Endüstriyel Otomatik Kontrol Sistemleri
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Dersin Konusu: Endüstriyel Otomatik Kontrol Sistemlerinde Kullanılan Algılayıcılar, Dönüştürücüler ve Uygulamaları

Dersin Amacı:
Endüstriyel otomatik kontrol sistemlerinde kullanılan algılayıcılar ve dönüştürücülerin özellikleri, iç donanımı ve elektronik devrelerinin incelenmesi, uygulama devrelerinin analizi, incelenmesi ve tasarlanmasının öğretilmesidir.

2.Endüstriyel Otomatik Kontrol Sistemlerinde Kullanılan Algılayıcılar (sensors), Dönüştürücüler (transducers) ve Uygulamaları

- 2.1. Algılayıcı seçiminde kullanılan ölçütler
  - 2.1.1. Duyarlılık
  - 2.1.2. Doğrusallık
  - 2.1.3. Sınırlar
  - 2.1.4. Yanıt süresi
  - 2.1.5. Doğruluk
  - 2.1.6. Tekrarlanabilirlik
  - 2.1.7. Ayırıcılık
  - 2.1.8. Çıkışın tipi
- 2.2. Dönüştürücülerin fiziksel karakteristikleri
  - 2.2.1. Büyüklük ve ağırlık
  - 2.2.2. Güvenirlik
  - 2.2.3. Arabirim
- 2.3. Dönüştürücülerin gruplanması
    - 2.3.1.1. Aktif/Pasif dönüştürücüler
    - 2.3.1.2. Temaslı/Temassız dönüştürücüler
  - 2.3.2. Temaslı dönüştürücüler

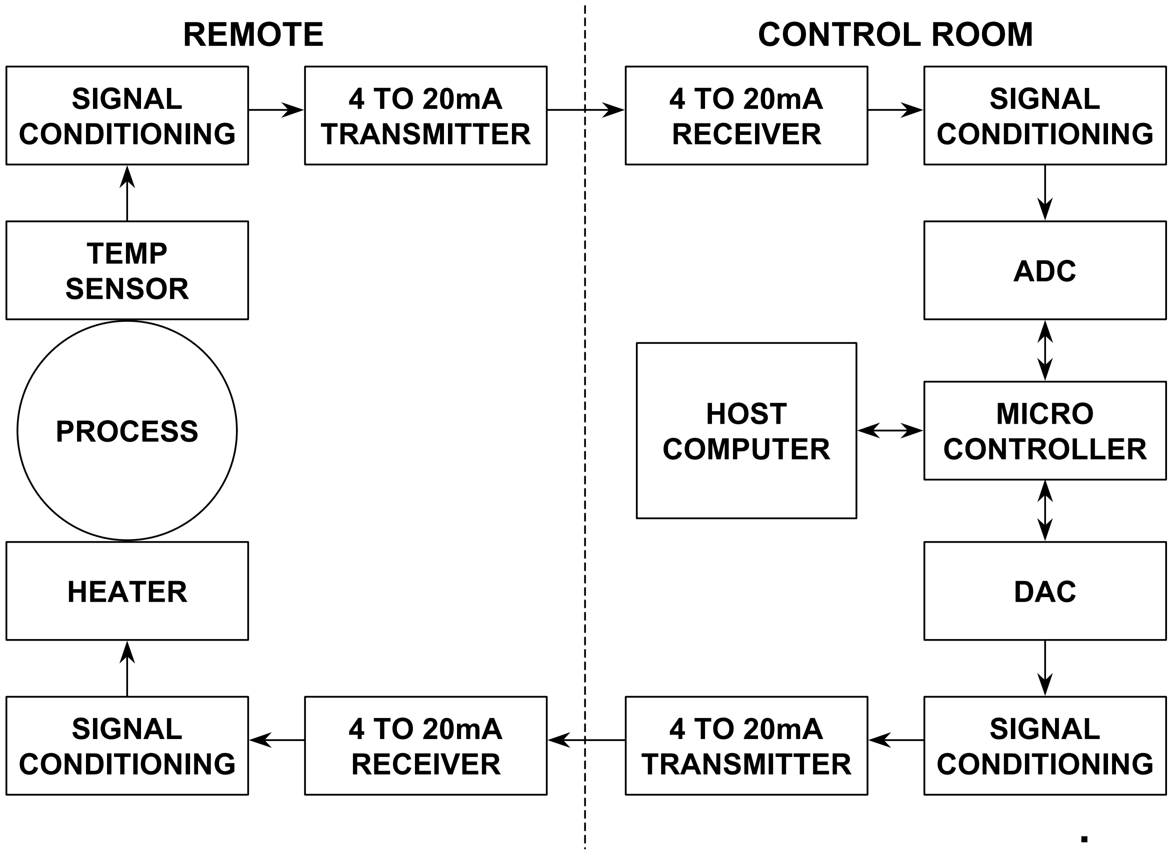
SENSOR OVERVIEW

- **Sensors:**
  Convert a Signal or Stimulus (Representing a Physical Property) into an Electrical Output
- **Transducers:**
  Convert One Type of Energy into Another
- **The Terms are often Interchanged**
- ***Active* Sensors Require an External Source of Excitation:**
  RTDs, Strain-Gages
- ***Passive* (Self-Generating) Sensors do not:**
  Thermocouples, Photodiodes

TYPICAL SENSORS AND THEIR OUTPUTS

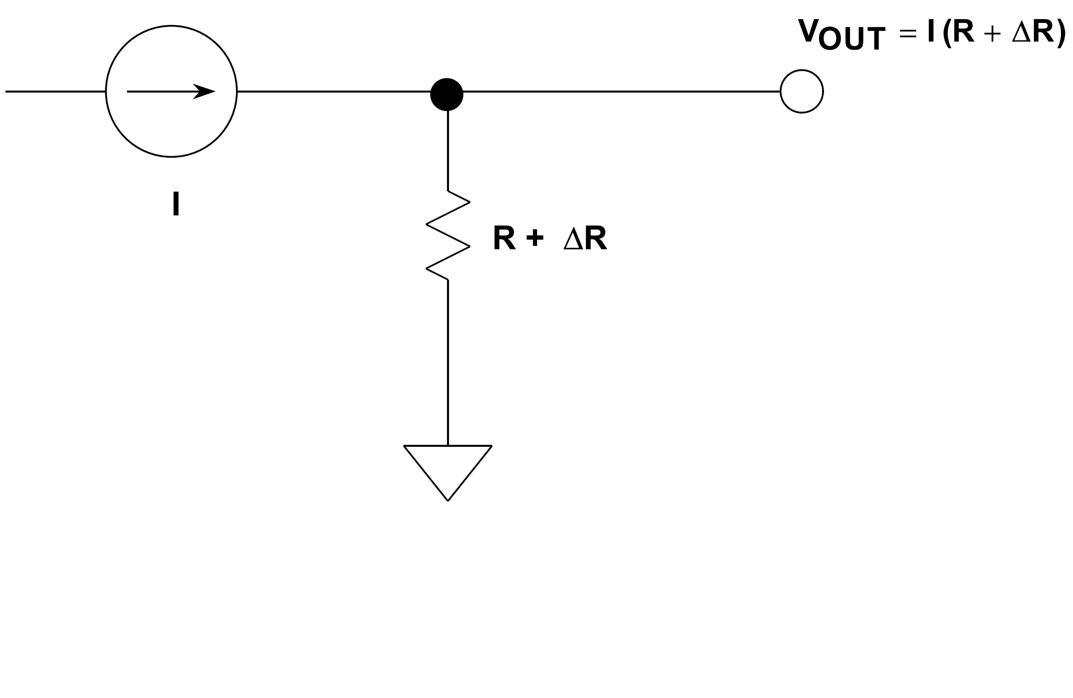
PROPERTY	SENSOR	ACTIVE/ PASSIVE	OUTPUT
Temperature	Thermocouple	Passive	Voltage
	Silicon	Active	Voltage/Current
	RTD	Active	Resistance
	Thermistor	Active	Resistance
Force / Pressure	Strain Gage	Active	Resistance
	Piezoelectric	Passive	Voltage
Acceleration	Accelerometer	Active	Capacitance
Position	LVDT	Active	AC Voltage
Light Intensity	Photodiode	Passive	Current

TYPICAL INDUSTRIAL PROCESS CONTROL LOOP

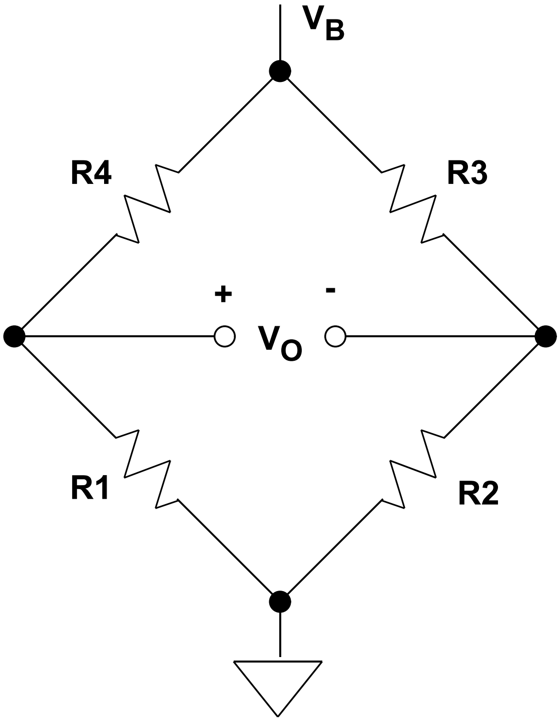


RESISTANCE OF POPULAR SENSORS

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



THE WHEATSTONE BRIDGE



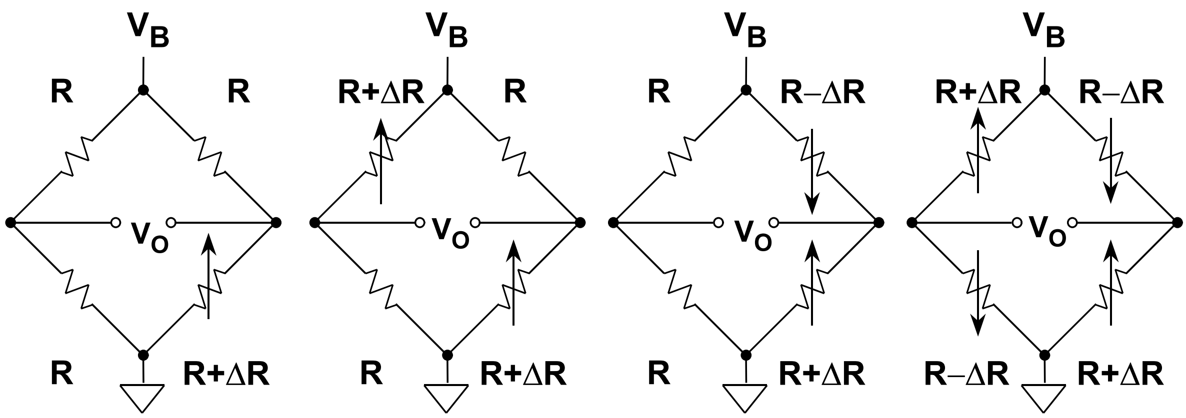
$$V_O = \frac{R1}{R1+R4}V_B - \frac{R2}{R2+R3}V_B$$

$$= \frac{\frac{R1}{R4} - \frac{R2}{R3}}{\left(1+\frac{R1}{R4}\right)\left(1+\frac{R2}{R3}\right)}V_B$$

AT BALANCE,

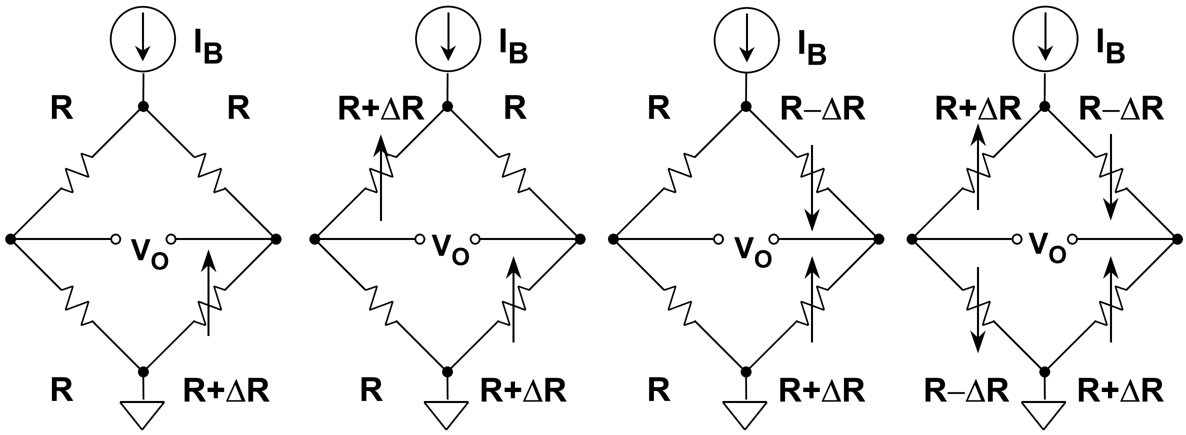
$$V_O = 0 \quad \text{IF} \quad \frac{R1}{R4} = \frac{R2}{R3}$$

OUTPUT VOLTAGE AND LINEARITY ERROR FOR CONSTANT VOLTAGE DRIVE BRIDGE CONFIGURATIONS



	(A) Single-Element Varying	(B) Two-Element Varying (1)	(C) Two-Element Varying (2)	(D) All-Element Varying
V_O:	$\frac{V_B}{4}\left[\frac{\Delta R}{R + \frac{\Delta R}{2}}\right]$	$\frac{V_B}{2}\left[\frac{\Delta R}{R + \frac{\Delta R}{2}}\right]$	$\frac{V_B}{2}\left[\frac{\Delta R}{R}\right]$	$V_B\left[\frac{\Delta R}{R}\right]$
Linearity Error:	0.5%/%	0.5%/%	0	0

