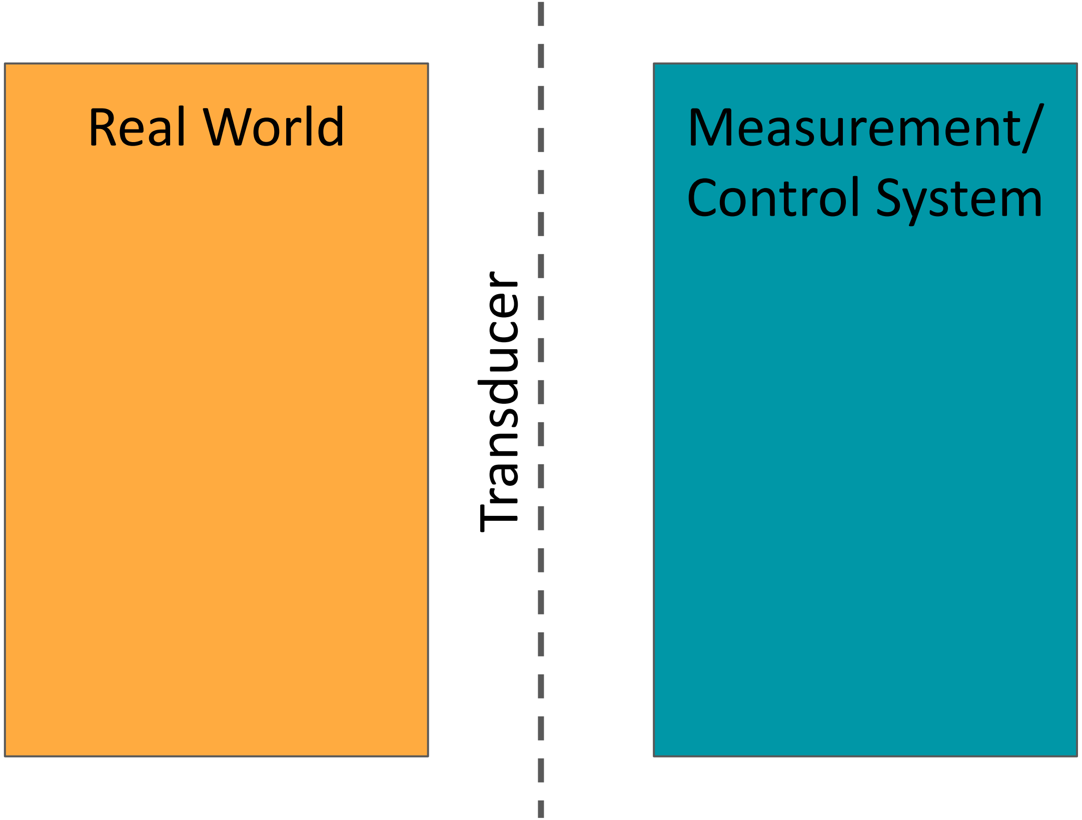
Transducers

John R. Leeman

8/3/21

Image: Applications Engineering

Transducers convert one form of energy into another



We classify transducers into three distinct types based on "direction"

Sensors

Actuators

Bidirectional

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Images: Automation Direct, Servo City, Antenna Associates

Transducers can be active or passive in nature

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Images: Transtek, Digikey, Amazon, Futek

A few of the MANY factors to consider when looking for transducers

- Range
- Span
- Linearity
- Sensitivity
- Response Time
- Stability
- Accuracy
- Noise
- Durability/Environmental
- Cost
- Signal Conditioning
- Technology
- Hysteresis
- Output

Image: Giphy

Range is the values over which the transducer is rated to perform

SPECIFICATIONS - ELECTRICAL

MODEL NUMBER	0240-0000	0241-0000	0242-0000	0243-0000	0244-0000	0245-0000	0246-0000	0246-00005
WORKING RANGE, ± Inches (mm)	0.050 (1.27)	0.100 (2.54)	0.250 (6.35)	0.500 (12.7)	1.00 (25.4)	2.00 (50.8)	3.00 (76.2)	3.00 (76.2)
MAX. USABLE RANGE, ± Inches (mm)	0.075 (1.78)	0.150 (3.75)	0.375 (9.53)	0.750 (19.1)	1.50 (38.1)	2.75 (69.8)	3.25 (82.5)	4.00 (101)
INPUT, VDC	6.0 Min. to 30 Max.							9.0 Min. to 30 Max.
NOMINAL F.S. OUTPUT, ±VDC with unloaded output								
@ 6 VOLT INPUT	1.3	2.4	1.8	3.1	4.6	3.9	3.3	N/A
@ 15 VOLT INPUT	3.4	6.4	4.8	8.3	12.1	10.2	8.7	10
@ 24 VOLT INPUT	5.5	10.4	7.8	13.5	18.7	16.5	14.1	16.3
@ 30 VOLT INPUT	7.0	13.0	9.7	17.0	24.8	20.7	17.7	30.5
INPUT CURRENT	8.3 mA @ 6 Volt input to 52 mA @ 30 Volt input							
[2] NON-LINEARITY	±0.5% Full Scale Over Total Working Range, ±1.0% Full Scale Over Maximum Usable Range							
INTERNAL CARRIER FREQUENCY, Hz	13000	12000	3600	3400	3200	1500	1400	1400
% RIPPLE, RMS (nominal)	0.7	0.7	0.8	0.8	0.8	1	1	1
OUTPUT IMPEDANCE, Ohms	2500	3500	5200	5500	5600	5500	5600	5600
FREQ. RESPONSE (3 dB down), Hz	300	140	115	110	100	110	75	75
TEMPERATURE RANGE	-65°F to +250°F (-54°C to +121°C)							
RESOLUTION	Infinite							

