BENHA UNIVERSITY
FACULTY OF ENGINEERING AT SHOUBRA

ECE-322
Electronic Circuits (B)

Lecture #3
Basic Op-Amp Circuits

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SPRING 2015

Agenda

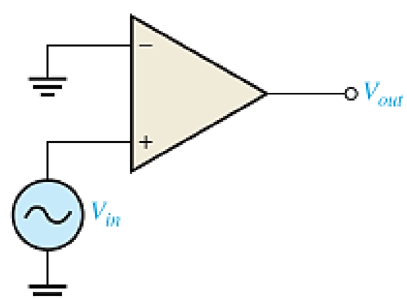
- Comparators
- Summing Amplifiers
- Integrators & Differentiators

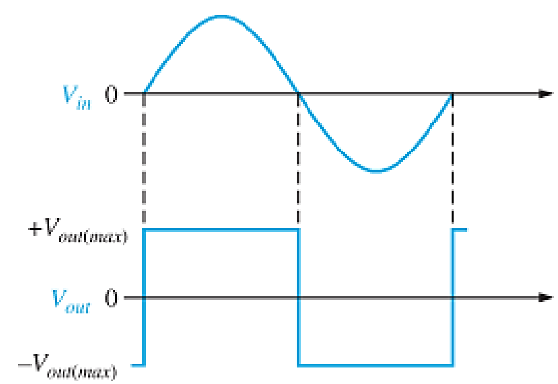
COMPARATORS

Zero Level Detection

- Operational amplifiers are often used as **comparators** to compare the **amplitude** of one voltage with another.
- In this application, the op-amp is used in the **open-loop** configuration, with the input voltage on one input and a **reference** voltage on the other.
- The **output** is always at either one of **two states**, indicating the greater or less than **relationship** between the inputs.
- Comparators provide very **fast switching times**.
- Comparators are often used to **interface** between an analog and digital circuit (output is in one of two states).

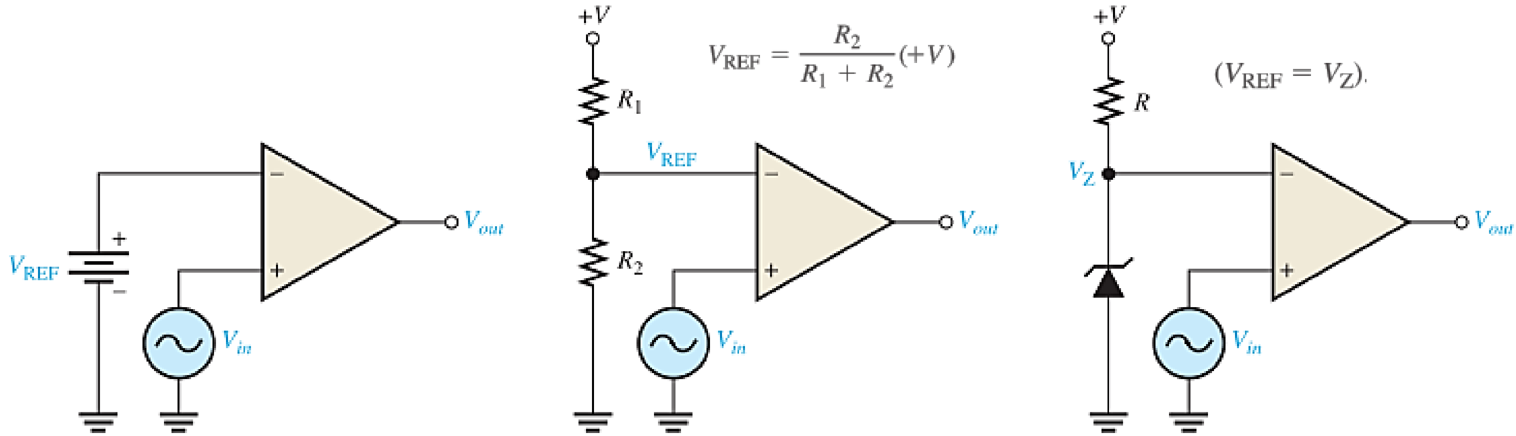
- One **application** of a comparator is to determine when an input voltage **exceeds** a certain **level**.