OUTPUT VOLTAGE AND LINEARITY ERROR FOR CONSTANT CURRENT DRIVE BRIDGE CONFIGURATIONS

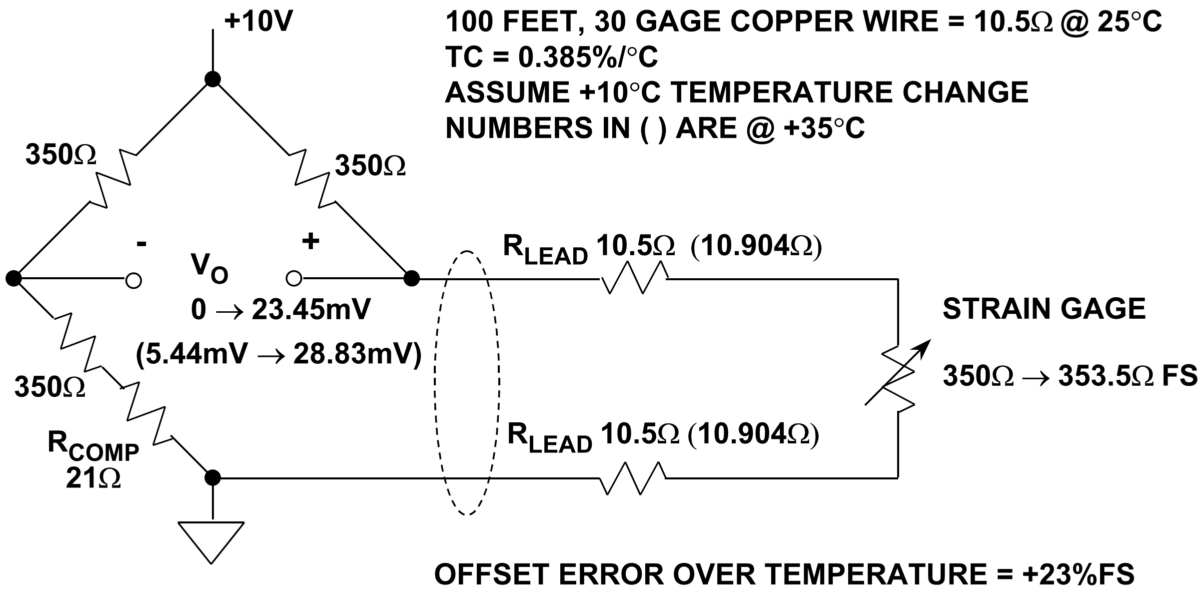


	(A)	(B)	(C)	(D)
V_O:	$\frac{I_B R}{4}\left[\frac{\Delta R}{R + \frac{\Delta R}{4}}\right]$	$\frac{I_B}{2}\left[\Delta R\right]$	$\frac{I_B}{2}\left[\Delta R\right]$	$I_B\left[\Delta R\right]$
Linearity Error:	0.25%/%	0	0	0
	(A) Single-Element Varying	(B) Two-Element Varying (1)	(C) Two-Element Varying (2)	(D) All-Element Varying

BRIDGE CONSIDERATIONS

- **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**

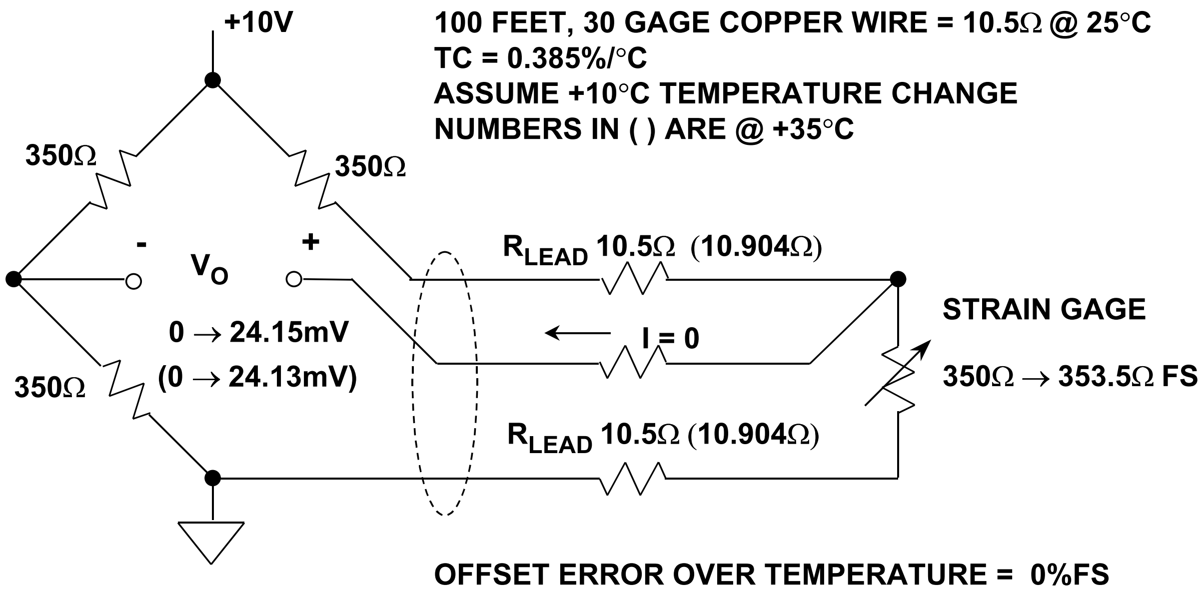
ERRORS PRODUCED BY WIRING RESISTANCE FOR REMOTE RESISTIVE BRIDGE SENSOR



OFFSET ERROR OVER TEMPERATURE = +23%FS

GAIN ERROR OVER TEMPERATURE = –0.26%FS

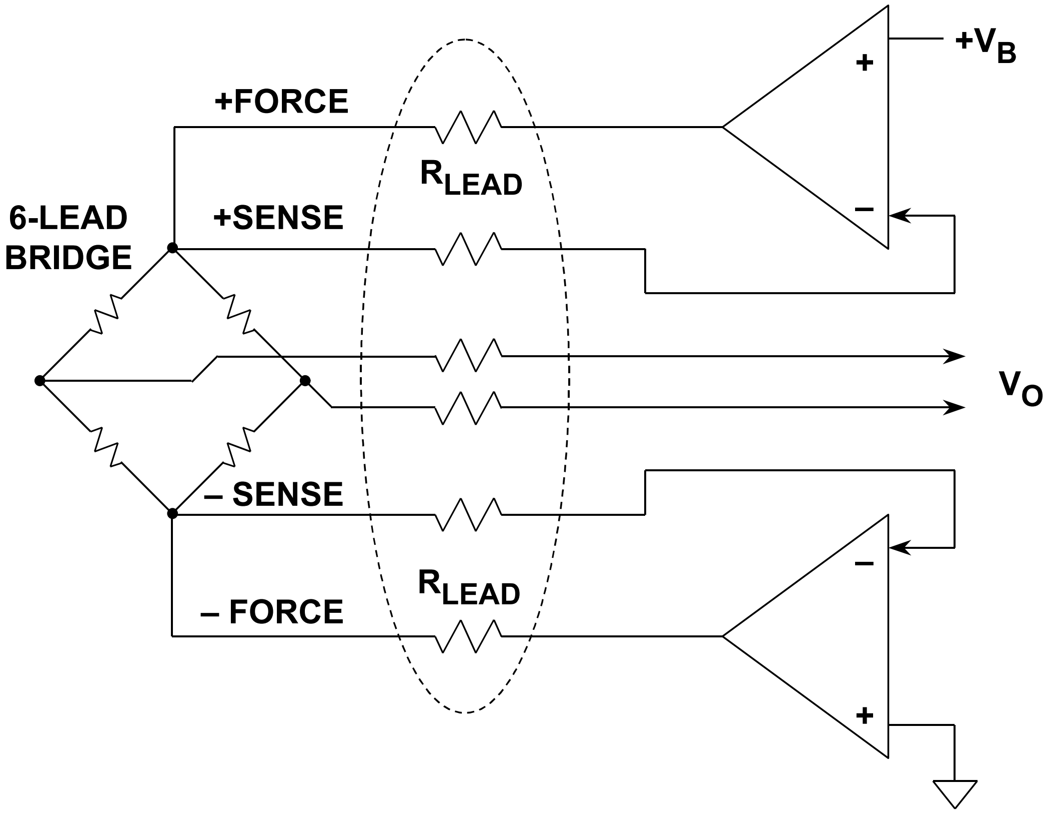
3-WIRE CONNECTION TO REMOTE BRIDGE ELEMENT (SINGLE-ELEMENT VARYING)



OFFSET ERROR OVER TEMPERATURE = 0%FS

GAIN ERROR OVER TEMPERATURE = –0.08%FS

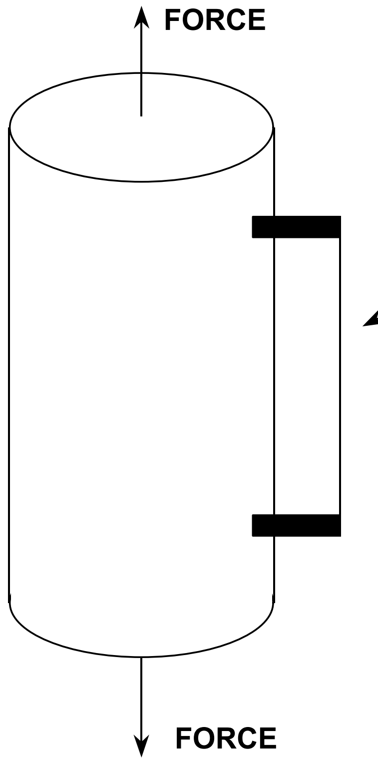
KELVIN (4-WIRE) SENSING MINIMIZES ERRORS DUE TO LEAD RESISTANCE



STRAIN GAGE BASED MEASUREMENTS

- **Strain:** **Strain Gage, PiezoElectric Transducers**
- **Force:** **Load Cell**
- **Pressure:** **Diaphragm to Force to Strain Gage**
- **Flow:** **Differential Pressure Techniques**

UNBONDED WIRE STRAIN GAGE



STRAIN
SENSING
WIRE

AREA = A
LENGTH = L
RESISTIVITY = ρ
RESISTANCE = R

$$R = \frac{\rho L}{A}$$

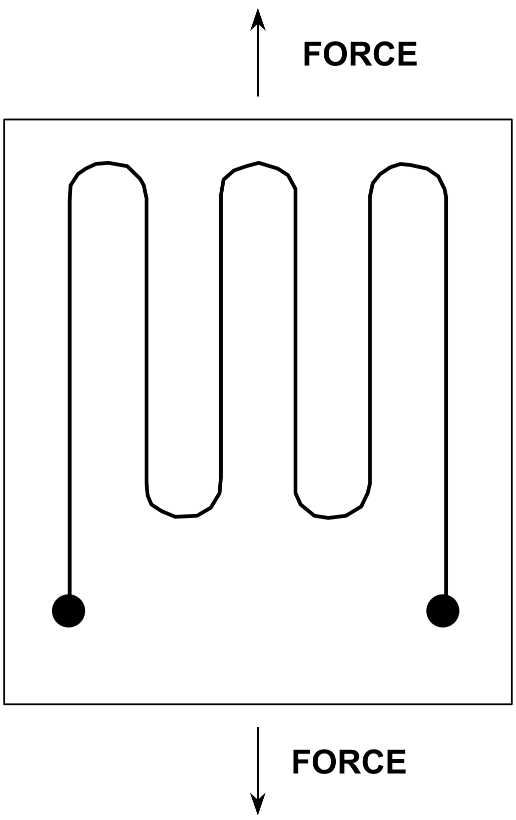
$$\frac{\Delta R}{R} = GF \cdot \frac{\Delta L}{L}$$

GF = GAGE FACTOR
2 TO 4.5 FOR METALS
>150 FOR SEMICONDUCTORS

$$\frac{\Delta L}{L} = \text{MICROSTRAINS } (\mu\varepsilon)$$

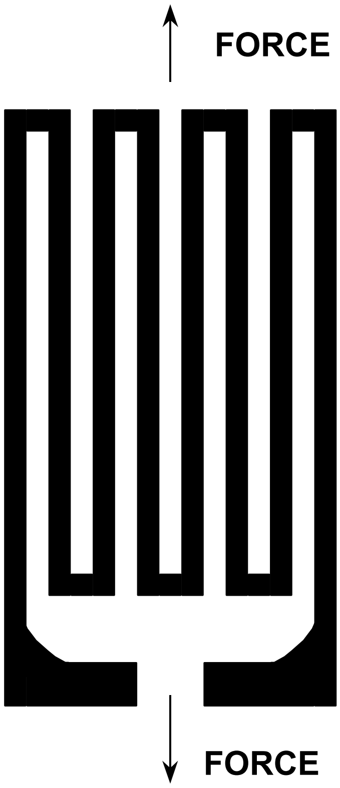
$$1\ \mu\varepsilon = 1\times10^{-6}\ \text{cm / cm} = 1\ \text{ppm}$$

BONDED WIRE STRAIN GAGE



- SMALL SURFACE AREA
- LOW LEAKAGE
- HIGH ISOLATION

METAL FOIL STRAIN GAGE

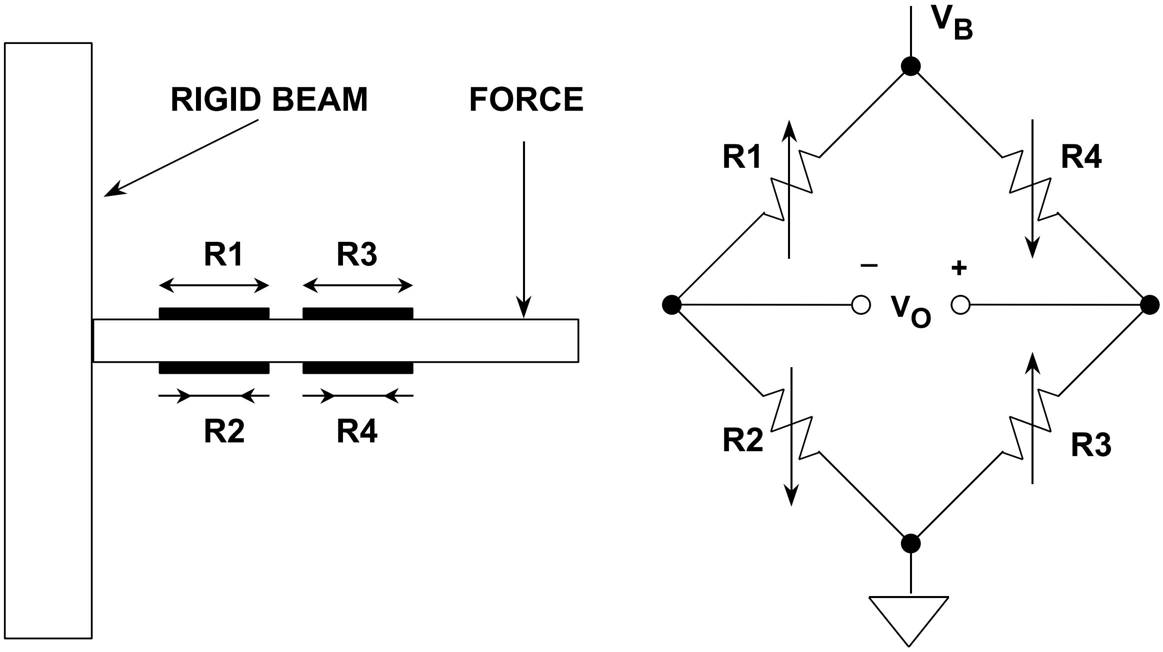


- PHOTO ETCHING TECHNIQUE
- LARGE AREA
- STABLE OVER TEMPERATURE
- THIN CROSS SECTION
- GOOD HEAT DISSIPATION

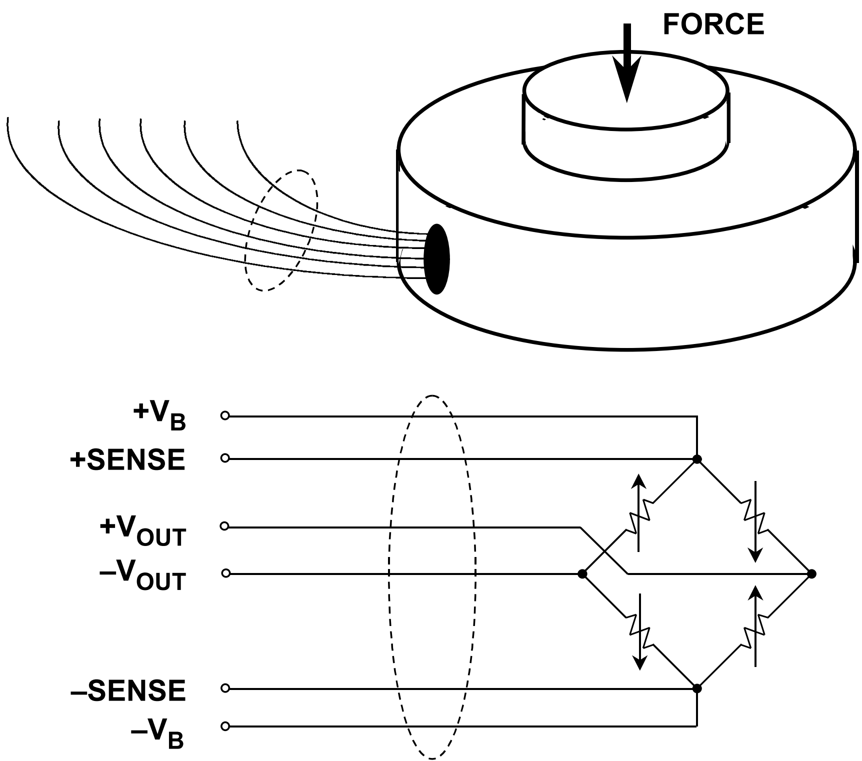
COMPARISON BETWEEN METAL AND SEMICONDUCTOR STRAIN GAGES

PARAMETER	METAL STRAIN GAGE	SEMICONDUCTOR STRAIN GAGE
Measurement Range	0.1 to 40,000 $\mu\varepsilon$	0.001 to 3000 $\mu\varepsilon$
Gage Factor	2.0 to 4.5	50 to 200
Resistance, Ω	120, 350, 600, …, 5000	1000 to 5000
Resistance Tolerance	0.1% to 0.2%	1% to 2%
Size, mm	0.4 to 150 Standard: 3 to 6	1 to 5