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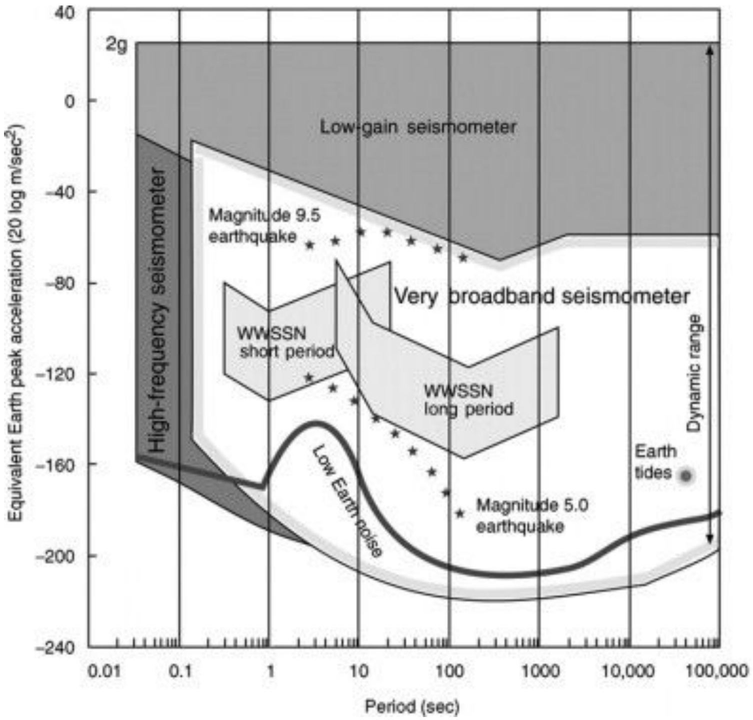
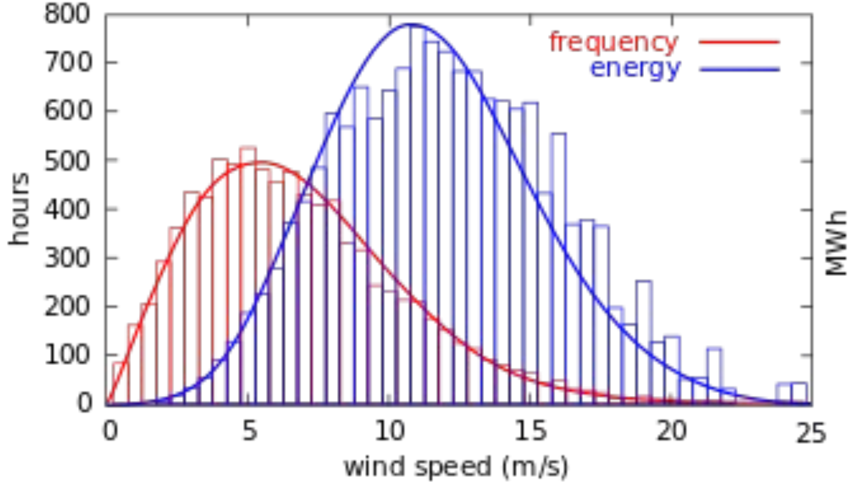
Images: Transtek

Dynamic range is the ratio of the largest to smallest input measured





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Images: Science Direct, WikiPedia

