Benha University
Faculty of Engineering at Shoubra

ECE-322
Electronic Circuits (B)

Lecture #4
Special-purpose Op-amp Circuits

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Agenda

- Instrumentation Amplifiers
- Isolation Amplifiers
- Operational Transconductance Amplifiers (OTAs)
- Log and Antilog Amplifiers
- Converters and Other Op-Amp Circuits

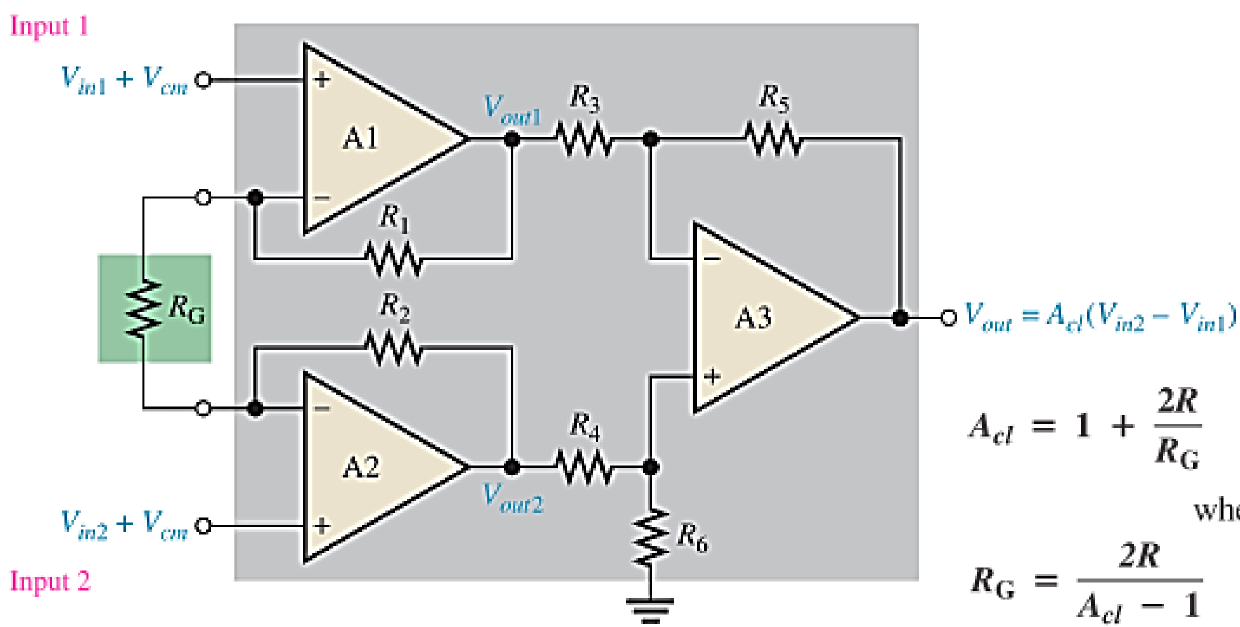
Intro.

- A **general-purpose op-amp**, such as the 741, is a versatile and widely used device.
- However, some **specialized IC amplifiers** are available that have **certain features** or characteristics oriented to **special applications**.
- These special circuits include:
  - The **instrumentation amplifier** that is used in **high- noise environments.**
  - The **isolation amplifier** that is used in **high-voltage and medical applications** .
  - The operational transconductance amplifier (**OTA**) that is used as a **voltage-to-current amplifier.**
  - The **logarithmic amplifiers** that are used for **linearizing** certain types of **inputs** and for **mathematical operations** and in communication systems, including **fiber optics**.

INSTRUMENTATION AMPLIFIERS

Basic Instrumentation Amplifier

- An **instrumentation amplifier** is a **differential voltage-gain device** that amplifies the difference between the voltages existing at its two input terminals.
- The main **purpose** of an instrumentation amplifier is to **amplify small signals** that may be **riding on large common-mode voltages**.
- The key **characteristics** are high input impedance, high common-mode rejection, low output offset, and low output impedance.



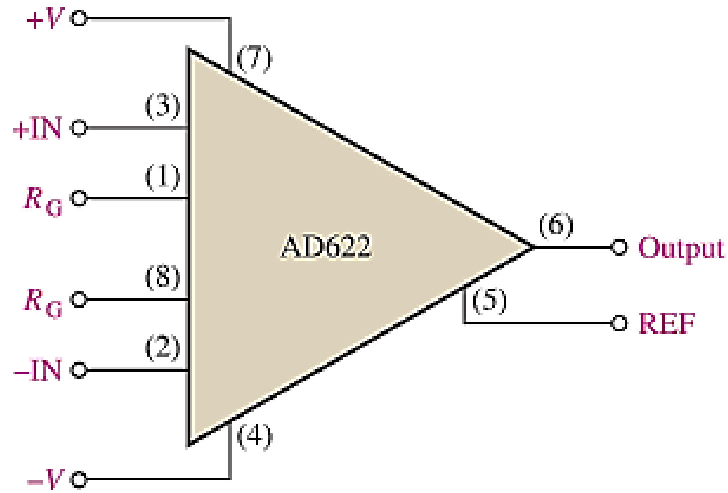
$$A_{cl} = 1 + \frac{2R}{R_G}$$

where $R_1 = R_2 = R$.

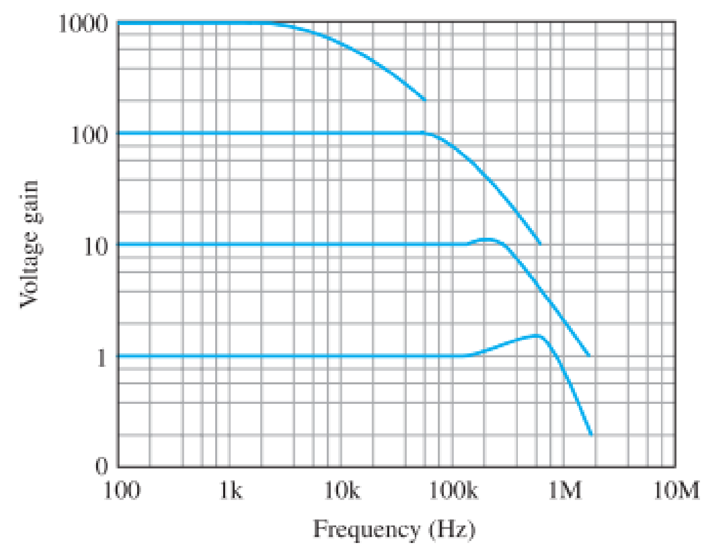
$$R_G = \frac{2R}{A_{cl} - 1}$$

Applications
A Specific Instrumentation Amplifier (AD622)