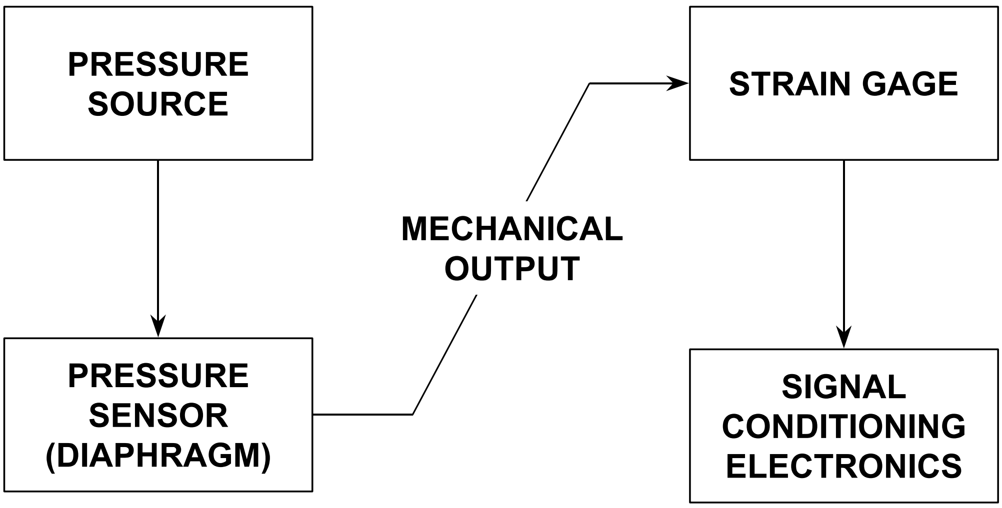
STRAIN GAGE BEAM FORCE SENSOR



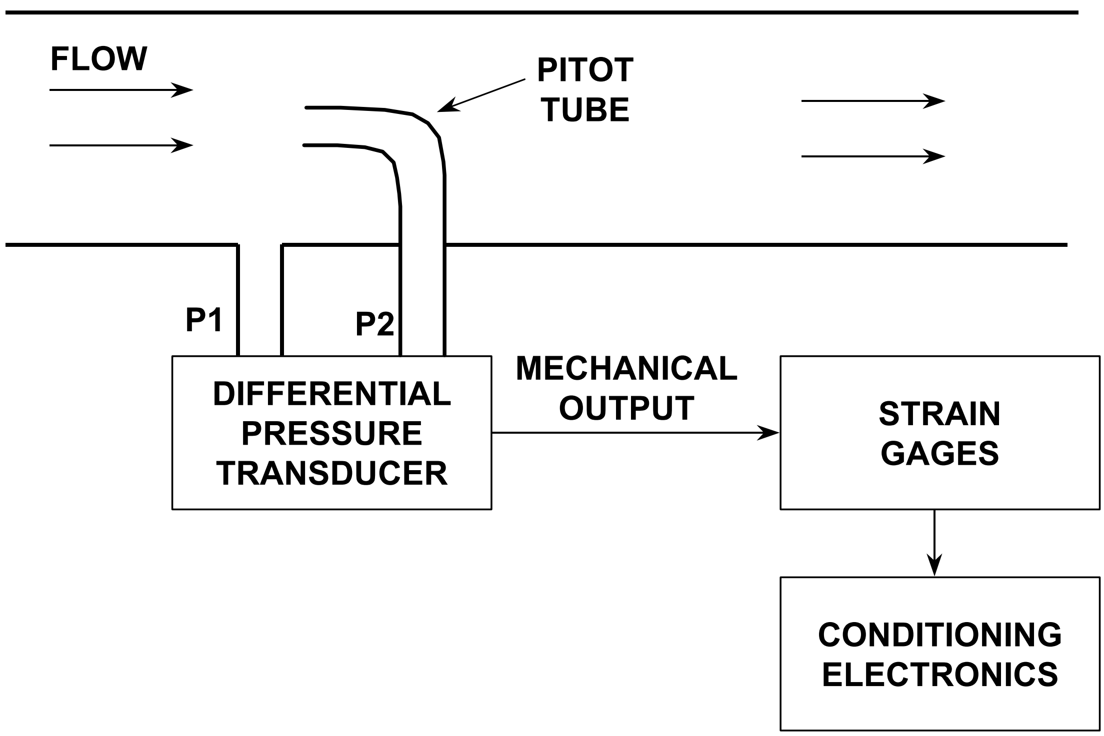
6-LEAD LOAD CELL



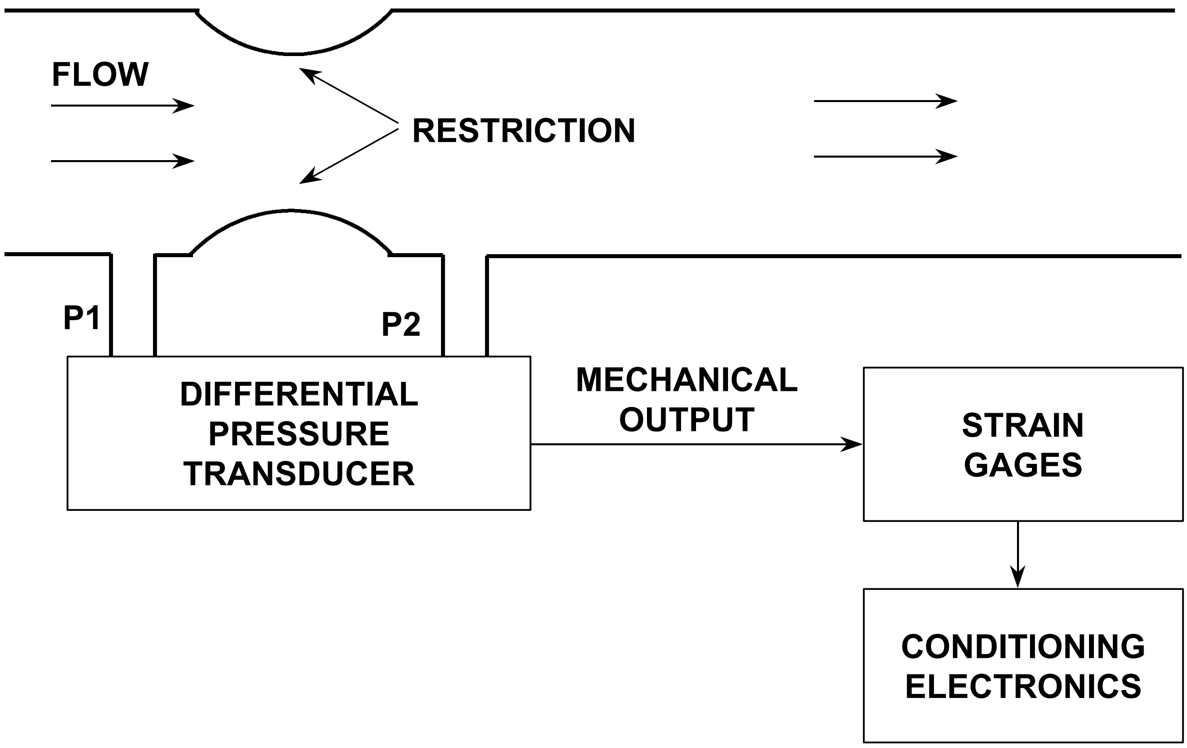
PRESSURE SENSORS



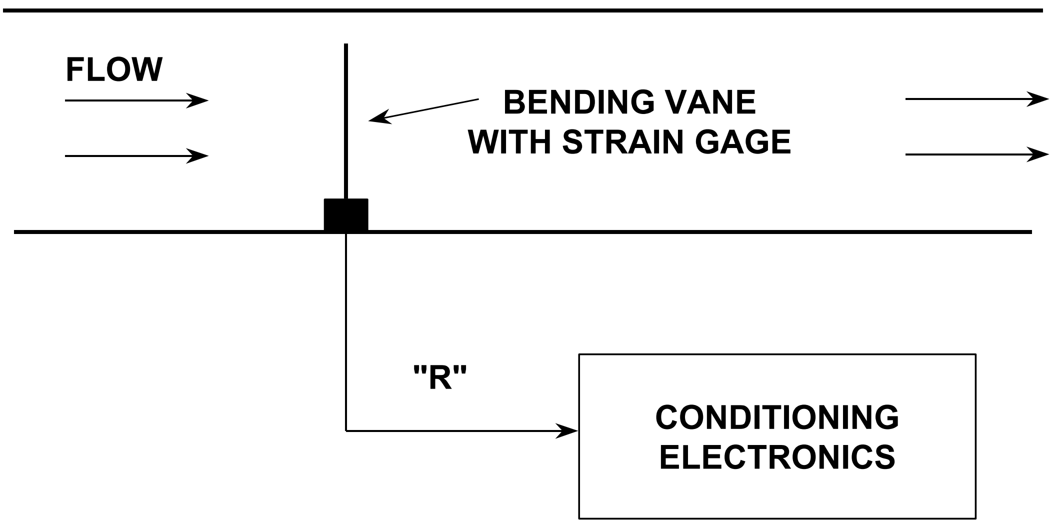
PITOT TUBE USED TO MEASURE FLOW RATE



MEASURING FLOW RATE USING THE VENTURI EFFECT



BENDING VANE WITH STRAIN GAGE USED TO MEASURE FLOW RATE



HIGH IMPEDANCE SENSORS

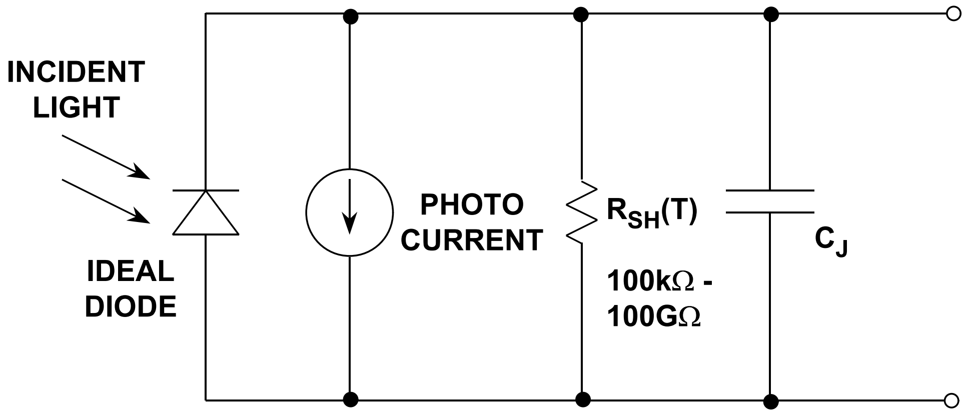
- Photodiode Preamplifiers
- Piezoelectric Sensors
  - Accelerometers
  - Hydrophones
- Humidity Monitors
- pH Monitors
- Chemical Sensors
- Smoke Detectors
- Charge Coupled Devices and

  Contact Image Sensors for Imaging

PHOTODIODE APPLICATIONS

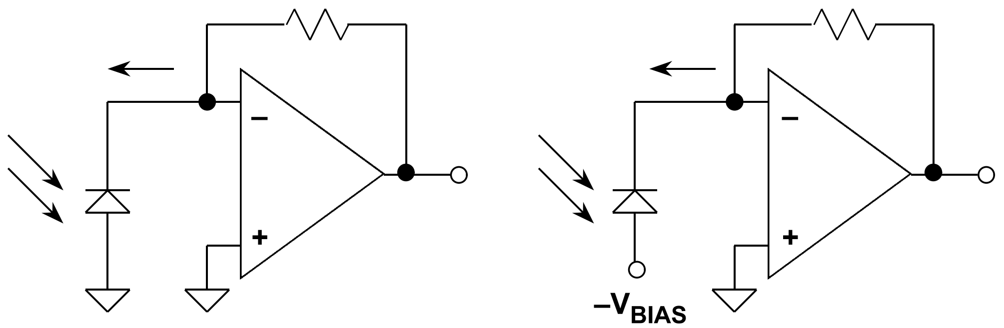
- Optical: Light Meters, Auto-Focus, Flash Controls
- Medical: CAT Scanners (X-Ray Detection), Blood Particle Analyzers
- Automotive: Headlight Dimmers, Twilight Detectors
- Communications: Fiber Optic Receivers
- Industrial: Bar Code Scanners, Position Sensors, Laser Printers

PHOTODIODE EQUIVALENT CIRCUIT



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

PHOTODIODE MODES OF OPERATION



PHOTOVOLTAIC	**PHOTOCONDUCTIVE**
■ Zero Bias	■ Reverse Bias
■ No "Dark" Current	■ Has "Dark" Current
■ Linear	■ Nonlinear
■ Low Noise (Johnson)	■ Higher Noise (Johnson + Shot)
■ Precision Applications	■ High Speed Applications

PHOTODIODE SPECIFICATIONS
Silicon Detector Part Number SD-020-12-001

- **Area: 0.2mm^2**
- **Capacitance: 50pF**
- **Shunt Resistance @ 25°C: 1000MΩ**
- **Maximum Linear Output Current: 40µA**
- **Response Time: 12ns**
- **Photosensitivity: 0.03µA / foot candle (fc)**

