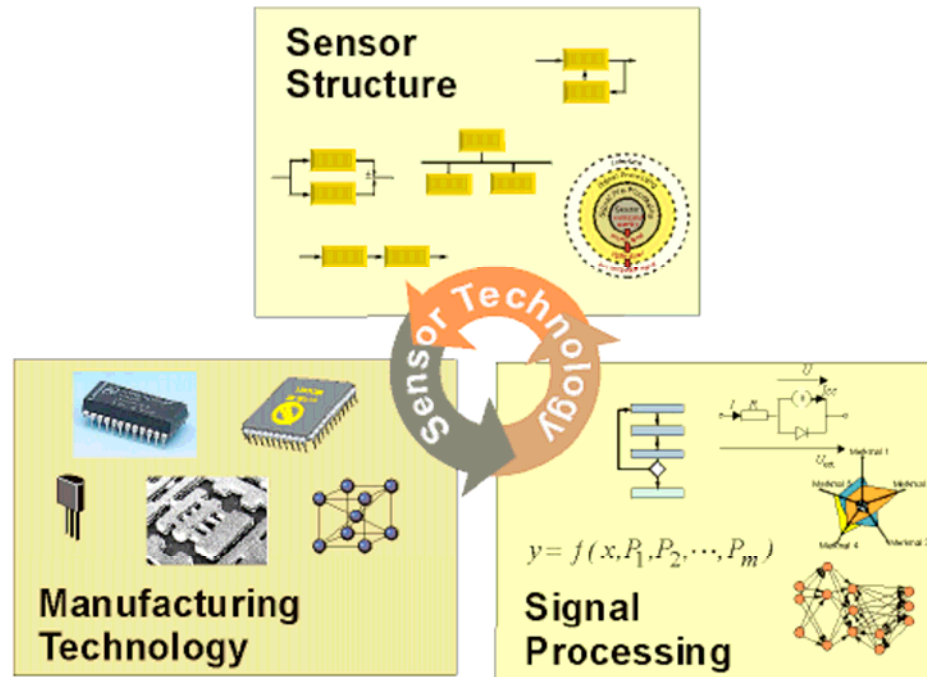
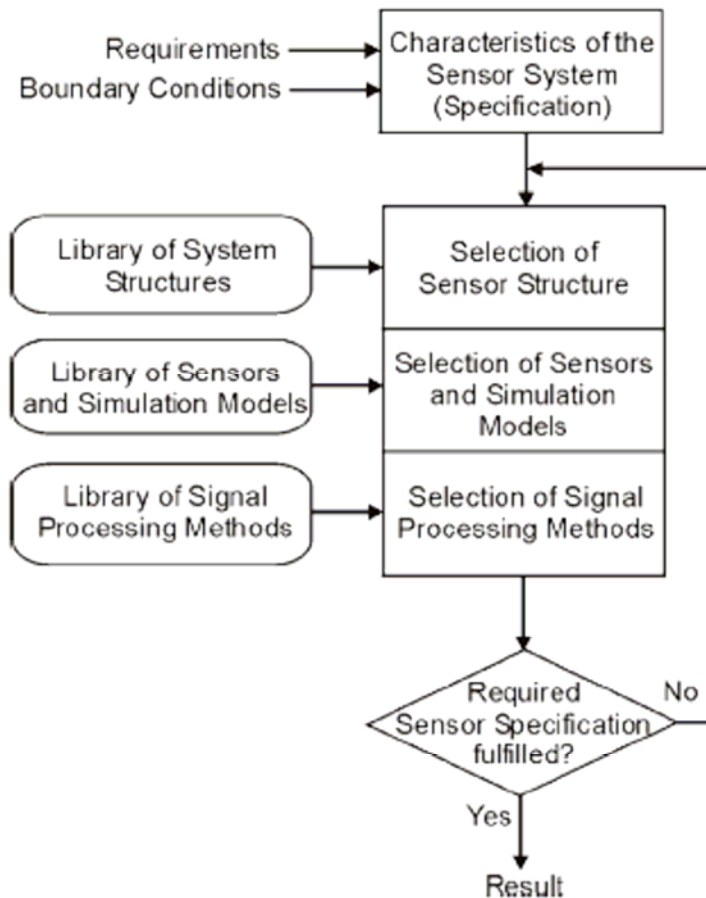


Processamento de sinais em microssistemas

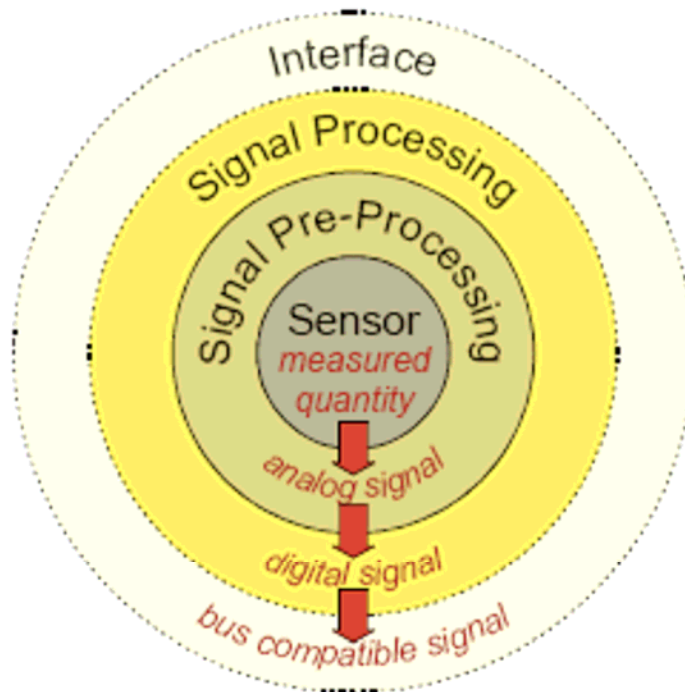
Arquitetura de um microssistema



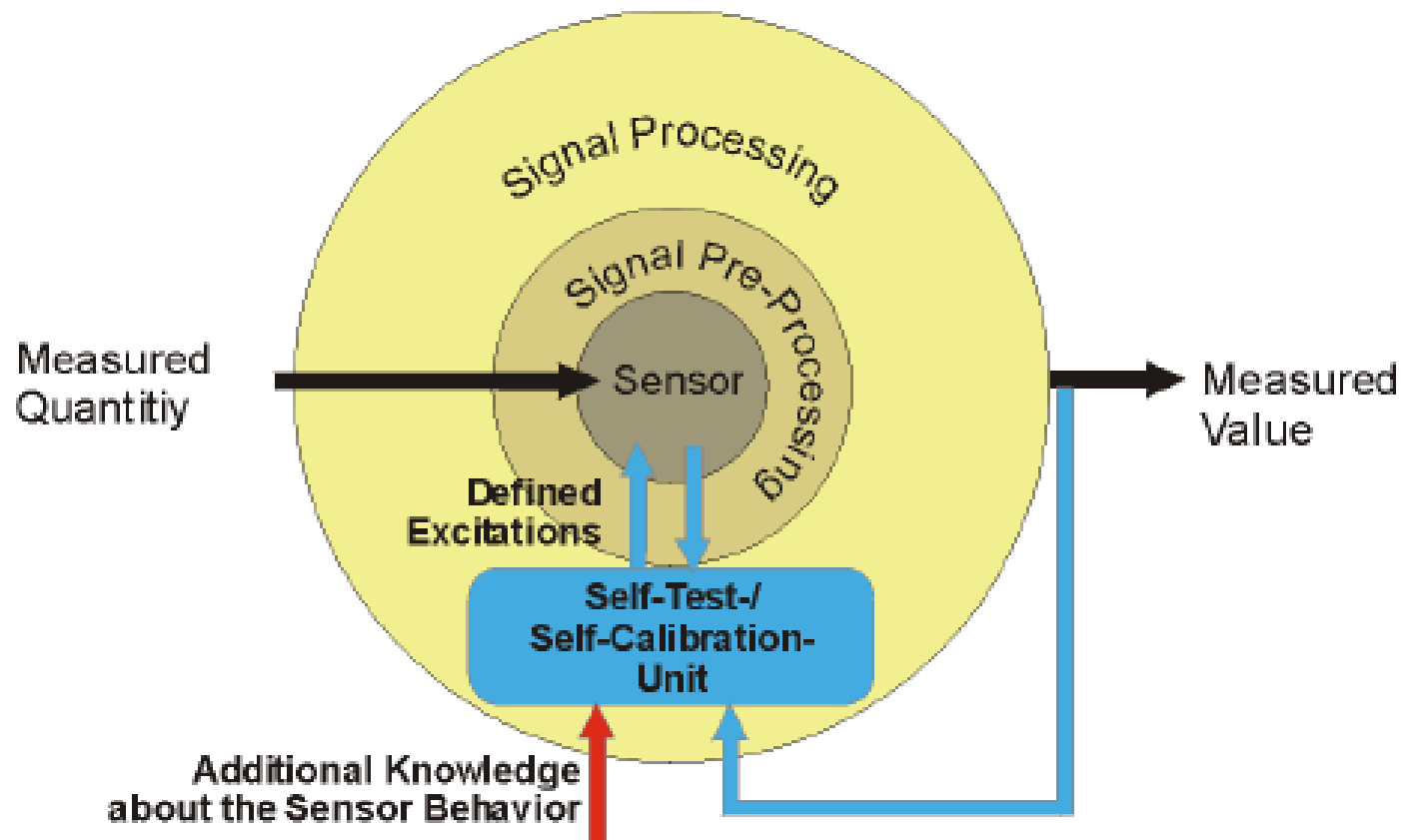
Metodologia de projeto de um Microsistema



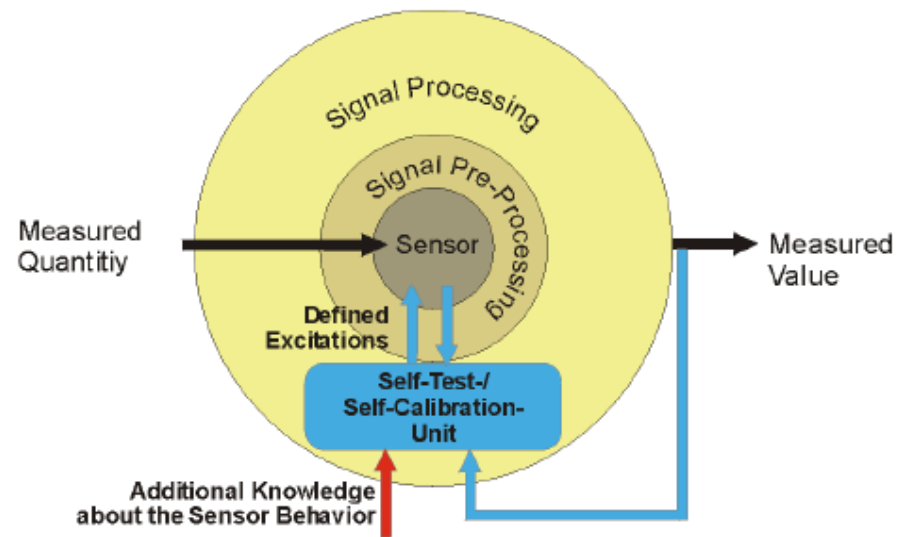
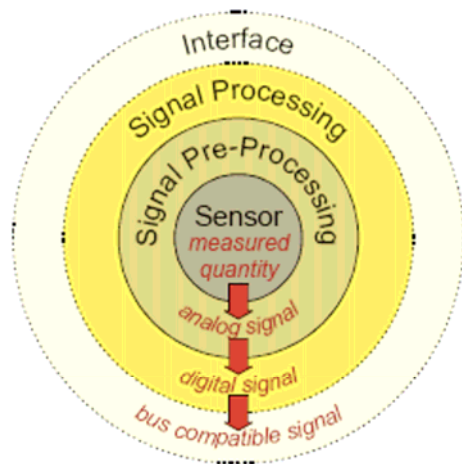
Estrutura convencional de Sistemas e Sensores



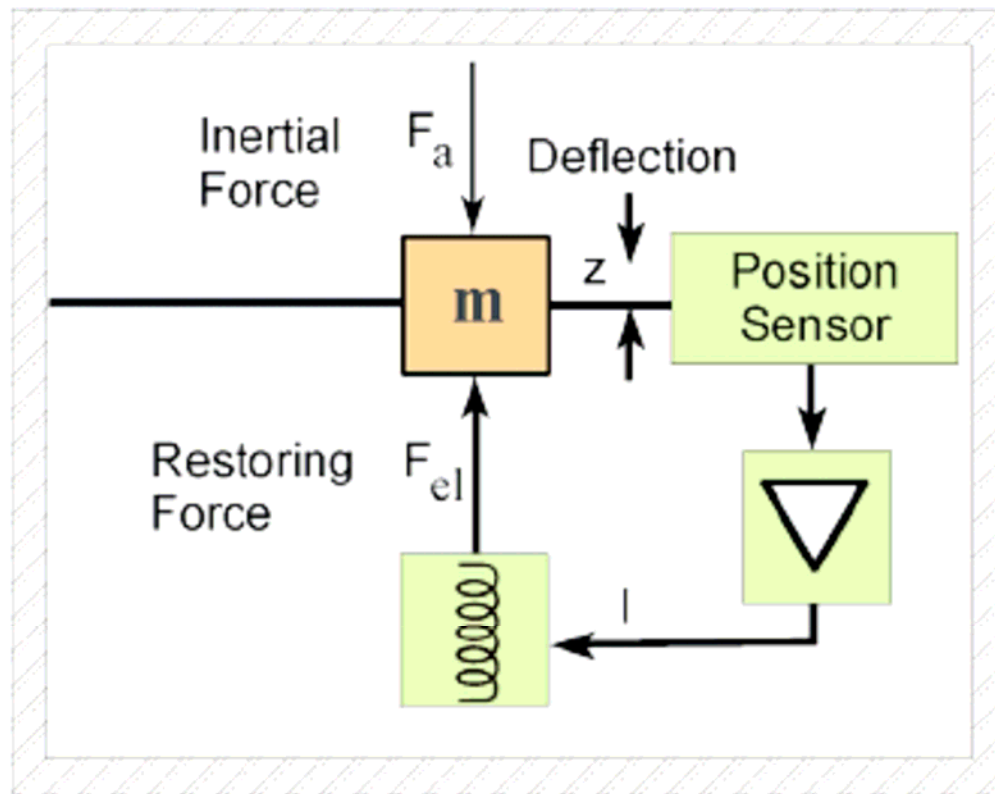
Nova metodologia para microsistemas



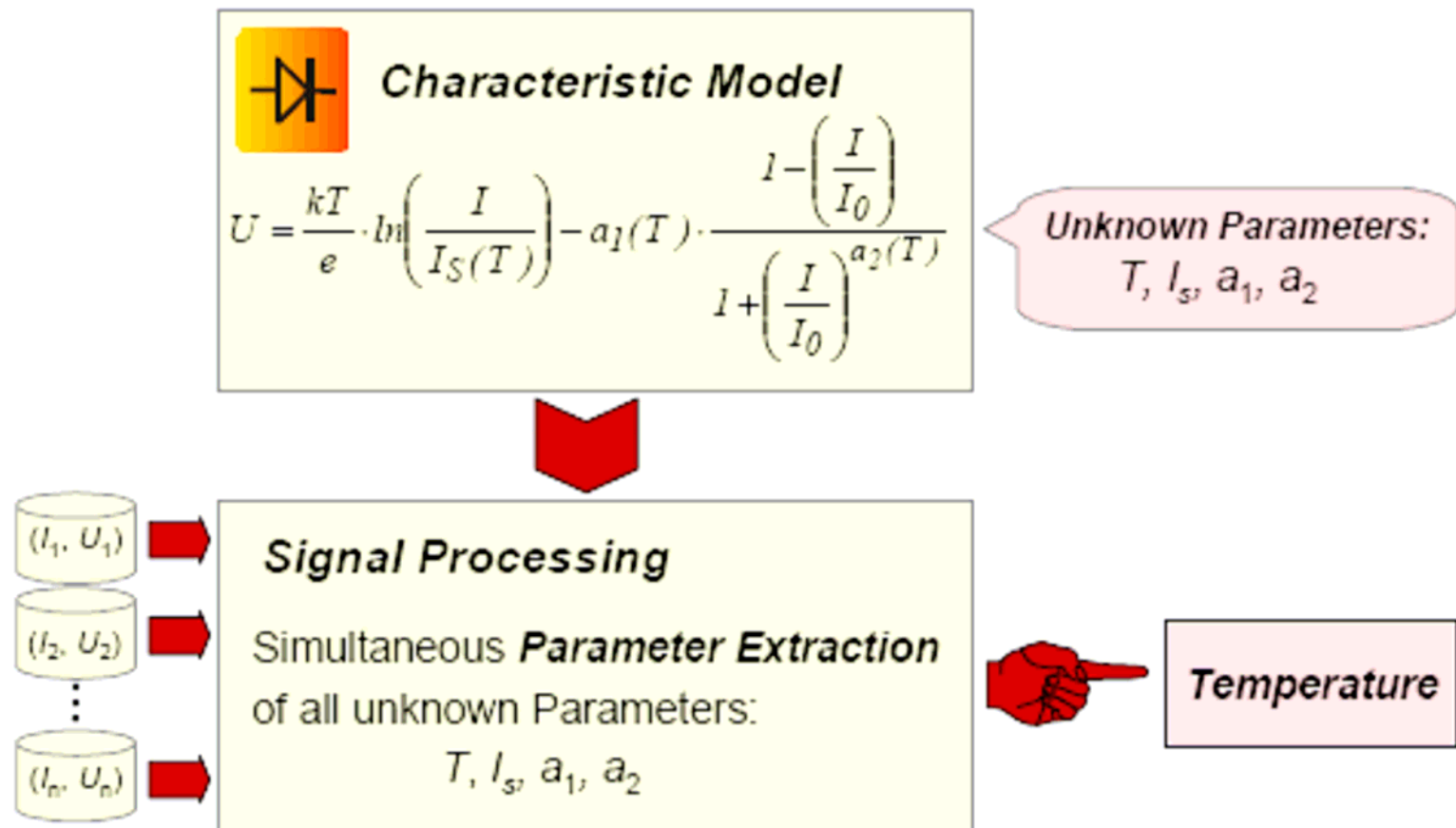
Comparação da metodologia para microssistemas



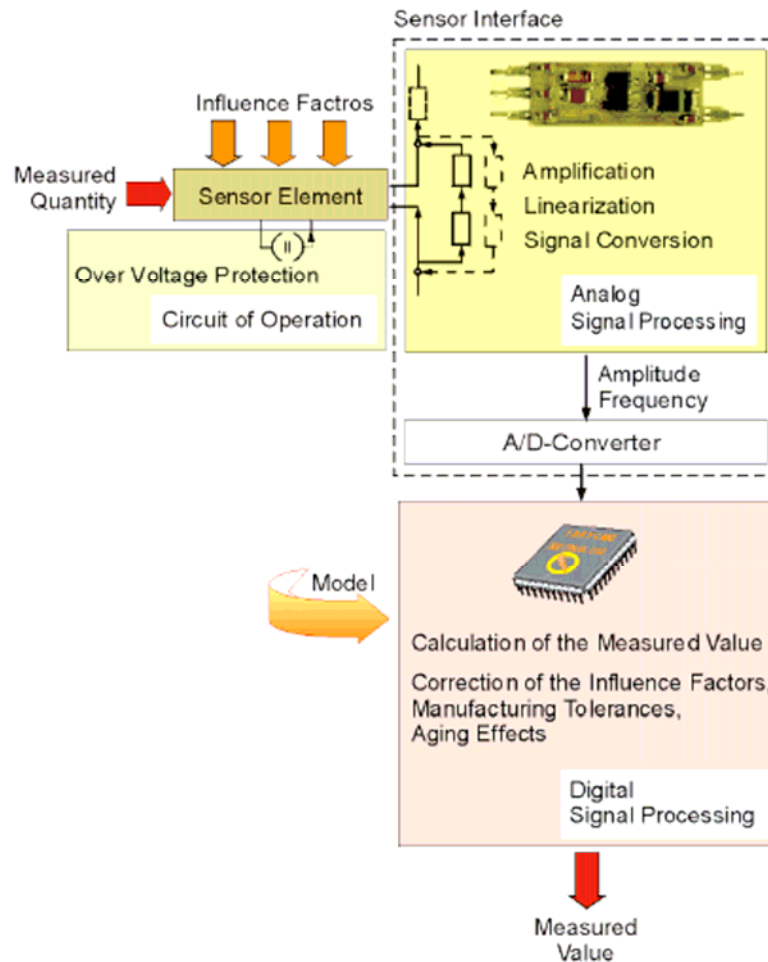
Exemplo sw metodologia para um acelerômetro



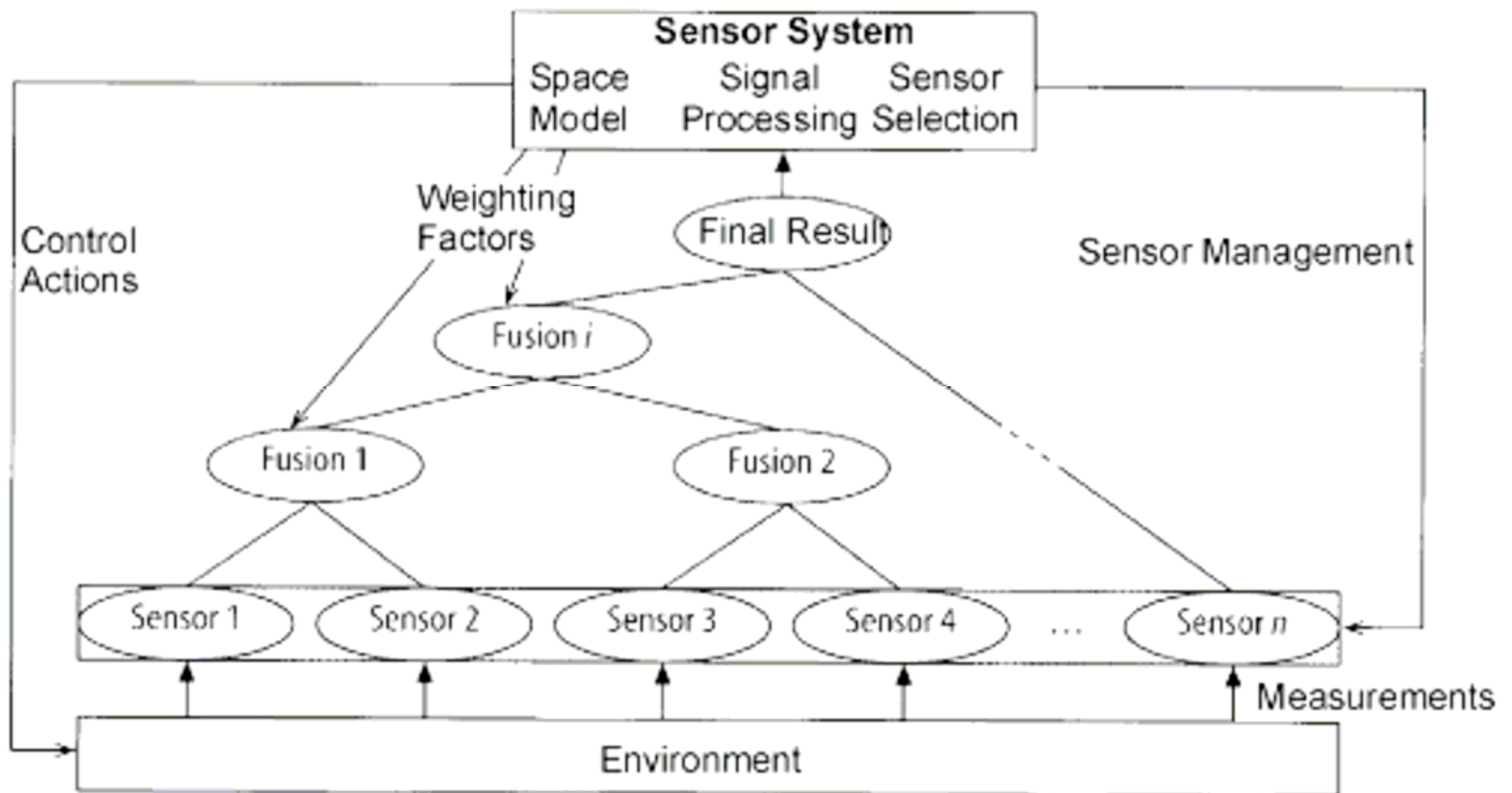
Sistemas de Compensação



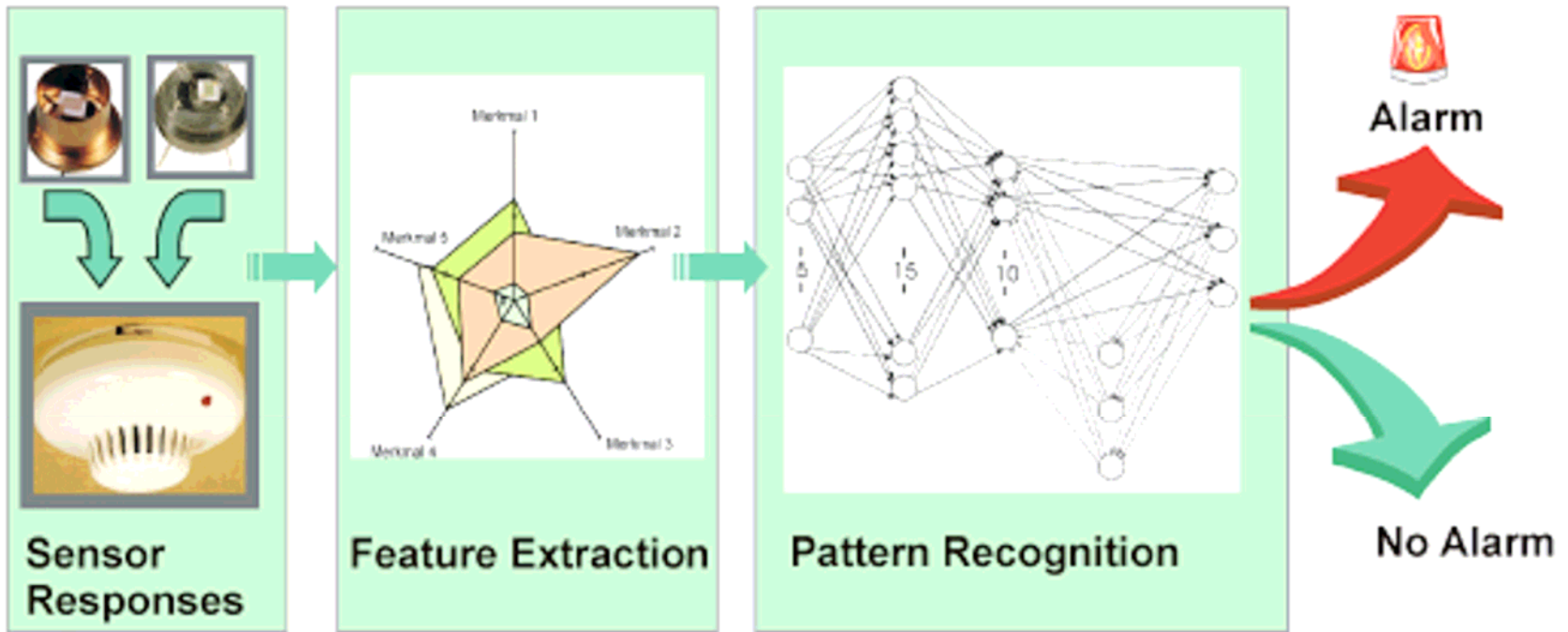
Metodologia para compensação de sensores