- If the level is Zero (Ground) → Zero Level Detection

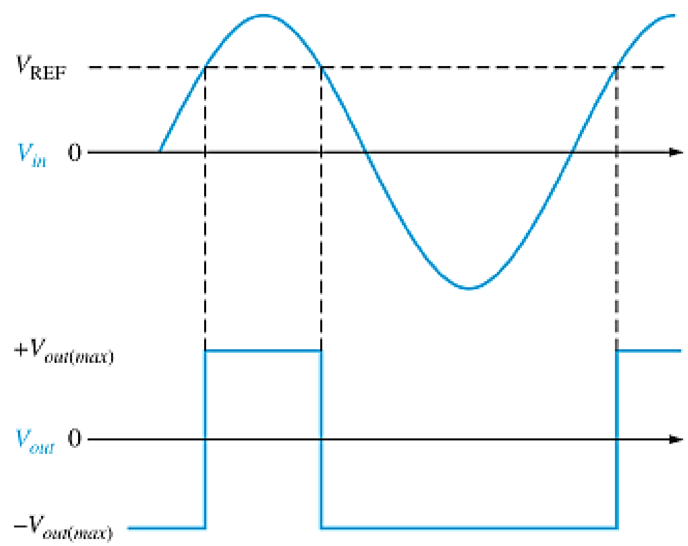
Nonzero-Level Detection



(a) Battery reference

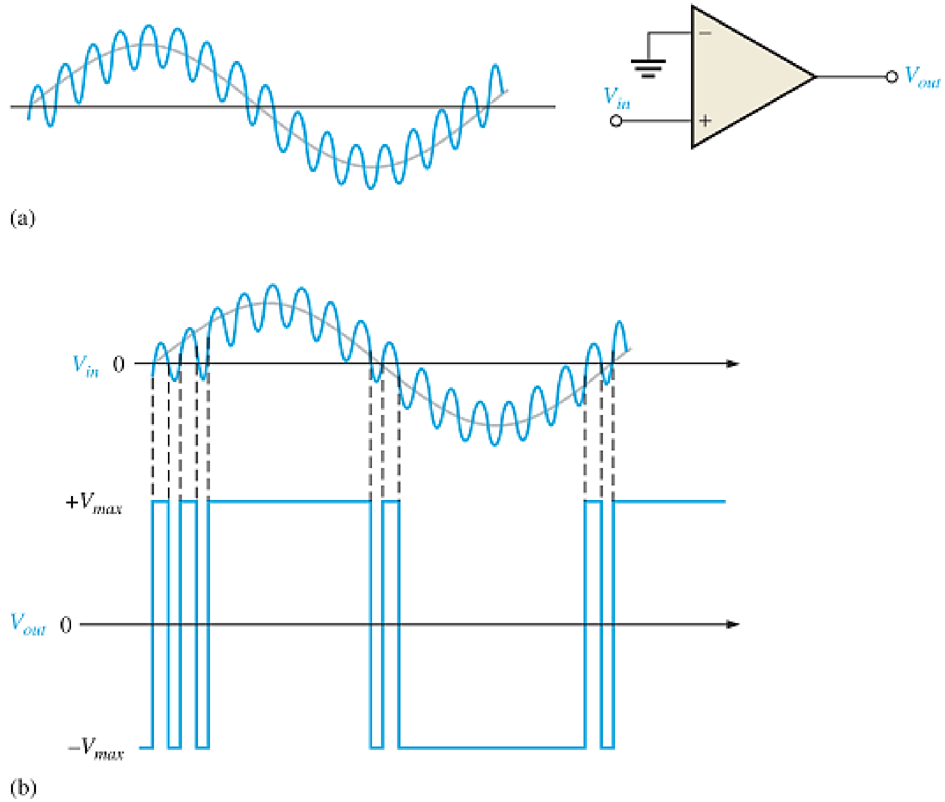
(b) Voltage-divider reference

(c) Zener diode sets reference voltage



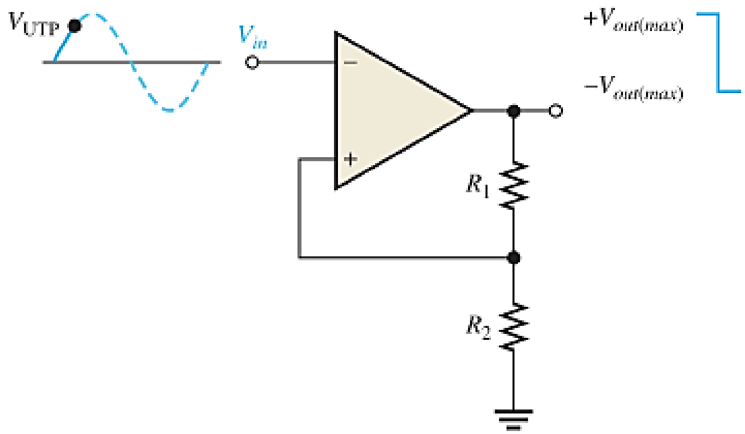
(d) Waveforms

Effects of Input Noise on Comparator Operation

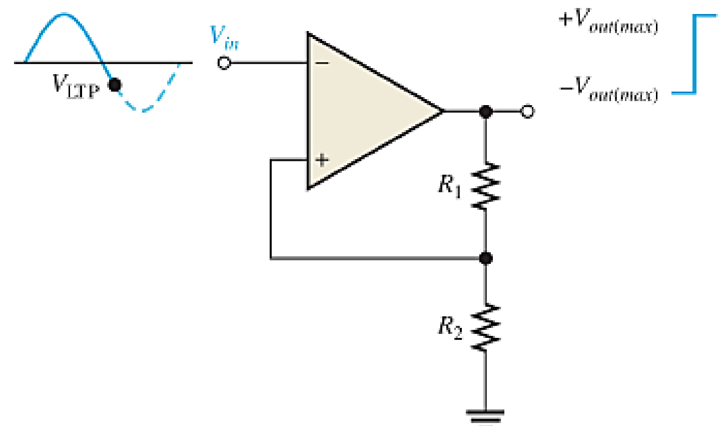


- To make the comparator less sensitive to noise, a technique uses positive feedback, called **hysteresis**, can be used.
- **Hysteresis** means that there is a higher reference level when the input voltage goes from a lower to higher value than when it goes from a higher to a lower value.
- A good **example** of hysteresis is a common house-hold thermostat that turns the furnace on at one temperature and off at another.

Reducing Noise Effects with Hysteresis



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

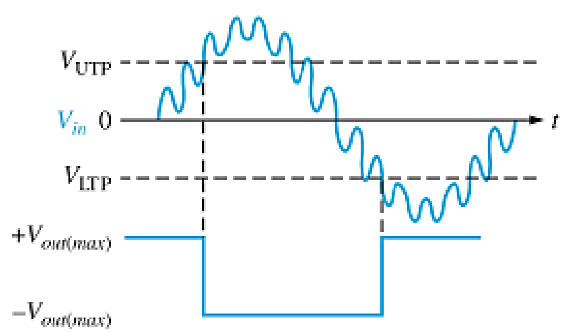


(b) When the output is at the maximum negative voltage and the input goes below LTP, the output switches back to the maximum positive voltage.