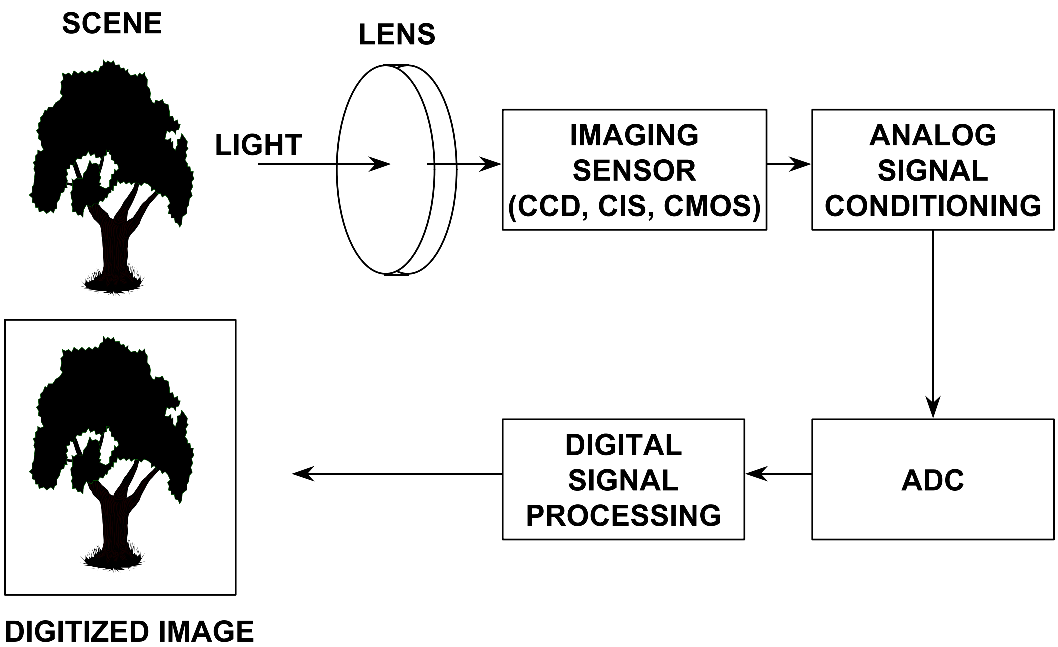
SHORT CIRCUIT CURRENT VERSUS LIGHT INTENSITY FOR PHOTODIODE (PHOTOVOLTAIC MODE)

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

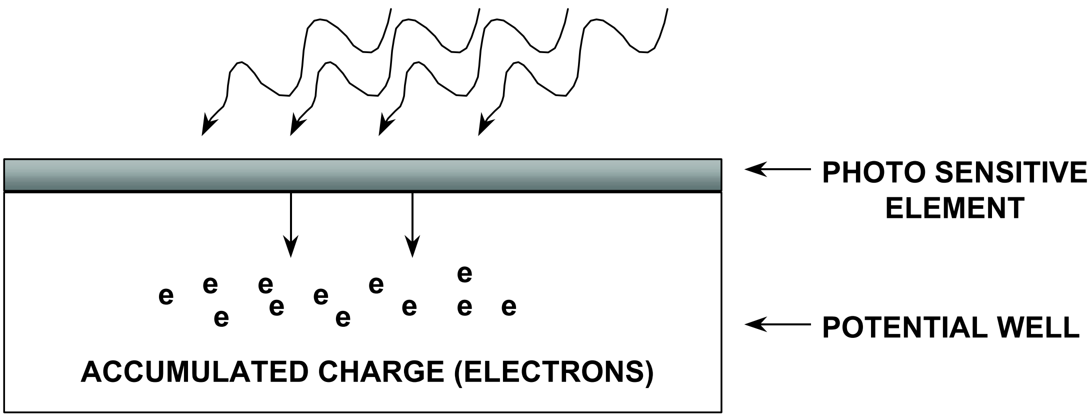
HP 5082-4204 PHOTODIODE

- Sensitivity: 350µA @ 1mW, 900nm
- Maximum Linear Output Current: 100µA
- Area: 0.002cm^2 (0.2mm^2)
- Capacitance: 4pF @ 10V Reverse Bias
- Shunt Resistance: $10^{11}\Omega$
- Risetime: 10ns
- Dark Current: 600pA @ 10V Reverse Bias

GENERIC IMAGING SYSTEM FOR SCANNERS OR DIGITAL CAMERAS

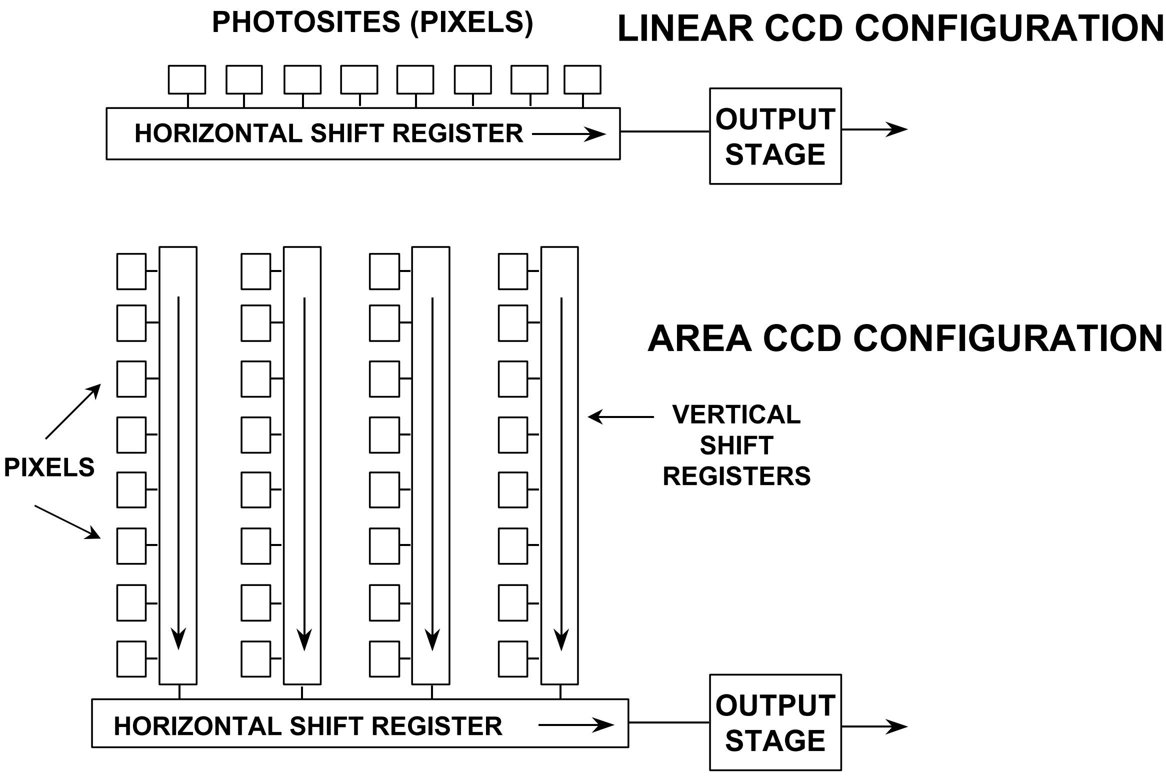


LIGHT SENSING ELEMENT



ONE PHOTOSITE OR "PIXEL"

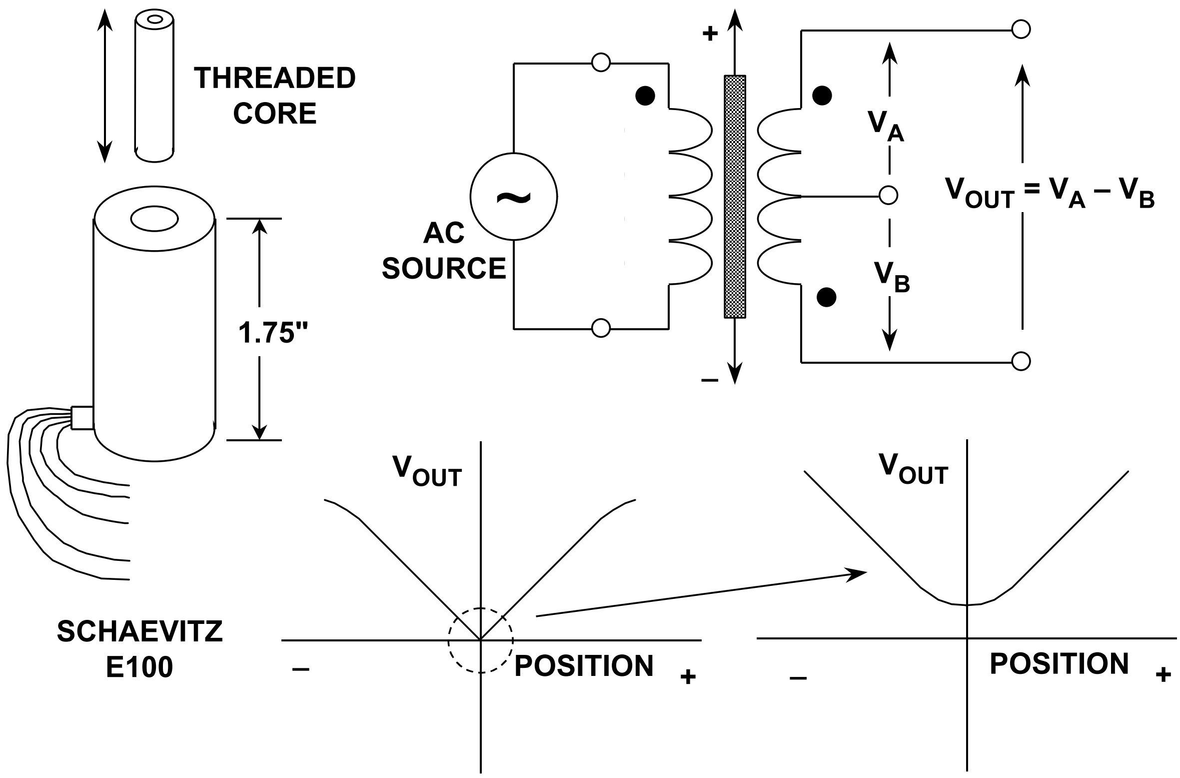
LINEAR AND AREA CCD ARRAYS



POSITION AND MOTION SENSORS

- Linear Position: Linear Variable Differential Transformers (LVDT)
- Hall Effect Sensors
  - Proximity Detectors
  - Linear Output (Magnetic Field Strength)
- Rotational Position:
  - Rotary Variable Differential Transformers (RVDT)
  - Optical Rotational Encoders
  - Synchros and Resolvers
  - Inductosyns (Linear and Rotational Position)
  - Motor Control Applications
- Acceleration and Tilt: Accelerometers

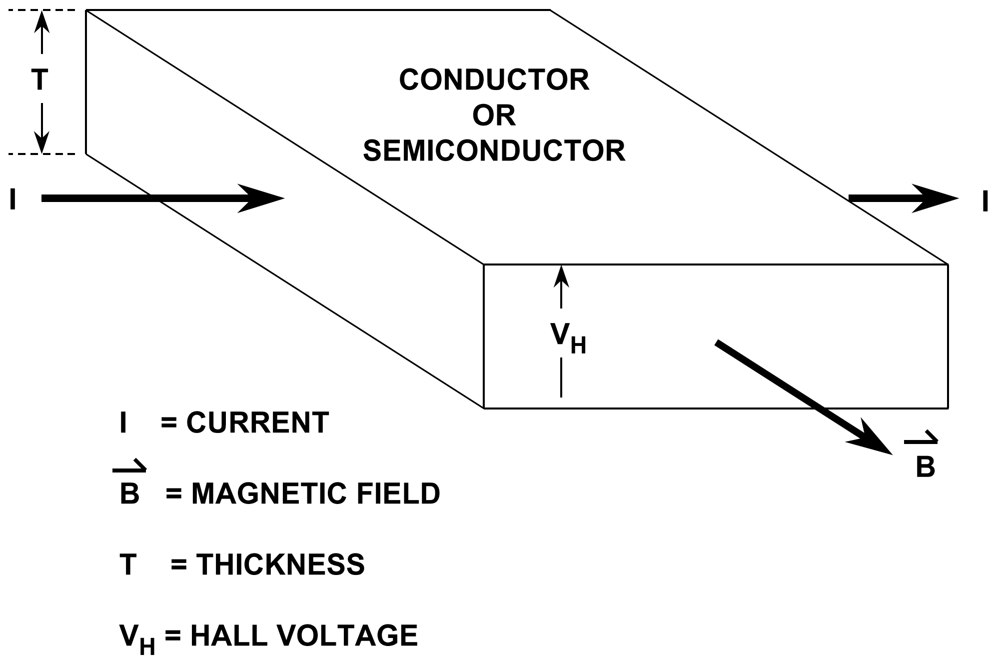
LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT)



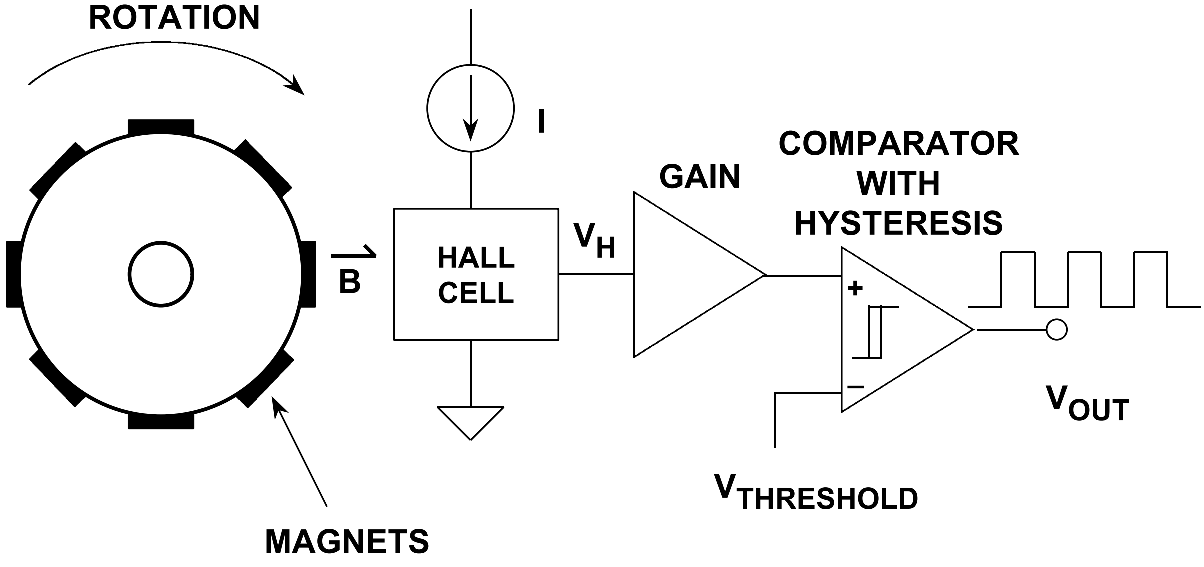
SCHAEVITZ E100 LVDT SPECIFICATIONS

- Nominal Linear Range: ±0.1 inches (± 2.54mm)
- Input Voltage: 3V RMS
- Operating Frequency: 50Hz to 10kHz (2.5kHz nominal)
- Linearity: 0.5% Fullscale
- Sensitivity: 2.4mV Output / 0.001in / Volt Excitation
- Primary Impedance: 660Ω
- Secondary Impedance: 960Ω

