EE 4BD4 Lecture 15

Strain (force) Gauges, pressure sensors and Load Cells

The Strain Gauge

- Measures the effects of very small displacements (lengthening or shortening) of a resistive sensor
- Is an isometric device with conductor strain gauges having a maximum resistive change of 1 to 3 %
- Resistive change based on both dimensional changes of conductor and strain placed on the sensor (piezoresistive effect)
- Sensors are small, but glued (bonded) to larger structures to increase range of forces measured

Basic Theory

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

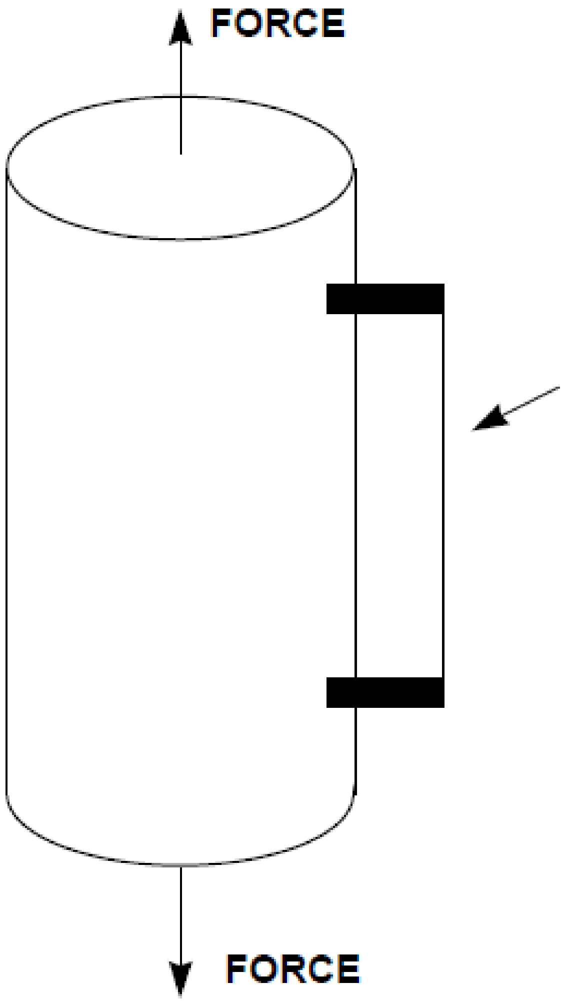
$$dR = \frac{\rho dL}{A} - \rho A^{-2} L\, dA + L\frac{d\rho}{A} \Rightarrow \frac{\Delta R}{R} = \frac{\Delta L}{L} - \frac{\Delta A}{A} + \frac{\Delta \rho}{\rho}$$

Poisson's ratio μ relates the change in diameter ΔD to the change in length, $\Delta D/D = -\mu\ \Delta L/L$. Substituting this into the center term of (2.3) yields

$$\frac{\Delta R}{R} = \underbrace{(1 + 2\mu)\frac{\Delta L}{L}}_{\text{Dimensional effect}} + \underbrace{\frac{\Delta \rho}{\rho}}_{\text{Piezoresistive effect}}$$

$$G = \frac{\Delta R/R}{\Delta L/L} = (1 + 2\mu) + \frac{\Delta \rho/\rho}{\Delta L/L}$$

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

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

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

Different Conductive Materials

Table 2.1 Properties of Strain-Gage Materials

Material	Composition (%)	Gage Factor	Temperature Coefficient of Resistivity (°C^{-1}–10^{-5})
Constantan (advance)	Ni_{45}, Cu_{55}	2.1	±2
Isoelastic	Ni_{36}, Cr_8 $(Mn, Si, Mo)_4$ Fe_{52}	3.52 to 3.6	+17
Karma	Ni_{74}, Cr_{20}, Fe_3 Cu_3	2.1	+2
Manganin	Cu_{84}, Mn_{12}, Ni_4	0.3 to 0.47	±2
Alloy 479	Pt_{92}, W_8	3.6 to 4.4	+24
Nickel	Pure	−12 to −20	670
Nichrome V	Ni_{80}, Cr_{20}	2.1 to 2.63	10
Silicon	(*p* type)	100 to 170	70 to 700
Silicon	(*n* type)	−100 to −140	70 to 700
Germanium	(*p* type)	102	
Germanium	(*n* type)	−150	

SOURCE: From R. S. C. Cobbold, *Transducers for Biomedical Measurements*, 1974, John Wiley & Sons, Inc.. Used with permission of John Wiley & Sons, Inc., New York.