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

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

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

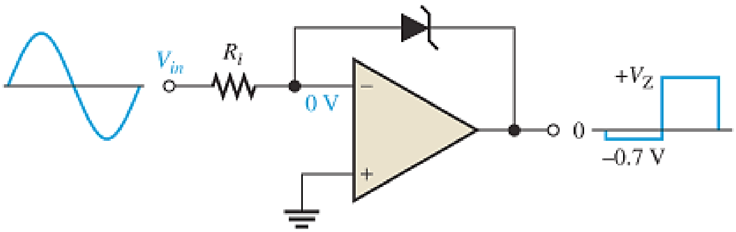


(c) Device triggers only once when UTP or LTP is reached; thus, there is immunity to noise that is riding on the input signal.

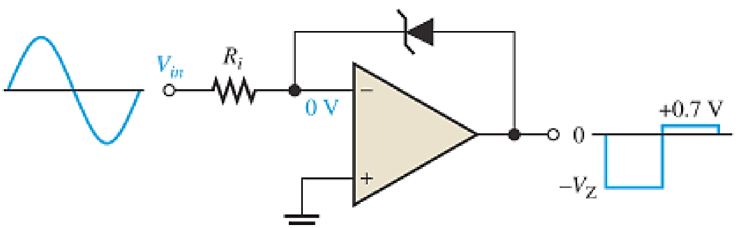
- A comparator with built-in hysteresis is sometimes known as a **Schmitt trigger**.
- The amount of hysteresis is defined by the difference of the two trigger levels.

Output Bounding

- The process of **limiting the output range** is called **bounding**.



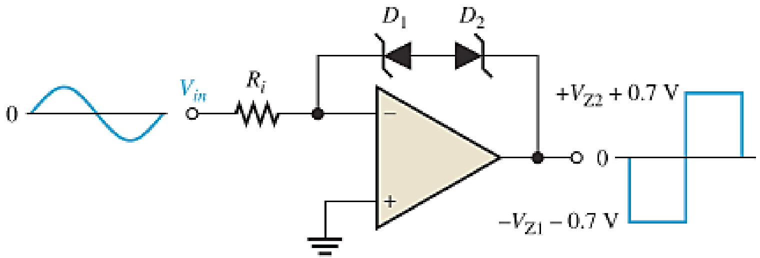
(a) Bounded at a positive value



(b) Bounded at a negative value

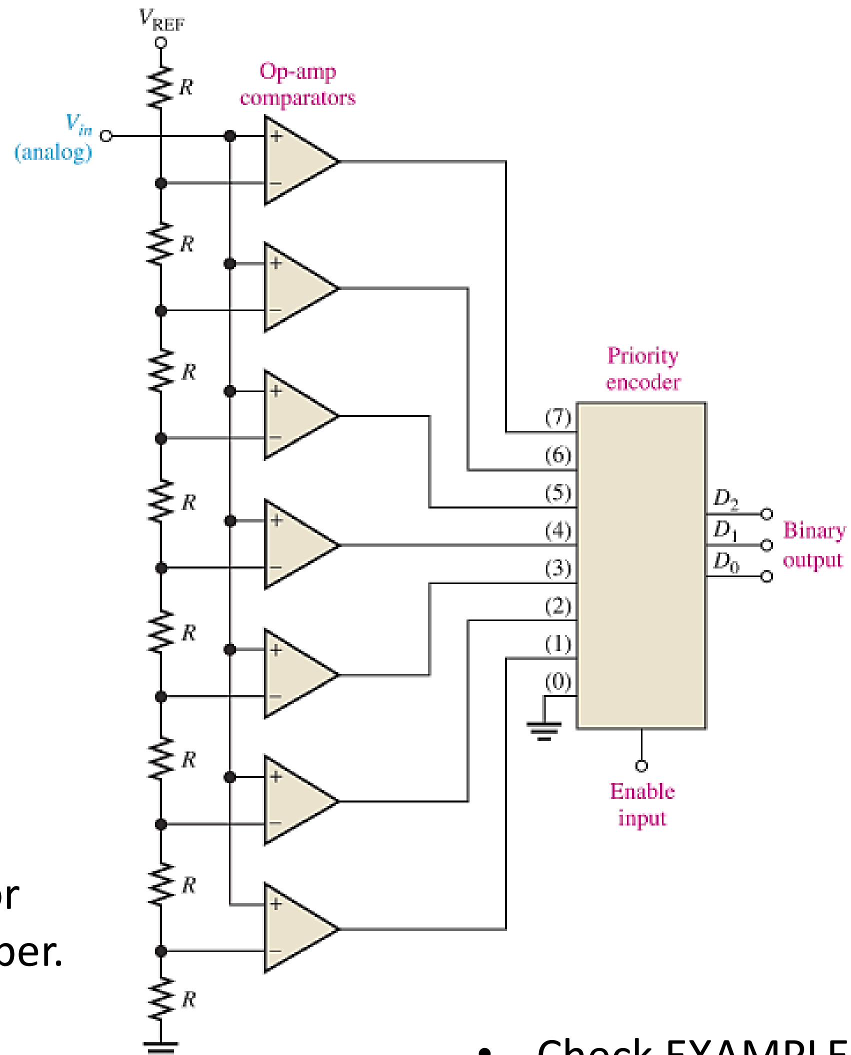
▶ FIGURE 13–12

Double-bounded comparator.



Comparator Applications
Analog-to-Digital (A/D) Conversion

- The **simultaneous**, or **flash**, method of A/D conversion uses **parallel comparators** to compare the linear input signal with **various reference** voltages developed by a voltage divider.
- When the **input** voltage **exceeds the reference** voltage for a given comparator, a **high level is produced** on that comparator's output.