Span is the output difference at the maximum and minimum values

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RESOLUTION	Infinite							

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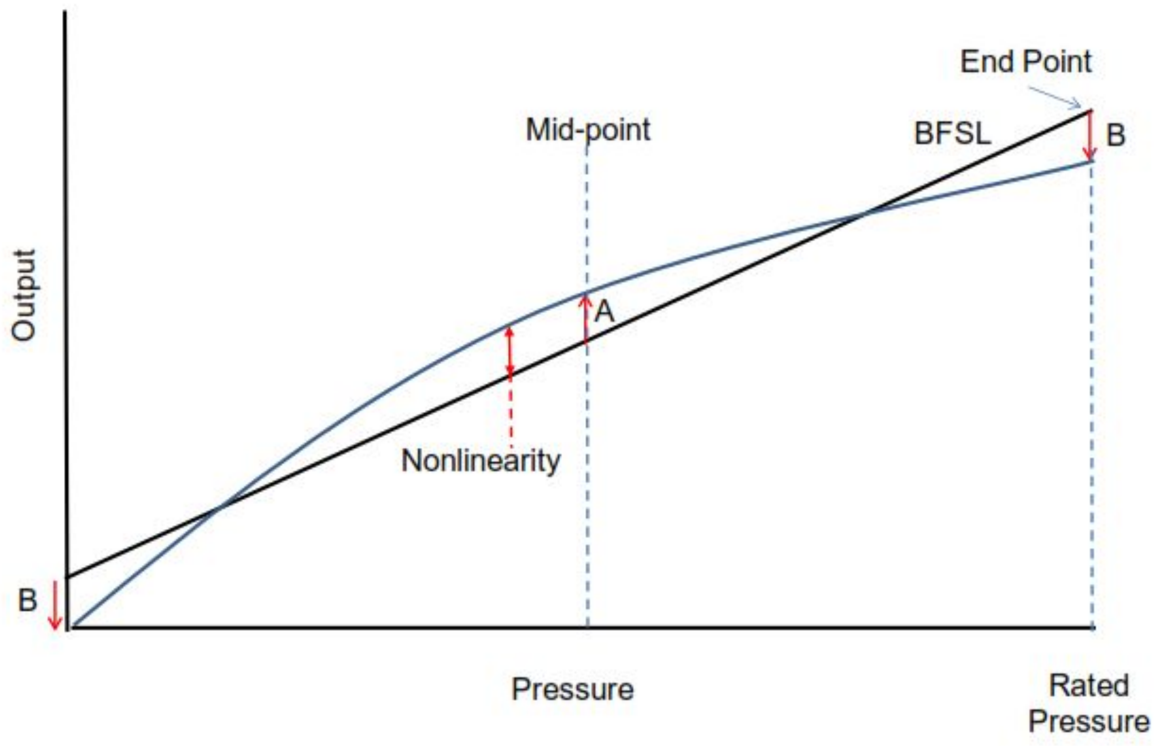
Images: Transtek

Linearity is deviation from an ideal linear output



245-)000	0246- 0000	0246-00005
2.00 50.8)	3.00 (76.2)	3.00 (76.2)
2.75 59.8)	3.25 (82.5)	4.00 (101)
		9.0 Min. to 30 Max.
3.9	3.3	N/A
10.2	8.7	10
16.5	14.1	16.3
20.7	17.7	30.5
/olt input		
Over Maximum Usable Range		
1500	1400	1400
1	1	1
5500	5600	5600
110	75	75
C)		

