Faculty of Engineering
Department of Electronics and Communications

GEE336
Electronic Circuits II

Lecture #4
Basic Op-Amp Circuits

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Agenda

- Some Op-Amp Parameters
- Comparators
- Summing Amplifiers
- Integrators & Differentiators

SOME OP-AMP PARAMETERS

Op-Amp Parameters
Common-Mode Rejection Ratio

- The common-mode rejection ratio, **CMRR**:

It's the ratio of the open-loop differential voltage gain, $\mathbf{A_{ol}}$, to the common-mode gain, $\mathbf{A_{cm}}$.

$$\text{CMRR} = \frac{A_{ol}}{A_{cm}} \qquad \text{CMRR} = 20\log\left(\frac{A_{ol}}{A_{cm}}\right)$$

- *Open-loop voltage gain* can range up to 200,000 (106 dB) and is not a well-controlled parameter.
- Datasheets often refer to the open-loop voltage gain as the *large-signal voltage gain*.
- A CMRR of 100,000, for example, means that the desired input signal (differential) is amplified 100,000 times more than the unwanted noise (common-mode).

Op-Amp Parameters (2)
Input Offset Voltage

- The ideal op-amp produces zero volts out for zero volts in.
- In a practical op-amp, a small dc voltage, $\mathbf{V_{OUT(error)}}$, appears at the output when no differential input voltage is applied.
- Its primary cause is a slight mismatch of the base-emitter voltages of the differential amplifier input stage of an op-amp.
- The input offset voltage, $\mathbf{V_{OS}}$, is the differential dc voltage required between the inputs to force the output to zero volts
- Typical values $\mathbf{V_{OS}}$, are in the range of 2 mV or less.

Effect of Input Offset Voltage

$$V_{OUT(error)} = A_{cl}V_{IO}$$

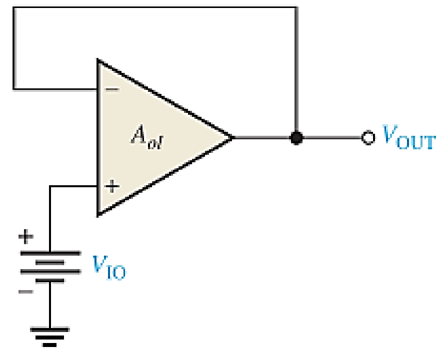
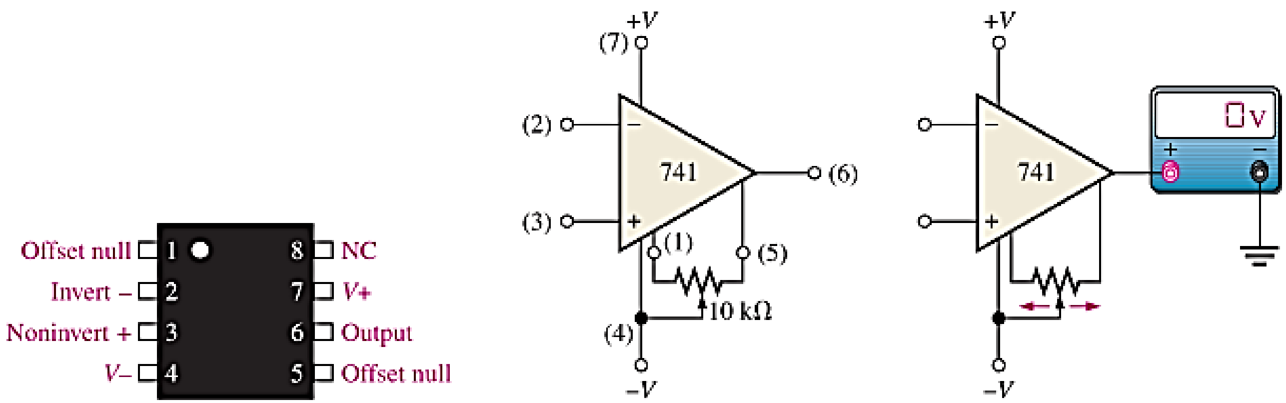


FIGURE 12–33
Input offset voltage equivalent.

Input Offset Voltage Compensation



(a) 8-pin DIP or SMT package (b) External potentiometer (c) Adjust for zero output

FIGURE 12–34
Input offset voltage compensation for a 741 op-amp.