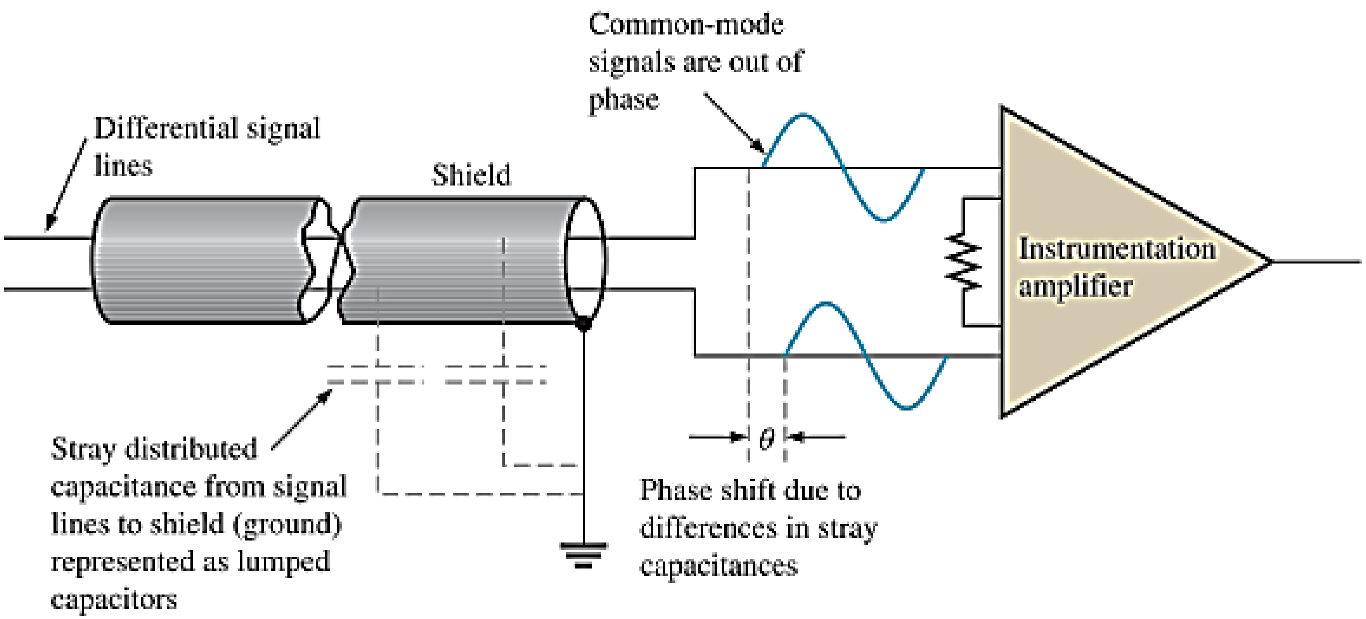
$$R_G = \frac{50.5\ k\Omega}{A_v - 1}$$



Features	Value
Voltage gain	2:1000
Input Impedance	10 GΩ
CMRR	66 dB
B.W.	800 kHz
Slew Rate	1.2 V/us



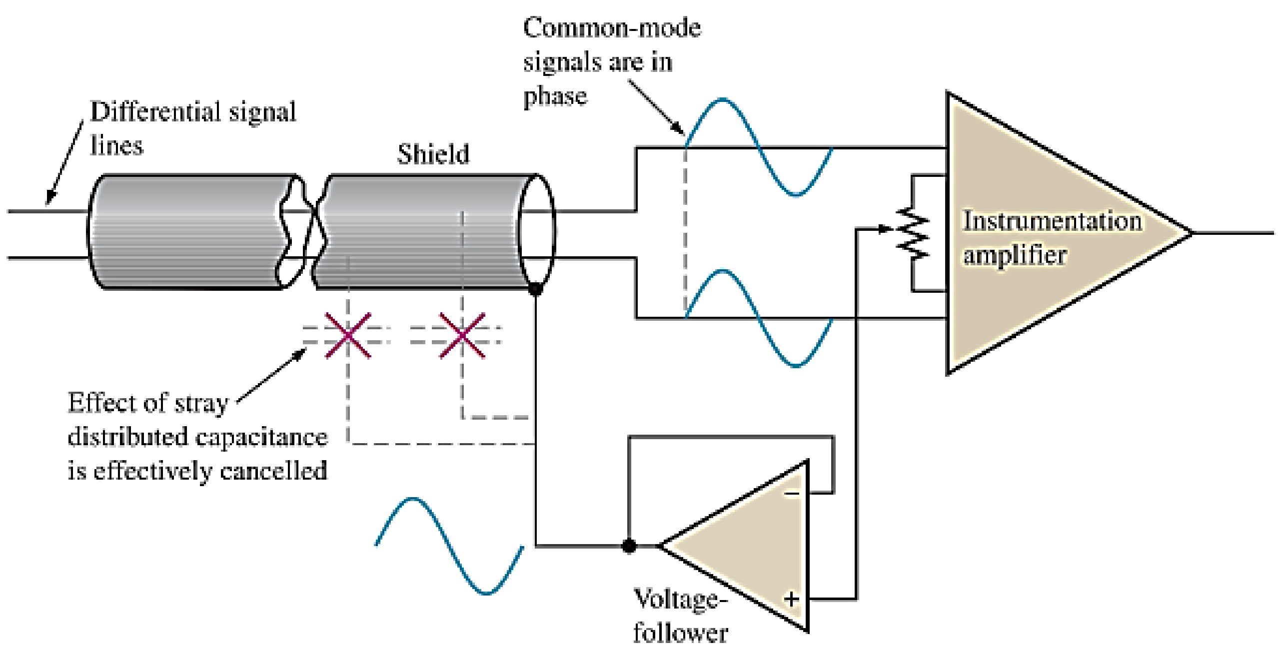
Noise Effects in Instrumentation Amplifier Applications



- Degradation of common-mode rejection in a shielded cable connection due to unwanted phase shifts.