Sistemas Multisensor



Exemplo de Sistemas Multisensor (Incendio)



Vantagens da Miniaturização

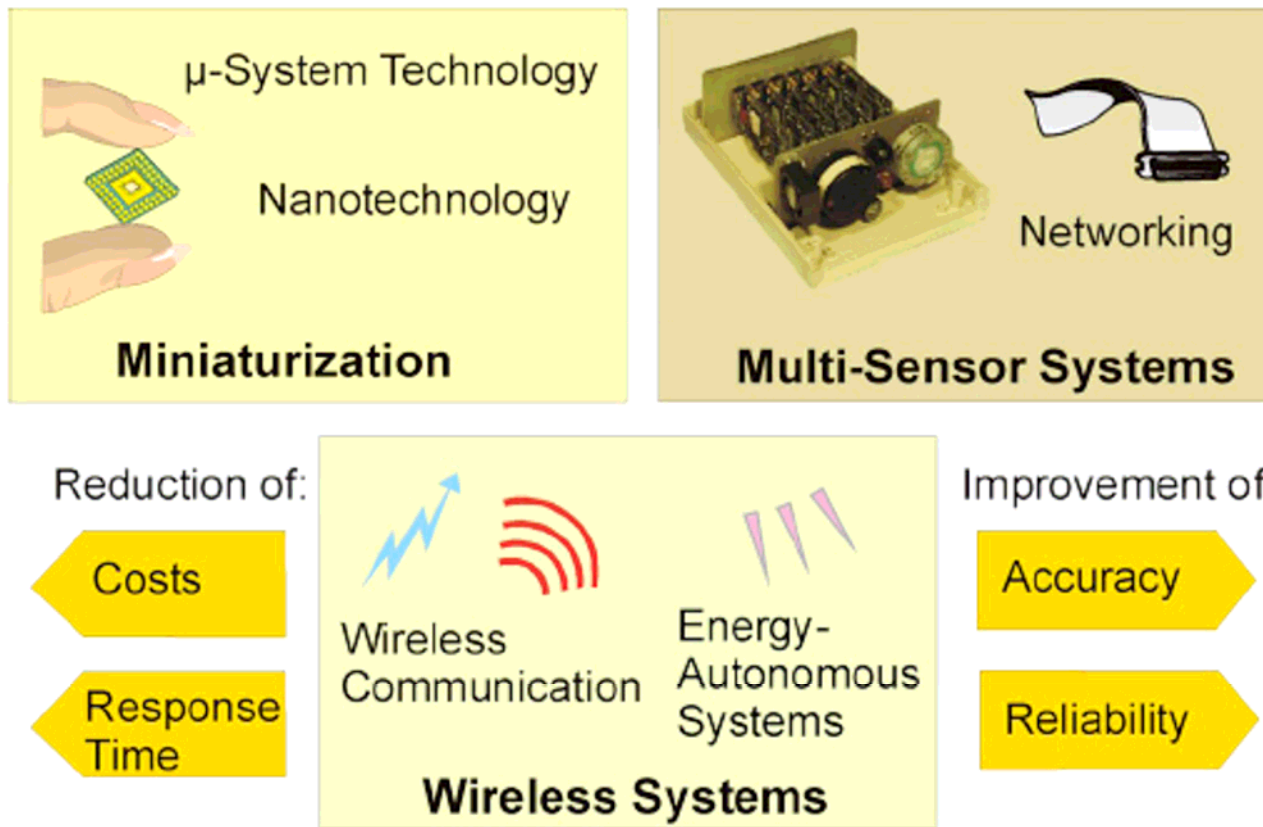
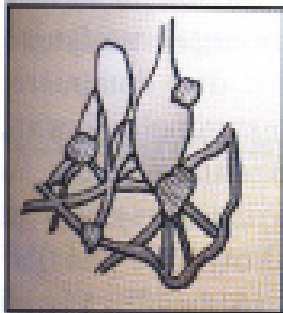


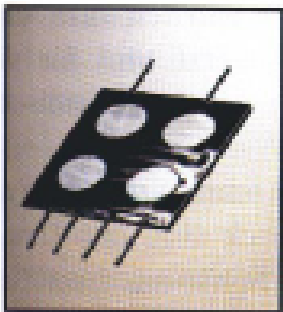
Figure 16: Future trends in sensor technology

Microsistemas Multifuncional

Sensors

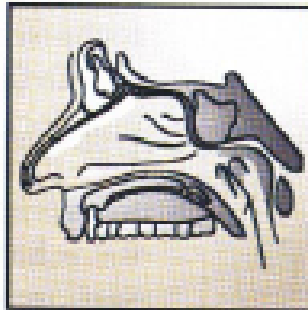


Receptors

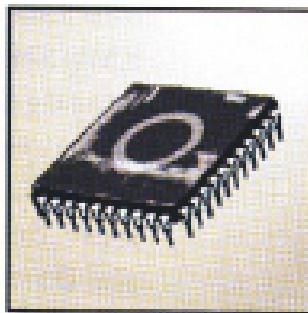


Sensor Array

Pattern
Extraction

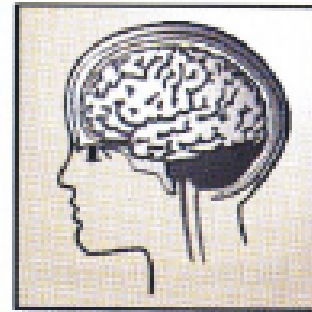


Odour Bulb



Microprocessor

Pattern
Classification



Brain



Software

Princípios do Processamento de Sinais

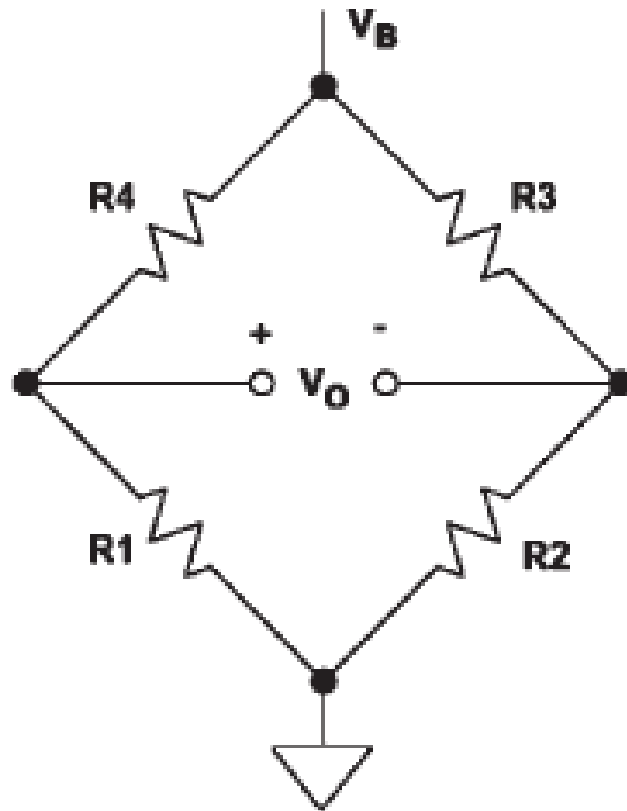
Sensores baseados em alteração da resistência

Sensor elements' resistances can range from less than 100 Ω to several hundred k Ω , depending on the sensor design and the physical environment to be measured (See Figure 4.1.1).

For example, RTDs (resistance temperature devices) are typically 100 Ω or 1000 Ω . Thermistors are typically 3500 Ω or higher.

■ Strain Gages	120 Ω , 350 Ω , 3500 Ω
■ Weigh-Scale Load Cells	350 Ω - 3500 Ω
■ Pressure Sensors	350 Ω - 3500 Ω
■ Relative Humidity	100k Ω - 10M Ω
■ Resistance Temperature Devices (RTDs)	100 Ω , 1000 Ω
■ Thermistors	100 Ω - 10M Ω

Ponte de Wheatstone

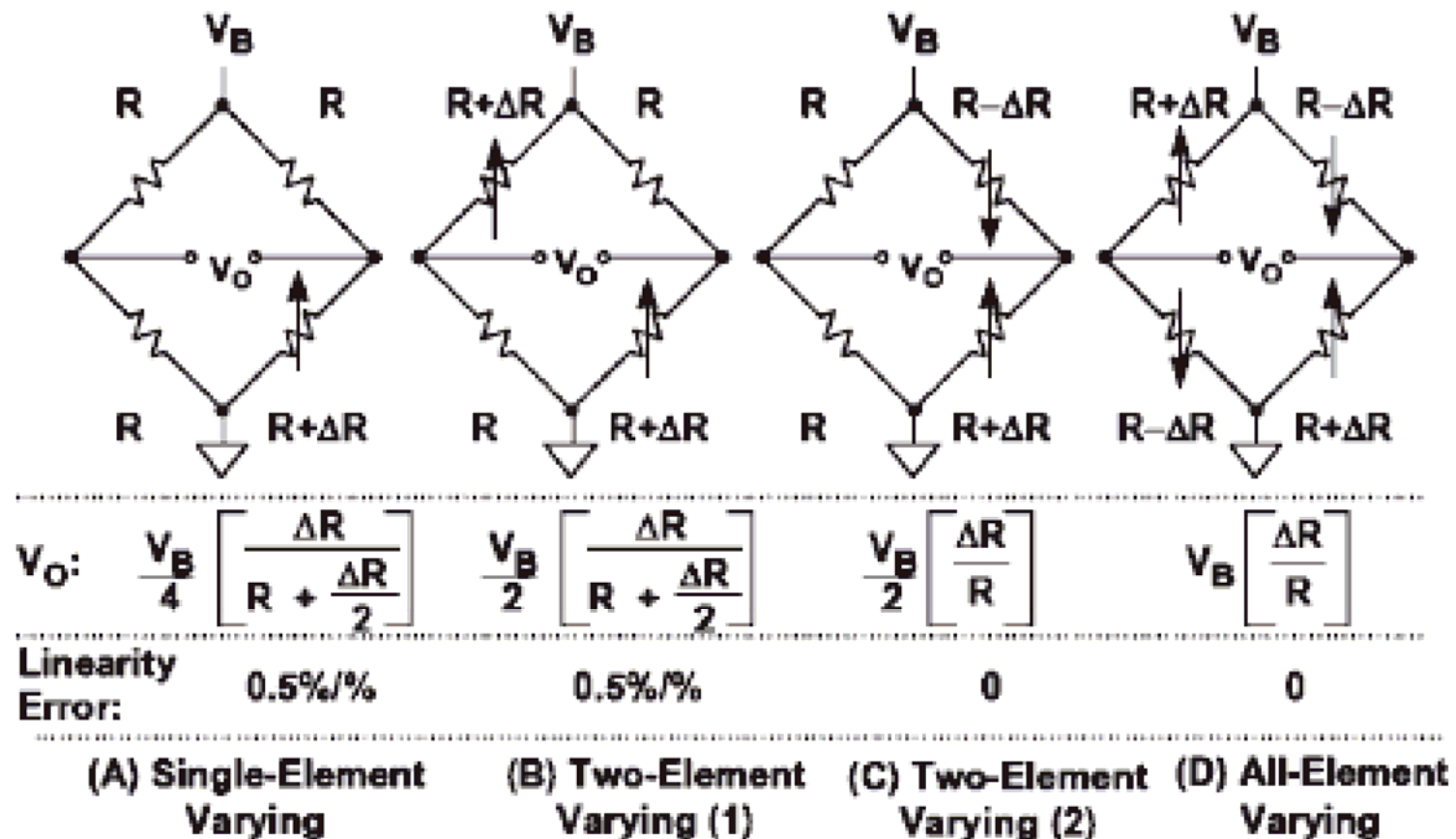


$$V_O = \frac{R_1}{R_1 + R_4} V_B - \frac{R_2}{R_2 + R_3} V_B$$
$$= \frac{\frac{R_1}{R_4} - \frac{R_2}{R_3}}{\left(1 + \frac{R_1}{R_4}\right)\left(1 + \frac{R_2}{R_3}\right)} V_B$$

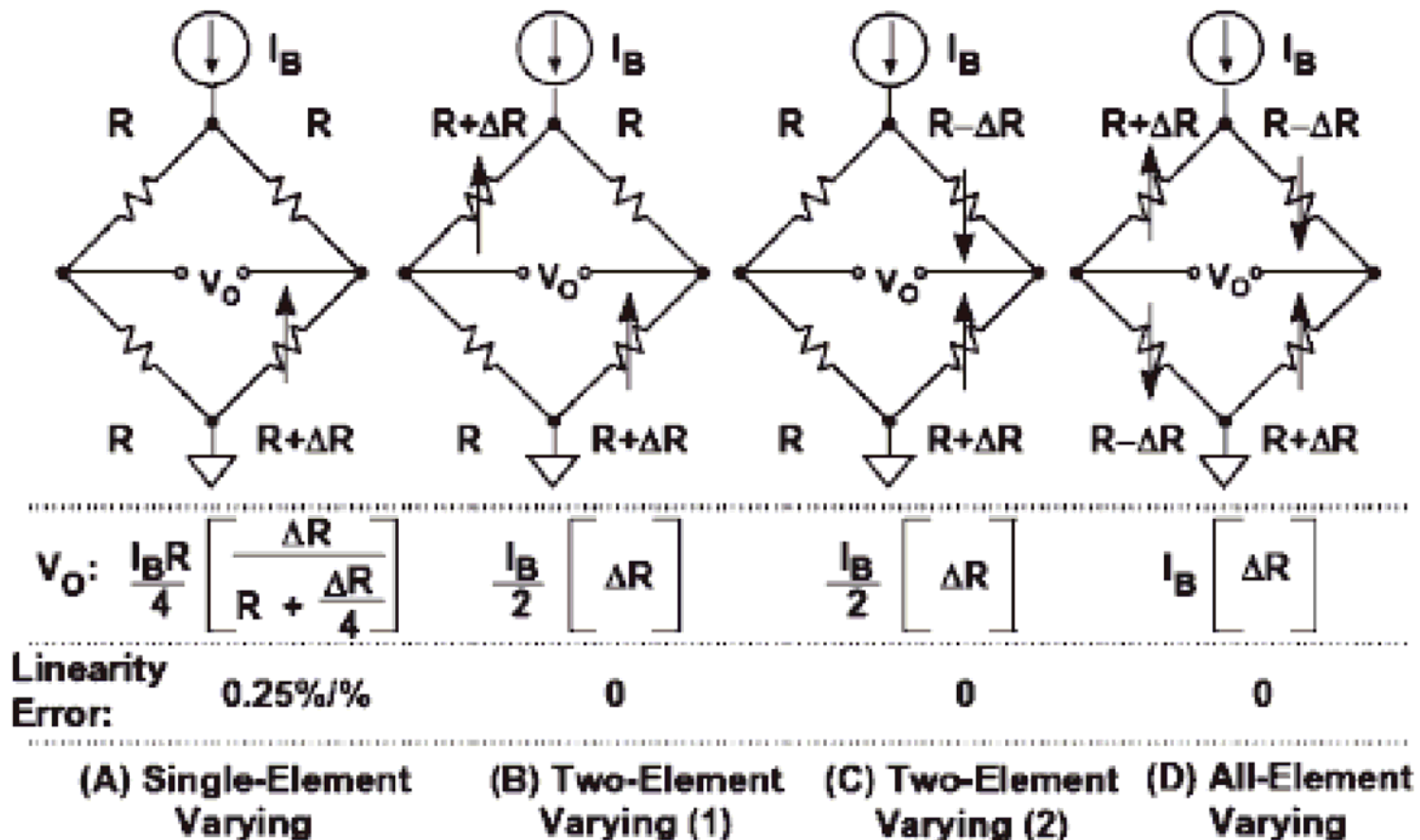
AT BALANCE,

$$V_O = 0 \quad \text{IF} \quad \frac{R_1}{R_4} = \frac{R_2}{R_3}$$

Pontes com mais de um elemento variando



Melhora da resolução da ponte



Requisitos para um sistema de condicionamento de sinal baseado em ponte

- **Selecting Configuration (1, 2, 4 - Element Varying)**
- **Selection of Voltage or Current Excitation**
- **Stability of Excitation Voltage or Current**
- **Bridge Sensitivity: FS Output / Excitation Voltage**
1mV / V to 10mV / V Typical
- **Fullscale Bridge Outputs: 10mV - 100mV Typical**
- **Precision, Low Noise Amplification / Conditioning**
Techniques Required
- **Linearization Techniques May Be Required**
- **Remote Sensors Present Challenges**

Ponte com Amp-Op

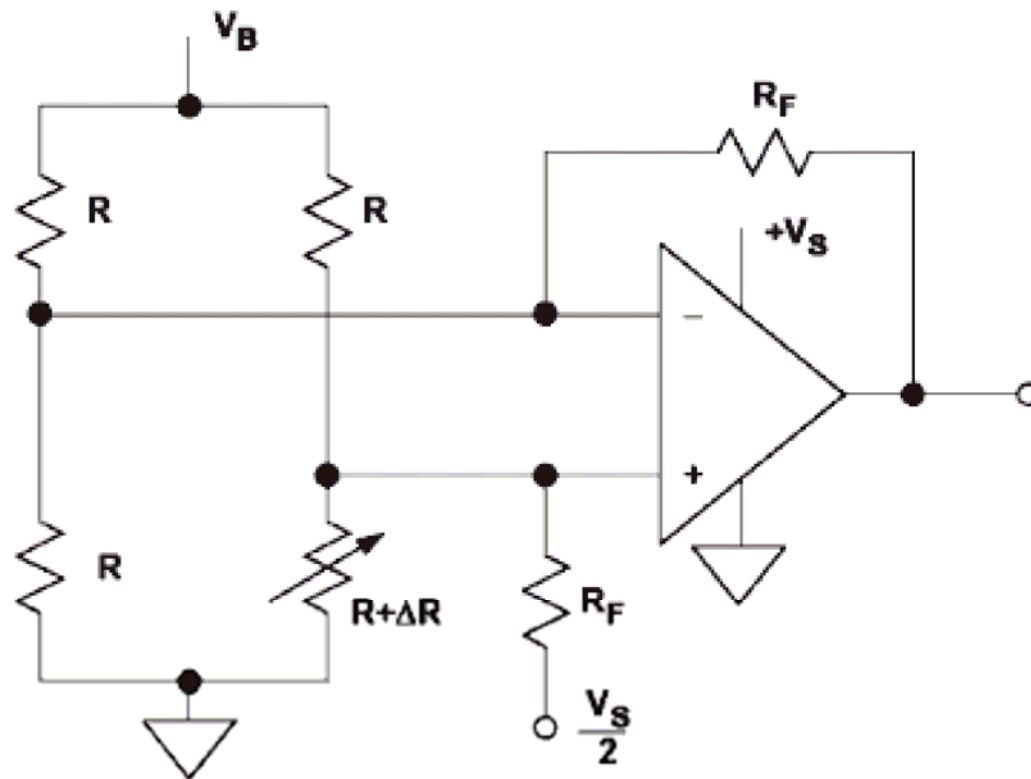


Figure 4.1.7: Using a single op amp as a bridge amplifier for a single-element varying bridge.

Ponte com Amp-Op em configuração diferencial

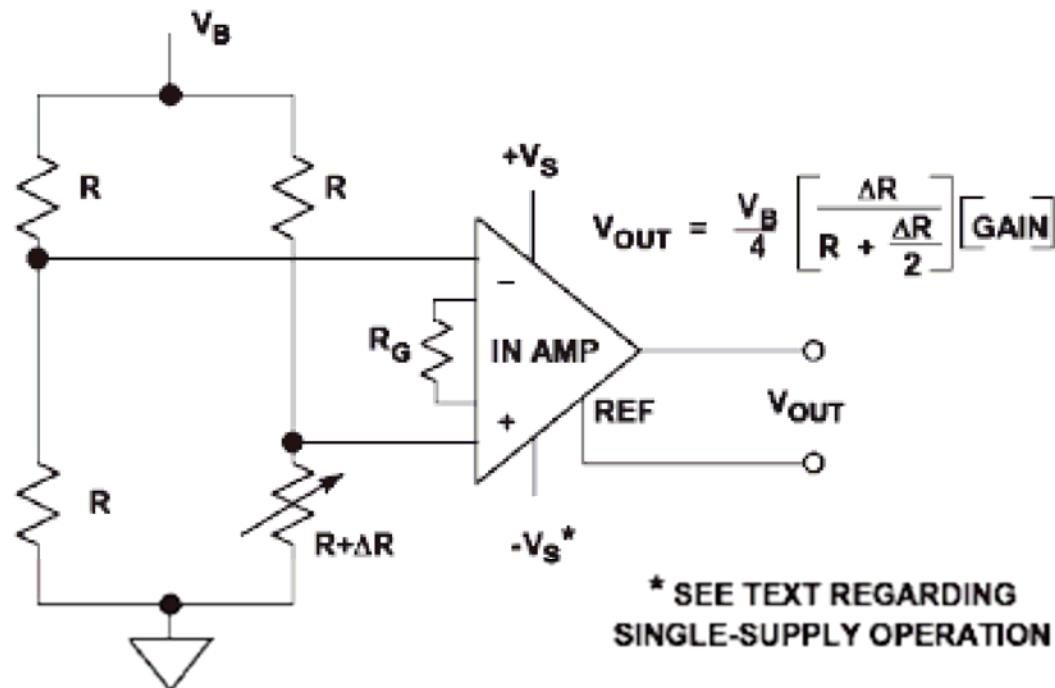
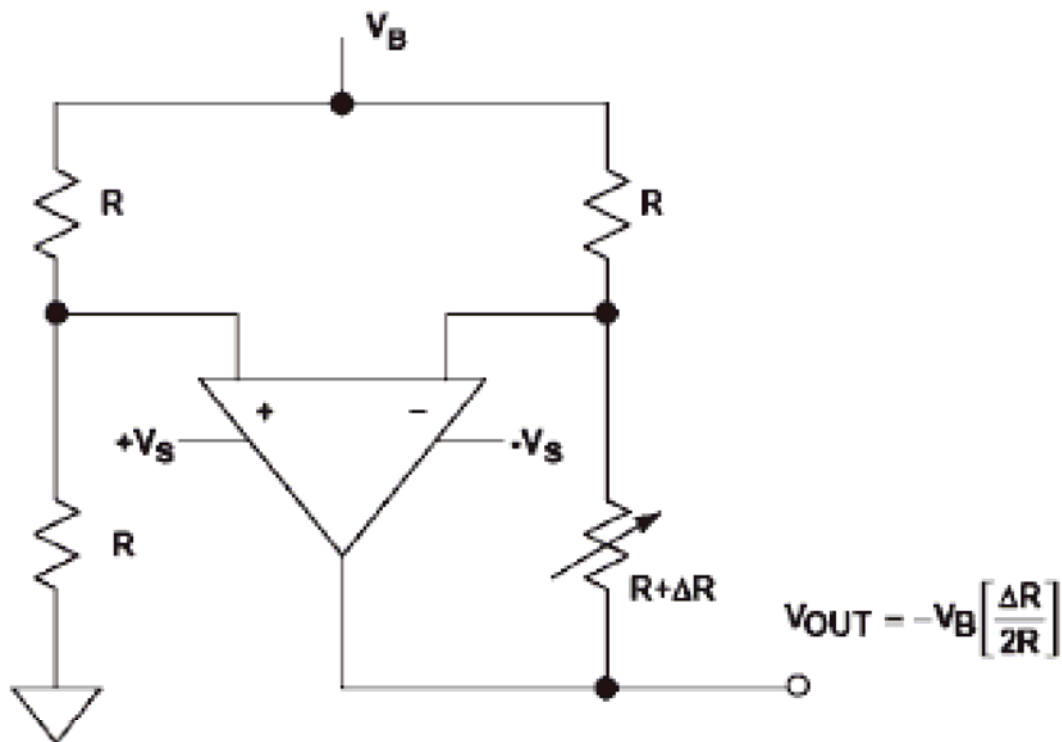
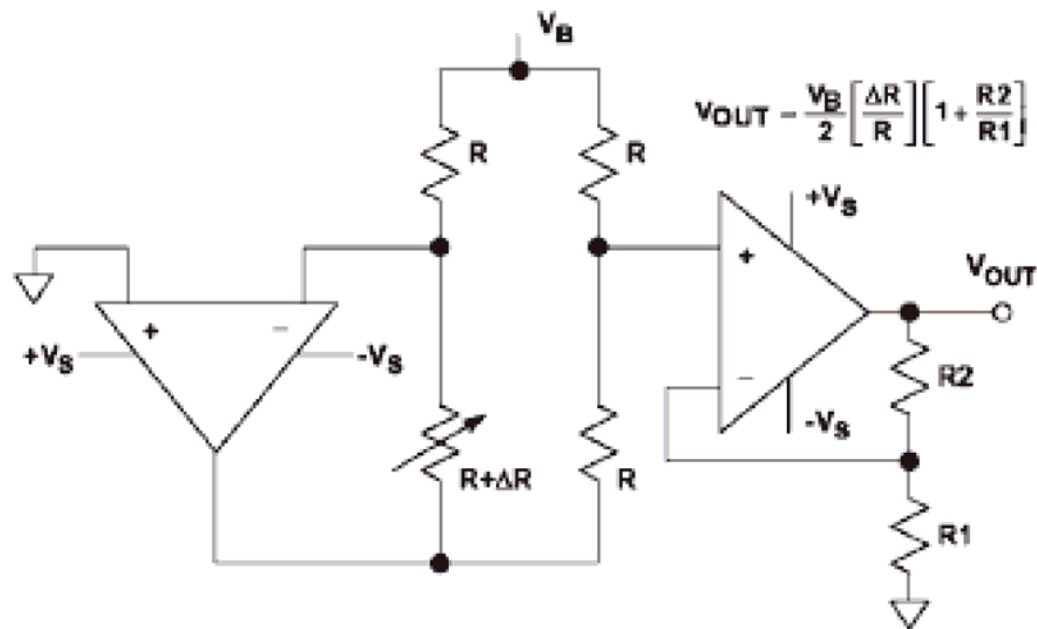


Figure 4.1.8: Using an instrumentation amplifier with a single-element varying bridge.

Linearização da ponte com Amp-Op



Linearização da ponte com Amp-Op



Linearização de ponte com dois elementos sensíveis

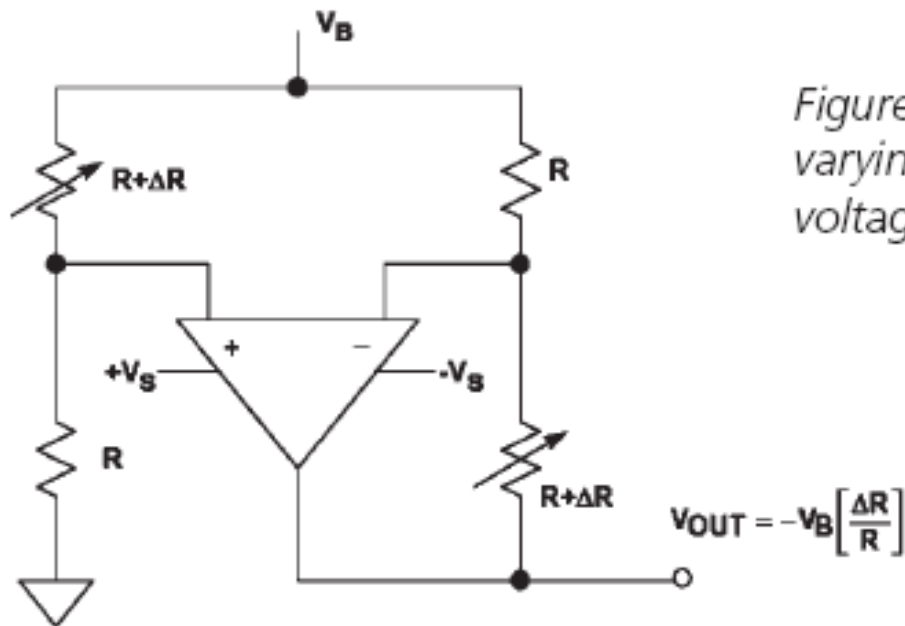


Figure 4.1.11: Linearizing a two-element varying bridge method 1 (constant voltage drive).