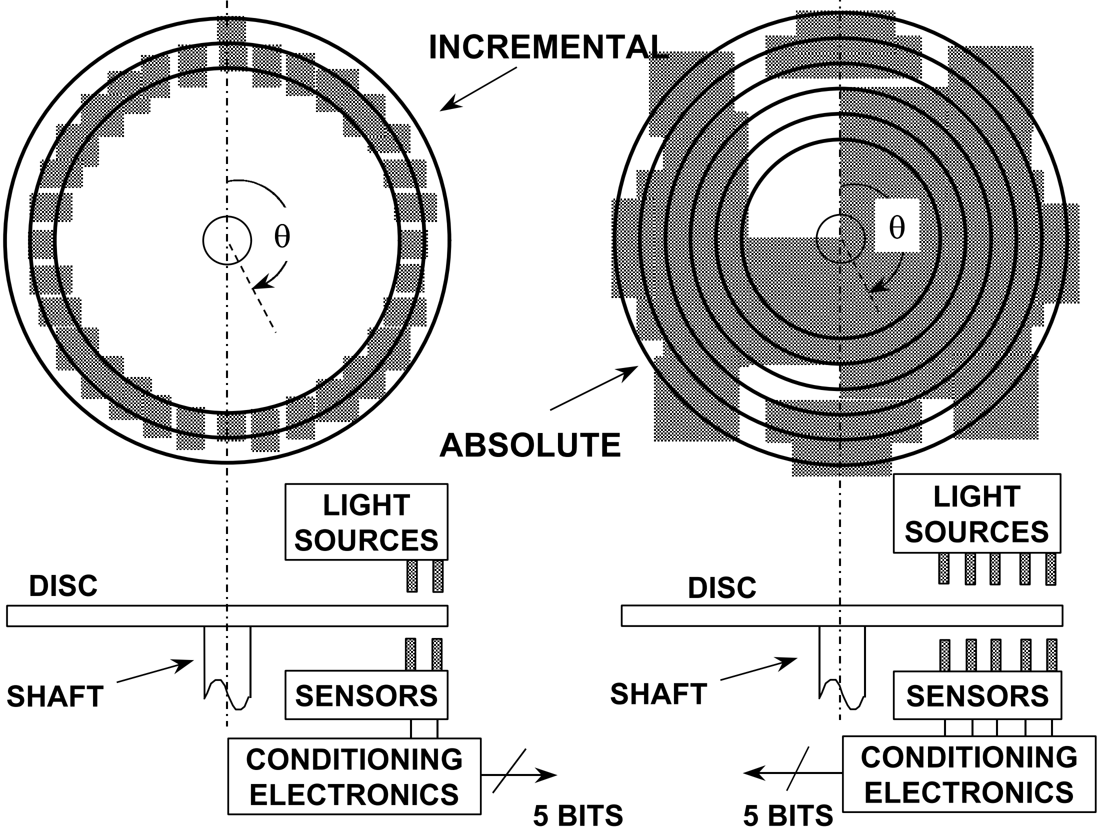
HALL EFFECT SENSORS

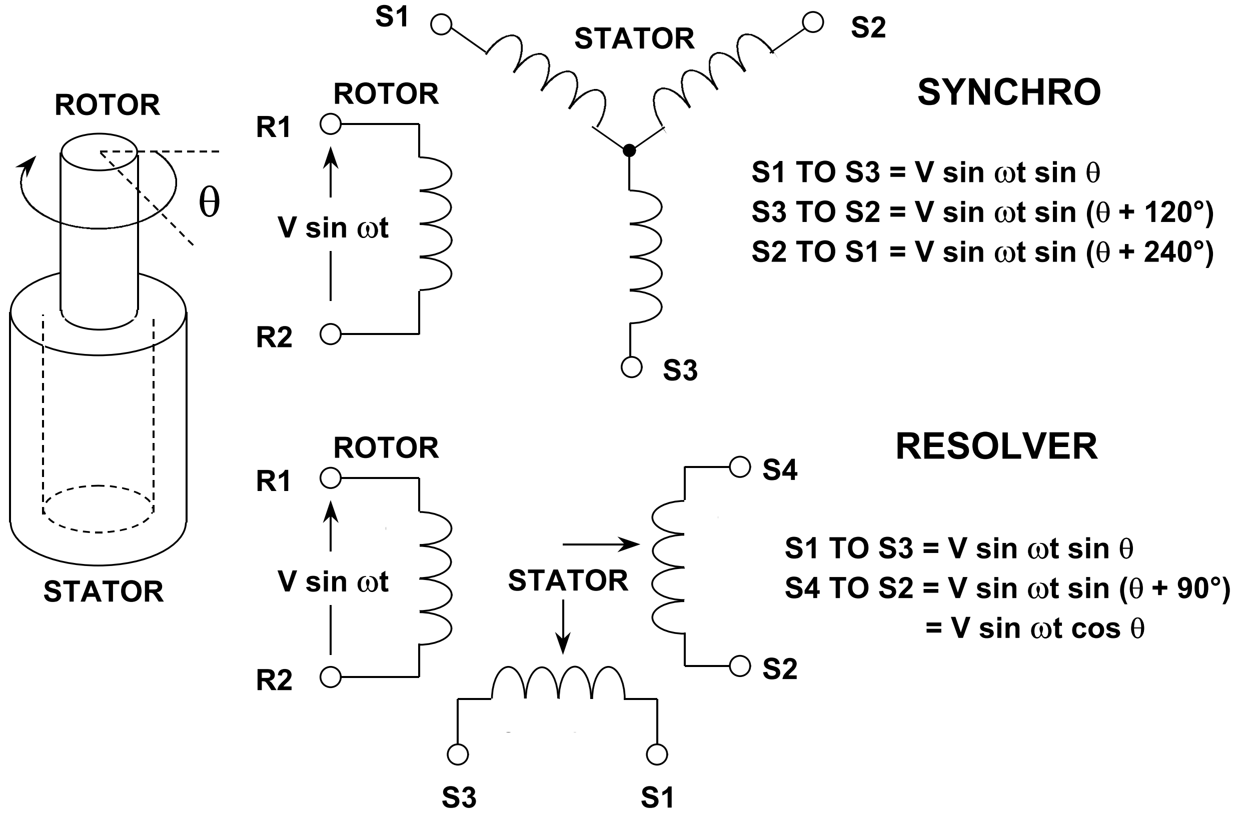


HALL EFFECT SENSOR USED AS A ROTATION SENSOR



INCREMENTAL AND ABSOLUTE OPTICAL ENCODERS

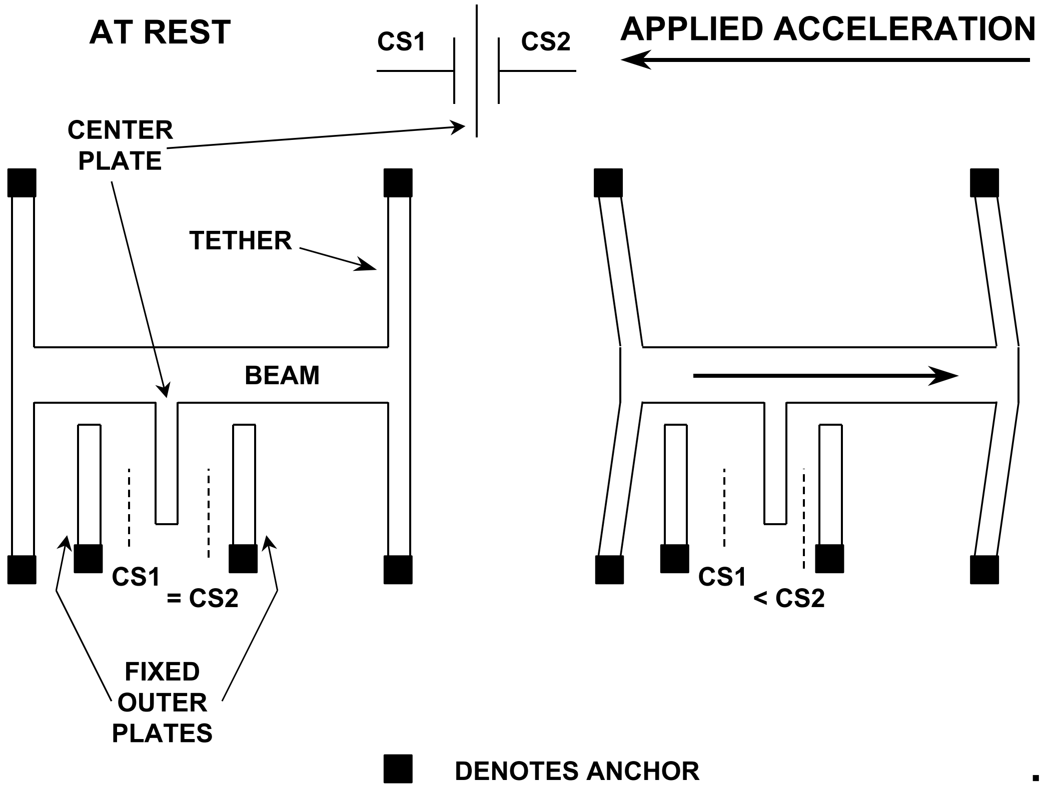




ACCELEROMETER APPLICATIONS

- Tilt or Inclination
  - Car Alarms
  - Patient Monitors
- Inertial Forces
  - Laptop Computer Disc Drive Protection
  - Airbag Crash Sensors
  - Car Navigation systems
  - Elevator Controls
- Shock or Vibration
  - Machine Monitoring
  - Control of Shaker Tables
- ADI Accelerometer Fullscale g-Range: ± 2g to ± 100g
- ADI Accelerometer Frequency Range: DC to 1kHz

ADXL-FAMILY MICROMACHINED ACCELEROMETERS (TOP VIEW OF IC)



APPLICATIONS OF TEMPERATURE SENSORS

- **Monitoring**
  - **Portable Equipment**
  - **CPU Temperature**
  - **Battery Temperature**
  - **Ambient Temperature**
- **Compensation**
  - **Oscillator Drift in Cellular Phones**
  - **Thermocouple Cold-Junction Compensation**
- **Control**
  - **Battery Charging**
  - **Process Control**

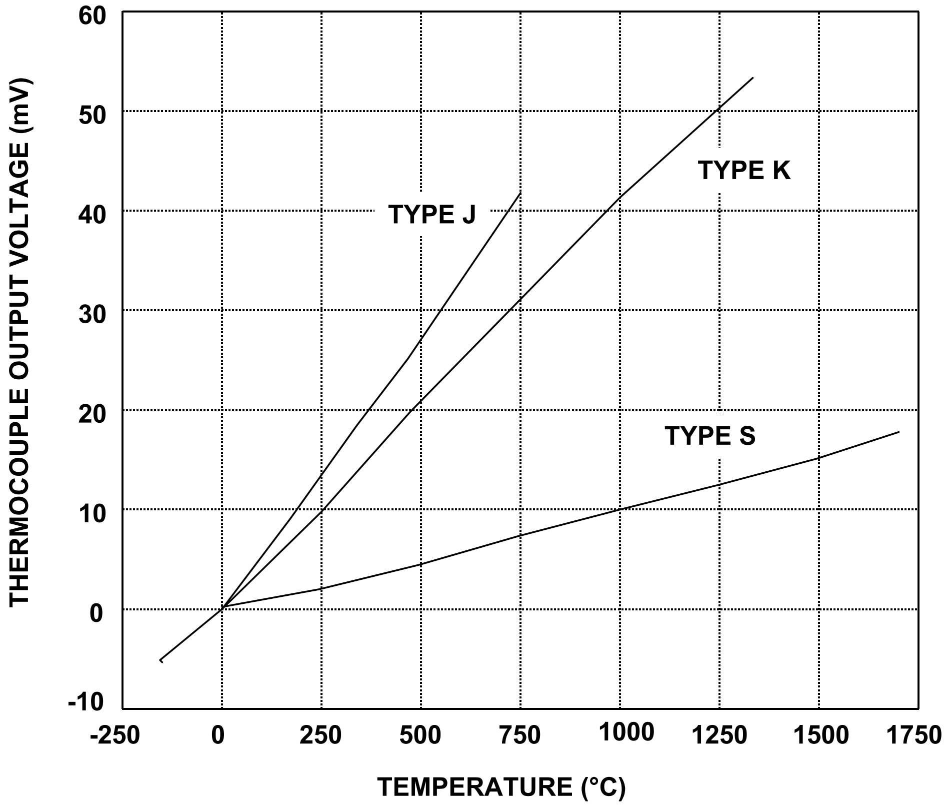
TYPES OF TEMPERATURE SENSORS

THERMOCOUPLE	RTD	THERMISTOR	SEMICONDUCTOR
Widest Range: –184ºC to +2300ºC	Range: –200ºC to +850ºC	Range: 0ºC to +100ºC	Range: –55ºC to +150ºC
High Accuracy and Repeatability	Fair Linearity	Poor Linearity	Linearity: 1ºC Accuracy: 1ºC
Needs Cold Junction Compensation	Requires Excitation	Requires Excitation	Requires Excitation
Low-Voltage Output	Low Cost	High Sensitivity	10mV/K, 20mV/K, or 1µA/K Typical Output

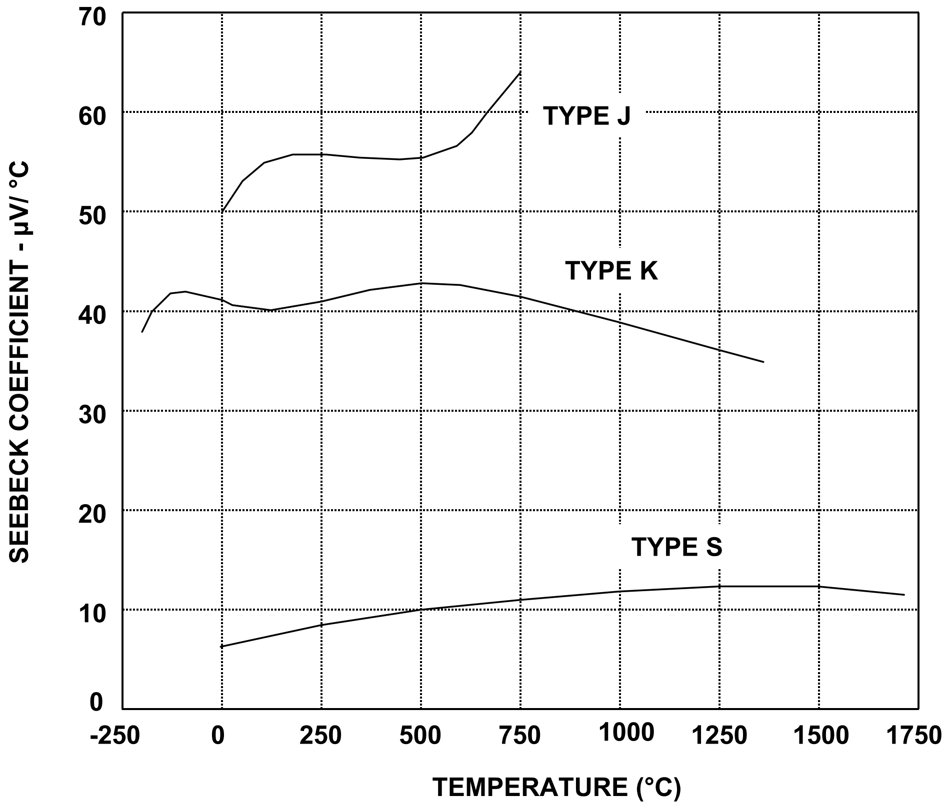
COMMON THERMOCOUPLES

JUNCTION MATERIALS	TYPICAL USEFUL RANGE (ºC)	NOMINAL SENSITIVITY (µV/ºC)	ANSI DESIGNATION
Platinum (6%)/ Rhodium-Platinum (30%)/Rhodium	38 to 1800	7.7	B
Tungsten (5%)/Rhenium - Tungsten (26%)/Rhenium	0 to 2300	16	C
Chromel - Constantan	0 to 982	76	E
Iron - Constantan	0 to 760	55	J
Chromel - Alumel	–184 to 1260	39	K
Platinum (13%)/Rhodium-Platinum	0 to 1593	11.7	R
Platinum (10%)/Rhodium-Platinum	0 to 1538	10.4	S
Copper-Constantan	–184 to 400	45	T