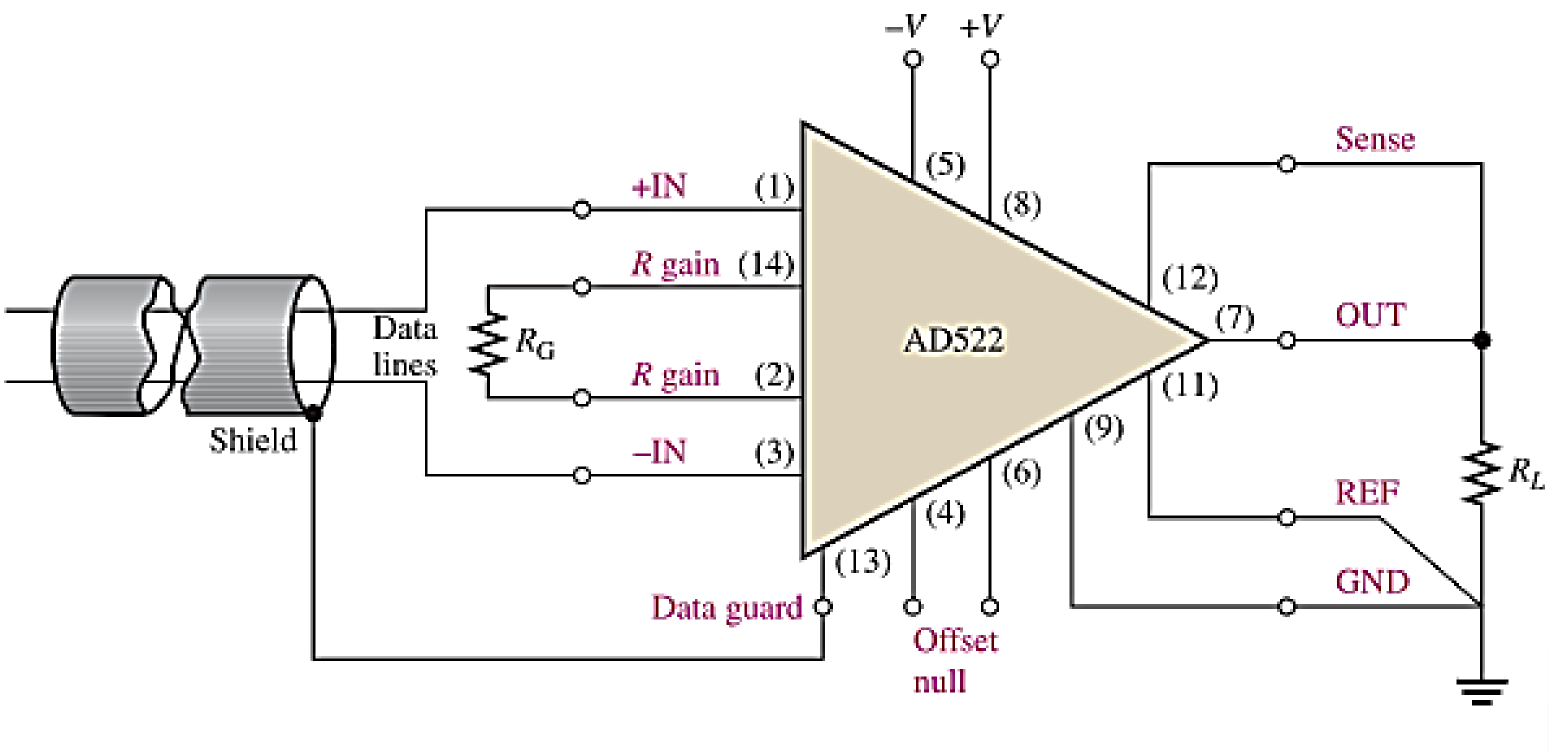
Noise Effects in Instrumentation Amplifier Applications ..

- Shield Guard: Guarding is a technique to reduce the effects of noise on the common-mode operation of an instrumentation amplifier operating in critical environments by connecting the common-mode voltage to the shield of a coaxial cable.



- Instrumentation amplifier with shield guard to prevent degradation of the CMR.

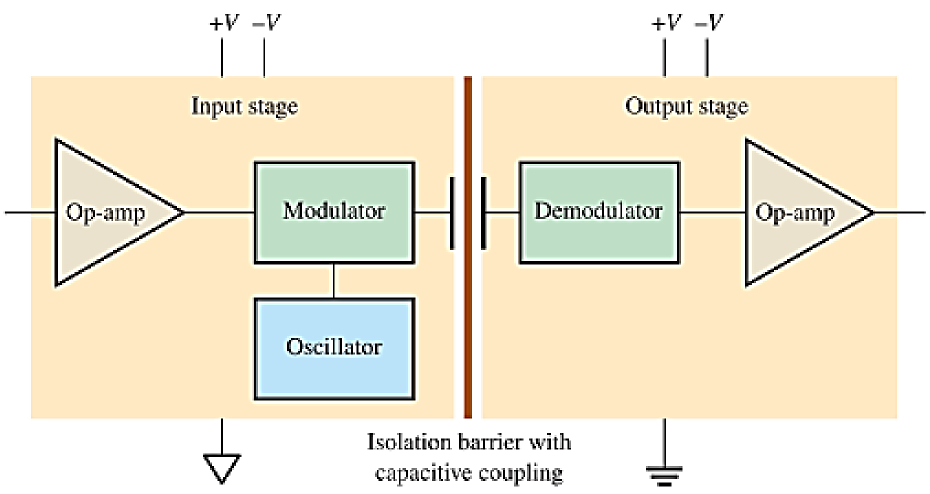
A Specific Instrumentation Amplifier with a Guard Output (AD522)



ISOLATION AMPLIFIERS

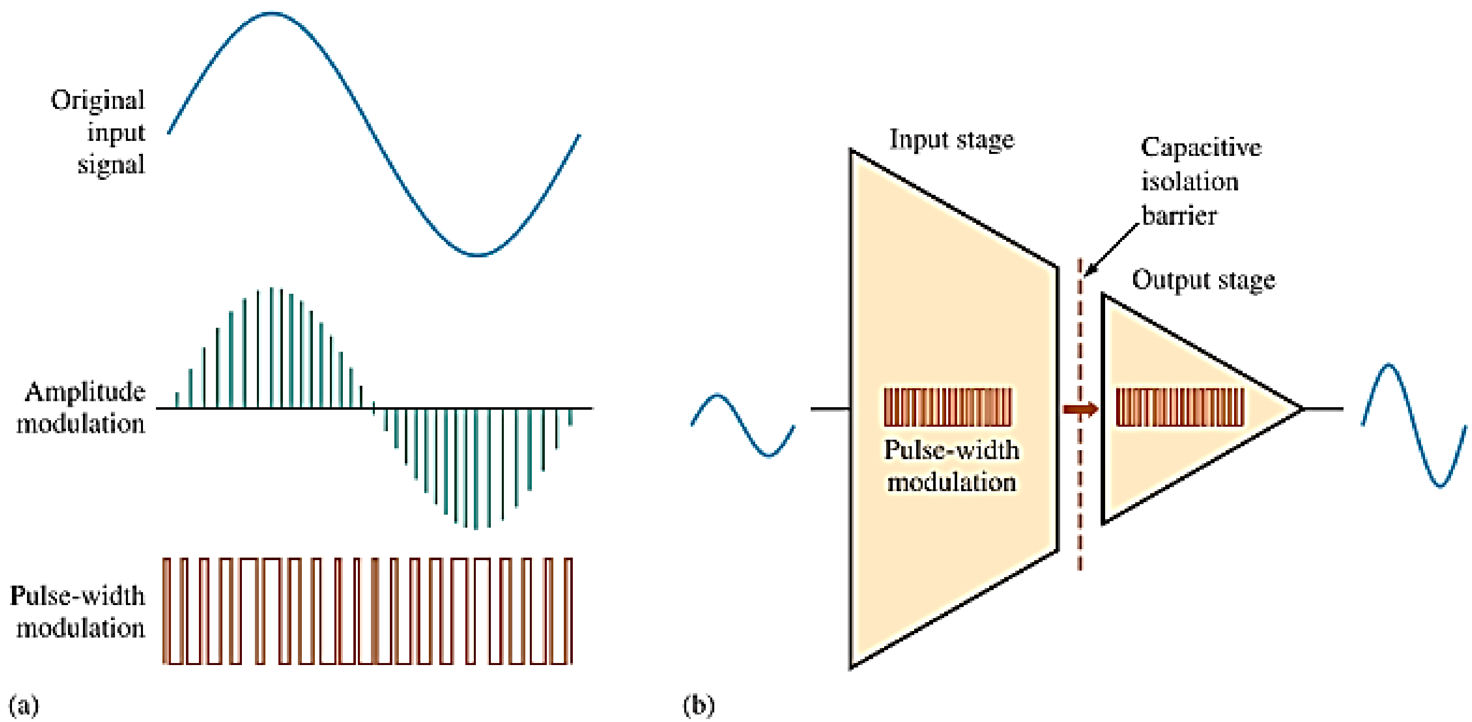
A Basic Capacitor-Coupled Isolation Amplifier

- An **isolation amplifier** is a device that consists of **two electrically isolated stages**.
- The input stage and the output stage are separated from each other by an **isolation barrier** so that a **signal** must be **processed** in order to be coupled across the isolation barrier.
- Isolation by:
  - **optical coupling**
  - **transformer coupling**
  - **capacitive coupling**
- Each stage has **separate supply voltages** and grounds so that there are no common electrical paths between them.