RESOLUTION	Infinite

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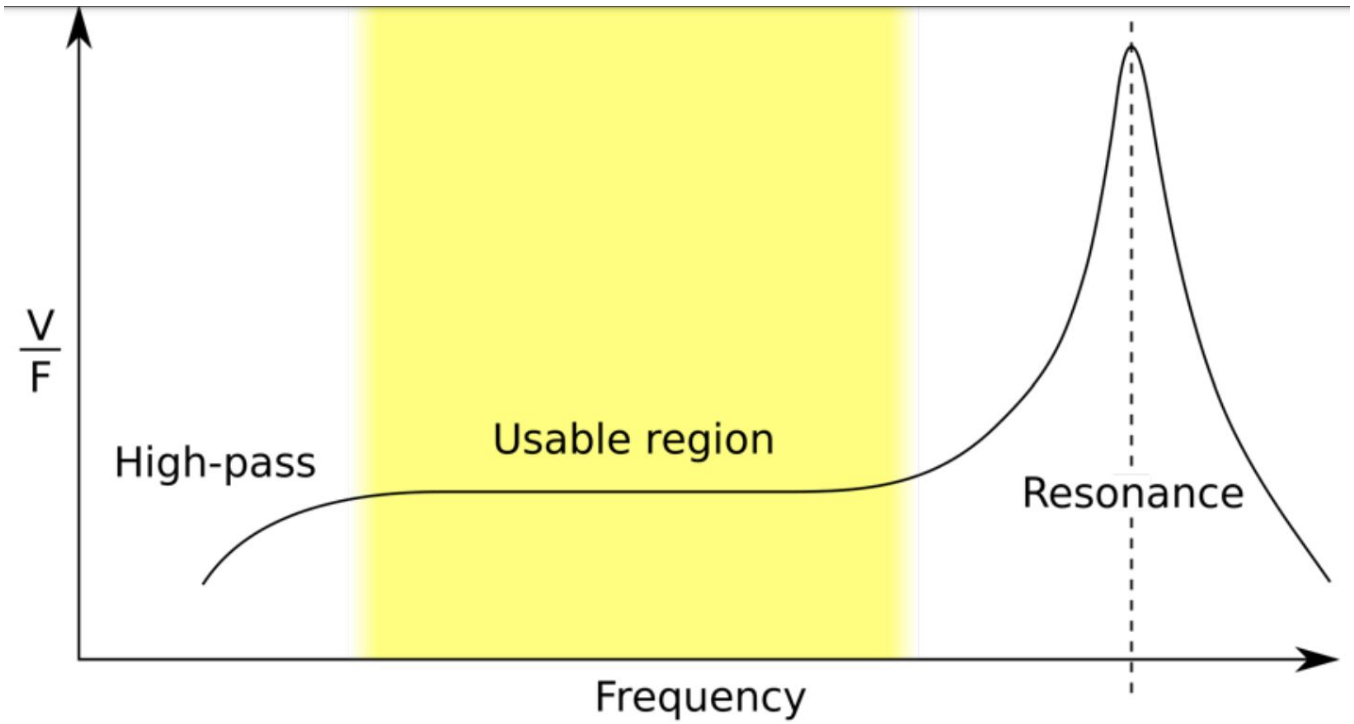
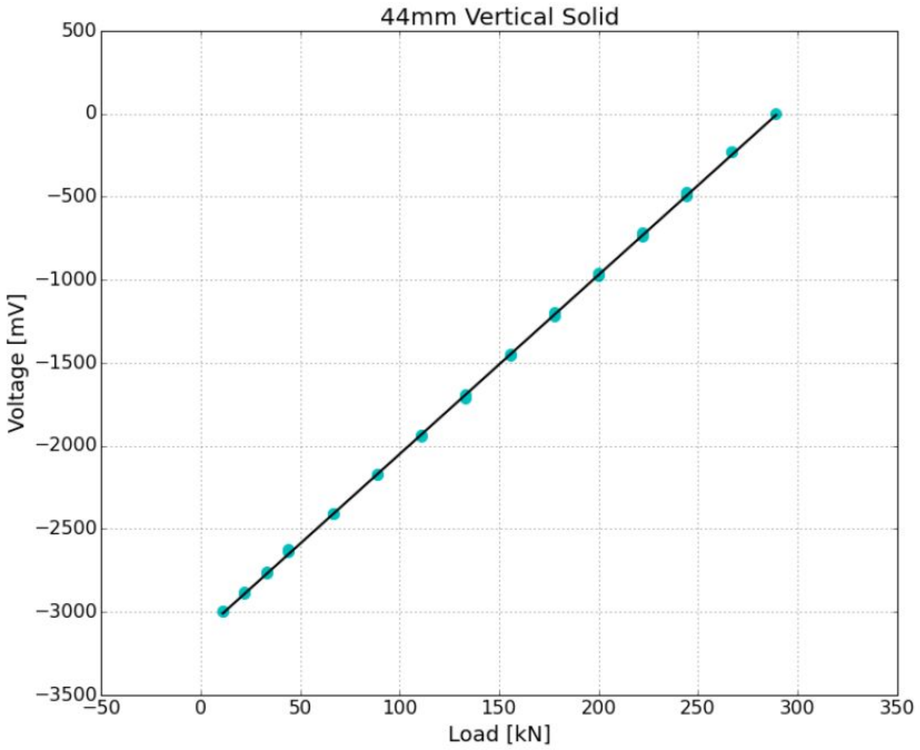
Images: All Sensors

There is also a frequency component "dynamic linearity"

