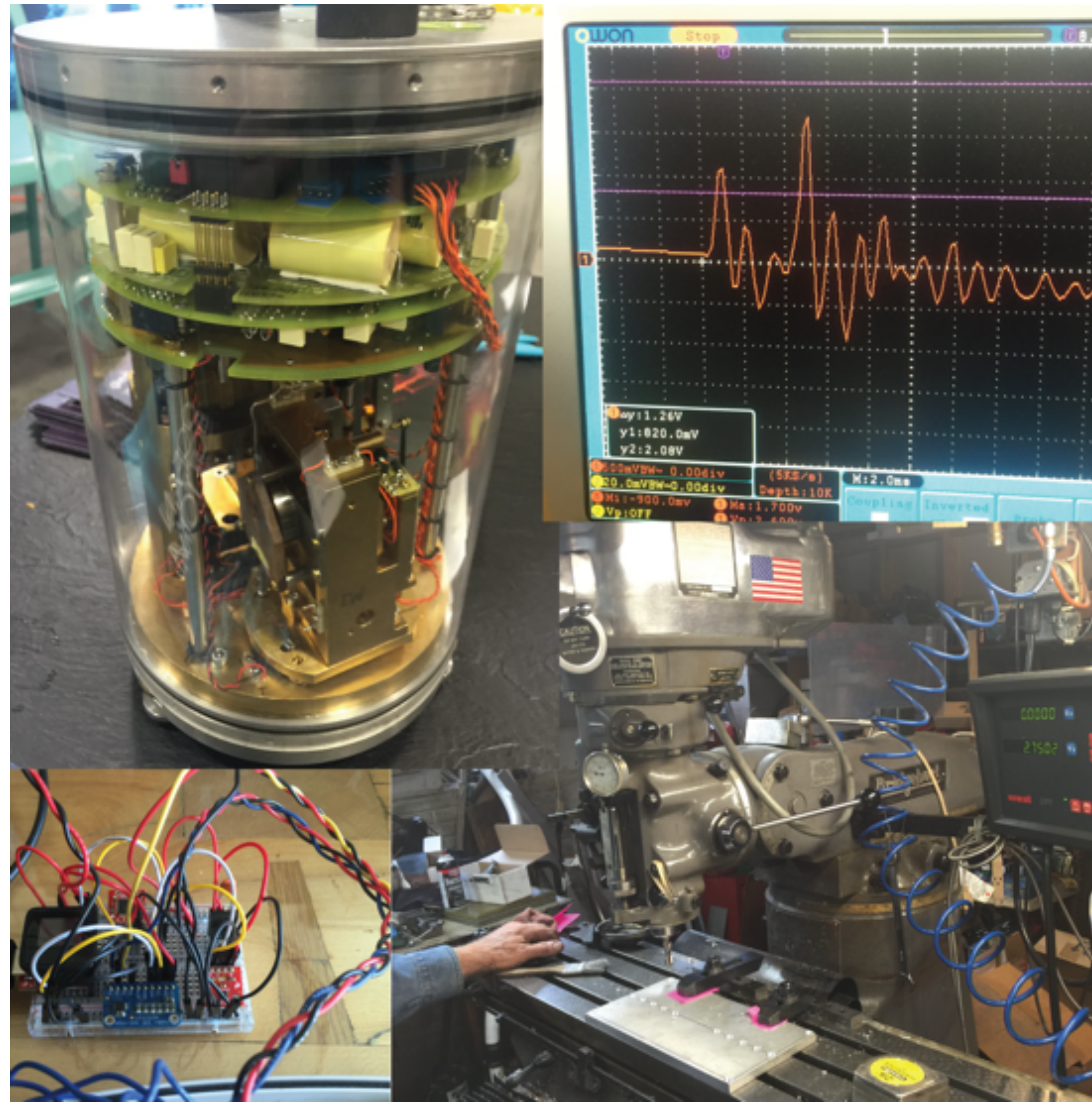
Transducers

J.R. Leeman and C. Marone

Techniques of Geoscientific Experimentation

October 18, 2016



Transducers are devices that convert one form of energy to another - we commonly use them as real-world interfaces

Active

Passive

Actuator

Bidirectional

Transducer Selection

When selecting a transducer, you must have a well defined application and consider a number of variables

- Range
- Linearity
- Sensitivity
- Response Time
- Stability
- Accuracy
- Durability
- Cost
- Signal Conditioning

Image: Wikipedia

Range is the span of values over which the transducer is rated to perform at

	Elite Series Best Performance Modular Design 		CPL230 Great Performance Compact Multi 	CPL350 Great Performance Compact Single 	CPA100 Analog Proximity Lower Cost 
	CPL490	CPL190/290			
Ranges	10-200 µm	10 µm to 12.5 mm	10 µm to 12.5 mm	10 µm to 12.5 mm	50 µm to 12.5 mm
Typical Resolution* @ 15 kHz	0.0007% F.S.*	0.003% F.S.*	0.004% F.S.*	0.004% F.S.*	0.03% F.S.*
Typical Linearity*	0.2%	0.2%	0.5%	0.5%	Nonlinear
Max Bandwidth	50 kHz	15 kHz	15 kHz	15 kHz	15 kHz
Zero/Offset Adjust	Yes	Yes	No	No	Yes
Gain Adjust	No	No	No	No	Yes
Setpoint/Switch Output	No	No	No	No	Yes
Typical Thermal Drift*	0.02% F.S./°C	0.04% F.S./°C	0.04% F.S./°C	0.04% F.S./°C	Driver: 0.2% F.S./°C Probe: 0.05% F.S./°C
LED Range Indicator	Yes	Yes	No	No	Yes
Cost	$$$$	$$$	$$	$$	$
Other Features	Optional Signal Processing and Meter Module Easy DAQ connection		Embeddable/OEM Design	Embeddable/OEM Design	Remote Zero and Gain Setpoint/Switch output

Linearity is how much the sensor diverges from an ideal linear sensor output

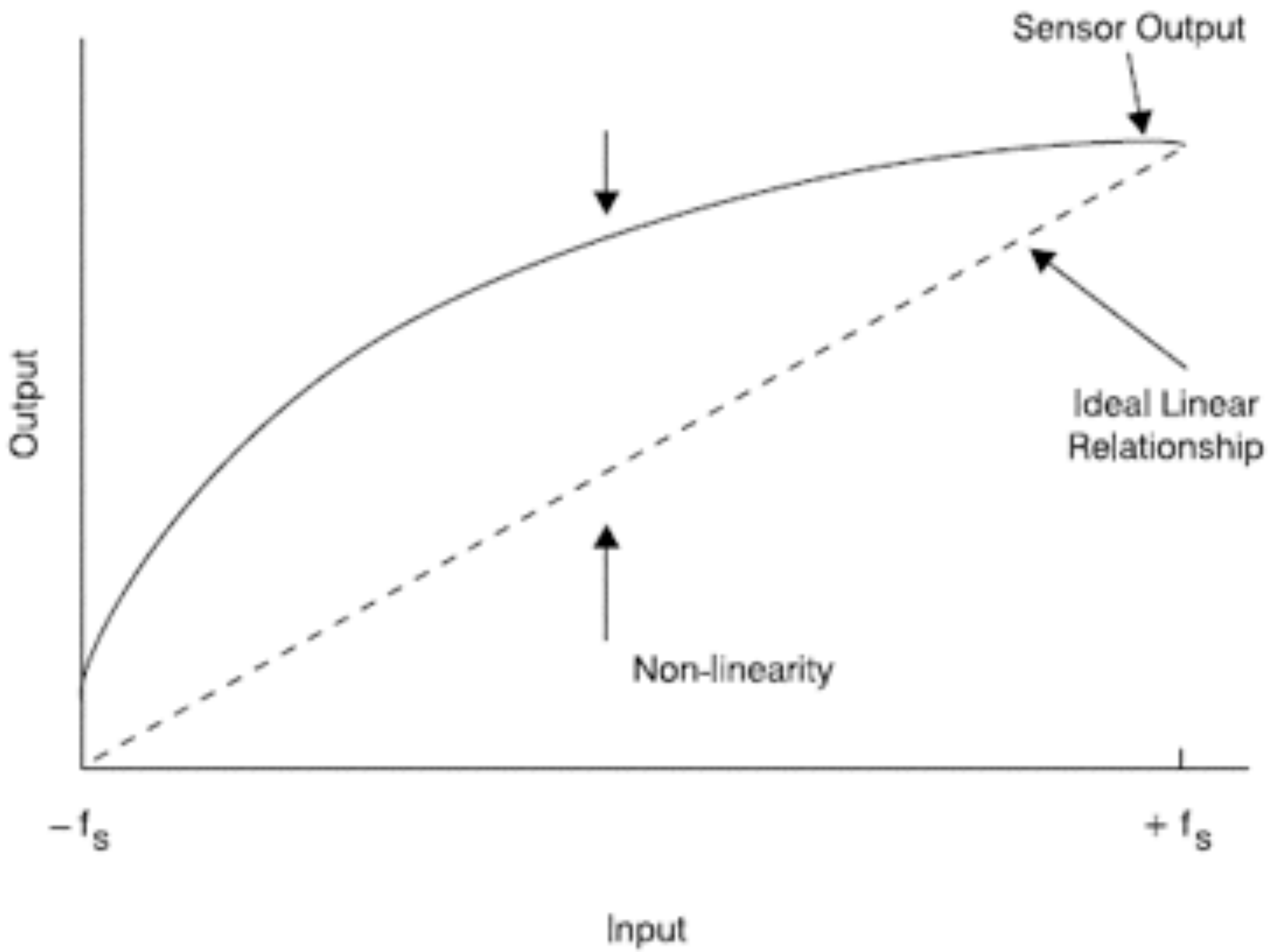


Image: dataforth.com

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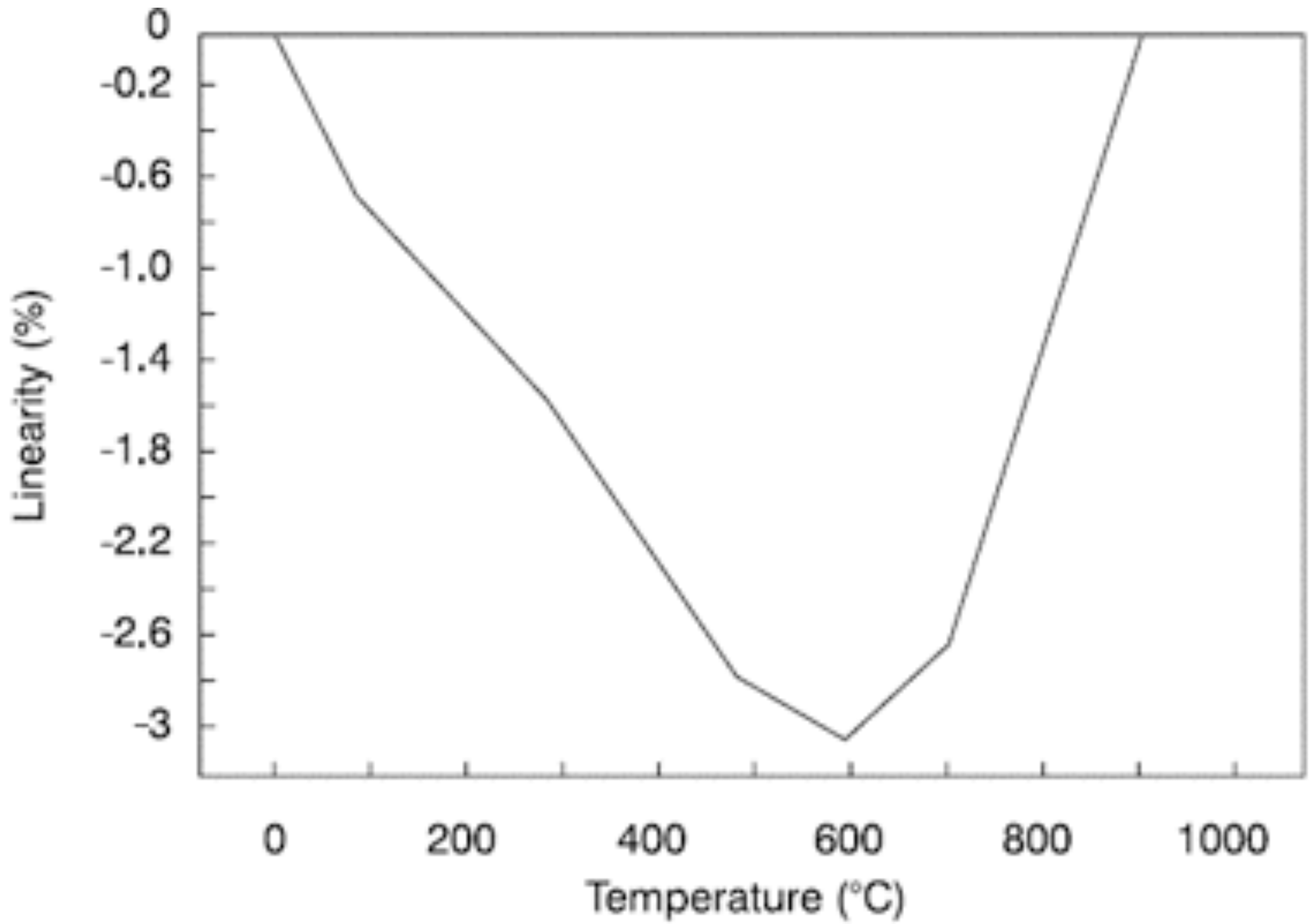


Image: dataforth.com

Sensitivity is the slope of the output - input curve

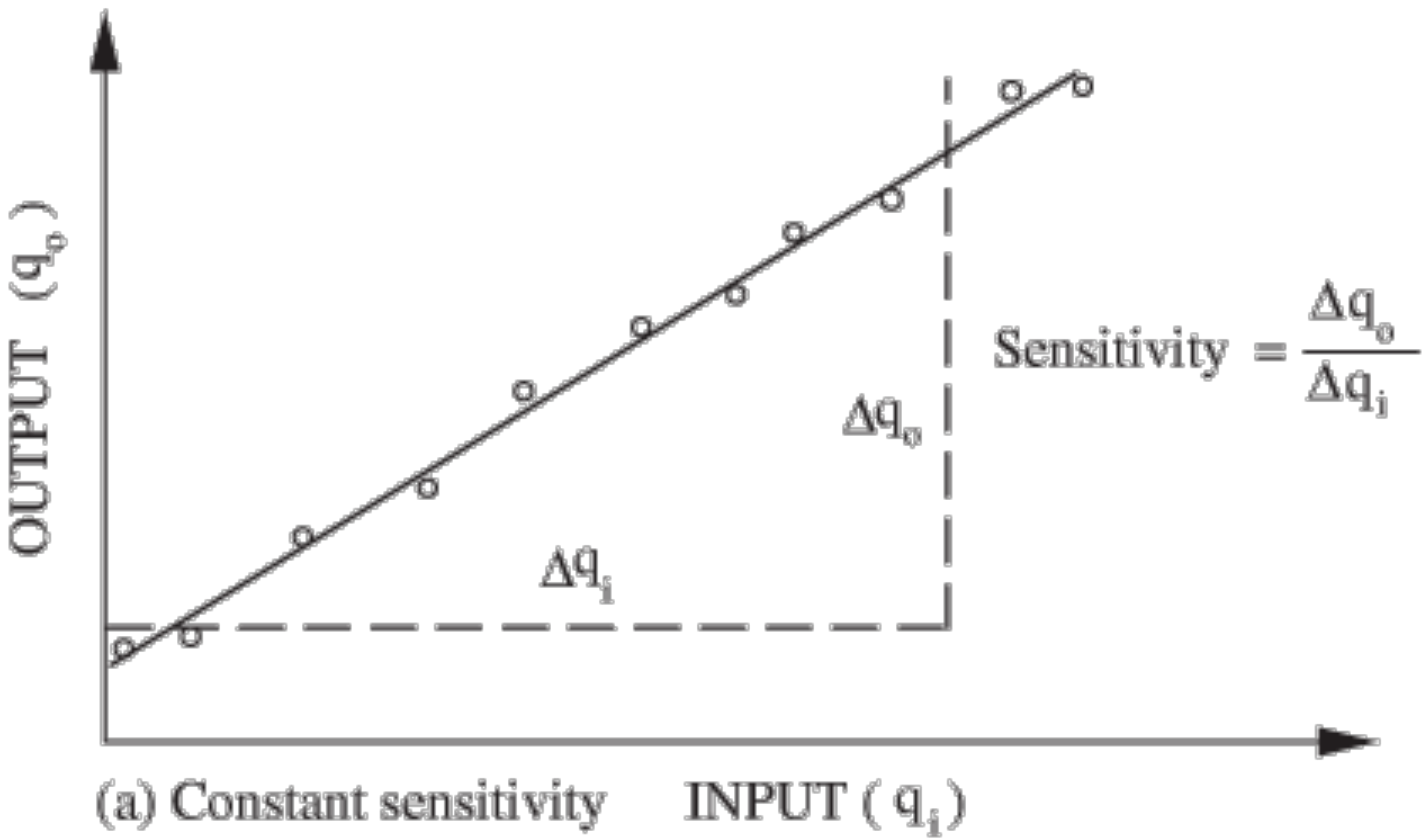


Image: USGS

Response time is how long the transducer takes to register a change in the physical quantity

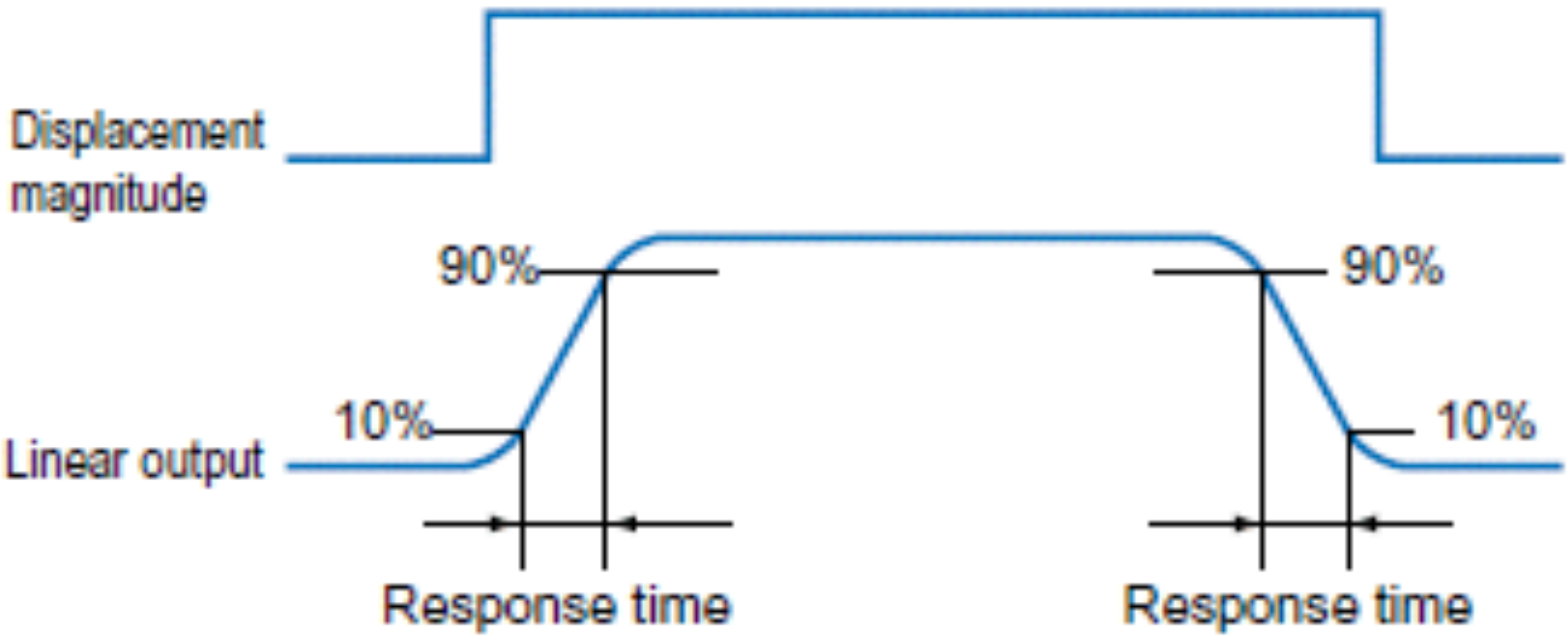


Image: Intech

Stability is how constant the output of a transducer remains when the physical stimulus is static