Linearização de ponte com dois elementos sensíveis

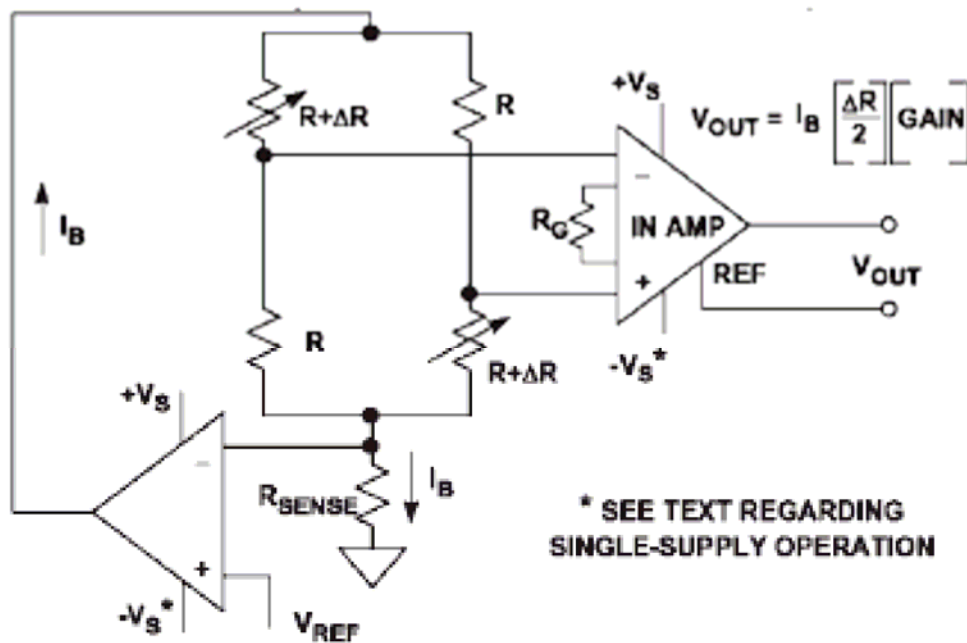
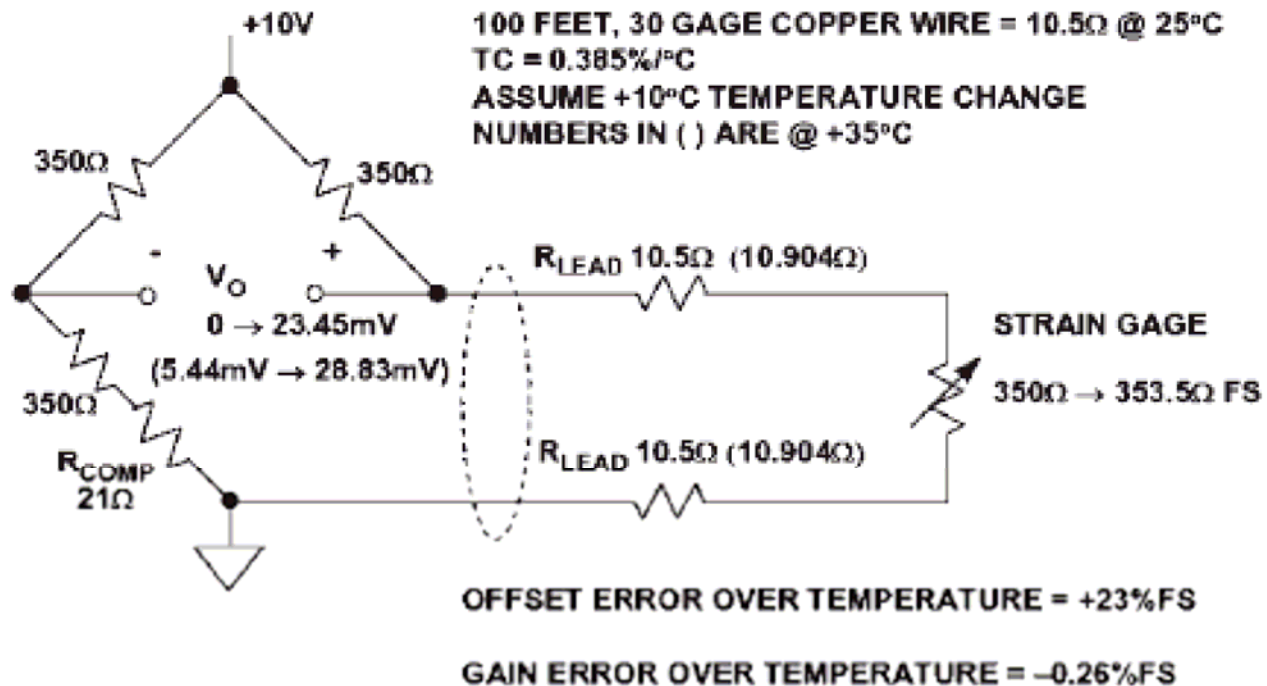
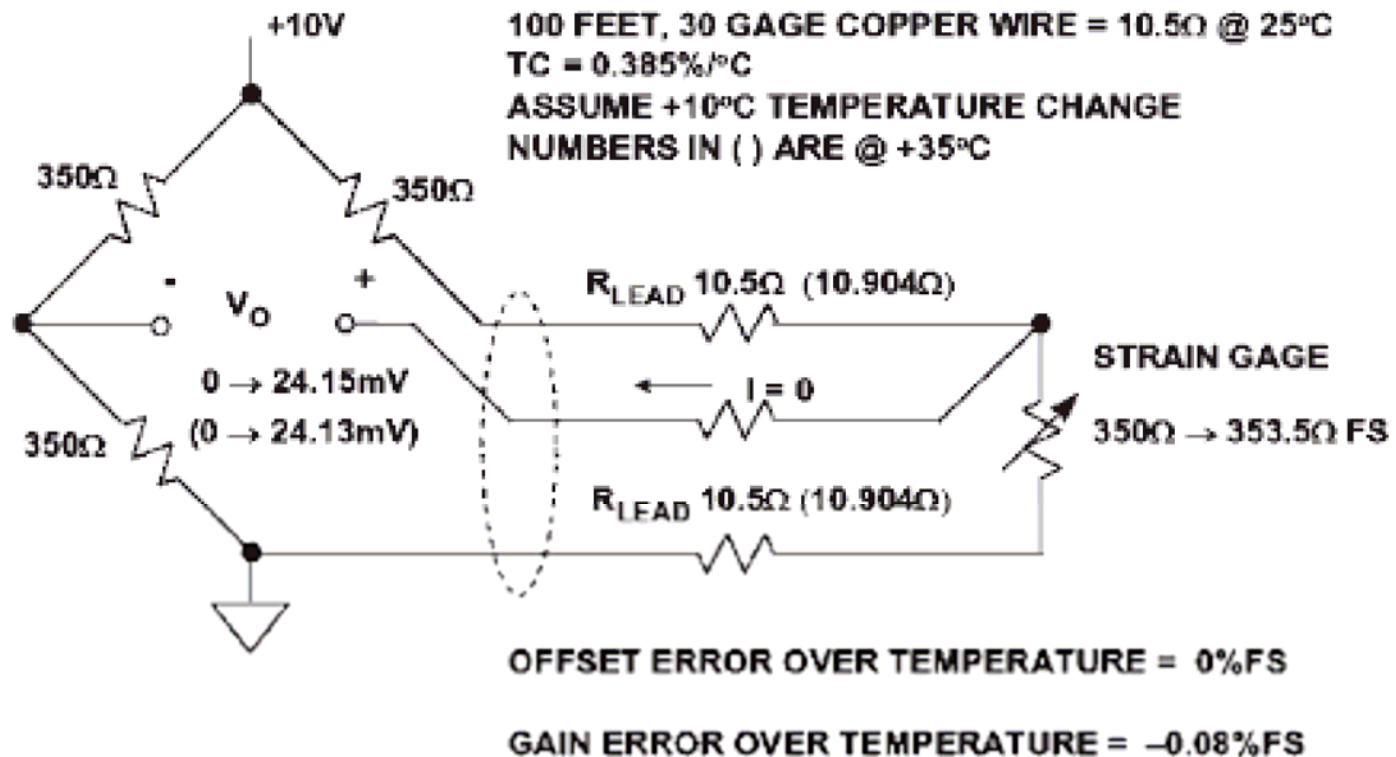


Figure 4.1.12: Linearizing a two-element varying bridge method 2 (constant voltage drive).

Erros observados em conexões de sensores



Compensação de erros de conexão



Compensação de erros de conexão

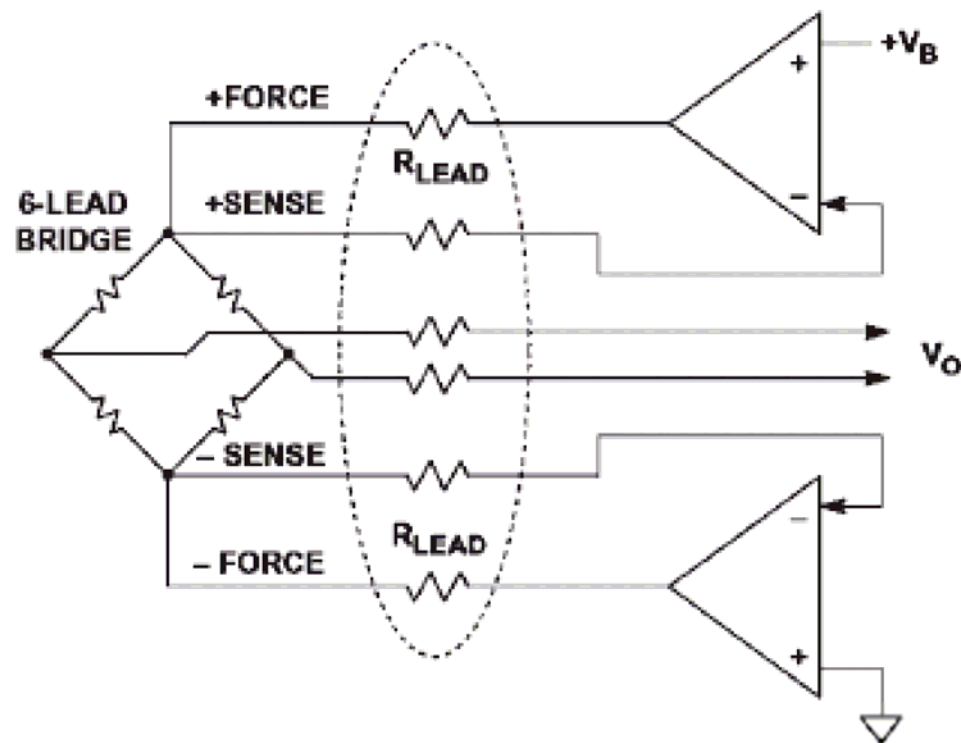


Figure 4.1.15: Kelvin (4-wire) sensing minimizes errors due to lead resistance.

Compensação de erros de conexão

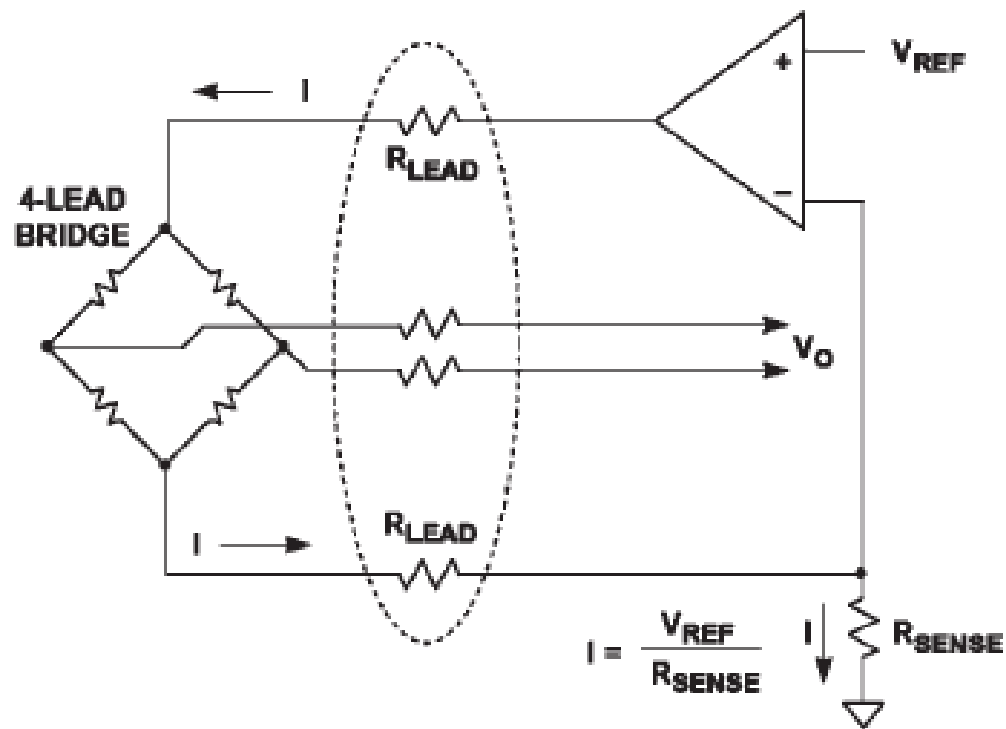


Figure 4.1.16: Constant current excitation minimizes wiring resistance errors.

Compensação de erros de conexão

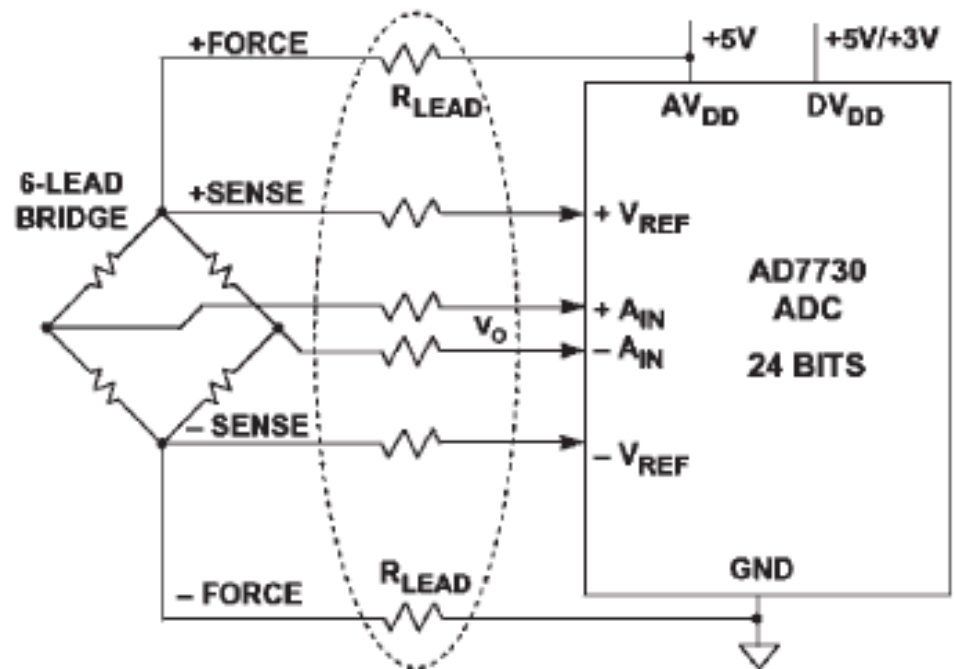
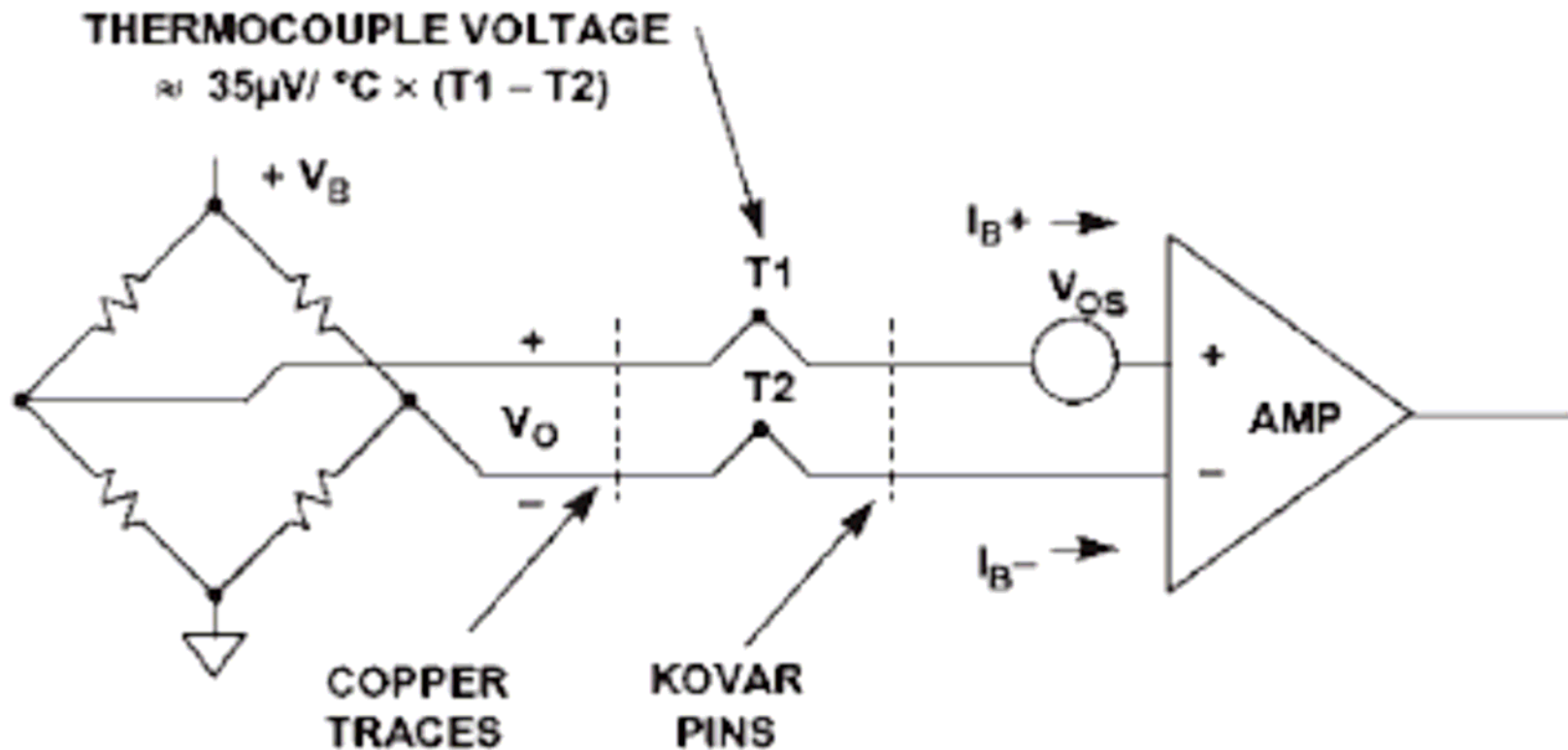


Figure 4.1.17: Driving remote bridge using Kelvin (4-wire) sensing and ratiometric connection to ADC.

Compensação de Offset térmico



Excitação alternada

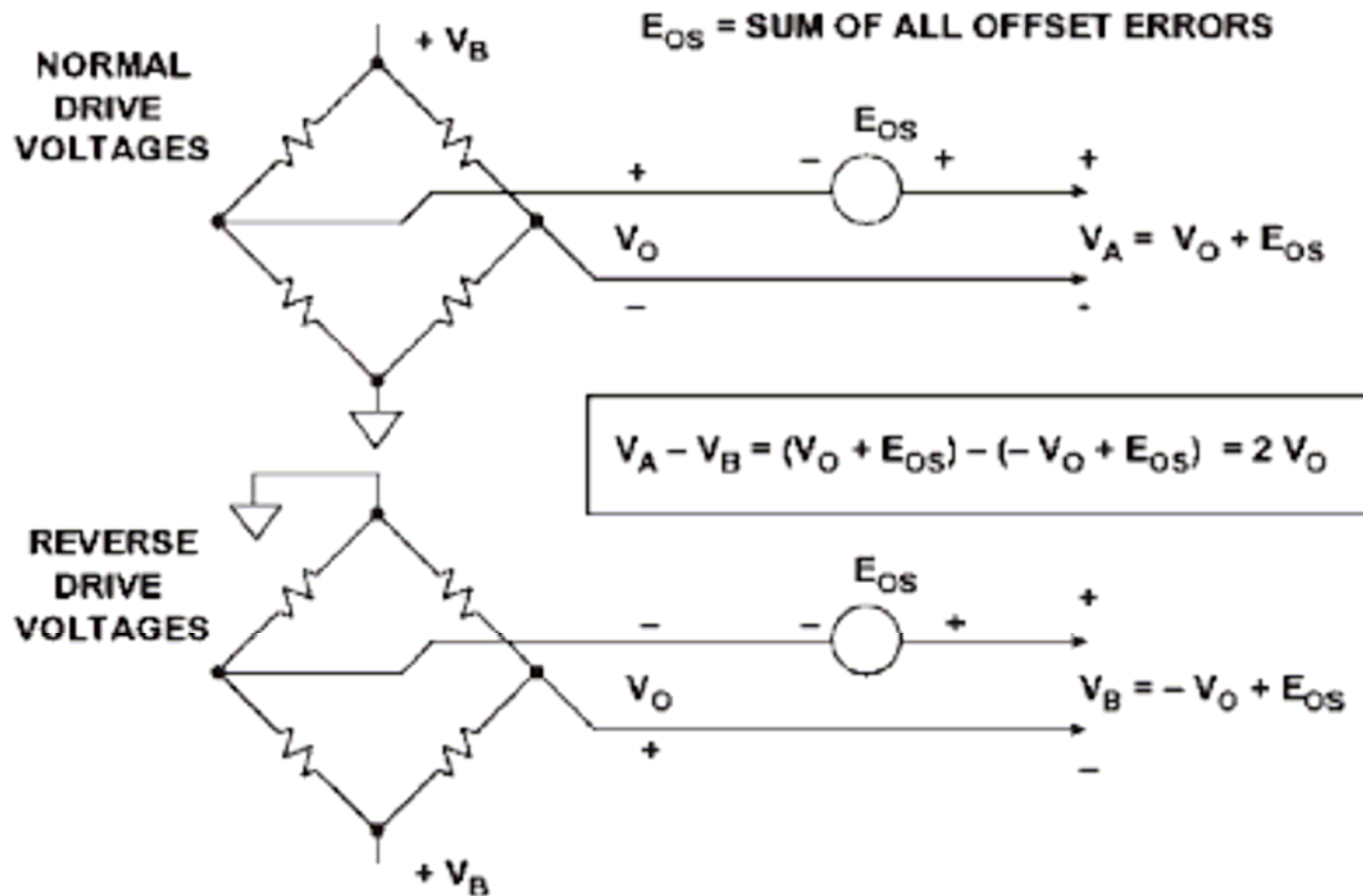


Figure 4.1.19: AC excitation minimizes offset errors.

Excitação alternada

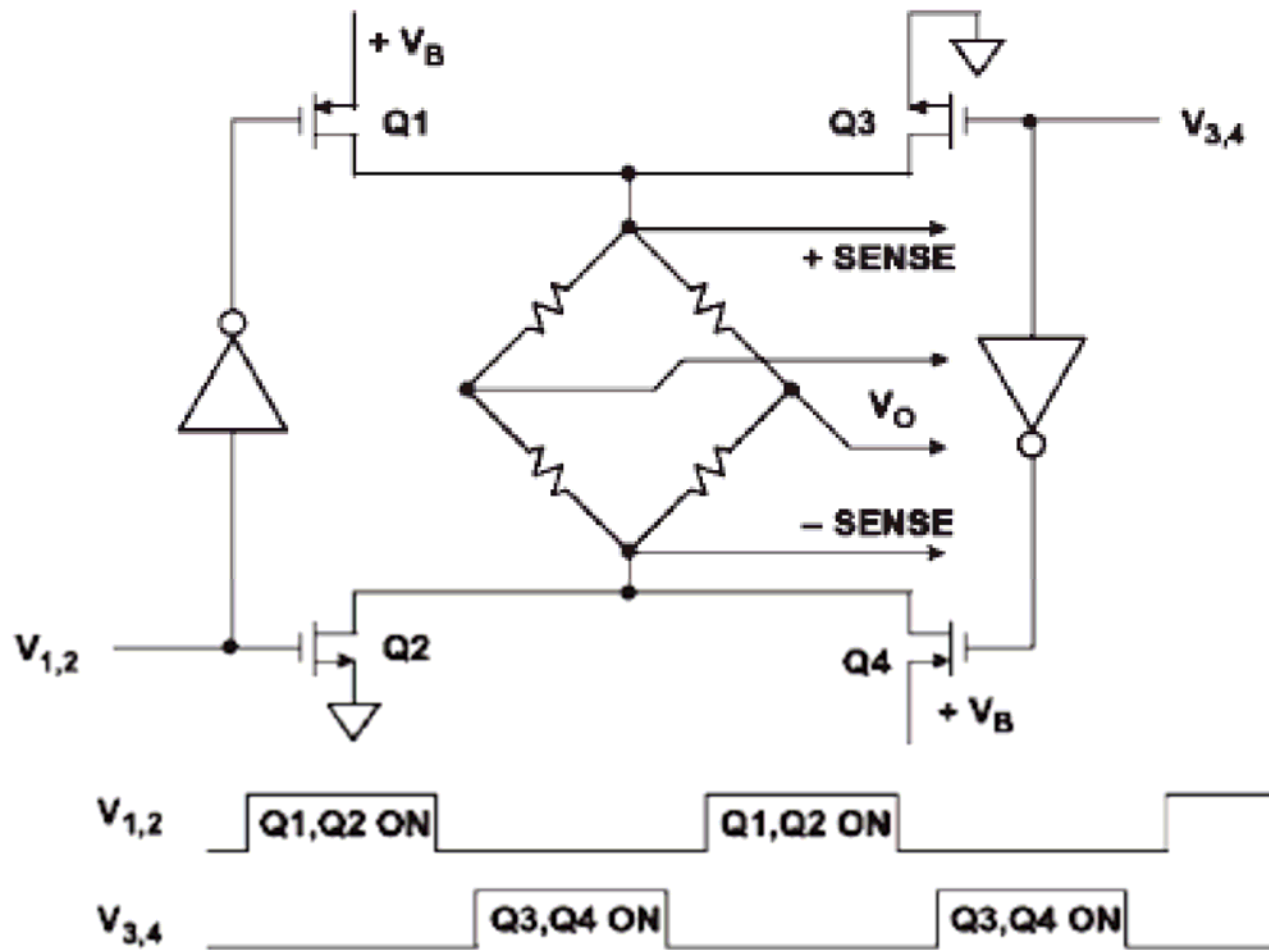


Figure 4.1.20: Simplified AC bridge drive circuit.