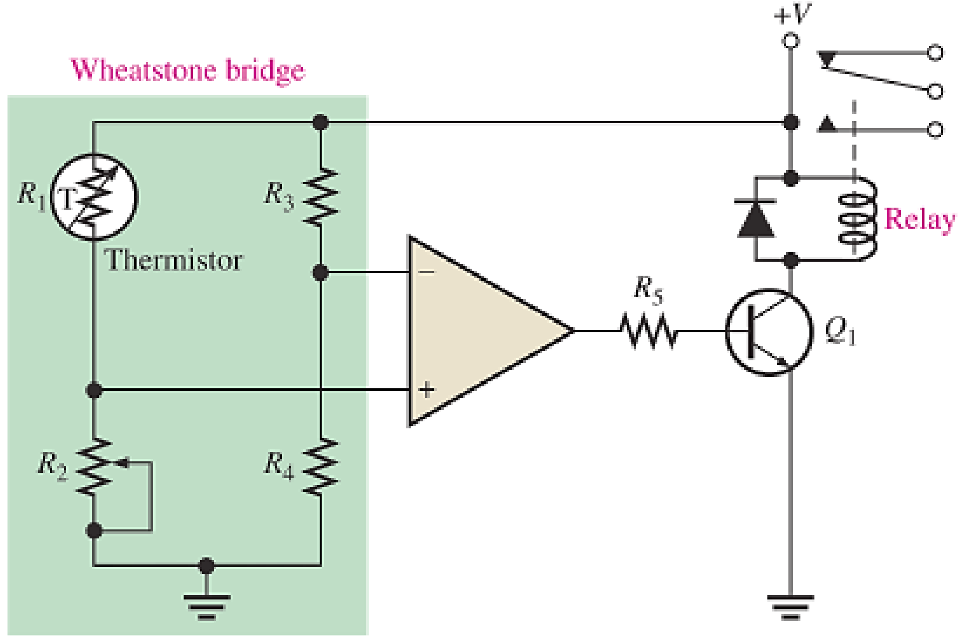


→**2ⁿ- 1** comparators are required for conversion to an **n-digit** binary number.

- Check EXAMPLE 13–4 !

Comparator Applications

Over-Temperature Sensing Circuit



Specific Comparators

- The **LM111** and **LM311** are examples of specific comparators that exhibit high switching speeds and other features not normally found on the general type of op-amp.

SUMMING AMPLIFIERS

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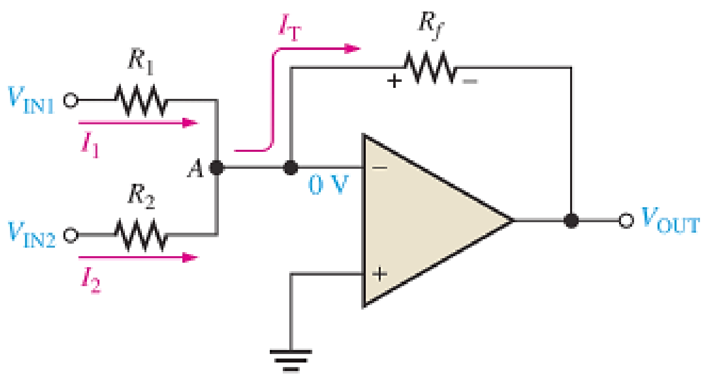
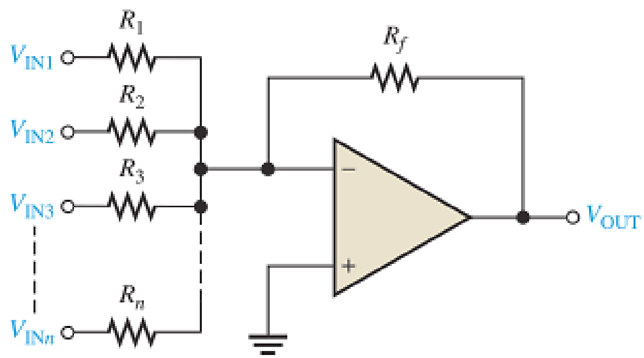
Summing Amplifier with Unity/ Non Unity Gain

- The summing amplifier is an **application of the inverting op-amp** configuration.
- A summing amplifier has **two or more inputs**, and its **output** voltage is proportional to the negative of the **algebraic sum** of its input voltages.





$$I_T = I_1 + I_2$$

$$V_{OUT} = -(I_1 + I_2)R_f = -\left(\frac{V_{IN1}}{R_1} + \frac{V_{IN2}}{R_2}\right)R_f$$

$$V_{OUT} = -(V_{IN1} + V_{IN2} + V_{IN3} + \cdots + V_{INn})$$

$R_1 = R_2 = R_f = R$ → **Unity Gain**

→ **Gain greater than Unity**

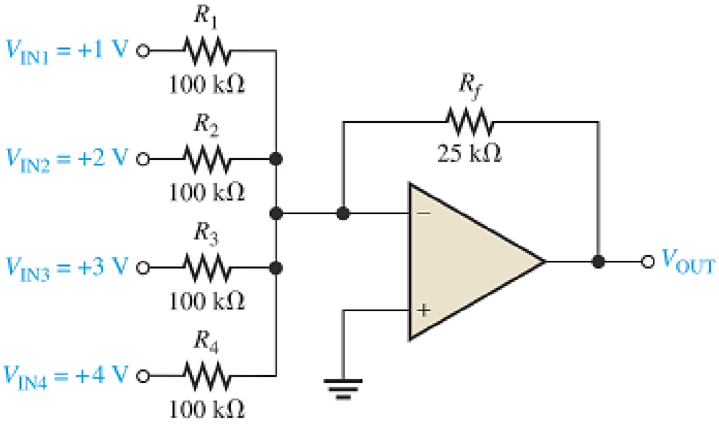
$$V_{OUT} = -\left(\frac{V_{IN1}}{R} + \frac{V_{IN2}}{R}\right)R = -(V_{IN1} + V_{IN2})$$

$$V_{OUT} = -\frac{R_f}{R}(V_{IN1} + V_{IN2} + \cdots + V_{INn})$$

Averaging & Scaling Amplifiers

- **Averaging:**

$$\frac{R_f}{R} = \frac{1}{n}$$



V_{out}= ?