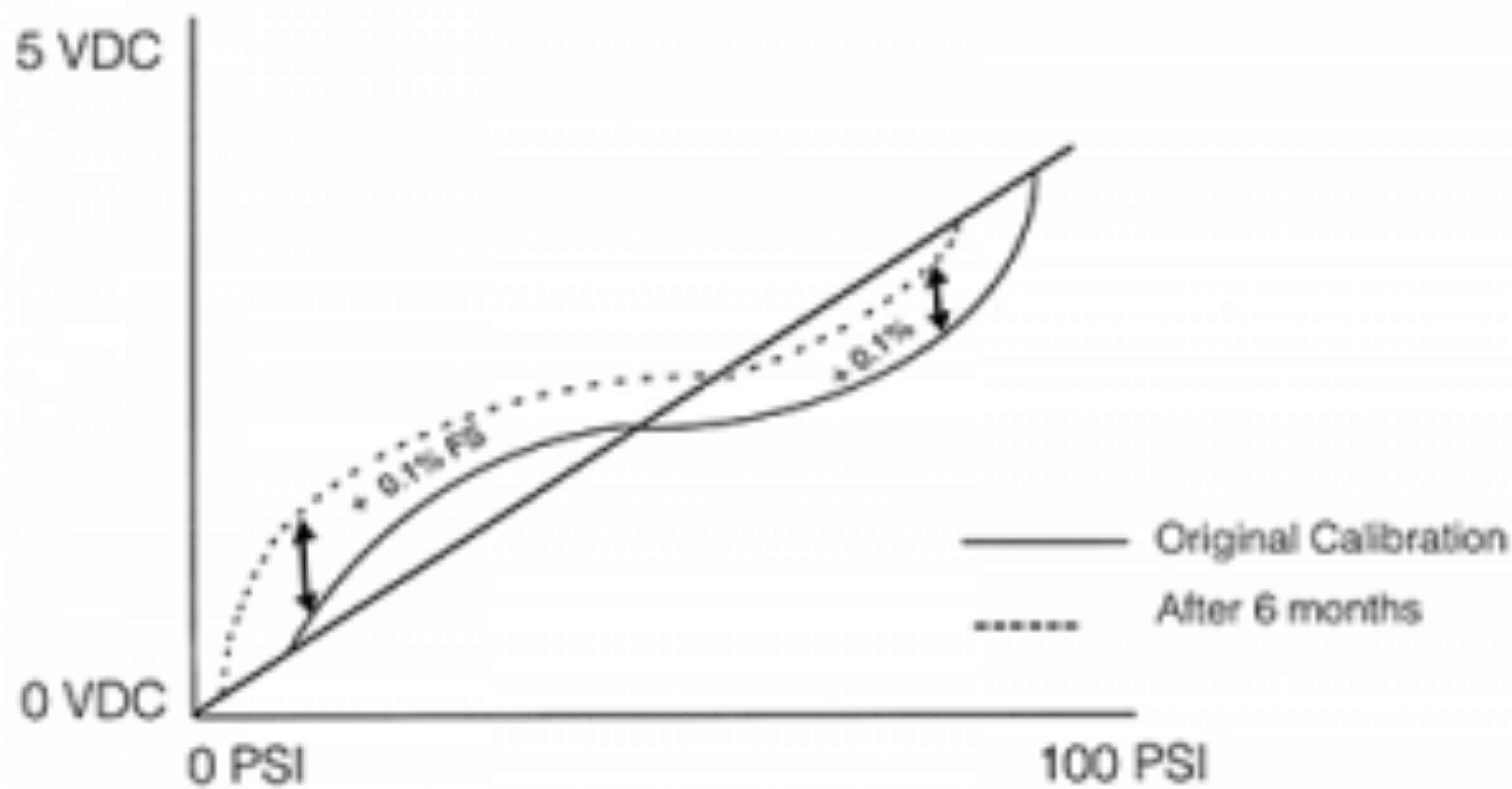


Image: Setra

Precision refers to the reproducibility of a given measurement

Accuracy is the maximum difference between the real and indicated values

Durability is how rugged the transducer is to the measurement environment it will be exposed to

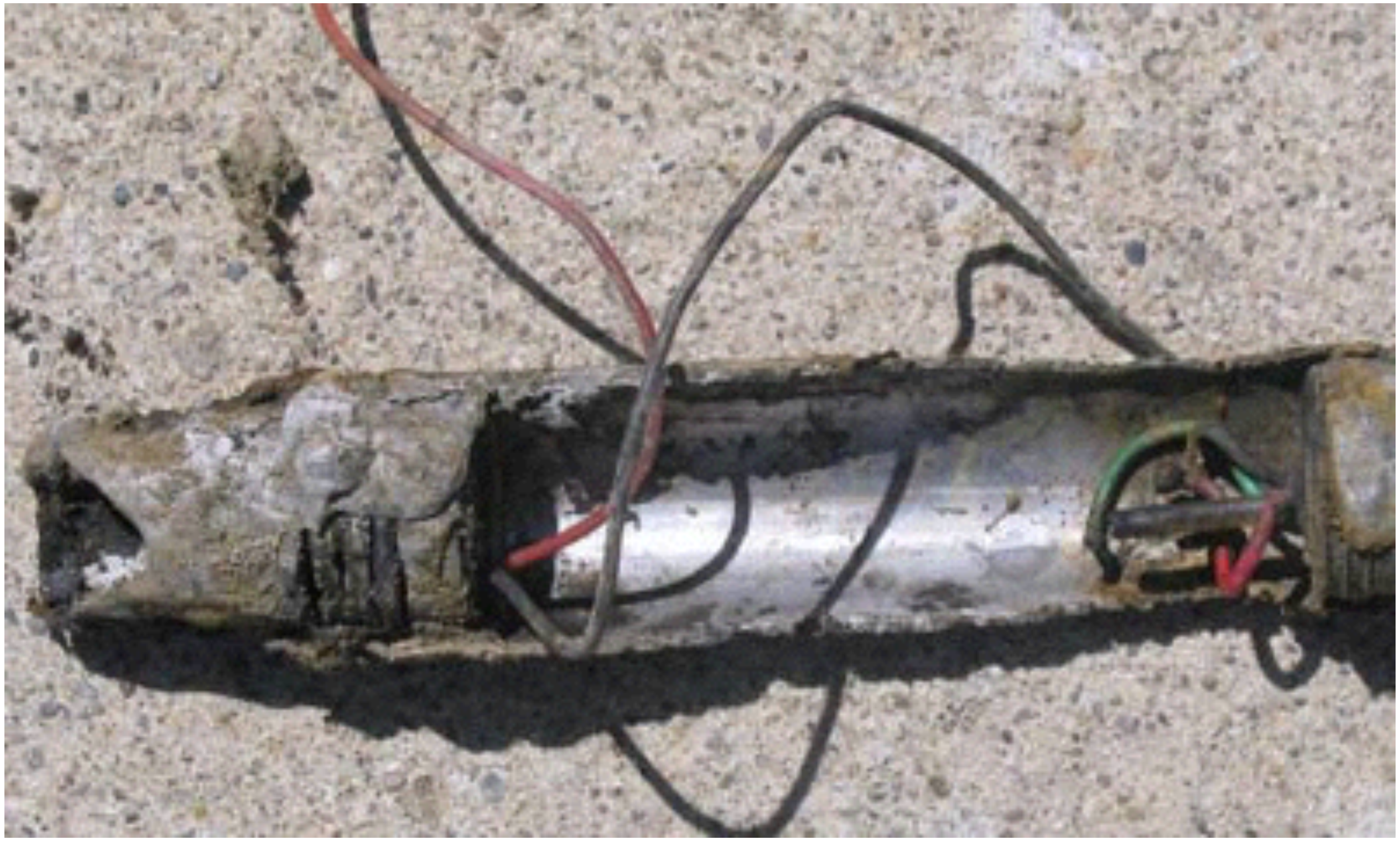


Image: APG Sensors

Signal conditioning requirements can greatly impact the ease of use and cost of a given transducer

Image: National Instruments

Offset refers to a DC bias is a given transducer's output

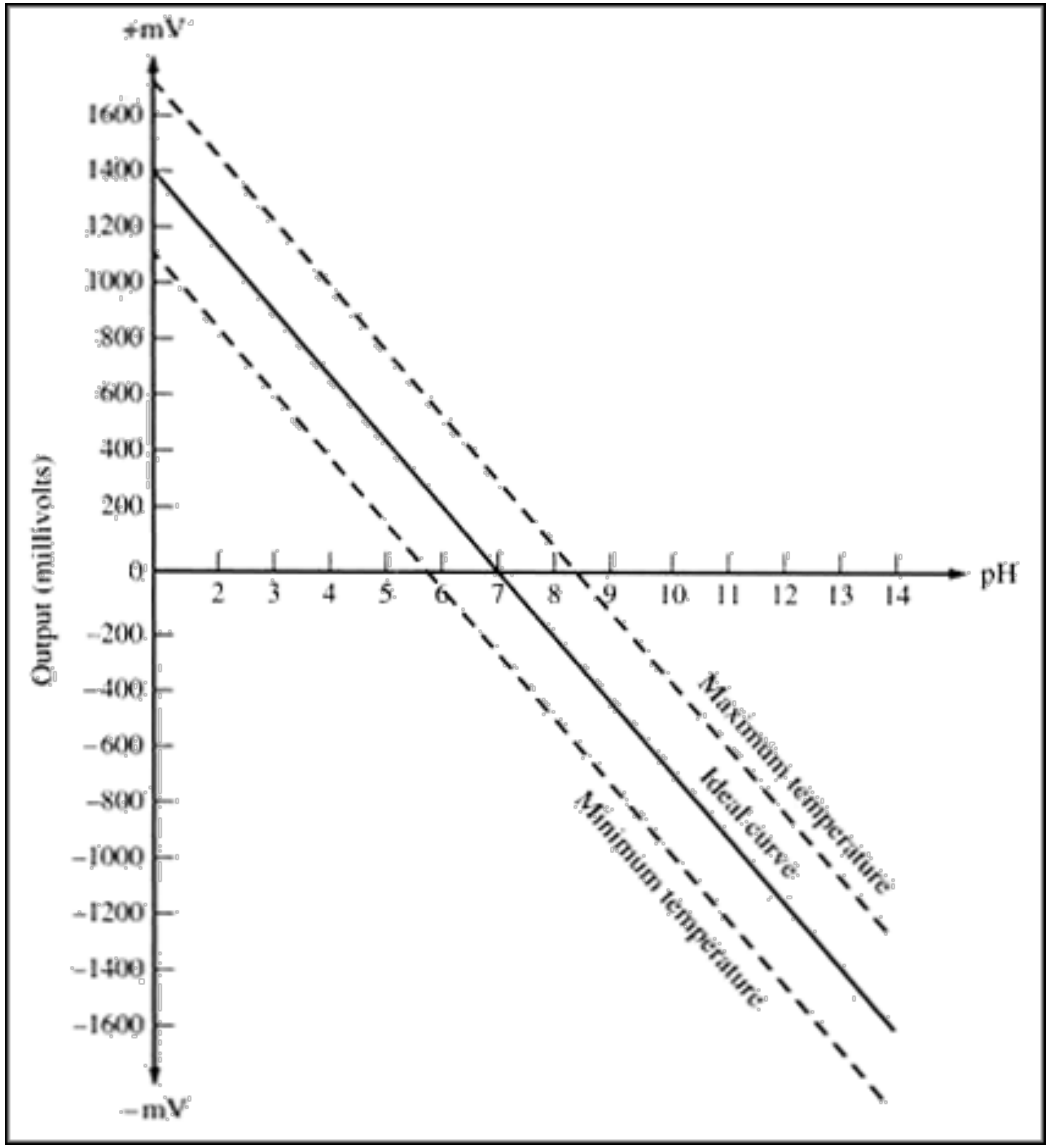


Image: National Instruments

Hysteresis is the transducer's sensitivity to which direction (up/down) the physical quantity is changing

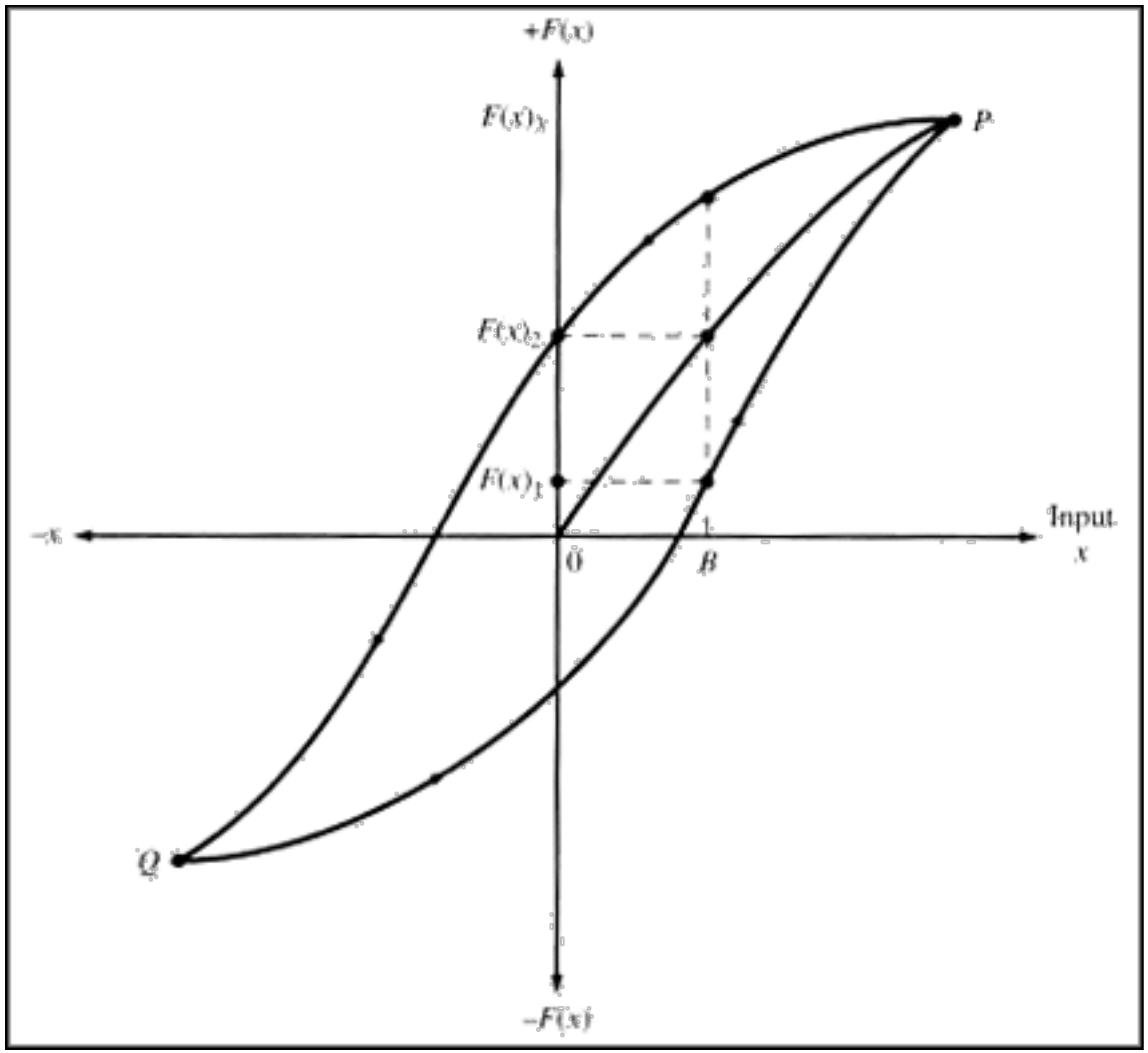


Image: National Instruments

Dynamic linearity describes how well a transducer's output can follow a rapidly changing quantity

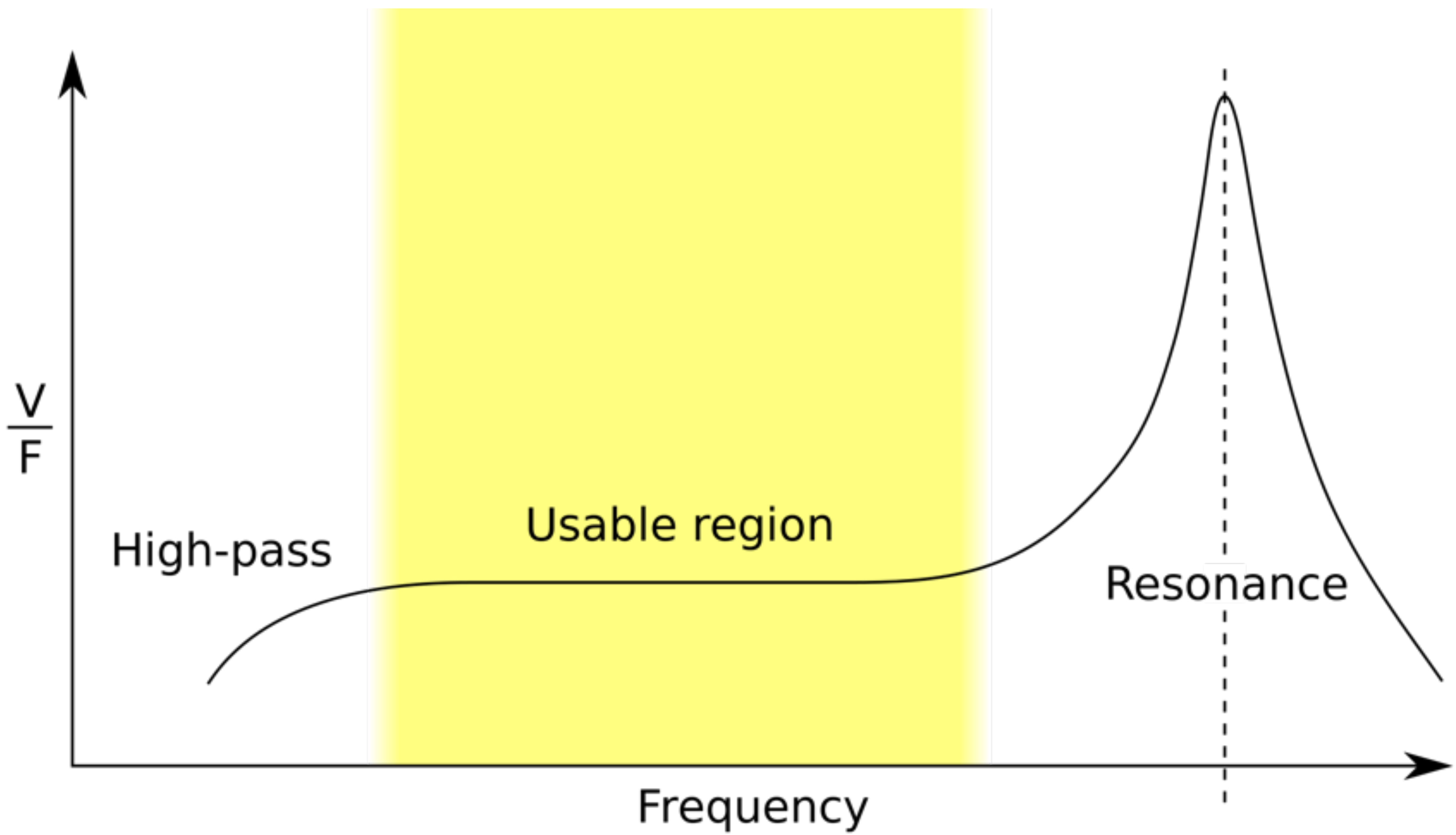
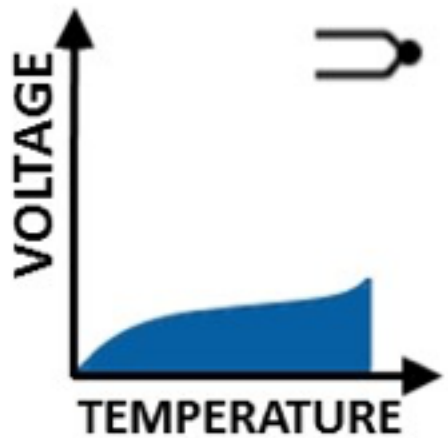
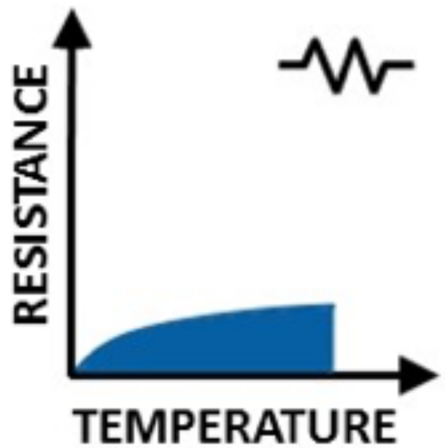
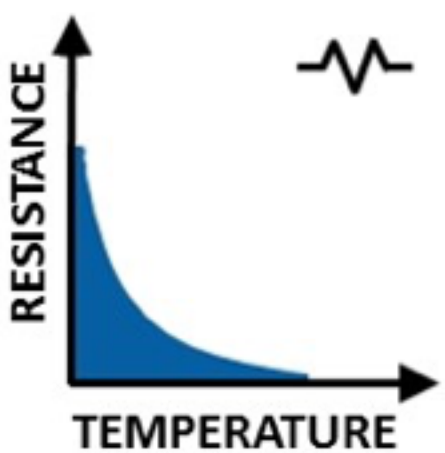