THERMOCOUPLE OUTPUT VOLTAGES FOR TYPE J, K, AND S THERMOCOUPLES

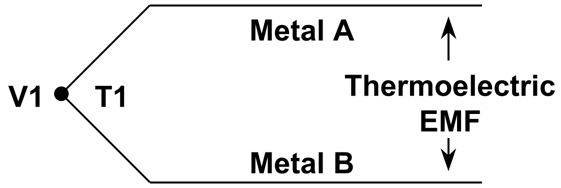


THERMOCOUPLE SEEBECK COEFFICIENT VERSUS TEMPERATURE

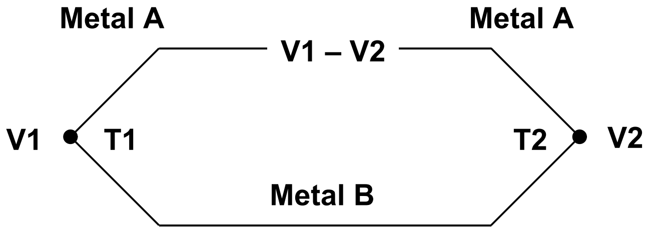


THERMOCOUPLE BASICS

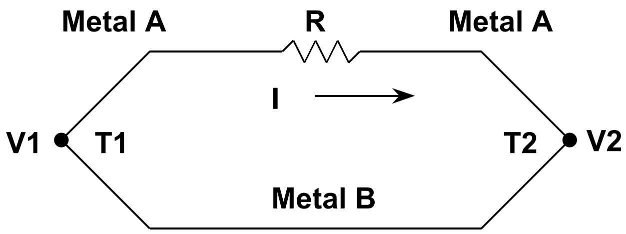
A. THERMOELECTRIC VOLTAGE



C. THERMOCOUPLE MEASUREMENT

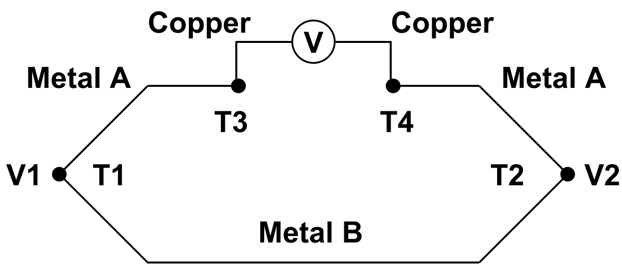


B. THERMOCOUPLE



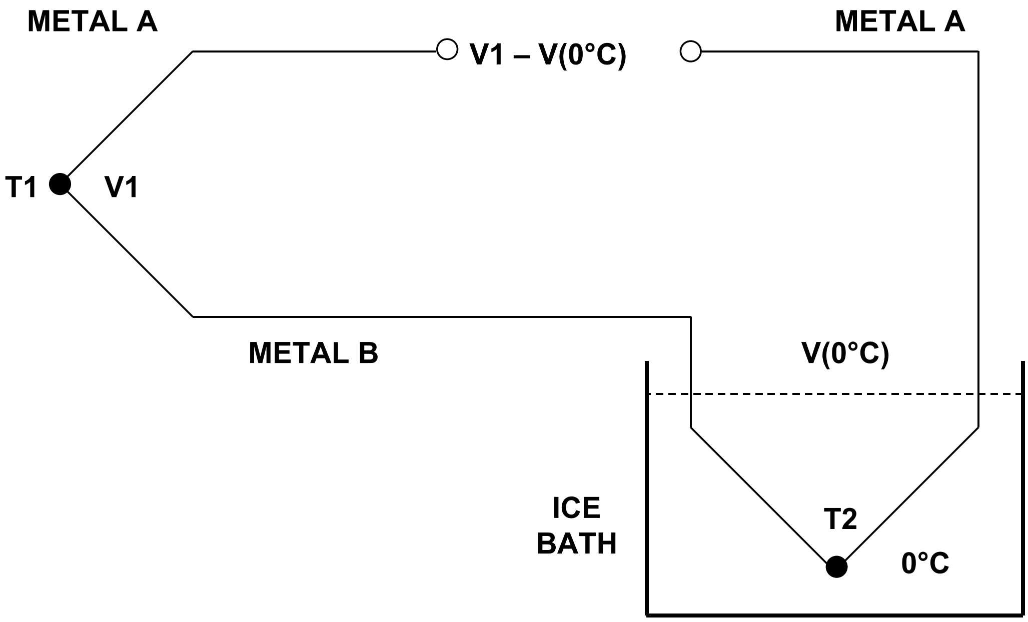
R = Total Circuit Resistance
I = (V1 – V2) / R

D. THERMOCOUPLE MEASUREMENT

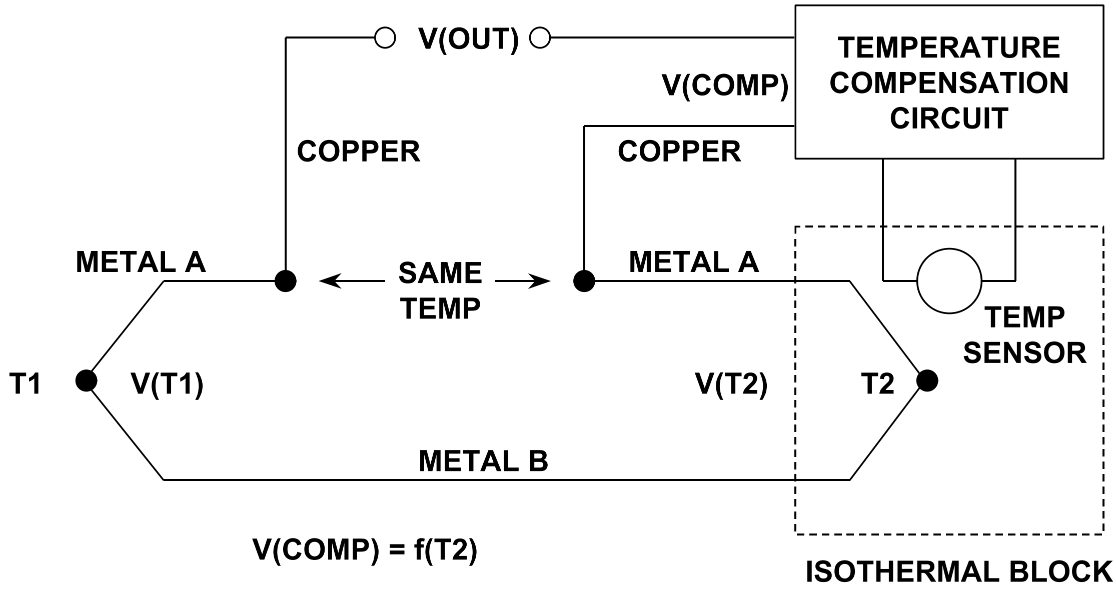


V = V1 – V2, If T3 = T4

CLASSICAL COLD-JUNCTION COMPENSATION USING AN ICE-POINT (0°C) REFERENCE JUNCTION



USING A TEMPERATURE SENSOR FOR COLD-JUNCTION COMPENSATION



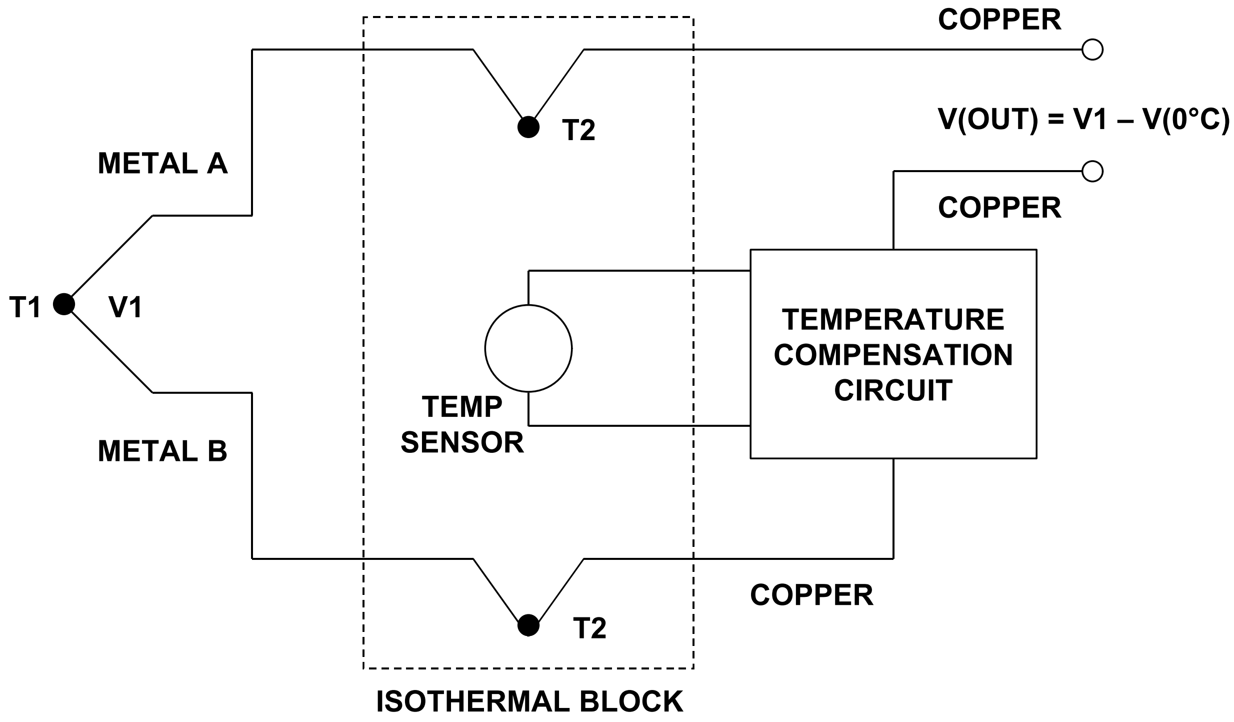
V(COMP) = f(T2)

V(OUT) = V(T1) – V(T2) + V(COMP)

IF V(COMP) = V(T2) – V(0°C), THEN

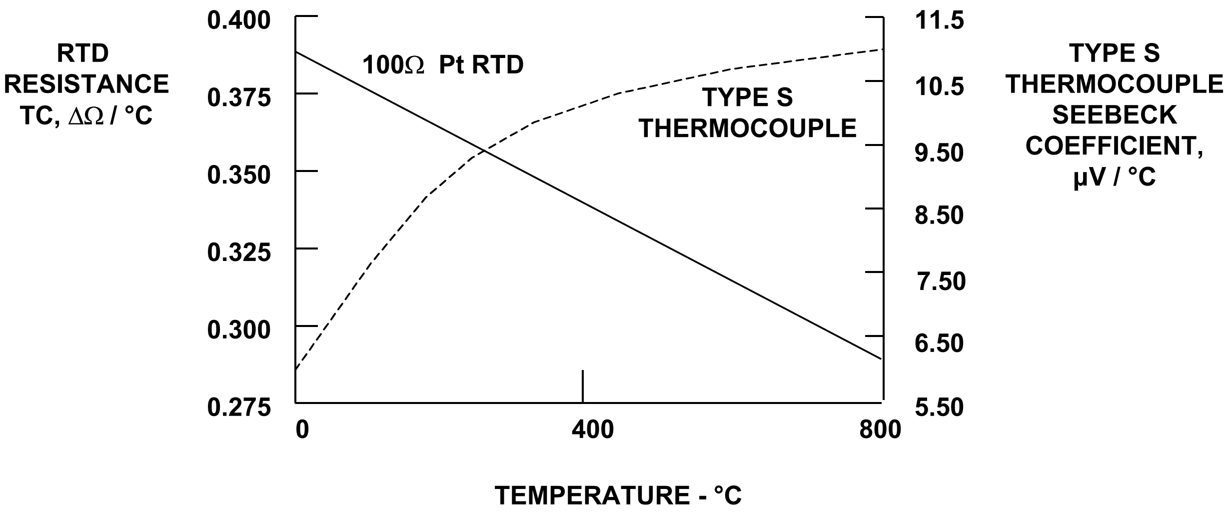
V(OUT) = V(T1) – V(0°C)

TERMINATING THERMOCOUPLE LEADS DIRECTLY TO AN ISOTHERMAL BLOCK

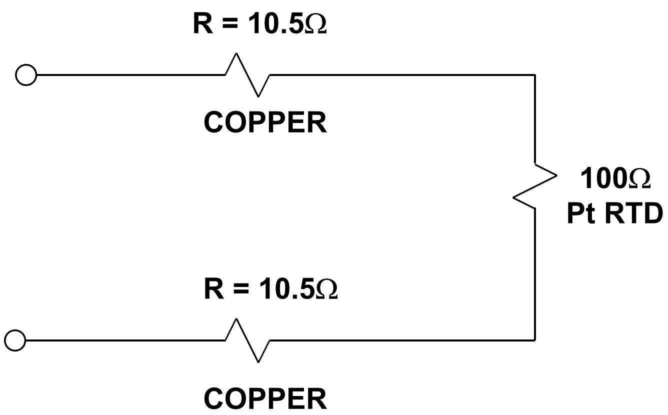


RESISTANCE TEMPERATURE DETECTORs (RTD)

- **Platinum (Pt) the Most Common**
- **100Ω, 1000Ω Standard Values**
- **Typical TC = 0.385% / °C,**
  0.385Ω / °C for 100Ω Pt RTD
- **Good Linearity - Better than Thermocouple, Easily Compensated**