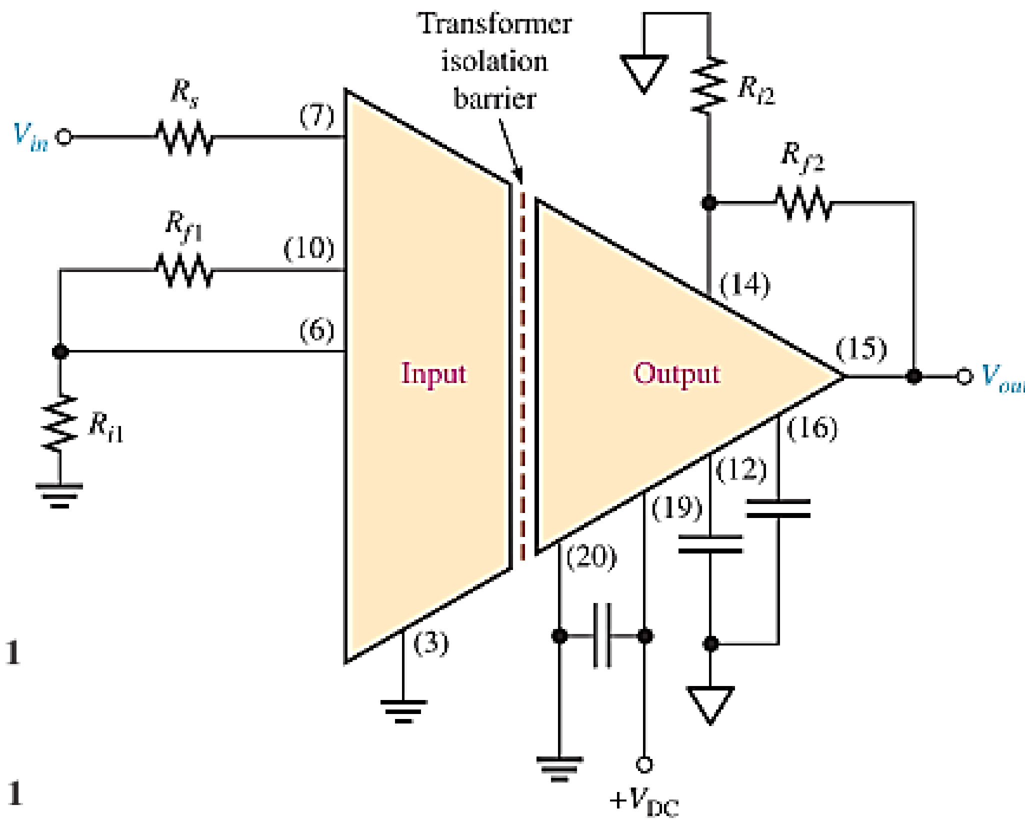


Modulation

Modulation is the process of allowing a signal containing **information** to **modify** a characteristic of **another signal**, such as amplitude, frequency, or pulse width, so that the information in the first signal is also contained in the second.



The 3656KG Transformer Coupled Isolation Amplifier

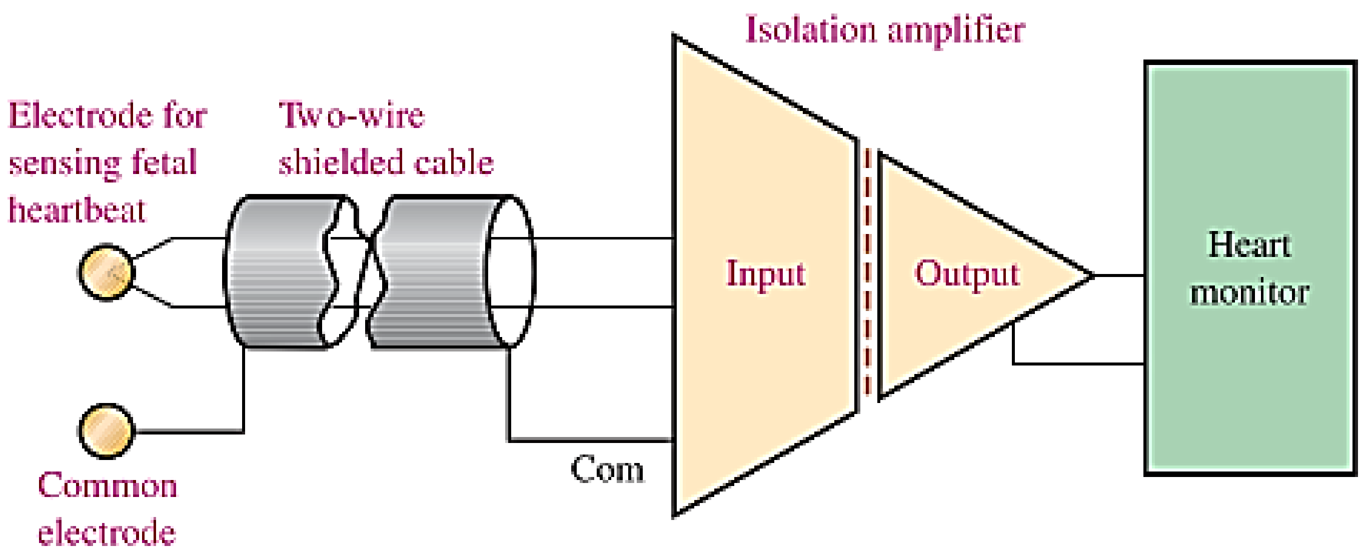


$$A_{v1} = \frac{R_{f1}}{R_{i1}} + 1$$

$$A_{v2} = \frac{R_{f2}}{R_{i2}} + 1$$

$$A_{v(tot)} = A_{v1}A_{v2}$$

Application: Fetal heartbeat monitoring using an isolation amplifier



Heart signals, which are very small, are combined with much larger common-mode signals caused by muscle noise, electrochemical noise, residual electrode voltage, and 60 Hz power-line pickup from the skin.

OPERATIONAL TRANSCONDUCTANCE AMPLIFIERS (OTAS)

OTA

- The operational transconductance amplifier (**OTA**) is primarily a **voltage-to-current amplifier** in which the **output current equals the gain times the input voltage**.