- **Scaling:**

A **different weight** can be assigned to each input by adjusting the values of the input resistors.

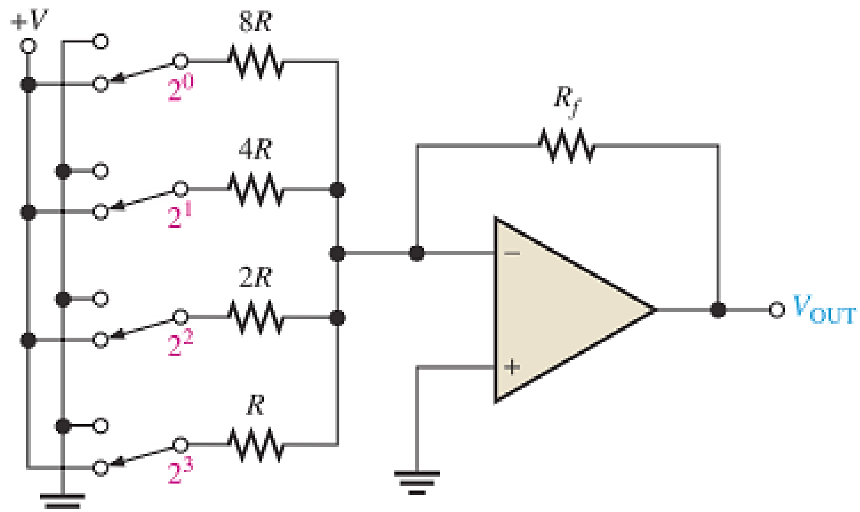
$$V_{OUT} = -\left(\frac{R_f}{R_1}V_{IN1} + \frac{R_f}{R_2}V_{IN2} + \cdots + \frac{R_f}{R_n}V_{INn}\right)$$

Example:

V_{out}= - ($3V_{IN1}$+ $0.5V_{IN2}$)