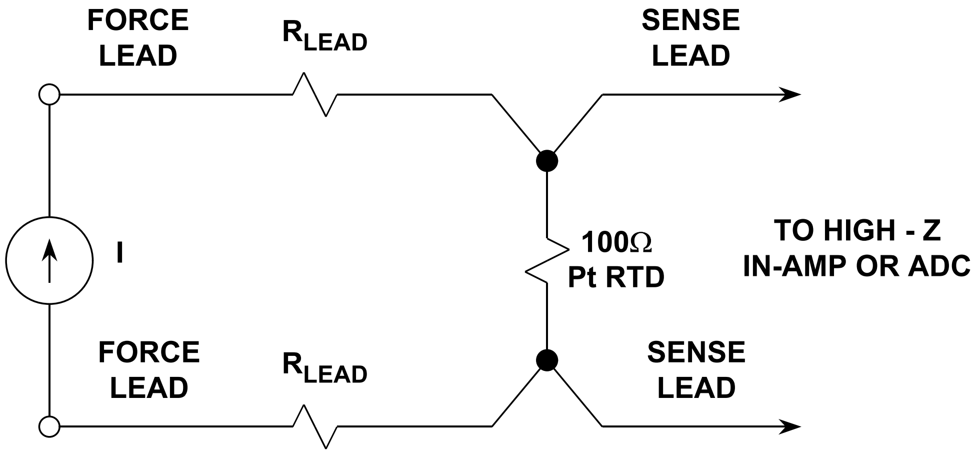
A 100Ω Pt RTD WITH 100 FEET OF 30-GAUGE LEAD WIRES



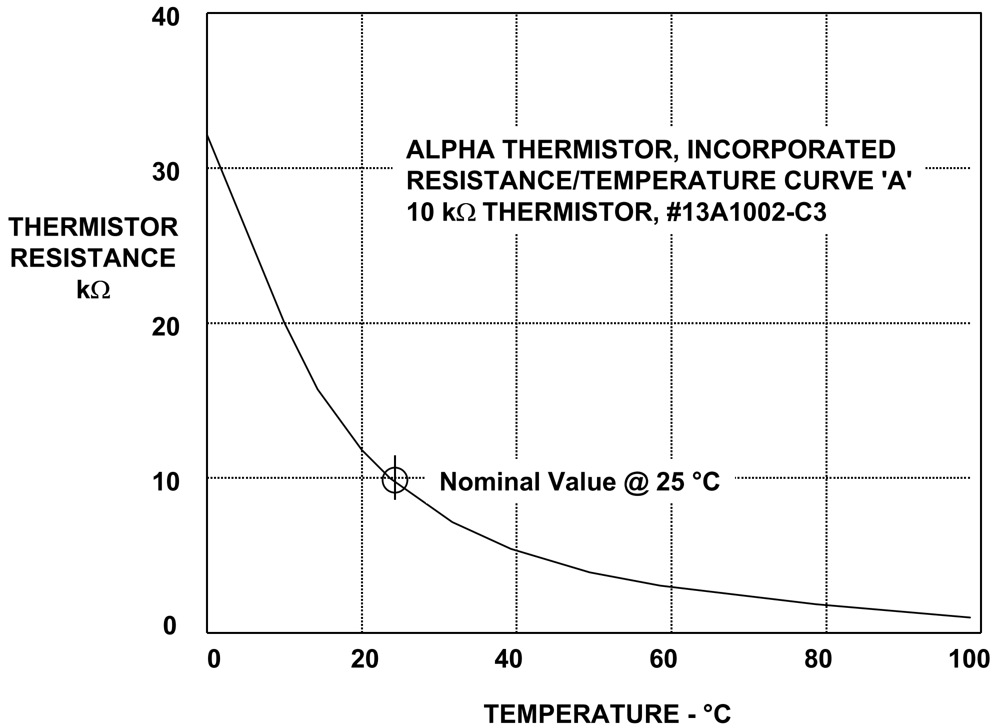
RESISTANCE TC OF COPPER = 0.40%/°C @ 20°C

RESISTANCE TC OF Pt RTD = 0.385%/ °C @ 20°C

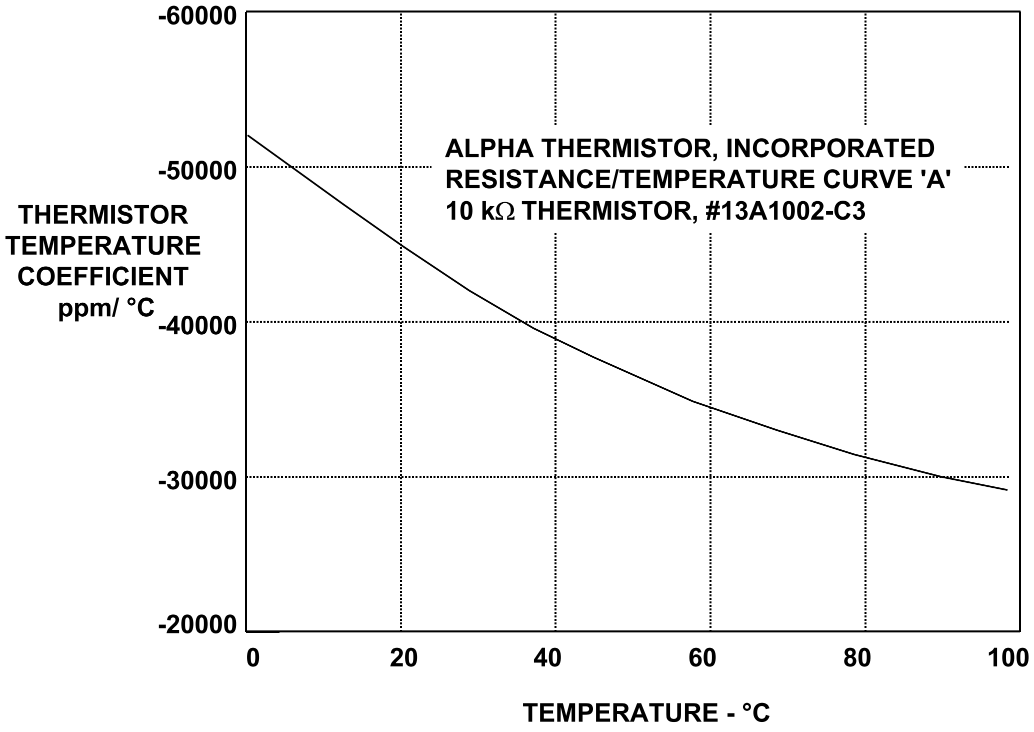
FOUR-WIRE OR KELVIN CONNECTION TO Pt RTD FOR ACCURATE MEASUREMENTS



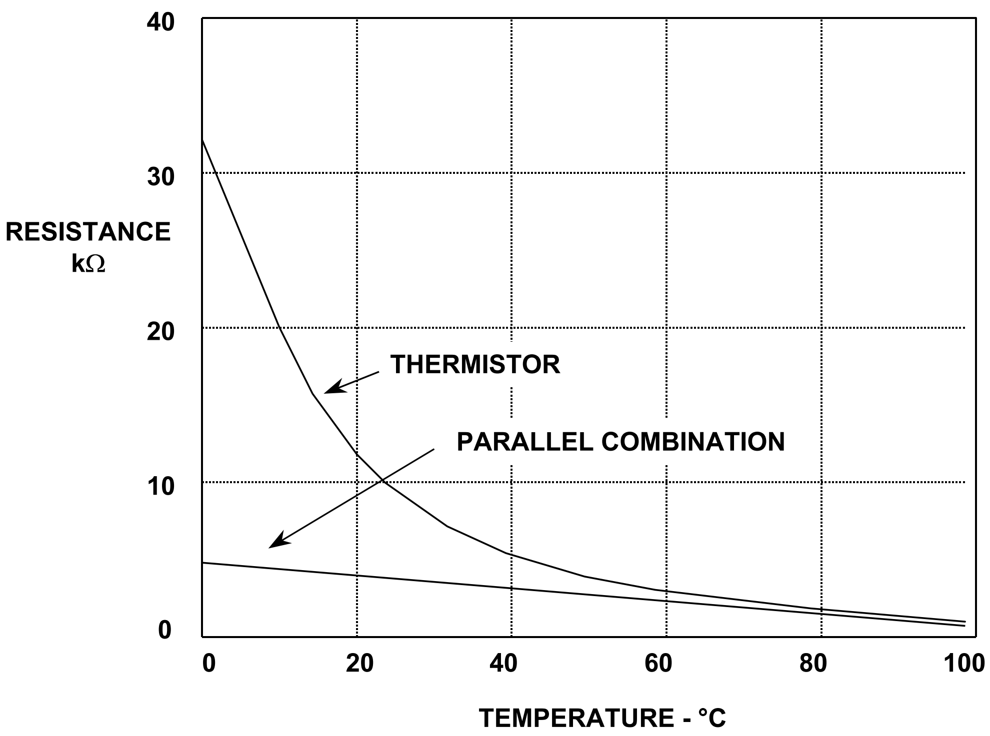
RESISTANCE CHARACTERISTICS OF A 10kΩ NTC THERMISTOR



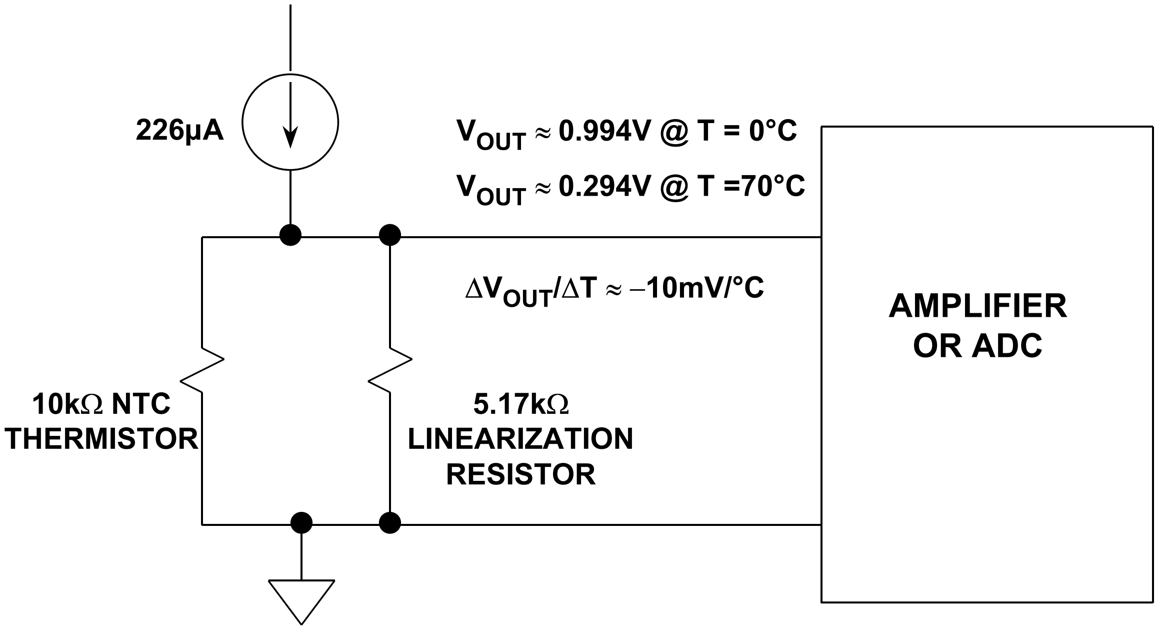
TEMPERATURE COEFFICIENT OF 10kΩ NTC THERMISTOR