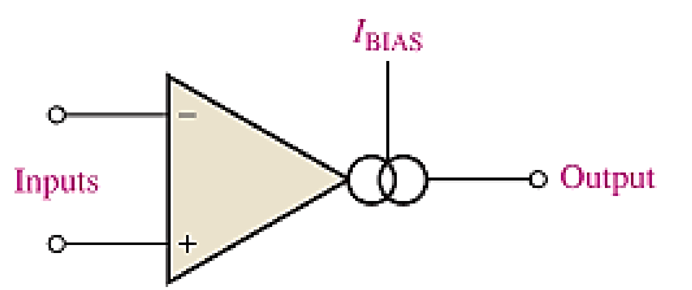
OTA	Conventional Op-Amp
Two Differential Input	✓
high input impedance	✓
high CMRR	✓
bias-current input terminal	x
high output impedance	x
no fixed open-loop voltage gain	x

- The transconductance of an electronic device is the ratio of the output current to the input voltage.

$$g_m = \frac{I_{out}}{V_{in}}$$

$$g_m = KI_{BIAS}$$

$$I_{out} = g_m V_{in} = KI_{BIAS} V_{in}$$

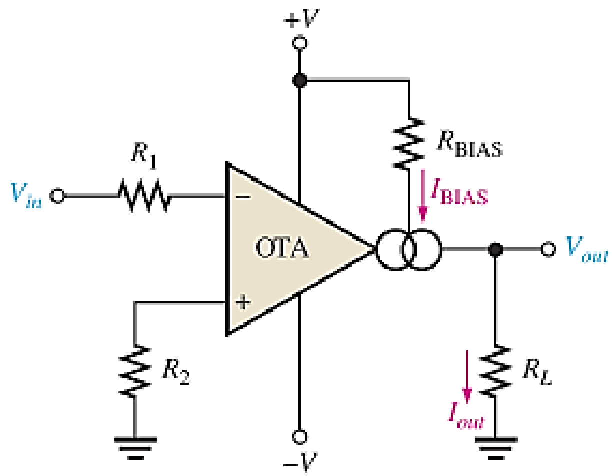


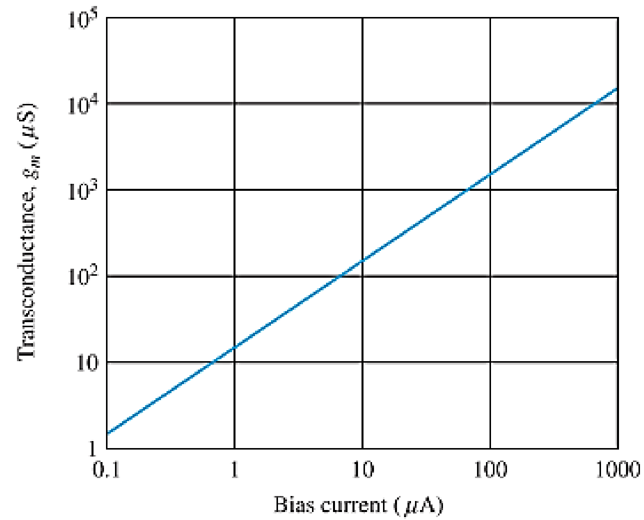
Basic OTA Circuits

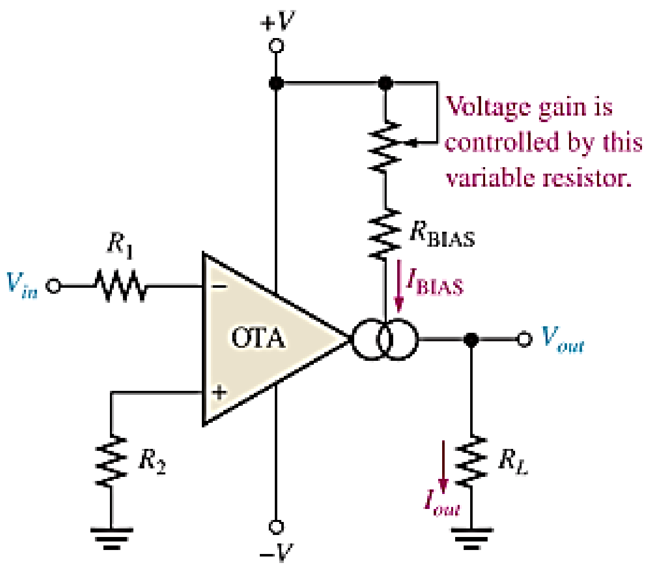
$$V_{out} = I_{out} R_L$$

$$\frac{V_{out}}{V_{in}} = \left(\frac{I_{out}}{V_{in}}\right) R_L$$

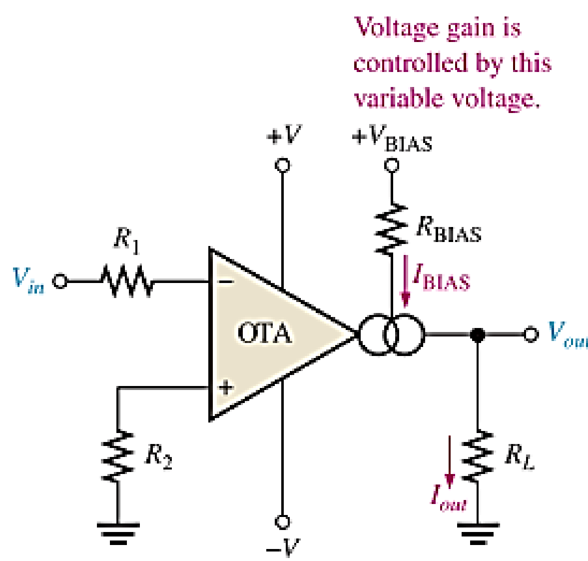
$$A_v = g_m R_L$$







(a) Amplifier with resistance-controlled gain

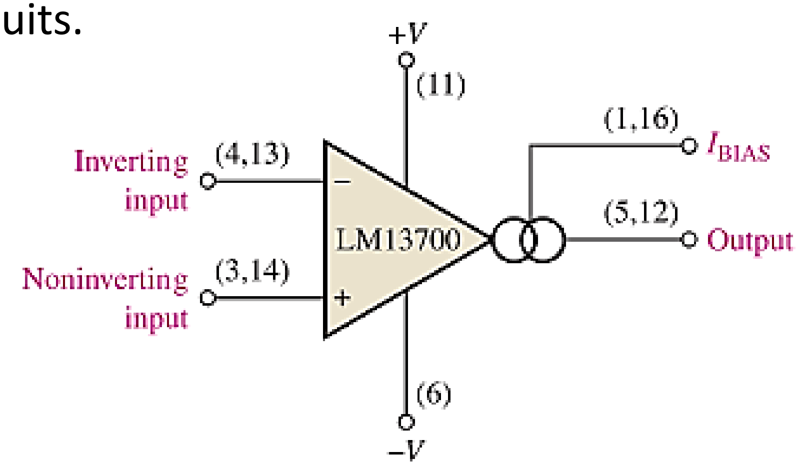


(b) Amplifier with voltage-controlled gain

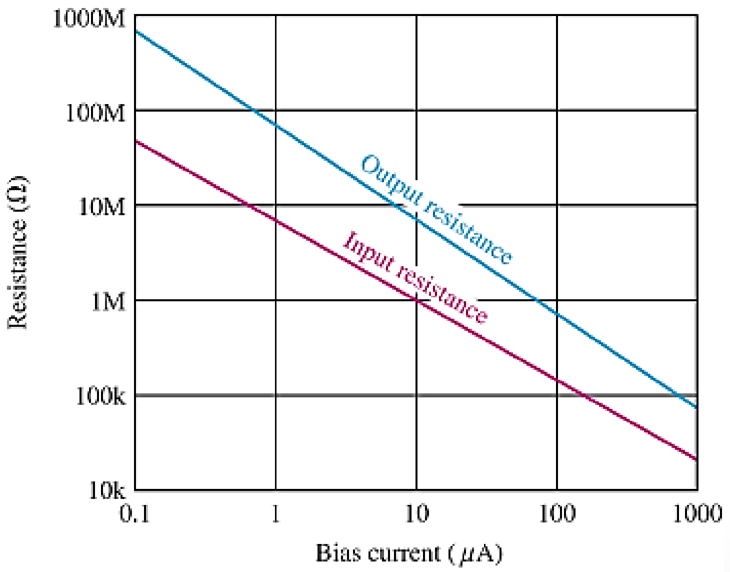
A Specific OTA (LM13700)