Requisitos para amplificadores de sinal

- Input Offset Voltage <100 μ V
- Input Offset Voltage Drift <1 μ V/ $^{\circ}$ C
- Input Bias Current <2nA
- Input Offset Current <2nA
- DC Open Loop Gain >1,000,000
- Unity Gain Bandwidth Product, f_u 500kHz - 5MHz
- Always Check Open Loop Gain at Signal Frequency!
- 1/f (0.1Hz to 10Hz) Noise <1 μ V p-p
- Wideband Noise <10nV/ $\sqrt{\text{Hz}}$
- CMR, PSR >100dB
- Single Supply Operation
- Power Dissipation

Medição de voltagem de offset

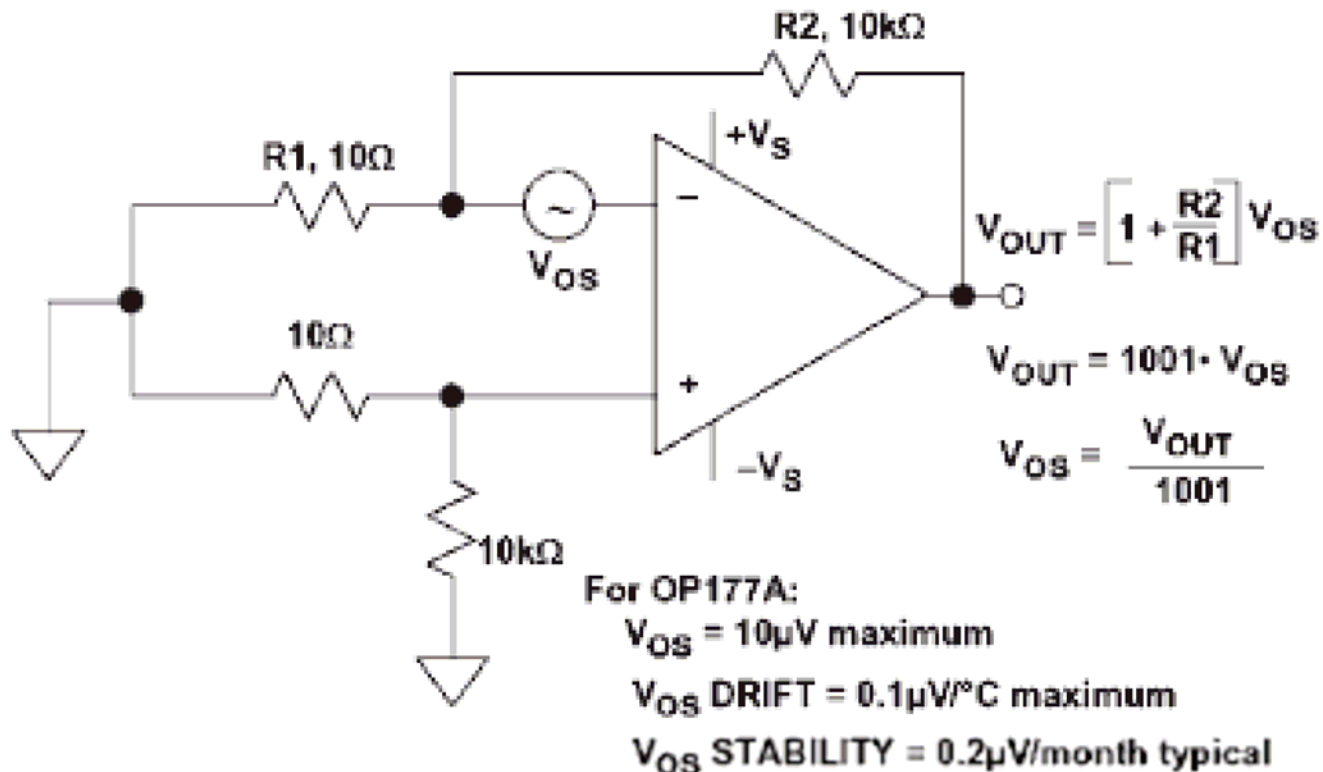
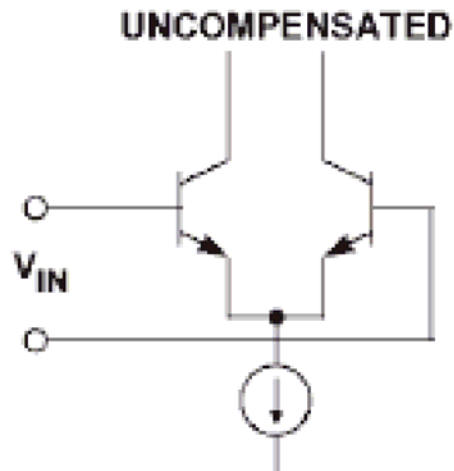
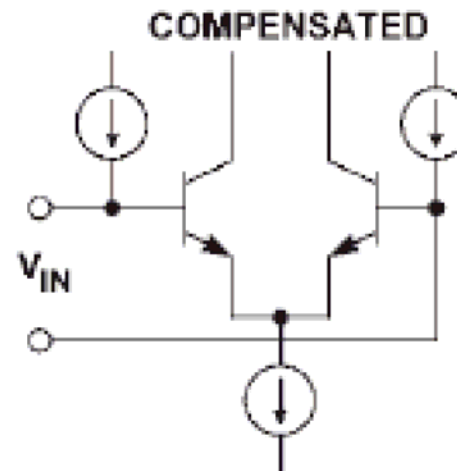


Figure 4.2.2: Measuring input offset voltage.

Compensação de corrente

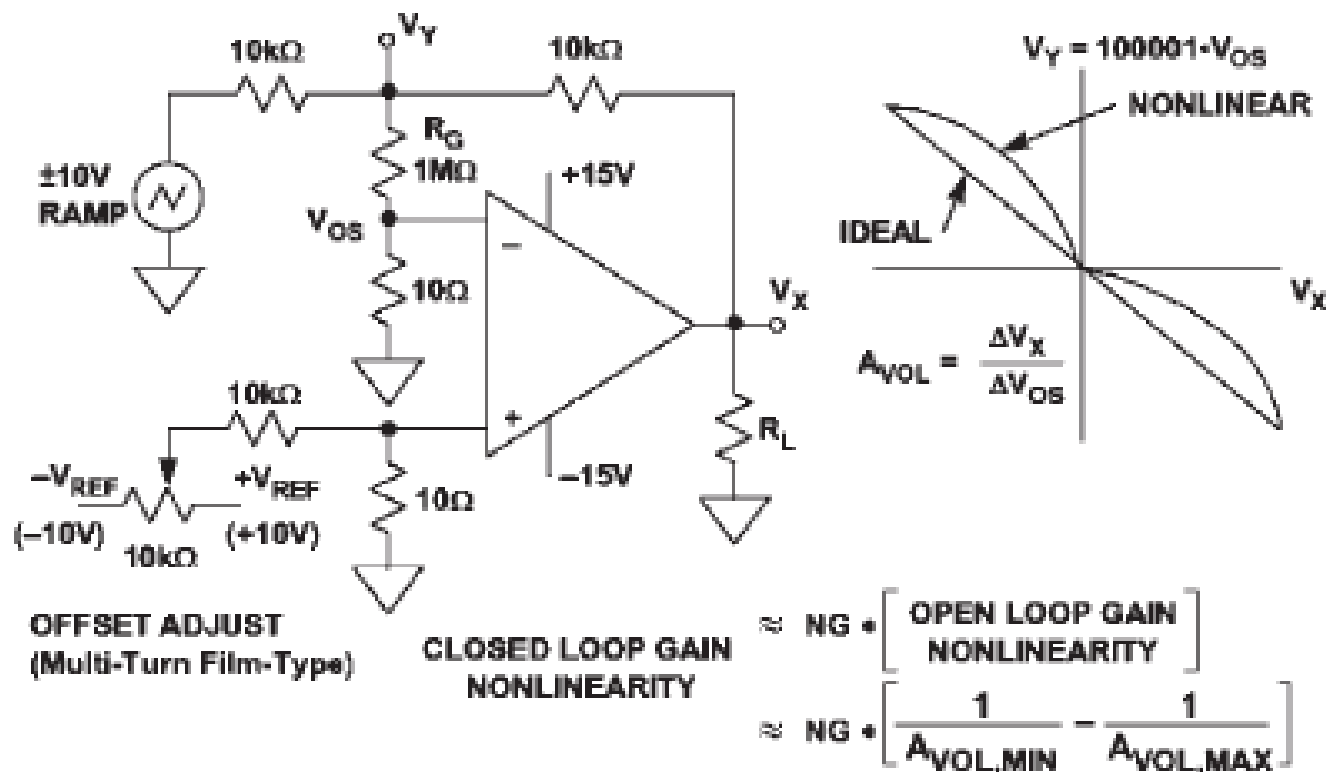


- MATCHED BIAS CURRENTS
- SAME SIGN
- 50nA - 10μA
- 50pA - 5nA (Super Beta)
- $I_{\text{OFFSET}} \ll I_{\text{BIAS}}$



- LOW, UNMATCHED BIAS CURRENTS
- CAN HAVE DIFFERENT SIGNS
- 0.5nA - 10nA
- HIGHER CURRENT NOISE
- $I_{\text{OFFSET}} \approx I_{\text{BIAS}}$

Circuito para medição de não linearidade



Exemplos de não linearidade

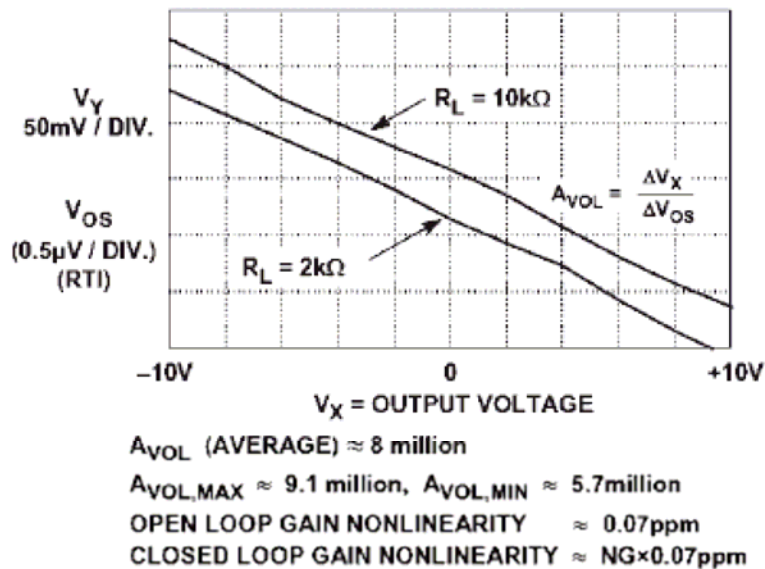


Figure 4.2.8: OP177 gain nonlinearity.

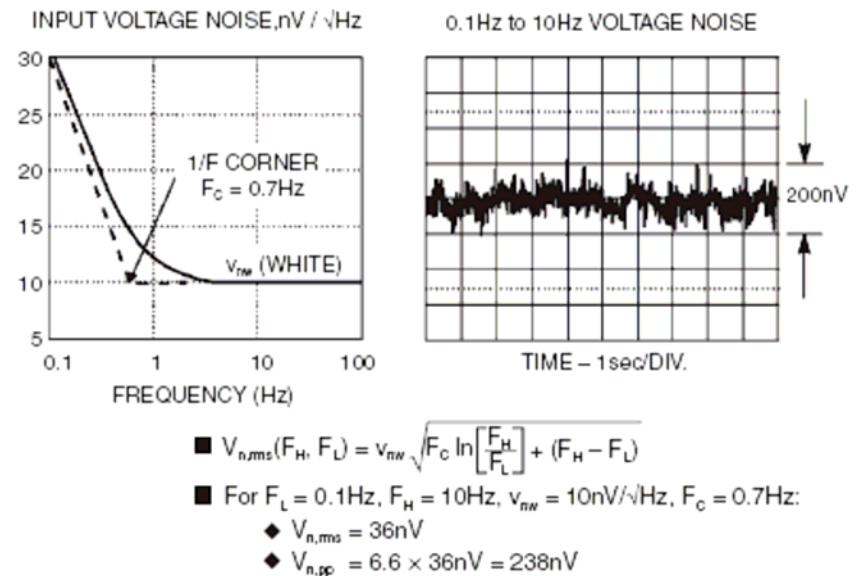
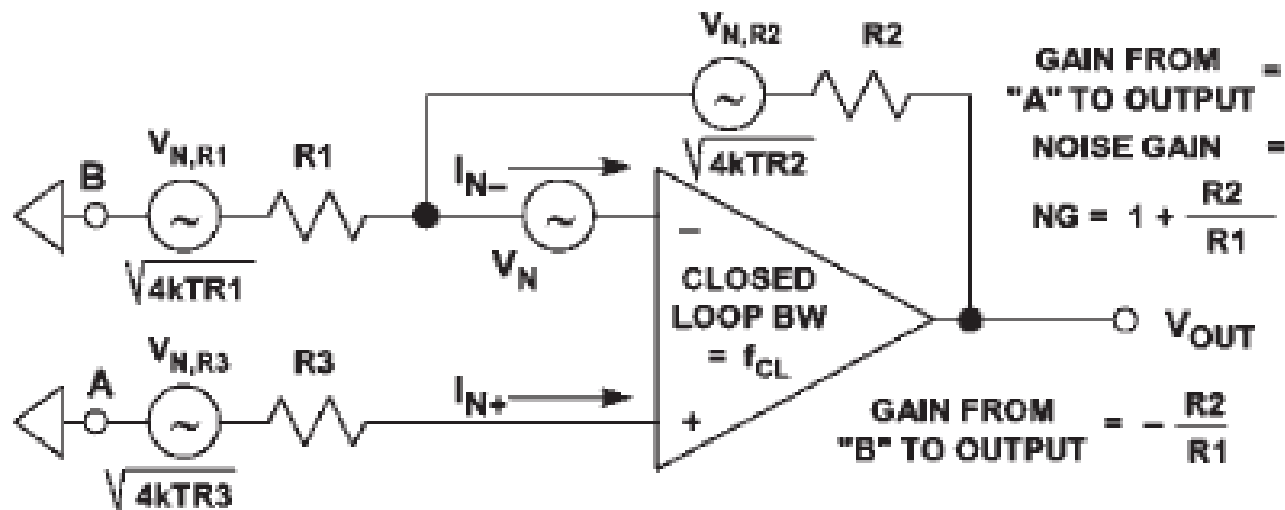


Figure 4.2.9: Input voltage noise for OP177/AD707.

Modelo de ruído em Op-amp



$$\blacksquare \text{ RTI NOISE} = \sqrt{BW} \cdot \sqrt{V_N^2 + 4kTR3 + 4kTR1 \left[\frac{R2}{R1+R2} \right]^2 + I_{N+}^2 R3^2 + I_{N-}^2 \left[\frac{R1+R2}{R1+R2} \right]^2 + 4kTR2 \left[\frac{R1}{R1+R2} \right]^2}$$

$$\blacksquare \text{ RTO NOISE} = NG \cdot \text{RTI NOISE}$$

$$\blacksquare BW = 1.57 f_{CL}$$

Exemplo de ruído em Op-amp

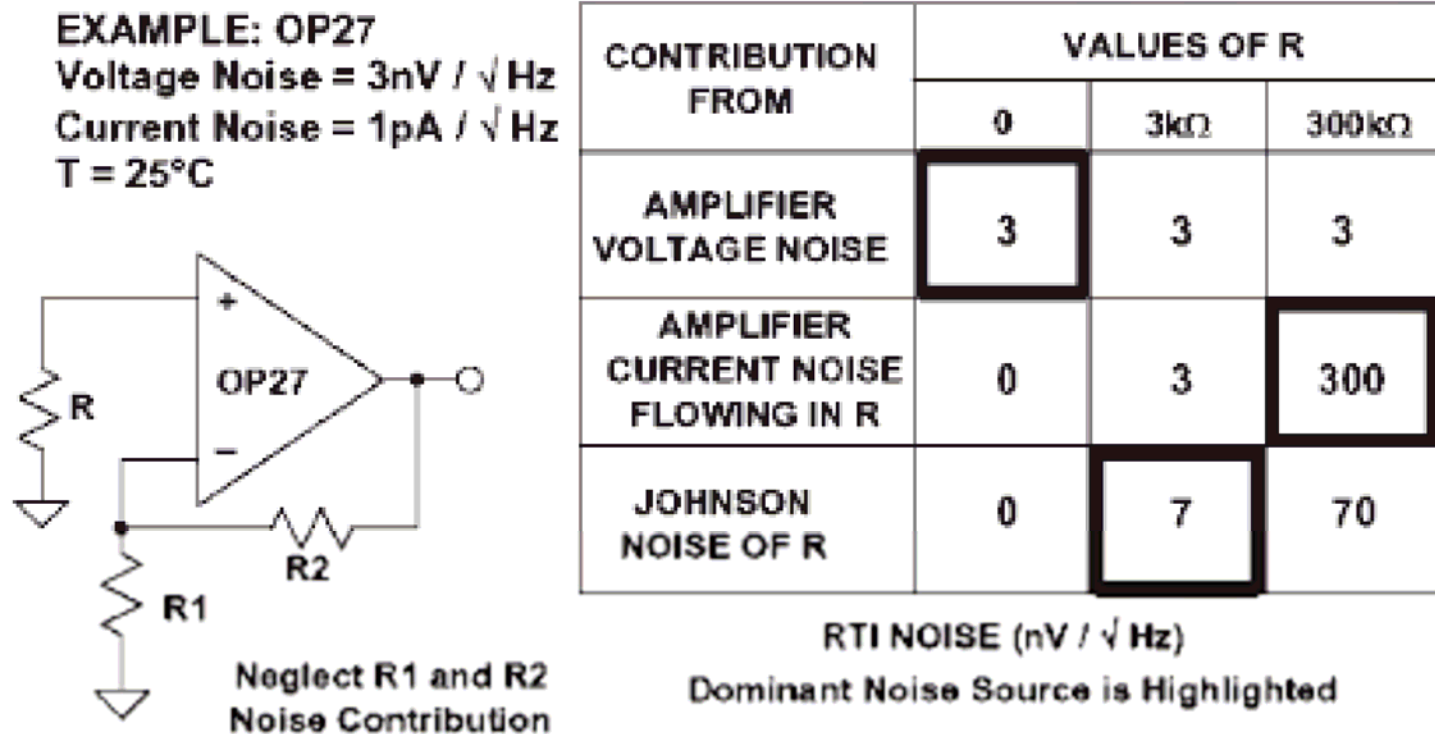


Figure 4.2.11: Different noise sources dominate at different source impedance.

Técnicas de desacoplamento de Amp-op

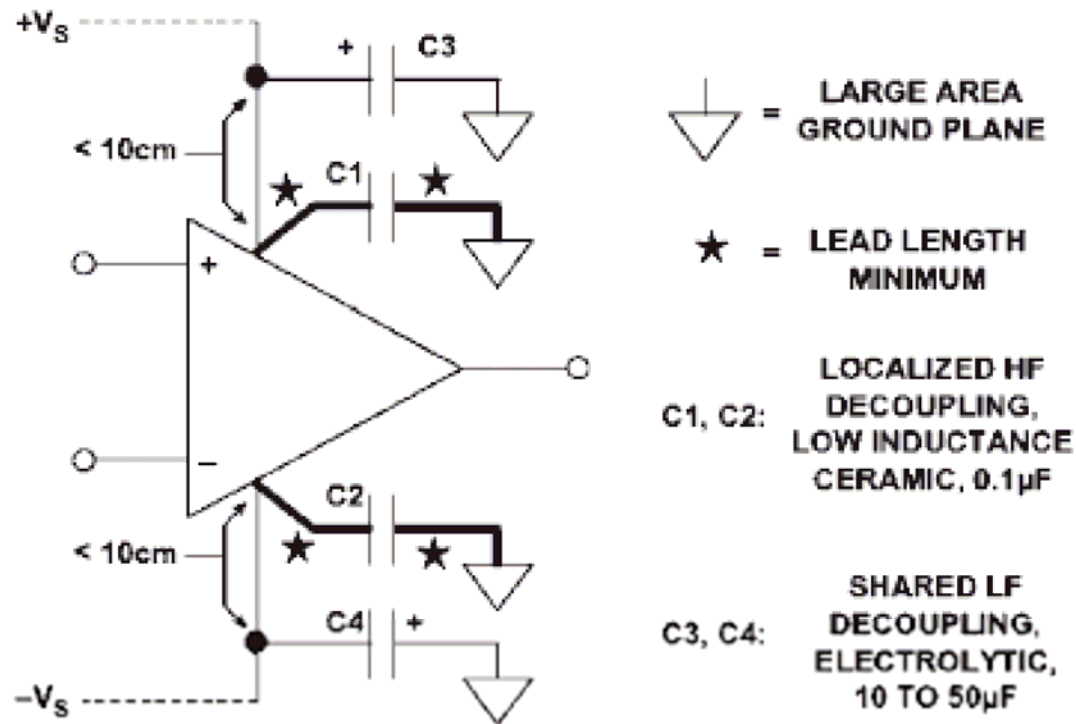


Figure 4.2.16: Proper low and high-frequency decoupling techniques for op amps.

Requisitos para amplificadores em microssistemas

■ Single Supply Offers:

- ◆ Lower Power
- ◆ Battery Operated Portable Equipment
- ◆ Requires Only One Voltage

■ Design Tradeoffs:

- ◆ Reduced Signal Swing Increases Sensitivity to Errors Caused by Offset Voltage, Bias Current, Finite Open-Loop Gain, Noise, etc.
- ◆ Must Usually Share Noisy Digital Supply
- ◆ Rail-to-Rail Input and Output Needed to Increase Signal Swing
- ◆ Precision Less than the best Dual Supply Op Amps but not Required for All Applications
- ◆ Many Op Amps Specified for Single Supply, but do not have Rail-to-Rail Inputs or Outputs

Estágios de amplificação

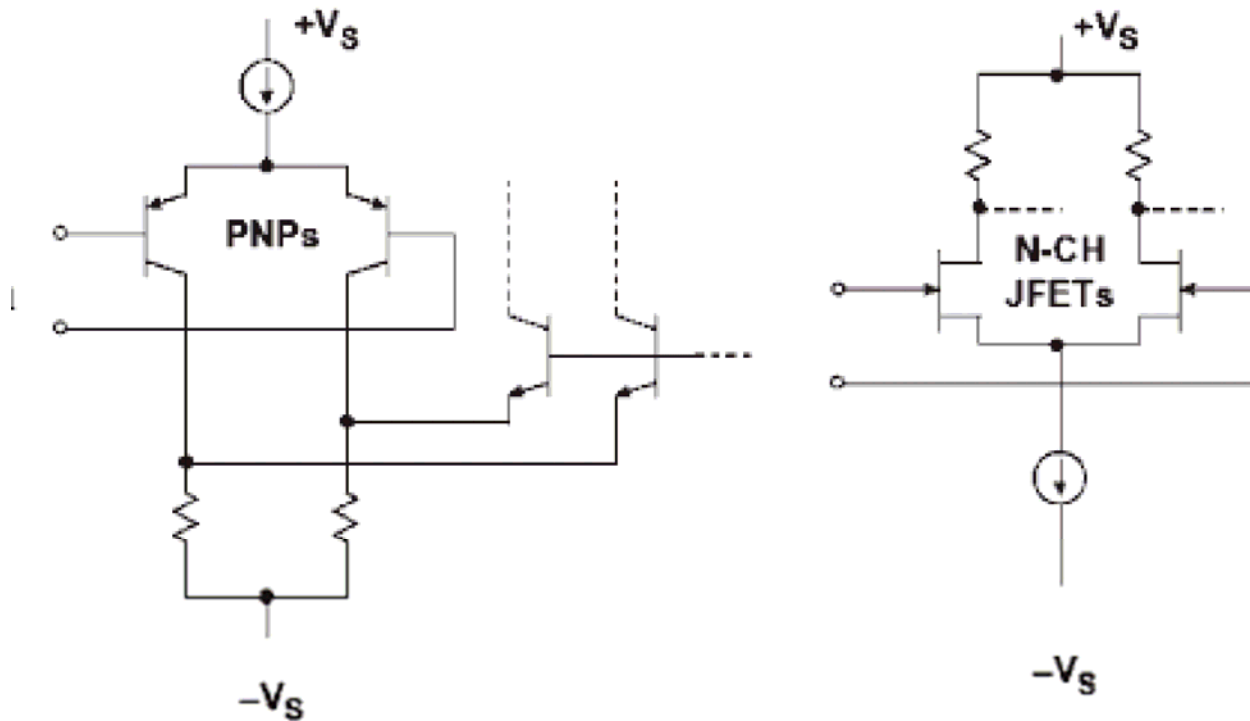
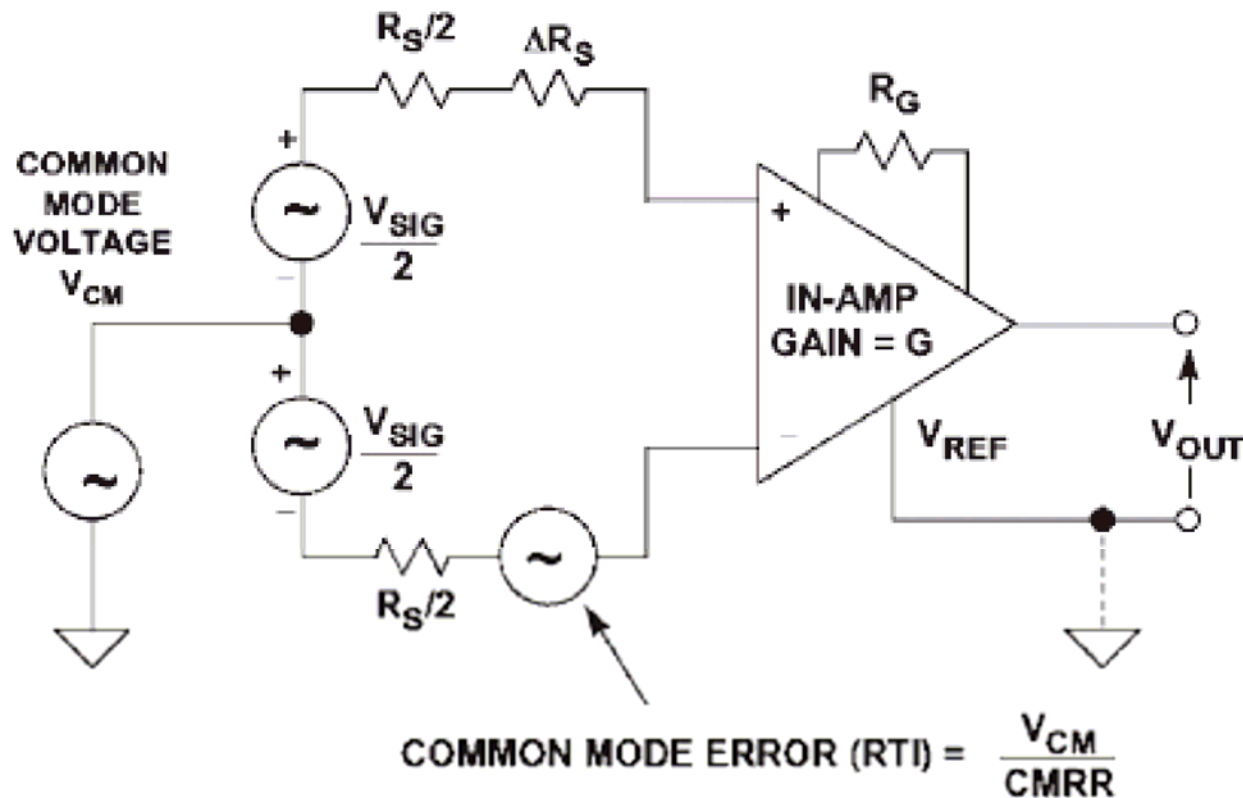


Figure 4.2.19: PNP or N-channel JFET stages allow input signal to go to the negative rail.

