Lecture 22

EC103

Topics remaining:

- Comparators
- Analog-Digital Converters
- Multivibrators

Comparators

Comparators

- Operational amplifiers are often used as non-linear devices to compare the amplitude of one voltage with another.

- In this application, Op-Amps are used in the open loop configuration, with the input voltage on one input and a reference voltage on the other.

Comparators

After completing this module (`Comparators'), you will be able to:

1. Understand the operation of several basic comparator circuits.
2. Describe the operation of a zero level detector.
3. Describe the operation of a non-zero level detector.
4. Discuss how input noise affects comparator operation.
5. Define *hysteresis*.

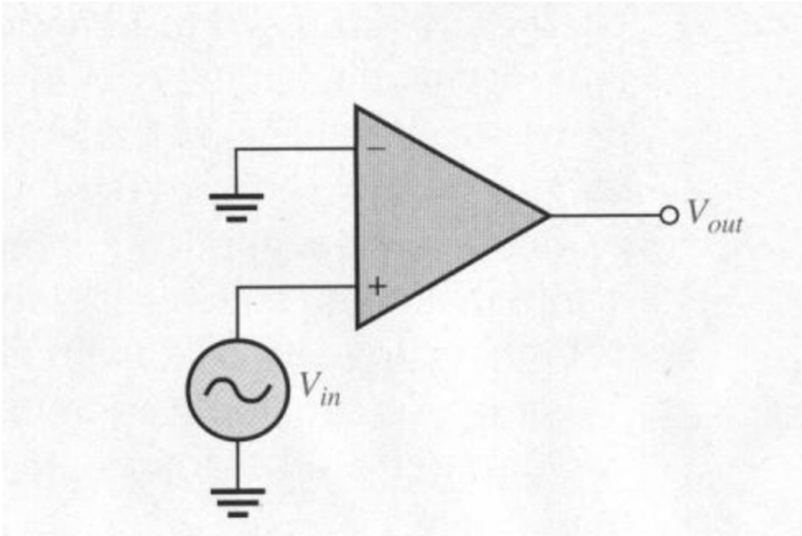
Comparators

After completing this module (`Comparators'), you will be able to: *(contd…)*

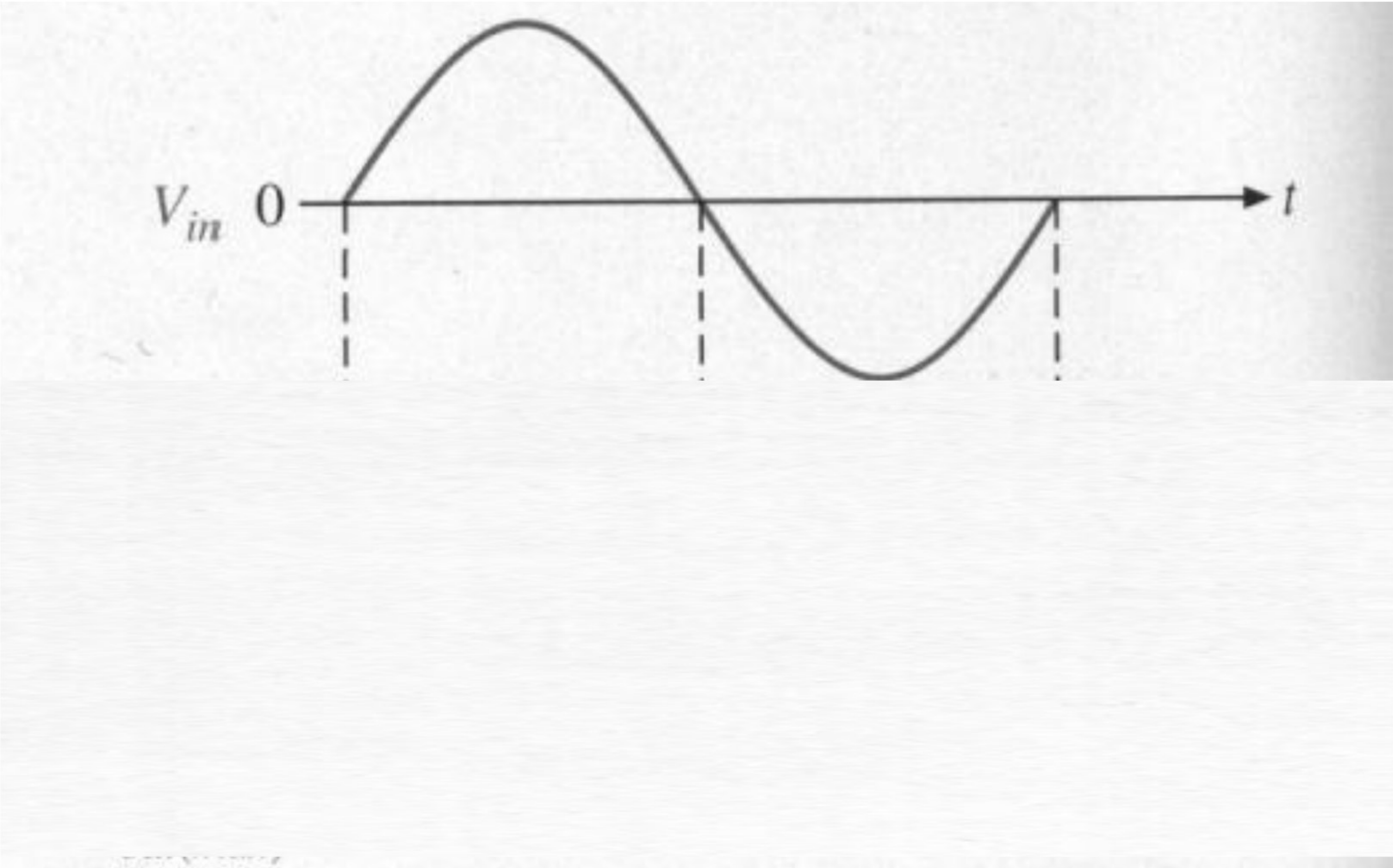
6. Describe a Schmitt trigger circuit.
7. Describe the operation of bounded comparators.
8. Describe the operation of a window comparator.
9. Describe some comparator applications.

Zero-Level Detection

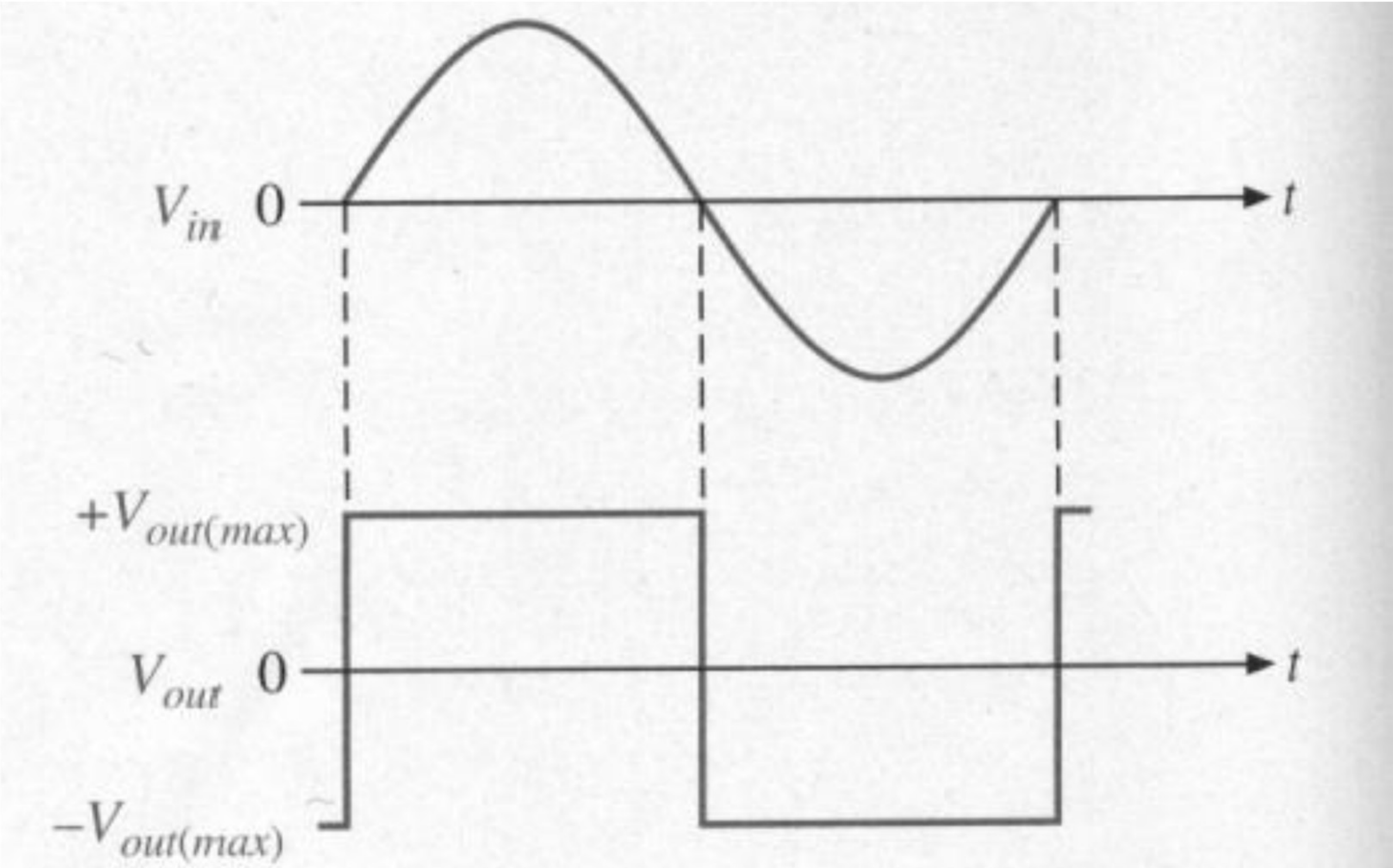
- One application of an Op-Amp used as a comparator is to determine when an input voltage exceeds a certain level.