Op-Amp Parameters(3)
Input Offset Current

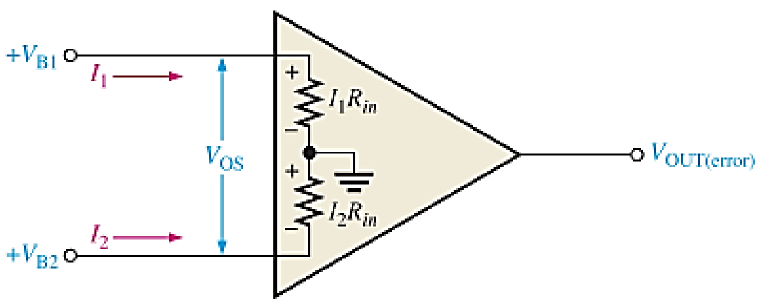
- Ideally, the two input bias currents are equal, and thus their difference is zero.
- In a practical op-amp, the bias currents are not exactly equal.
- The input offset current, I_{OS}, is the difference of the input bias currents, expressed as an absolute value.

$$I_{OS} = |I_1 - I_2|$$

$$V_{OS} = I_1 R_{in} - I_2 R_{in} = (I_1 - I_2) R_{in}$$

$$V_{OS} = I_{OS} R_{in}$$

$$V_{OUT(error)} = A_v I_{OS} R_{in}$$

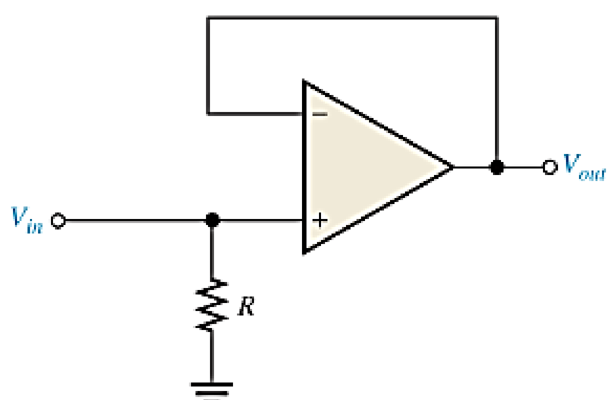


Op-Amp Parameters (4)
Slew Rate

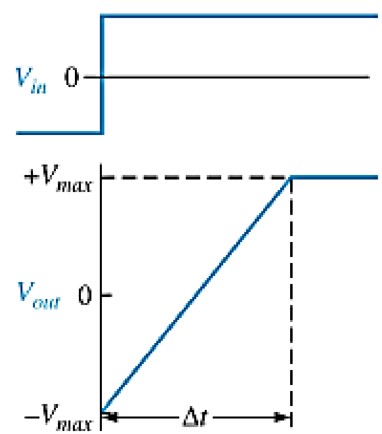
- The maximum rate of change of the output voltage in response to a step input voltage is the slew rate of an op-amp.
- The slew rate is dependent upon the high-frequency response of the amplifier stages within the op-amp.

$$\text{Slew rate} = \frac{\Delta V_{out}}{\Delta t}$$

- **Slew-rate measurement**



(a) Test circuit



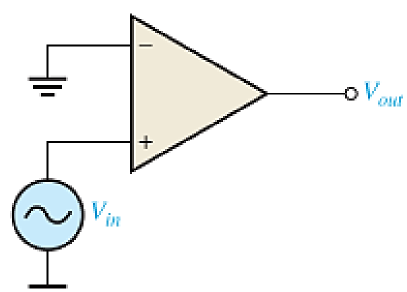
(b) Step input voltage and the resulting output voltage

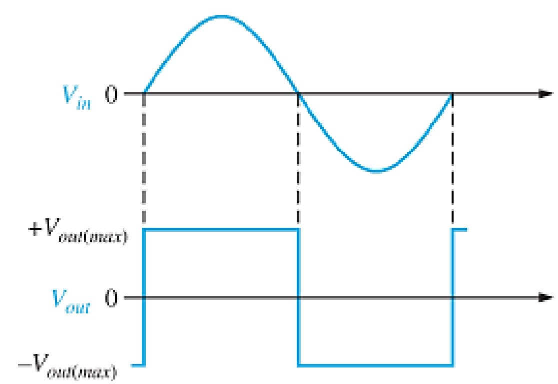
COMPARATORS

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).