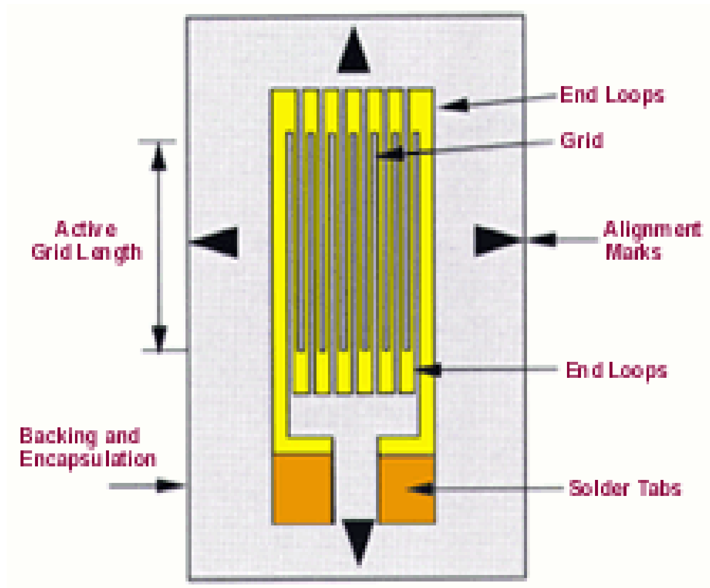
Selection of Type

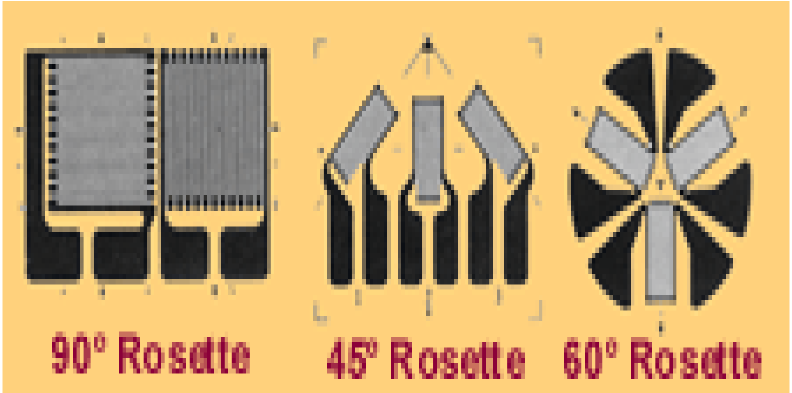
- Metal foil gauges have a linear resistance change with strain but are less sensitive
- Semiconductor gauges based on piezoresistive effect in germanium and silicon and are much more temperature sensitive
- Resistance change is nonlinear for S-C strain gauges and are not as commonly used as metal foil

COMPARISON BETWEEN METAL AND SEMICONDUCTOR STRAIN GAGES

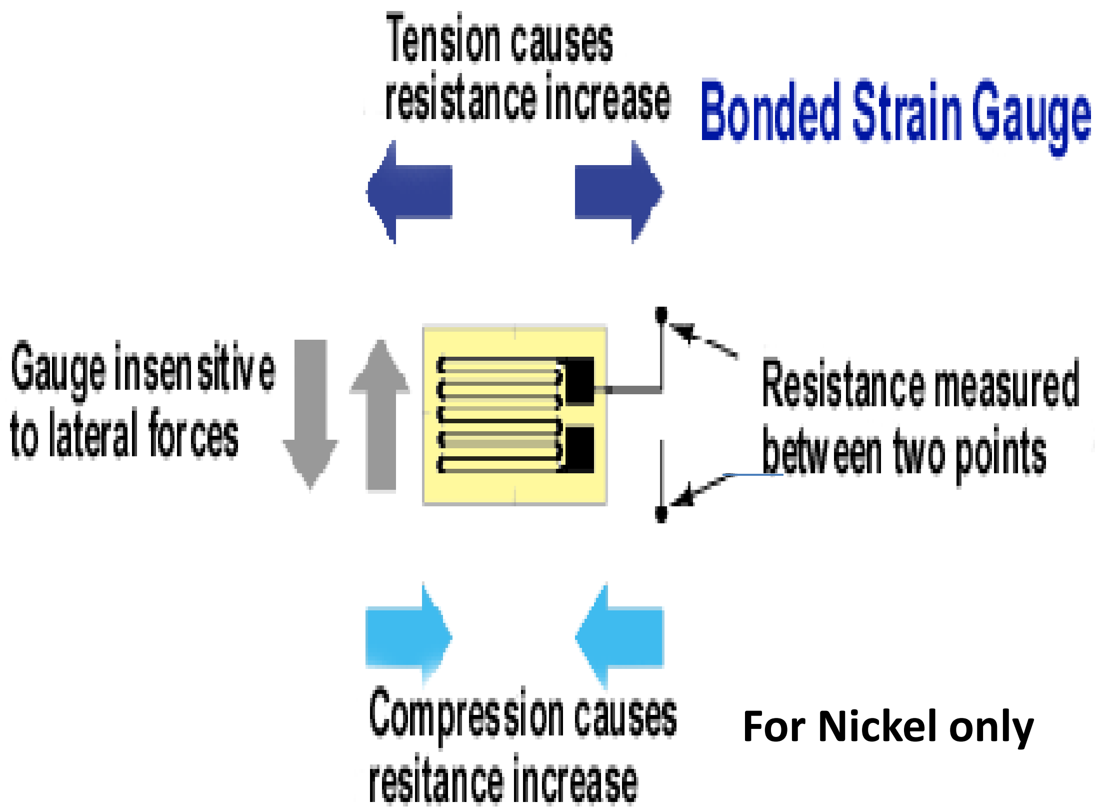
PARAMETER	METAL STRAIN GAGE	SEMICONDUCTOR STRAIN GAGE
Measurement Range	0.1 to 40,000 $\mu\varepsilon$	0.001 to 3000 $\mu\varepsilon$
Gage Factor	2.0 to 4.5	50 to 200
Resistance, Ω	120, 350, 600, …, 5000	1000 to 5000
Resistance Tolerance	0.1% to 0.2%	1% to 2%
Size, mm	0.4 to 150 Standard: 3 to 6	1 to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