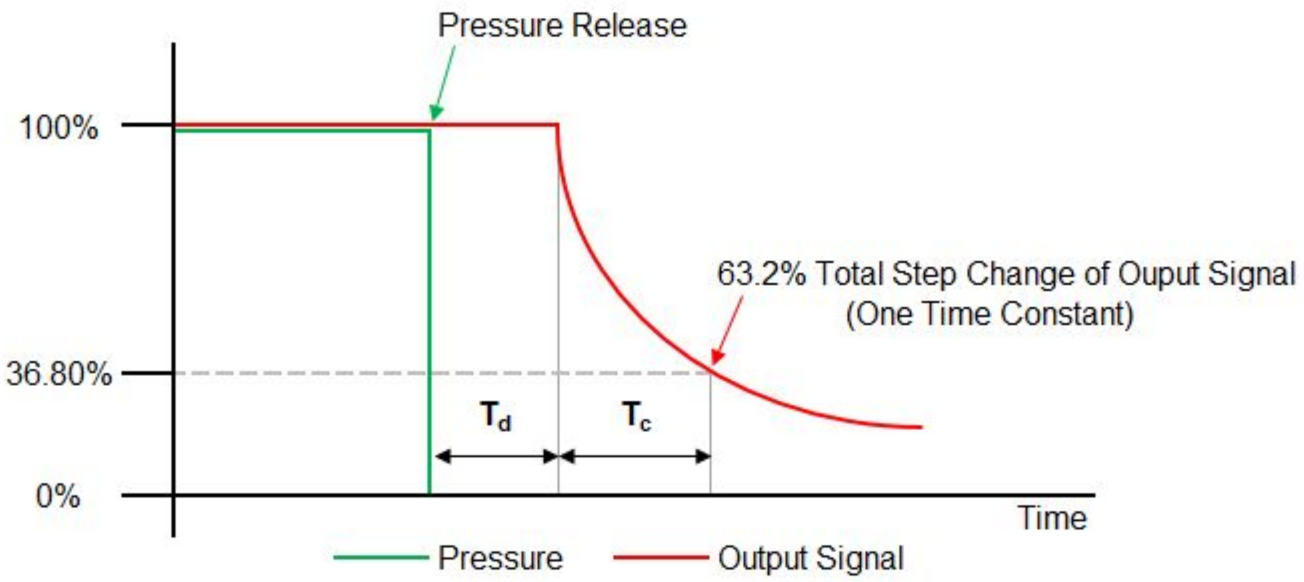


Images: WikiPedia

Sensitivity is the slope of the input-output curve (calibration slope)



Response time must be much smaller than the timescale of the phenomena you want to measure (or it can be your low pass filter)!



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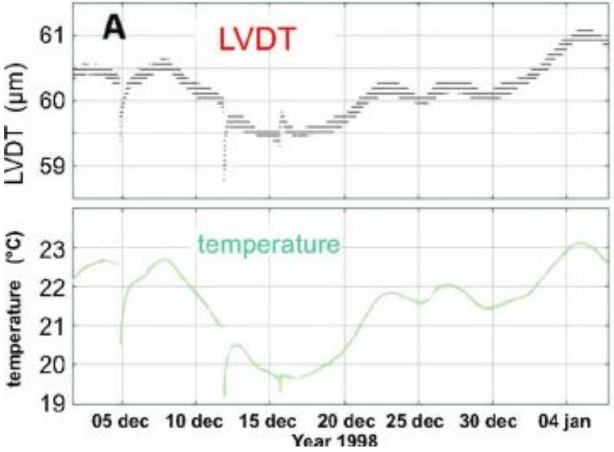
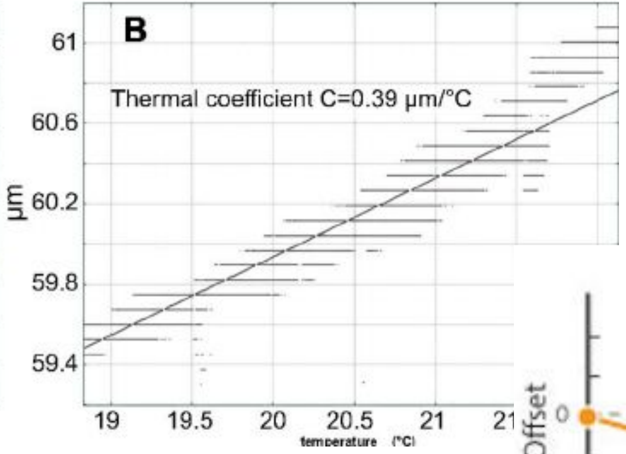
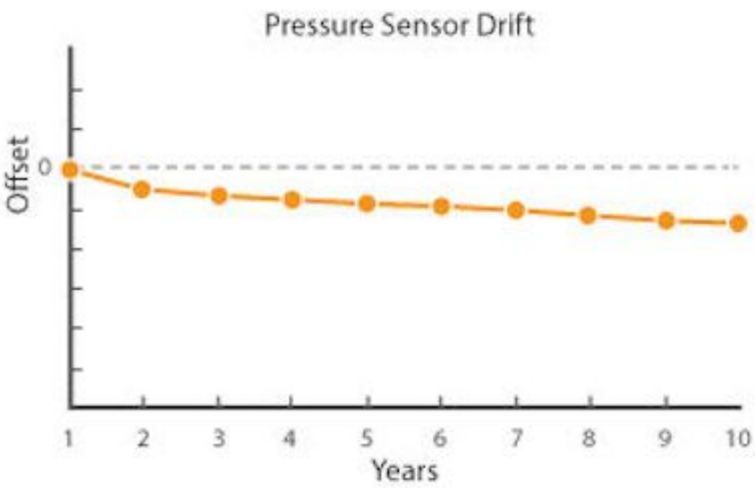
Images: Yokogawa Instruments

Stability is how constant the output of a transducer is when the physical stimulus is static (drift, environmental, and more)