Applications

DAC, Scaling Adder as a four-digit DAC



$I_0=+V/8R$

$I_1=+V/4R$

$I_2=+V/2R$

$I_3=+V/R$

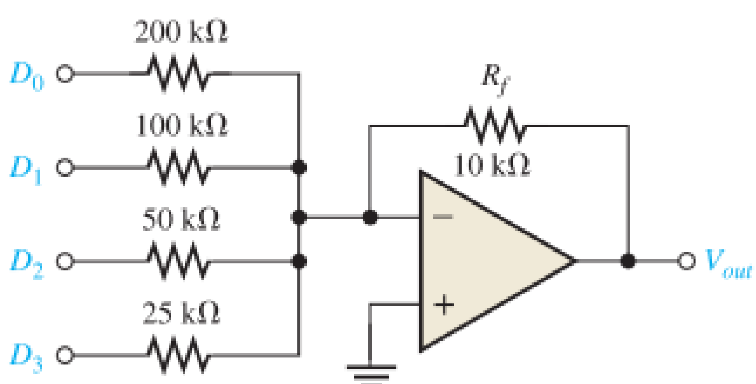
$V_{out(D0)}=-R_f\ I_0$

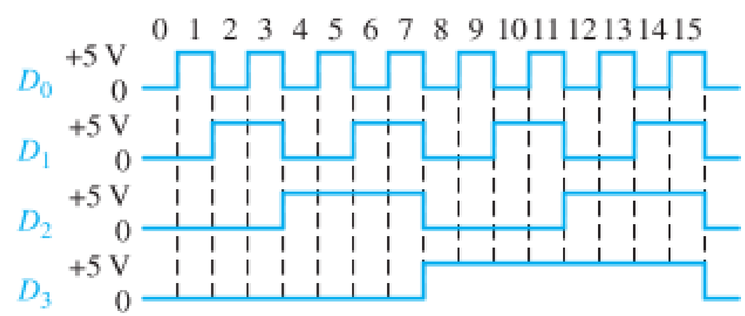
$V_{out(D1)}=-R_f\ I_1$

$V_{out(D2)}=-R_f\ I_2$

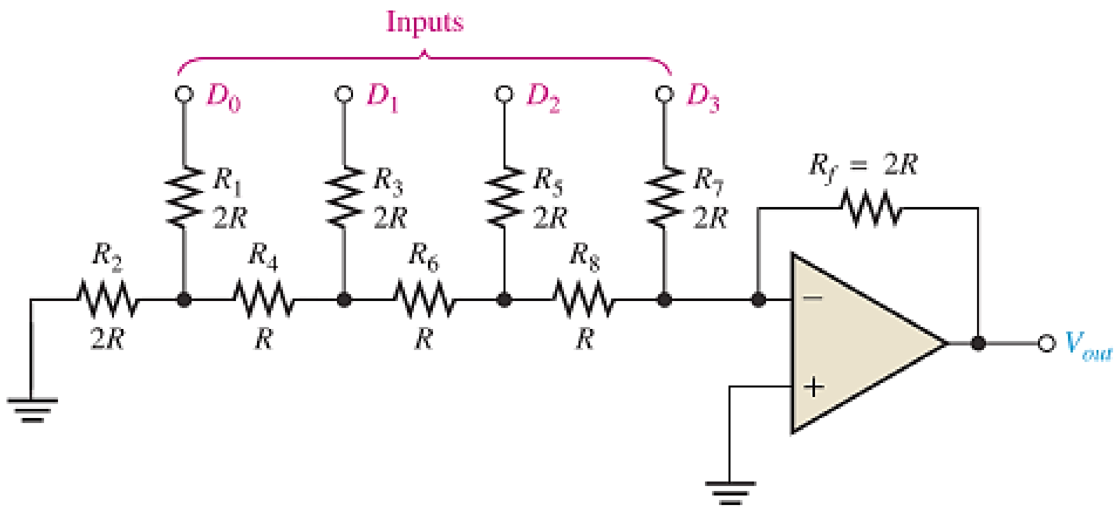
$V_{out(D3)}=-R_f\ I_3$

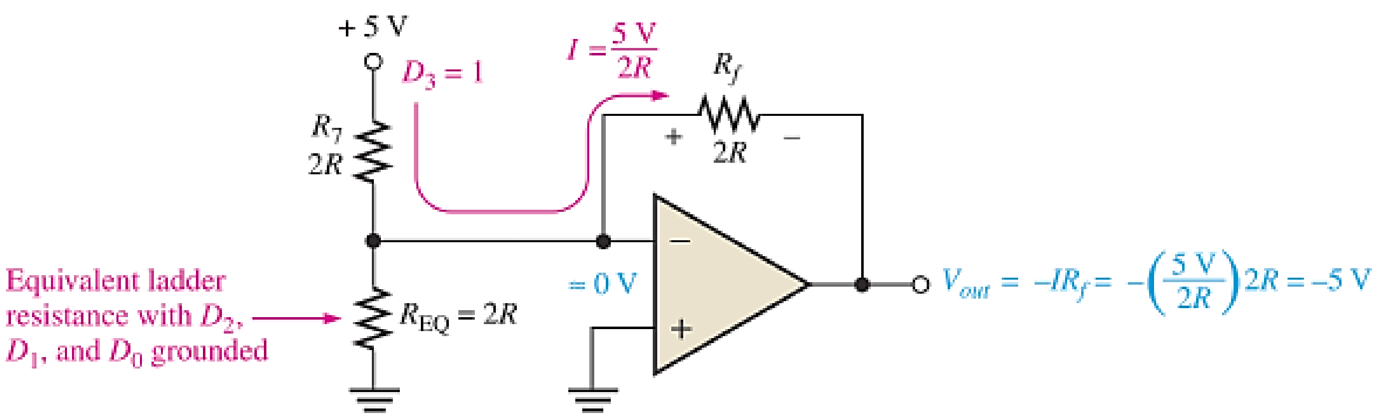
- Example 13-9





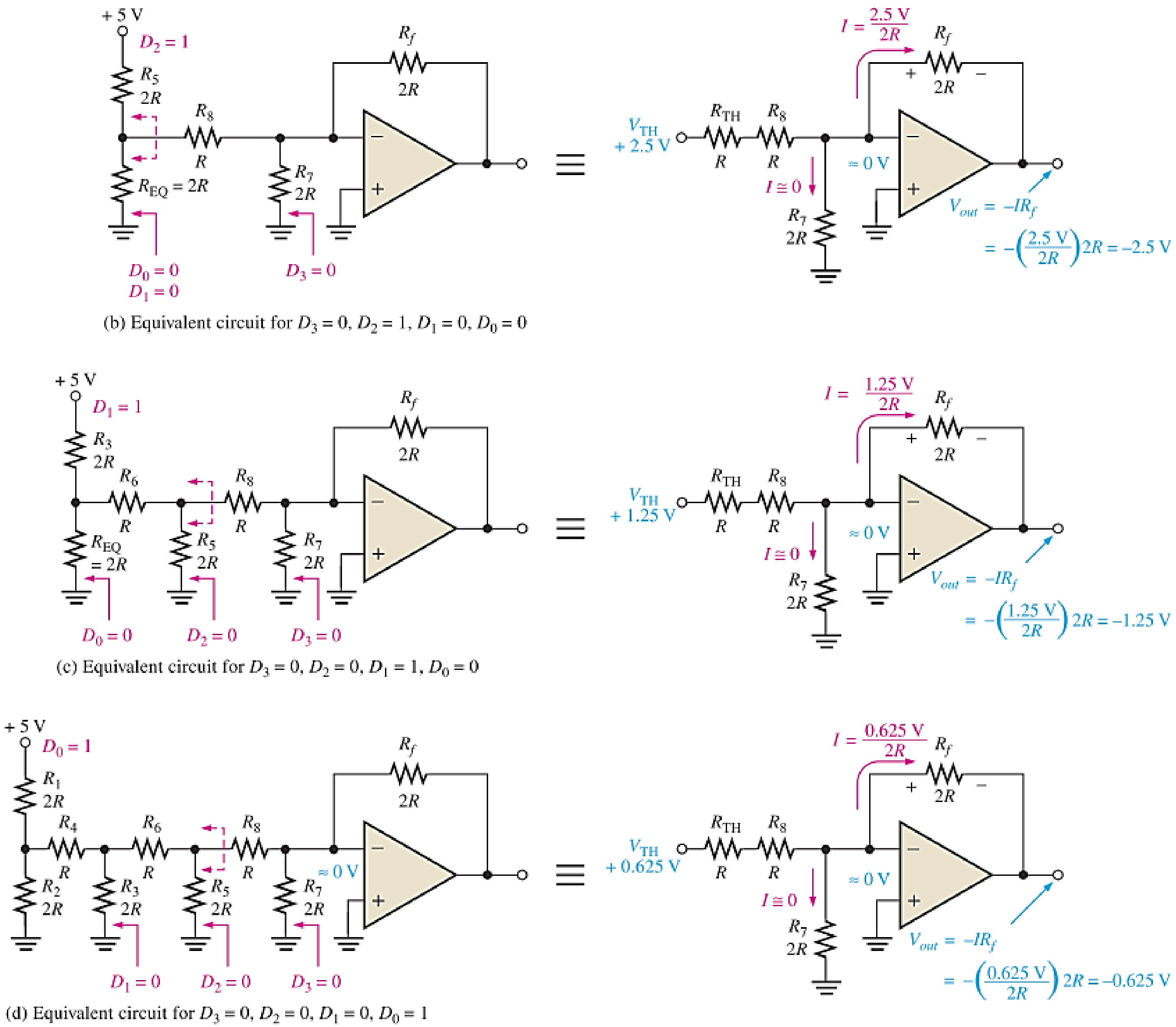
Applications
DAC, An R/2R ladder DAC





(a) Equivalent circuit for $D_3 = 1$, $D_2 = 0$, $D_1 = 0$, $D_0 = 0$

An R/2R ladder DAC ..



