# Instrumentos de Medida

- Osciloscópio analógico
- Analisador de espectro
- Frequencímetro

# Condicionamento de Sinais

- OPAMP
- Multiplexação analógica
- Demodulador Síncrono
- Filtros

Dispositivos analógicos de medição de corrente elétrica

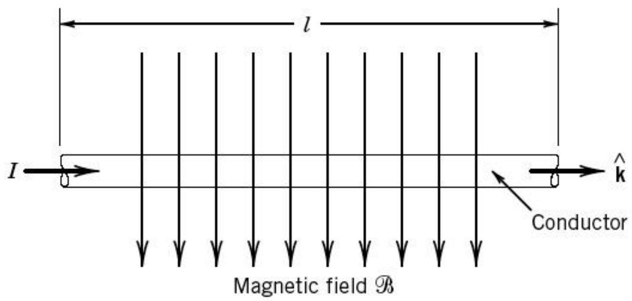



**Figure 6.1** Current-carrying conductor in a magnetic field.

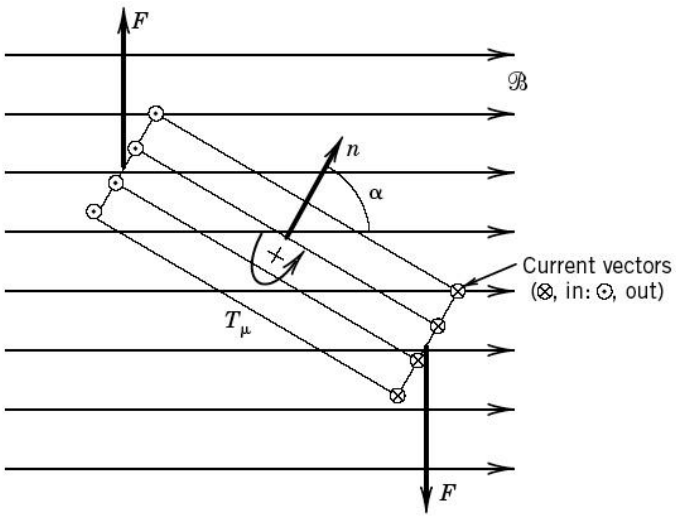



**Figure 6.2** Forces and resulting torque on a current loop in a magnetic field.

## Dispositivos analógicos de medição de corrente elétrica

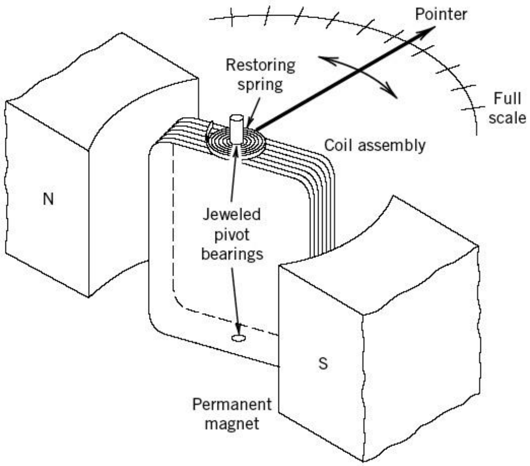



**Figure 6.3** Basic D'Arsonval meter movement.

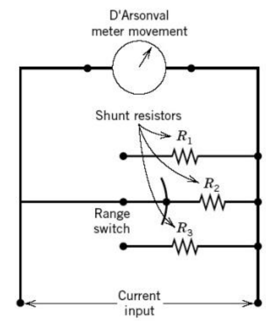



**Figure 6.4** Simple multirange ammeter (with make-before-break selector switch). Shunt resistors determine meter range.

## Dispositivos analógicos de medição de tensão elétrica

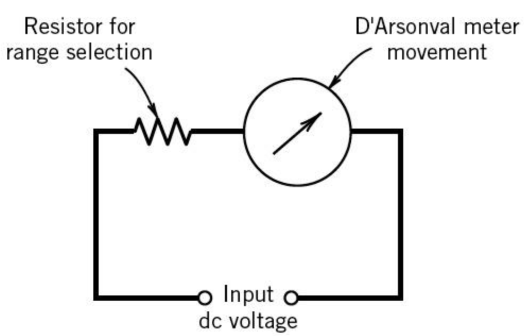



**Figure 6.6** A dc voltmeter circuit.

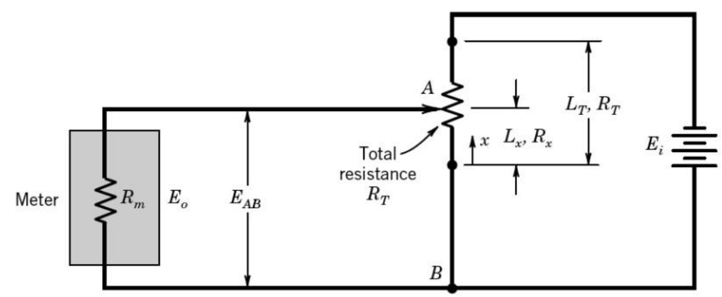
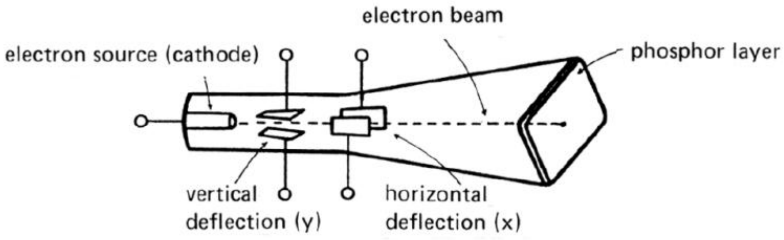



**Figure 6.9** Voltage divider circuit.

Exemplo de medida de um valor de resistência
Ligação a jusante e a montante
Método de quatro fios

Dispositivos analógicos de medição de tensão elétrica

Osciloscópio




(a)

Entrada de disparo - trigger

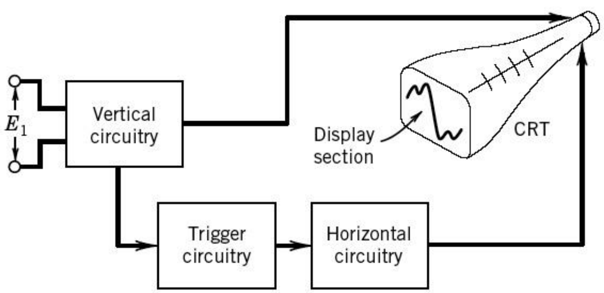
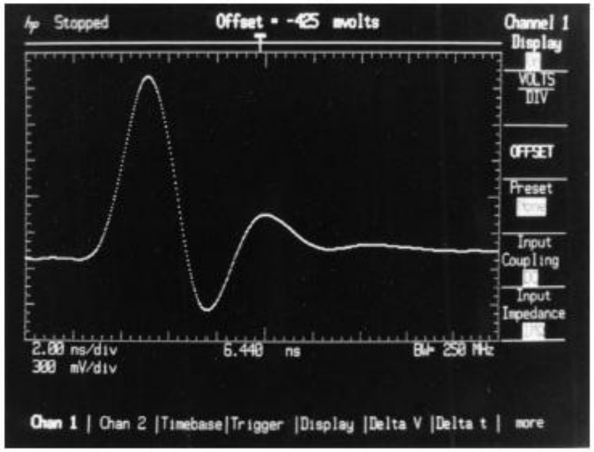



**Figure 6.7** Schematic of basic cathod-ray tube oscilloscope.




(b)

**Figure 6.8** (*a*) Digital oscilloscope. (Photograph courtesy of Tektronix, Inc.) (*b*) Oscilloscope output. (Photograph courtesy of Hewlett-Packard Company.)

## Dispositivos analógicos de medição de resistência elétrica

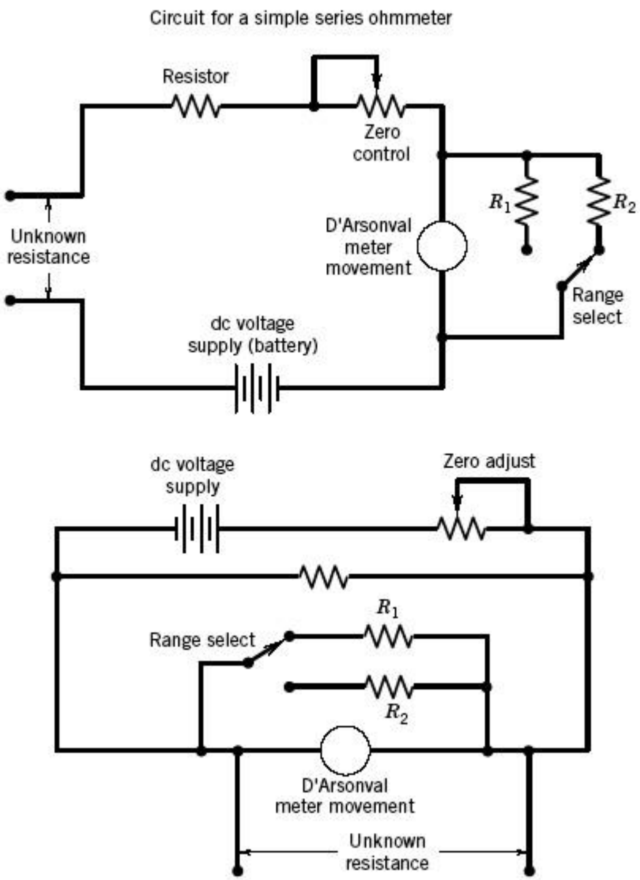



**Figure 6.12** Multirange ohmmeter circuits.

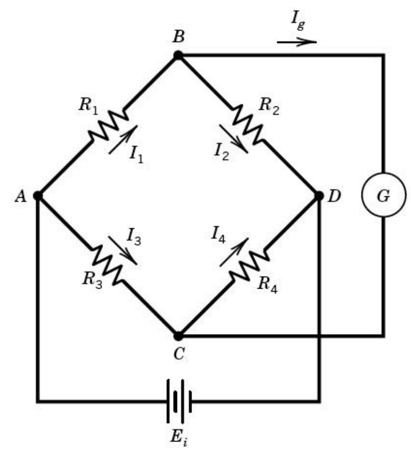
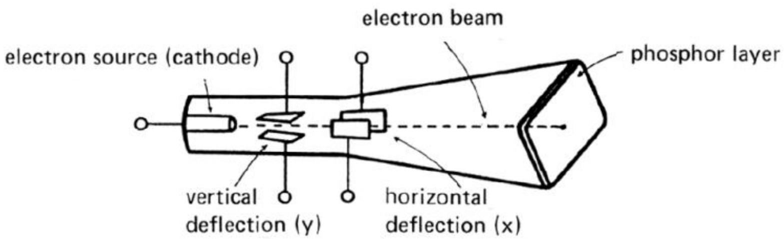