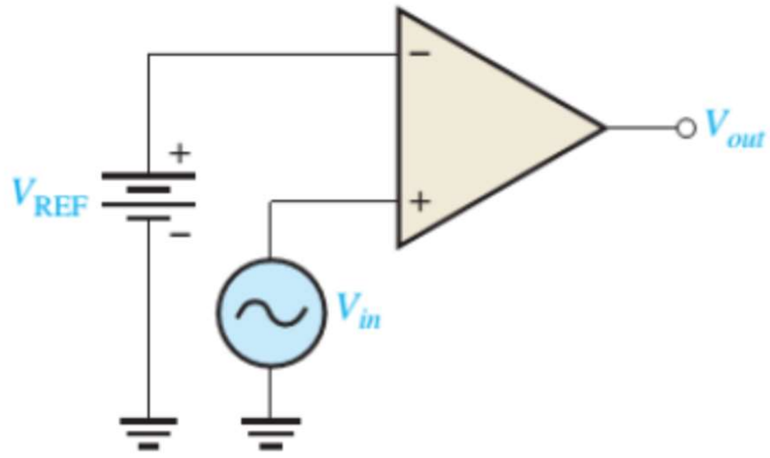
Zero-Level Detection



Zero-Level Detection

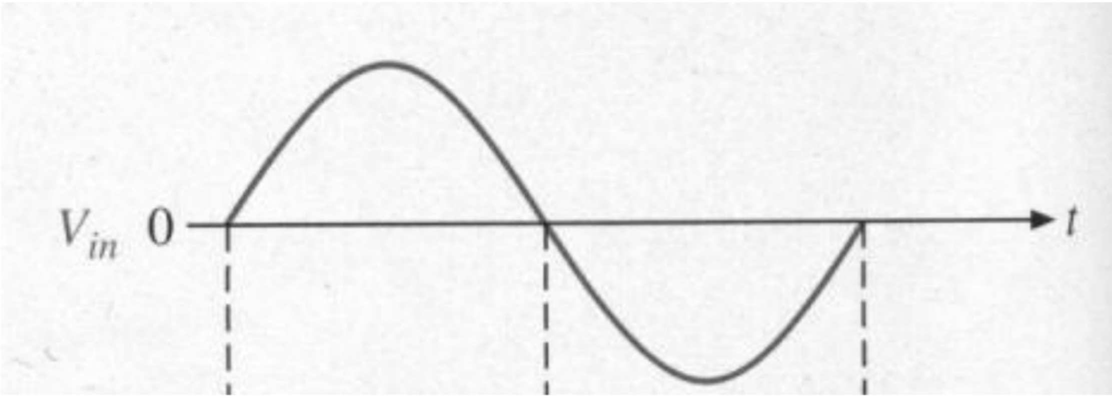


Nonzero-Level Detection

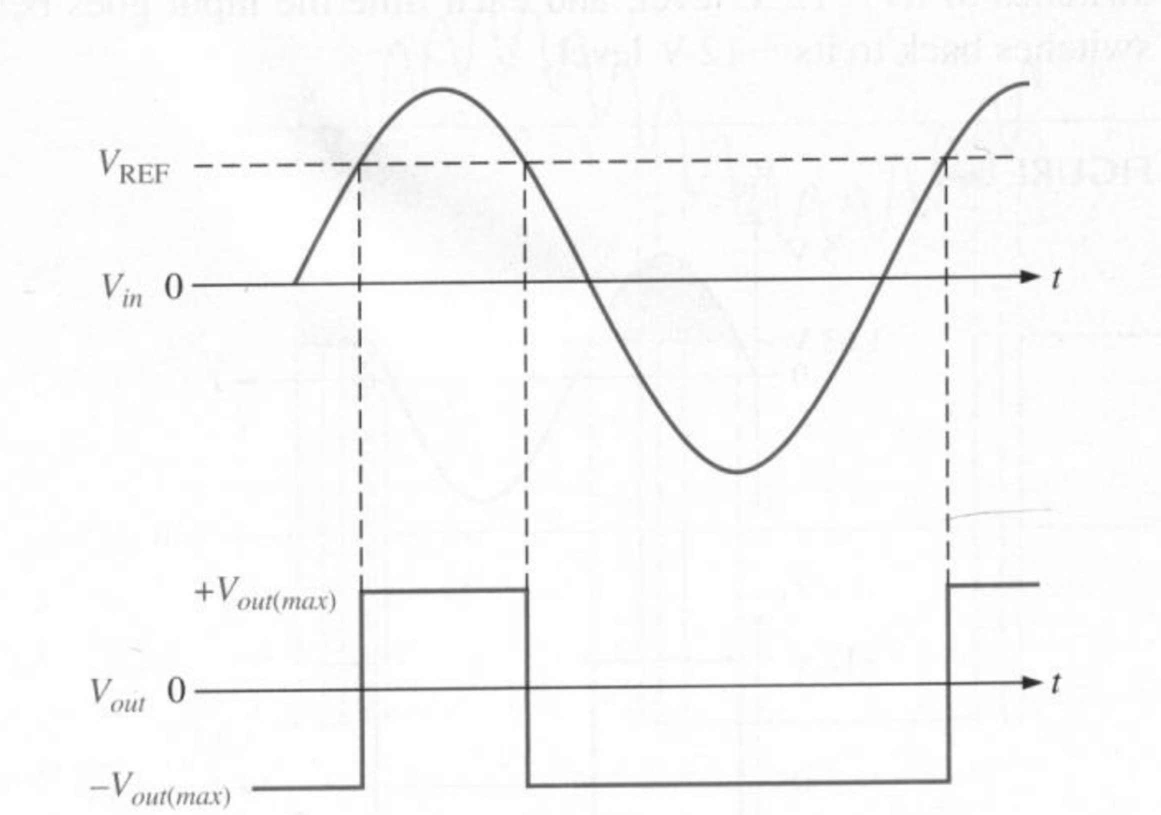


(a) Battery reference

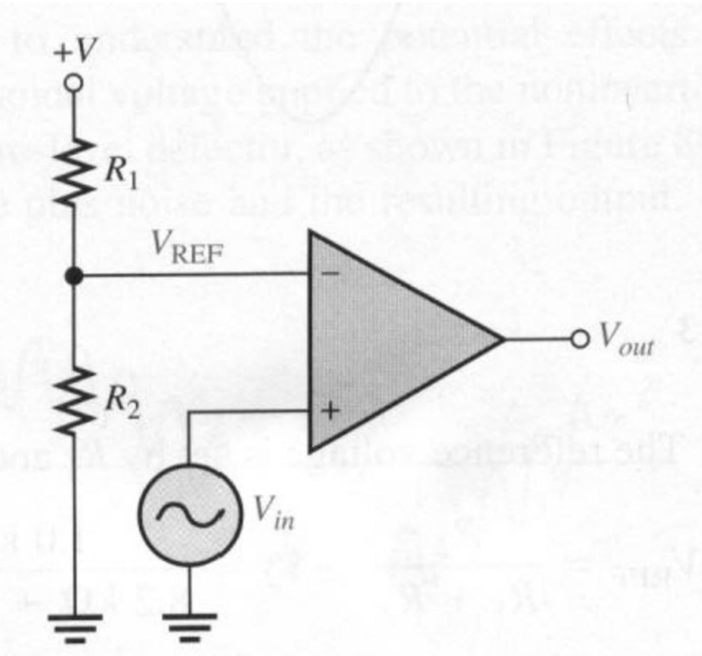
Nonzero-Level Detection



Nonzero-Level Detection

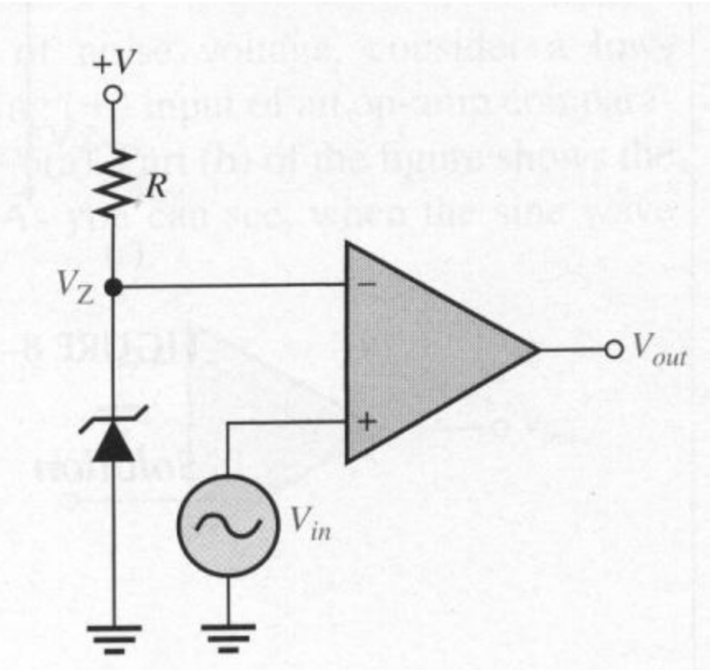


Nonzero-Level Detection



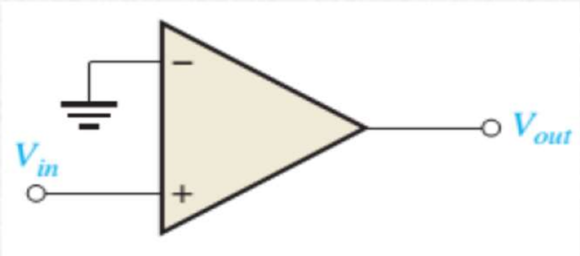
$$V_{REF} = \frac{R_2}{R_1 + R_2}(+V)$$

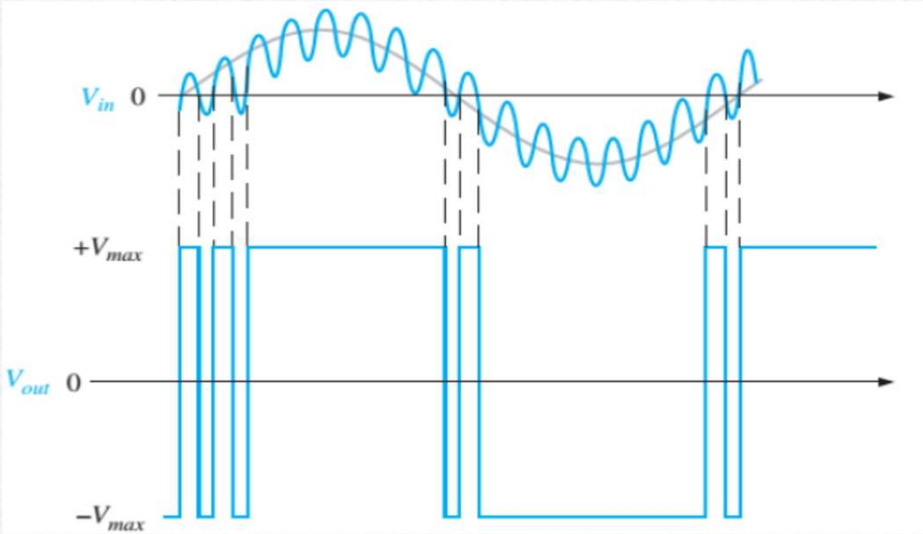
Nonzero-Level Detection



Effect of Input Noise on Comparator Operation

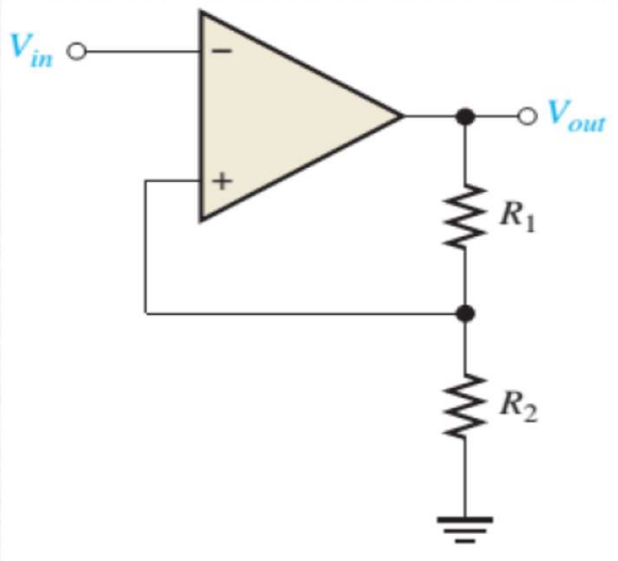
- Consider a zero-level detector and a sinusoidal voltage input at the noninverting input of the comparator
- The input sine wave and the resulting output voltage are shown.
- When the input voltage reaches zero, the disturbance due to noise may cause the input to fluctuate about the zero voltage value many times and thus producing an output that is not the desired one.





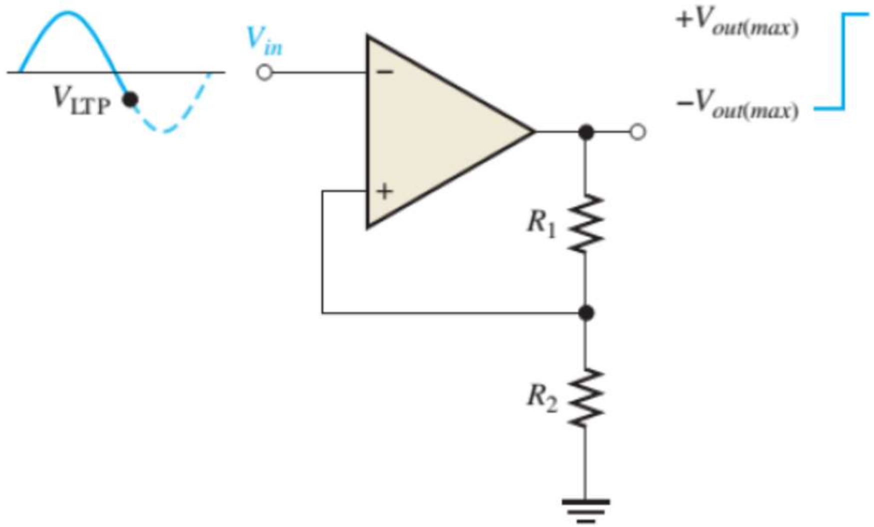
Reducing Noise Effects with Hysteresis

- Whenever the input signal hovers around the reference voltage, any small disturbance like noise will produce disturbed output.
- To reduce this noise effect, a technique called hysteresis is used.