▲ FIGURE 13–30

Analysis of the *R*/2*R* ladder DAC.

- An op-amp **integrator** simulates mathematical integration, which is basically a **summing** process that determines **the total area under the curve** of a function.
- An op-amp **differentiator** simulates mathematical differentiation, which is a process of determining the **instantaneous rate of change** of a function.

INTEGRATORS & DIFFERENTIATORS

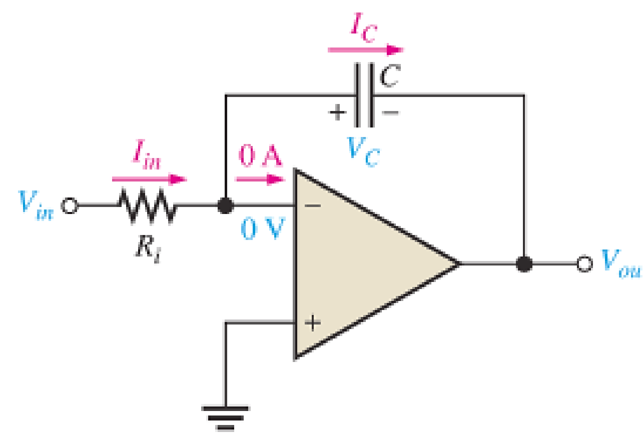
The Op-Amp Integrator Ideal

$$Q = I_C t$$

$$Q = CV_C \longrightarrow V_C = \left(\frac{I_C}{C}\right)t$$

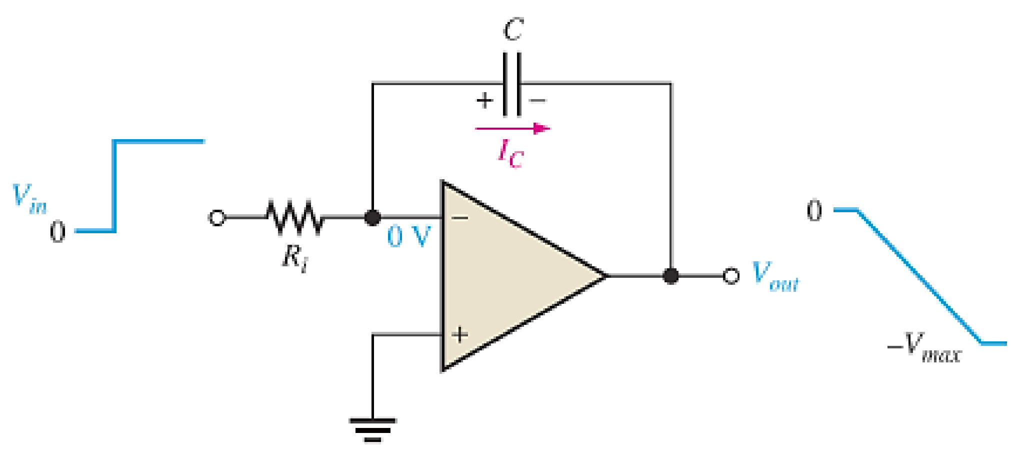
$$I_{in} = \frac{V_{in}}{R_i}$$

$$I_C = I_{in} \qquad I_C = V_{in}/R_i,$$



rate of change or slope of the integrator’s output voltage:

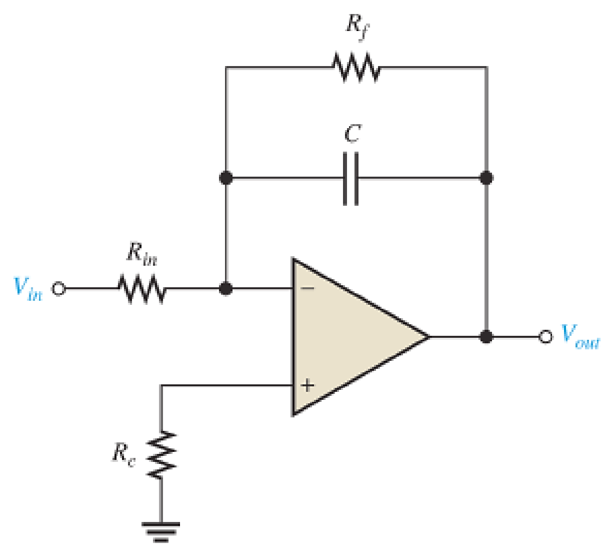
$$\frac{\Delta V_{out}}{\Delta t} = -\frac{V_{in}}{R_i C}$$



The Op-Amp Integrator Practical

- The ideal integrator uses a **capacitor** in the feedback path, which is **open to dc**.
- The gain at dc is the **open-loop gain** of the op-amp.
- In a practical integrator, any **dc error voltage due to offset error** will cause the output to produce a **ramp** that moves toward either positive or negative saturation (depending on the offset), even when no signal is present.