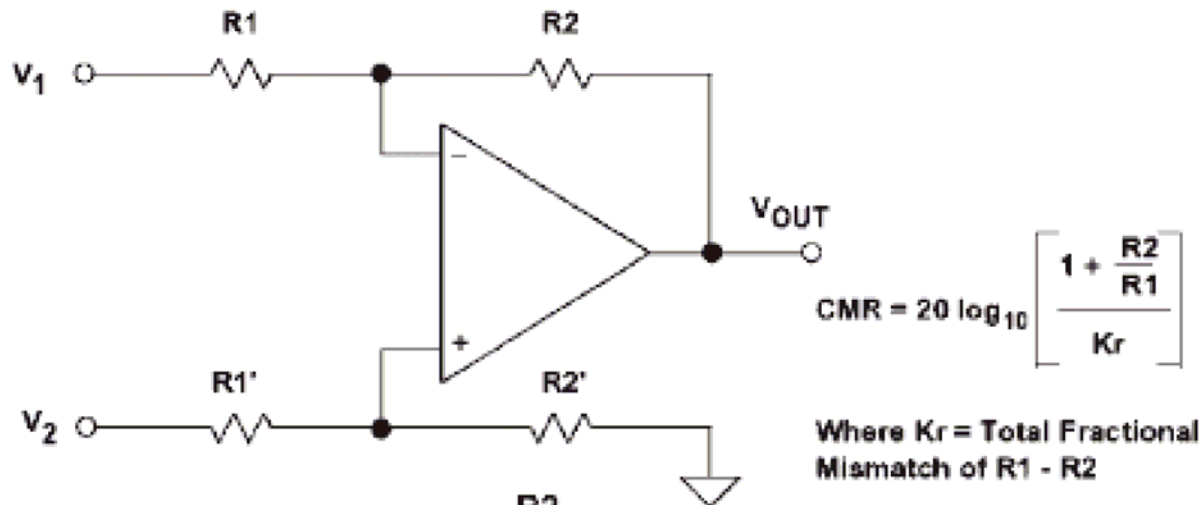
Comparação de estágios de amplificação

- **BIPOLAR (NPN-BASED):** This is Where it All Started!!
- **COMPLEMENTARY BIPOLAR (CB):** Rail-to-Rail, Precision, High Speed
- **BIPOLAR + JFET (BiFET):** High Input Impedance, High Speed
- **COMPLEMENTARY BIPOLAR + JFET (CBFET):** High Input Impedance, Rail-to-Rail Output, High Speed
- **COMPLEMENTARY MOSFET (CMOS):** Low Cost, Non-Critical Op Amps
- **BIPOLAR + CMOS (BiCMOS):** Bipolar Input Stage adds Linearity, Low Power, Rail-to-Rail Output
- **COMPLEMENTARY BIPOLAR + CMOS (CBCMOS):** Rail-to-Rail Inputs, Rail-to-Rail Outputs, Good Linearity, Low Power

Amplificador de Instrumentação

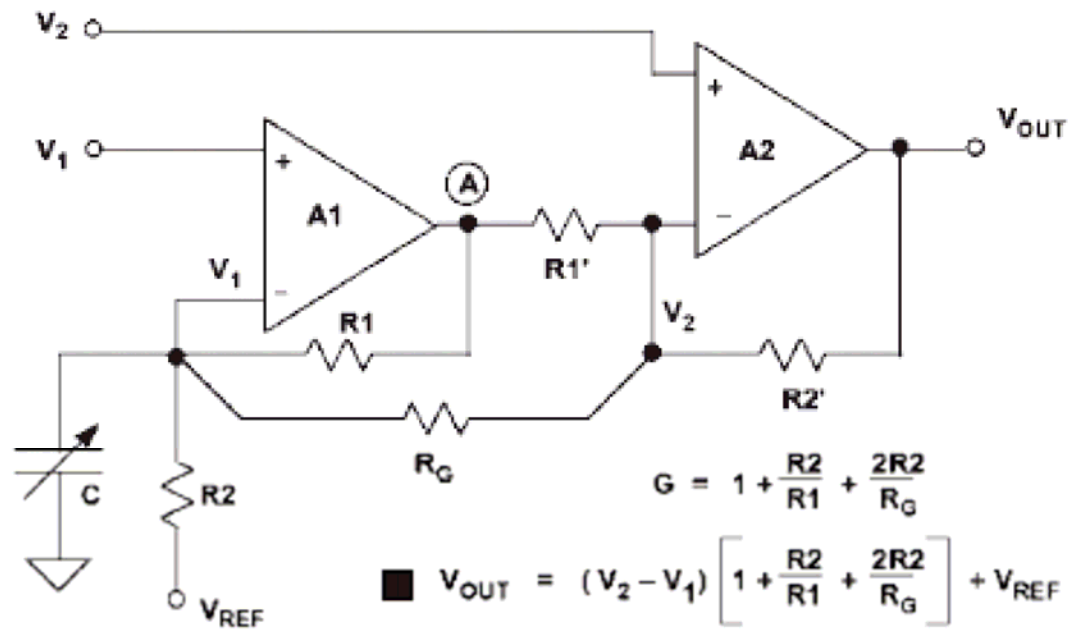


Subtrator para instrumentação



- $V_{OUT} = (V_2 - V_1) \frac{R2}{R1}$
- $\frac{R2}{R1} = \frac{R2'}{R1'}$ CRITICAL FOR HIGH CMR
- EXTREMELY SENSITIVE TO SOURCE IMPEDANCE IMBALANCE
- 0.1% TOTAL MISMATCH YIELDS $\approx 66\text{dB}$ CMR FOR $R1 = R2$

Amplificador de dois estágios



■ $V_{OUT} = (V_2 - V_1) \left[1 + \frac{R2}{R1} + \frac{2R2}{RG} \right] + V_{REF}$

■ $\frac{R2}{R1} = \frac{R2'}{R1'}$

■ $CMR \leq 20 \log \left[\frac{GAIN \times 100}{\% \text{ MISMATCH}} \right]$

Chip de amplificação comercial

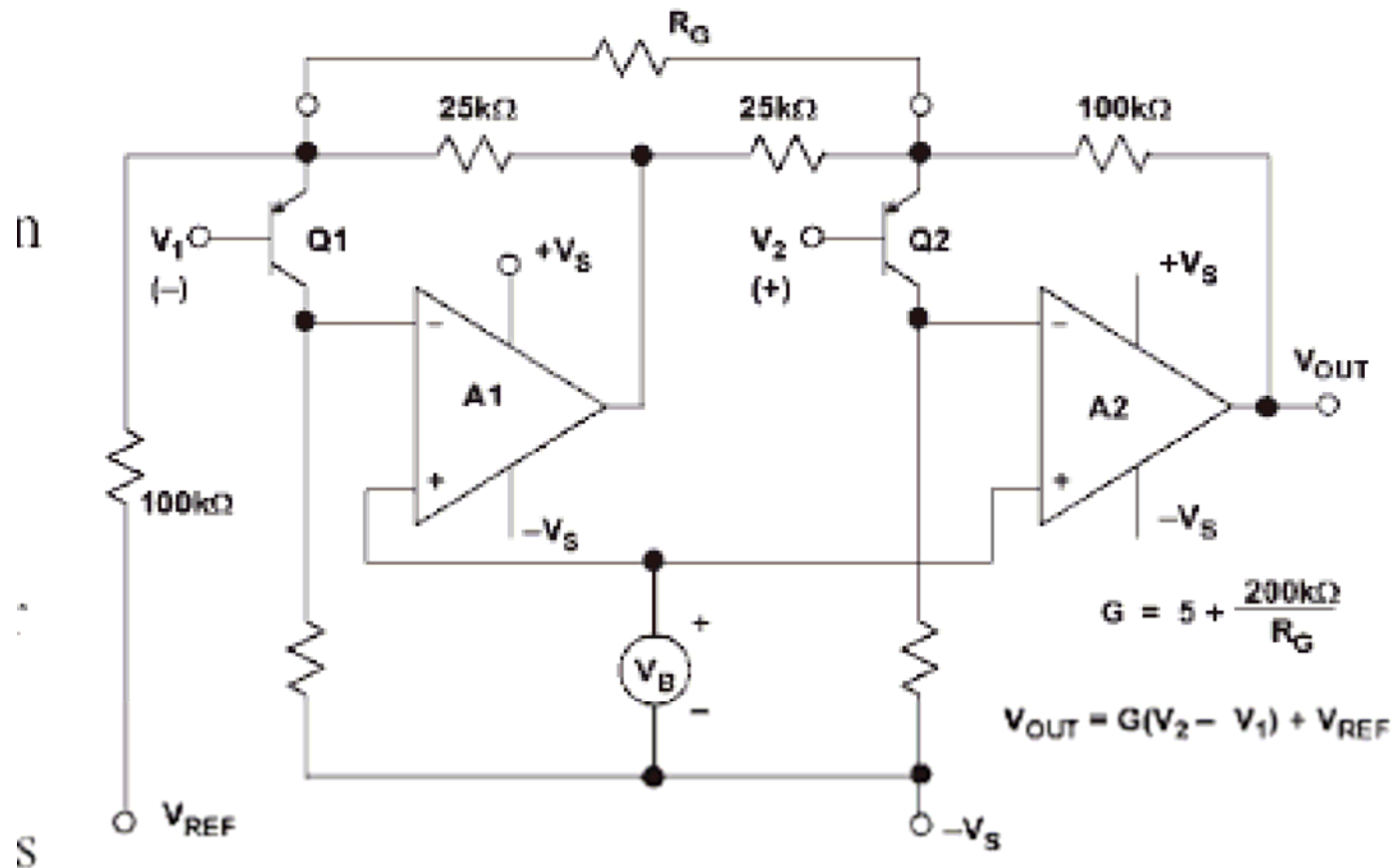
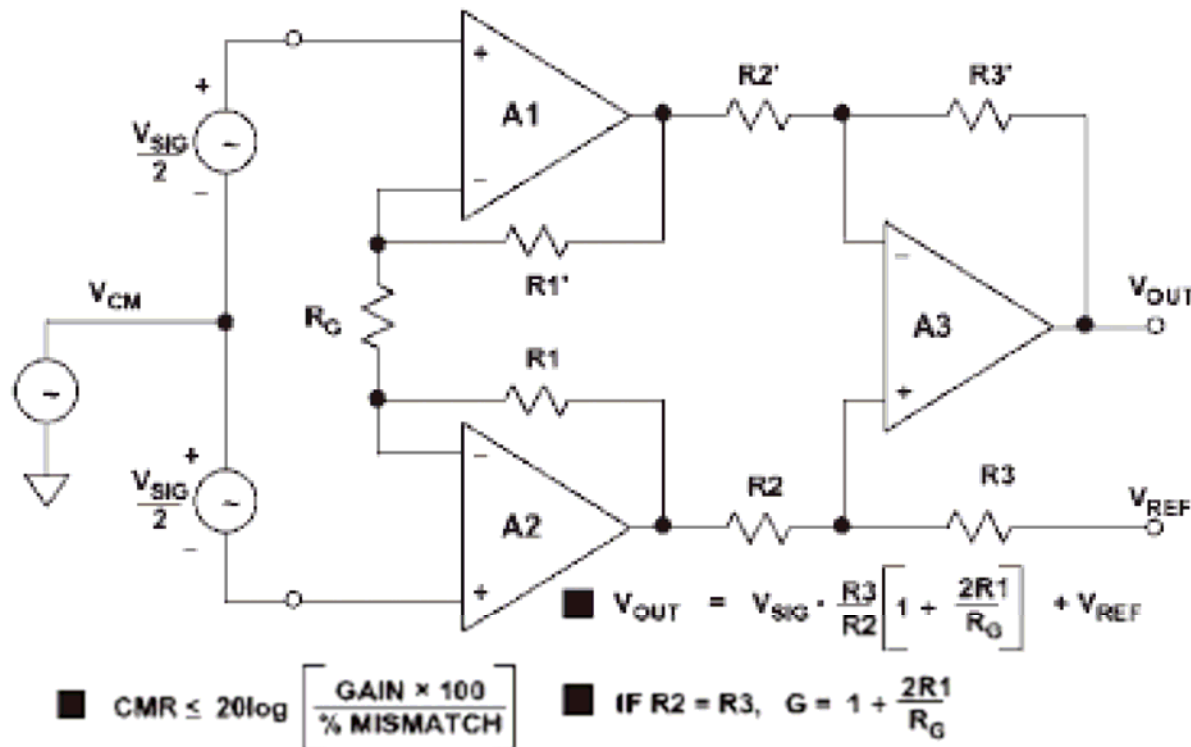


Figure 4.2.30: AD627 in-amp architecture.

Estágio de amplificação com três Amp-op



Estágio de amplificação com três Amp-op

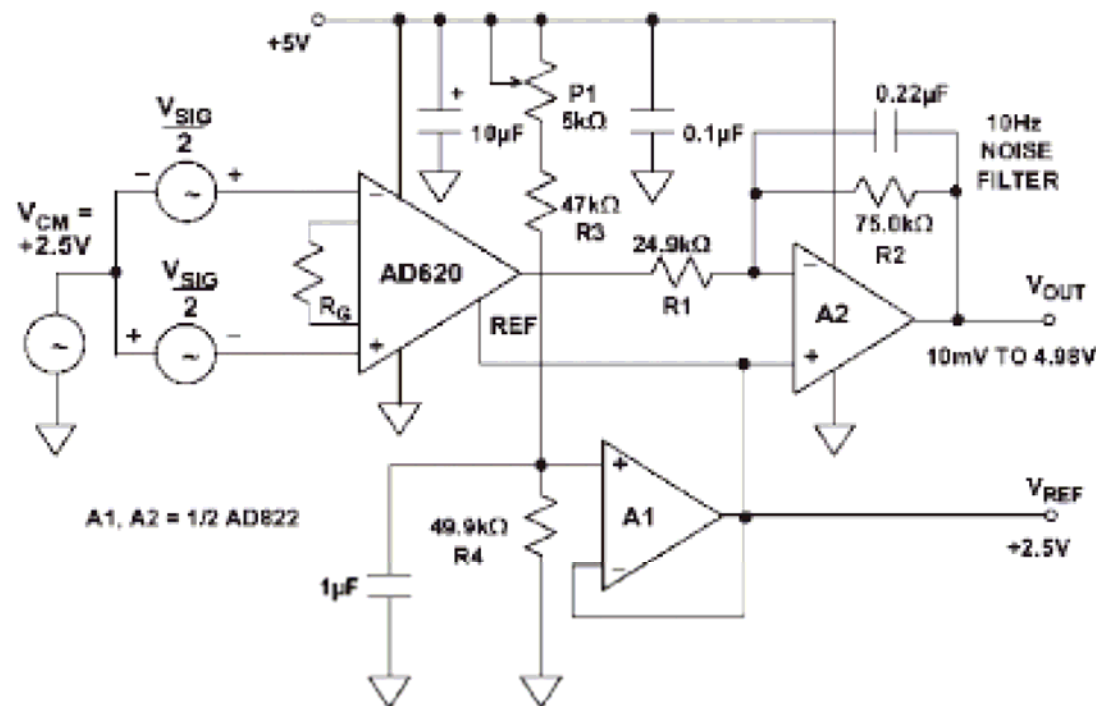
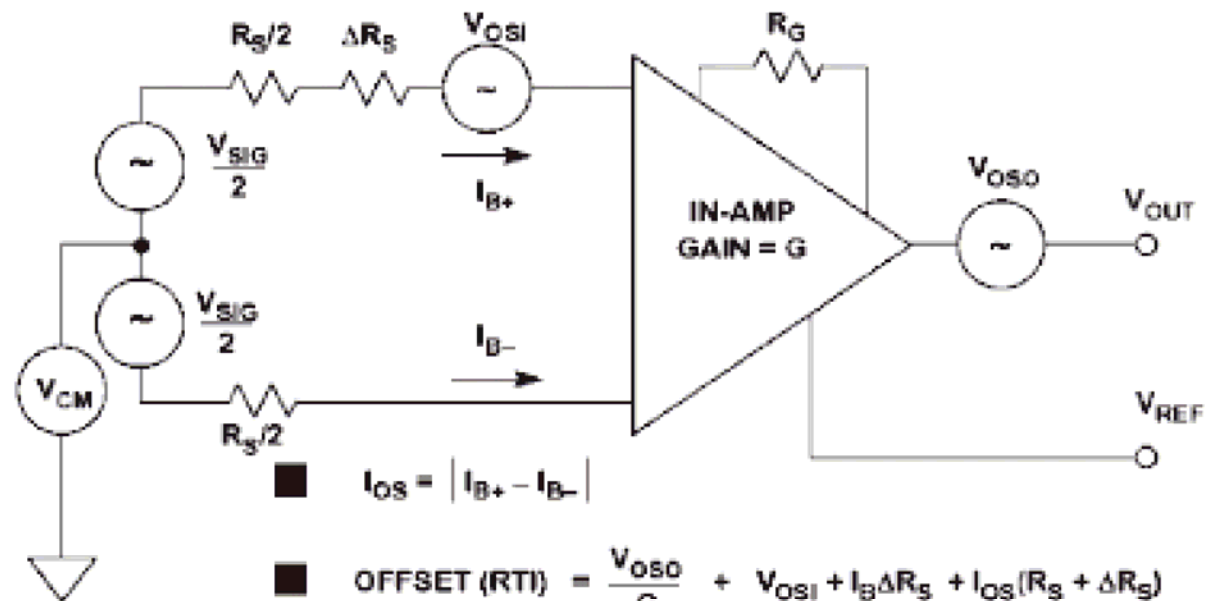


Figure 4.2.35: A precision single-supply composite in-amp with rail-to-rail output.

Modelo de offset para Amp-op

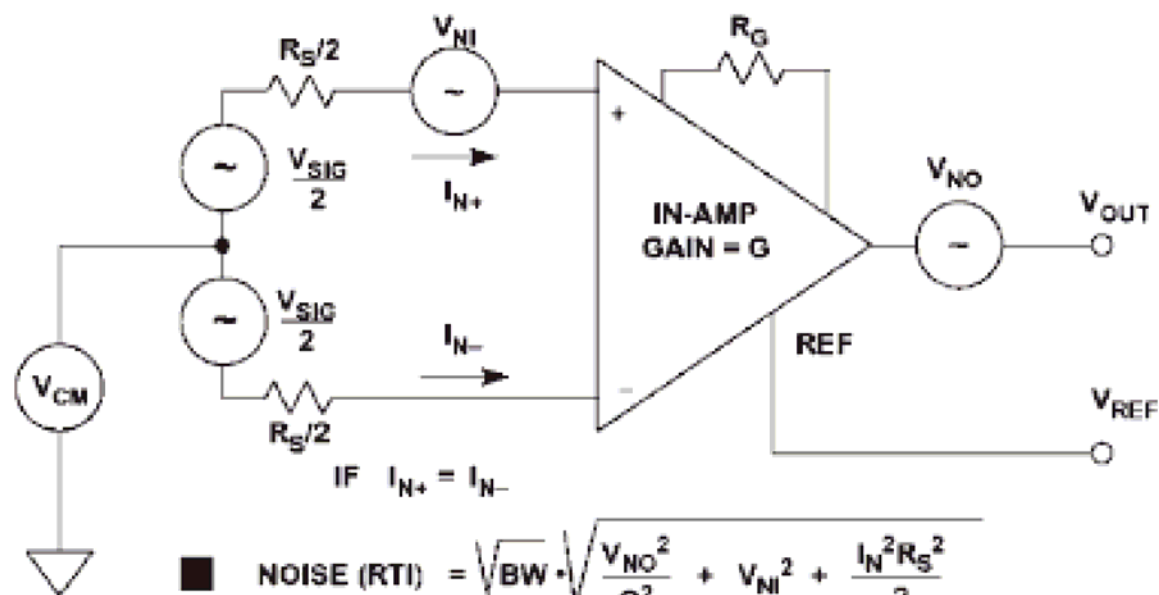


■ $I_{OS} = |I_{B+} - I_{B-}|$

■ $OFFSET (RTI) = \frac{V_{OSO}}{G} + V_{OSI} + I_B \Delta R_S + I_{OS}(R_S + \Delta R_S)$

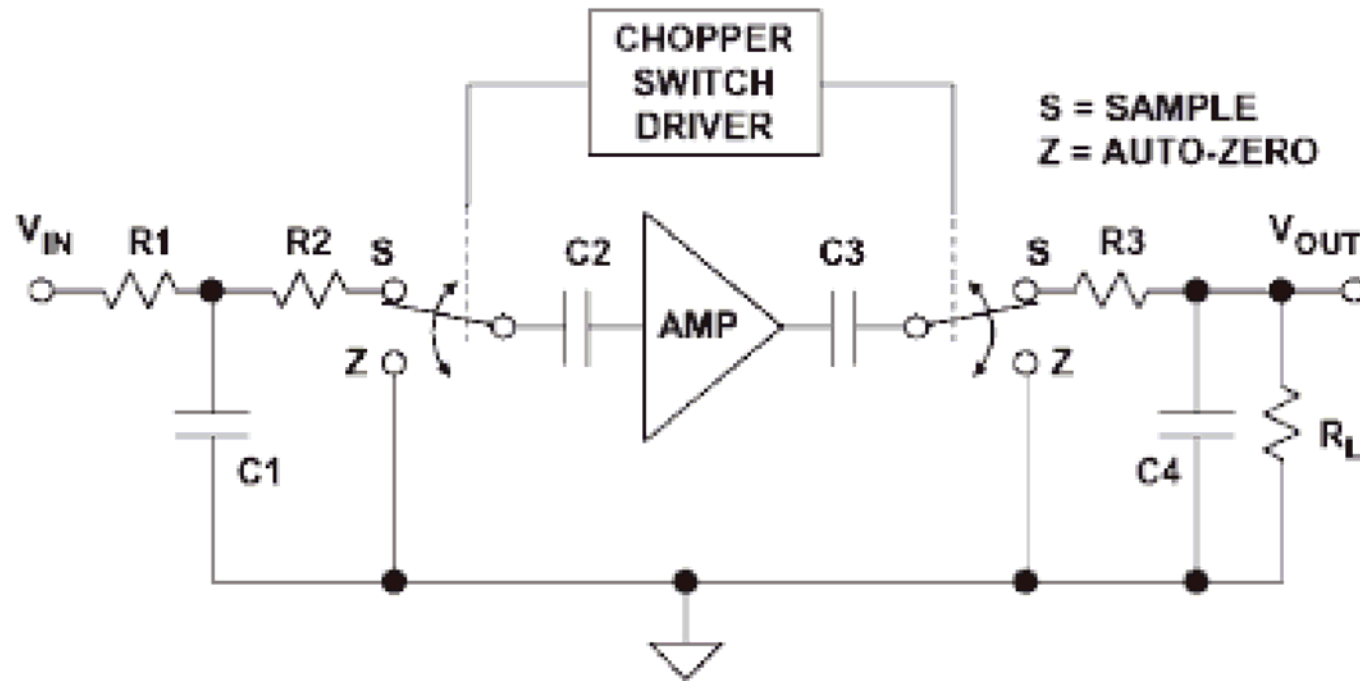
■ $OFFSET (RTO) = V_{OSO} + G[V_{OSI} + I_B \Delta R_S + I_{OS}(R_S + \Delta R_S)]$

Modelo de ruído em Amp-op



- NOISE (RTI) = $\sqrt{BW} \cdot \sqrt{\frac{V_{NO}^2}{G^2} + V_{NI}^2 + \frac{I_N^2 R_S^2}{2}}$
- NOISE (RTO) = $\sqrt{BW} \cdot \sqrt{V_{NO}^2 + G^2 \left[V_{NI}^2 + \frac{I_N^2 R_S^2}{2} \right]}$
- BW = 1.57 × IN-AMP Bandwidth @ Gain = G

Amplificador com Chopper



Amplificador com Chopper

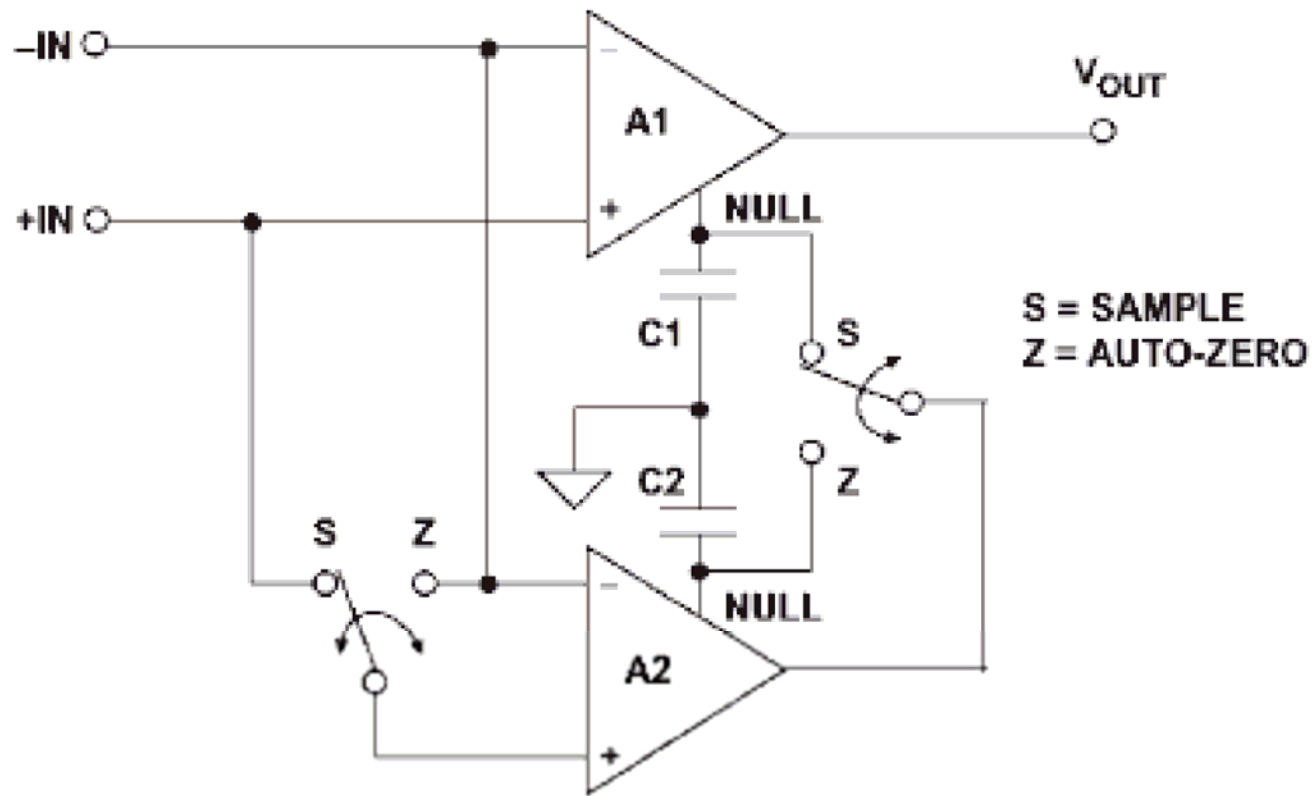
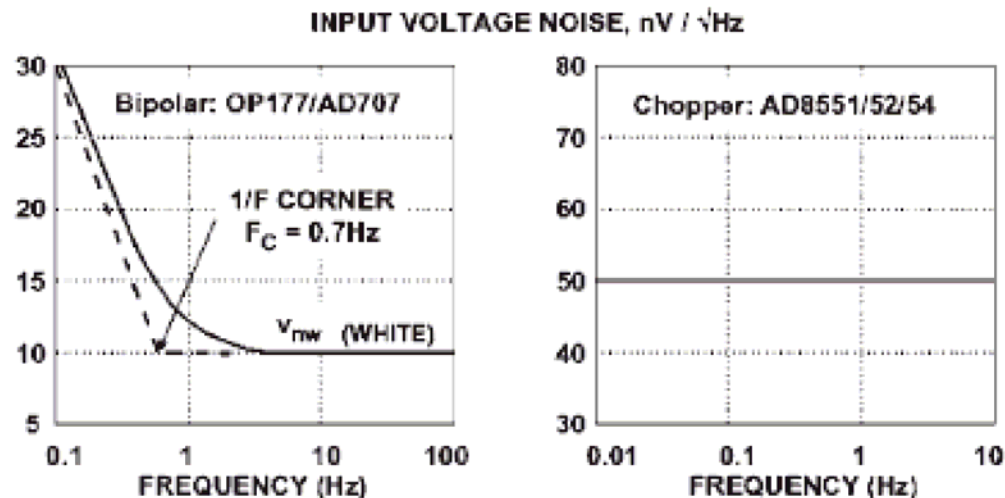


Figure 4.2.47: Chopper stabilized amplifier.