Image: Wikipedia

Temperature

	Advantages	Disadvantages
THERMOCOUPLES 	✓ Simple ✓ Rugged ✓ Inexpensive ✓ No external power ✓ Wide temperature range ✓ Variety of styles	× Nonlinear response × Small sensitivity × Small output voltage × Requires CJC × Least stable
RTD 	✓ Most stable ✓ Good Linearity ✓ Most accurate	× Low sensitivity × Externally powered × Costly × Small output resistance × Self-heating error
THERMISTOR 	✓ Fast ✓ High output ✓ Minimal lead resistance error	× Limited temperature range × Externally powered × Nonlinear × More fragile × Self-heating error

Each type of temperature sensor has a different output curve

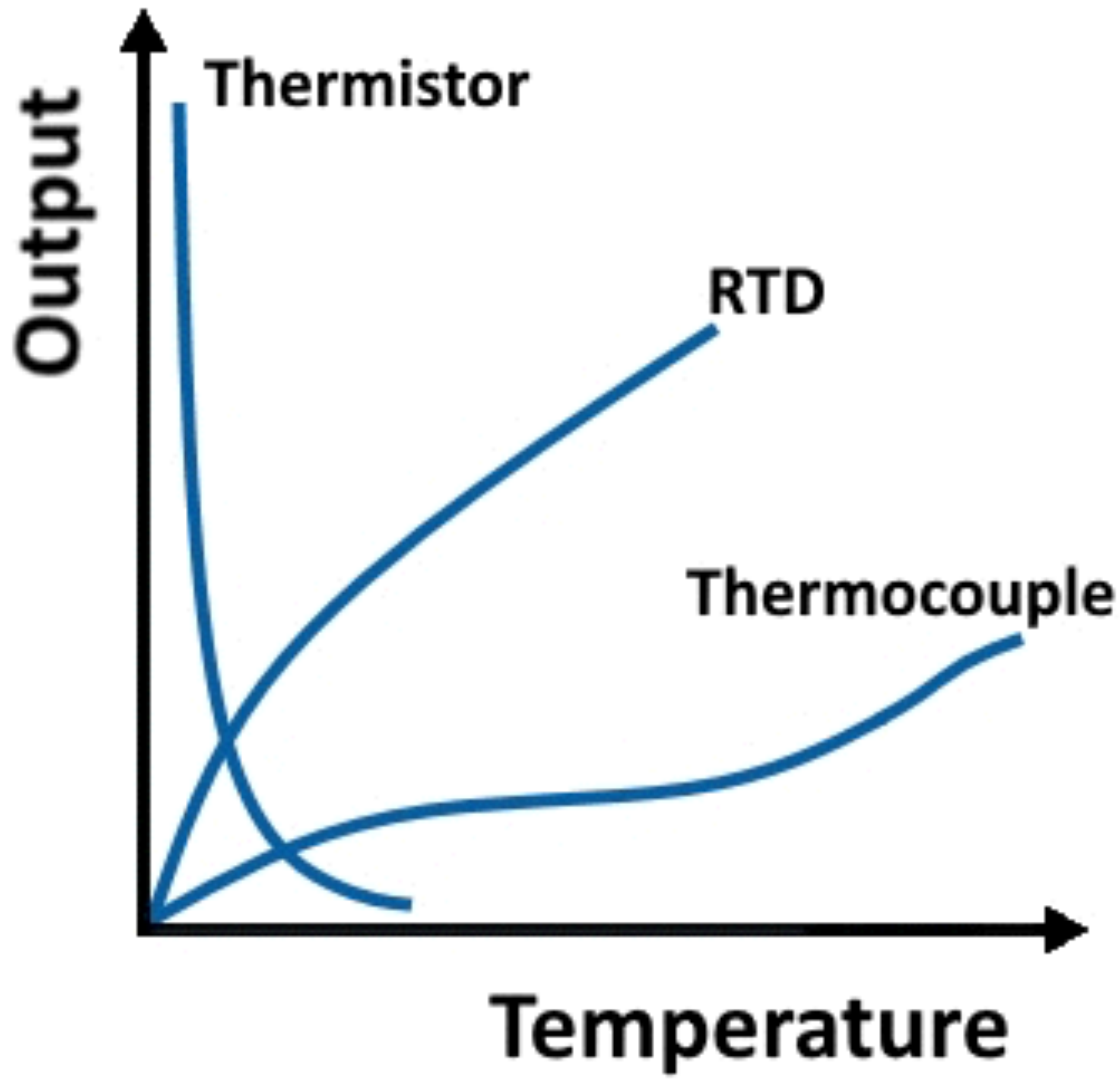


Image: National Instruments

Thermocouples work on a principle called the Seebeck effect

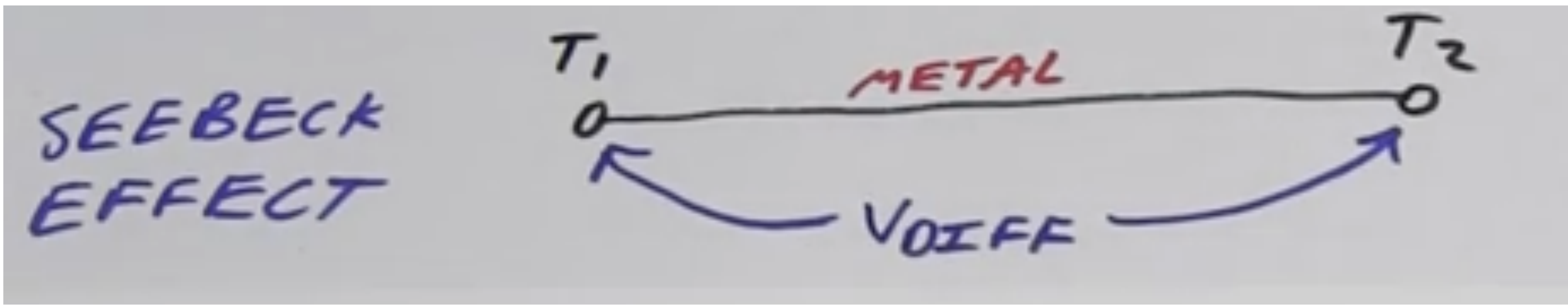


Image: EEVBlog

Two dissimilar metals are joined to make a transducer

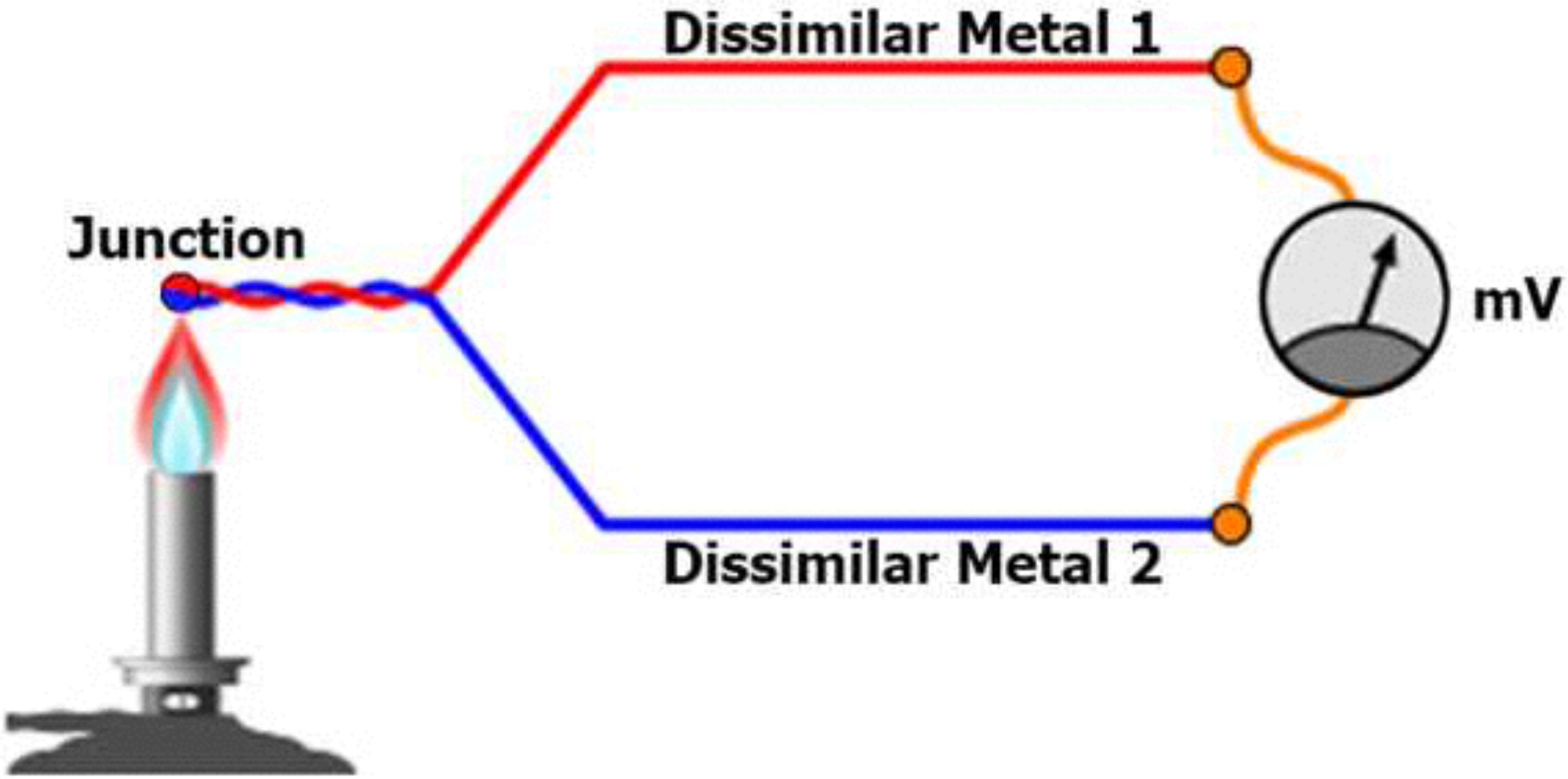


Image: Sterling Sensors

There are many metal combinations or types of thermocouples

Common Thermocouple Temperature Ranges			
Calibration	Temperature Range	Standard Limits of Error	Special Limits of Error
J	0° to 750°C (32° to 1382°F)	Greater of 2.2°C or 0.75%	Greater of 1.1°C or 0.4%
K	-200° to 1250°C (-328° to 2282°F)	Greater of 2.2°C or 0.75%	Greater of 1.1°C or 0.4%
E	-200° to 900°C (-328° to 1652°F)	Greater of 1.7°C or 0.5%	Greater of 1.0°C or 0.4%
T	-250° to 350°C (-328° to 662°F)	Greater of 1.0°C or 0.75%	Greater of 0.5°C or 0.4%

Image: OMEGA

The challenge is unintentional junctions in the system

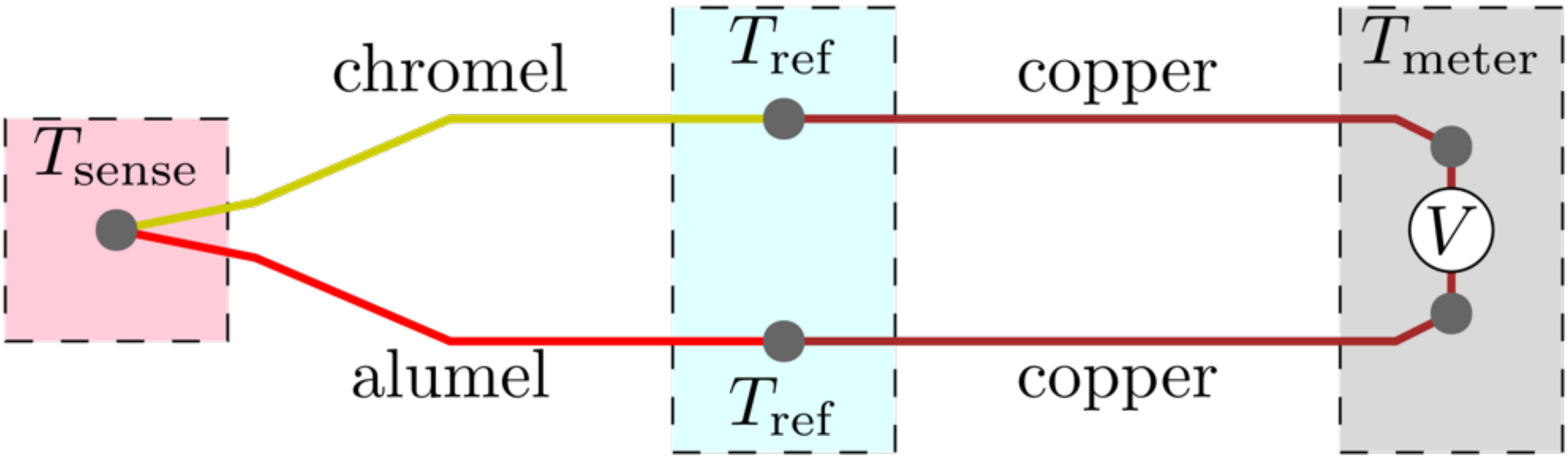


Image: Wikipedia

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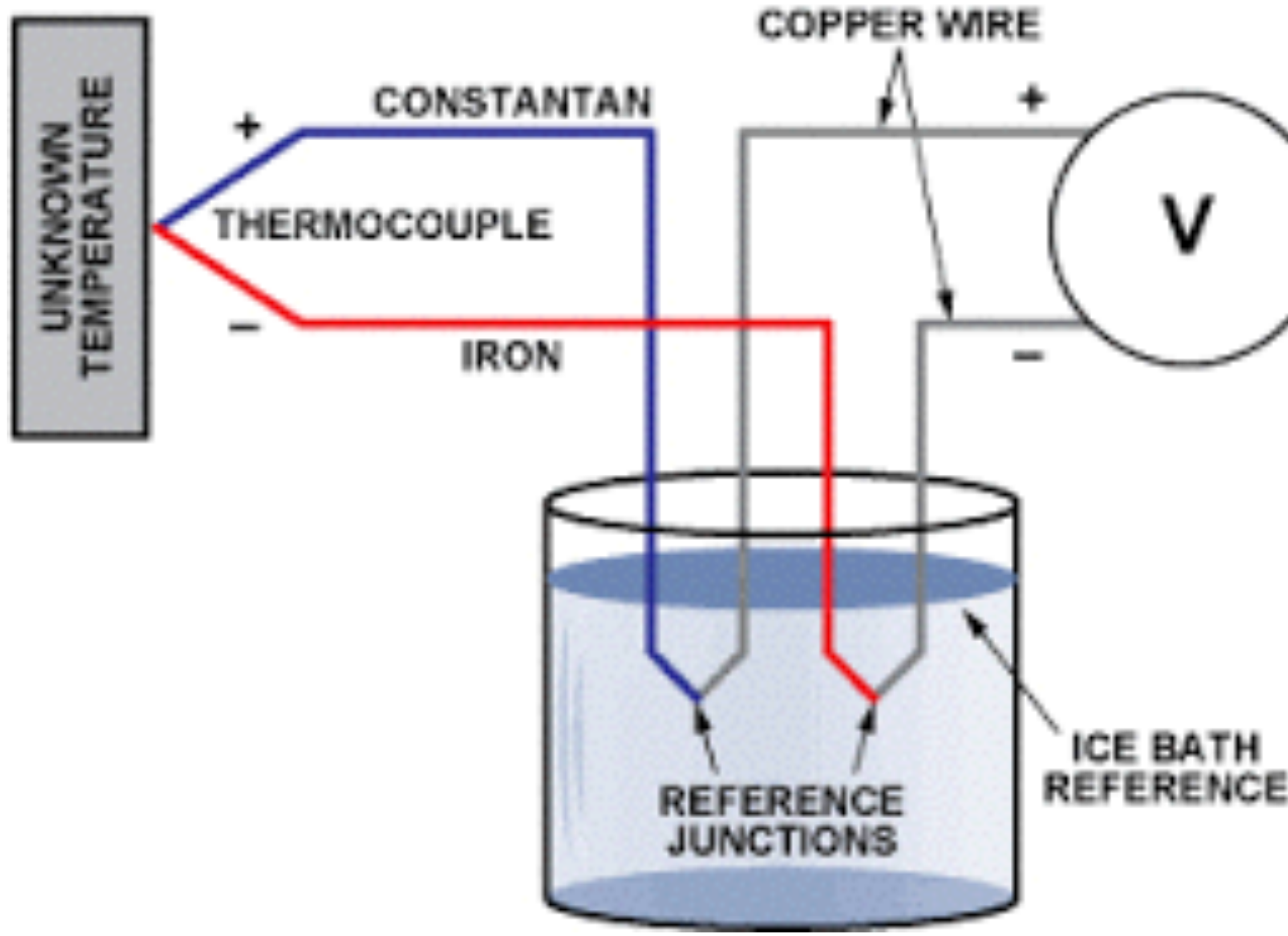


Image: Analog Devices

We measure the temperature of the "cold junction" and compensate for it with NIST tables