**Figure 6.13** Basic Wheatstone bridge circuit ($G$, galvanometer).

Dispositivos analógicos de medição de tensão elétrica

Osciloscópio



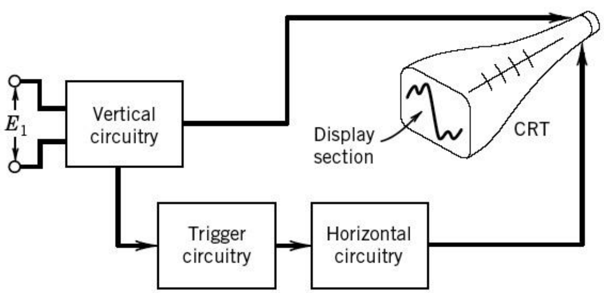




**Figure 6.7** Schematic of basic cathod-ray tube oscilloscope.

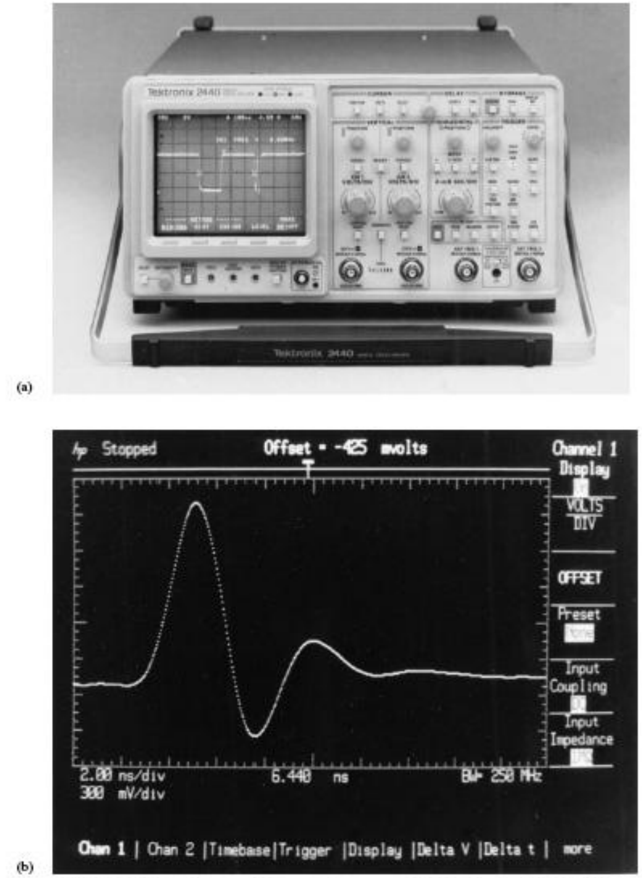
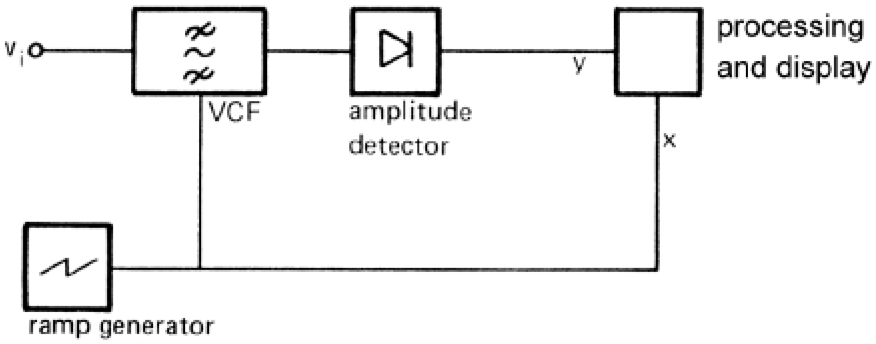



**Figure 6.8** (*a*) Digital oscilloscope. (Photograph courtesy of Tektronix, Inc.) (*b*) Oscilloscope output. (Photograph courtesy of Hewlett-Packard Company.)

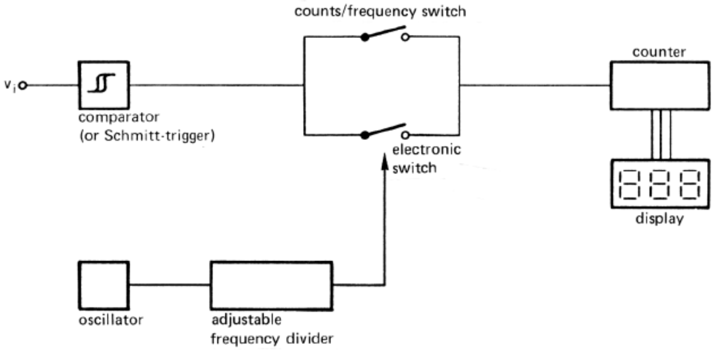
# Instrumentos de Medida

Analisador de espectro




Medida de V, Vrms, P
Casamento de impedância
Linha de transmissão
Espectro de potência
Densidade espectral de potência

Contador, frequencímetro, cronômetro



Erros de carregamento

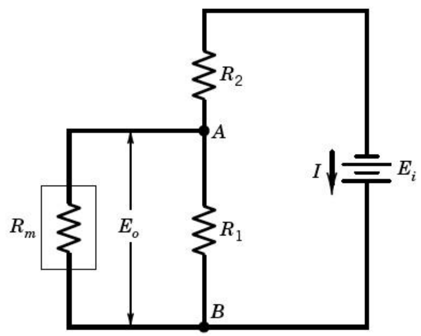



**Figure 6.15** Instruments in parallel to signal path form an equivalent voltage dividing circuit.

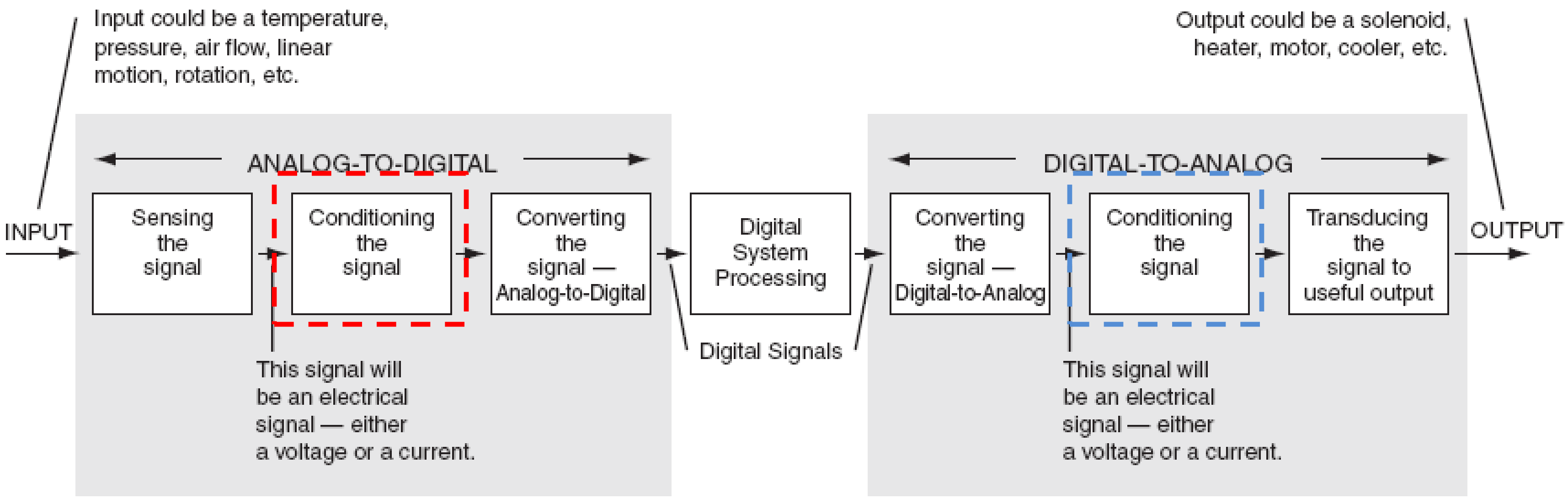
Impedância de entrada de osciloscópios
Impedância de entrada em analisadores de espectro
Resistência interna de voltímetros

Classificação de instrumentos de medição

Ativo x Passivo
Anulação x Deflexão
Analógico x Digital
Indicadores x Sinal de saída
Autônomos x embarcados

# Condicionamento de Sinais






- *Adequação dos sinais de entrada a grandezas e faixas de valores de grandezas aceitáveis para a entrada do conversor AD*

- *Proporcionar amplificação do sinal de saída do conversor DA de modo a permitir o acionamento de dispositivos de atuação*