The LM13700 is a **dual-device package** containing two OTAs and buffer circuits.

$$I_{BIAS} = \frac{+V_{BIAS} - (-V) - 1.4\text{ V}}{R_{BIAS}}$$

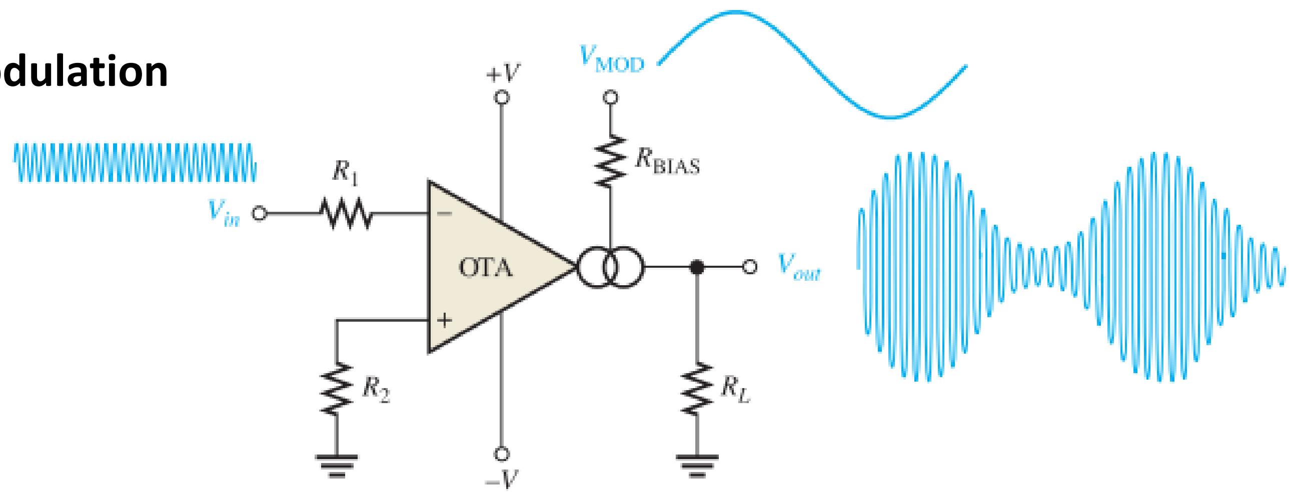


- The input and output resistances varies also with the bias current.

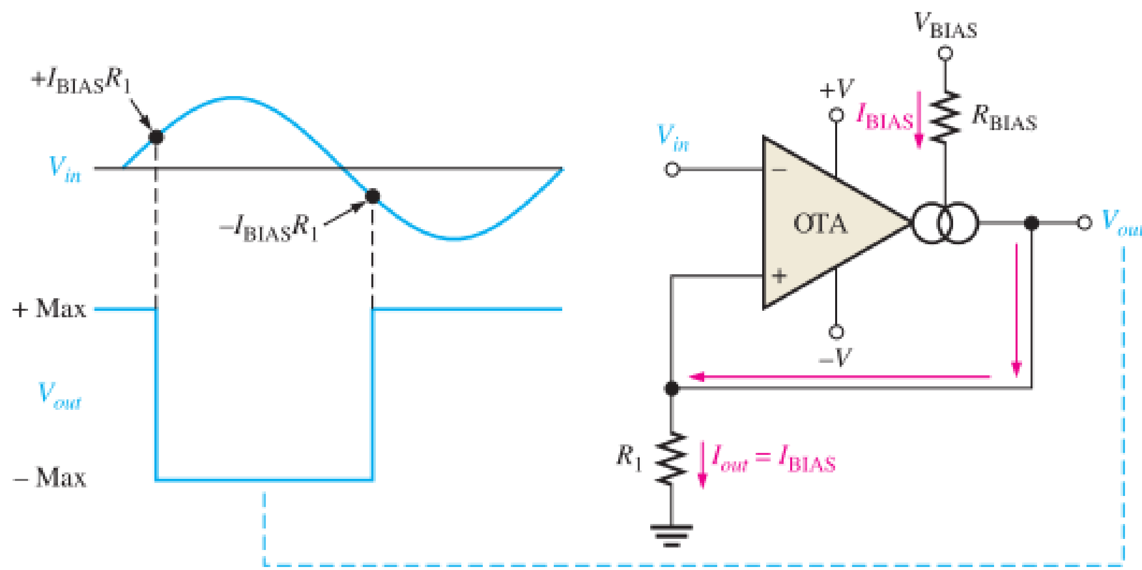


OTA Applications

- **Amplitude Modulation**



- **Shcmitt Trigger**



LOG AND ANTILOG AMPLIFIERS

Basic Logarithmic Amplifier

- **Log and antilog amplifiers** are used in applications that require **compression** of analog input data, **linearization** of transducers that have **exponential outputs**, and analog **multiplication and division**.
- They are often used in **high-frequency communication systems**, including fiber optics, for processing wide dynamic range signals.
- The **key element** in a log amplifier is a device that exhibits a **logarithmic characteristic** that, when placed in the feedback loop of an op-amp, produces a logarithmic response.