Types of Foil Strain Gauges





Principle of Operation

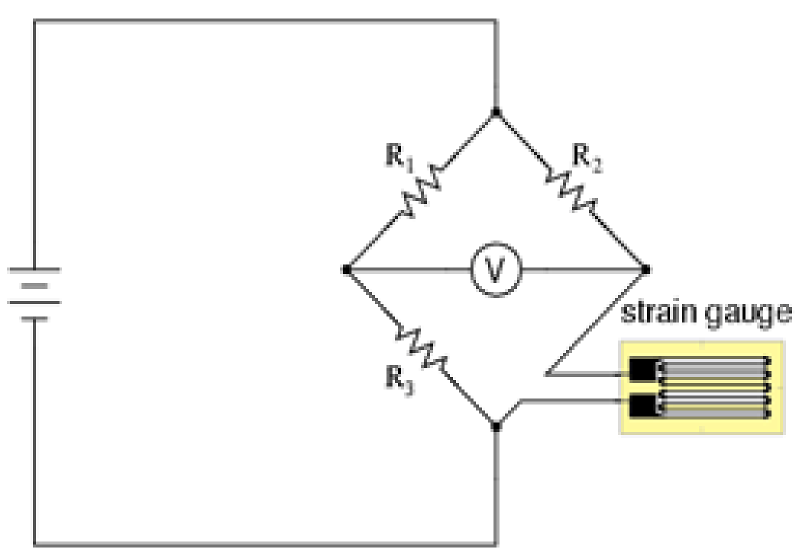


For Nickel only

Measurement Circuits

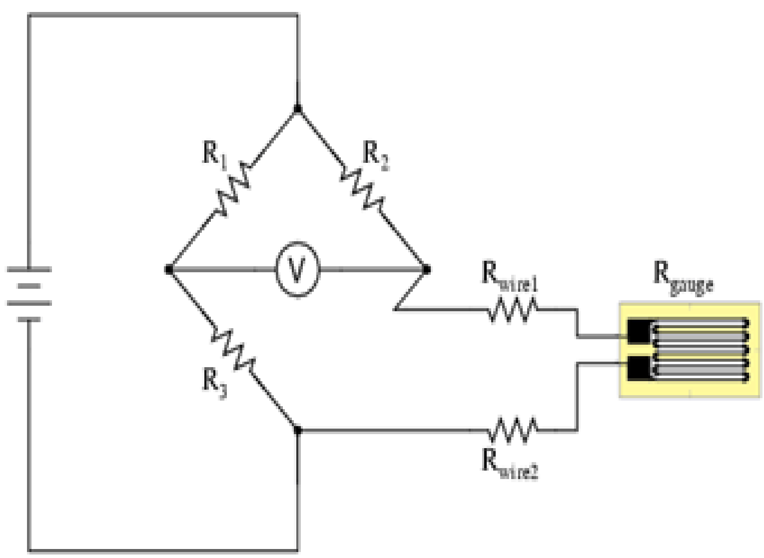
- Base resistance for bonded gauges between 30 Ω and 3 kΩ (typically 350 Ω)

Quarter-bridge strain gauge circuit

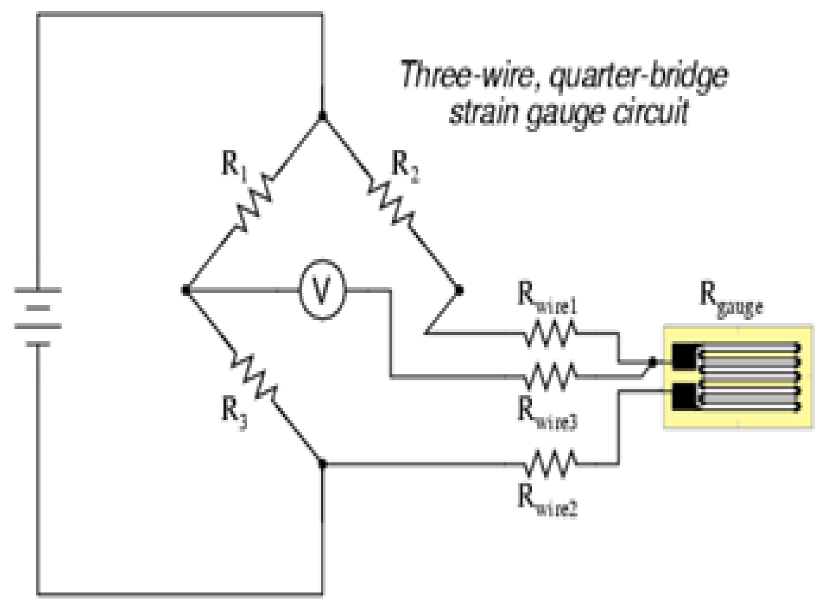


- R1 R2 and R3 are balancing resistors (e.g. 350 Ω so bridge balanced at 0 strain and V = 0
- Temperature changes cause change in dimensions of structure and gauge and resistivity of gauge resulting in baseline drift