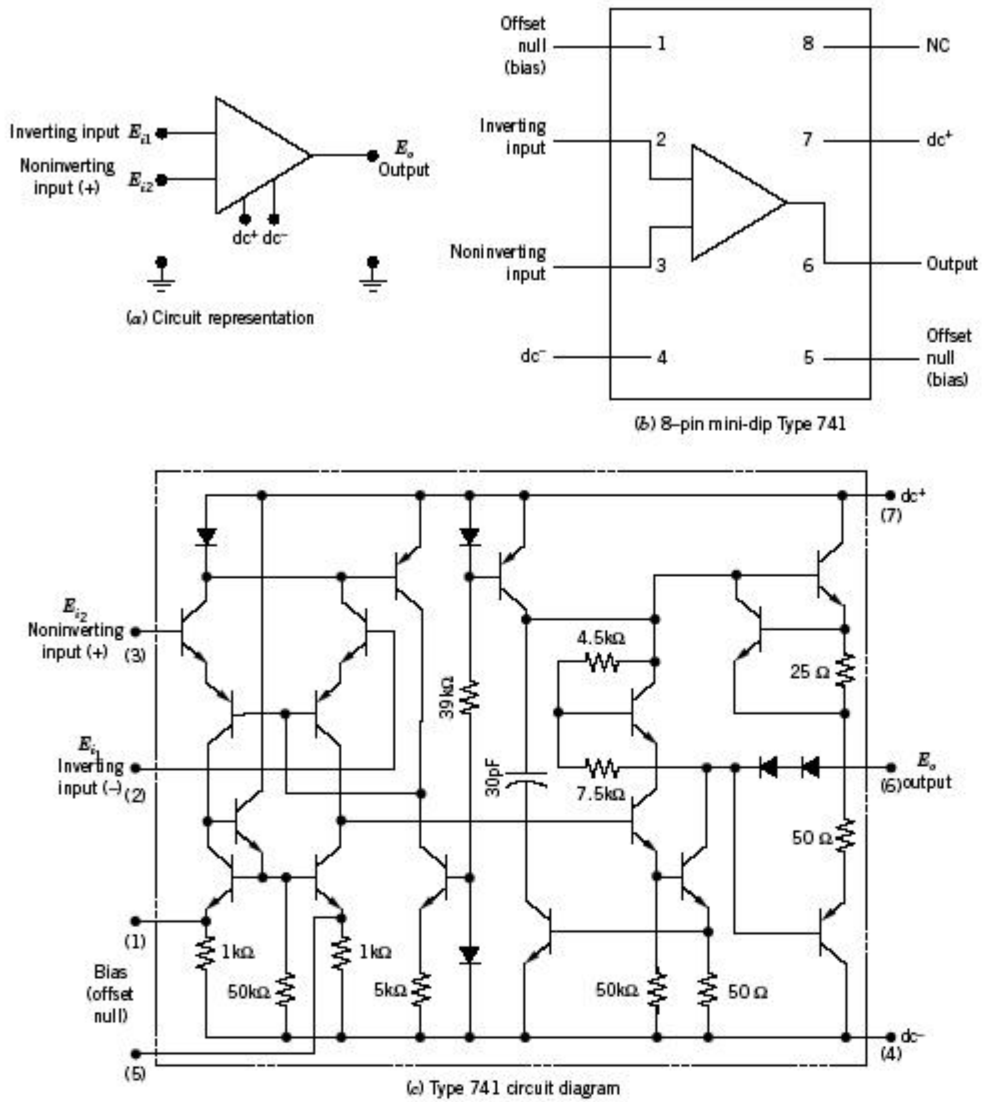
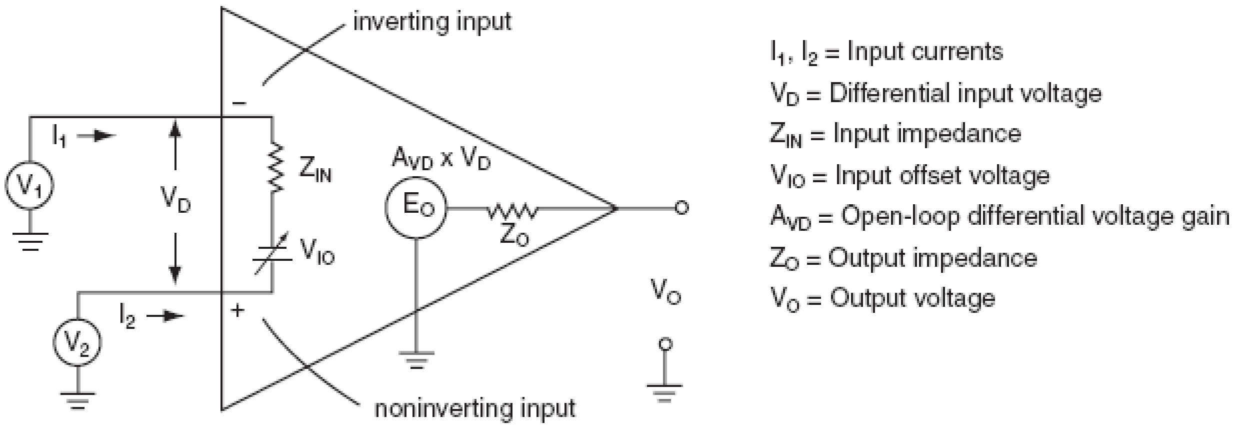


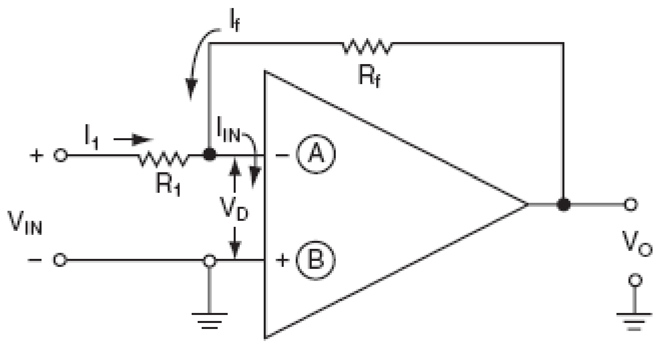

**Figure 6.19** Operational amplifier.



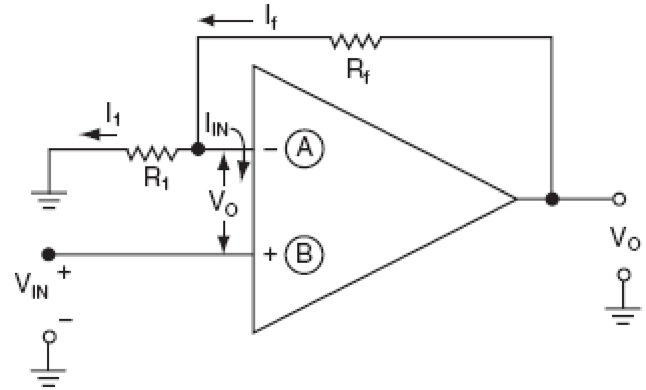

*Ganho de malha aberta muito alto - A*
*Alta razão de rejeição de modo comum – CMRR*
*Alta impedância de entrada*
*Baixa impedância de saída*

*Configurações simples*

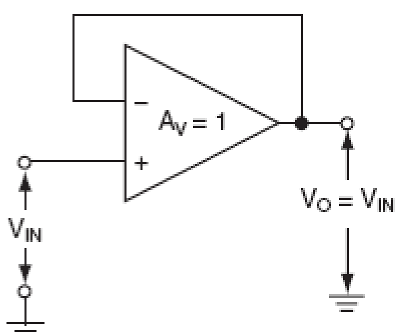
*Amplif. Inversor*



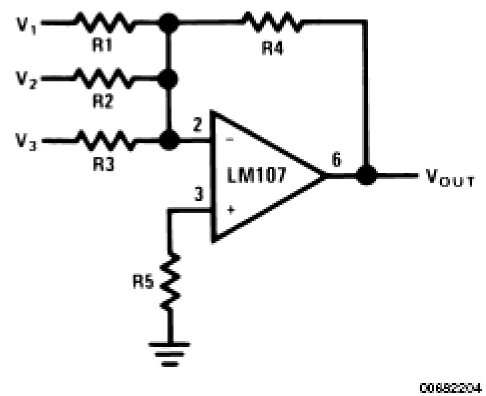

*Amplif. Não-Inversor*




*Seguidor de tensão*



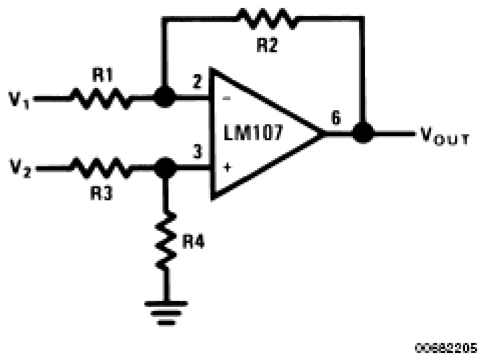

*Somador*




$$V_{OUT} = -R4\left(\frac{V_1}{R1} + \frac{V_2}{R2} + \frac{V_3}{R3}\right)$$

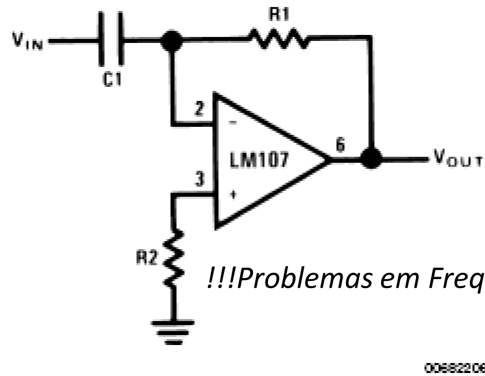
# OPAMP

## *Amplif. de Diferença*



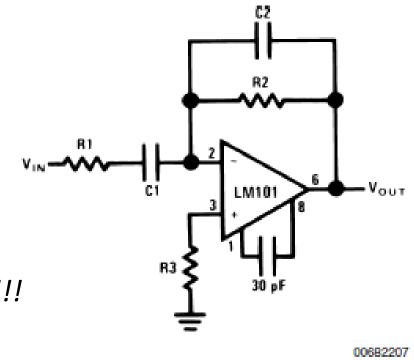

$$V_{OUT} = \left(\frac{R1 + R2}{R3 + R4}\right)\frac{R4}{R1}V_2 - \frac{R2}{R1}V_1$$