ITS-90 Table for type K thermocouple

Thermoelectric Voltage in mV

°C	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10
-270	-6.458										
-260	-6.441	-6.444	-6.446	-6.448	-6.450	-6.452	-6.453	-6.455	-6.456	-6.457	-6.458
-250	-6.404	-6.408	-6.413	-6.417	-6.421	-6.425	-6.429	-6.432	-6.435	-6.438	-6.441
-240	-6.344	-6.351	-6.358	-6.364	-6.370	-6.377	-6.382	-6.388	-6.393	-6.399	-6.404
-230	-6.262	-6.271	-6.280	-6.289	-6.297	-6.306	-6.314	-6.322	-6.329	-6.337	-6.344
-220	-6.158	-6.170	-6.181	-6.192	-6.202	-6.213	-6.223	-6.233	-6.243	-6.252	-6.262
-210	-6.035	-6.048	-6.061	-6.074	-6.087	-6.099	-6.111	-6.123	-6.135	-6.147	-6.158
-200	-5.891	-5.907	-5.922	-5.936	-5.951	-5.965	-5.980	-5.994	-6.007	-6.021	-6.035
-190	-5.730	-5.747	-5.763	-5.780	-5.797	-5.813	-5.829	-5.845	-5.861	-5.876	-5.891
-180	-5.550	-5.569	-5.588	-5.606	-5.624	-5.642	-5.660	-5.678	-5.695	-5.713	-5.730
-170	-5.354	-5.374	-5.395	-5.415	-5.435	-5.454	-5.474	-5.493	-5.512	-5.531	-5.550
-160	-5.141	-5.163	-5.185	-5.207	-5.228	-5.250	-5.271	-5.292	-5.313	-5.333	-5.354
-150	-4.913	-4.936	-4.960	-4.983	-5.006	-5.029	-5.052	-5.074	-5.097	-5.119	-5.141
-140	-4.669	-4.694	-4.719	-4.744	-4.768	-4.793	-4.817	-4.841	-4.865	-4.889	-4.913
-130	-4.411	-4.437	-4.463	-4.490	-4.516	-4.542	-4.567	-4.593	-4.618	-4.644	-4.669
-120	-4.138	-4.166	-4.194	-4.221	-4.249	-4.276	-4.303	-4.330	-4.357	-4.384	-4.411
-110	-3.852	-3.882	-3.911	-3.939	-3.968	-3.997	-4.025	-4.054	-4.082	-4.110	-4.138
-100	-3.554	-3.584	-3.614	-3.645	-3.675	-3.705	-3.734	-3.764	-3.794	-3.823	-3.852
-90	-3.243	-3.274	-3.306	-3.337	-3.368	-3.400	-3.431	-3.462	-3.492	-3.523	-3.554
-80	-2.920	-2.953	-2.986	-3.018	-3.050	-3.083	-3.115	-3.147	-3.179	-3.211	-3.243
-70	-2.587	-2.620	-2.654	-2.688	-2.721	-2.755	-2.788	-2.821	-2.854	-2.887	-2.920
-60	-2.243	-2.278	-2.312	-2.347	-2.382	-2.416	-2.450	-2.485	-2.519	-2.553	-2.587
-50	-1.889	-1.925	-1.961	-1.996	-2.032	-2.067	-2.103	-2.138	-2.173	-2.208	-2.243
-40	-1.527	-1.564	-1.600	-1.637	-1.673	-1.709	-1.745	-1.782	-1.818	-1.854	-1.889
-30	-1.156	-1.194	-1.231	-1.268	-1.305	-1.343	-1.380	-1.417	-1.453	-1.490	-1.527
-20	-0.778	-0.816	-0.854	-0.892	-0.930	-0.968	-1.006	-1.043	-1.081	-1.119	-1.156
-10	-0.392	-0.431	-0.470	-0.508	-0.547	-0.586	-0.624	-0.663	-0.701	-0.739	-0.778
0	0.000	-0.039	-0.079	-0.118	-0.157	-0.197	-0.236	-0.275	-0.314	-0.353	-0.392
°C	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10

Image: NIST

Or use a high order polynomial fit

Type K Thermocouples - coefficients of approximate inverse functions giving temperature, t_{90}, as a function of the thermoelectric voltage, E, in selected temperature and voltage ranges. The functions are of the form:

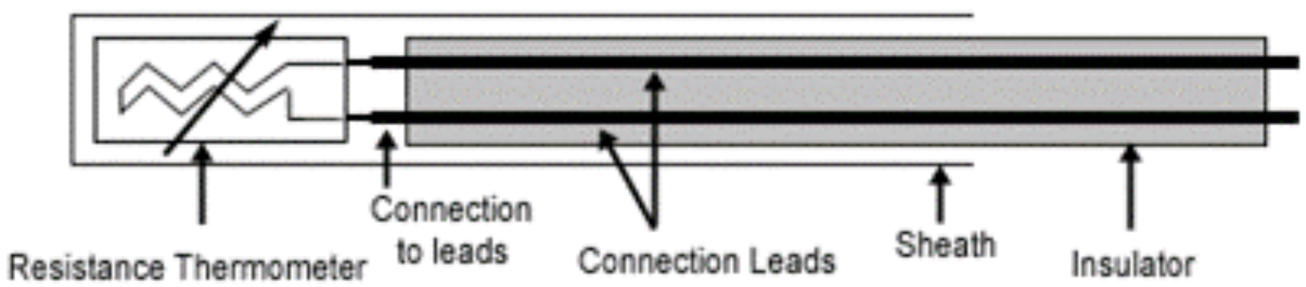
$$t_{90} = c_o + c_1 E + c_2 E^2 \quad c_i E^i$$

where E is in microvolts and t_{90} is in degrees Celsius.

Temperature Range:	**-200 to 0°C**	**0 to 500°C**	**500 to 1,372°C**
Voltage Range:	**-5891 to 0 µV**	**0 to 20,644 µV**	**20,644 to 54,886 µV**
$c_0 =$	0.000 000 0	0.000 000	$-1.318\,058 \times 10^{2}$
$c_1 =$	$2.517\,346\,2 \times 10^{-2}$	$2.508\,355 \times 10^{-2}$	$4.830\,222 \times 10^{-2}$
$c_2 =$	$-1.166\,287\,8 \times 10^{-6}$	$7.860\,106 \times 10^{-8}$	$-1.646\,031 \times 10^{-6}$
$c_3 =$	$-1.083\,363\,8 \times 10^{-9}$	$-2.503\,131 \times 10^{-10}$	$5.464\,731 \times 10^{-11}$
$c_4 =$	$-8.977\,354\,0 \times 10^{-13}$	$8.315\,270 \times 10^{-14}$	$-9.650\,715 \times 10^{-16}$
$c_5 =$	$-3.734\,237\,7 \times 10^{-16}$	$-1.228\,034 \times 10^{-17}$	$8.802\,193 \times 10^{-21}$
$c_6 =$	$-8.663\,264\,3 \times 10^{-20}$	$9.804\,036 \times 10^{-22}$	$-3.110\,810 \times 10^{-26}$
$c_7 =$	$-1.045\,059\,8 \times 10^{-23}$	$-4.413\,030 \times 10^{-26}$	
$c_8 =$	$-5.192\,057\,7 \times 10^{-28}$	$1.057\,734 \times 10^{-30}$	
$c_9 =$		$-1.052\,755 \times 10^{-35}$	
Error Range:	0.04°C to -0.02°C	0.04°C to -0.05°C	0.06°C to -0.05°C

Image: OMEGA

RTDs change resistance based on the temperature



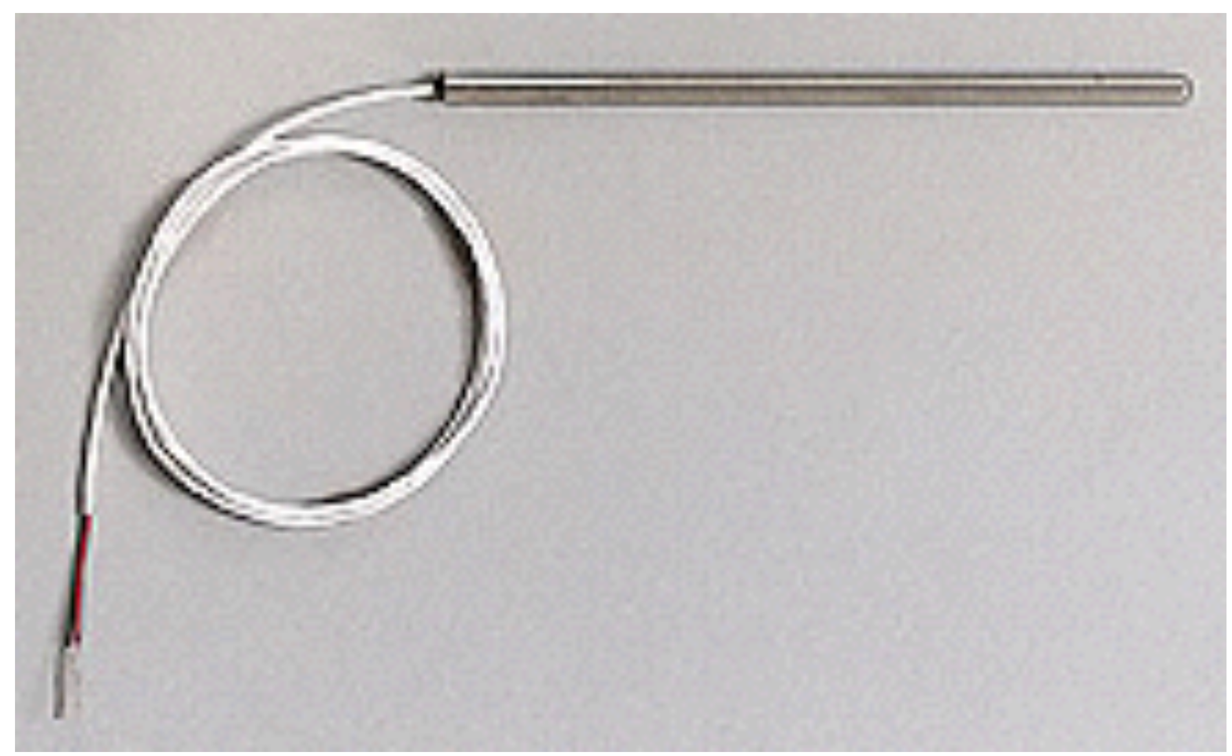
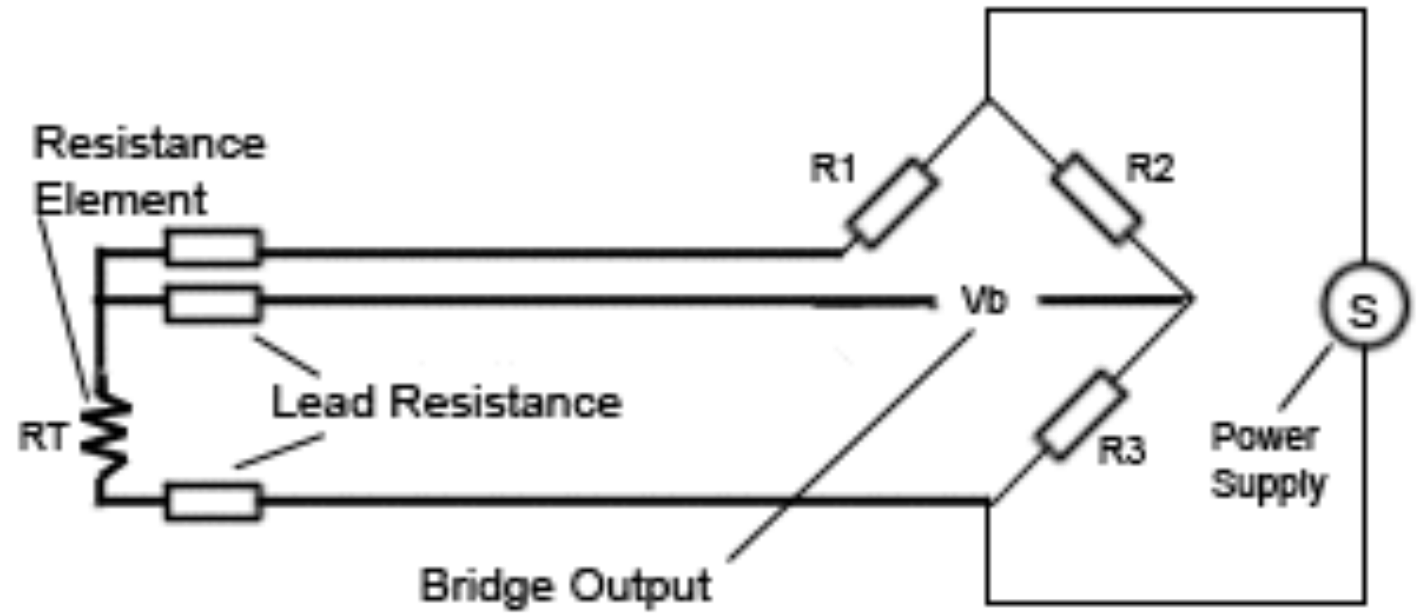
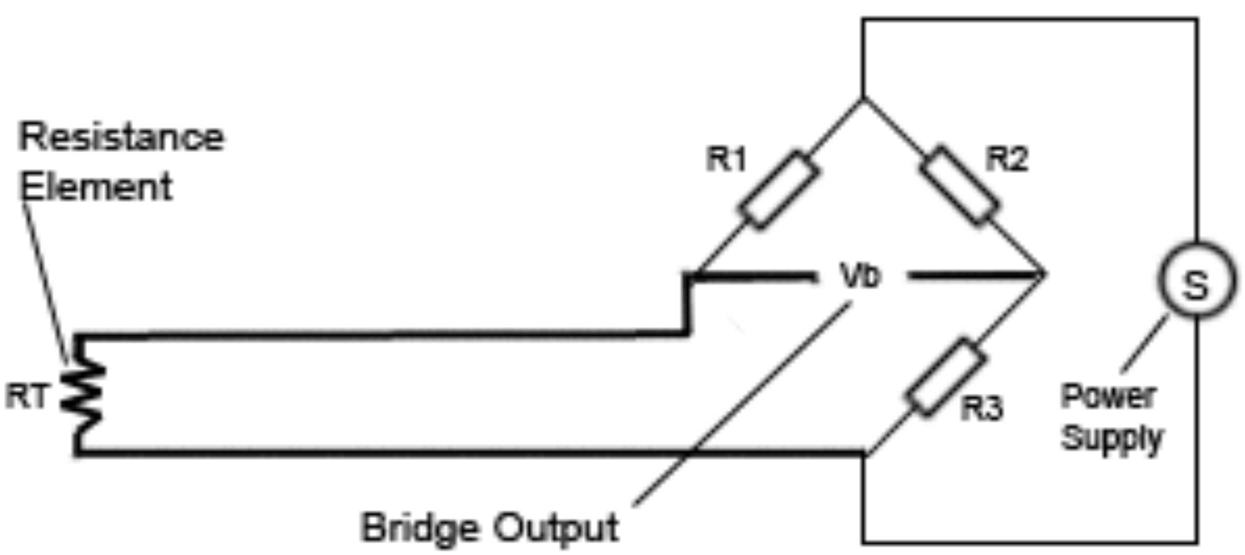


Image: Wikipedia/OMEGA

Multiple signal conditioning strategies can be used depending on the requirements and cost tradeoff





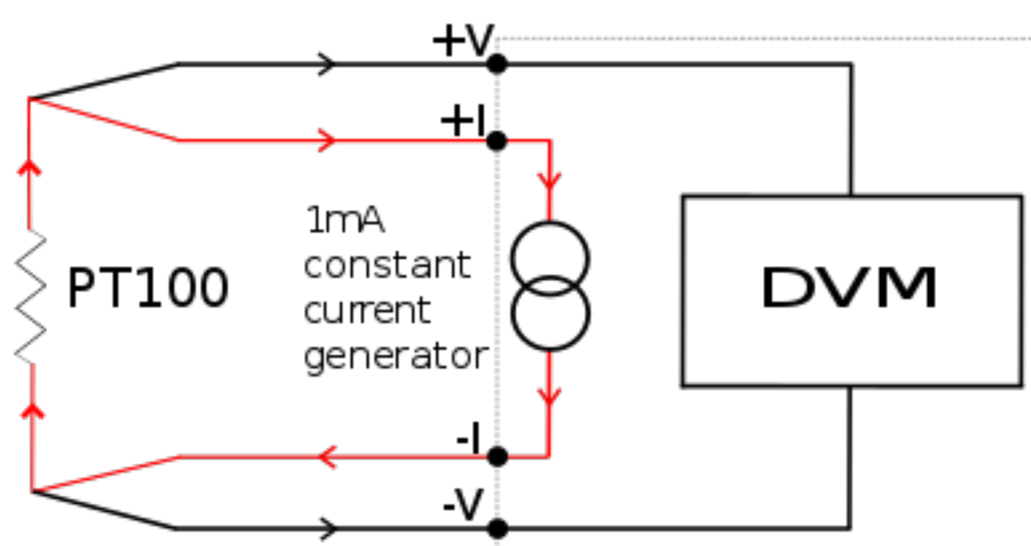


Image: Wikipedia

Thermistors also change their resistance with temperature

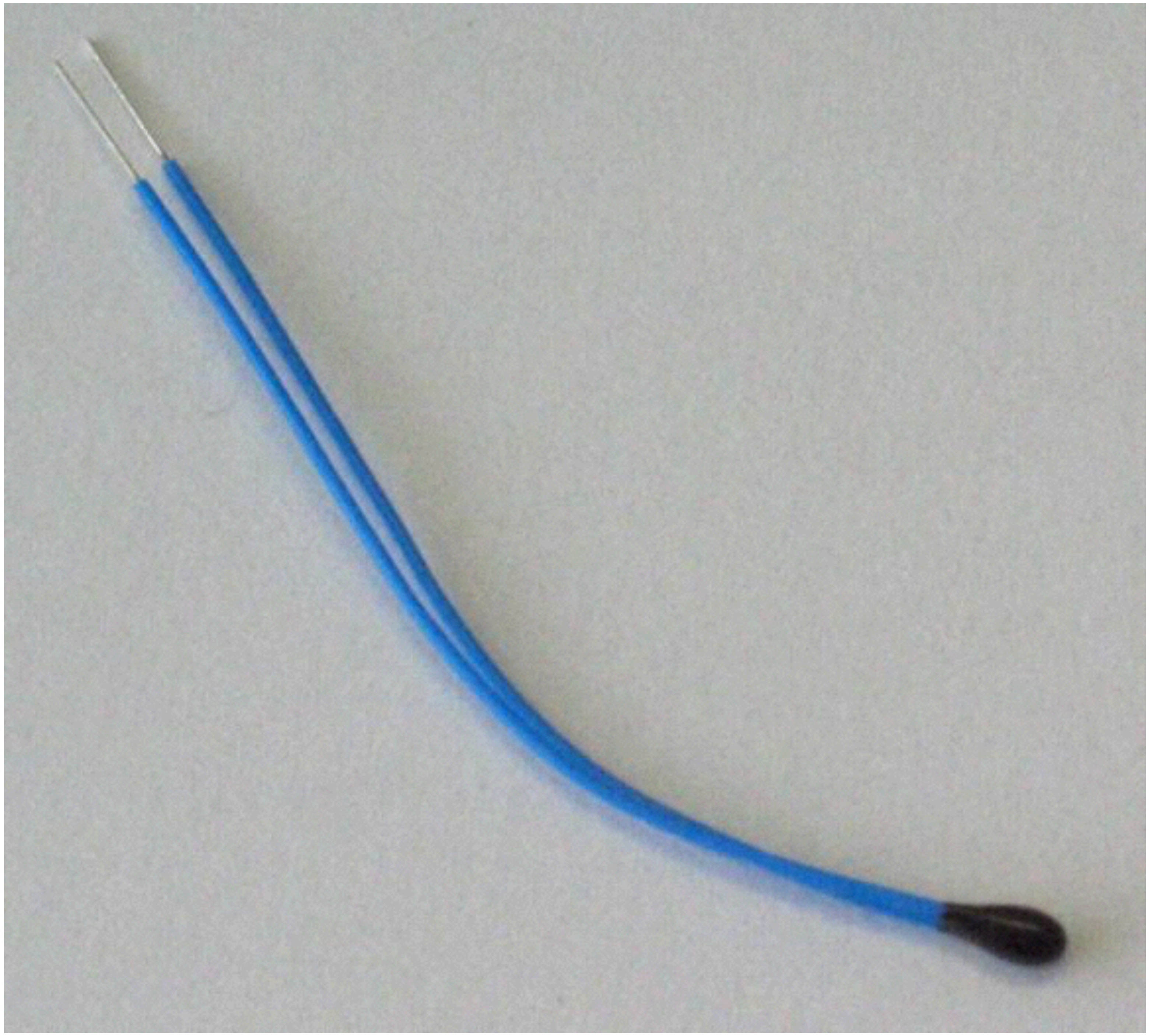
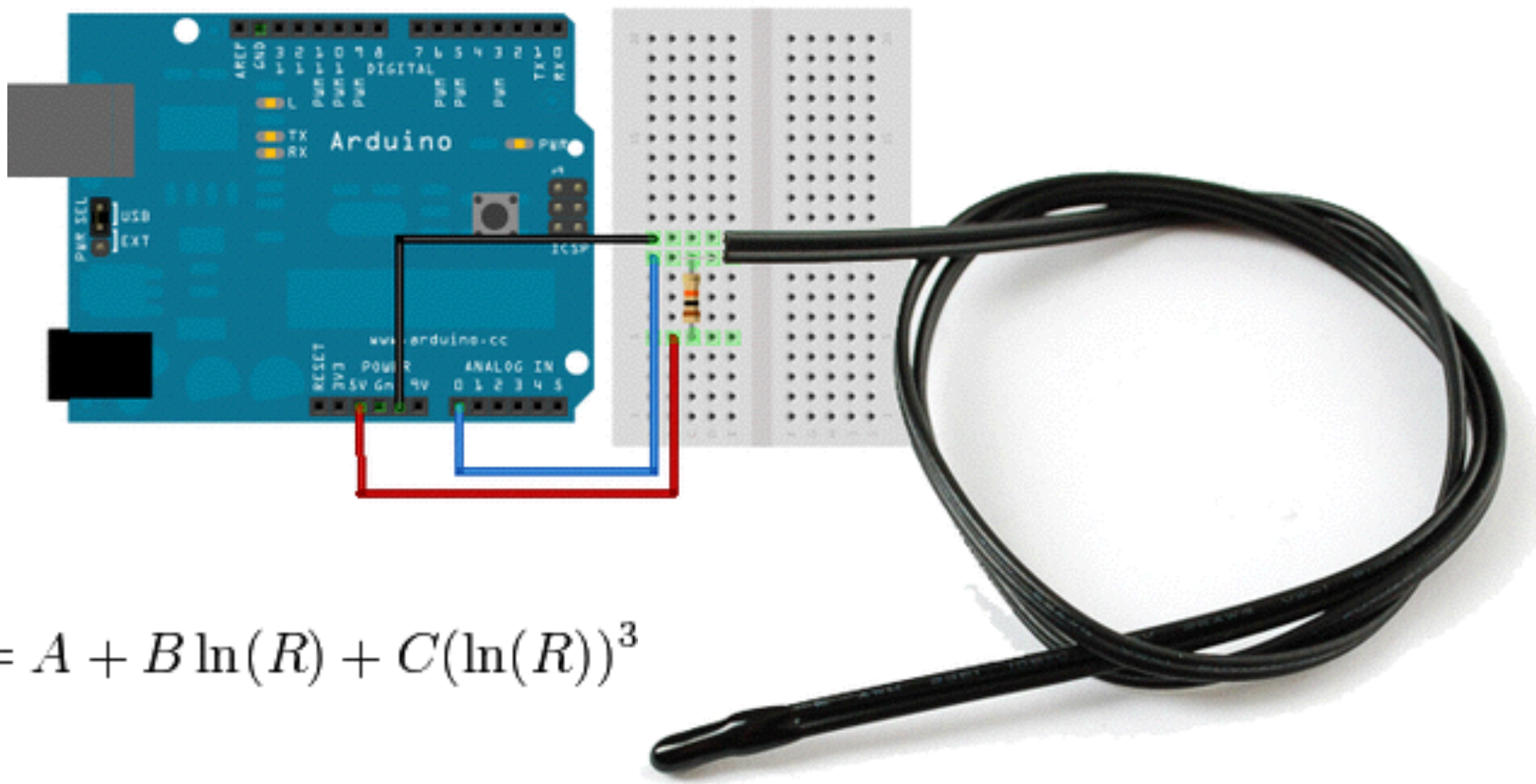