- Effects of lead resistance temperature changes

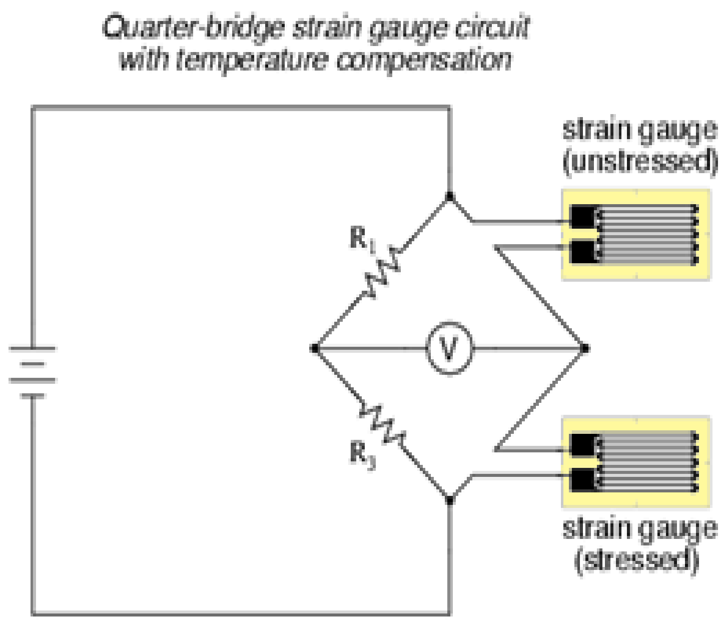


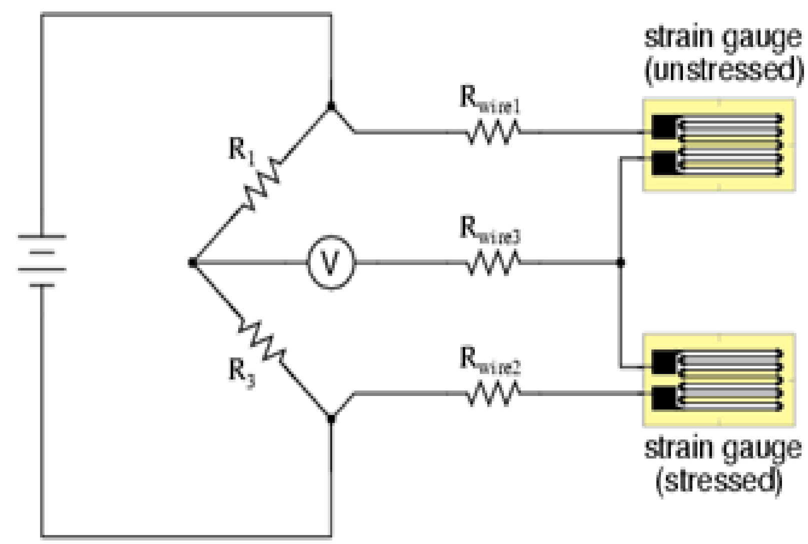
- Lead temperauture compensated bridge



Using an Extra Gauge for Temperature Compensation

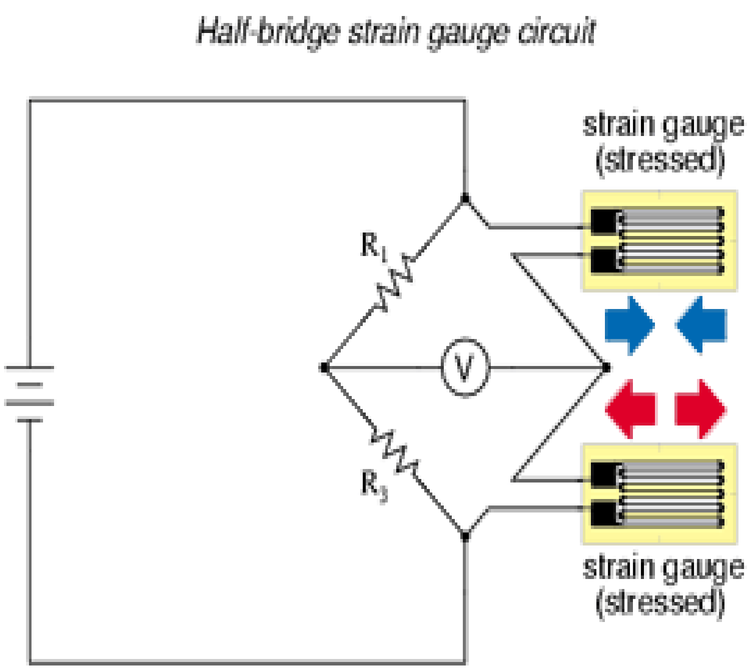
- Circuit to compensate for temperature effects on structure and gauges
- Fully temperature compensated circuit