## *Diferenciador*




*!!!Problemas em Frequências Altas!!!*

$$V_{OUT} = -R1C1\frac{d}{dt}(V_{IN})$$

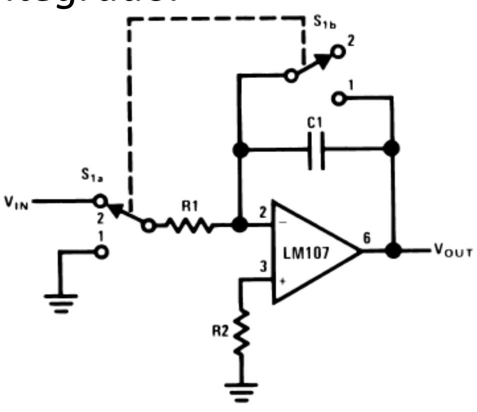



$$f_c = \frac{1}{2\pi R2C1}$$

$$f_h = \frac{1}{2\pi R1C1} = \frac{1}{2\pi R2C2}$$

$$f_c \ll f_h \ll f_{unity\ gain}$$

## *Integrador*

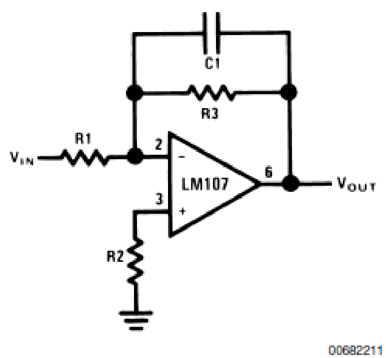



$$V_{OUT} = \frac{1}{R1C1}\int_{t_1}^{t_2} V_{IN}\,dt$$

$$f_c = \frac{1}{2\pi R1C1}$$

$$R1 = R2$$

## *Filtro PB*

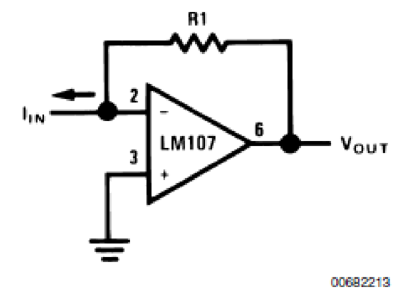



$$f_L = \frac{1}{2\pi R1C1}$$

$$f_c = \frac{1}{2\pi R3C1}$$

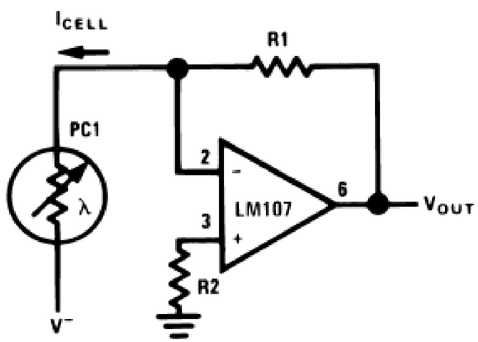
$$A_L = \frac{R3}{R1}$$

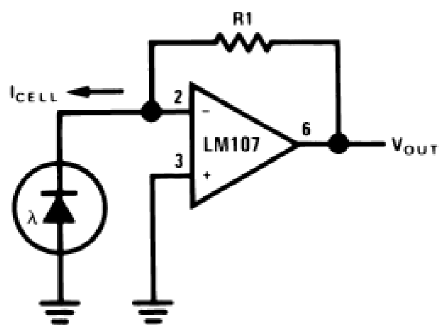
## *Conversor I-V*



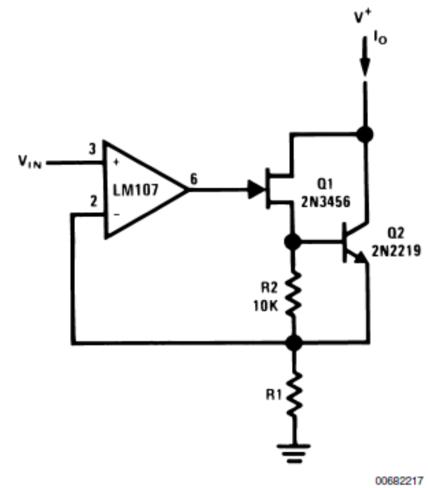

$$V_{OUT} = I_{IN}\,R1$$

*Amplif. p/ Célula Fotocondutora e fotovoltaica*




*Fonte de Corrente*




$$I_O = \frac{V_{IN}}{R1}$$

**An Applications Guide for Op Amps**

National Semiconductor
Application Note 20
February 1969

## *Características Importantes (Exemplo de caso)*

ANALOG DEVICES

**Low Noise, Precision Operational Amplifier**

**OP-27**

**ABSOLUTE MAXIMUM RATINGS** (Note 4)

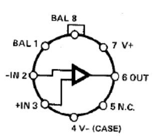
Supply Voltage ........................ ±22V
Input Voltage (Note 1) ........................ ±22V
Output Short-Circuit Duration ........................ Indefinite
Differential Input Voltage (Note 2) ........................ ±0.7V
Differential Input Current (Note 2) ........................ ±25mA
Storage Temperature Range ........................ –65°C to +150°C

Operating Temperature Range
OP-27A, OP-27B, OP-27C (J, Z, RC)........ –55°C to +125°C
OP-27E, OP-27F (J, Z) ........................ –25°C to +85°C
OP-27E, OP-27F (P) ........................ 0°C to +70°C
OP-27G (P, S, J, Z) ........................ –40°C to +85°C
Lead Temperature Range (Soldering, 60 sec) ............. 300°C
Junction Temperature ........................ –65°C to +150°C

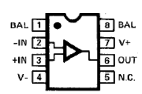
| PACKAGE TYPE | $\Theta_{jA}$ (Note 3) | $\Theta_{jc}$ | UNITS |
|---|---|---|---|
| TO-99 (J) | 150 | 18 | °C/W |
| 8-Pin Hermetic DIP (Z) | 148 | 16 | °C/W |
| 8-Pin Plastic DIP (P) | 103 | 43 | °C/W |
| 20-Contact LCC (RC) | 98 | 38 | °C/W |
| 8-Pin SO (S) | 158 | 43 | °C/W |

**NOTES:**

1. For supply voltages less than ±22V, the absolute maximum input voltage is equal to the supply voltage.
2. The OP-27's inputs are protected by back-to-back diodes. Current limiting resistors are not used in order to achieve low noise. If differential input voltage exceeds ±0.7V, the input current should be limited to 25mA.
3. $\Theta_{jA}$ is specified for worst case mounting conditions, i.e., $\Theta_{jA}$ is specified for device in socket for TO, CerDIP, P-DIP, and LCC packages; $\Theta_{jA}$ is specified for device soldered to printed circuit board for SO package.
4. Absolute maximum ratings apply to both DICE and packaged parts, unless otherwise noted.



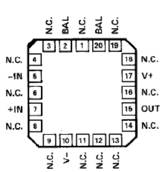

**TO-99 (J-Suffix)**




**8-PIN HERMETIC DIP (Z-Suffix)**

**EPOXY MINI-DIP (P-Suffix)**

**8-PIN SO (S-Suffix)**




**OP-27BRC/883 LCC PACKAGE (RC-Suffix)**

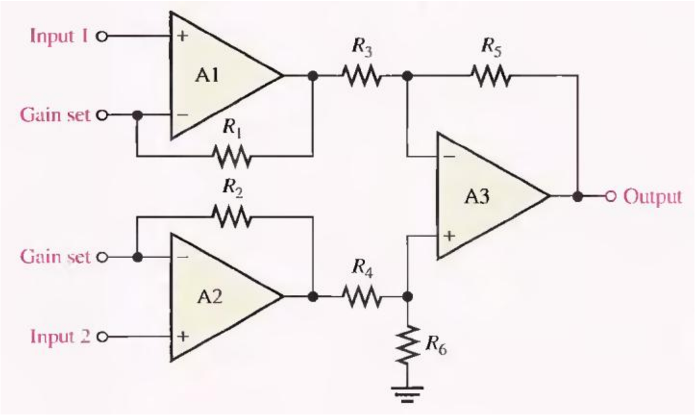
**ELECTRICAL CHARACTERISTICS** at $V_S = \pm15V$, $T_A = 25°C$, unless otherwise noted.