Image: Wikipedia

Conditioning happens with various resistor bridge/divider circuits



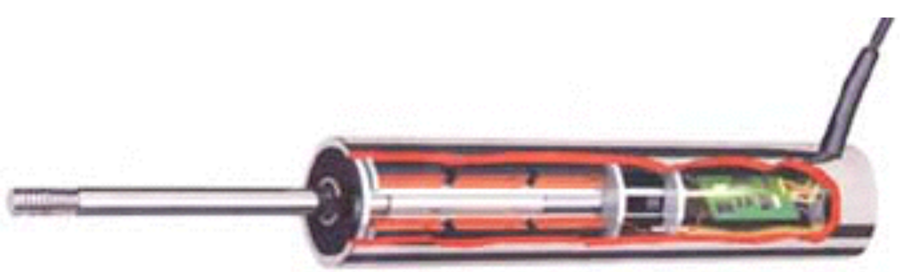
$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3$$

$$\frac{1}{T} = \frac{1}{T_0} + \frac{1}{B}\ln\left(\frac{R}{R_0}\right)$$

Image: Adafruit

Displacement

Displacement measurements can be performed in absolute or relative ways with a WIDE variety of transducers



DCDTs/LVDTs are a differential transformer

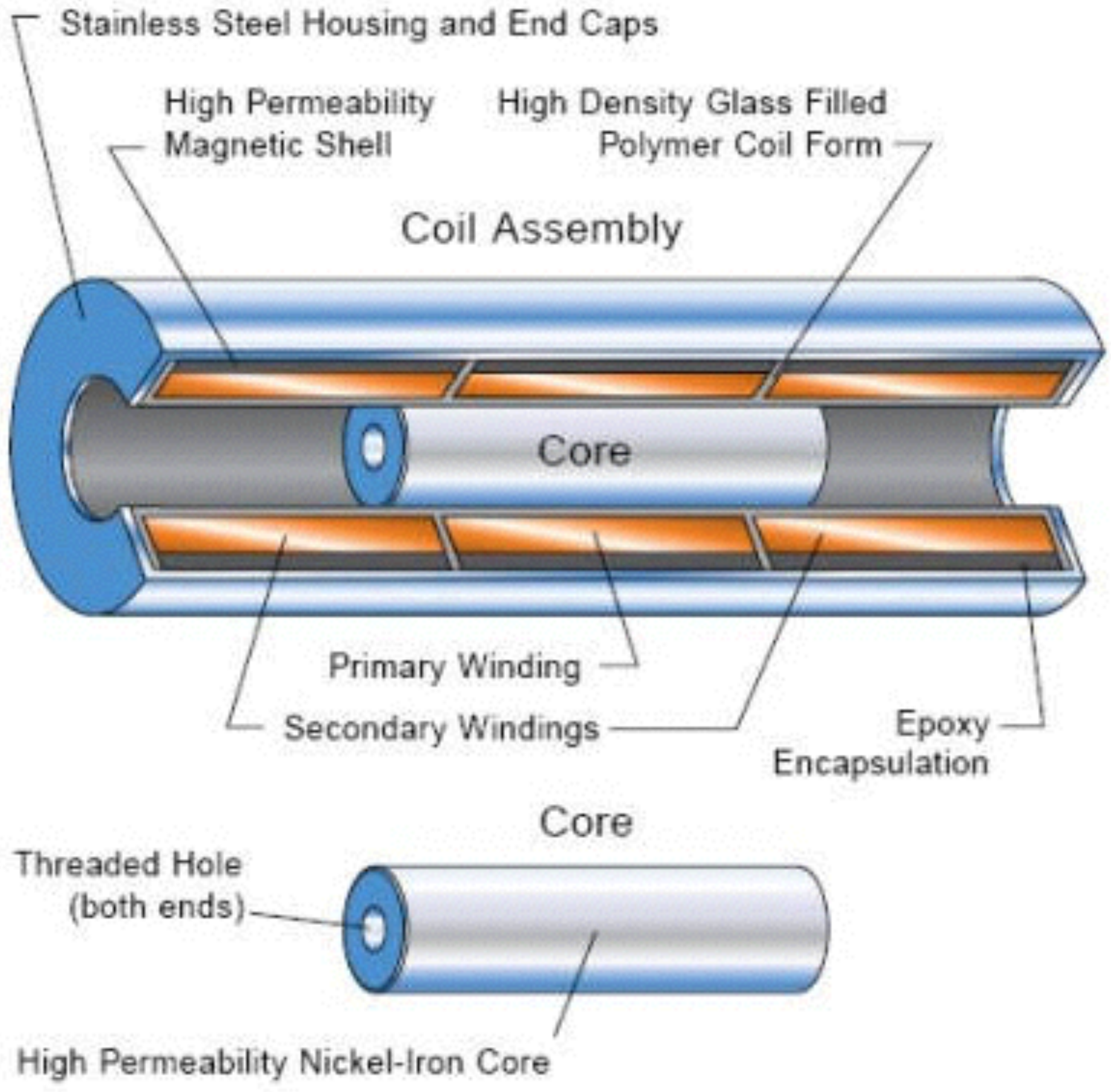


Image: te.com

DCDTs/LVDTs are a differential transformer

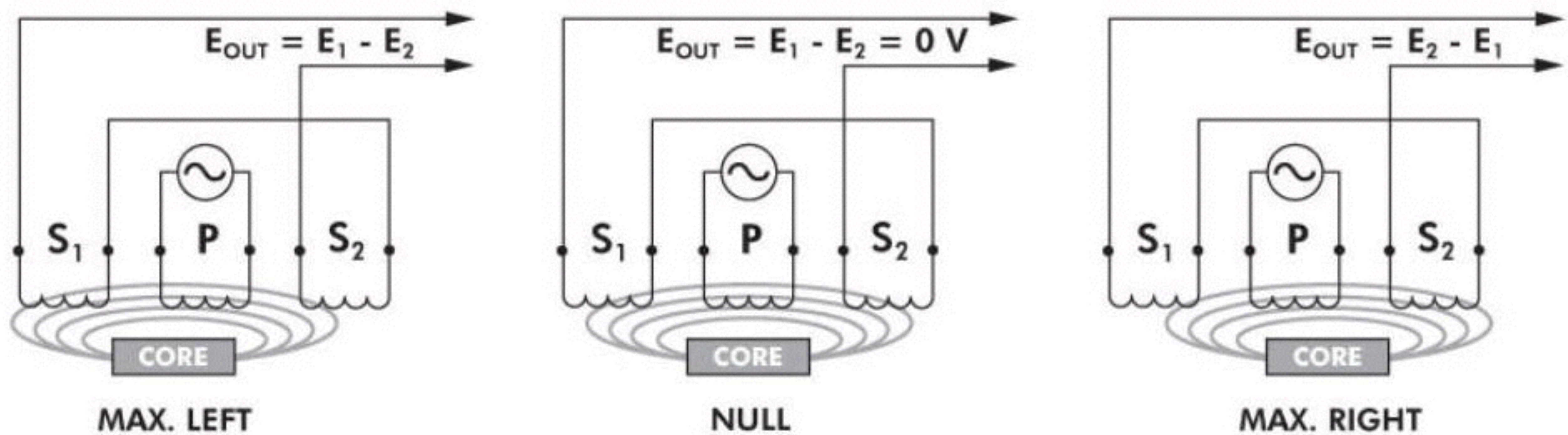


Image: te.com

DCDTs/LVDTs are a differential transformer

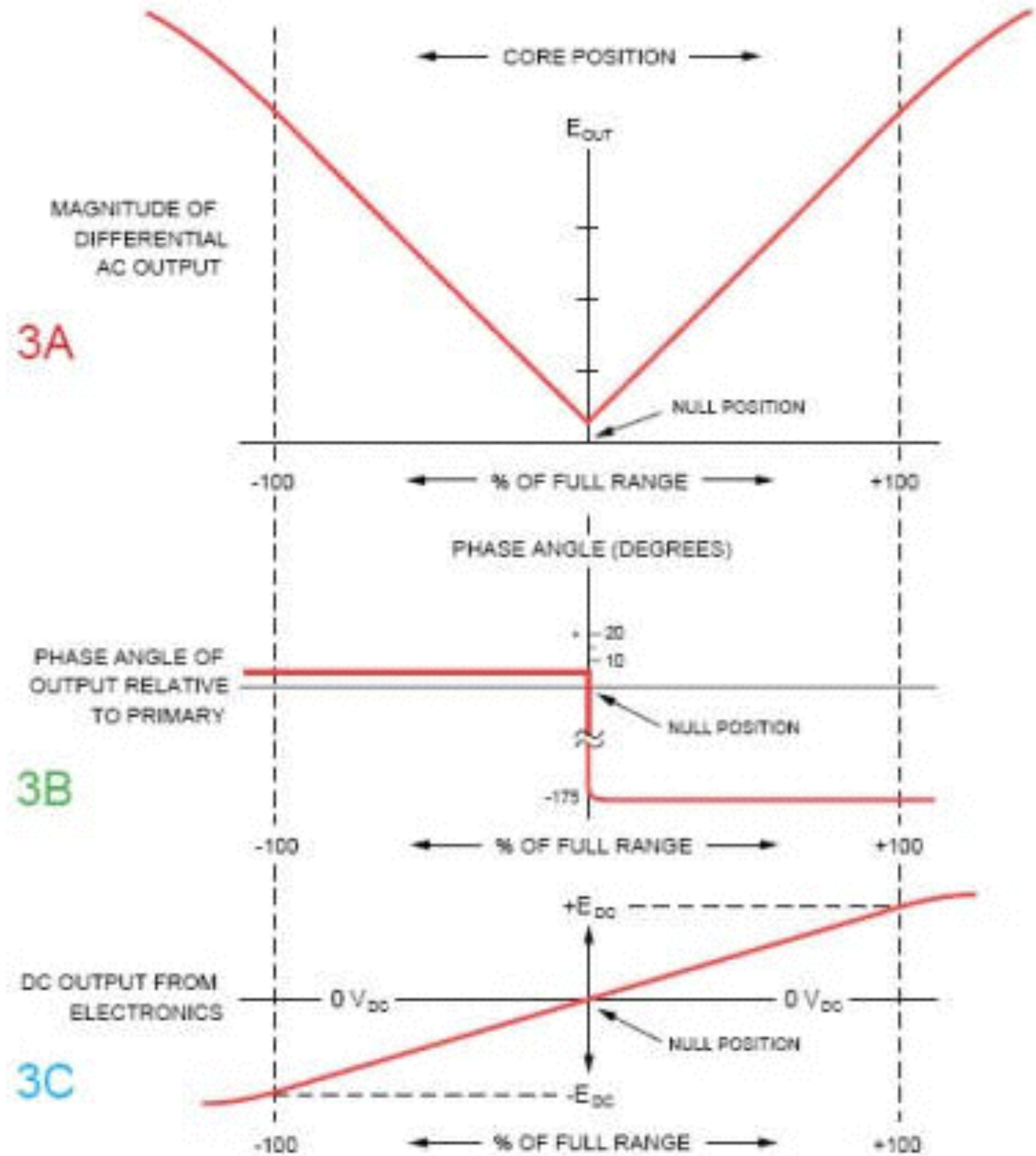


Image: te.com

DCDTs include all of the necessary driving/conditioning electronics

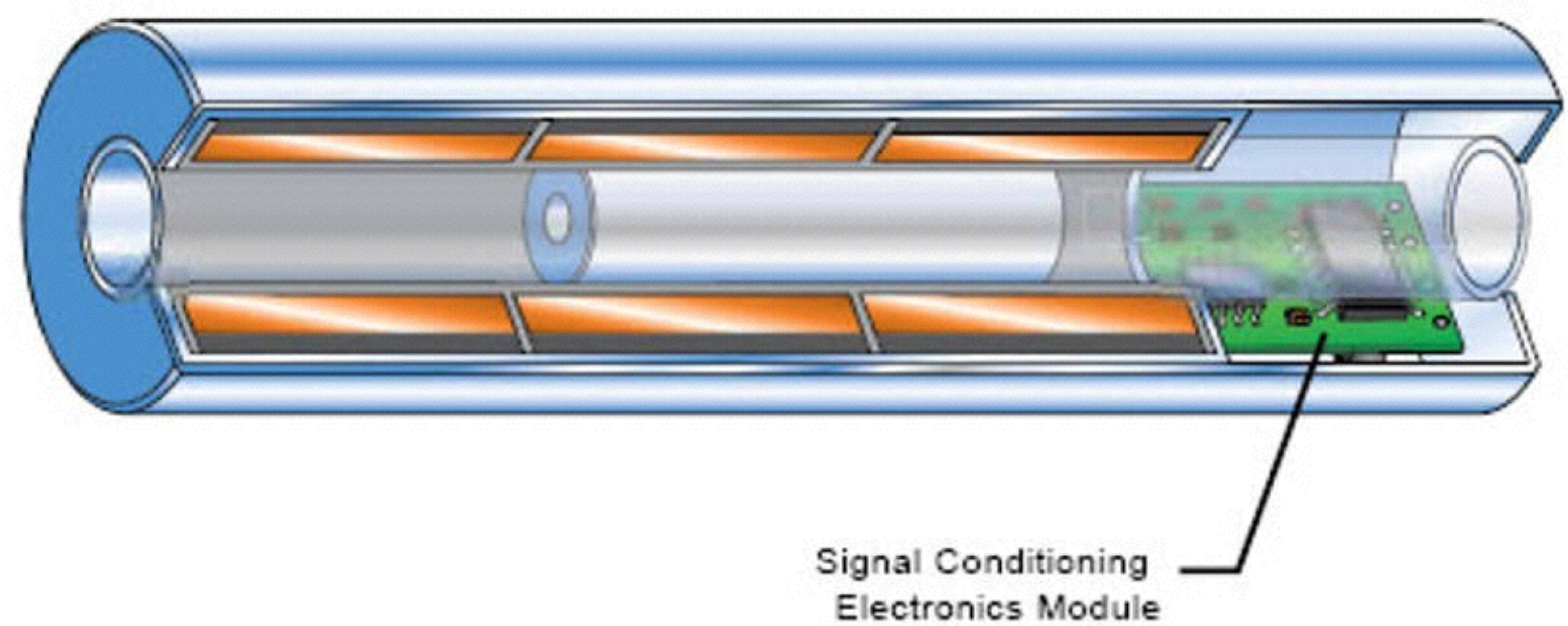
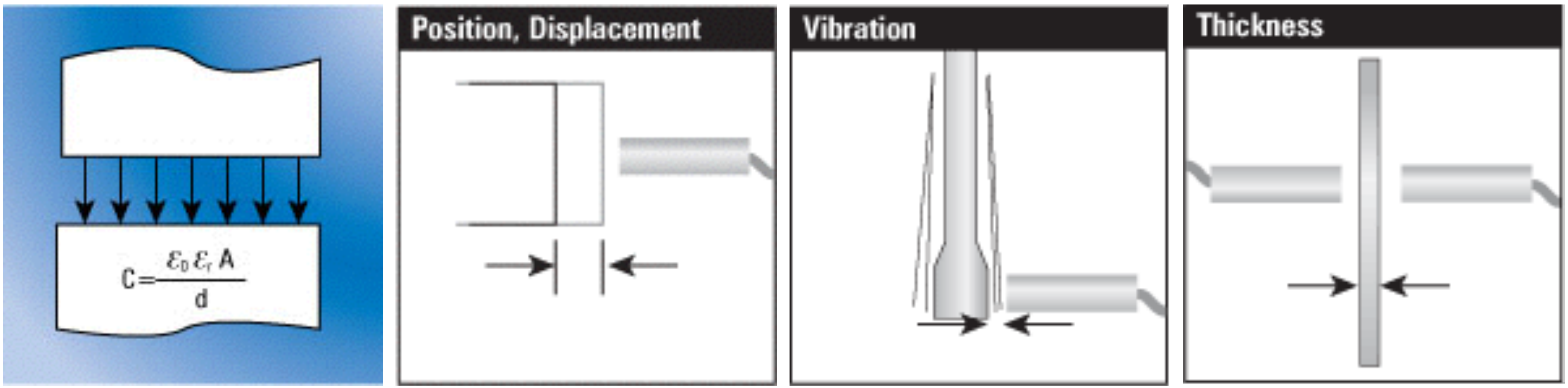