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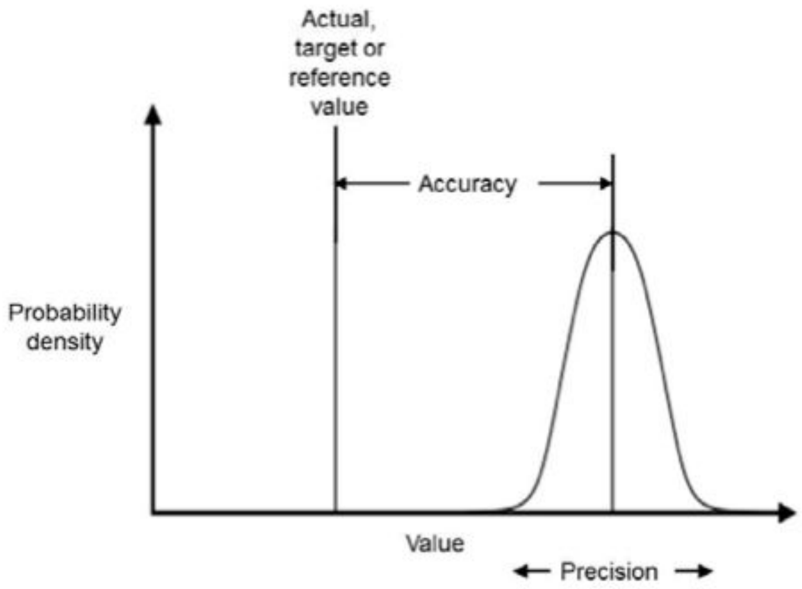
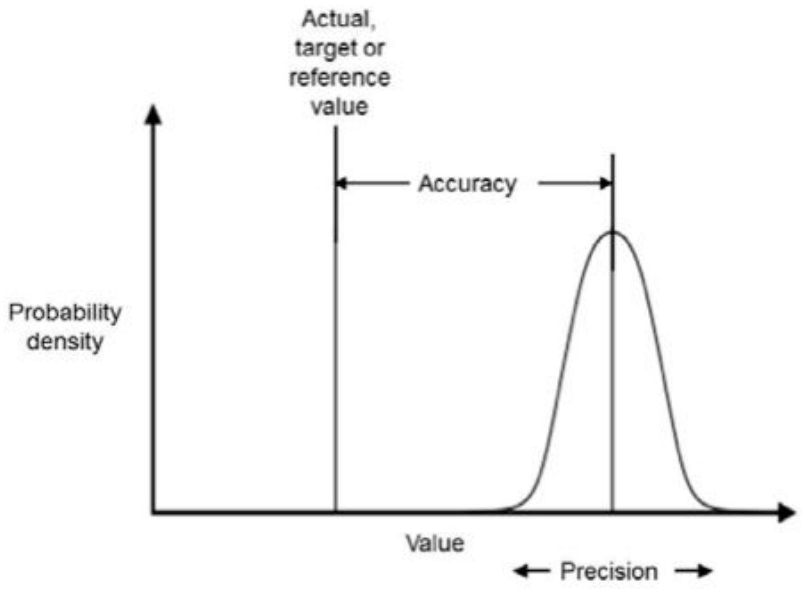
Images: ResearchGate, Solinst

Accuracy represents the maximum difference between the real and indicated values (commonly offsets, not always constant though)



Images: Allsensors

Noise is how much variation there is relation to the real signal and is related to the precision of the instrument (often SNR)



Images: Allsensors

The sensor must be matched to the environment in which it will operate - and overrated generally

Cost is always a factor - can you afford it, are you going to get it back, is it more than you really need?

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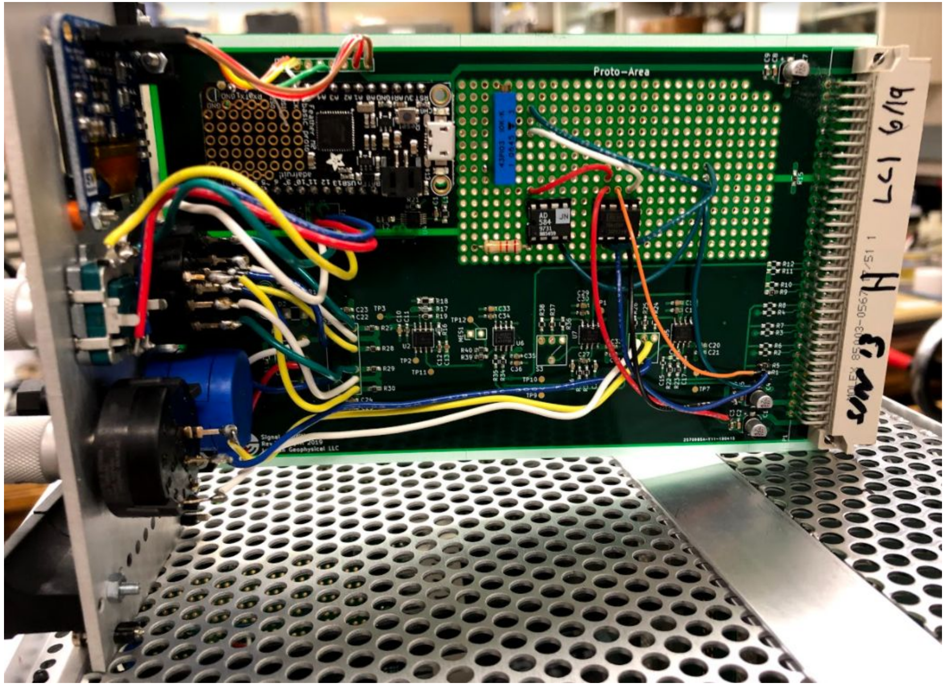
Image: Giphy