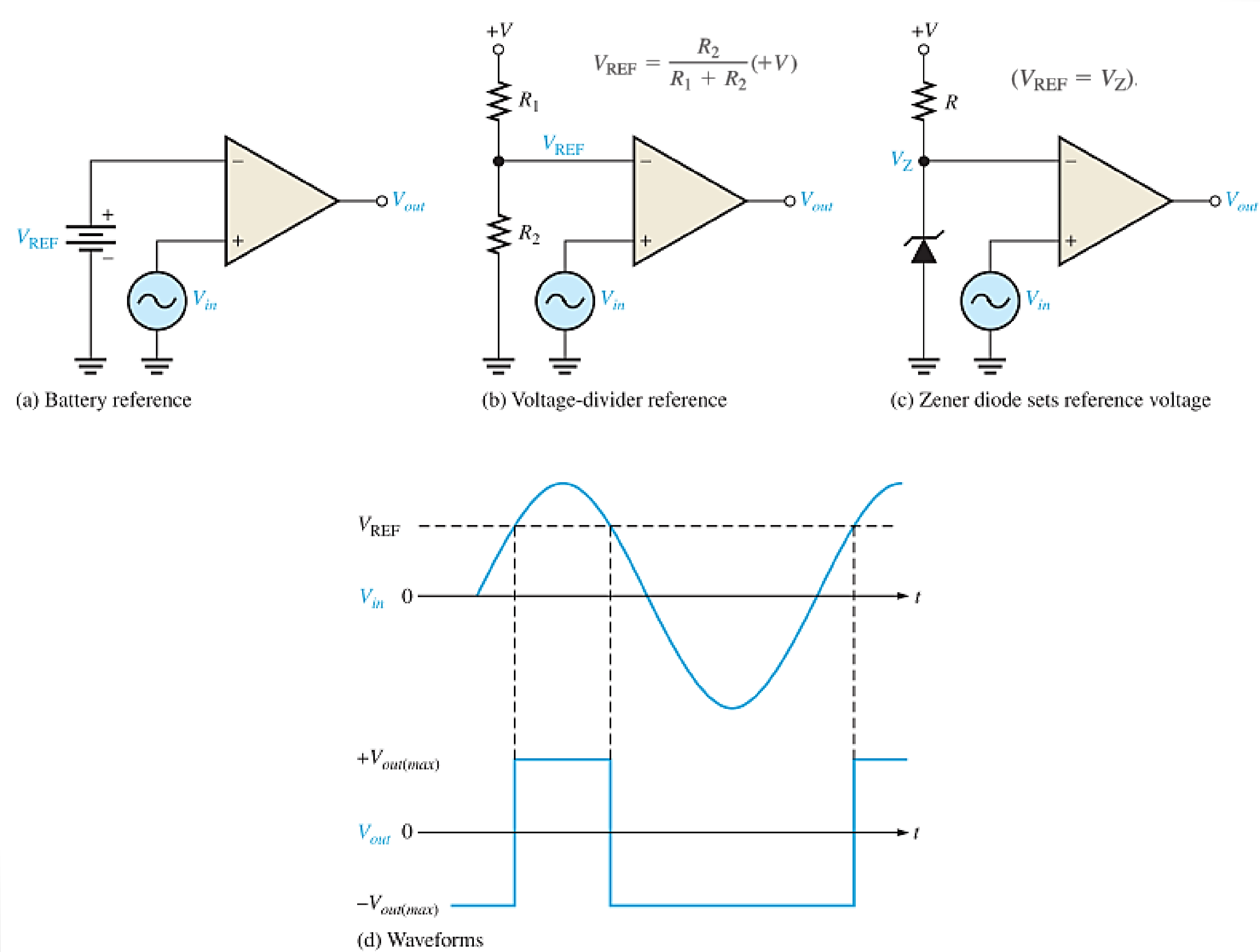
- One **application** of a comparator is to determine when an input voltage **exceeds** a certain **level**.