- This requires the comparator to be used with positive feedback.
- The idea is to have 2 reference voltages. One reference is higher and the other is lower.

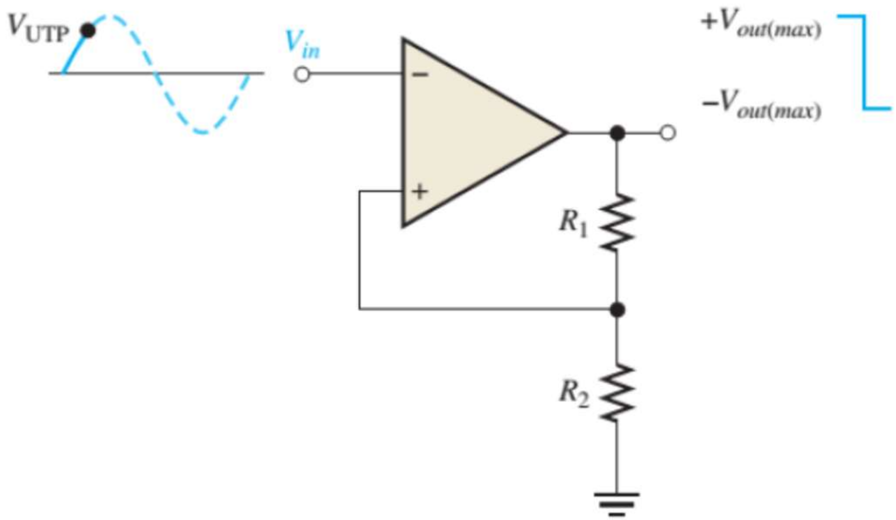


Comparator with Hysteresis

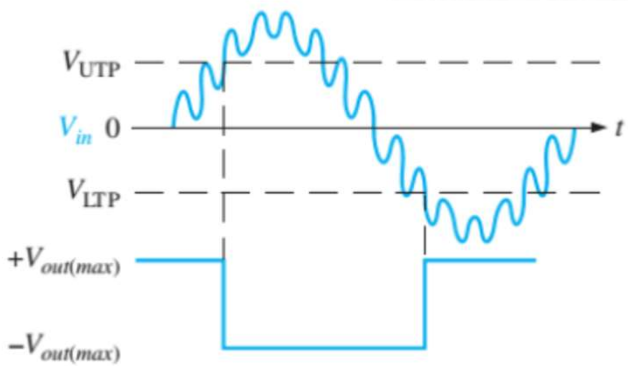
- The higher reference is for when the input signal goes from lower voltage to higher one and the lower reference is for when the input signal goes from higher to lower voltage.
- The two references are called upper trigger point (UTP) and lower trigger point (LTP).
- This two-level hysteresis is established with a positive feedback
- The noninverting end is connected to a resistive voltage divider such that a portion of the output voltage is fed back to the input.
- The input signal is applied to the inverting input.
- The basic operation of the comparator with hysteresis is shown in next slide



(b) When the output is at the maximum negative voltage and the input goes below LTP, the output switches back to the maximum positive voltage.



(a) When the output is at the maximum positive voltage and the input exceeds UTP, the output switches to the maximum negative voltage.



(c) Device triggers only once when UTP or LTP is reached; thus, there is immunity to noise that is riding on the input signal.