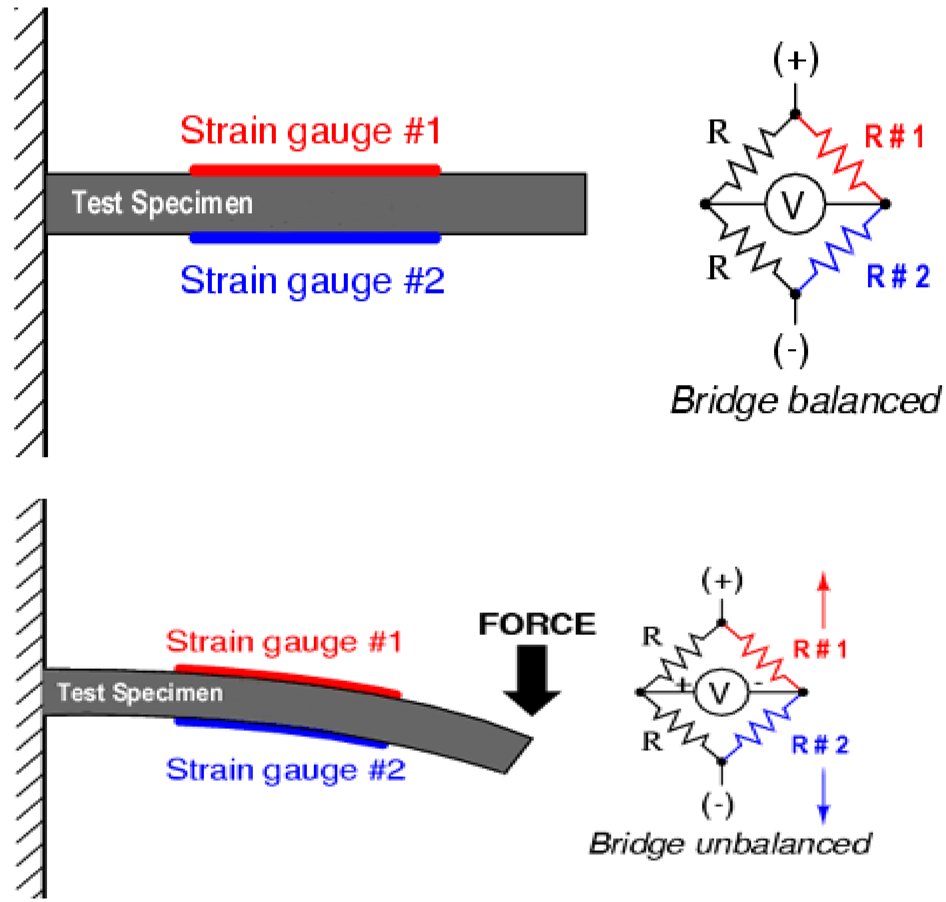


Beam with Two Gauges

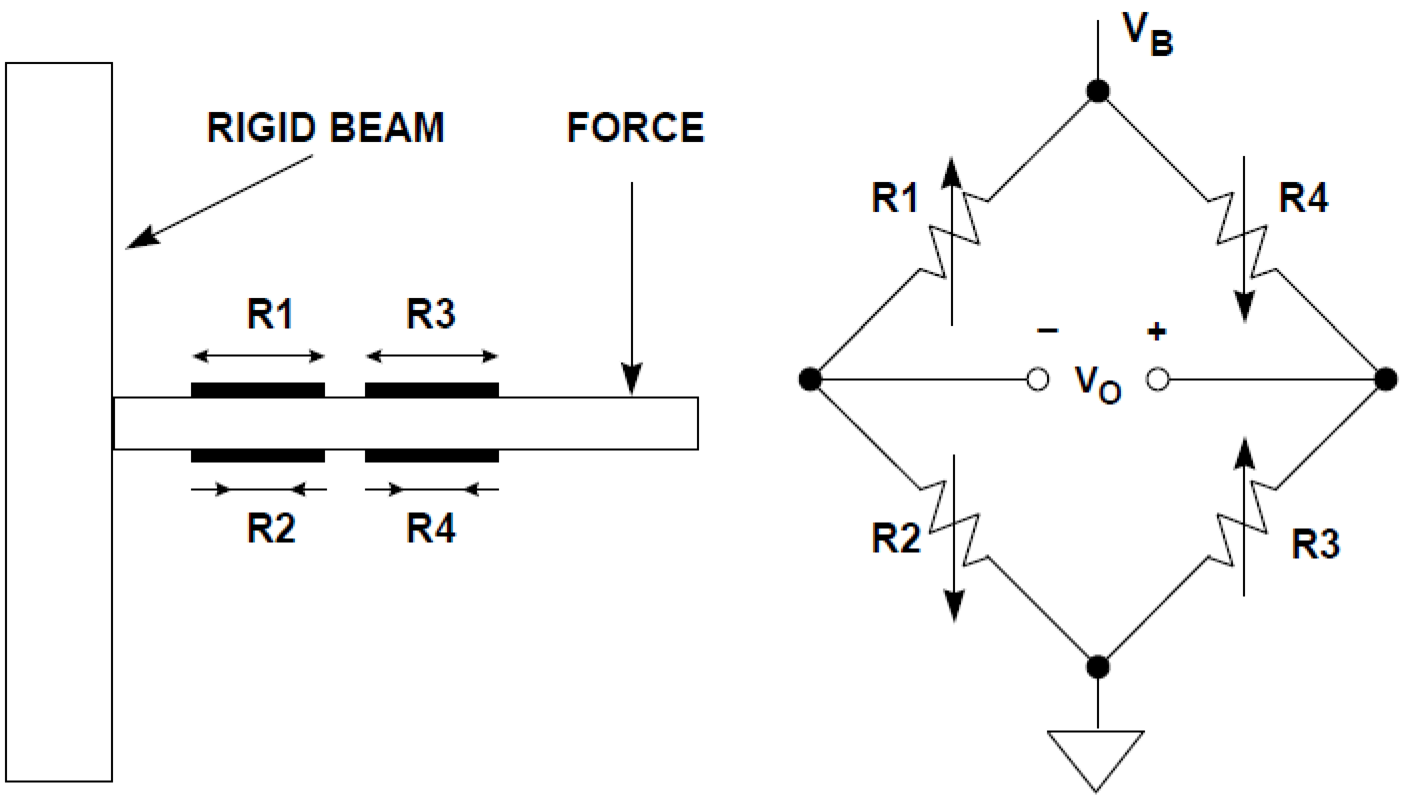
- Two stressed gauges



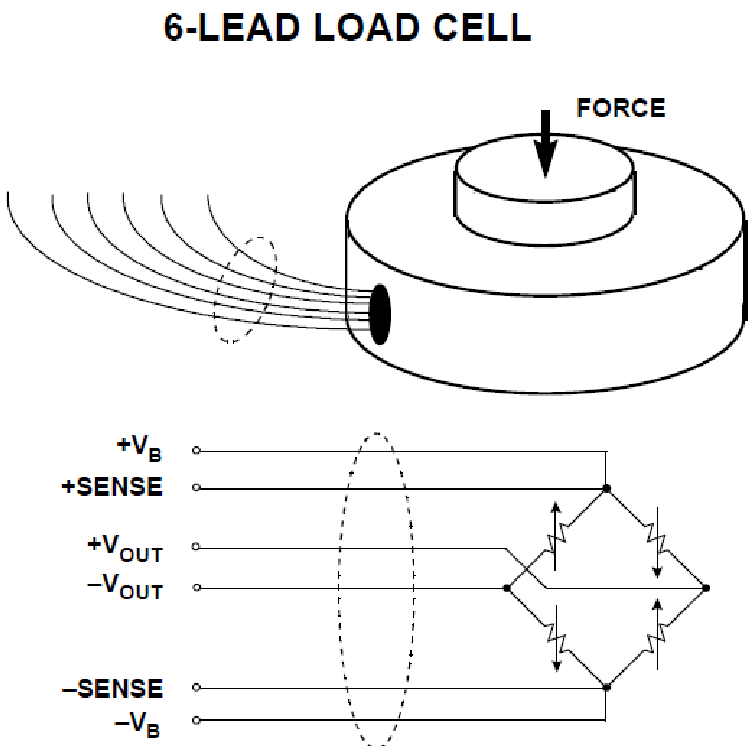