| PARAMETER | SYMBOL | CONDITIONS | OP-27A/E MIN | OP-27A/E TYP | OP-27A/E MAX | OP-27B/F MIN | OP-27B/F TYP | OP-27B/F MAX | OP-27C/G MIN | OP-27C/G TYP | OP-27C/G MAX | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Input Offset Voltage | $V_{OS}$ | (Note 1) | — | 10 | 25 | — | 20 | 60 | — | 30 | 100 | μV |
| Long-Term $V_{OS}$ Stability | $V_{OS}$/Time | (Notes 2, 3) | — | 0.2 | 1.0 | — | 0.3 | 1.5 | — | 0.4 | 2.0 | μV/Mo |
| Input Offset Current | $I_{OS}$ | | — | 7 | 35 | — | 9 | 50 | — | 12 | 75 | nA |
| Input Bias Current | $I_B$ | | — | ±10 | ±40 | — | ±12 | ±55 | — | ±15 | ±80 | nA |
| Input Noise Voltage | $e_{np-p}$ | 0.1Hz to 10Hz (Notes 3, 5) | — | 0.08 | 0.18 | — | 0.08 | 0.18 | — | 0.09 | 0.25 | μVp-p |
| Input Noise Voltage Density | $e_n$ | $f_O$ = 10Hz (Note 3) | — | 3.5 | 5.5 | — | 3.5 | 5.5 | — | 3.8 | 8.0 | nV/√Hz |
| | | $f_O$ = 30Hz (Note 3) | — | 3.1 | 4.5 | — | 3.1 | 4.5 | — | 3.3 | 5.6 | |
| | | $f_O$ = 1000Hz (Note 3) | — | 3.0 | 3.8 | — | 3.0 | 3.8 | — | 3.2 | 4.5 | |
| Input Noise Current Density | $i_n$ | $f_O$ = 10Hz (Notes 3,6) | — | 1.7 | 4.0 | — | 1.7 | 4.0 | — | 1.7 | — | pA/√Hz |
| | | $f_O$ = 30Hz (Notes 3, 6) | — | 1.0 | 2.3 | — | 1.0 | 2.3 | — | 1.0 | — | |
| | | $f_O$ = 1000Hz (Notes 3, 6) | — | 0.4 | 0.6 | — | 0.4 | 0.6 | — | 0.4 | 0.6 | |
| Input Resistance — Differential-Mode | $R_{IN}$ | (Note 7) | 1.3 | 6 | — | 0.94 | 5 | — | 0.7 | 4 | — | MΩ |
| Input Resistance — Common-Mode | $R_{INCM}$ | | — | 3 | — | — | 2.5 | — | — | 2 | — | GΩ |
| Input Voltage Range | IVR | | ±11.0 | ±12.3 | — | ±11.0 | ±12.3 | — | ±11.0 | ±12.3 | — | V |
| Common-Mode Rejection Ratio | CMRR | $V_{CM} = \pm11V$ | 114 | 126 | — | 106 | 123 | — | 100 | 120 | — | dB |
| Power Supply Rejection Ratio | PSRR | $V_S = \pm4V$ to $\pm18V$ | — | 1 | 10 | — | 1 | 10 | — | 2 | 20 | μV/V |
| Large-Signal Voltage Gain | $A_{VO}$ | $R_L \geq 2k\Omega$, $V_O = \pm10V$ | 1000 | 1800 | — | 1000 | 1800 | — | 700 | 1500 | — | V/mV |
| | | $R_L \geq 600\Omega$, $V_O = \pm10V$ | 800 | 1500 | — | 800 | 1500 | — | 600 | 1500 | — | |
| Output Voltage Swing | $V_O$ | $R_L \geq 2k\Omega$ | ±12.0 | ±13.8 | — | ±12.0 | ±13.8 | — | ±11.5 | ±13.5 | — | V |
| | | $R_L \geq 600\Omega$ | ±10.0 | ±11.5 | — | ±10.0 | ±11.5 | — | ±10.0 | ±11.5 | — | |
| Slew Rate | SR | $R_L \geq 2k\Omega$ (Note 4) | 1.7 | 2.8 | — | 1.7 | 2.8 | — | 1.7 | 2.8 | — | V/μs |

**ELECTRICAL CHARACTERISTICS** at $V_S = \pm15V$, $T_A = 25°C$, unless otherwise noted. (Continued)

| PARAMETER | SYMBOL | CONDITIONS | OP-27A/E MIN | OP-27A/E TYP | OP-27A/E MAX | OP-27B/F MIN | OP-27B/F TYP | OP-27B/F MAX | OP-27C/G MIN | OP-27C/G TYP | OP-27C/G MAX | UNITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gain Bandwidth Prod. | GBW | (Note 4) | 5.0 | 8.0 | — | 5.0 | 8.0 | — | 5.0 | 8.0 | — | MHz |
| Open-Loop Output Resistance | $R_O$ | $V_O = 0$, $I_O = 0$ | — | 70 | — | — | 70 | — | — | 70 | — | Ω |
| Power Consumption | $P_d$ | $V_O$ | — | 90 | 140 | — | 90 | 140 | — | 100 | 170 | mW |
| Offset Adjustment Range | | $R_P = 10k\Omega$ | — | ±4.0 | — | — | ±4.0 | — | — | ±4.0 | — | mV |

*Amplificador de Instrumentação*




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

Alta impedância de entrada
Rejeição de modo comum

# Filtros



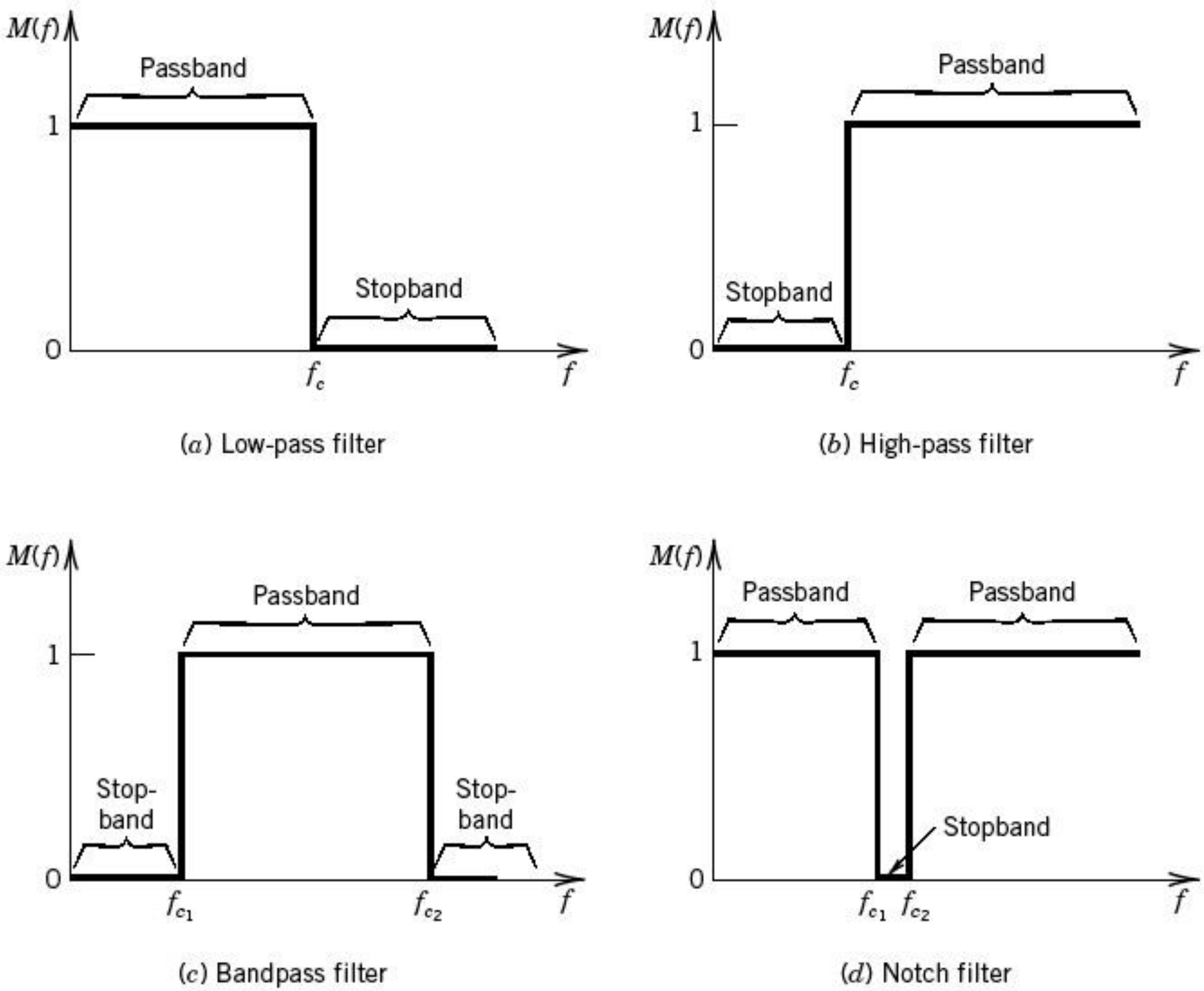
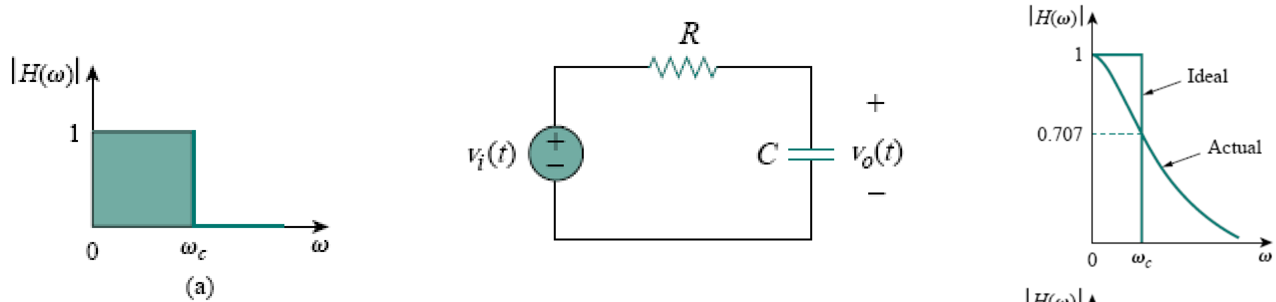