Comparação de ruído em amplificador bipolar versus chooper



NOISE BW	BIPOLAR (OP177/AD707)	CHOPPER (AD8551/52/54)
0.1Hz to 10Hz	0.238 μV p-p	1.04 μV p-p
0.01Hz to 1Hz	0.135 μV p-p	0.33 μV p-p
0.001Hz to 0.1Hz	0.120 μV p-p	0.104 μV p-p
0.0001Hz to 0.01Hz	0.118 μV p-p	0.033 μV p-p

Uso de Amplificadores de isolação

- **Sensor is at a High Potential Relative to Other Circuitry
(or may become so under Fault Conditions)**
- **Sensor May Not Carry Dangerous Voltages, Irrespective
of Faults in Other Circuitry
(e.g. Patient Monitoring and Intrinsically Safe Equipment
for use with Explosive Gases)**
- **To Break Ground Loops**

Amplificador comercial de isolação

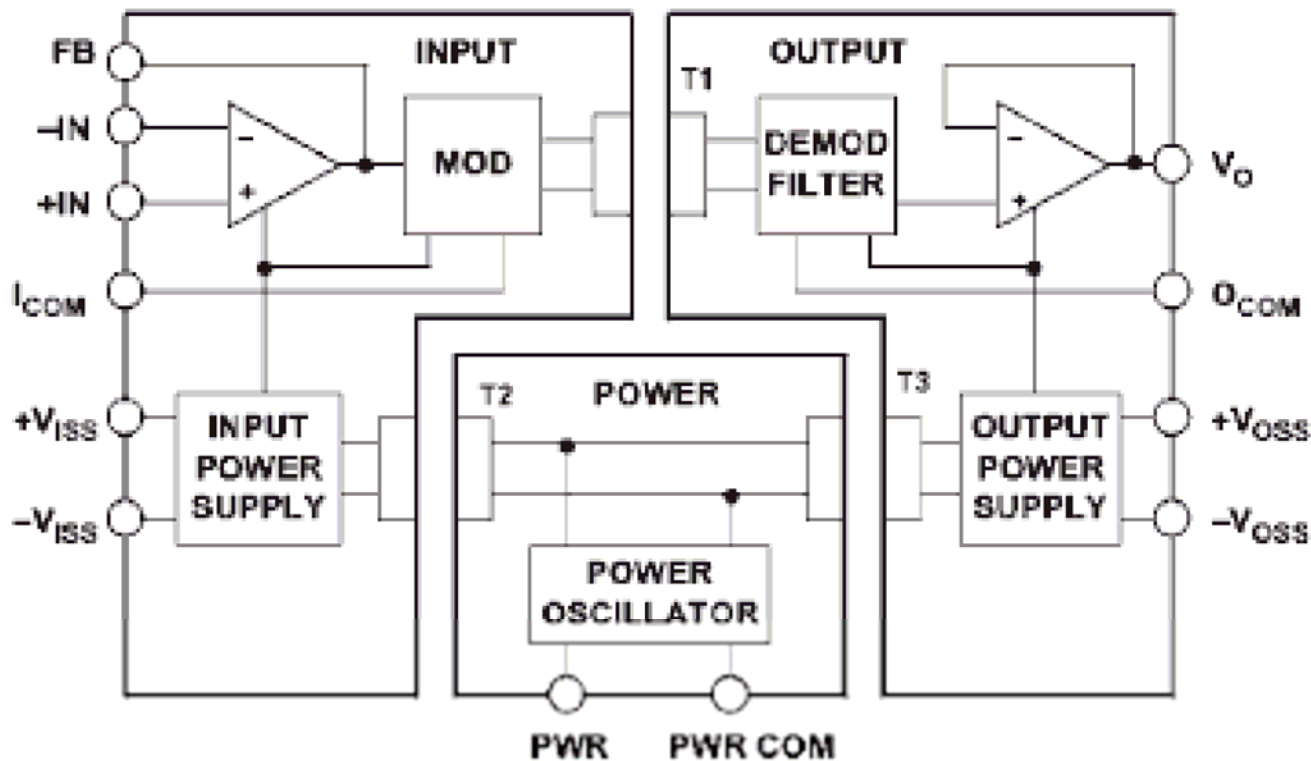


Figure 4.2.51: AD210 3-port isolation amplifier.

Requisitos do amplificador de isolação

- Transformer Coupled
- High Common Mode Voltage Isolation:
 - ◆ 2500V RMS Continuous
 - ◆ $\pm 3500\text{V}$ Peak Continuous
- Wide Bandwidth: 20kHz (Full Power)
- 0.012% Maximum Linearity Error
- Input Amplifier: Gain 1 to 100
- Isolated Input and Output Power Supplies, $\pm 15\text{V}$, $\pm 5\text{mA}$

Figure 4.2.52: AD210 isolation amplifier key features.

Aplicação do amplificador de isolação

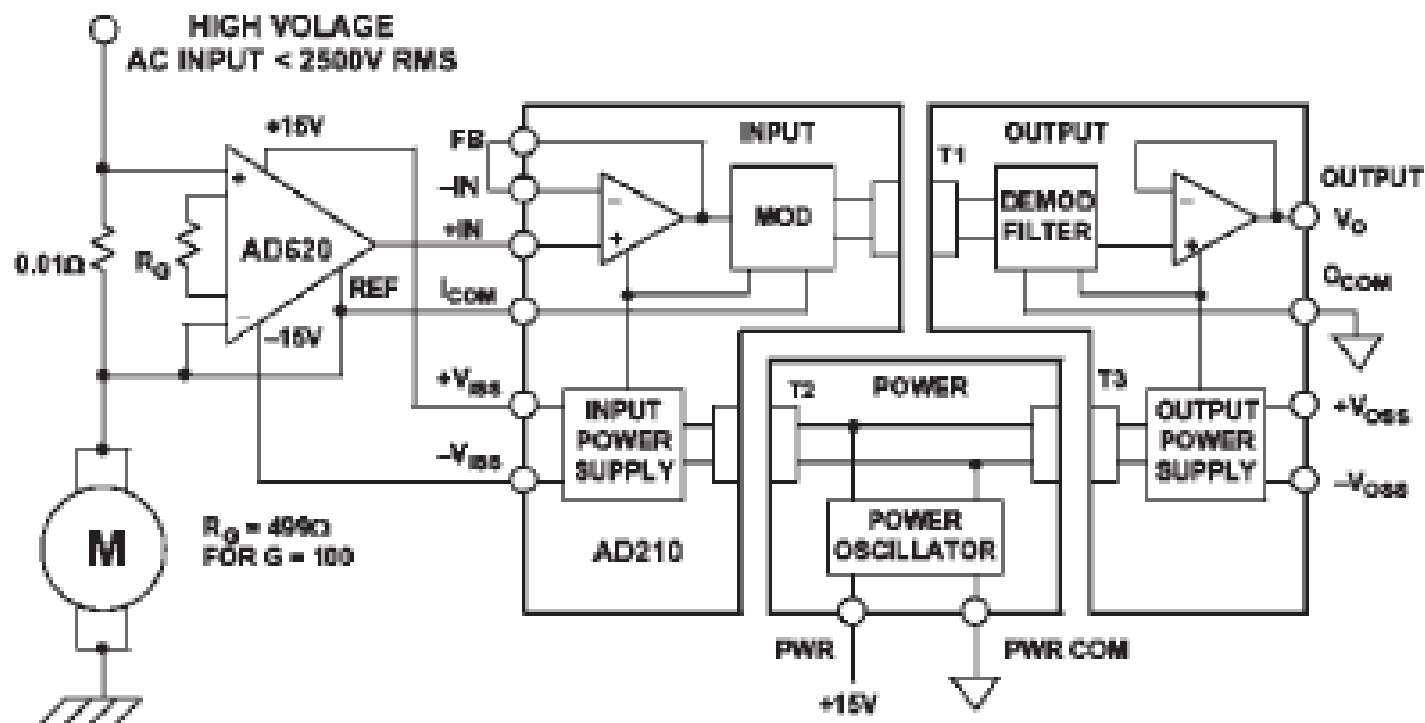


Figure 4.2.53: Motor control current sensing.

Sensores não resistivos

Conversor Analógico-Digital

- Typical Supply Voltages: $\pm 5V$, $+5V$, $+5/+3V$, $+3V$
- Lower Signal Swings Increase Sensitivity to all Types of Noise (Device, Power Supply, Logic, etc.)
- Device Noise Increases at Low Currents
- Common Mode Input Voltage Restrictions
- Input Buffer Amplifier Selection Critical
- Auto-Calibration Modes Desirable at High Resolutions

Figure 4.3.1: Low power, low voltage ADC design issues.

Conversor Analógico-Digital

■ Successive Approximation

- ◆ Resolutions to 16-bits
- ◆ Minimal Throughput Delay Time
- ◆ Used in Multiplexed Data Acquisition Systems

■ Sigma-Delta

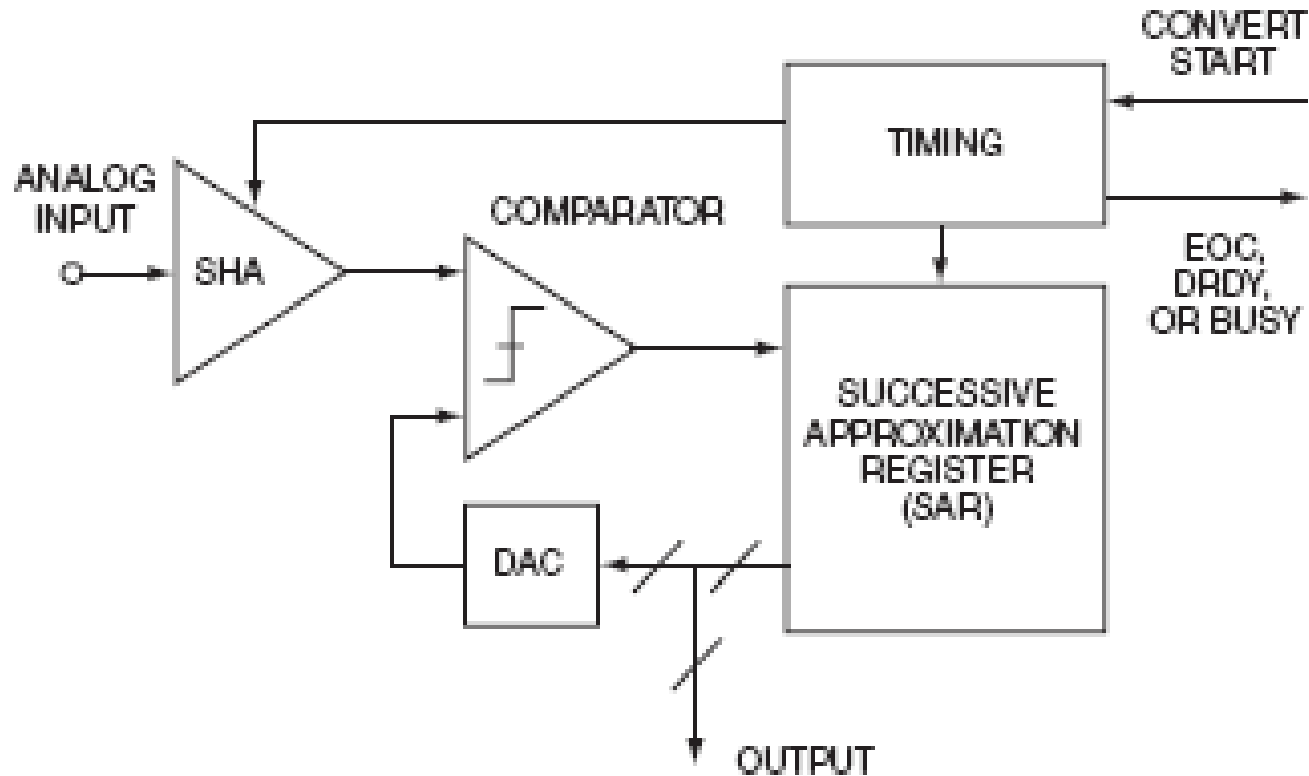
- ◆ Resolutions to 24-bits
- ◆ Excellent Differential Linearity
- ◆ Internal Digital Filter, Excellent AC Line Rejection
- ◆ Long Throughput Delay Time
- ◆ Difficult to Multiplex Inputs Due to Digital Filter Settling Time

■ High Speed Architectures:

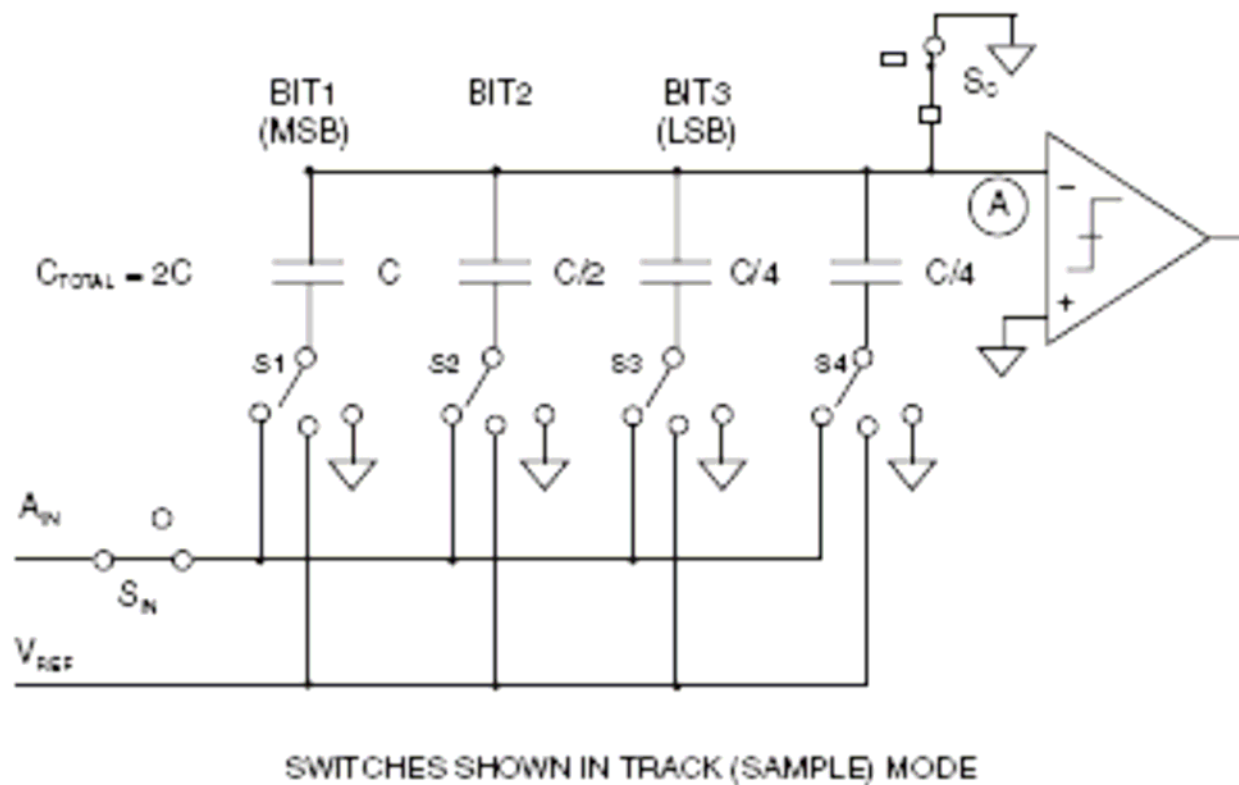
- ◆ Flash Converter
- ◆ Subranging or Pipelined

*Figure 4.3.2:
ADCs for signal conditioning.*

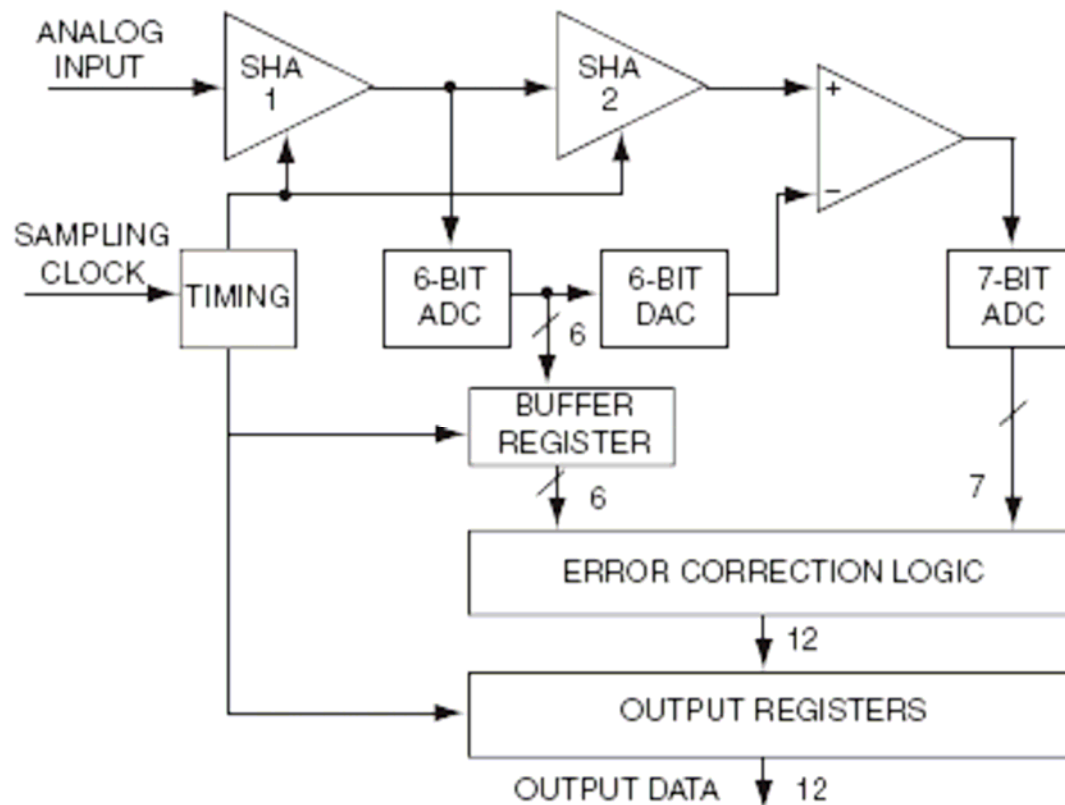
Conversor Analógico-Digital



Conversor baseado em capacitores



Conversor AD de dois estágios



Conversor AD comercial

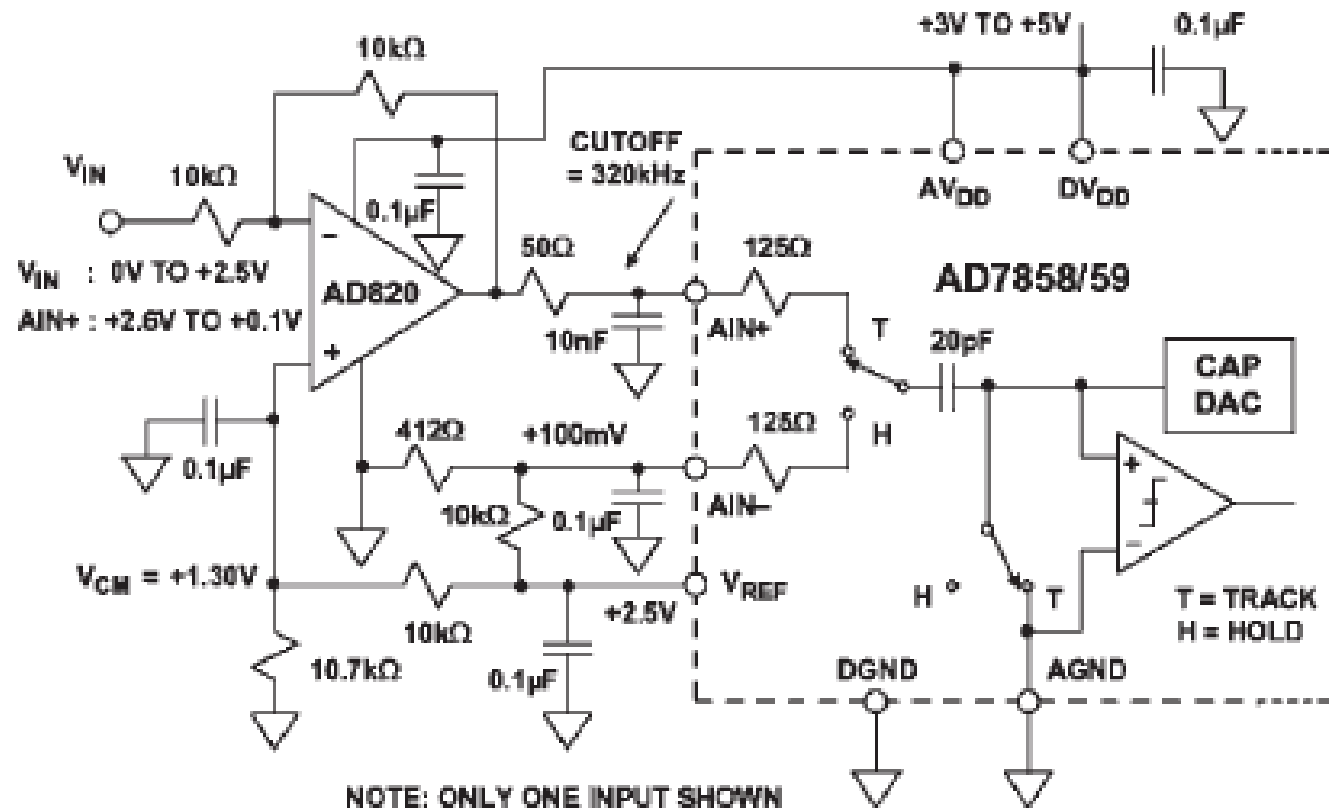


Figure 4.3.9: Driving switched capacitor inputs of AD7858/59 12-bit, 200 kSPS ADC.

Conversor AD

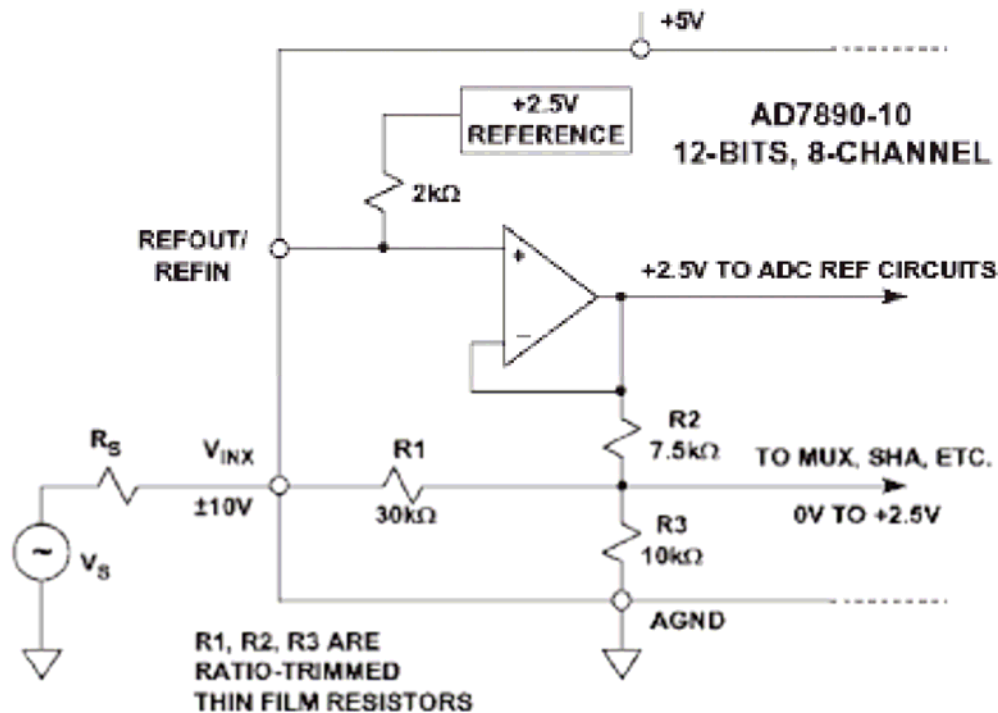
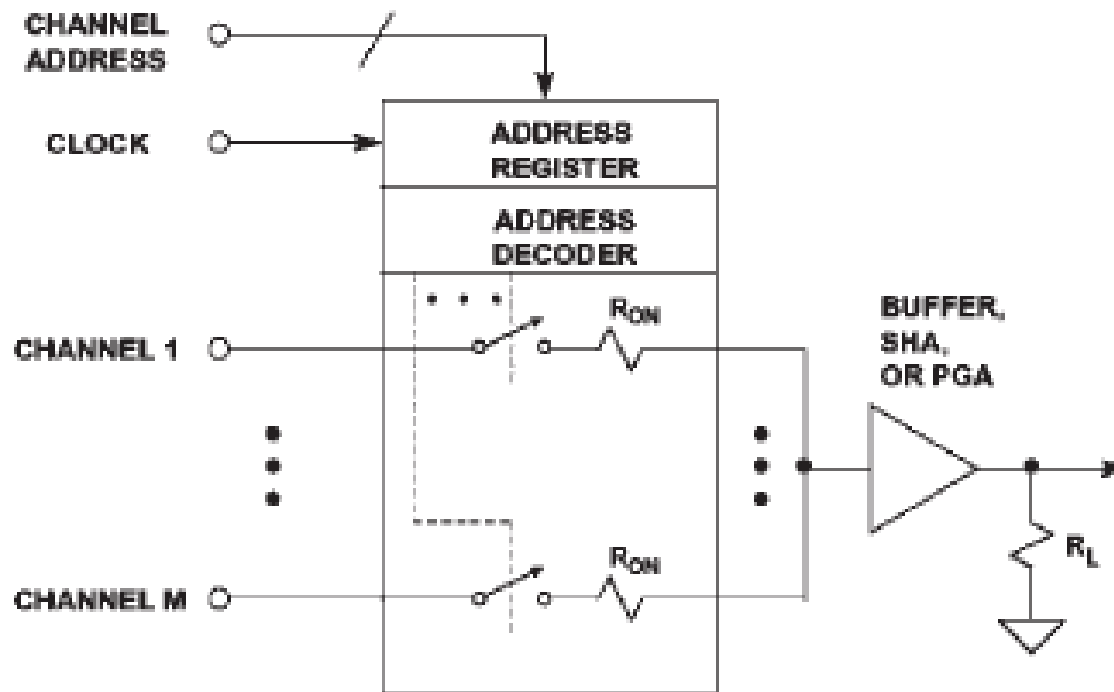
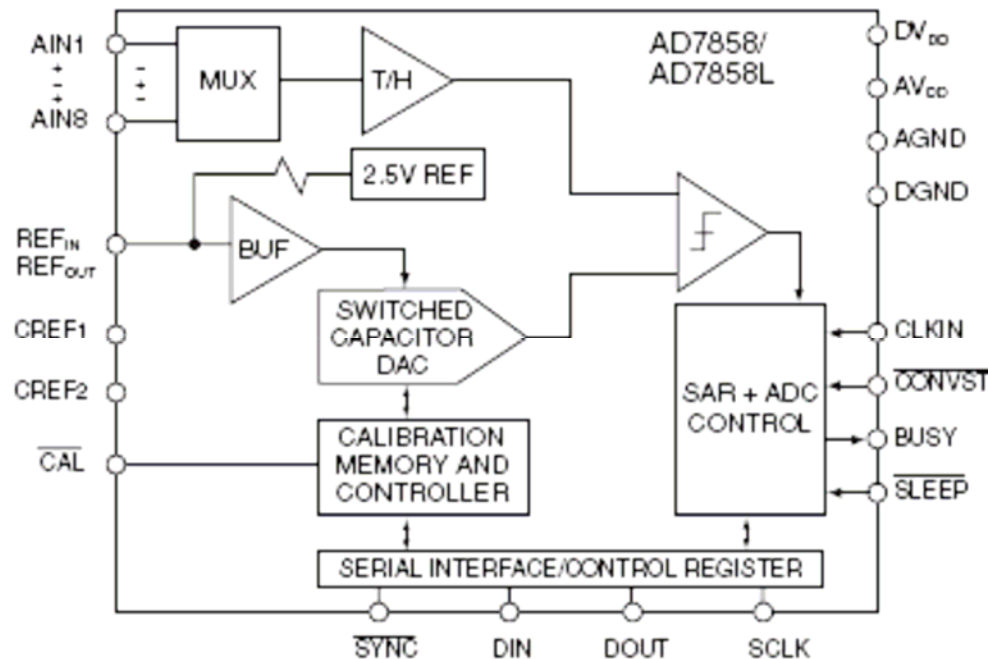


Figure 4.3.10: Driving single-supply ADCs with scaled inputs.