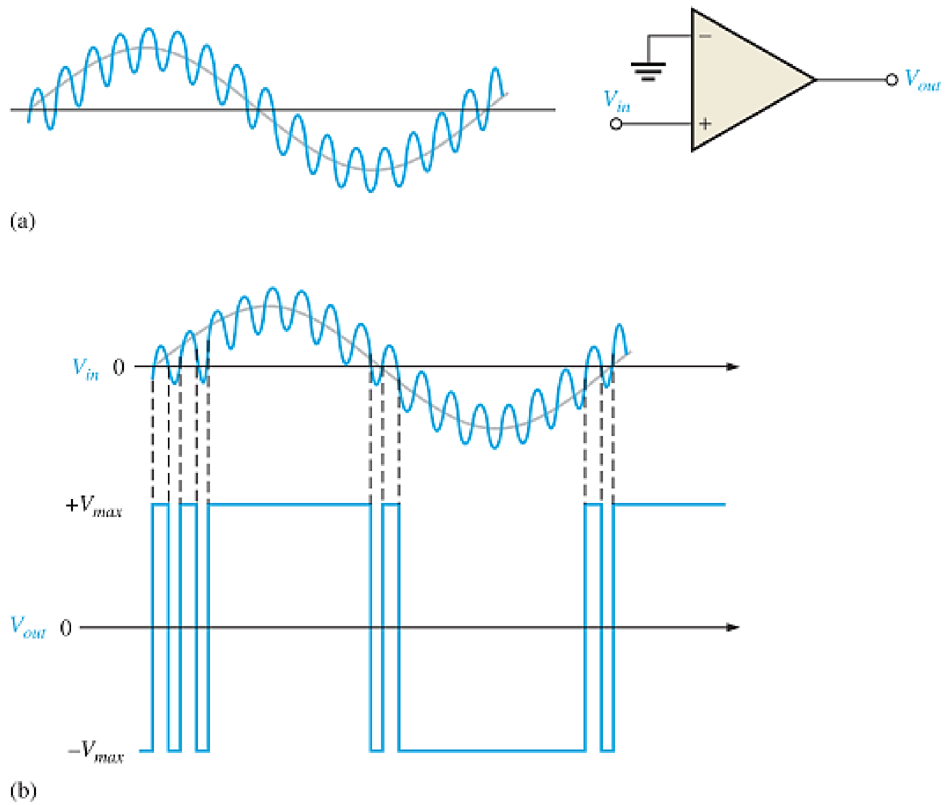


- If the level is Zero (Ground) → Zero Level Detection

Nonzero-Level Detection

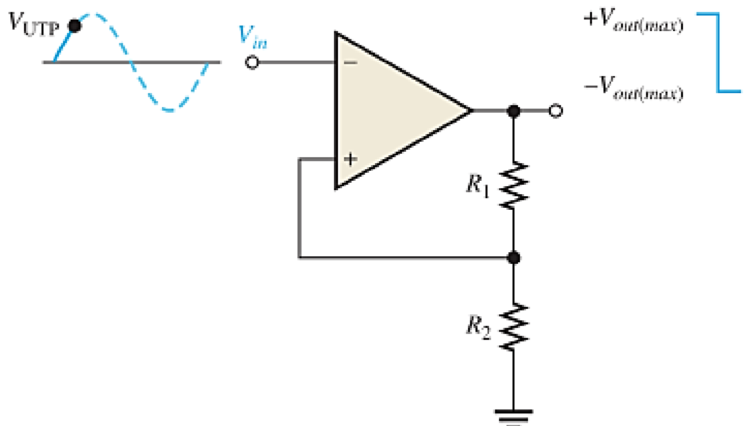


Effects of Input Noise on Comparator Operation

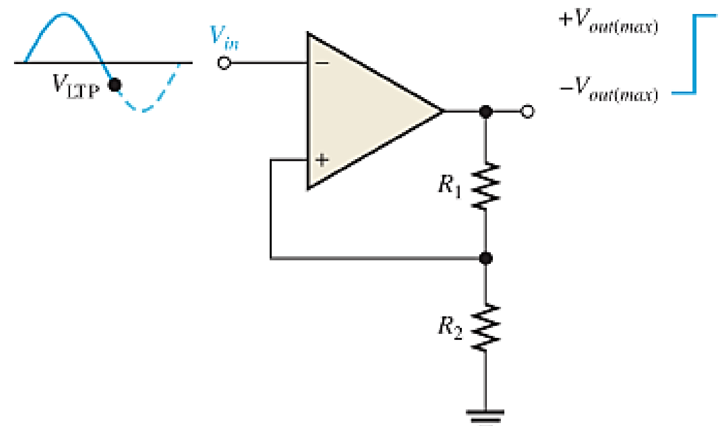


- To make the comparator less sensitive to noise, a technique uses positive feedback, called **hysteresis**, can be used.
- **Hysteresis** means that there is a higher reference level when the input voltage goes from a lower to higher value than when it goes from a higher to a lower value.
- A good **example**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

Schmitt trigger
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.