Image: te.com

Capacitive displacement sensors are very low noise and high resolution



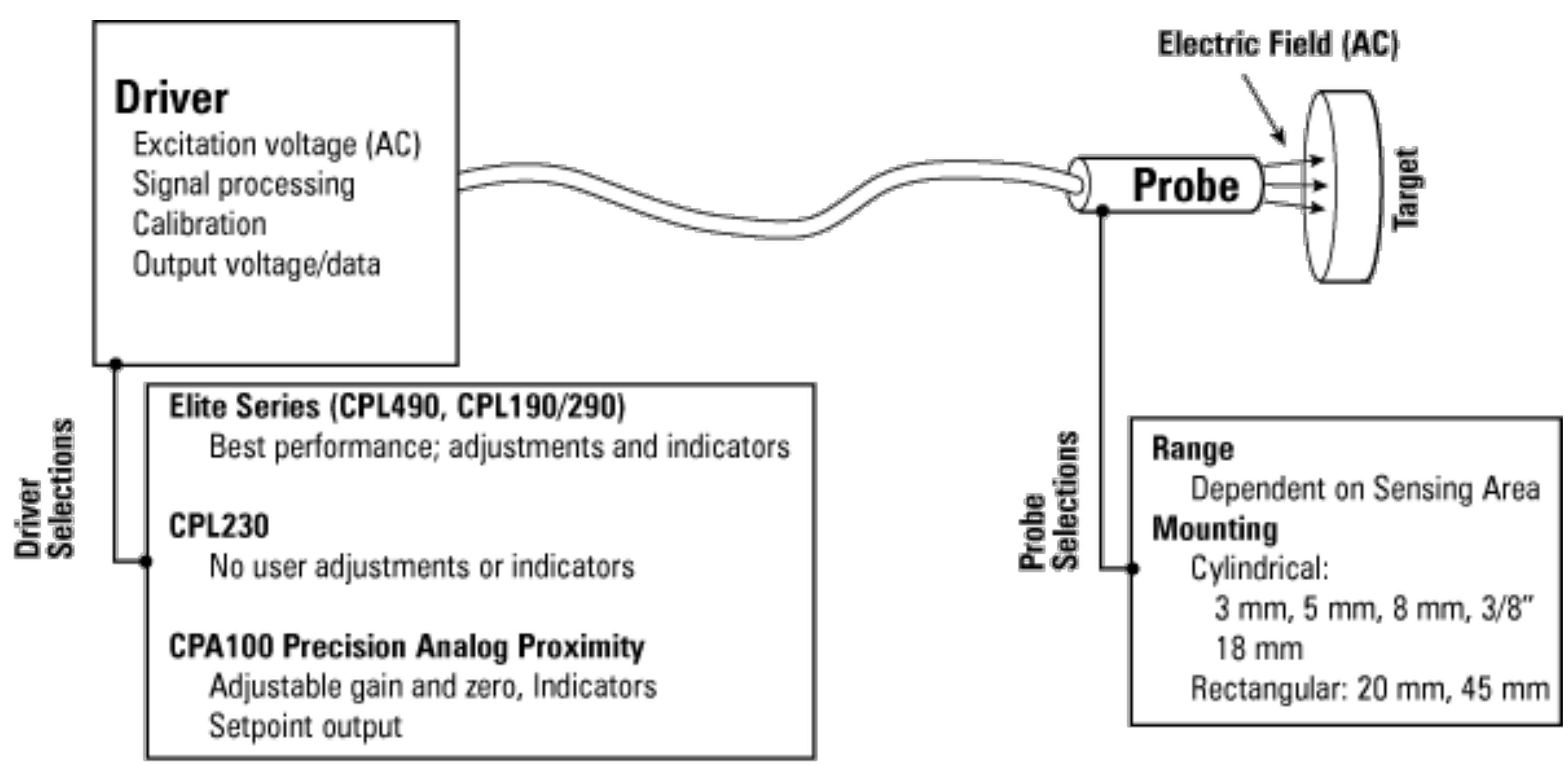


Image: lionprecision.com

Eddy current sensors are less expensive and still relatively low noise

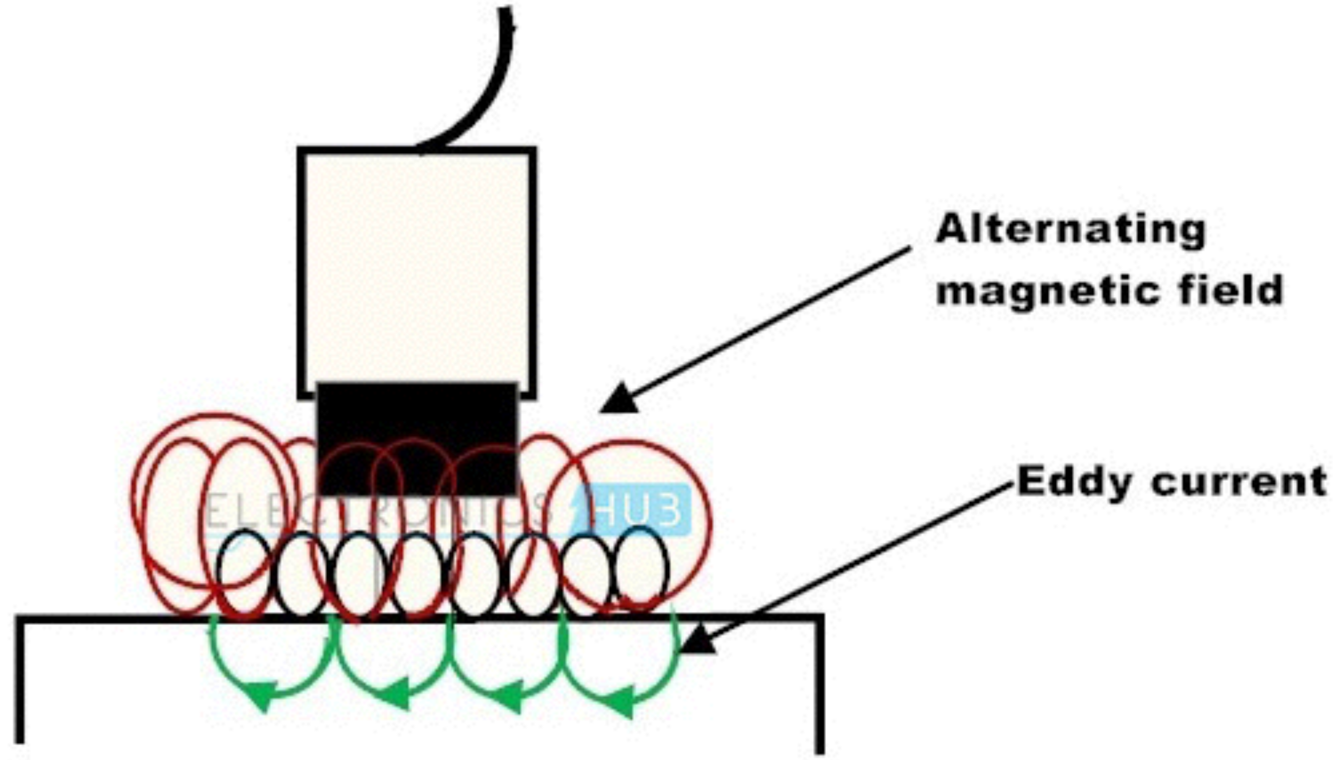


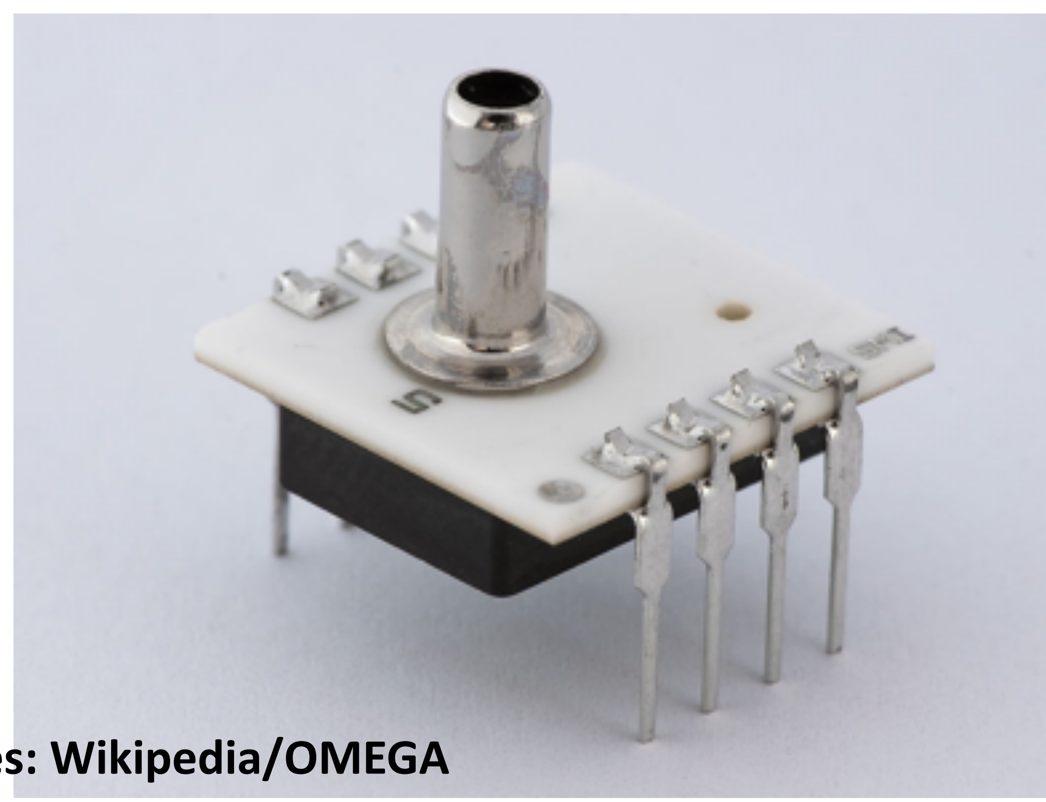
Image: electronics hub/ lionprecision.com

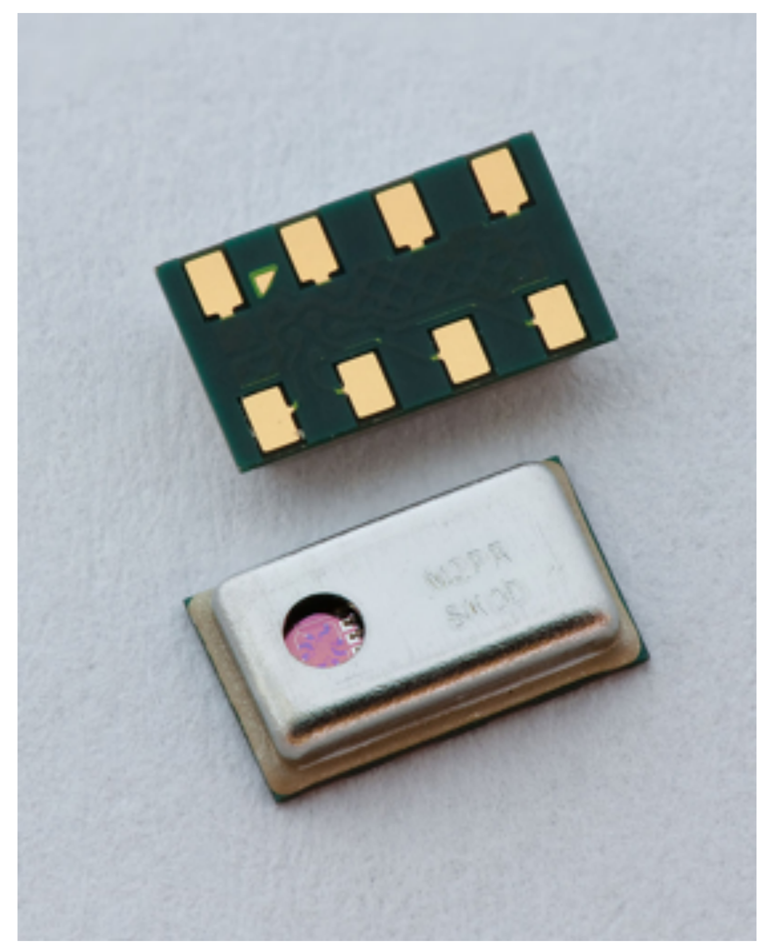
Pressure

Pressure transducers come in several types

- **Absolute - measure w.r.t. a perfect vacuum**
- **Gage - measure w.r.t. external (atmospheric) pressure**
- **Vacuum - measure pressures below atmospheric**
- **Differential - measure difference between two points**
- **Sealed - measure w.r.t. a sealed fixed pressure**

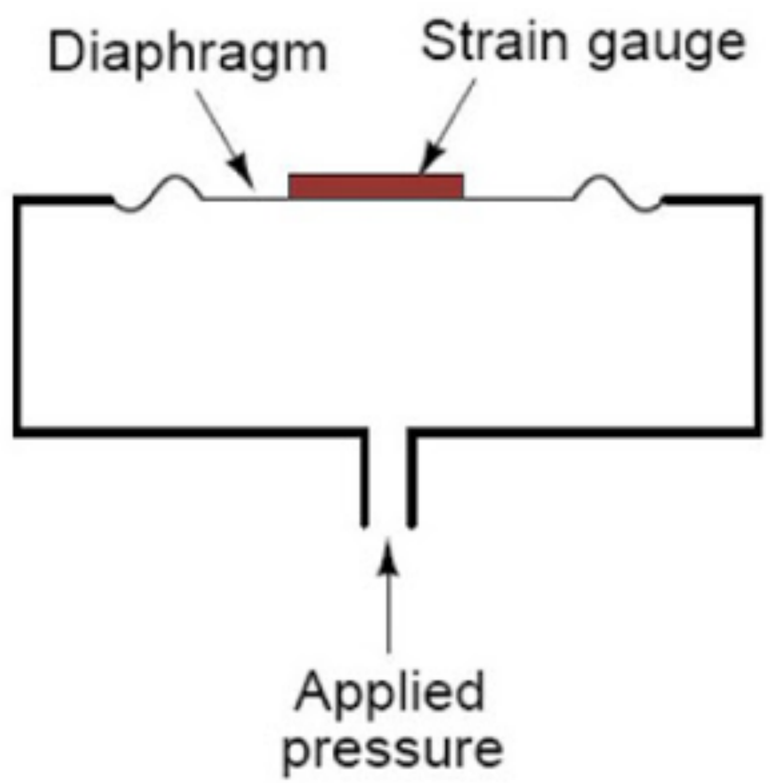
Housings can vary from PCB mount to industrial