Conversor AD com multiplexe



Conversor AD- Mux comercial



*Figure 4.3.13: AD7858
12-bit, 200 kSPS 8-channel
single-supply ADC.*

Conversor AD Sigma-Delta

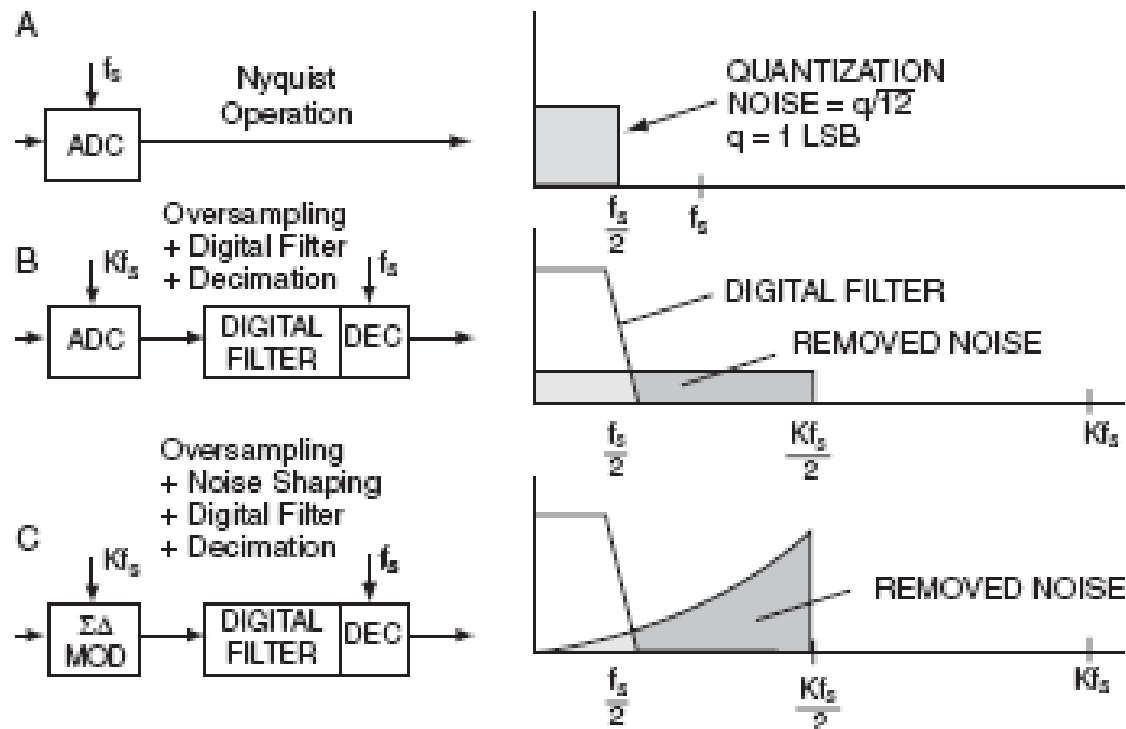
Sigma-Delta ($\Sigma\Delta$) Measurement ADCs

Sigma-delta analog-digital converters ($\Sigma\Delta$ ADCs) have been known for nearly thirty years, but only recently has the technology (high-density digital VLSI) existed to manufacture them as inexpensive monolithic integrated circuits. They are now used in many applications where a low-cost, low-bandwidth, low-power, high-resolution ADC is required.

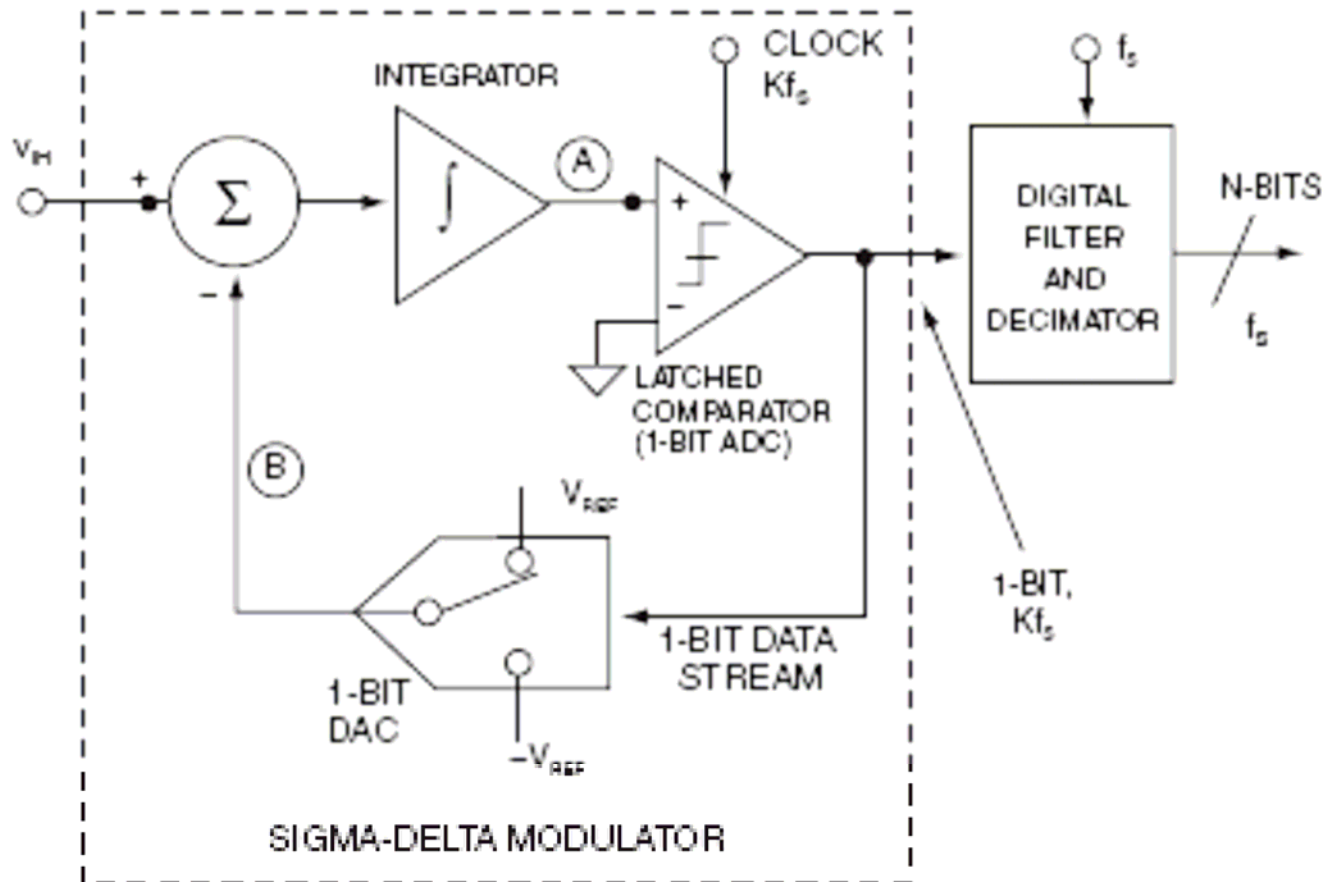
Conversor AD Sigma-Delta

- Low Cost, High Resolution (to 24-bits) Excellent DNL,
- Low Power, but Limited Bandwidth
- Key Concepts are Simple, but Math is Complex
 - ◆ Oversampling
 - ◆ Quantization Noise Shaping
 - ◆ Digital Filtering
 - ◆ Decimation
- Ideal for Sensor Signal Conditioning
 - ◆ High Resolution
 - ◆ Self, System, and Auto Calibration Modes

Comparação de conversores AD



Conversor AD Sigma-Delta



Sensores de alta impedância

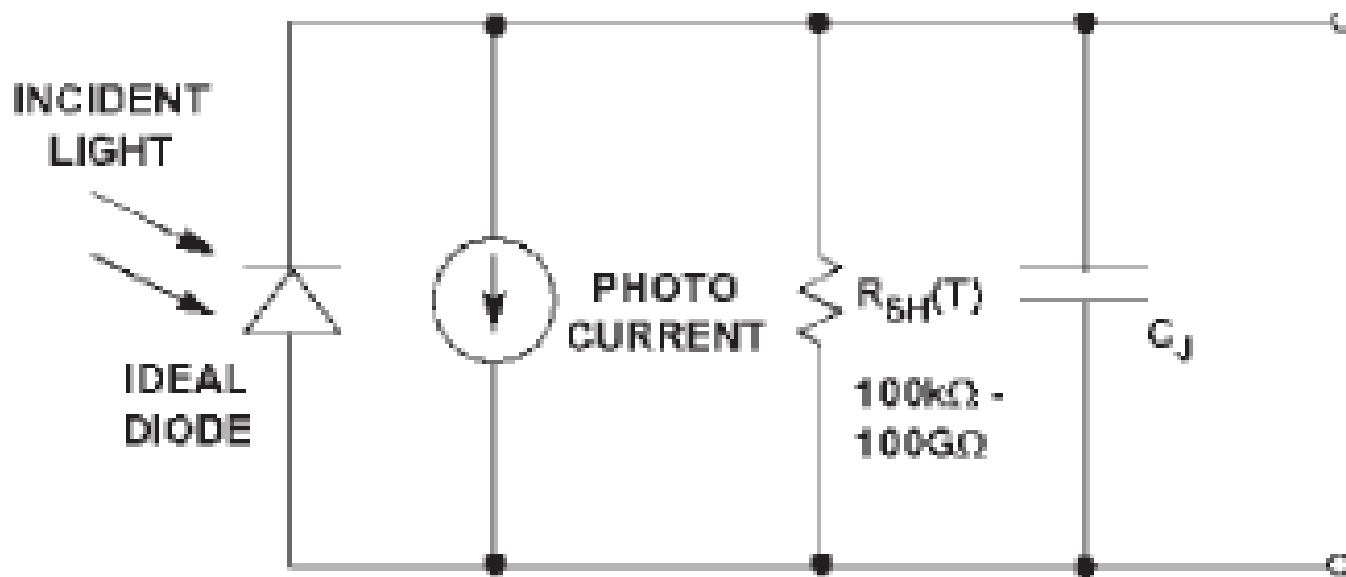
Sensores de Alta Impedância

- Photodiode Preamplifiers
- Piezoelectric Sensors
 - ◆ Accelerometers
 - ◆ Hydrophones
- Humidity Monitors
- pH Monitors
- Chemical Sensors
- Smoke Detectors
- Charge Coupled Devices and
Contact Image Sensors for Imaging

Aplicações de Fotodiodos

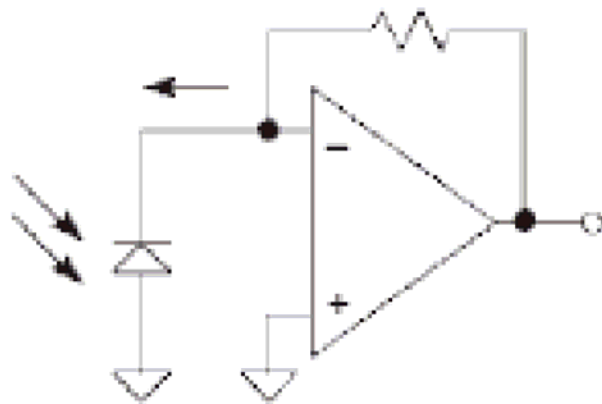
- Optical: Light Meters, Auto-Focus, Flash Controls
- Medical: CAT Scanners (X-Ray Detection), Blood Particle Analyzers
- Automotive: Headlight Dimmers, Twilight Detectors
- Communications: Fiber Optic Receivers
- Industrial: Bar Code Scanners, Position Sensors, Laser Printers

Circuito equivalente dos fotodiodos



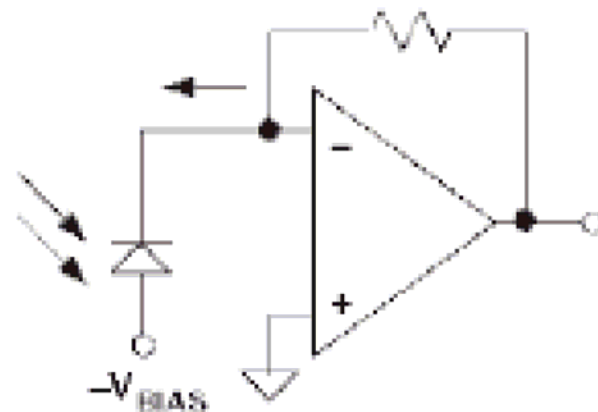
NOTE: R_{SH} HALVES EVERY 10°C TEMPERATURE RISE

Operação dos fotodiodos



PHOTOVOLTAIC

- Zero Bias
- No "Dark" Current
- Linear
- Low Noise (Johnson)
- Precision Applications



PHOTOCONDUCTIVE

- Reverse Bias
- Has "Dark" Current
- Nonlinear
- Higher Noise (Johnson + Shot)
- High Speed Applications

Características dos fotodiodos

ENVIRONMENT	ILLUMINATION (fc)	SHORT CIRCUIT CURRENT
Direct Sunlight	1000	30 μ A
Overcast Day	100	3 μ A
Twilight	1	0.03 μ A
Full Moonlit Night	0.1	3000pA
Clear Night / No Moon	0.001	30pA

Conversor para fotodiodo

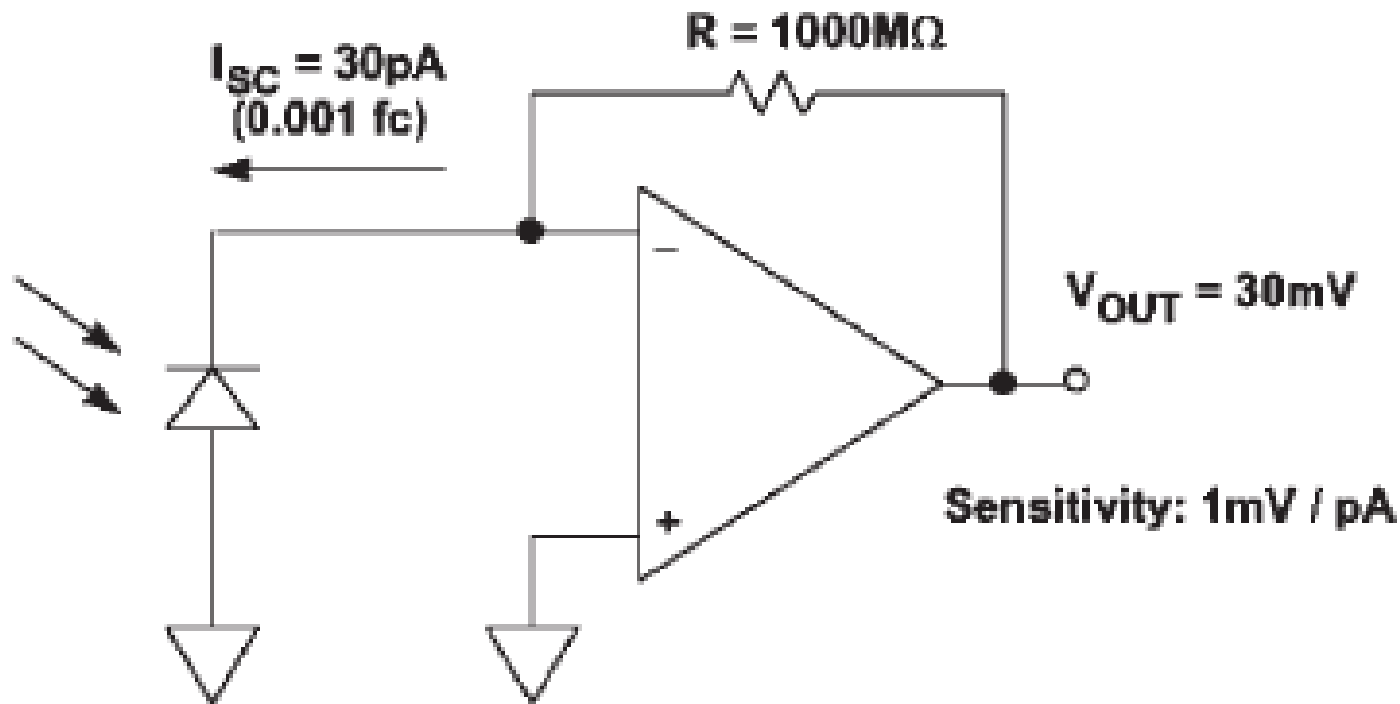
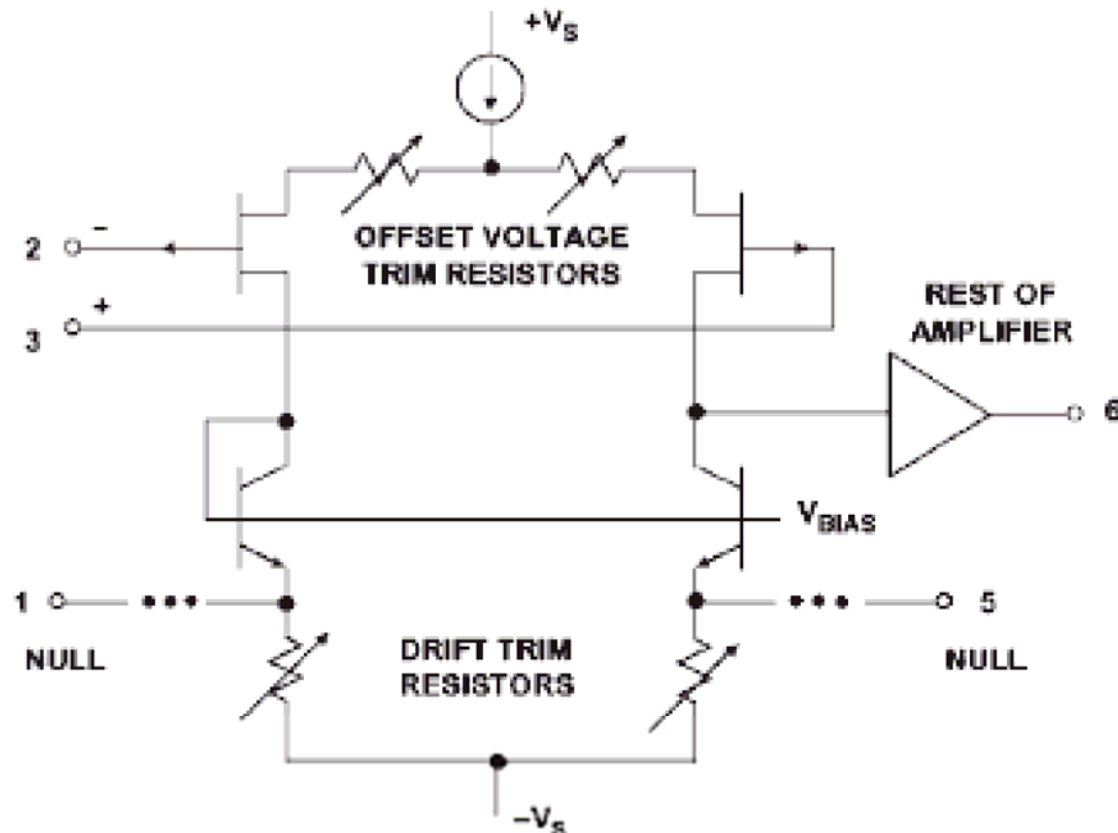


Figure 4.4.7: Current-to-voltage converter (simplified).

Estágio de pré-amplificação



Circuito comercial de pre-amplificação

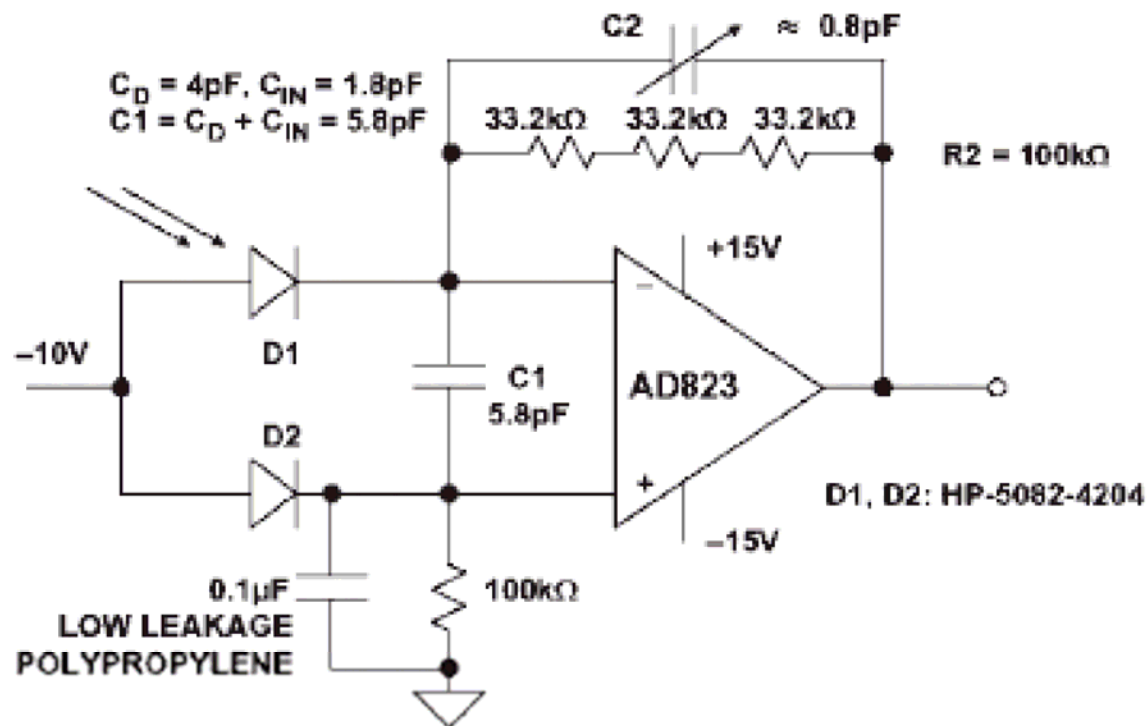
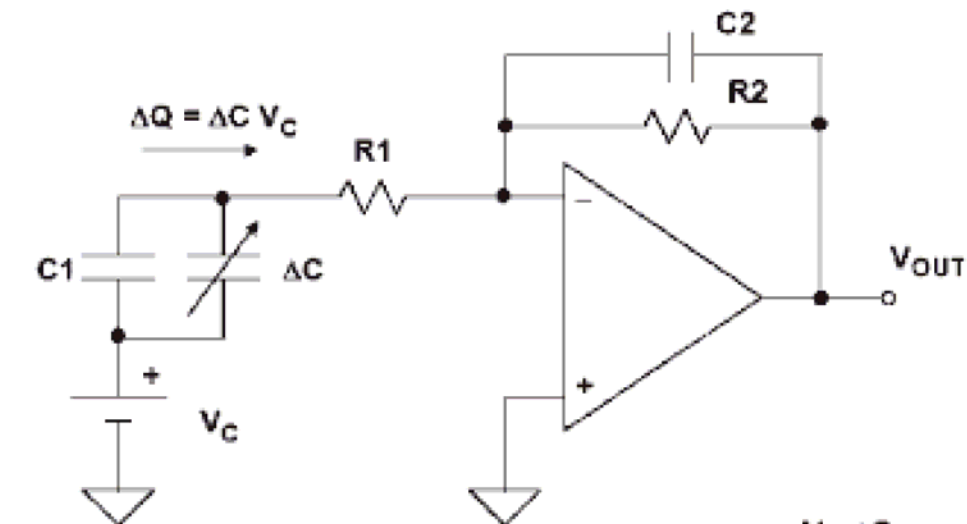


Figure 4.4.27: 2 MHz bandwidth photodiode preamp with dark current compensation.