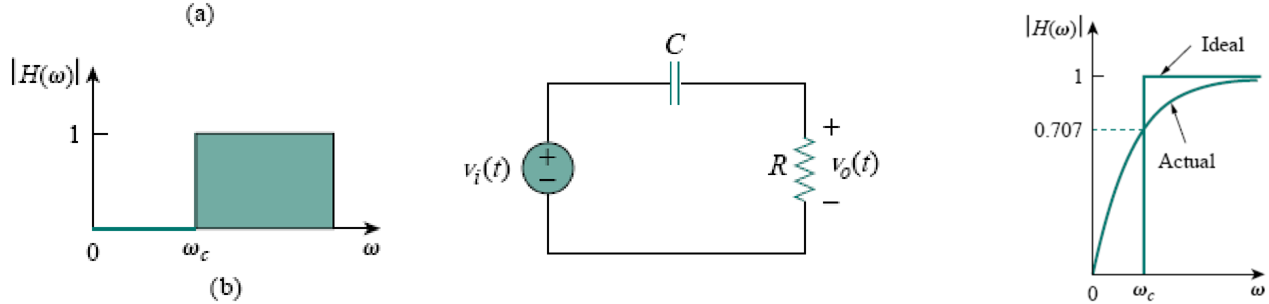

**Figure 6.27** Ideal filter characteristics.

# Filtros

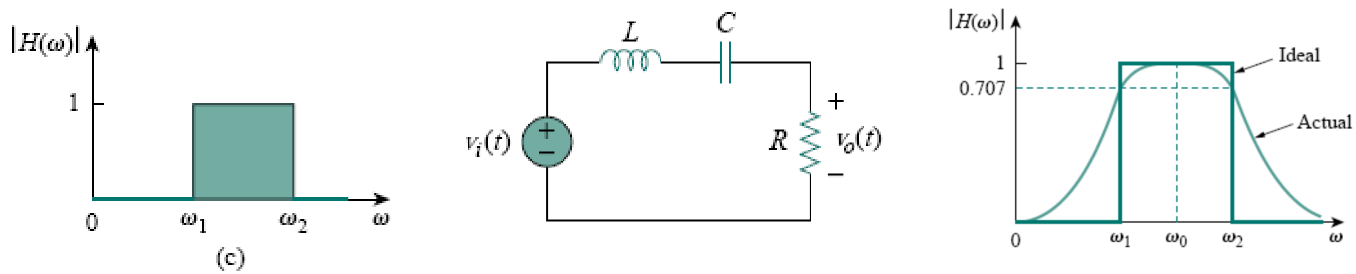
**Passa-baixa**



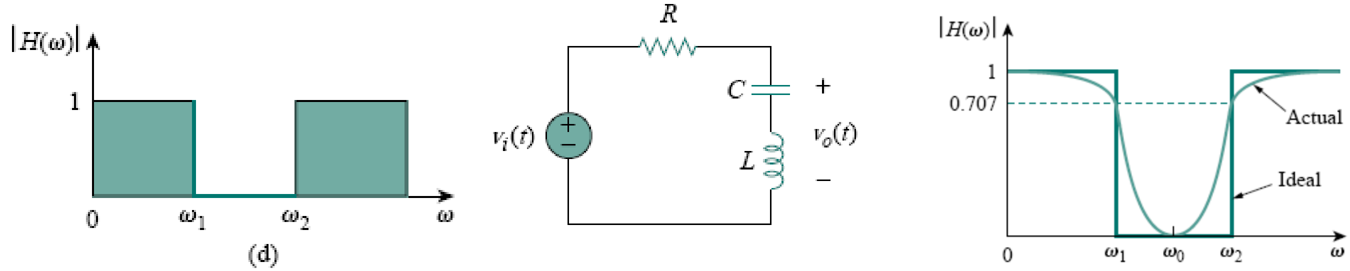

**Passa-alta**




**Passa-banda**




**Rejeita-banda**



# Filtros

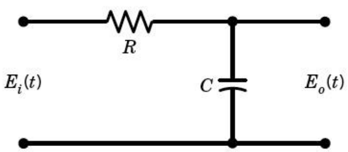



**Figure 6.29** Low-pass *RC* Butterworth filter circuit.

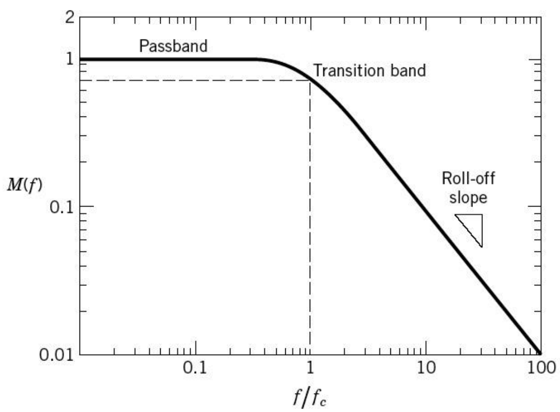



**Figure 6.28** Magnitude ratio for a low-pass Butterworth filter.

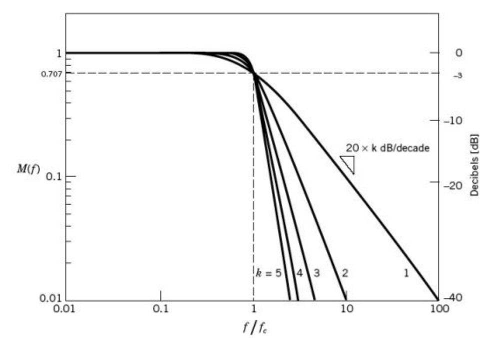
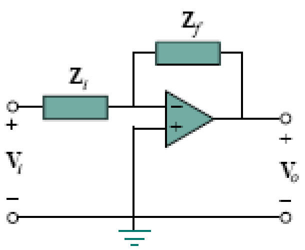
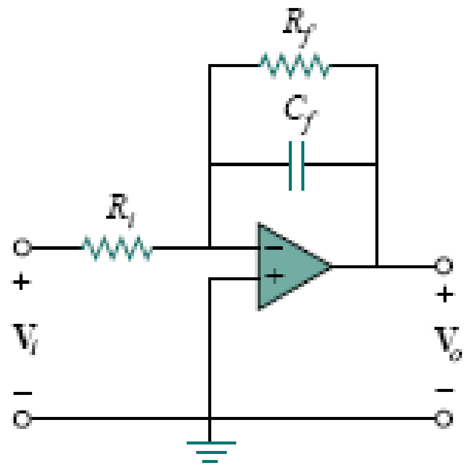


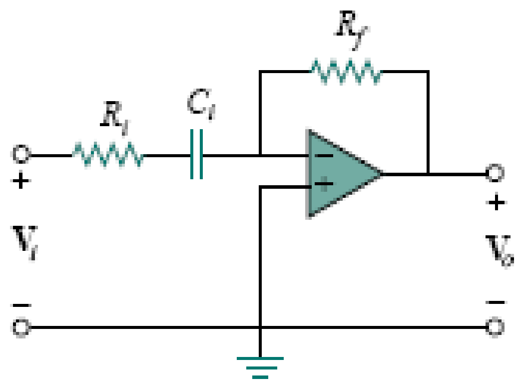

**Figure 6.31** Magnitude characteristics for Butterworth low-pass filters of various stages.

# Filtros

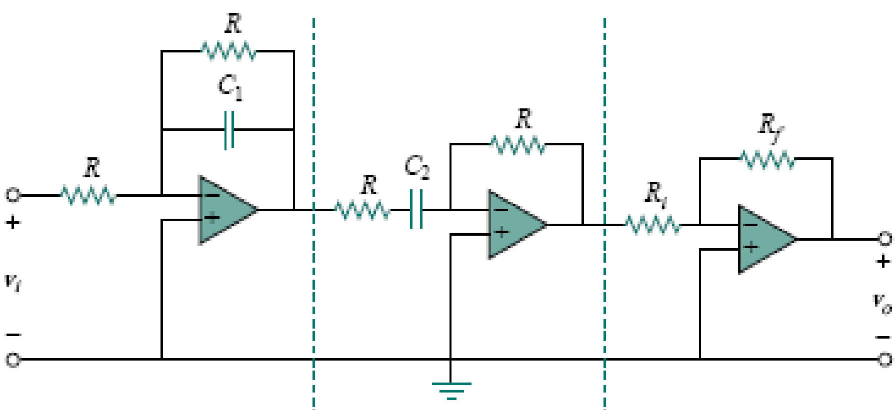


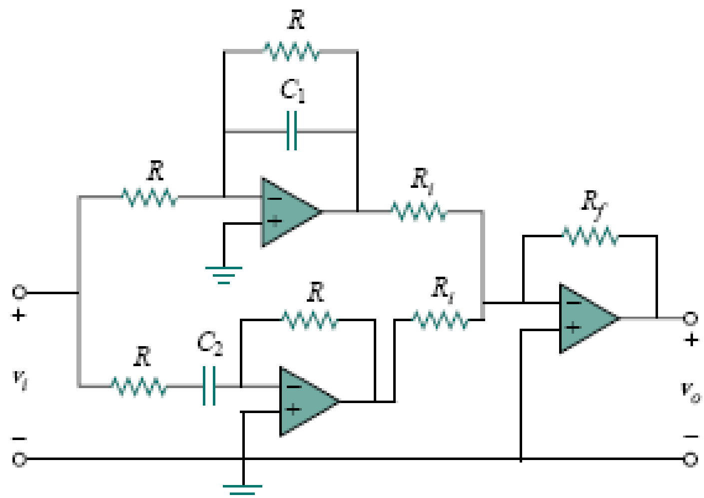

Passa-baixa




Passa-alta




Passa-banda




Rejeita-banda

**Respostas em frequência afetam amplitude e fase**

Butterworth, Bessel, Chebyshev

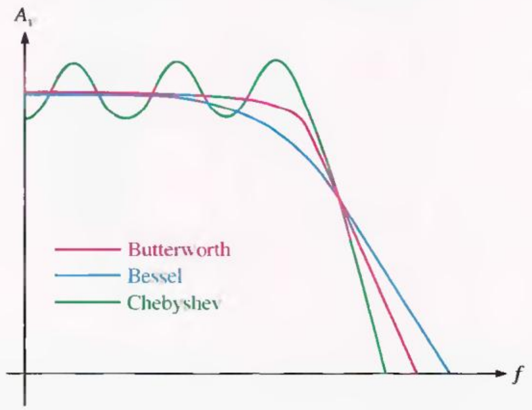
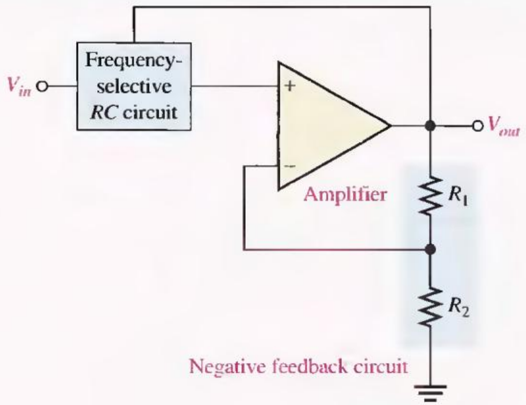



**FIGURE 15–5**

Comparative plots of three types of filter response characteristics.