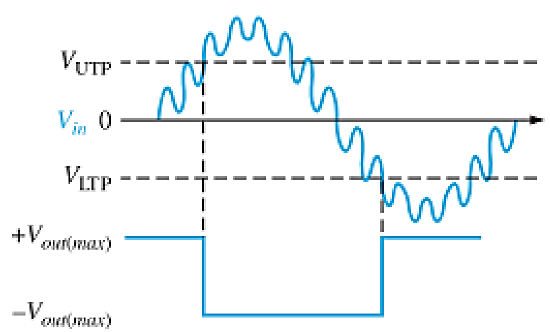


(b) When the output is at the maximum negative voltage and the input goes below LTP, the output switches back to the maximum positive voltage.

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

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

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



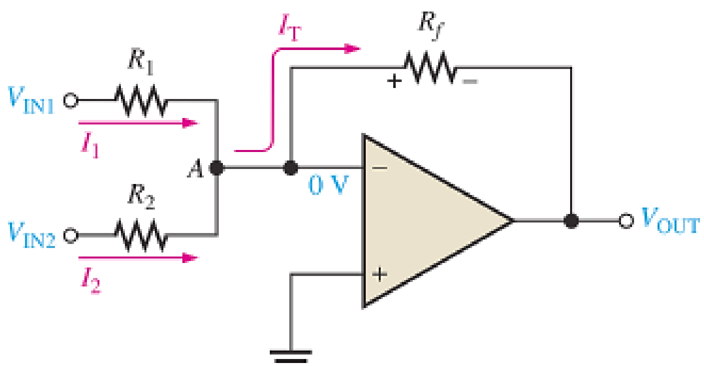
(c) Device triggers only once when UTP or LTP is reached; thus, there is immunity to noise that is riding on the input signal.

- 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.

SUMMING AMPLIFIERS

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.

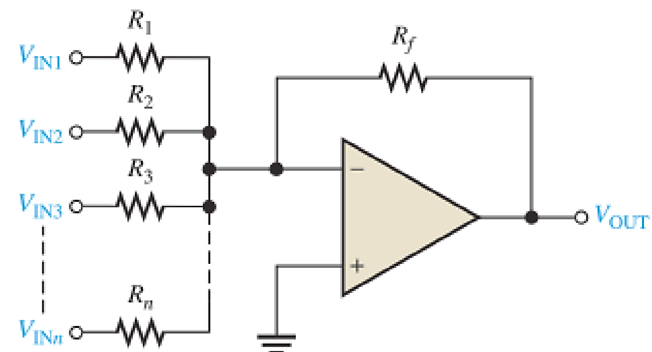


$$I_T = I_1 + I_2$$

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

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

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



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

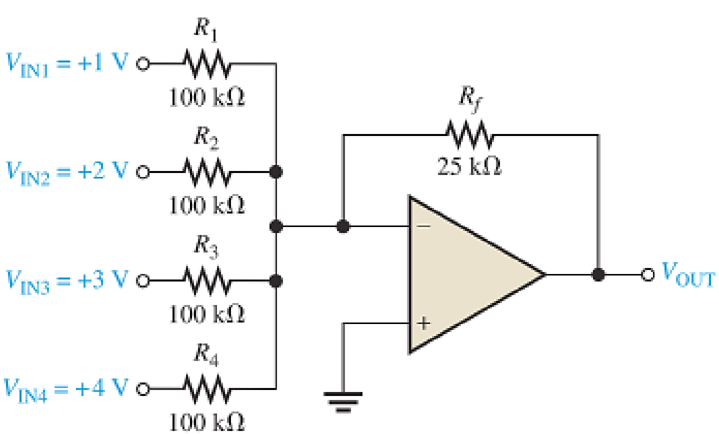
→ **Gain greater than Unity**

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

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.