$$V_{out} = -K\ln(V_{in})$$

$$I_F \cong I_R e^{qV_F/kT}$$

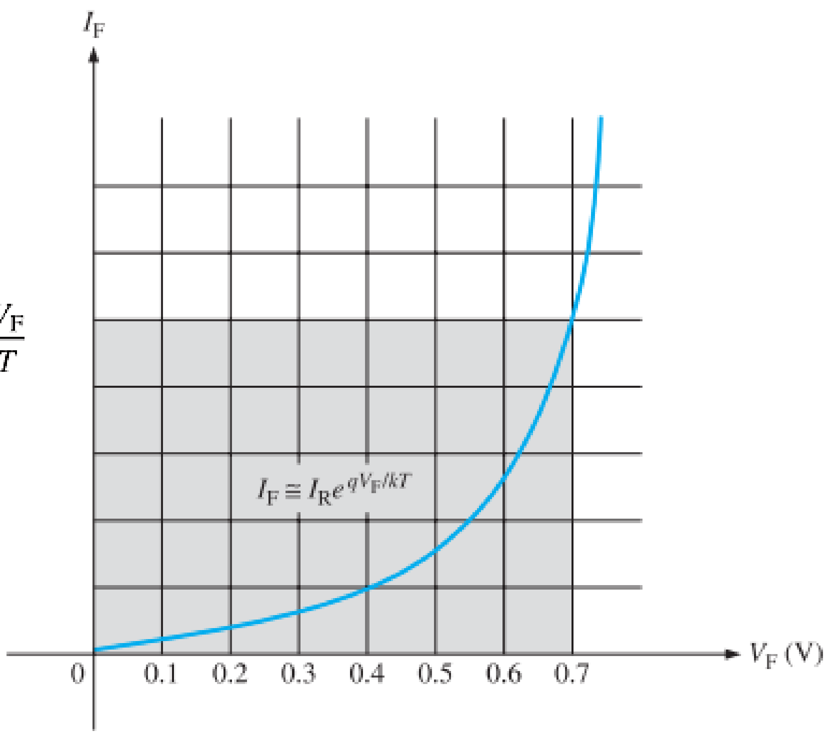
$$\ln I_F = \ln I_R e^{qV_F/kT}$$

$$\ln I_F = \ln I_R + \ln e^{qV_F/kT} = \ln I_R + \frac{qV_F}{kT}$$

$$\ln I_F - \ln I_R = \frac{qV_F}{kT}$$

$$\ln\left(\frac{I_F}{I_R}\right) = \frac{qV_F}{kT}$$

$$V_F = \left(\frac{kT}{q}\right)\ln\left(\frac{I_F}{I_R}\right)$$



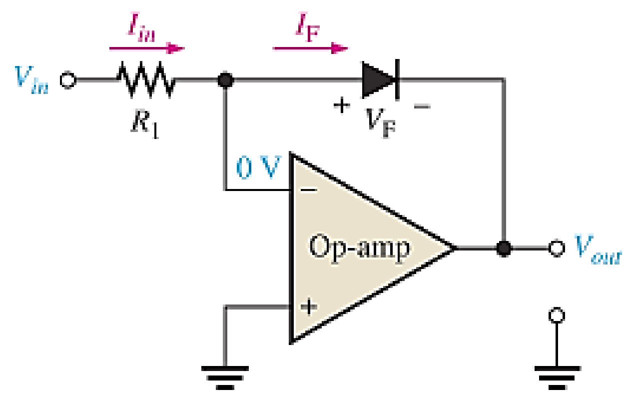
Log Amplifier with a Diode/BJT

$$V_{out} = -V_F$$

$$I_F = I_{in} = \frac{V_{in}}{R_1}$$

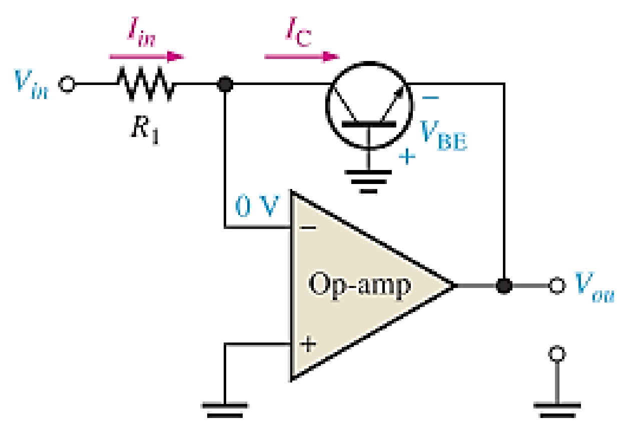
$$V_{out} = -\left(\frac{kT}{q}\right)\ln\left(\frac{V_{in}}{I_R R_1}\right)$$