**FIGURE 15–6**

General diagram of an active filter.



# Filtros

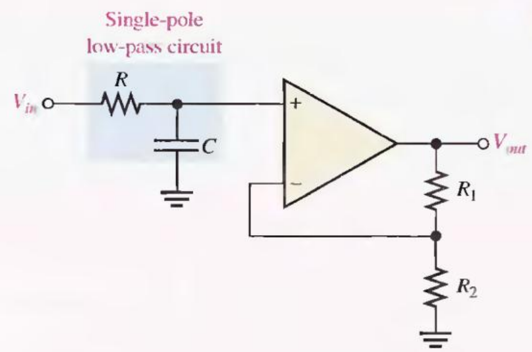



FIGURE 15–7

First-order (one-pole) low-pass filter.

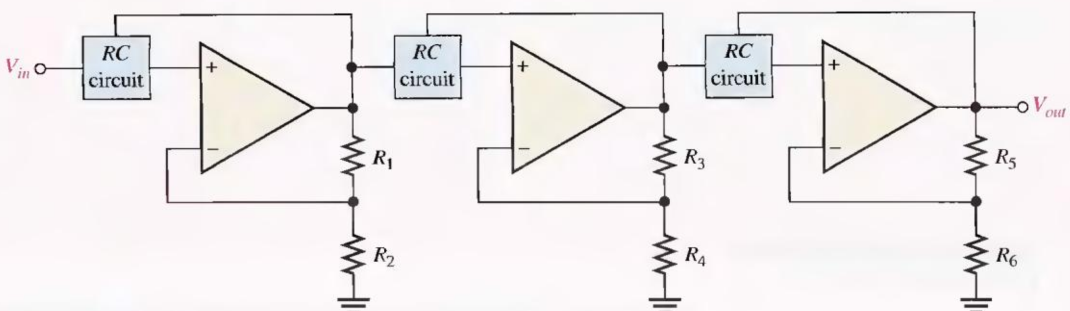
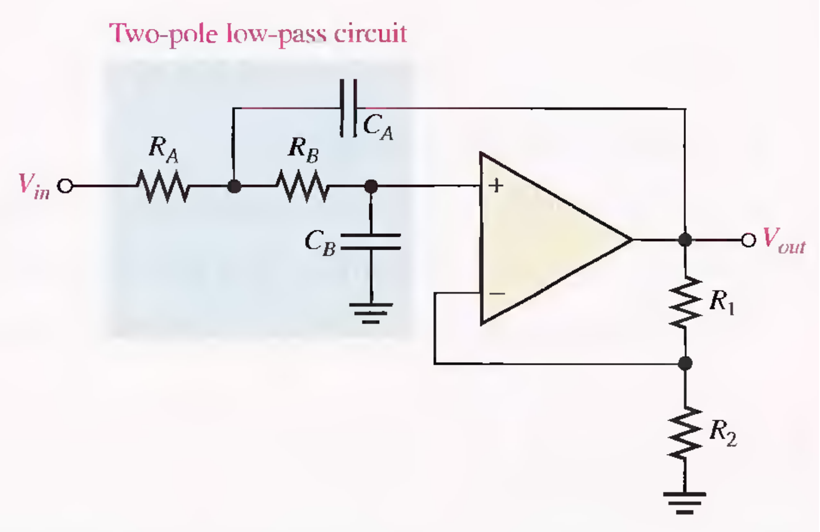



FIGURE 15–8

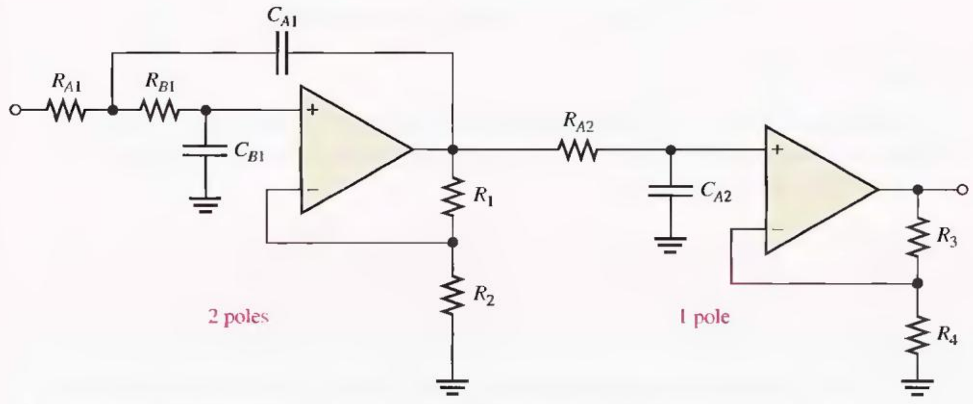
The number of filter poles can be increased by cascading.

Filtro PB Sallen-Key

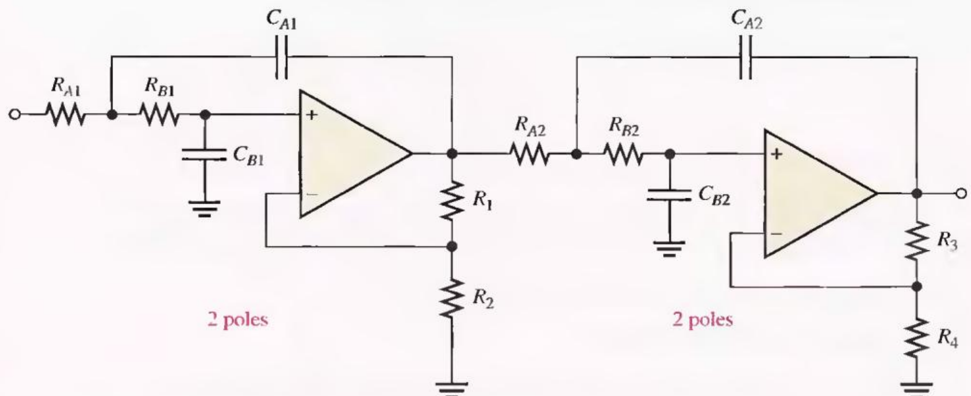
$$f_c = \frac{1}{2\pi\sqrt{R_A R_B C_A C_B}}$$



Filtros em cascata




(a) Third-order configuration




(b) Fourth-order configuration

Filtros PA

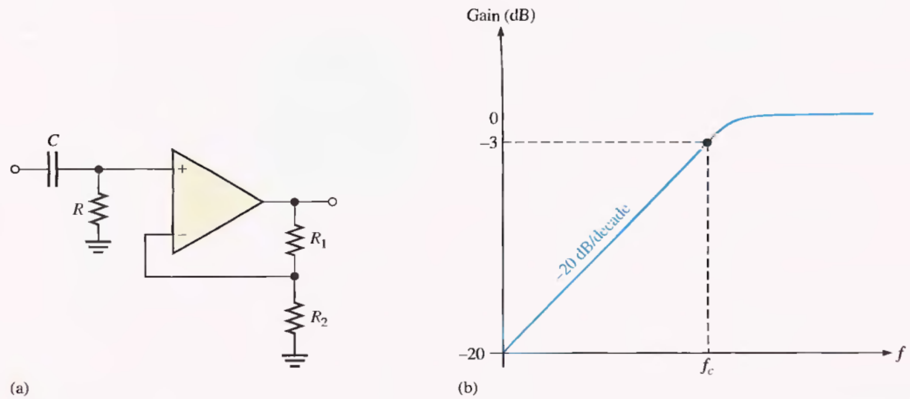
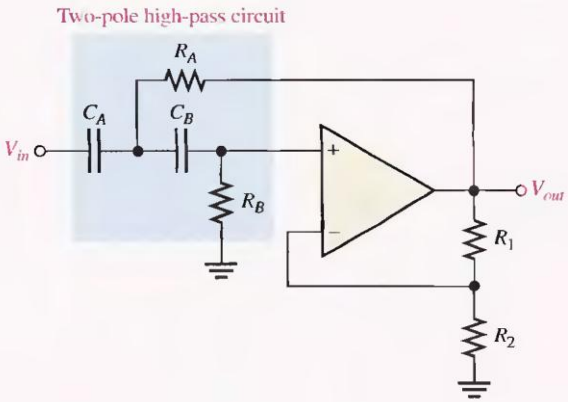