- Beam example



STRAIN GAGE BEAM FORCE SENSOR

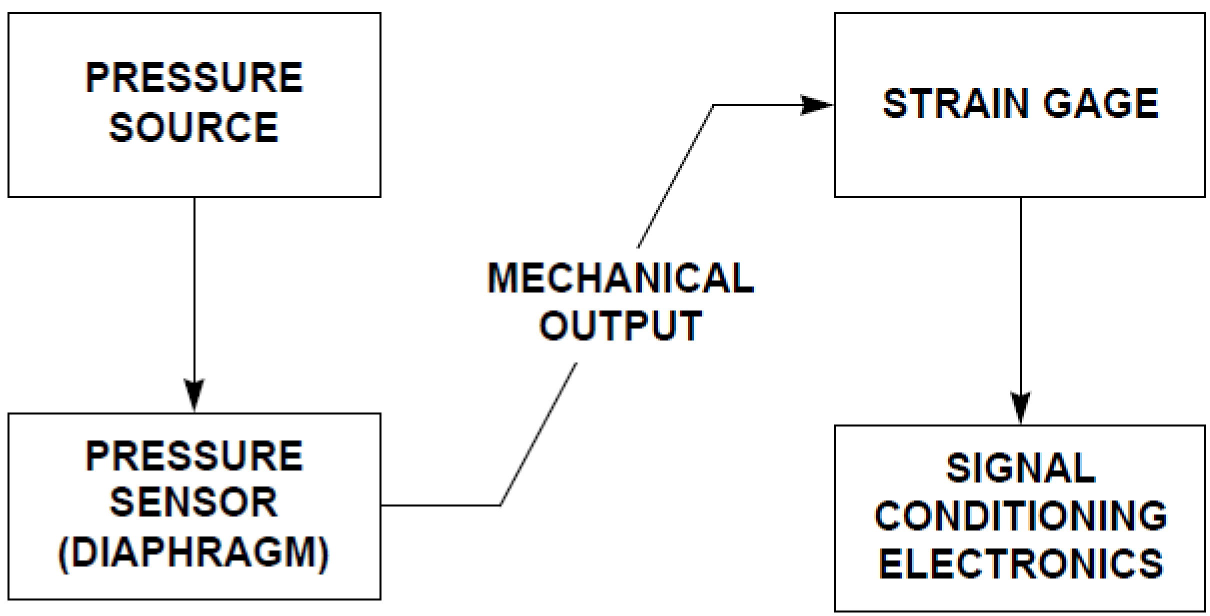


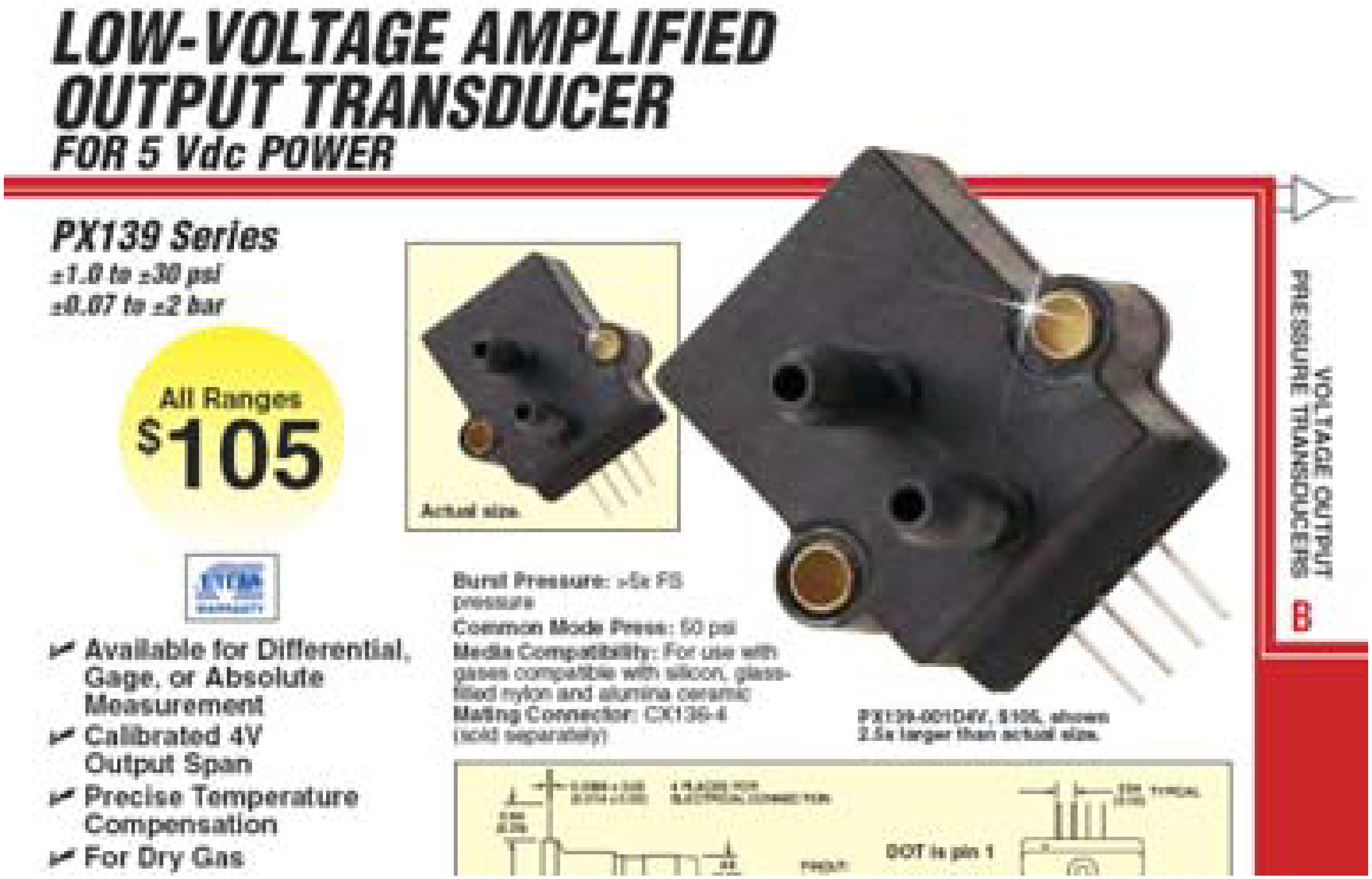
Load Cells



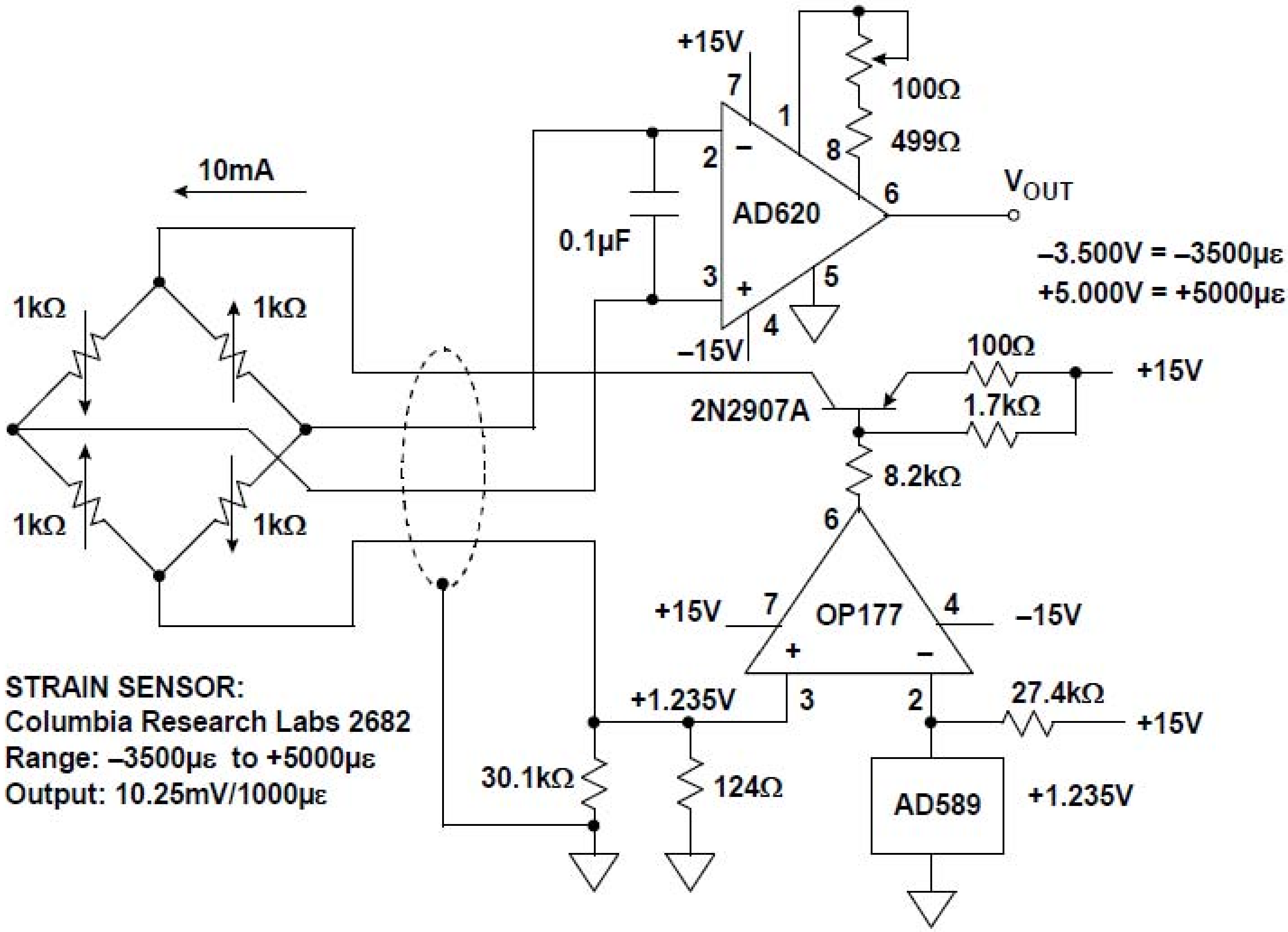
- Force range based on size of load cell structure and beams
- Typical 30 mV output for full load
- If source voltage too high you get excessive heating of resistors