- Practical integrators must overcome the effects of offset and bias current.
- Various **solutions** are available, such as **chopper stabilized amplifiers**.
- The **simplest** solution is to **use a resistor in parallel** with the capacitor in the feedback path.

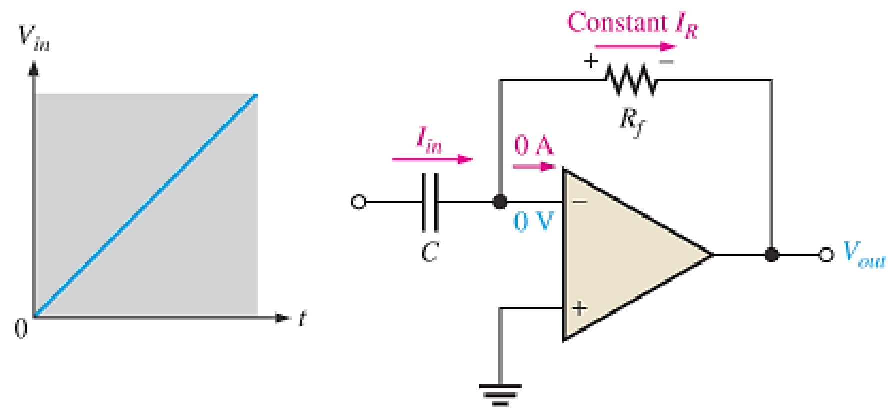


The Op-Amp Differentiator Ideal

$$I_C = \left(\frac{V_C}{t}\right)C$$

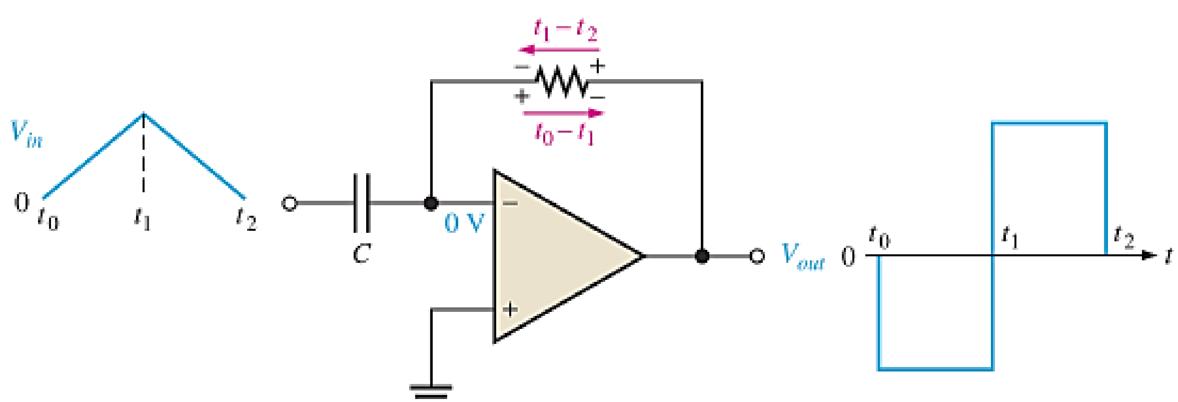
$$V_{out} = I_R R_f = I_C R_f$$

$$V_{out} = -\left(\frac{V_C}{t}\right)R_f C$$



▶ FIGURE 13–39

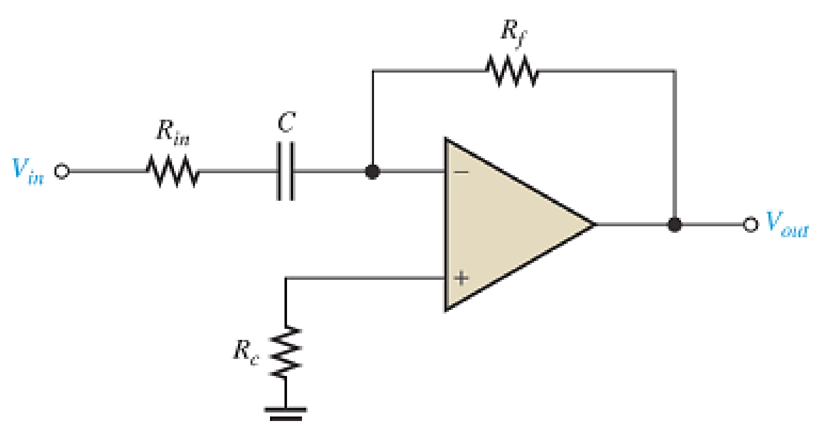
Output of a differentiator with a series of positive and negative ramps (triangle wave) on the input.



The Op-Amp Differentiator Practical

- The ideal differentiator uses a **capacitor** in series with the inverting input.
- Because a capacitor has very **low impedance** at high frequencies, the combination of R_f and C form a **very high gain amplifier** at high frequencies.
- This means that a differentiator circuit tends to be **noisy** because electrical noise mainly consists of high frequencies.

- The solution to this problem is simply to **add** a resistor, $\mathbf{R_{in}}$, in series with the capacitor to act as a **LPF** and reduce the gain at high frequencies.
- The resistor should be **small** compared to the feedback resistor in order to have a **negligible effect** on the desired signal.



Proj. Tasks:
Op-Amp based TX/RX

#	Task	Mark
1	Simulation	2
2	PCB board	3
3	Valid Oscilloscope waveforms in the lab	3
4	Valid part (Combination of TX/RX)→ Wired	2
5	Wireless Validation → Antenna	(bonus 2)

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- For more details, refer to:
  - Chapter 13, T. Floyd, **Electronic Devices**, 9th edition.
- The lecture is available online at:
  - http://bu.edu.eg/staff/ahmad.elbanna-courses/12135
- For inquires, send to:
  - ahmad.elbanna@feng.bu.edu.eg