- Assume the output voltage is at its positive maximum, $V_{out(max)}$.
- The voltage fed back to the noninverting input is V_{UTP} and is given as

$$V_{UTP} = \frac{R_2}{R_1 + R_2}(+V_{out(max)})$$

- When V_{in} exceeds V_{UTP}, the output voltage drops to its negative maximum, $-V_{out(max)}$. The voltage fed back to the noninverting input is V_{LTP} and is given as

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

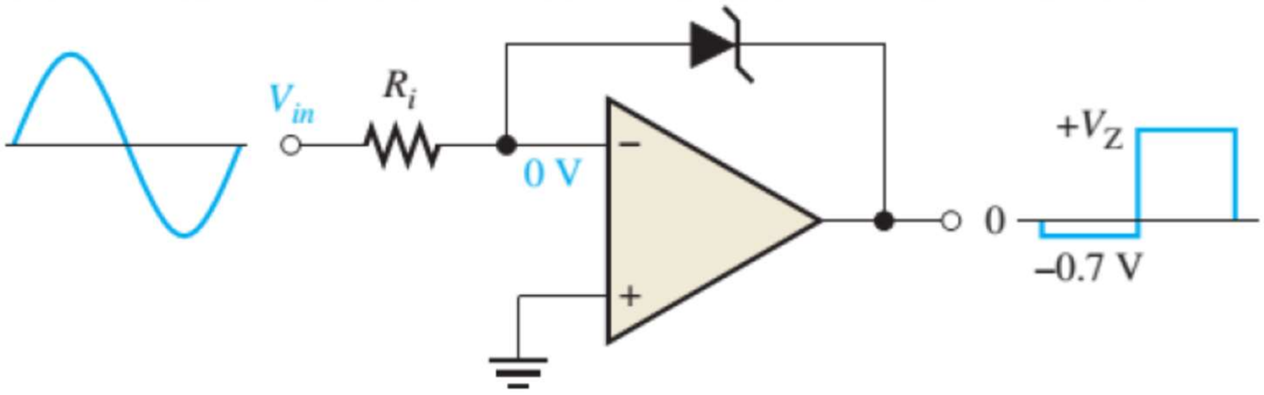
- The input voltage must now fall below V_{TLP} before the device will switch from maximum negative voltage to maximum positive voltage
- This means that a small amount of noise voltage has no effect on the output.
- The comparator with built-in hysteresis is sometimes known as a **Schmitt trigger**.
- The amount of hysteresis is defined as the difference of the two trigger levels.

$$V_{HYS} = V_{UTP} - V_{LTP}$$

Comparator with Output Bounding

- The output swing of a zero-crossing detector may be too large in some applications.
- In some applications, it is necessary to limit the output voltage levels of comparator to a value less than provided by the saturated op-amp.
- We can bound the output by using a zener diode – limit the output voltage to the zener voltage in one direction

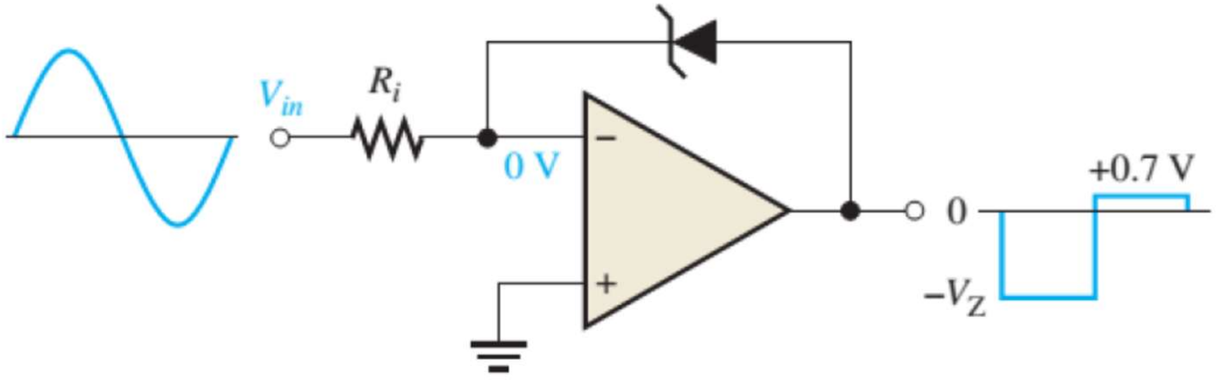
Bounded at Positive Value



(a) Bounded at a positive value

- The anode of the zener is connected to the inverting input.
- When output voltage reaches positive value equal to the zener voltage, it limits at that value
- At negative output, zener acts as a regular diode and becomes forward biased at 0.7V and limits the negative output voltage to this value.

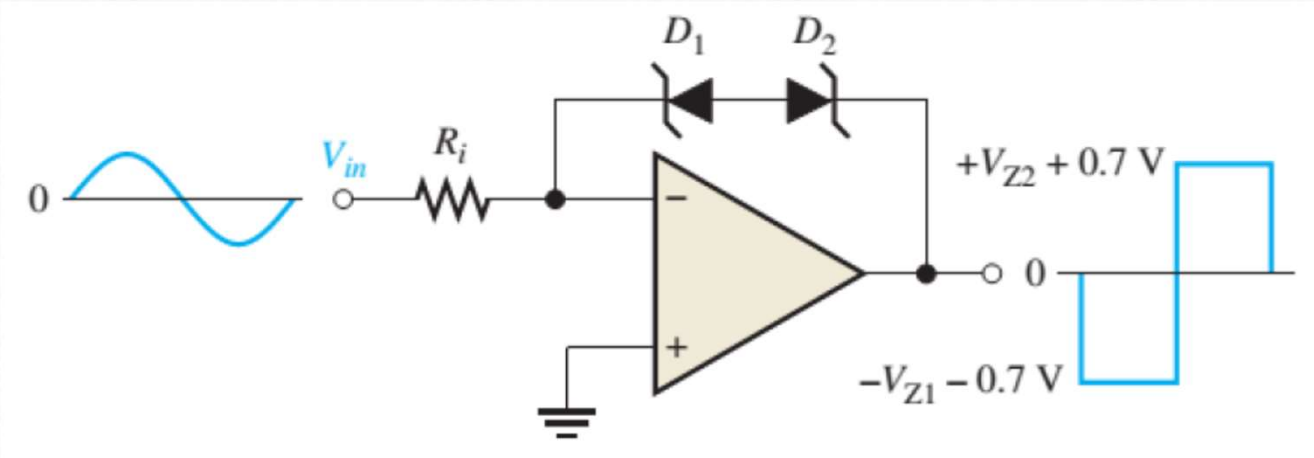
Bounded at Negative Value



(b) Bounded at a negative value

- ❑ The cathode of the zener is connected to the inverting input.
- ❑ The output voltage limits in the opposite direction.

Double Bounded

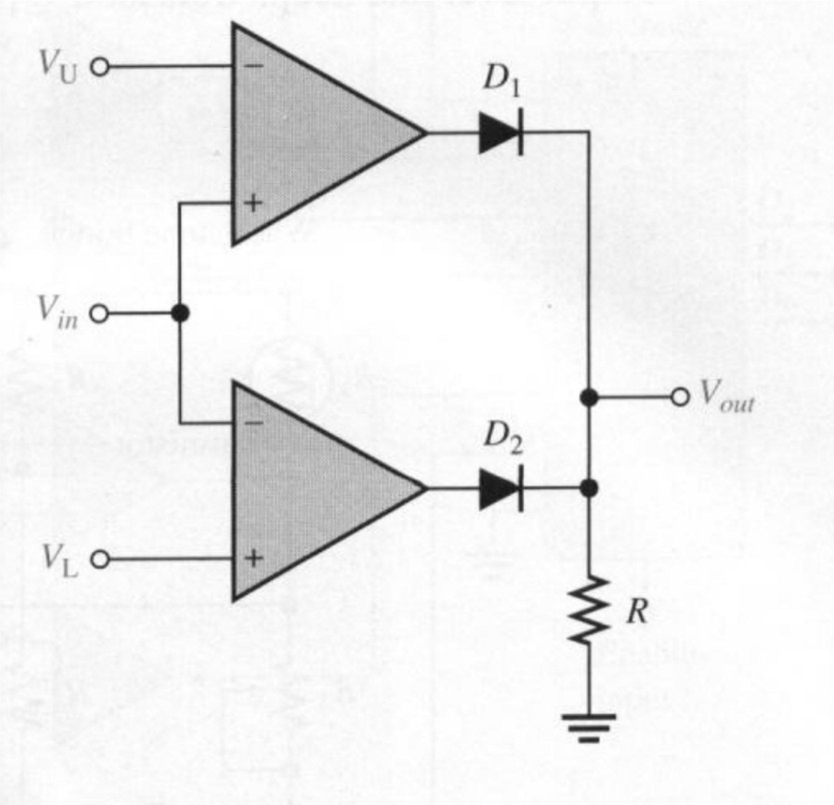


Two zener diodes arranged – limit the output voltage to the zener voltage plus forward biased 0.7V (positively and negatively).

Lecture 23

EC103

Window Comparator



- Two individual op-amp comparators arranged as in the adjacent figure form a `Window Comparator'.