LINEARIZATION OF NTC THERMISTOR USING A 5.17kΩ SHUNT RESISTOR

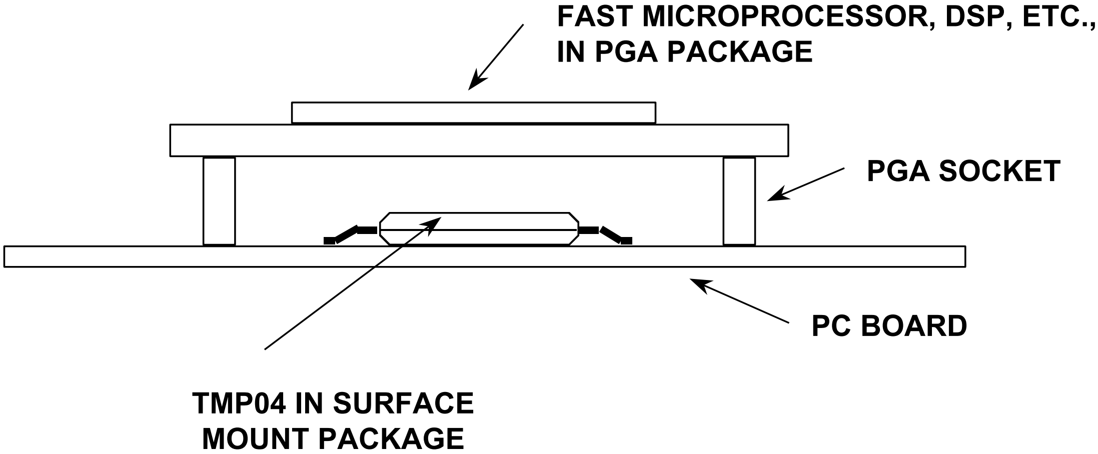


LINEARIZED THERMISTOR AMPLIFIER

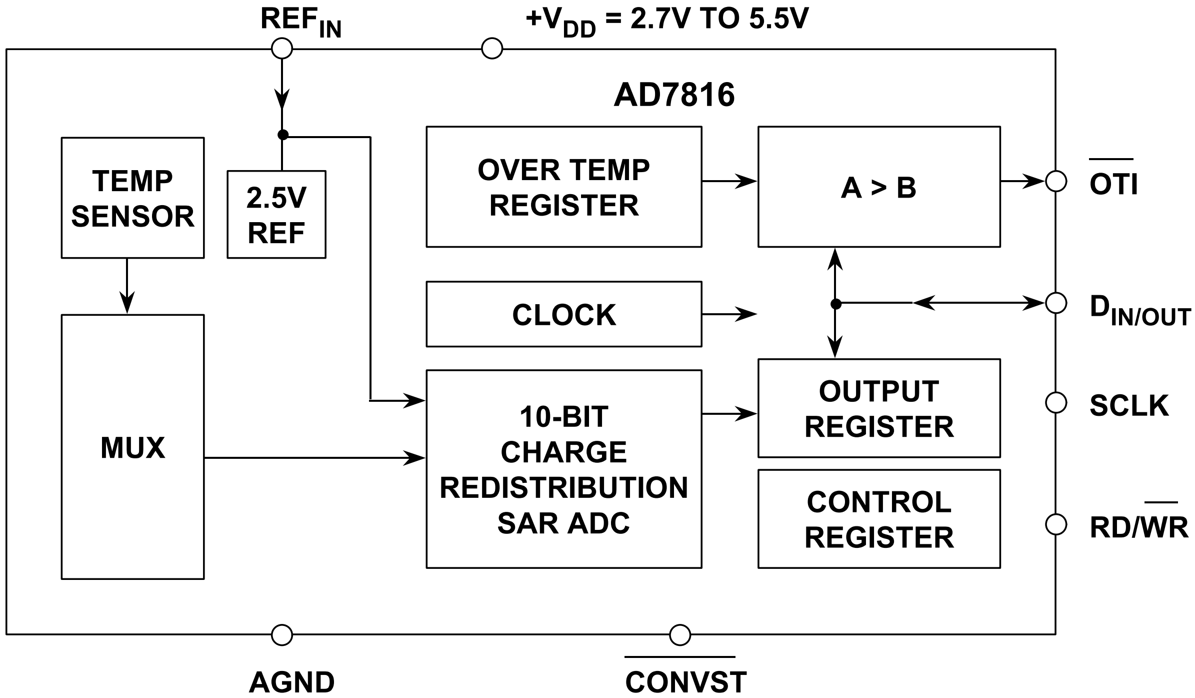


LINEARITY $\approx \pm$ 2°C, 0°C TO +70°C

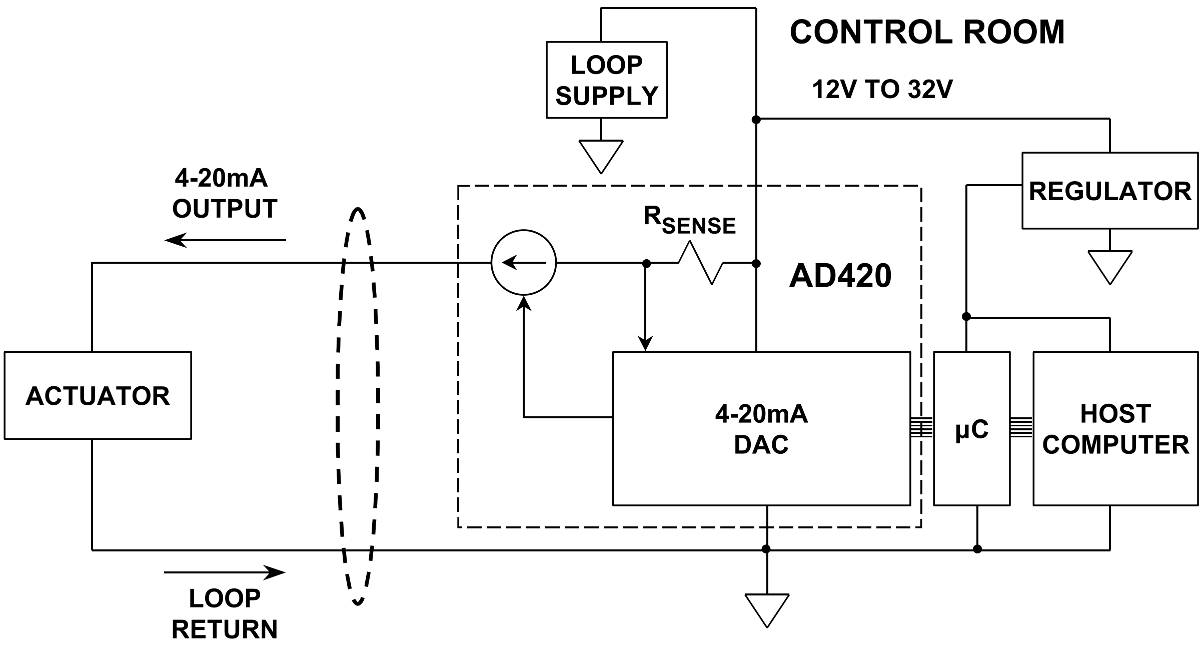
MONITORING HIGH POWER MICROPROCESSOR OR DSP WITH TMP04



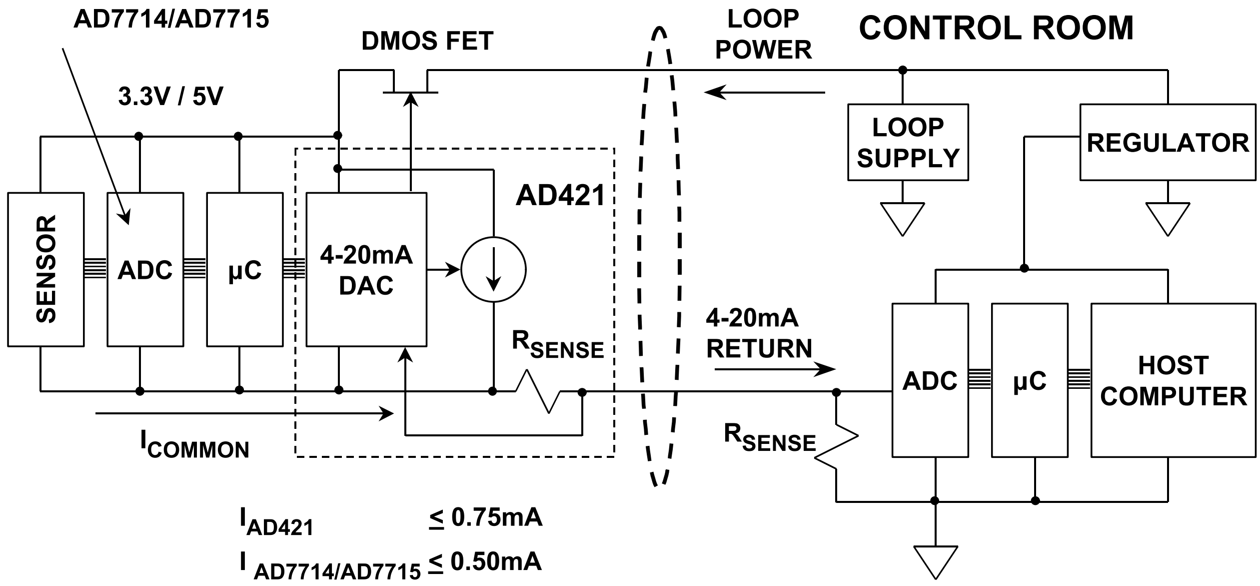
AD7816 10-BIT DIGITAL TEMPERATURE SENSOR WITH SERIAL INTERFACE



CONTROLLING A REMOTE ACTUATOR USING A 4-20mA LOOP



4-20mA LOOP POWERED SMART SENSOR



I_{AD421} ≤ 0.75mA

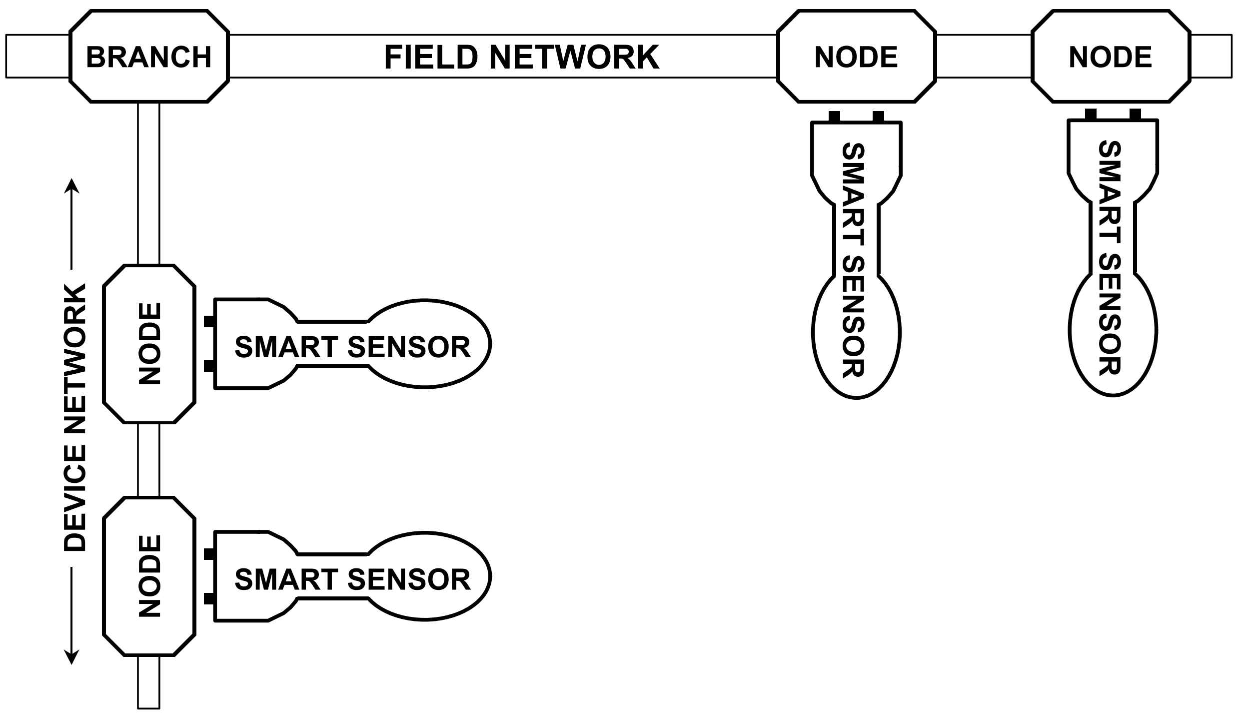
$I_{AD7714/AD7715}$ ≤ 0.50mA

$I_{\mu C+SENSOR}$ ≤ 2.75mA

I_{COMMON} ≤ 4.00mA

DMOS FET: Supertex DN2535
Siliconix ND2020L or ND2410L

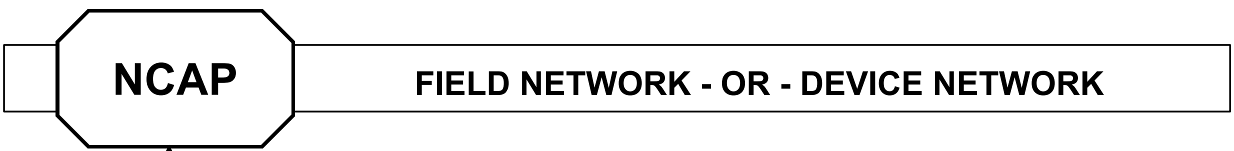
INDUSTRIAL NETWORKING

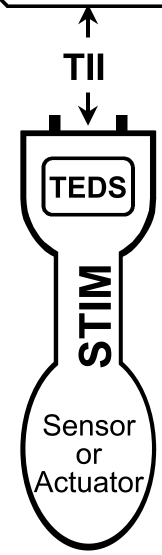


SOME OF THE STANDARDS

- Ethernet
- Foundation Fieldbus
- Lonwork
- Profibus
- Interbus-S
- Universal Serial Bus (USB)
- CAN-Bus
- Device-Net
- WorldFIP
- P-NET
- HART
- ASI

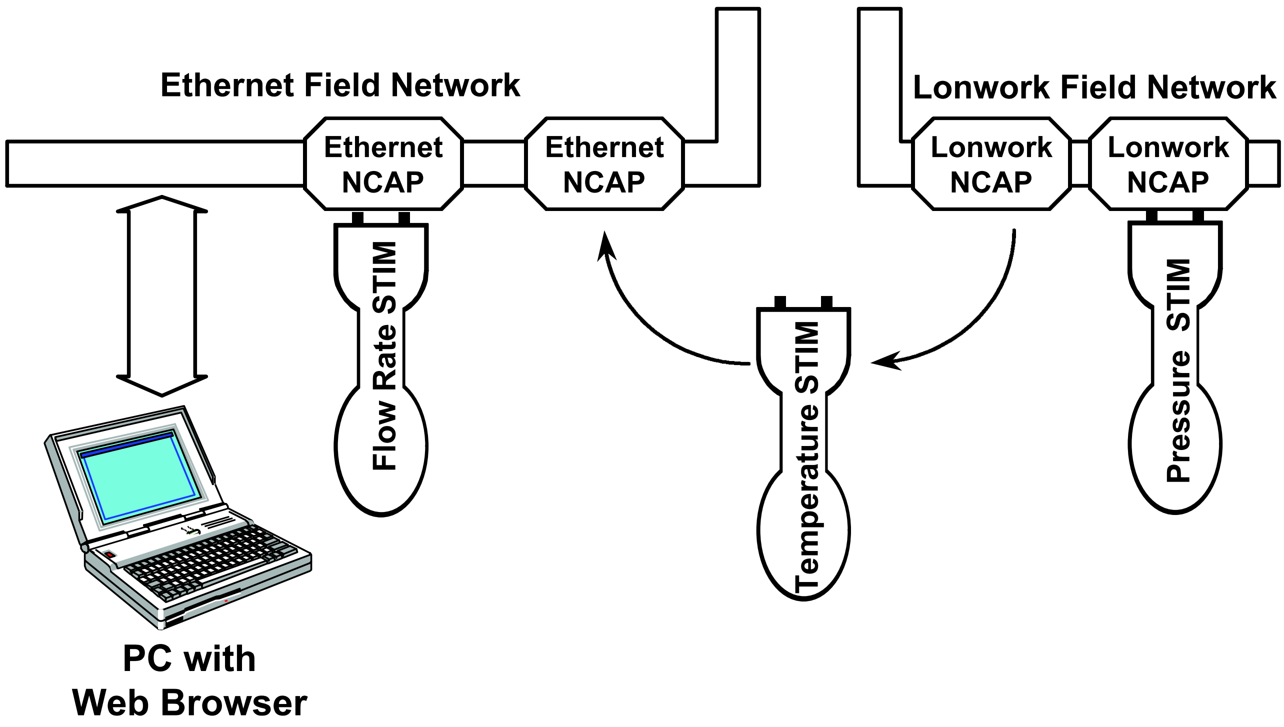
THE IEEE 1451.2 SENSOR INTERFACE STANDARD



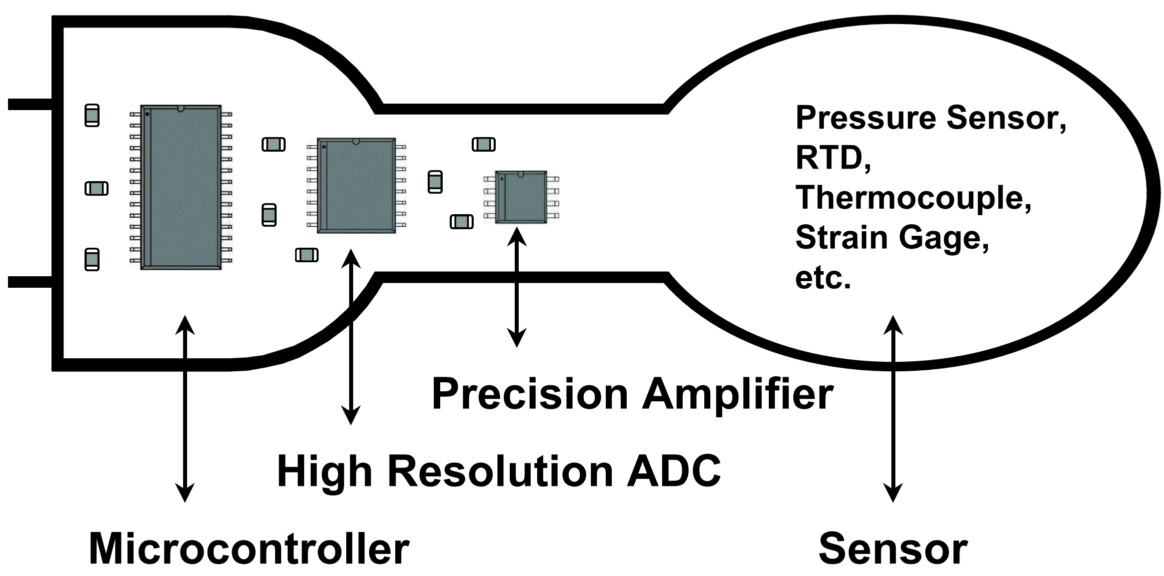


- <u>NCAP</u> = Network Capable Application Processor
- <u>TII</u> = Transducer Independent Interface
- <u>TEDS</u> = Transducer Electronic Datasheet
- <u>STIM</u> = Smart Transducer Interface Module

TRUE "PLUG AND PLAY"



THE SMART SENSOR



KAYNAKLAR

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