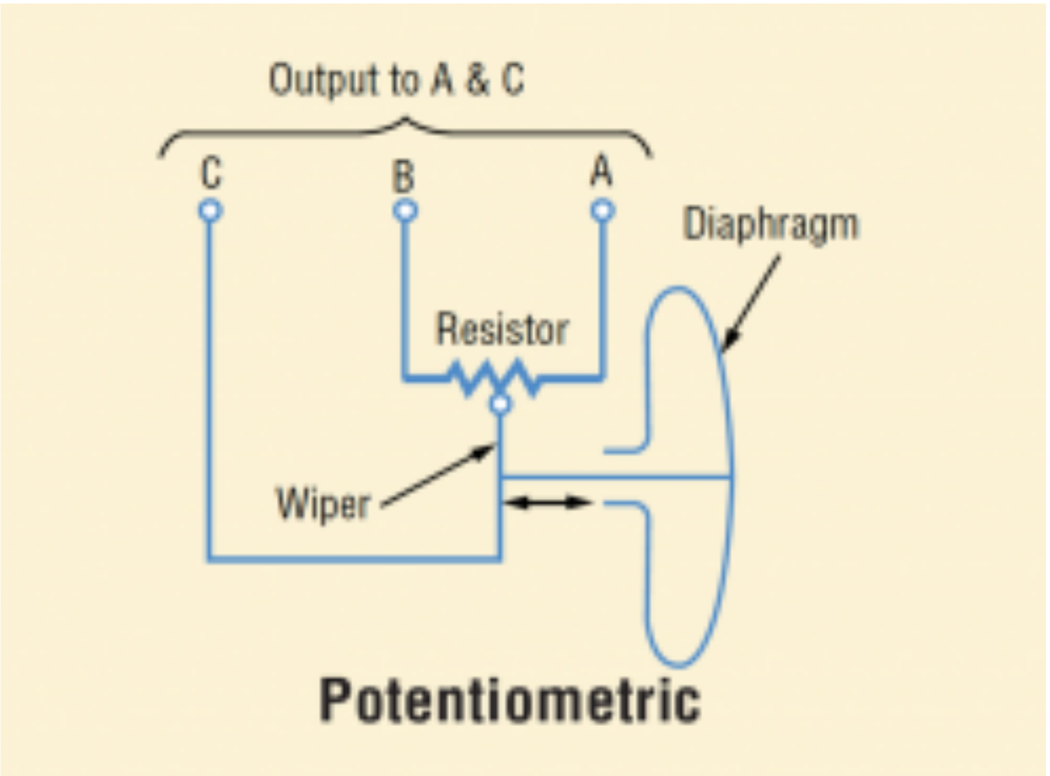


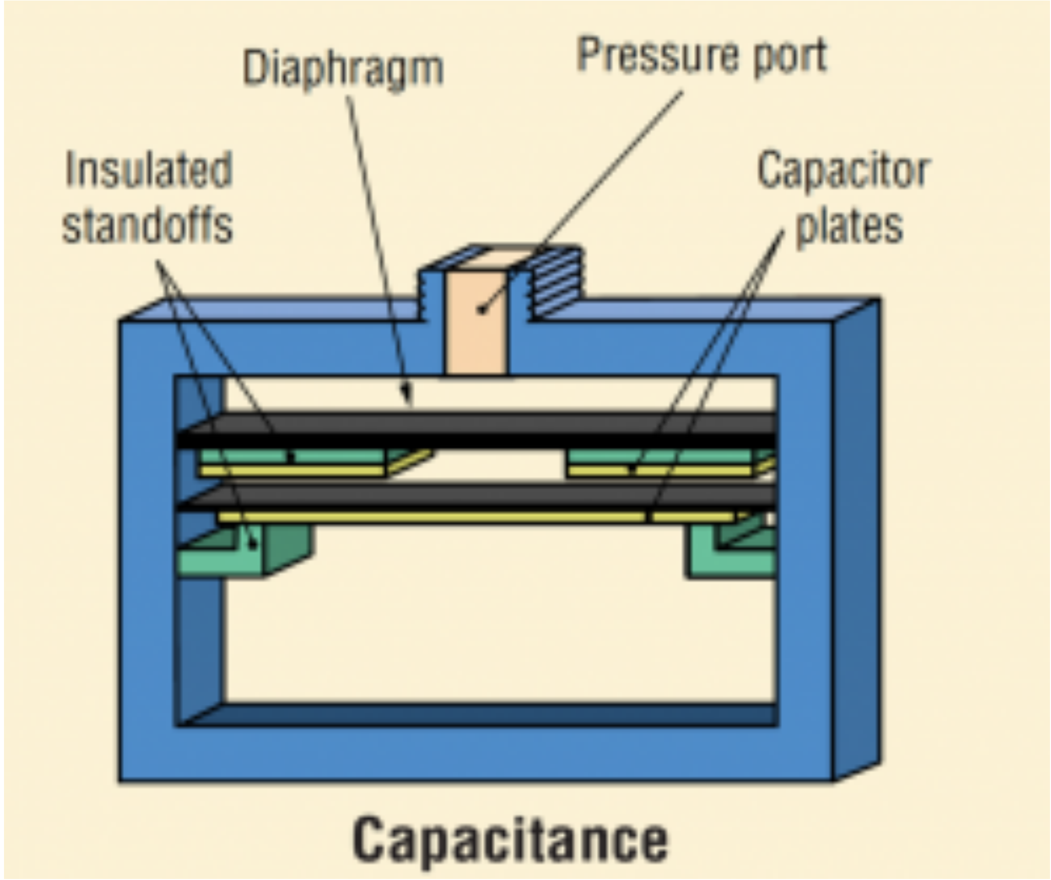


Images: Wikipedia/OMEGA

Pressure sensors are generally a deflection measurement based technology







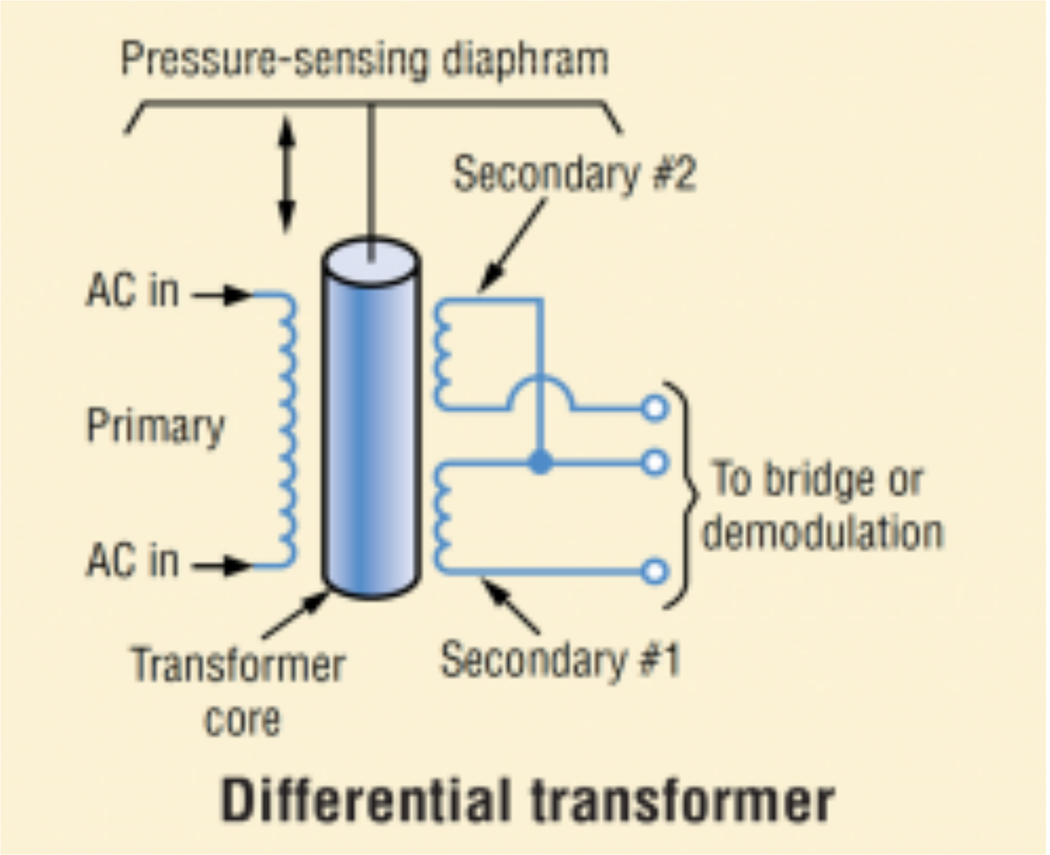
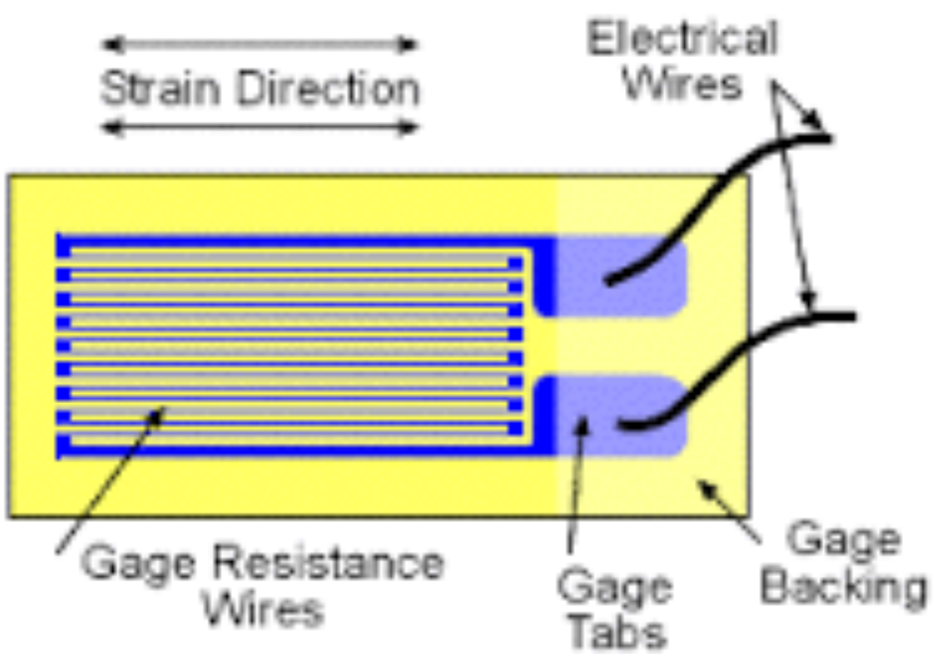


Image: hydraulicspneumatics.com/instrumentationtoolbox.com

Strain

Strain gages change resistance based upon their stretching/ compression



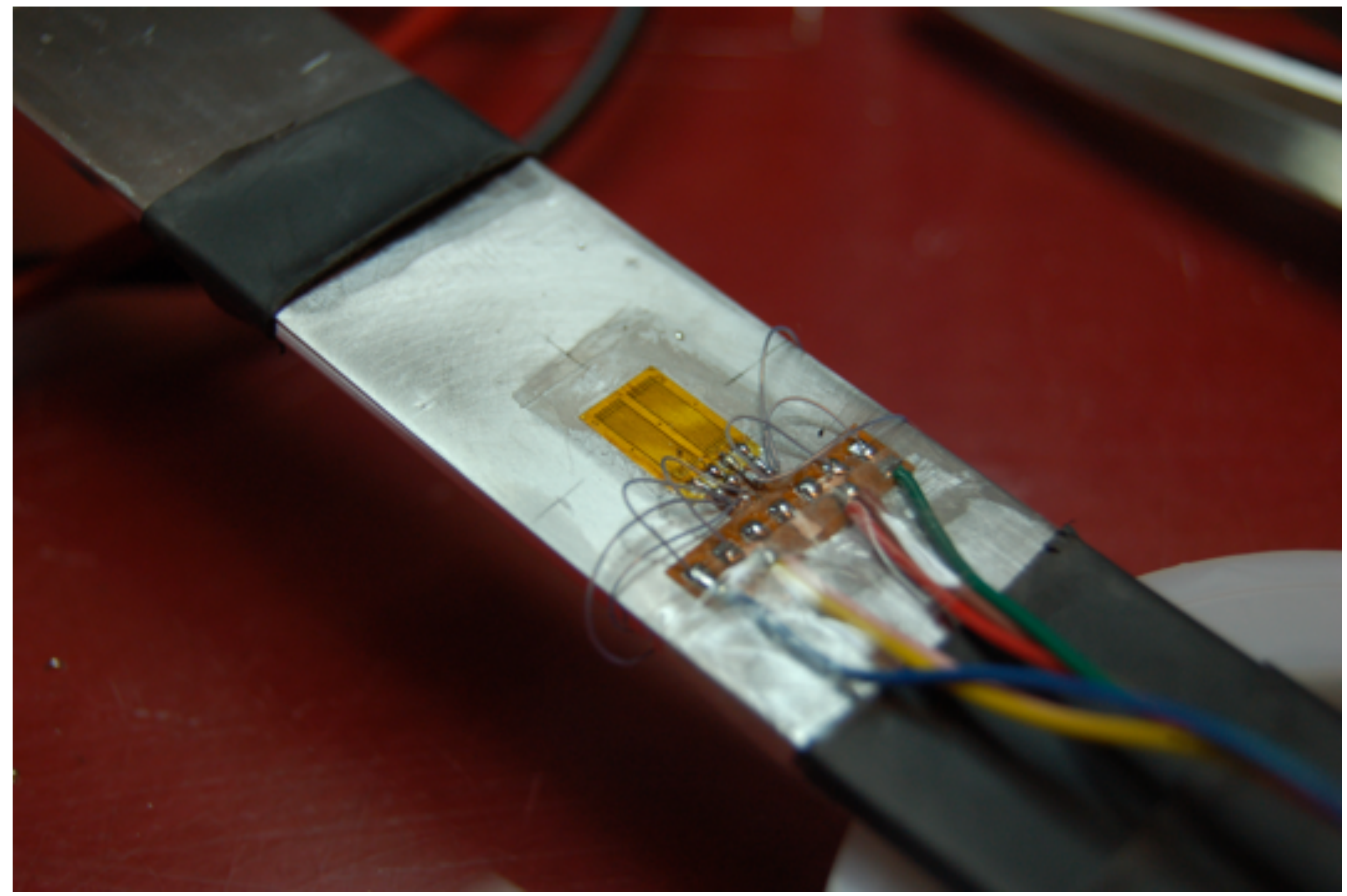
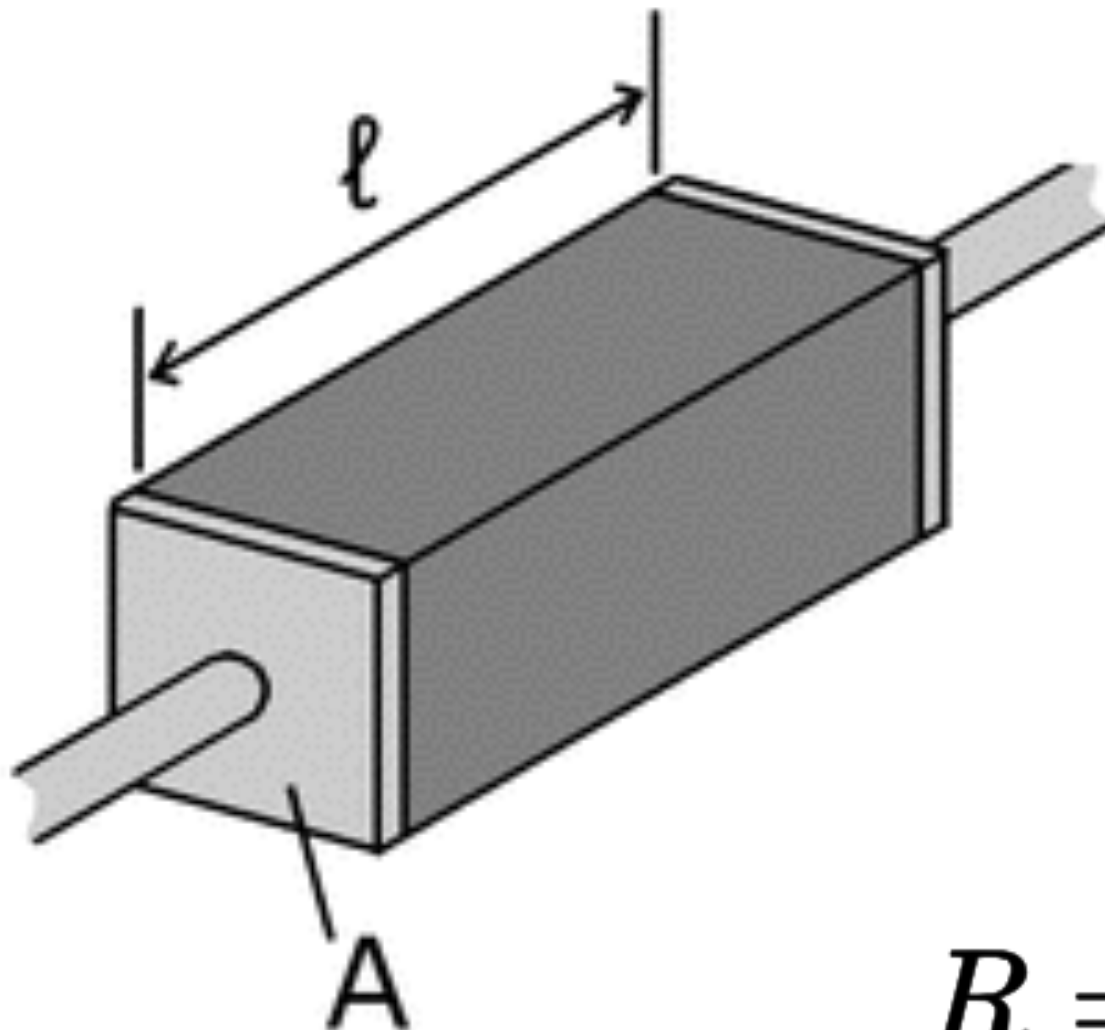


Image: OU/SensorWiki

Resistance of a material depends on the area of contact, resistivity, and length



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

Image: Wikipedia

So tension increases resistance, compression decreases resistance

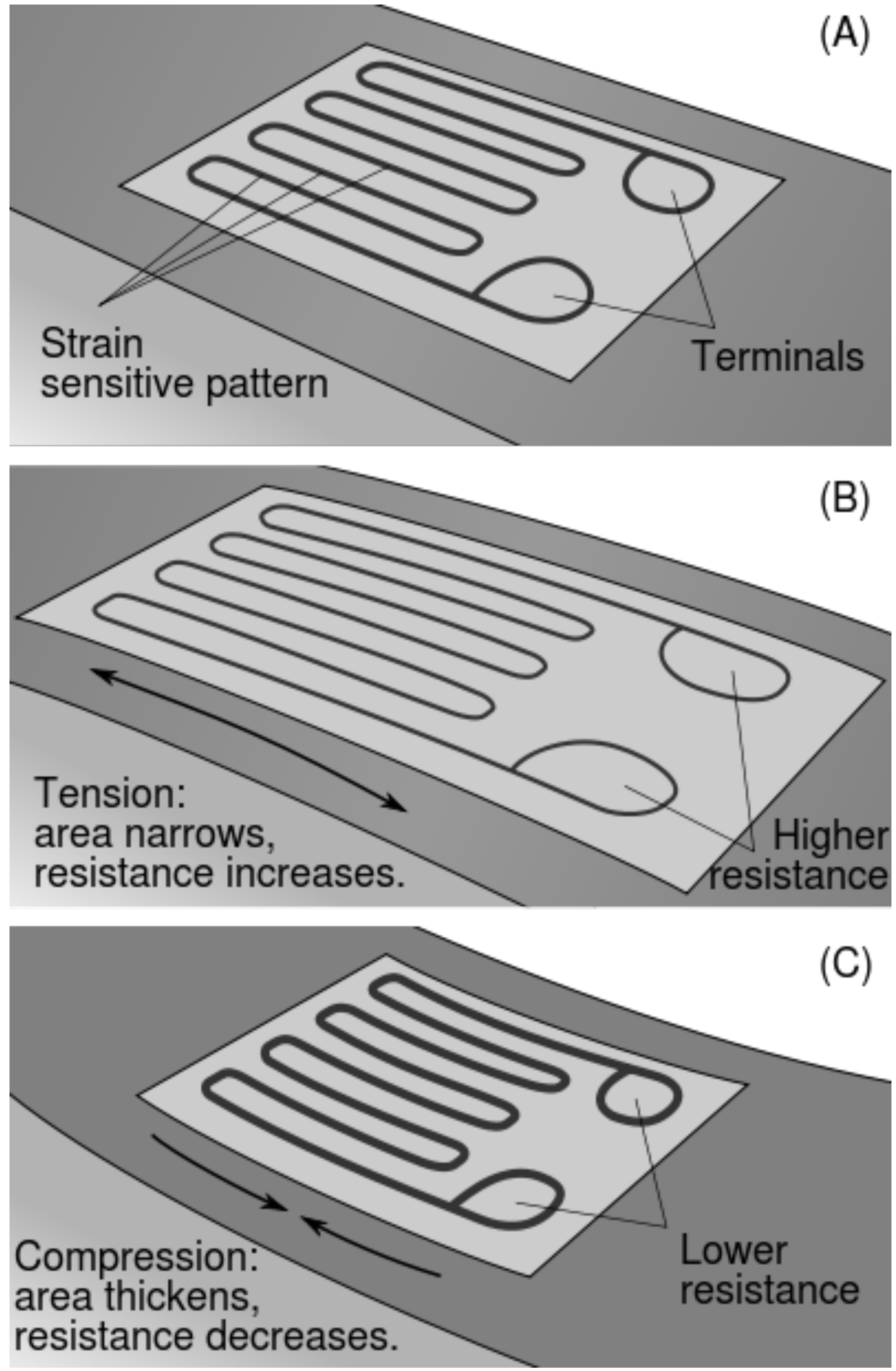
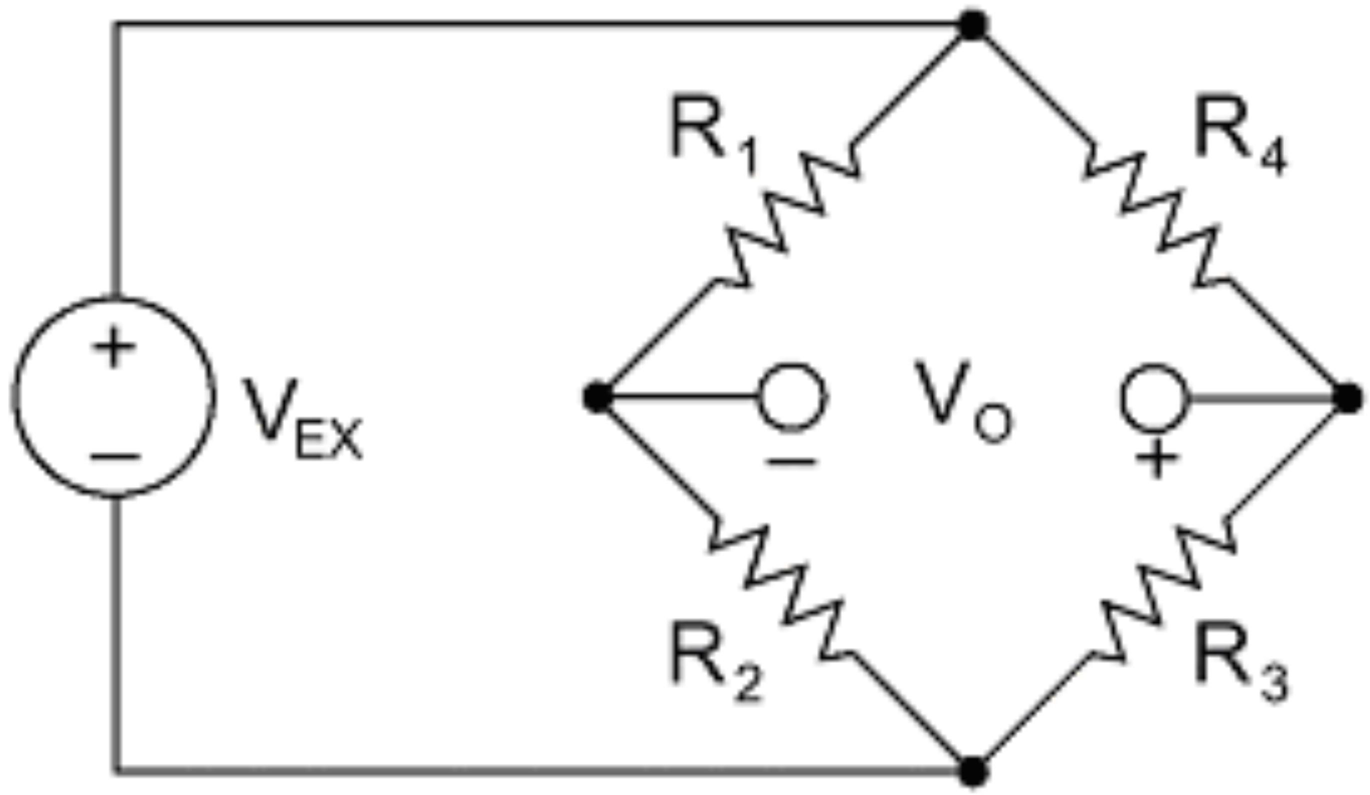


Image: Wikipedia

Most strain gage circuits are based on the Wheatstone Bridge



$$V_O = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + 2}\right] * V_{EX}$$