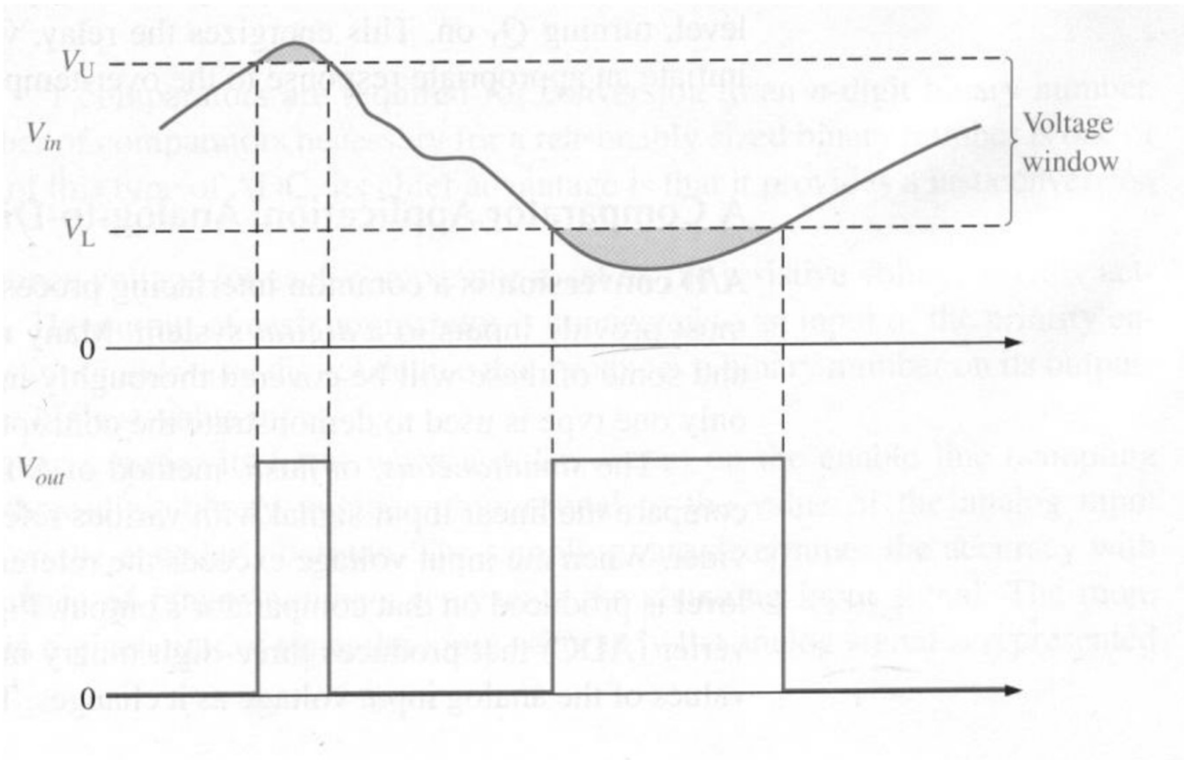
- The circuit detects when an input voltage is between a `window', i.e., between an upper limit and a lower limit.

- The upper and lower limits are set by two reference voltages.

- If lower limit < input voltage < upper limit, the output of each comparator is at its low saturation level. Both diodes are reverse biased, and the output is zero.

- If input voltage > upper limit , or, input voltage < lower limit, one of the comparators goes to its high saturation level, and the associated diode is forward biased and a high-level output is produced.

Window Comparator

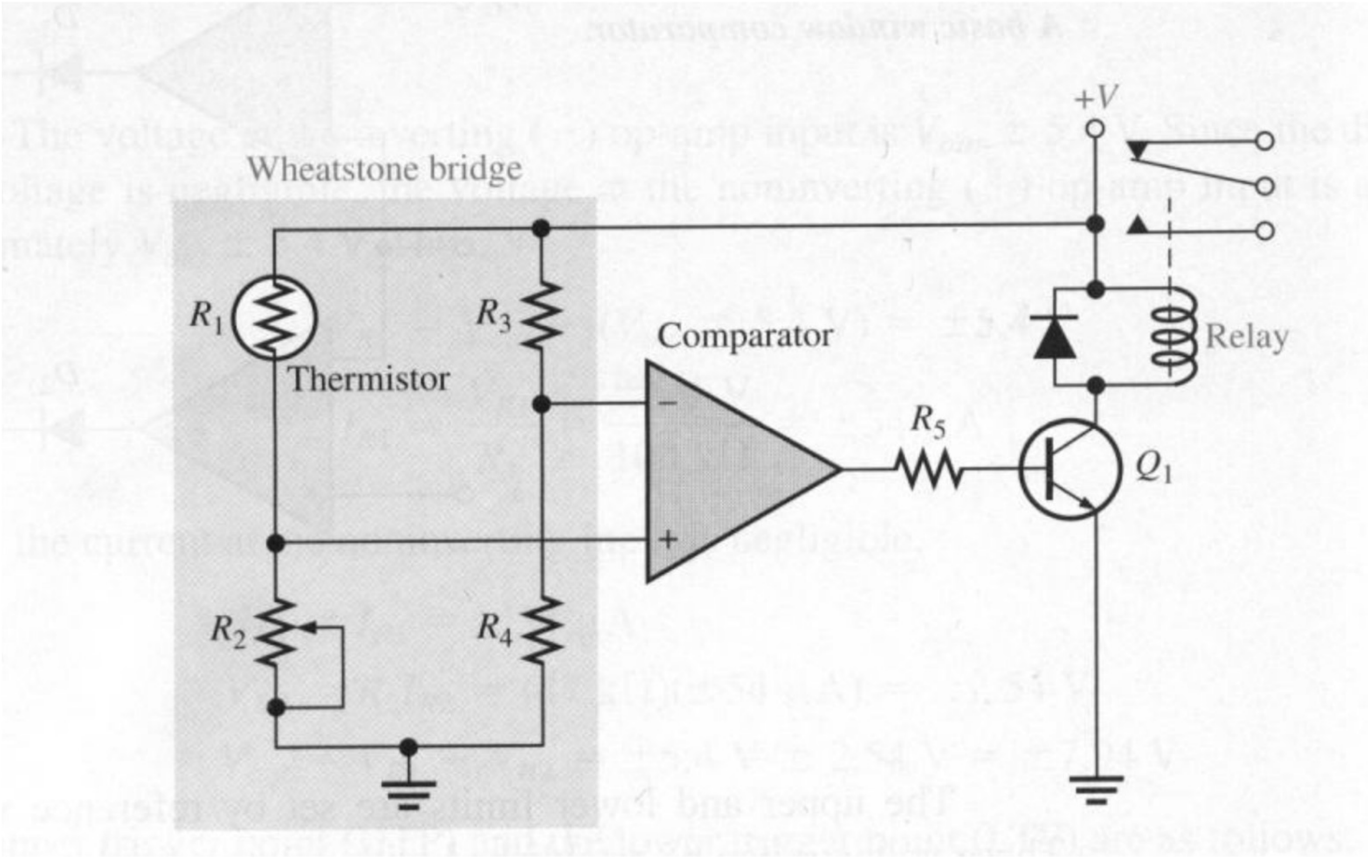


A Comparator Application: Over-Temperature Sensing Circuit

- Important components:

1. A Wheatstone bridge,
2. A thermistor,
3. An electromagnetic relay,
4. A transistor,
5. A comparator.

A Comparator Application: Over-Temperature Sensing Circuit



A Comparator Application: Over-Temperature Sensing Circuit

- The last figure shows an op-amp comparator used in a precision over-temperature sensing circuit to determine when the temperature reaches a certain critical value.
- The circuit consists of a Wheatstone bridge with the op-amp used to detect when the bridge is balanced.
- One leg of the bridge contains a thermistor (R1) which is a temperature-sensing resistor with a negative temperature coefficient (its resistance decreases as temperature increases).
- The potentiometer (R2) is set at a value equal to the resistance of the thermistor at the critical temperature.
- R3 = R4

A Comparator Application: Over-Temperature Sensing

- At normal temperature (below critical), R1 > R2, thus creating an unbalanced condition that drives the op-amp to its low saturated output level, and keeps transistor Q1 off.
- As the temperature increases, the R1 decreases. When the temperature reaches the critical value, R1=R2. The bridge becomes balanced since R3=R4.
- At this point, the op-amp switches to its high saturated output level, turning Q1 on.
- This energizes the relay, which can be used to activate an alarm or initiate an appropriate response to the over-temperature condition.

Another Comparator Application: Flash Analog to Digital Converters (ADC)

- We will study this in detail in the next module of ADCs and DACs (digital to analog converters)

Lecture 24

EC103

Analog Switches

- Analog switches are important in many types of electronic systems where it is necessary to switch signals on and off electronically.
- Major applications are in signal selecting, routing, and processing.
- They generally employ a FET as the basic switching component.

Analog Switches

After completing this sub-module (Analog Switches), you should be able to

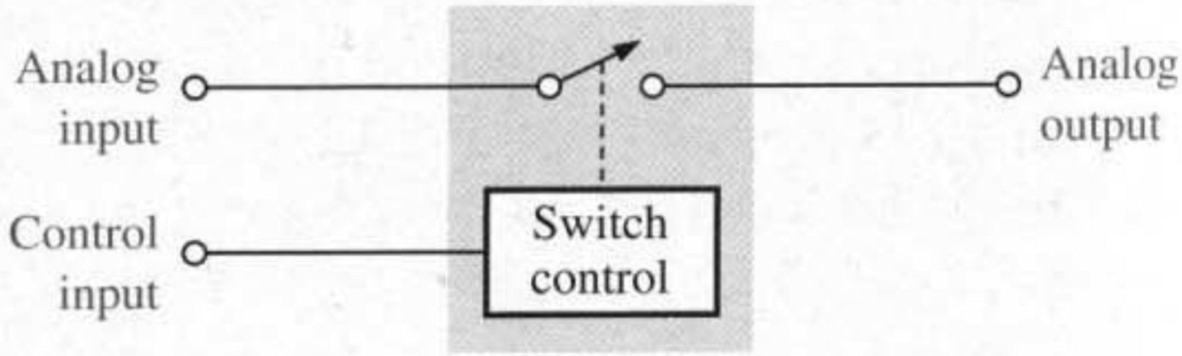
- Explain analog switches and identify each type
- Identify single-pole-single-throw analog switch
- Identify single-pole-double-throw analog switch
- Identify double-pole-single-throw analog switch
- Discuss multiple channel analog switches

Types of Analog Switches

- Four basic types of analog switches are:

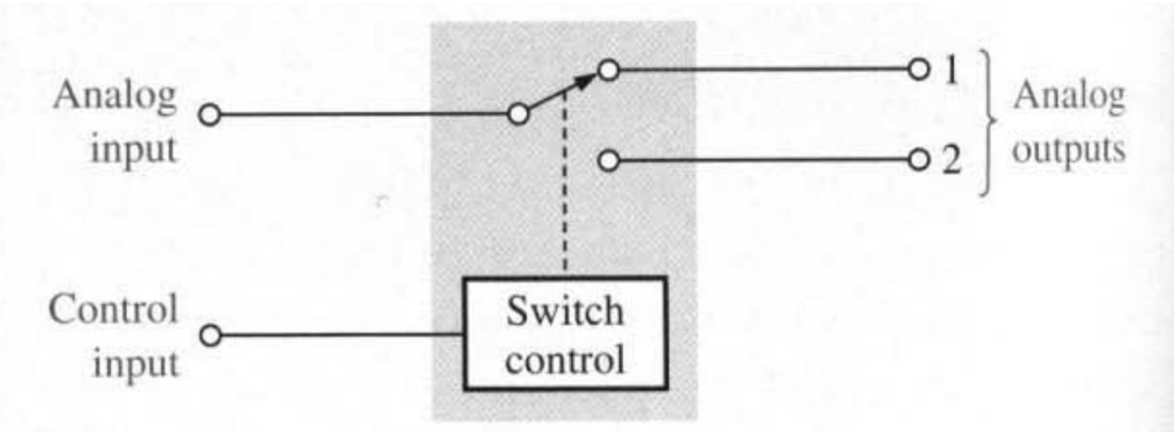
1. single-pole-single-throw(SPST) analog switches,
2. single-pole-double-throw(SPDT) analog switches
3. double-pole-single-throw(DPST) analog switches
4. double-pole-double-throw(DPDT) analog switches

SPST

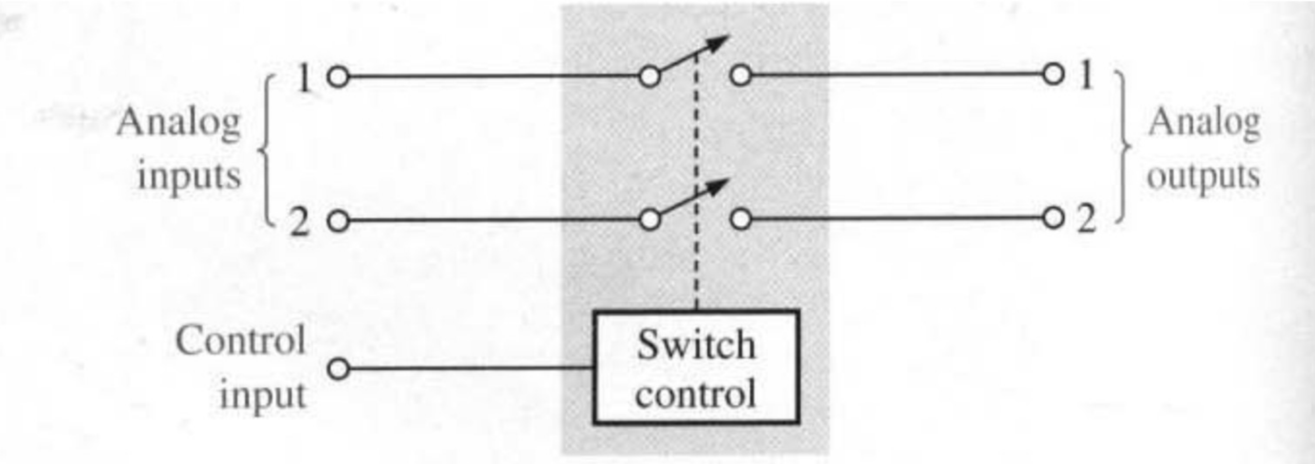


(a) Single pole–single throw (SPST)

SPDT


Analog input
Control input
Switch control
1
2
Analog outputs

DPST



(c) Double pole–single throw (DPST)

DPDT

- Draw yourself.

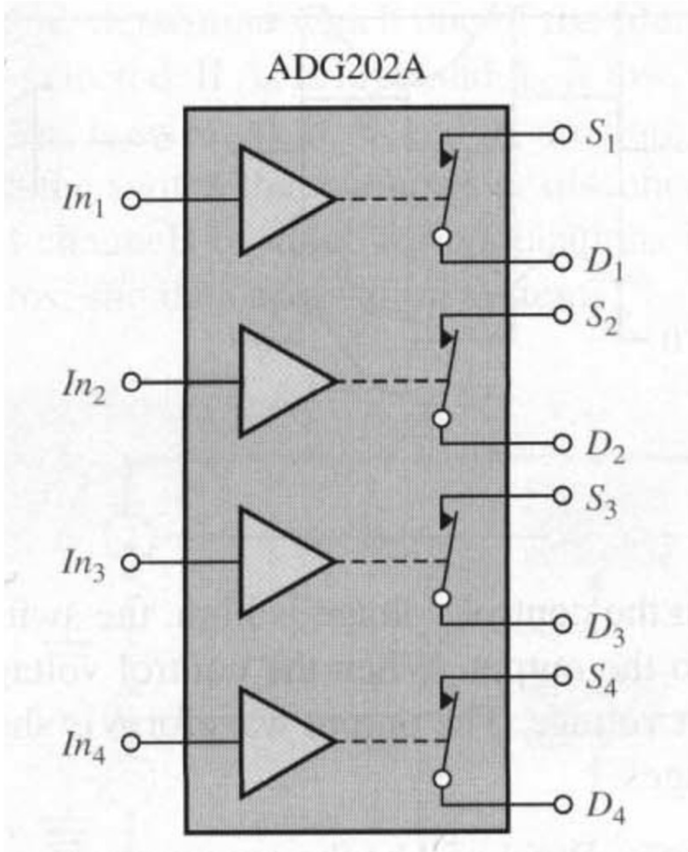
ADG202A

- An example of an analog switch is ADG202A.

- This IC device has four independently operated normally closed SPST switches.

- When the control voltage is at high (at least 2.4 V. for this device) level, the switch is `on'.
- When the control voltage is at low (no Greater than 0.8 V. for this device) level, the switch is `off'.

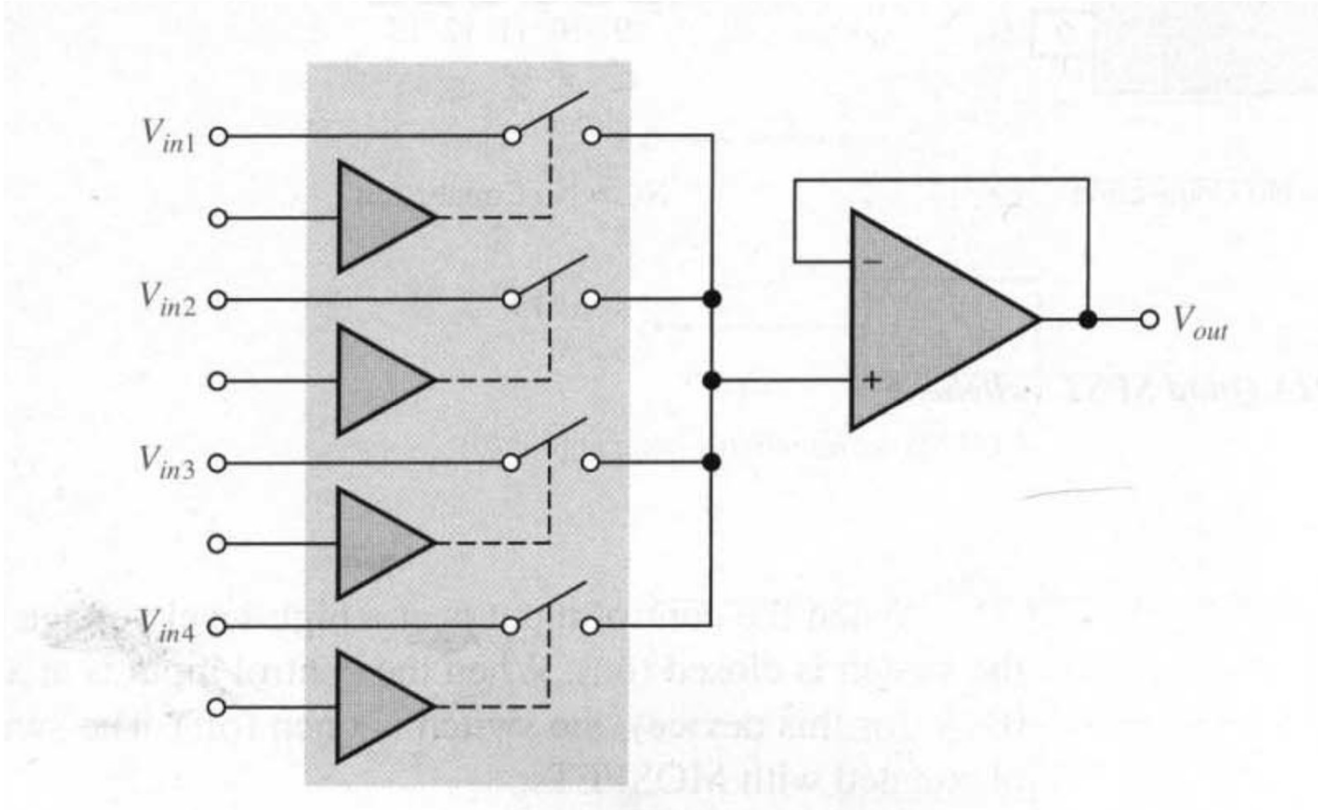
- The switches are generally implemented with MOSFETs.



Multiple Channel Analog Switches

- In data acquisition systems where inputs from several different sources must be independently converted to the digital form for processing, a technique called `multiplexing’ is used.
- A separate analog switch is used for each separate analog source.
- All of the outputs of the analog switches are connected together to form a common output.
- Only one switch can be closed at a given time.
- The common output is connected to the input of a voltage follower.
- A good examples of IC analog multiplexer is AD9300.