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

<u>Example</u>:

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

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

INTEGRATORS & DIFFERENTIATORS

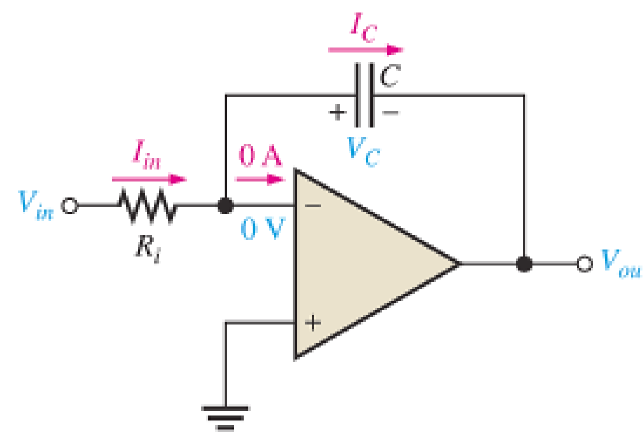
The Op-Amp Integrator
Ideal

$$Q = I_C t$$

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

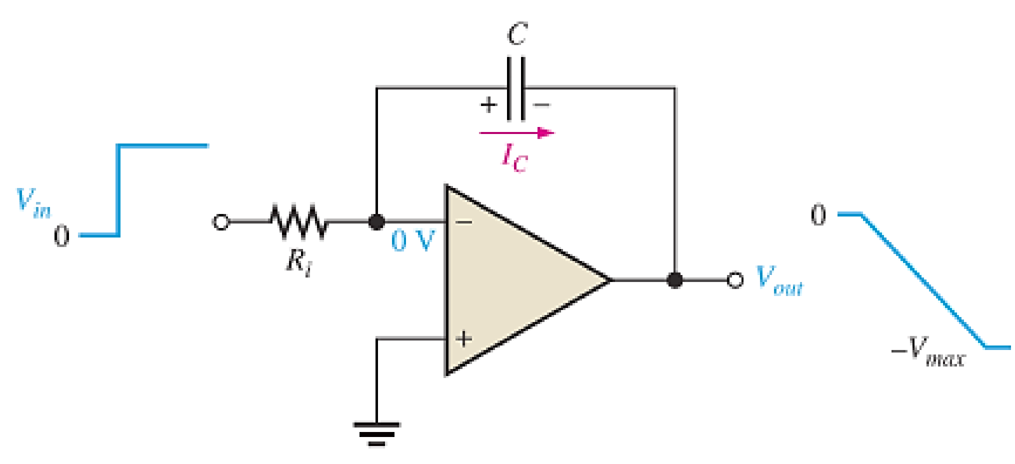
$$I_{in} = \frac{V_{in}}{R_i}$$

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



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

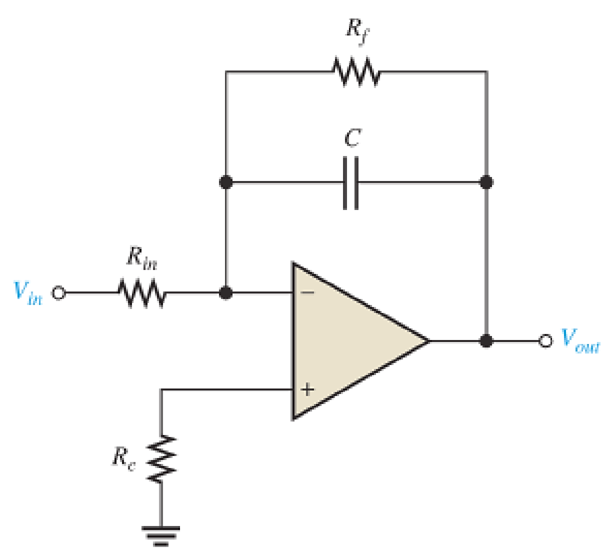
$$\frac{\Delta V_{out}}{\Delta t} = -\frac{V_{in}}{R_i C}$$



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.