FIGURE 15–13

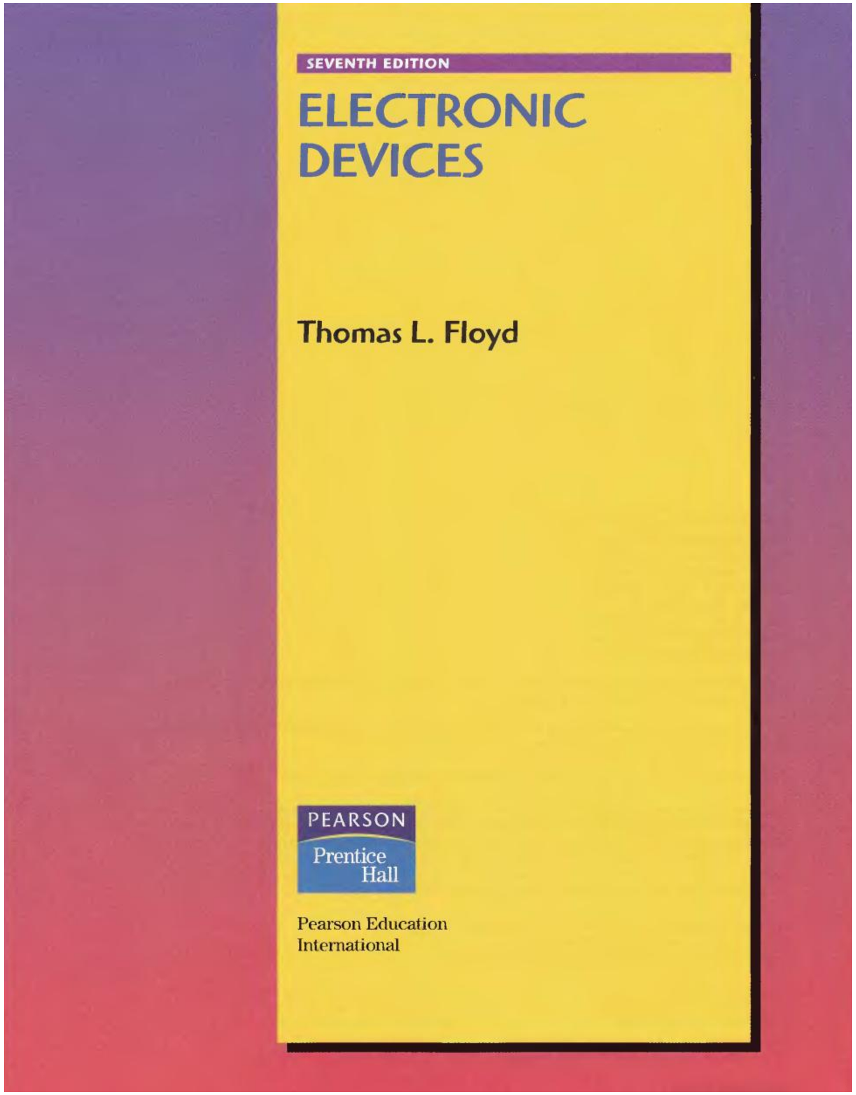
Single-pole active high-pass filter and response curve.

FIGURE 15–15

Basic Sallen-Key high-pass filter.



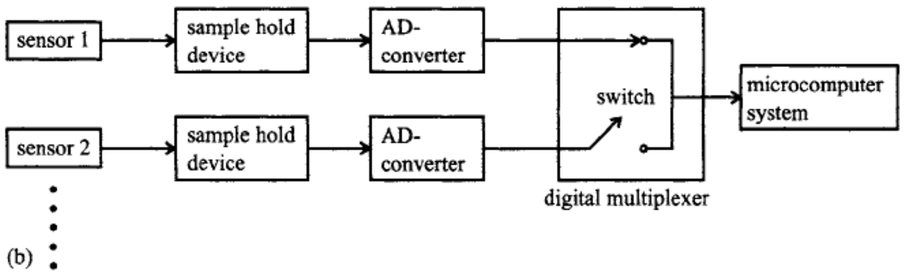
# Filtros

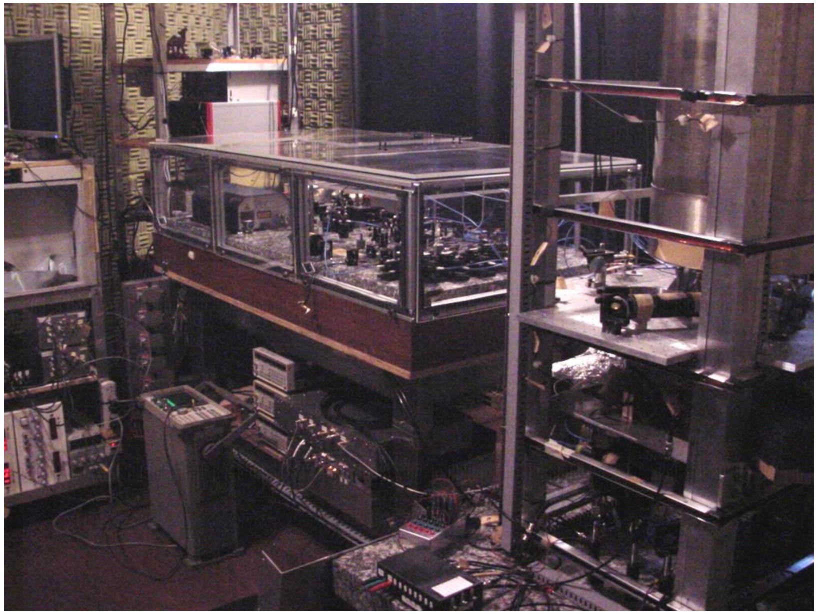

SEVENTH EDITION
ELECTRONIC DEVICES
Thomas L. Floyd
PEARSON
Prentice Hall
Pearson Education International

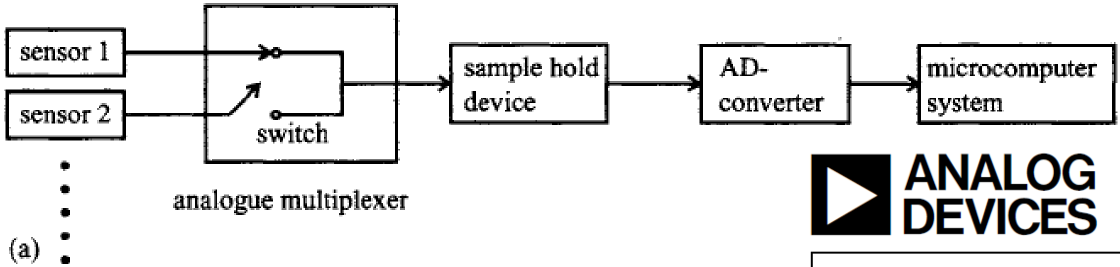
# Multiplexação Analógica



## *Aquisição de Sinais de Vários Sensores*






ANALOG DEVICES

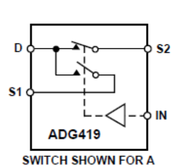
**LC$^2$MOS Precision Mini-DIP Analog Switch**

**ADG419**

**FEATURES**
44 V Supply Maximum Ratings
$V_{SS}$ to $V_{DD}$ Analog Signal Range
Low On Resistance (< 35 Ω)
Ultralow Power Dissipation (< 35 μW)
Fast Transition Time (160 ns max)
Break-Before-Make Switching Action
Plug-In Replacement for DG419

**APPLICATIONS**
Precision Test Equipment
Precision Instrumentation
Battery Powered Systems
Sample Hold Systems

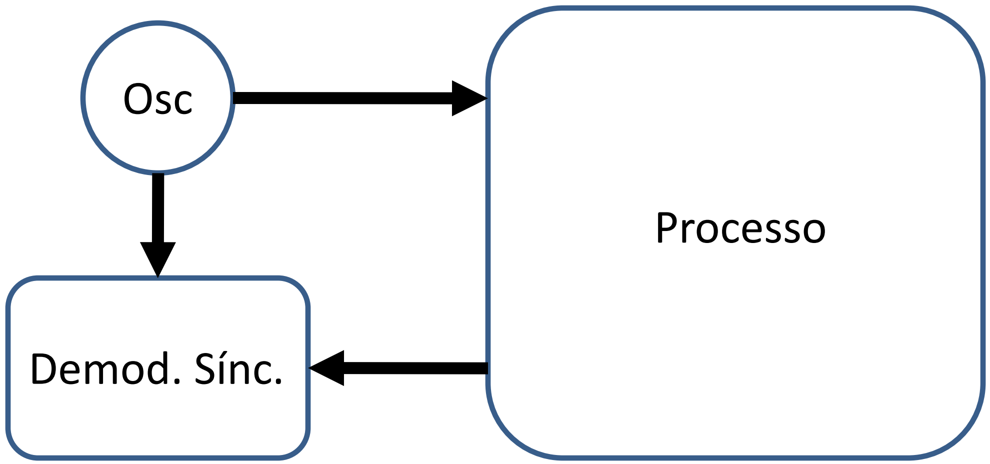
FUNCTIONAL BLOCK DIAGRAM

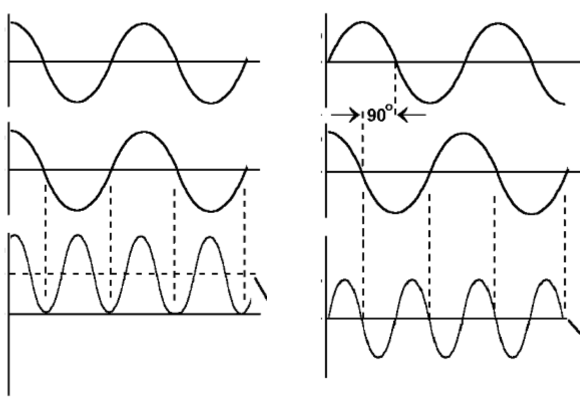


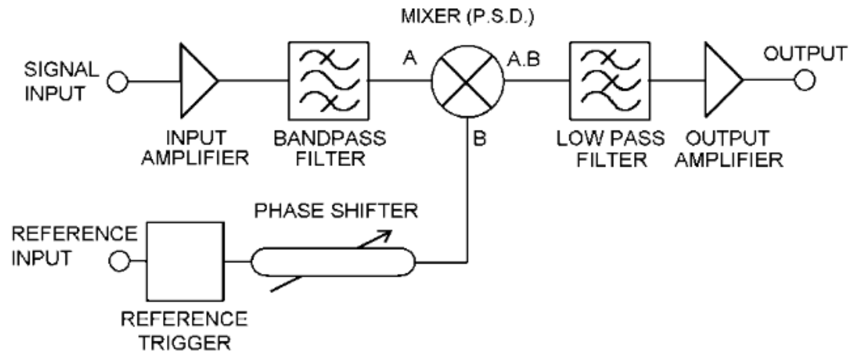

SWITCH SHOWN FOR A LOGIC "1" INPUT

# Demodulação Síncrona

*Sinais muito pequenos*
*Modulação injetada no sistema*
*Demodulação sensível à fase do sinal medido*



# Demodulação Síncrona