Multiple Channel Analog Switches



Sample-and-Hold Amplifiers

- A sample-and-hold amplifier samples an analog input voltage at a certain point in time and retains or holds the sampled voltage for an extended time after the sample is taken.

- The sample-and-hold process keeps the sampled analog voltage constant for the length of time necessary to allow an analog-to-digital converter (ADC) to convert the voltage to digital form.

Sample-and-Hold Amplifiers (SHA)

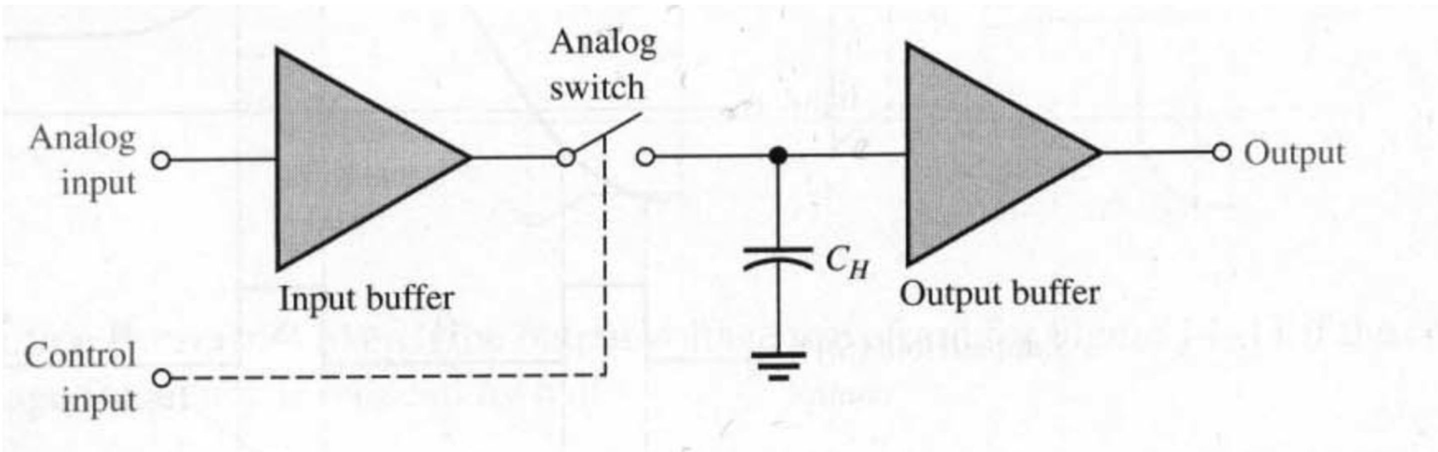
After completing this sub-module (SHA), you should be able to

- Discuss the operation of SHA
- Describe the tracking in a SHA
- Define *aperture time, aperture jitter, acquisition time, droop*, and *feedthrough.*

A Basic Sample-and-Hold Circuit

- A basic sample-and-hold circuit consists of

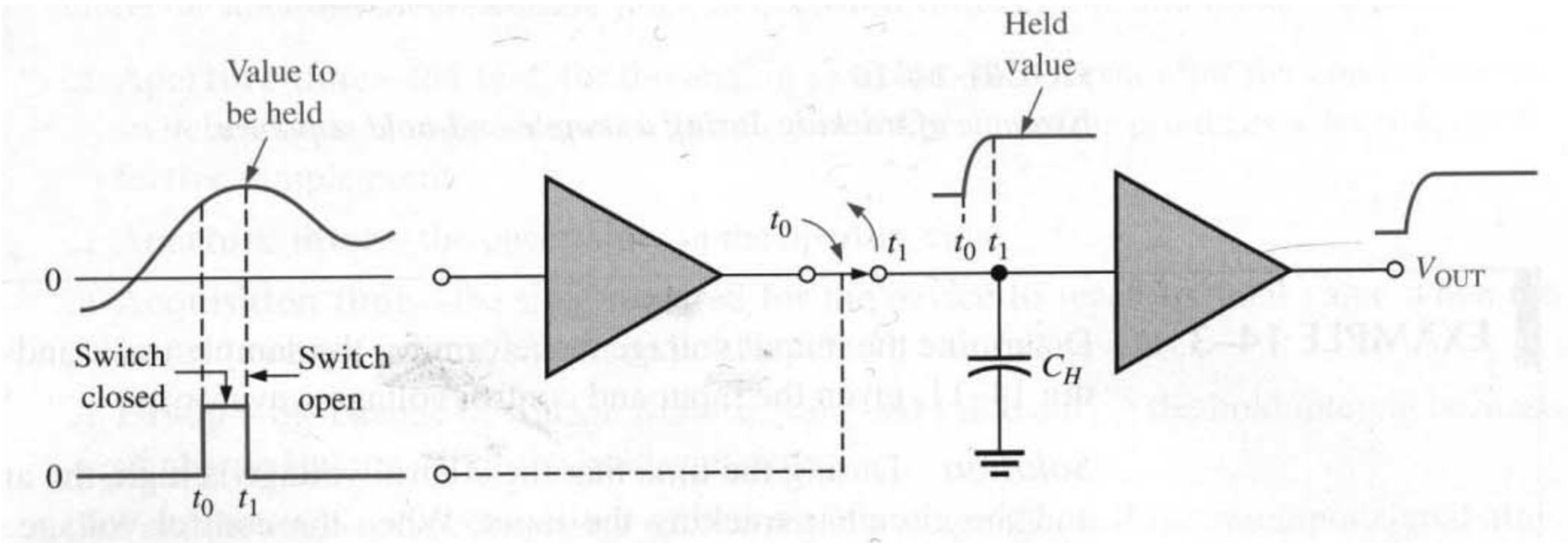
1. An analog switch,
2. A capacitor,
3. Input and output buffer amplifiers.



A Basic Sample-and-Hold Circuit

- The analog switch samples the analog input voltage through the input buffer amplifier.
- The capacitor stores or holds the sampled voltage for a period of time.
- The output buffer amplifier provides a high input impedance to prevent the capacitor from discharging quickly.

Basic action of a Sample-and-Hold Circuit



Basic action of a Sample-and-Hold Circuit

- A relatively narrow control voltage pulse closes the analog switch and allows the capacitor to charge to the value of the input voltage.

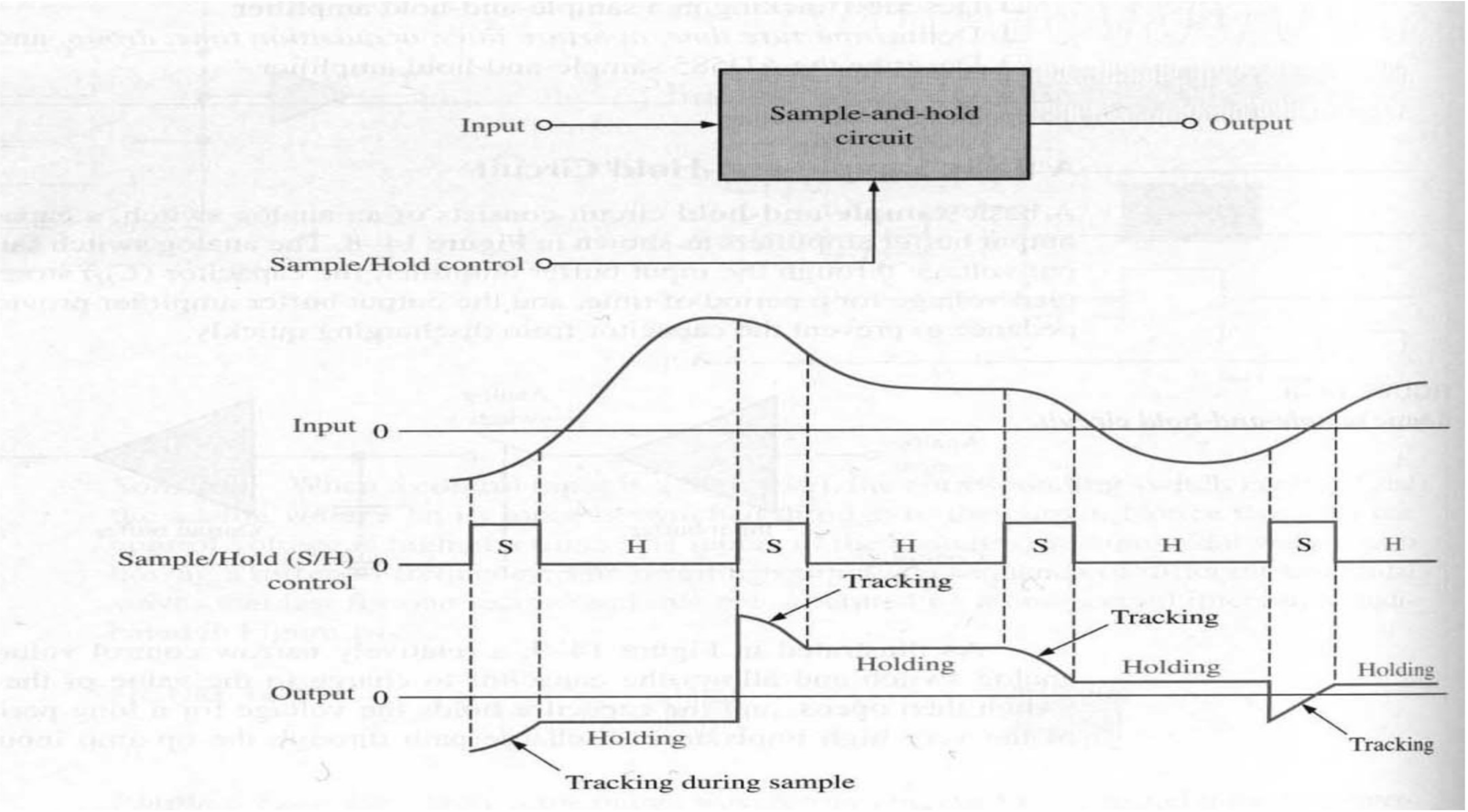
- The switch then opens, and the capacitor holds the voltage for a long period of time because sample-and –hold circuit converts an instantaneous value of the analog input voltage to a DC voltage.