Signal conditioning can add more cost than the instrument and create more environmental concerns



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Images: Omega, CTEmag

Technology used can present significant pros and cons based on your particular application

- What is the physical method
- What are the cross-sensitivities
- How stable is it
- How experimental is it

Images: Digikey, Amazon

Transducer hysteresis is analogous to mechanical backlash and may or may not matter to you

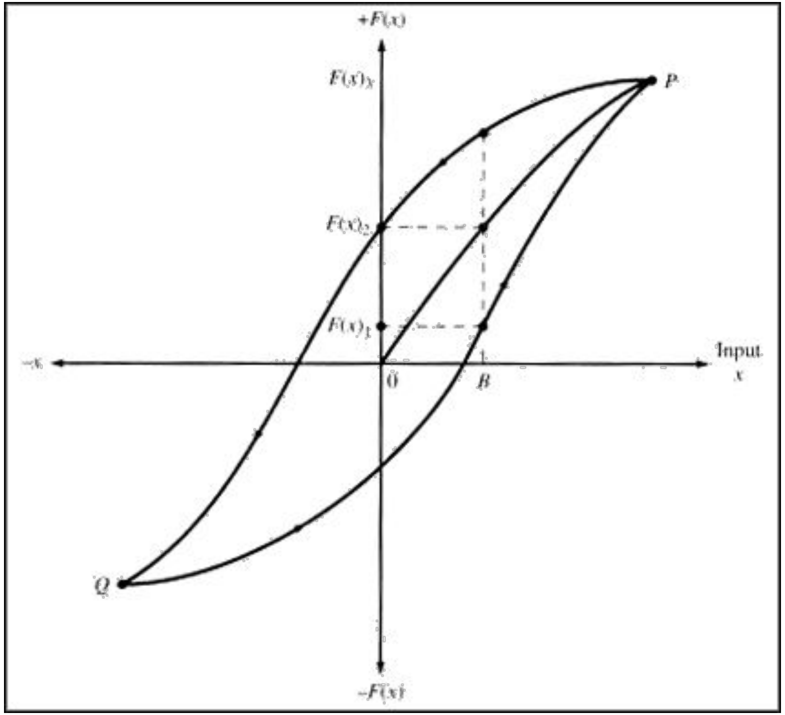
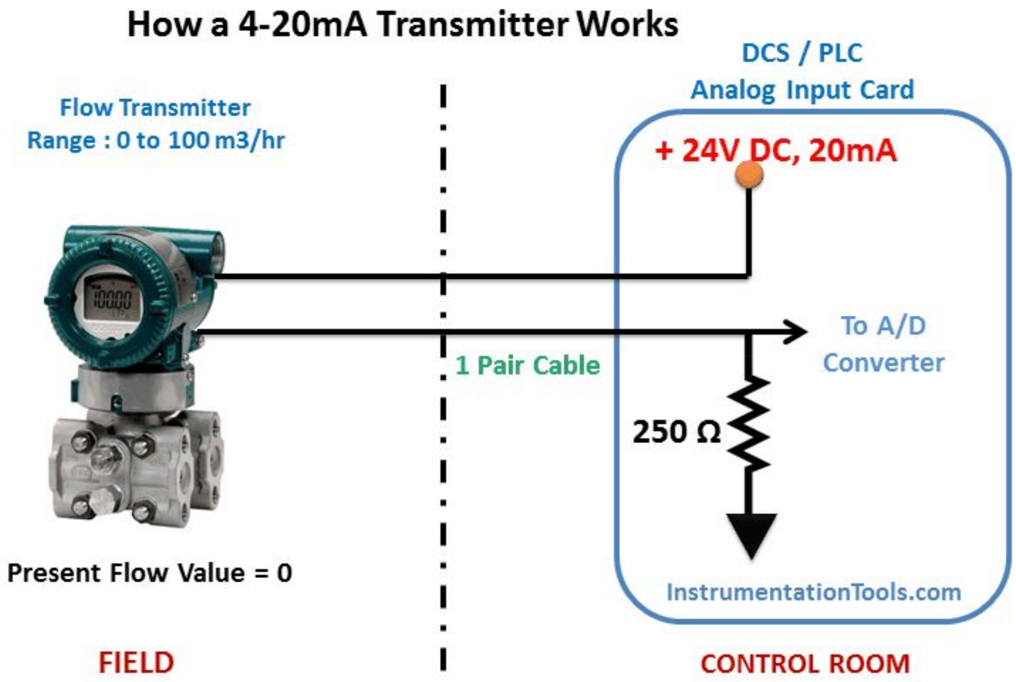