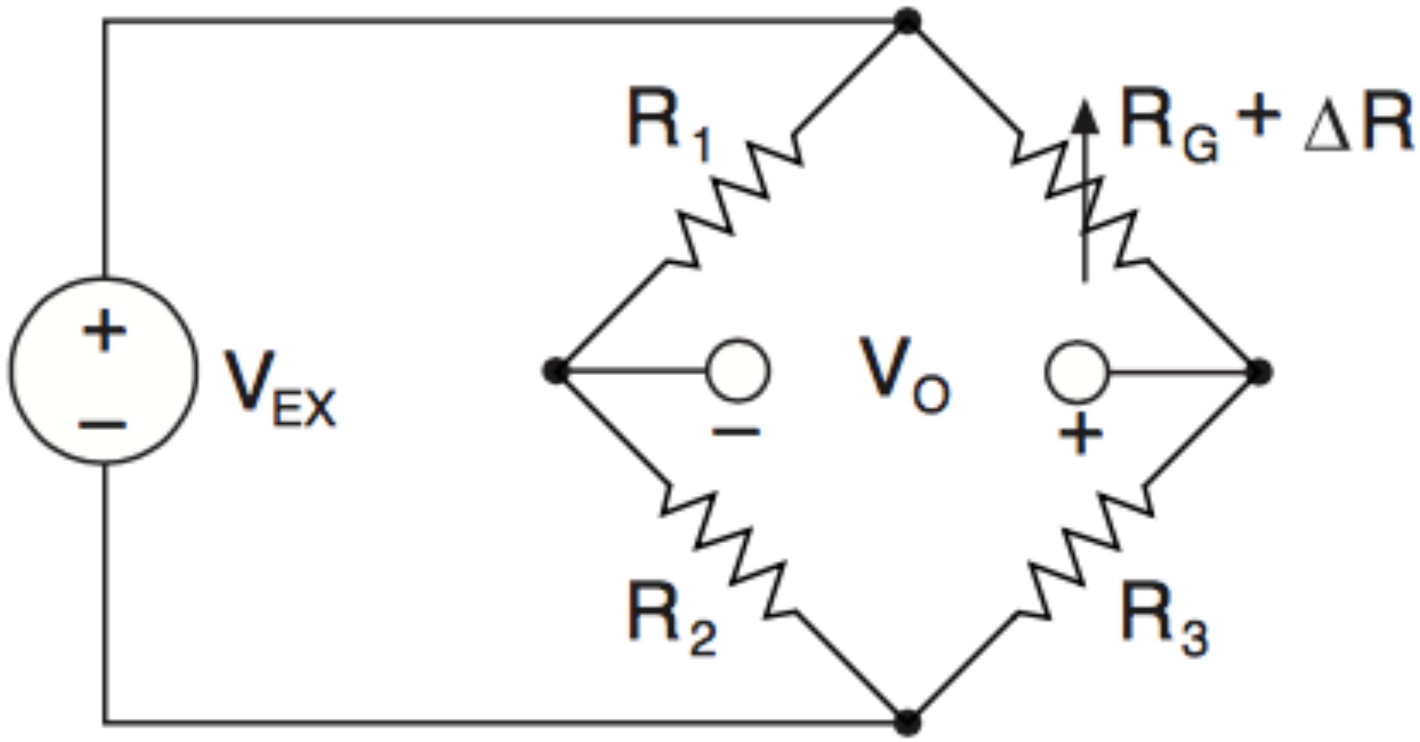
Image: National Instruments

The gage factor is the relative change is resistance with strain

$$GF = \frac{\frac{\Delta R}{R}}{\varepsilon}$$

Image: National Instruments

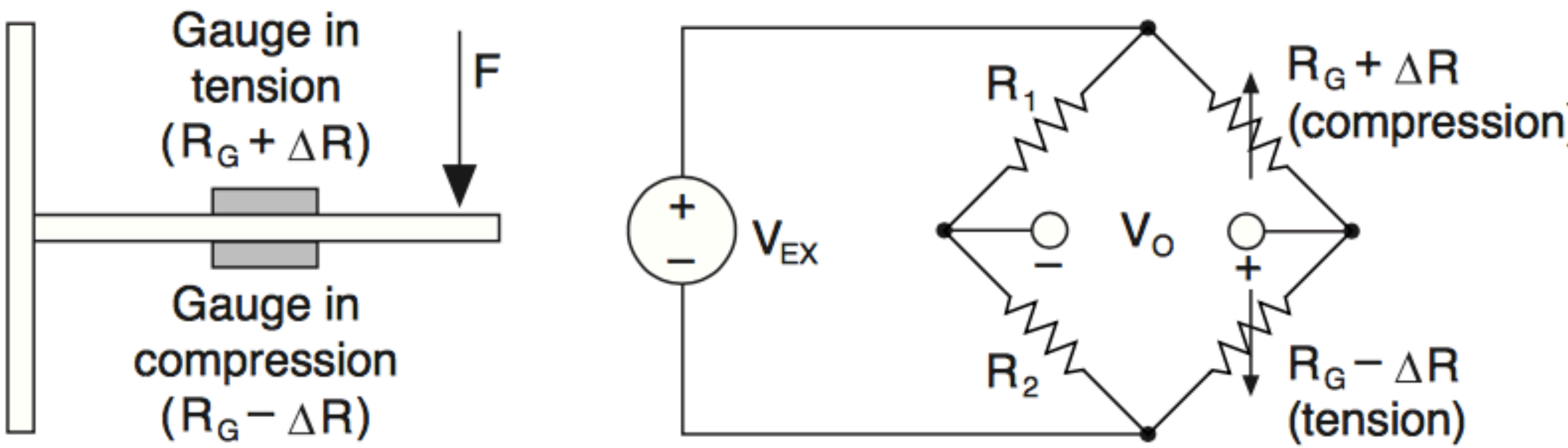
The quarter bridge is the least sensitive, but only requires one active element



$$\frac{V_O}{V_{EX}} = -\frac{GF \bullet \varepsilon}{4}\left(\frac{1}{1 + GF \bullet \frac{\varepsilon}{2}}\right)$$

Image: National Instruments

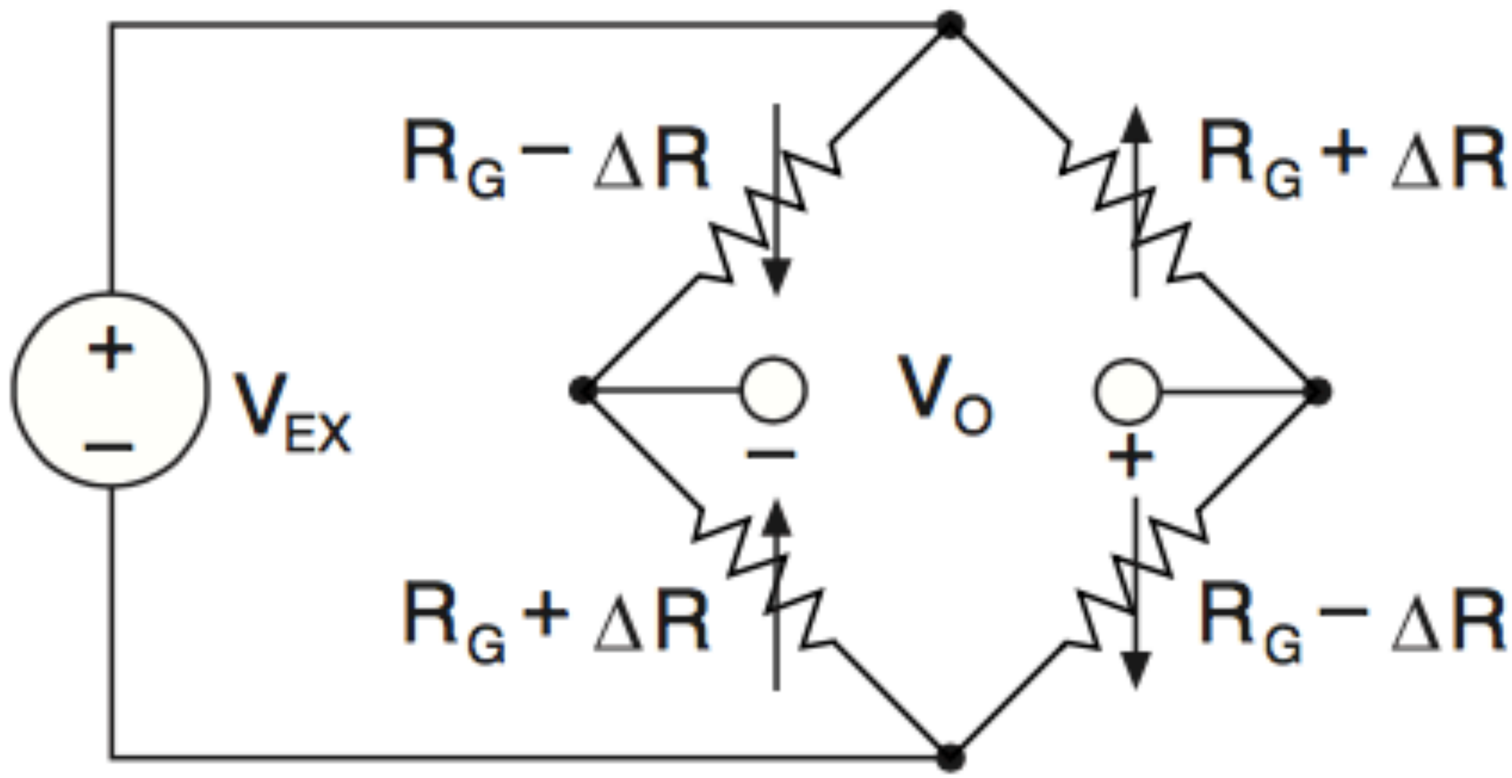
Half bridges require only two active elements



$$\frac{V_O}{V_{EX}} = -\frac{GF \bullet \varepsilon}{2}$$

Image: National Instruments

The full bridge is the most sensitive arrangement



$$\frac{V_O}{V_{EX}} = -GF \bullet \varepsilon$$

Image: National Instruments

Measurement Type	Quarter Bridge		Half-Bridge		Full-Bridge		
	Type I	Type II	Type I	Type II	Type I	Type II	Type III
Axial Strain	Yes	Yes	Yes	No	No	No	Yes
Bending Strain	Yes	Yes	Yes	Yes	Yes	Yes	No
Compensation							
Transverse Sensitivity	No	No	Yes	No	No	Yes	Yes
Temperature	No	Yes	Yes	Yes	Yes	Yes	Yes
Sensitivity							
Sensitivity at 1000 με	~0.5 mV/V	~0.5 mV/V	~0.65 mV/V	~1.0 mV/V	~2.0 mV/V	~1.3 mV/V	~1.3 mV/V
Installation							
Number of Bonded Gages	1	1*	2	2	4	4	4
Mounting Location	Single Side	Single Side	Single Side	Opposite Sides	Opposite Sides	Opposite Sides	Opposite Sides
Number of Wires	2 or 3	3	3	3	4	4	4
Bridge Completion Resistors	3	2	2	2	0	0	0
*A second strain gage is placed in close thermal contact with structure but is not bonded.							

Image: National Instruments

Temperature plays a role as well though

$$\frac{\Delta R}{R} = GF\varepsilon + \alpha\theta$$

Where

- α = temperature coefficient
- θ = temperature change

Image: National Instruments

A "dummy gauge" is often used for temperature compensation

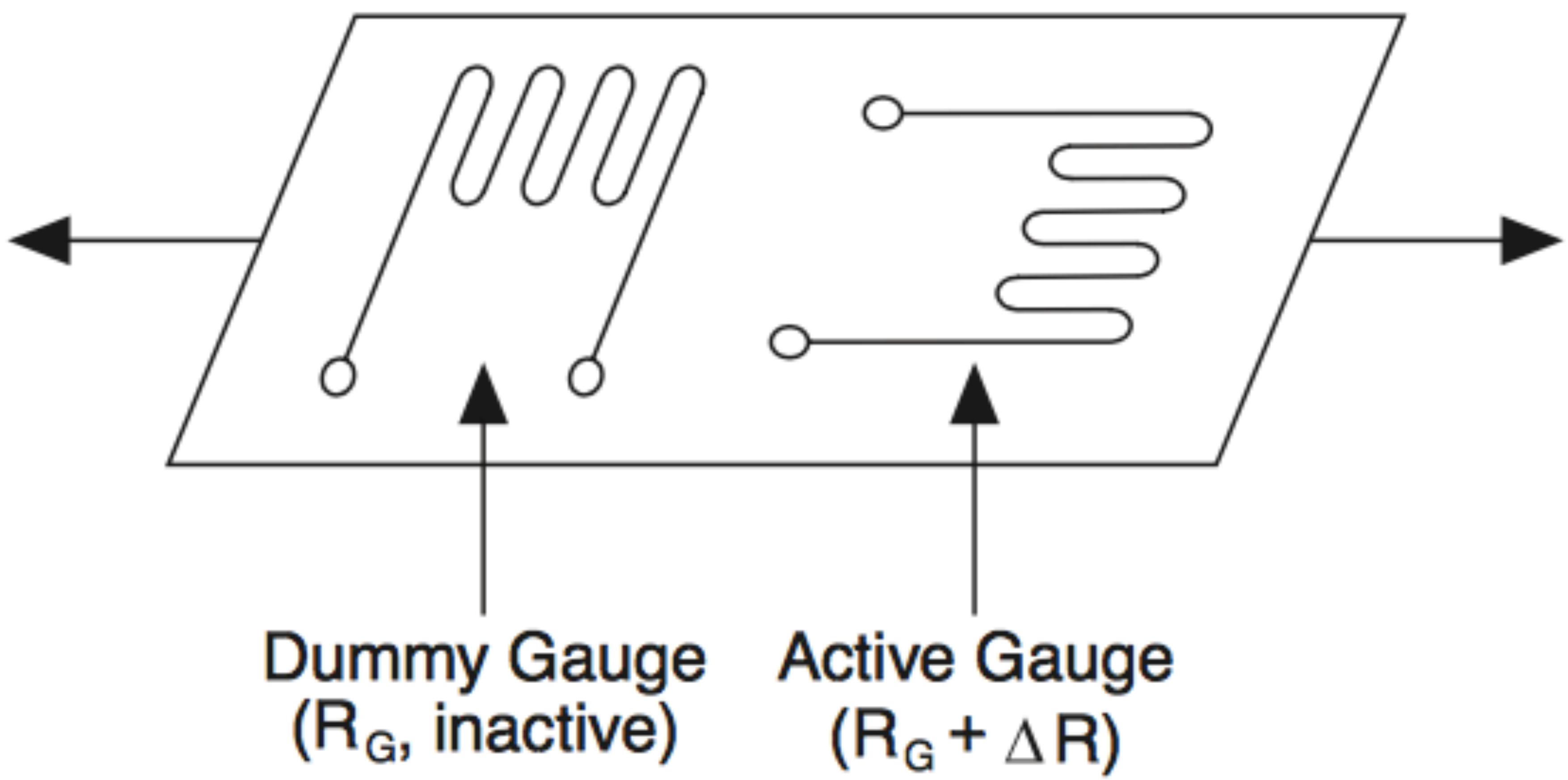


Image: National Instruments

Careful wiring and creative placement are often necessary

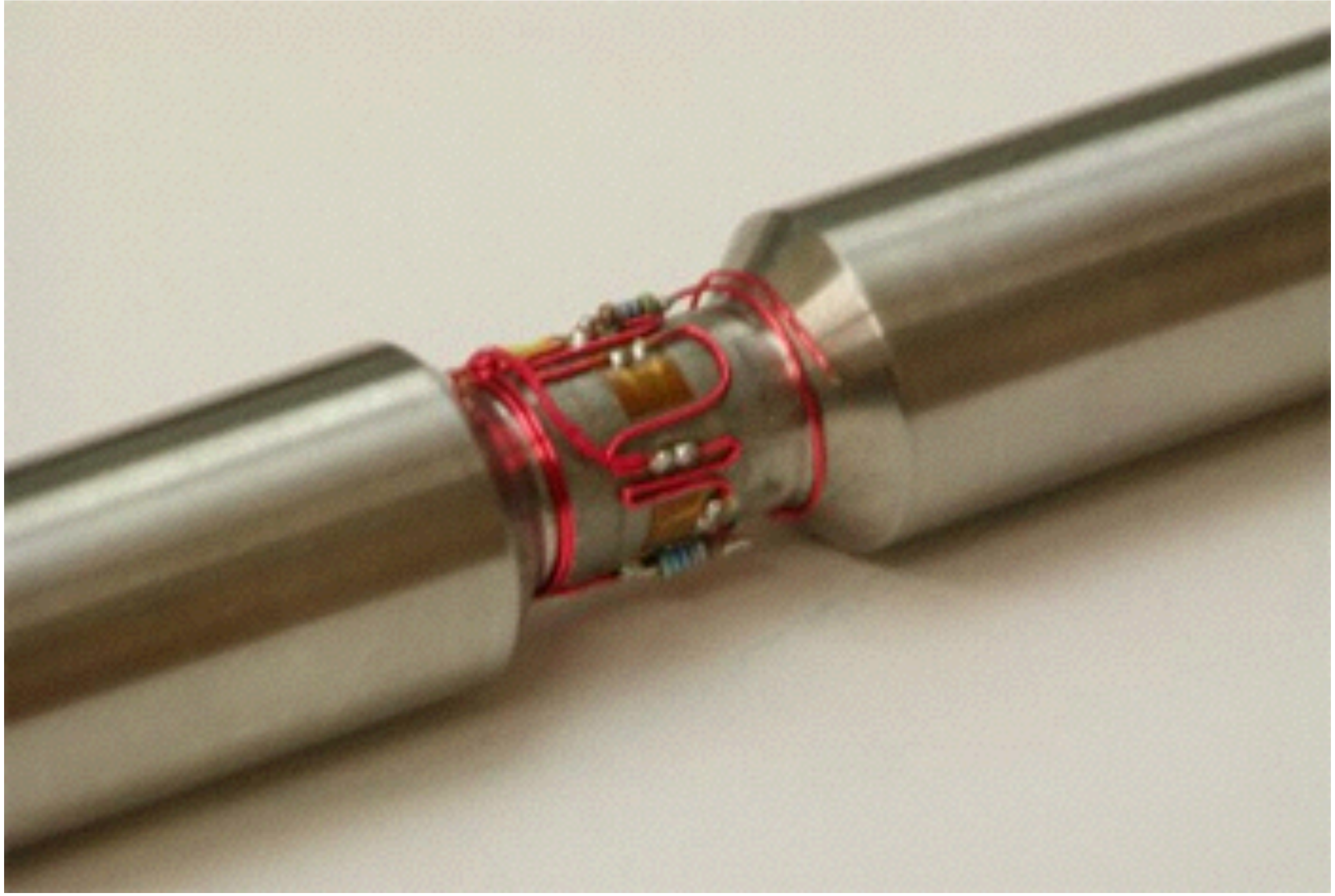
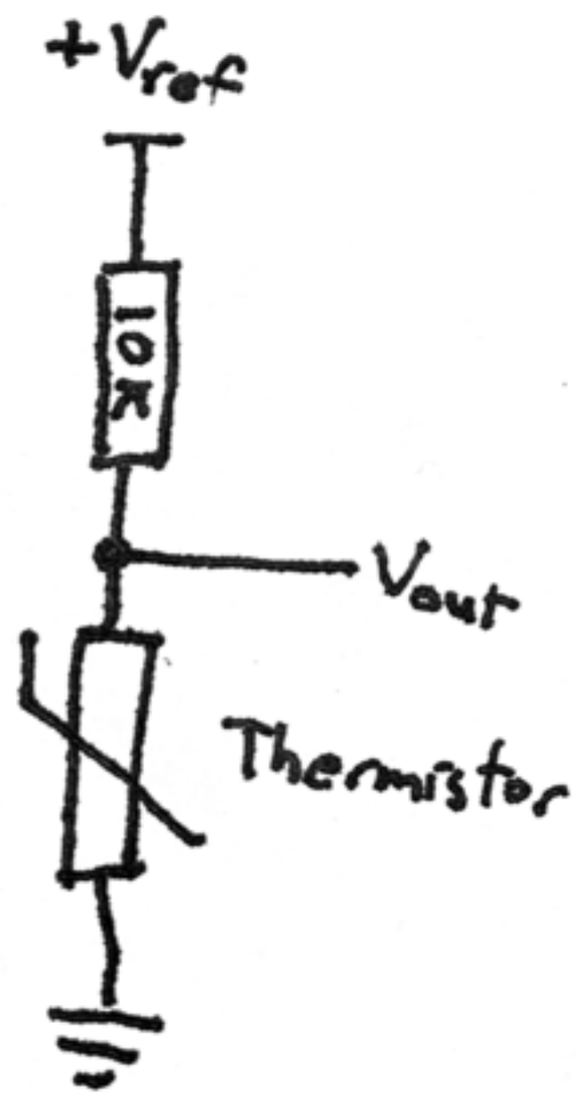


Image: b2bicdesign.com

Activity: Calculate the temperature measurements from the data included with the "Thermistor Calculation" activity



Due : 10/20

Assignment: Find something to affix strain gauges to for our next lab activity

Due : 10/25