PRESSURE SENSORS



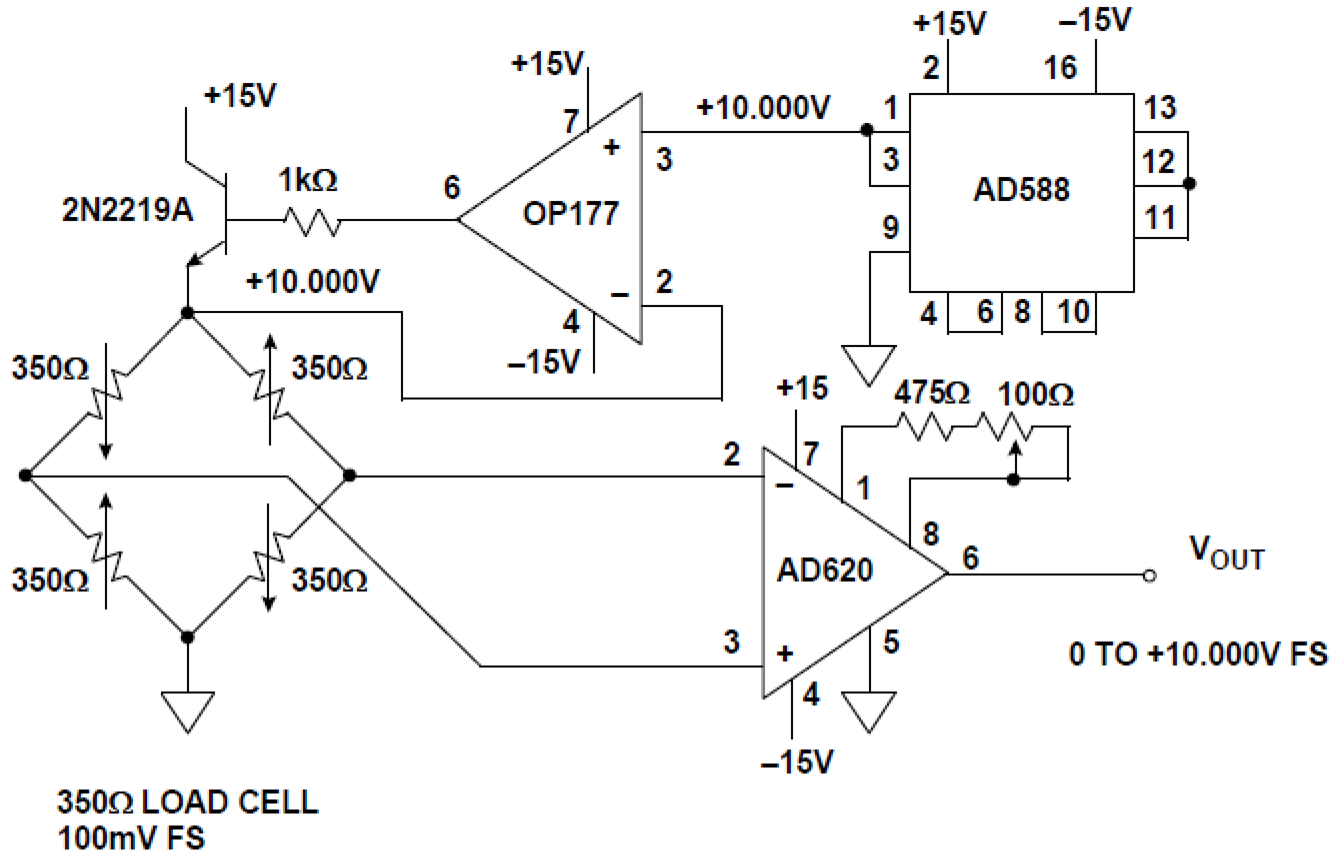

LOW-VOLTAGE AMPLIFIED
OUTPUT TRANSDUCER
FOR 5 Vdc POWER
PX139 Series
±1.0 to ±30 psi
±0.07 to ±2 bar
All Ranges
$105
Available for Differential, Gage, or Absolute Measurement
Calibrated 4V Output Span
Precise Temperature Compensation
For Dry Gas
Actual size.
Burst Pressure: >5x FS pressure
Common Mode Press: 50 psi
Media Compatibility: For use with gases compatible with silicon, glass-filled nylon and alumina ceramic
Mating Connector: CX136-4 (sold separately)
PX139-001D4V, $105, shown 2.5x larger than actual size.
DOT is pin 1
VOLTAGE OUTPUT PRESSURE TRANSDUCERS
B

PRECISION STRAIN GAGE SENSOR AMPLIFIER



STRAIN SENSOR:
Columbia Research Labs 2682
Range: –3500µε to +5000µε
Output: 10.25mV/1000µε

PRECISION LOAD CELL AMPLIFIER



SINGLE SUPPLY LOAD CELL AMPLIFIER