Sensores capacitivos

Amplificador para sensores capacitivos



- FOR CAPACITIVE SENSORS: $\Delta V_{OUT} = \frac{-V_C \Delta C}{C2}$
- FOR CHARGE-EMITTING SENSORS: $\Delta V_{OUT} = \frac{-\Delta Q}{C2}$
- UPPER CUTOFF FREQUENCY = $f_2 = \frac{1}{2\pi R2 C2}$
- LOWER CUTOFF FREQUENCY = $f_1 = \frac{1}{2\pi R1 C1}$

Compensação de ruídos em sensores capacitivos

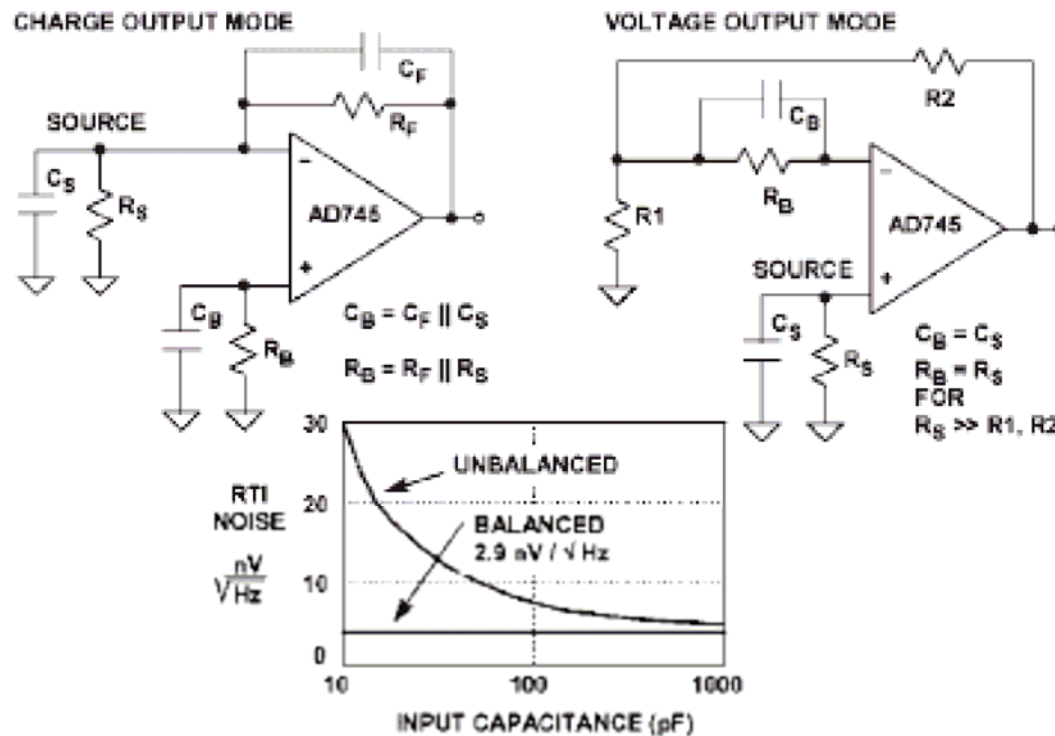
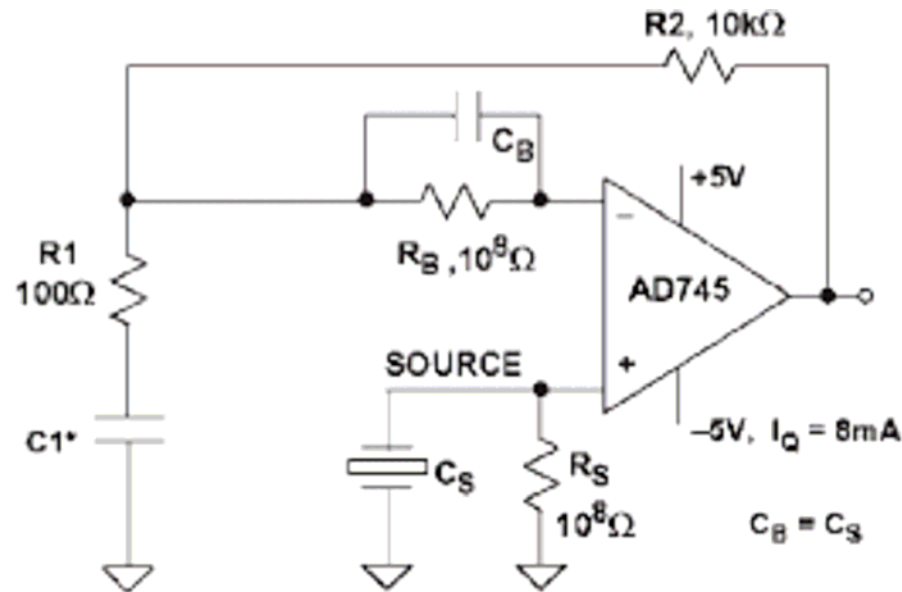


Figure 4.4.30: Balancing source impedances minimizes effects of bias currents and reduces input noise.

Sensores piezoelétricos

Amplificadores para sensores piezoeléctricos



- $\pm 5\text{V}$ Power Supplies Reduce I_B for 0°C to $+85^\circ\text{C}$ Operation, $P_D = 80\text{mW}$
- C_1 Allows -55°C to $+125^\circ\text{C}$ Operation

Sensor de PH

Amplificador para sensor de PH

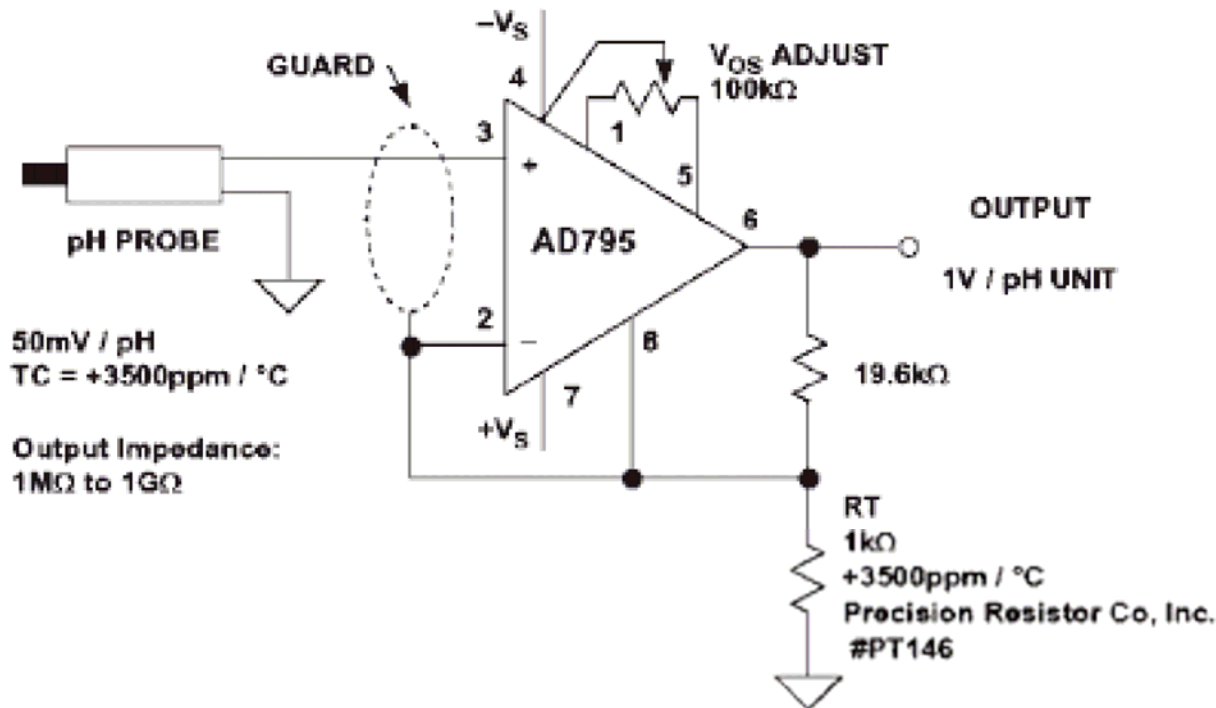


Figure 4.4.33: A pH probe buffer amplifier with a gain of 20 using the AD795 precision BiFET op amp.

Sensores de imagem

Sistema para imagens

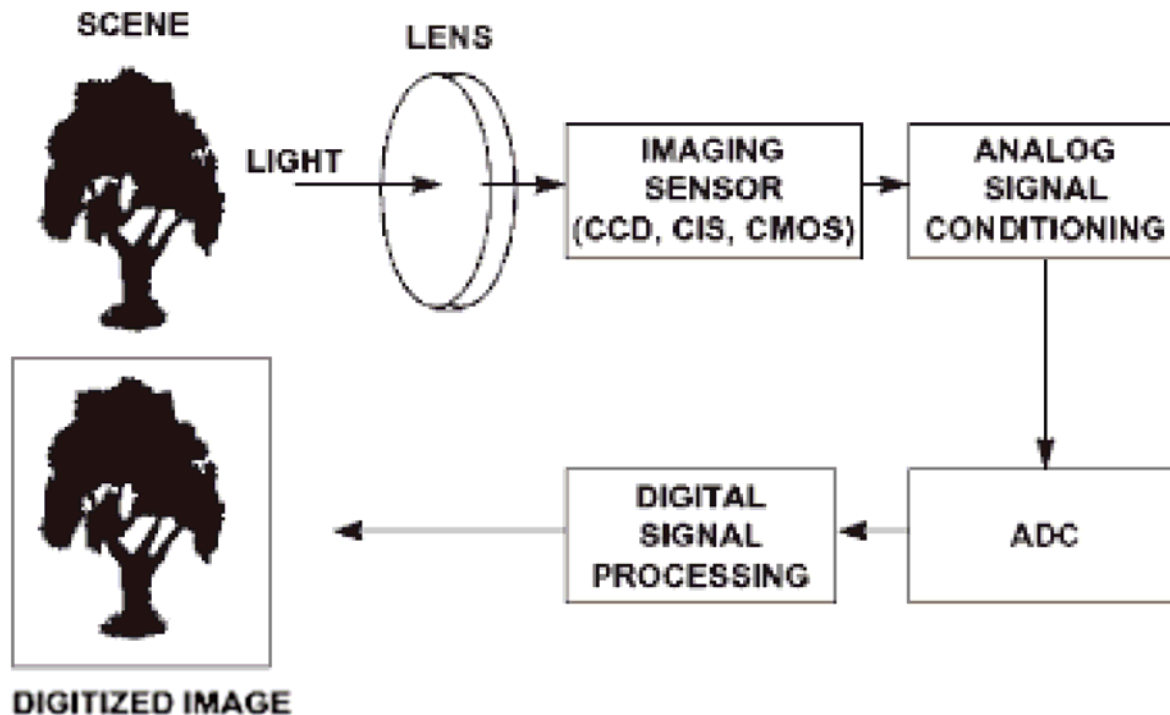
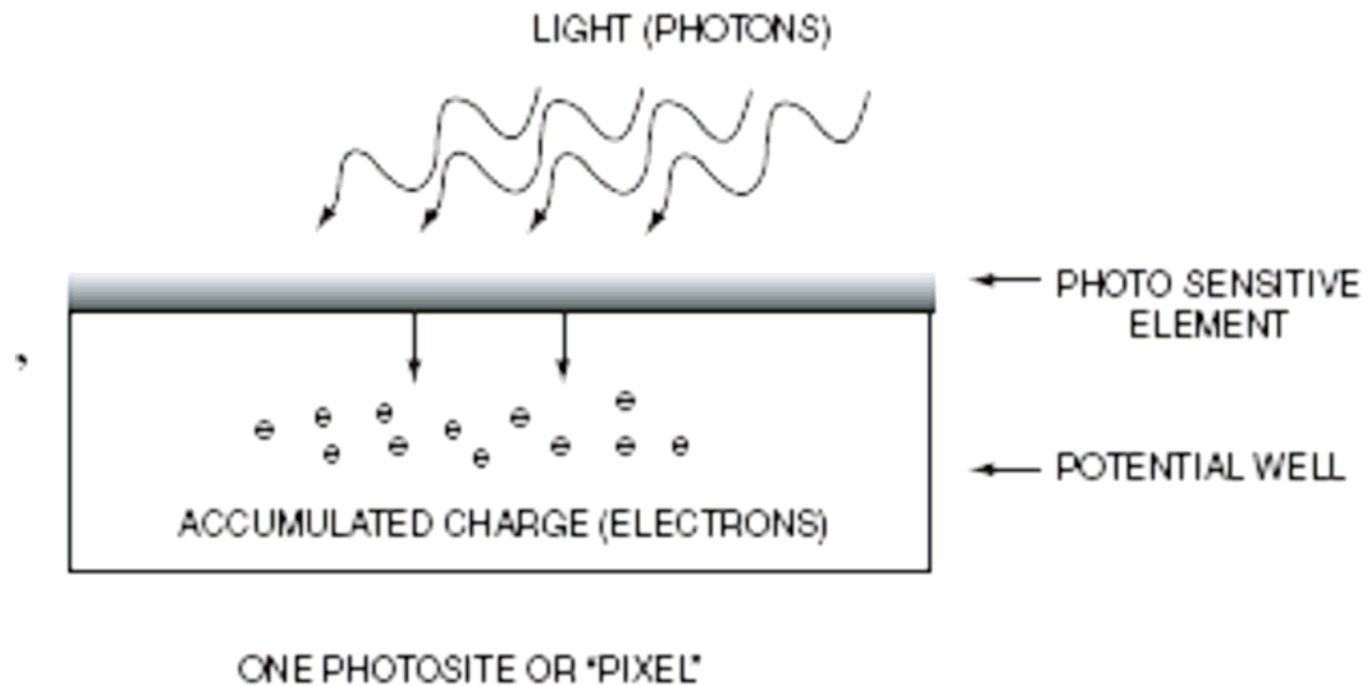
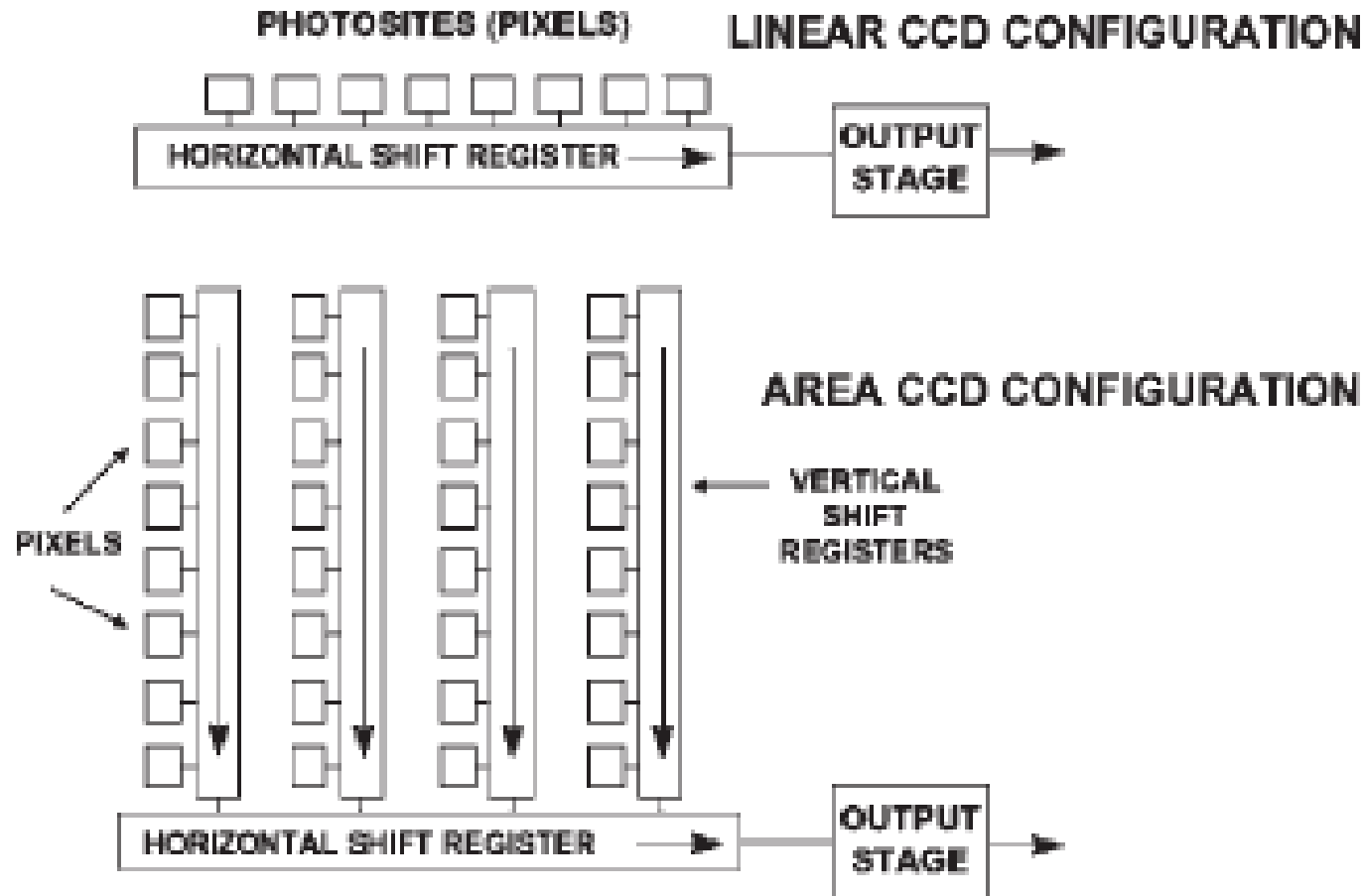


Figure 4.4.34: Generic imaging system for scanners or digital cameras.

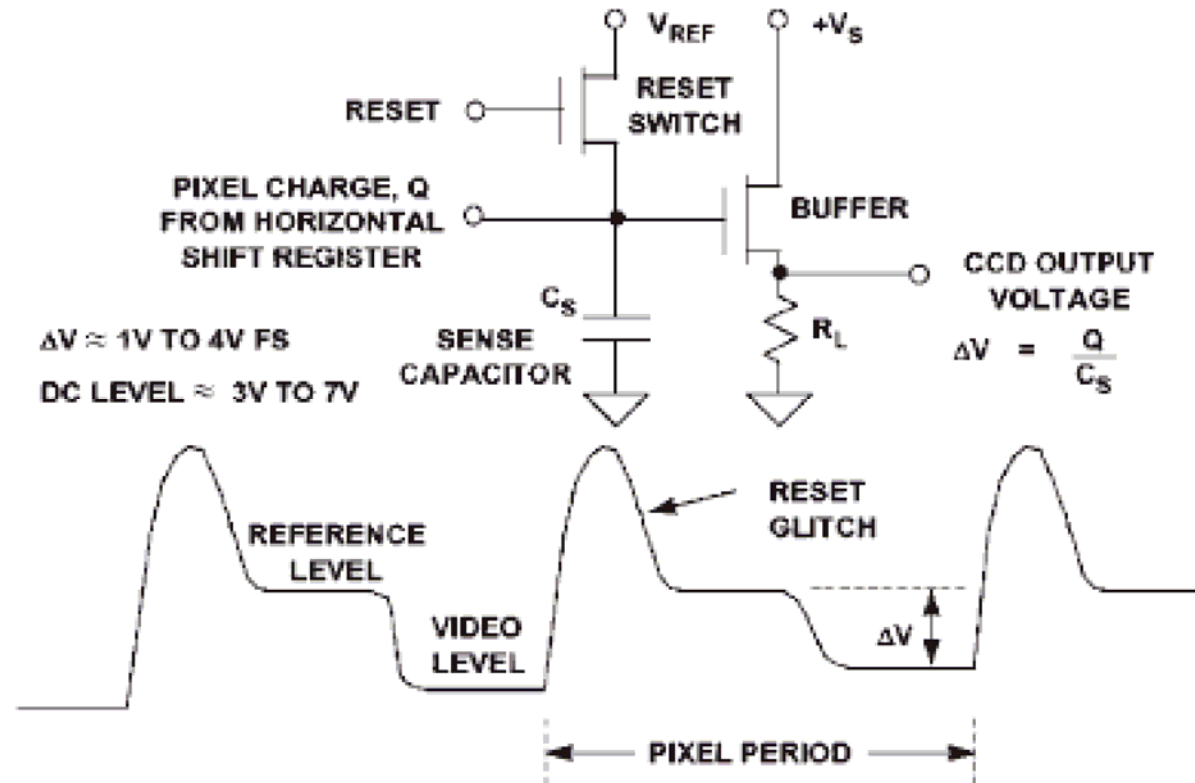
CCD



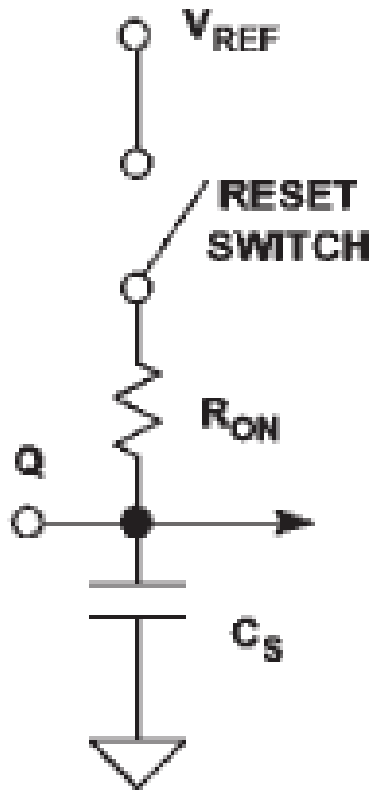
CCD Arrays



Estágio de saída de CCDs



Ruídos em CCDs



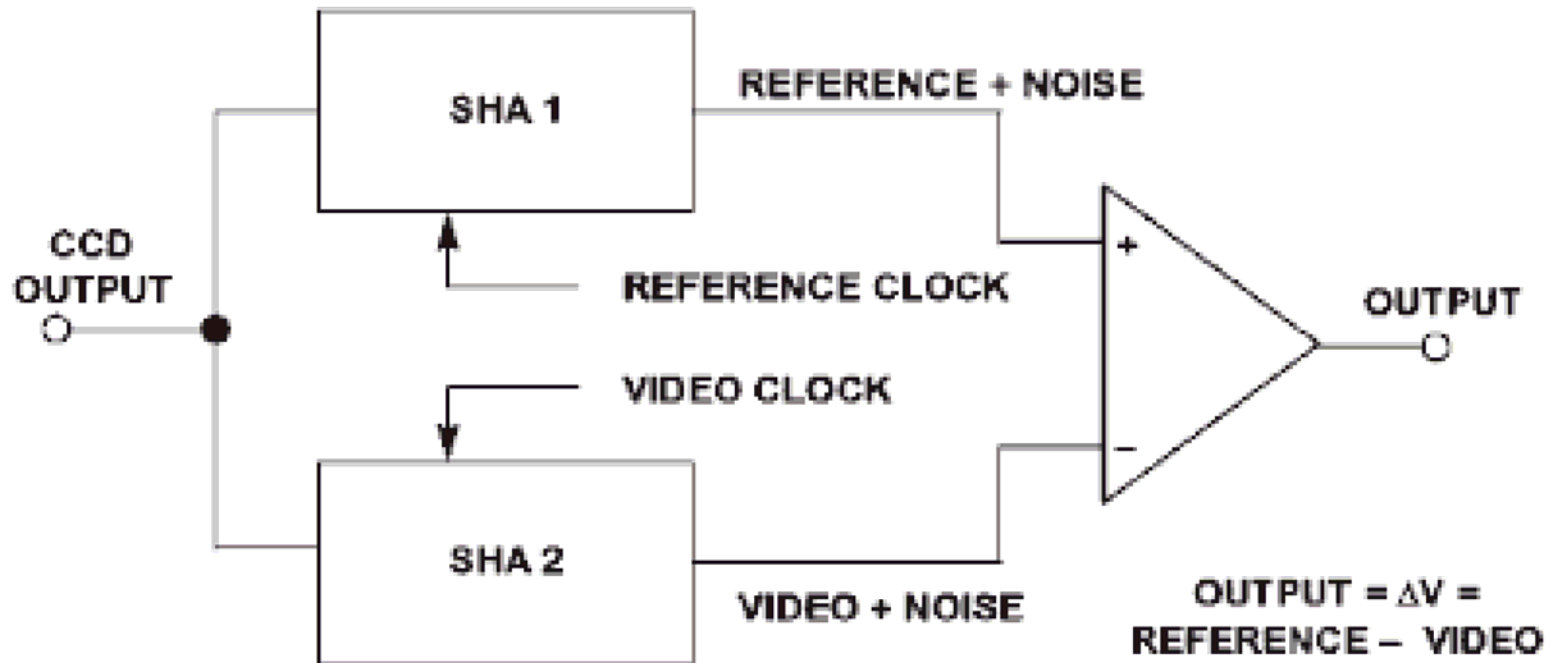
$$\text{THERMAL NOISE} = \sqrt{4kT \cdot BW \cdot R_{ON}}$$

$$\text{NOISE BW} = \frac{\pi}{2} \left[\frac{1}{2\pi R_{ON} C_S} \right] = \frac{1}{4 R_{ON} C_S}$$

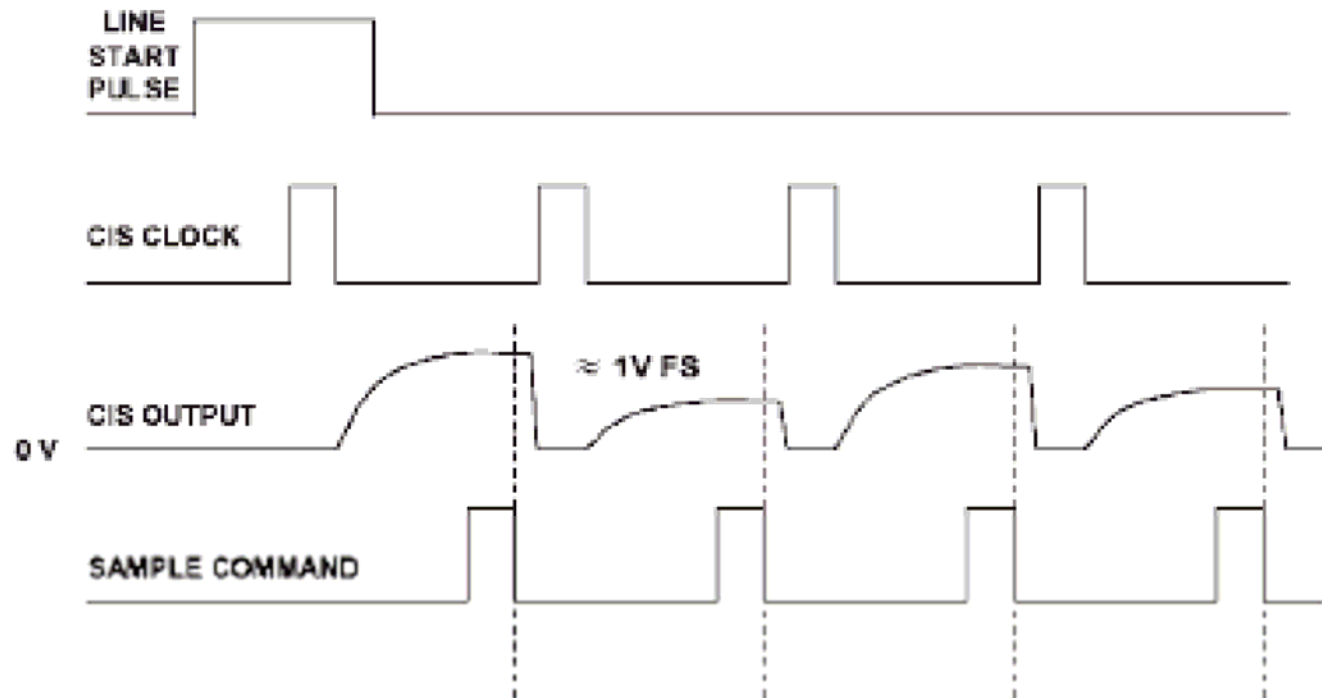
$$\text{THERMAL NOISE} = \sqrt{\frac{kT}{C_S}}$$

**SAME VALUE PRESENT DURING
REFERENCE AND VIDEO LEVELS
WHILE RESET SWITCH IS OPEN**

Amplificação por redundâncias



Sistema de Chaveamento em CCDs



Circuito comercial para controle de CCDs