Tracking during Sample Time

- Perhaps a more appropriate designation for a sample-and-hold amplifier is sample/track-and-hold because the circuit actually tracks the input voltage during the sample interval.

- As indicated in the next figure, the output follows the input during the time that the control voltage is high; and when the control voltage goes low, the last voltage is held until the next sample interval.

Tracking during Sample Time

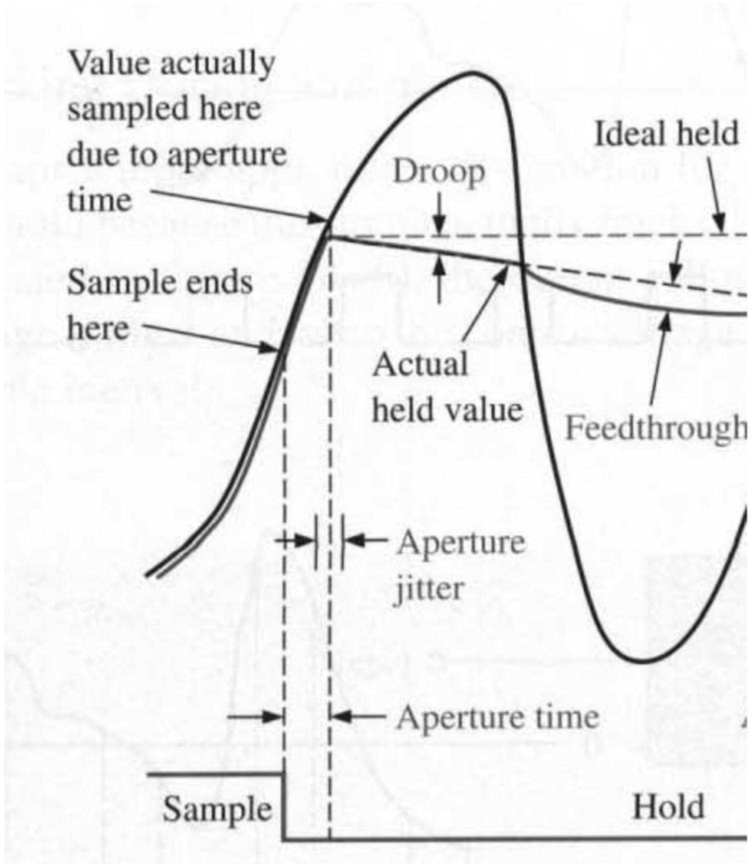


Performance Specifications

❑ **Aperture time**:

The time for the analog switch to fully open after the control voltage switches from its sample level to its hold level.

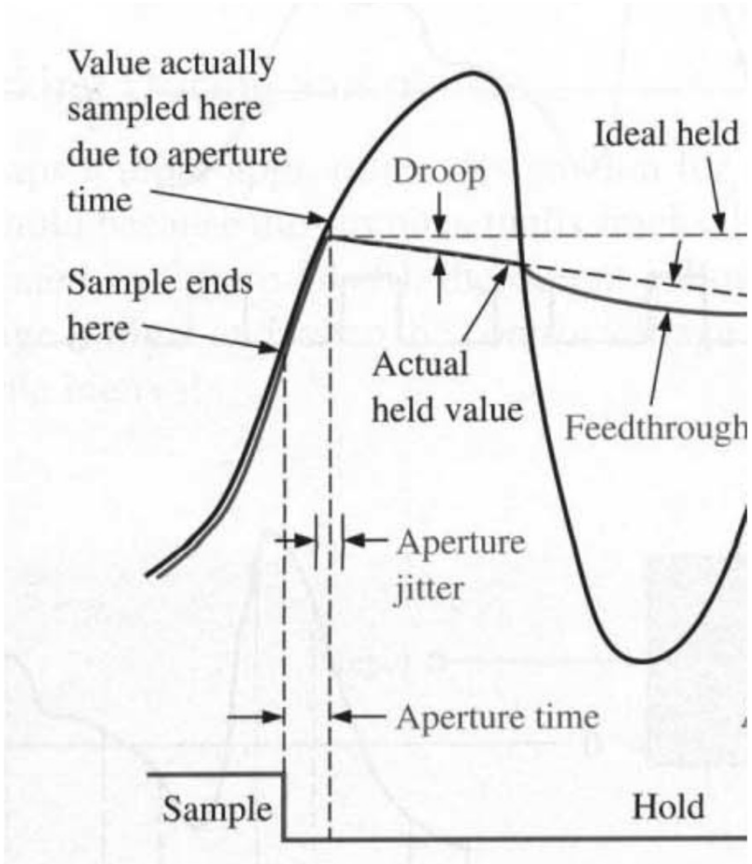
Aperture time produces a delay in the effective sample point.



Performance Specifications

❑ **Aperture jitter**:

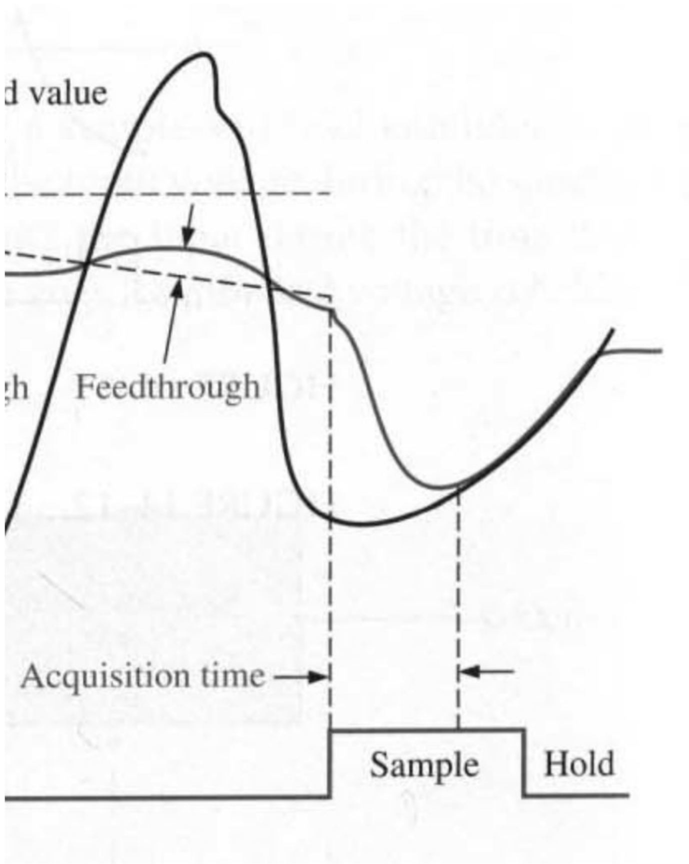
The uncertainty in the aperture time.



Performance Specifications

❑ **Acquisition time**:

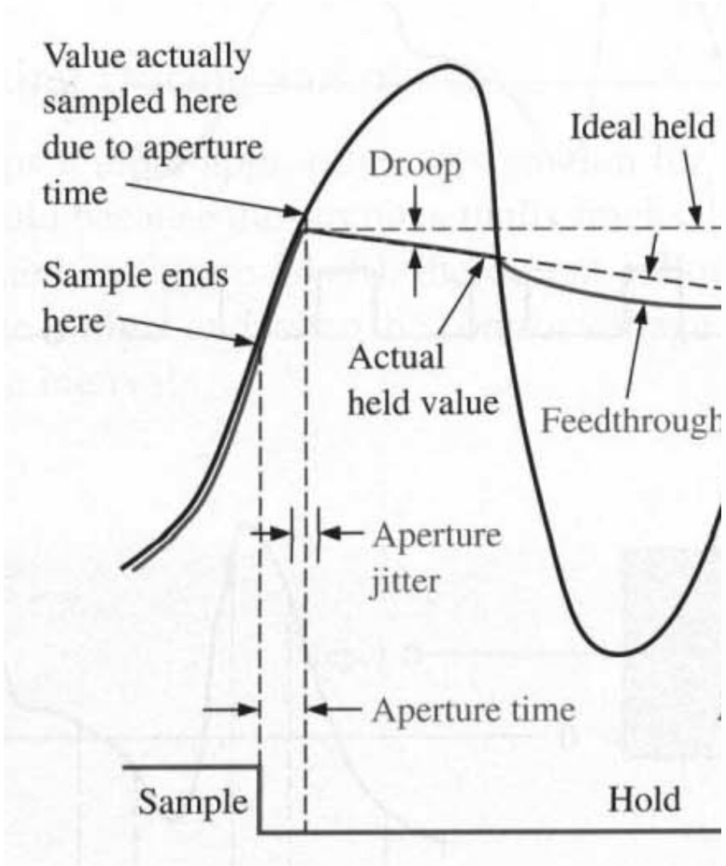
The time required for the device to reach its final value when the control voltage switches from its hold level to its sample level.



Performance Specifications

❑ **Droop**:

The change in voltage from the sampled value during the hold interval because of charge leaking off the hold capacitor.



- ❑ **Feedthrough**—the component of the output voltage that follows the input signal after the analog switch is opened. The inherent capacitance from the input to the output of the switch causes feedthrough.