$$V_{out} \cong -(0.025\ \text{V})\ln\left(\frac{V_{in}}{I_R R_1}\right)$$



$$I_C = I_{EBO} e^{qV_{BE}/kT}$$

$$V_{out} = -(0.025\ \text{V})\ln\left(\frac{V_{in}}{I_{EBO} R_1}\right)$$



Basic Antilog Amplifier

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

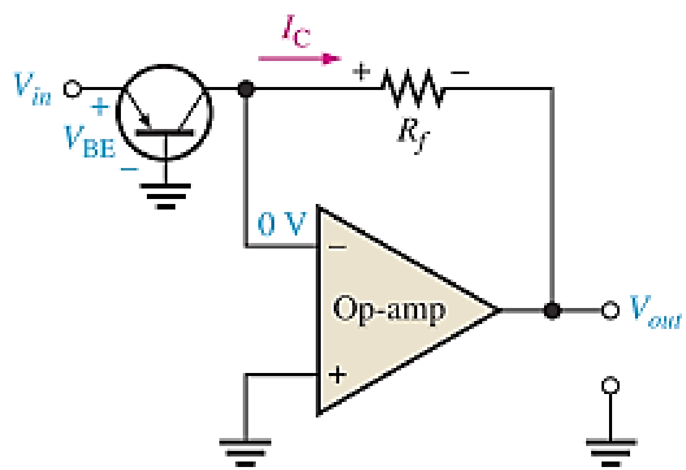
$$I_C = I_{EBO} e^{qV_{BE}/kT}$$

$$V_{out} = -R_f I_{EBO} e^{qV_{BE}/kT}$$

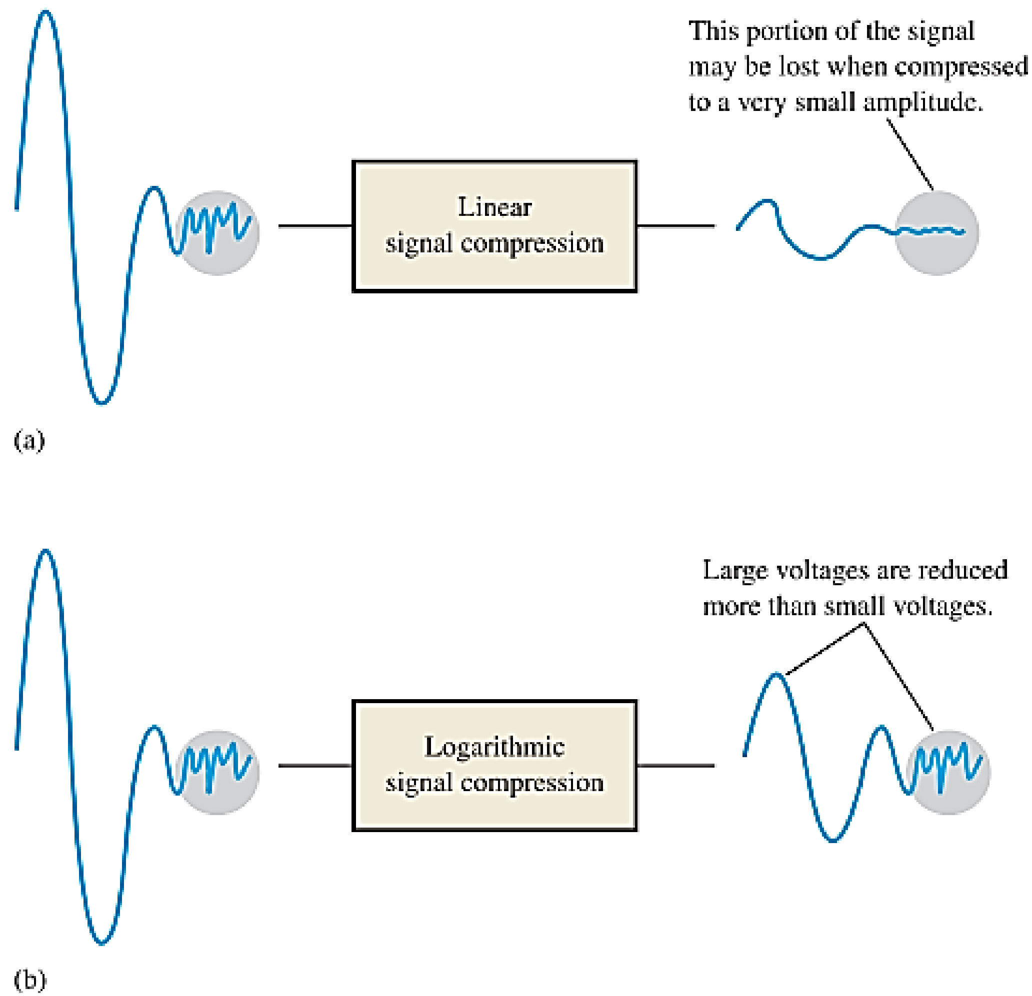
$$V_{out} = -R_f I_{EBO} e^{qV_{in}/kT}$$

$$V_{out} = -R_f I_{EBO} \text{antilog}\left(\frac{V_{in} q}{kT}\right)$$

$$V_{out} = -R_f I_{EBO} \text{antilog}\left(\frac{V_{in}}{25\text{ mV}}\right)$$



Signal Compression with Logarithmic Amplifiers

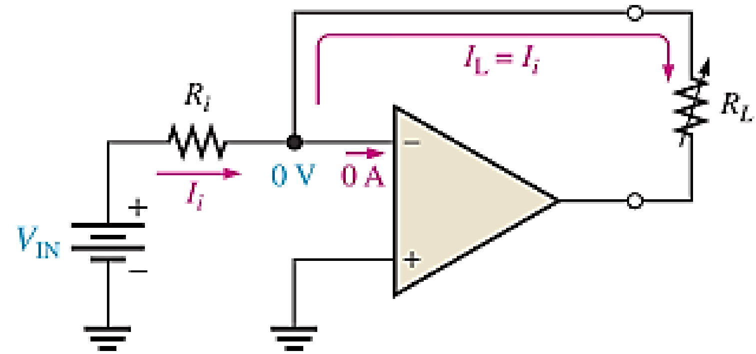


CONVERTERS AND OTHER OP-AMP CIRCUITS

Constant-Current Source

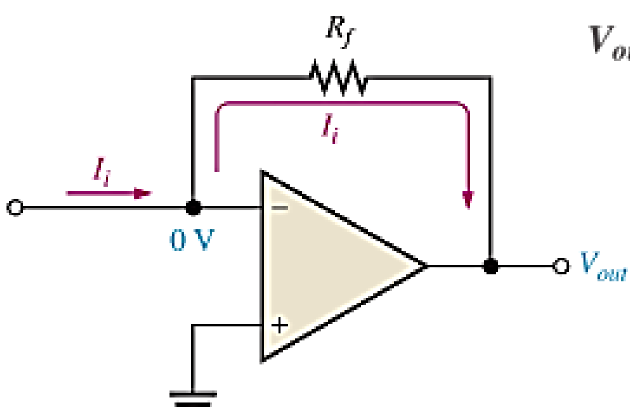
$$I_i = \frac{V_{IN}}{R_i}$$

$$I_L = \frac{V_{IN}}{R_i}$$

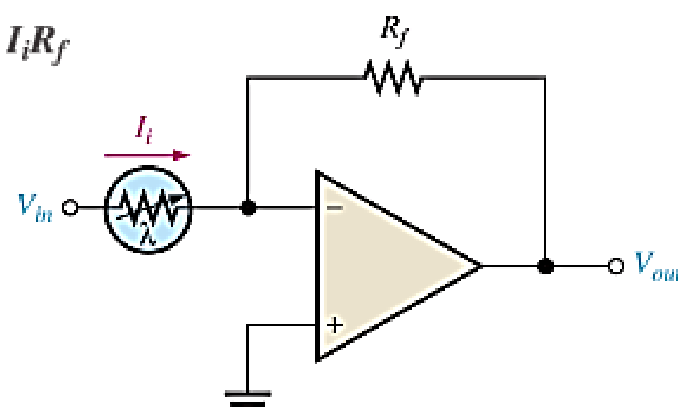


Current-to-Voltage Converter

$$V_{out} = I_i R_f$$



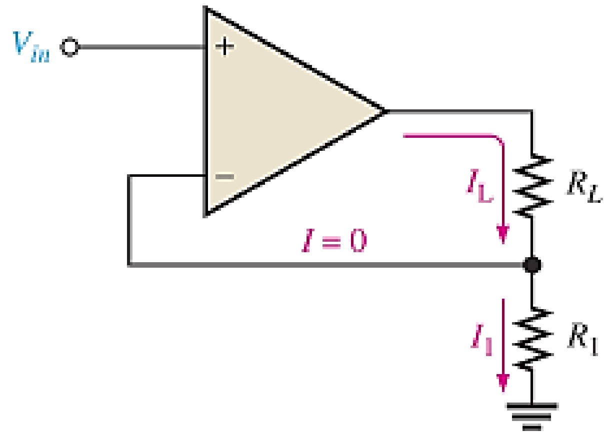
(a) Basic circuit



(b) Circuit for sensing light level and converting it to a proportional output voltage

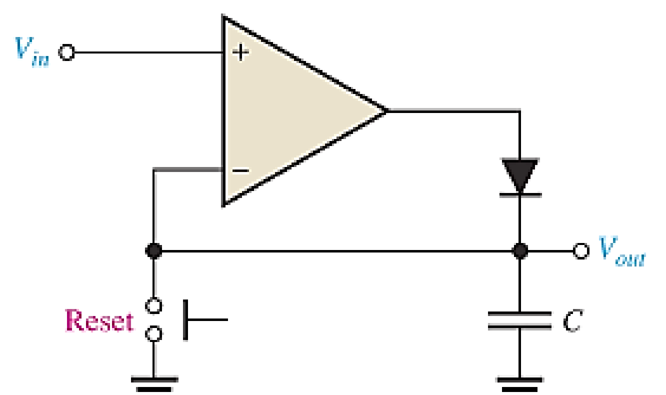
Voltage-to-Current Converter

$$I_L = \frac{V_{in}}{R_1}$$



Peak Detector

This circuit is used to detect the peak of the input voltage and store that peak voltage on a capacitor.



- For more details, refer to:
  - Chapter 14, 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