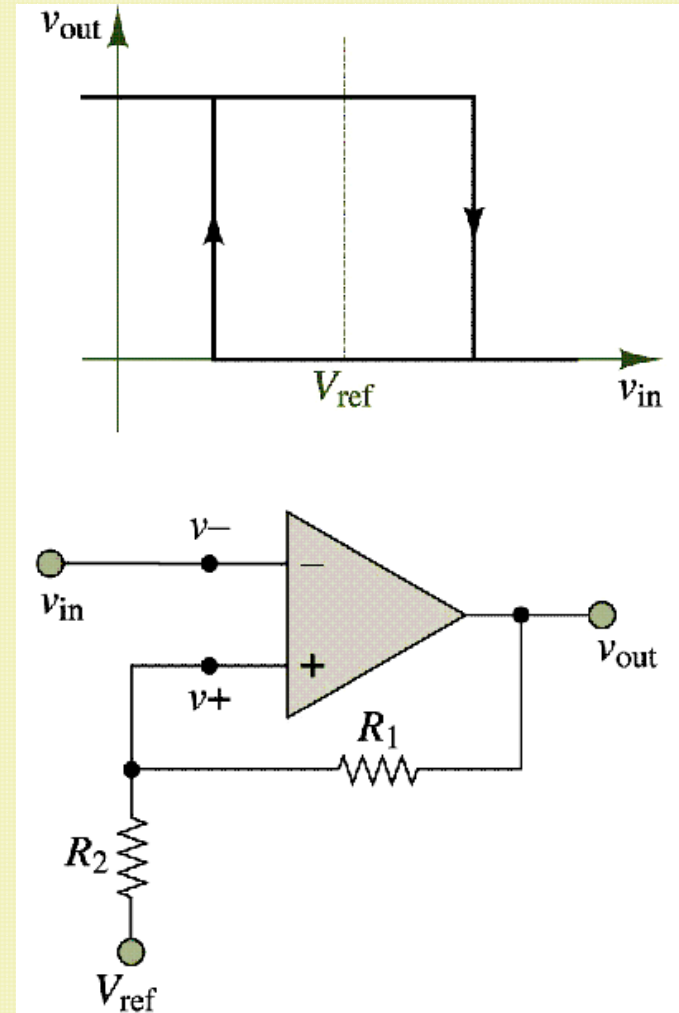
Switching levels for the Schmitt Trigger are:

$$V_{in} > \frac{R_2}{R_2 + R_1} V_{sat} + V_{ref} \frac{R_1}{R_2 + R_1}$$

positive-going transition

$$V_{in} < -\frac{R_2}{R_2 + R_1} V_{sat} + V_{ref} \frac{R_1}{R_2 + R_1}$$

negative-going transition



- In effect, the Schmitt trigger provides a noise rejection range equal to  $\pm V_{\text{sat}} [R_2 / (R_2 + R_1)]$  within which the comparator cannot switch.
- Thus if the noise amplitude is contained within this range, the Schmitt trigger will prevent multiple triggering.