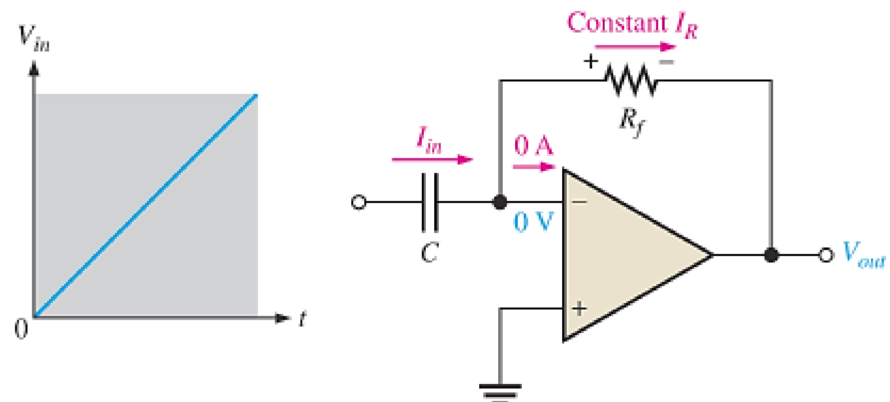


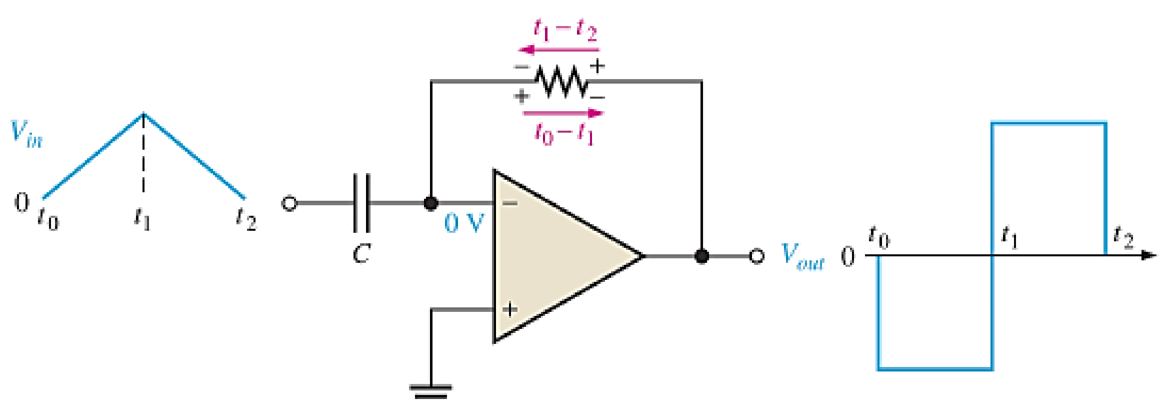
The Op-Amp Differentiator Ideal

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

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

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





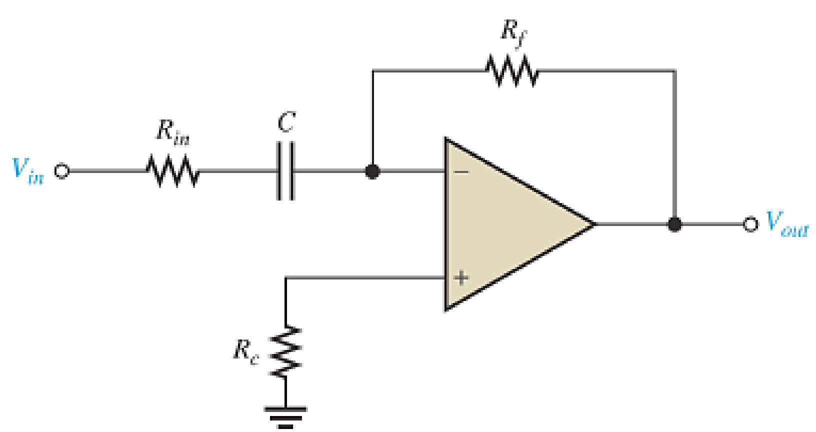
▶ FIGURE 13–39

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.



- For more details, refer to:
  - Chapter 13, T. Floyd, **Electronic Devices**, 9^{th} edition.
- The lecture is available online at:
  - http://bu.edu.eg/staff/ahmad.elbanna-courses/12884
- For inquires, send to:
  - ahmad.elbanna@feng.bu.edu.eg