Image: National Instruments

Output should be matched to your system if possible



- Voltage
- Current
- Resistance
- Digital

Image: Inst Tools

We'll cover a few common measurement applications and how to approach them, many others are similar

- Temperature
- Position/Distance
- Pressure
- Strain
- Rotation
- MEMS

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Image: Giphy

Temperature measurement has many potential technologies

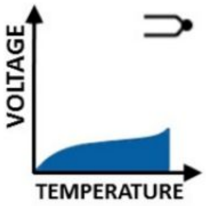
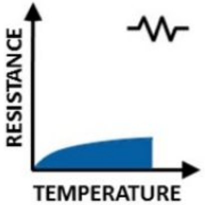
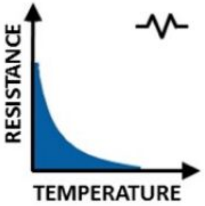
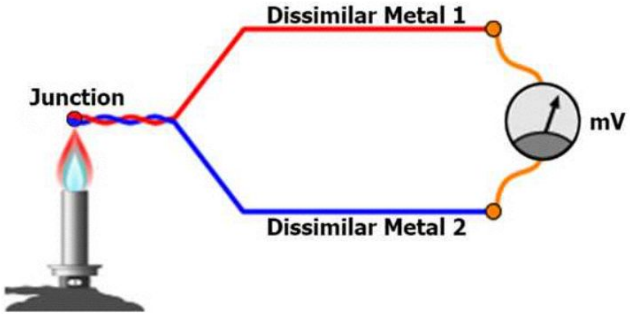
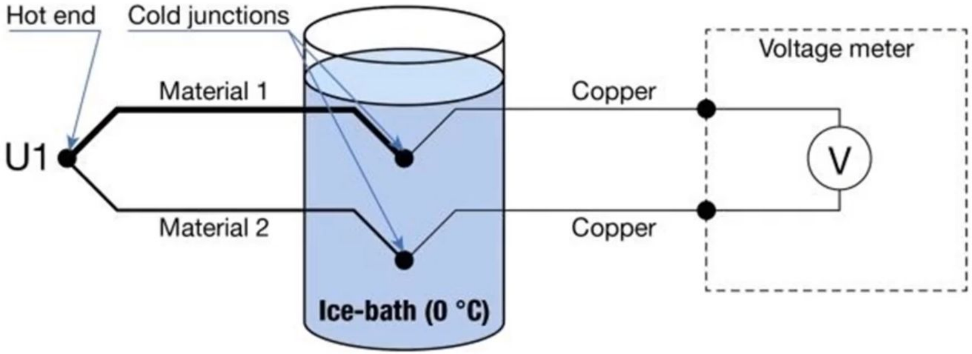
	Advantages	Disadvantages
THERMOCOUPLES 	✓ Simple ✓ Rugged ✓ Inexpensive ✓ No external power ✓ Wide temperature range ✓ Variety of styles	× Nonlinear response × Small sensitivity × Small output voltage × Requires CJC × Least stable
RTD 	✓ Most stable ✓ Good Linearity ✓ Most accurate	× Low sensitivity × 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

Image: National Instruments

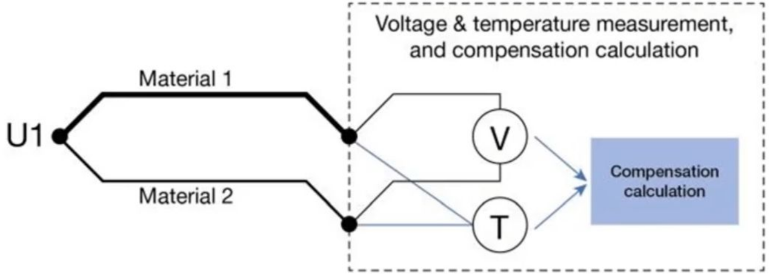
Thermocouples use the Seebeck effect





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%



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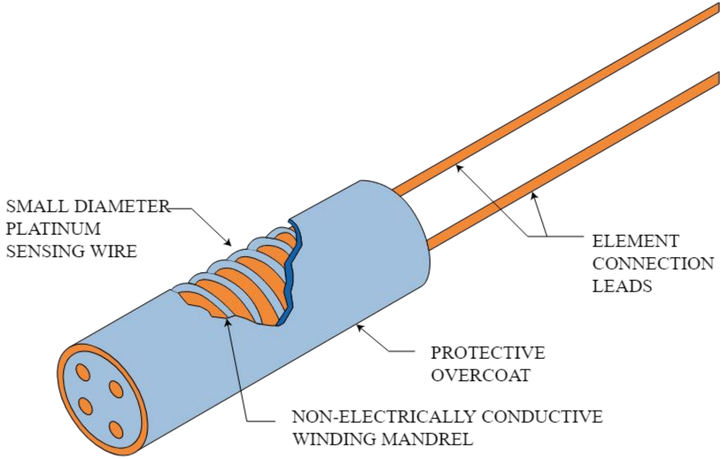
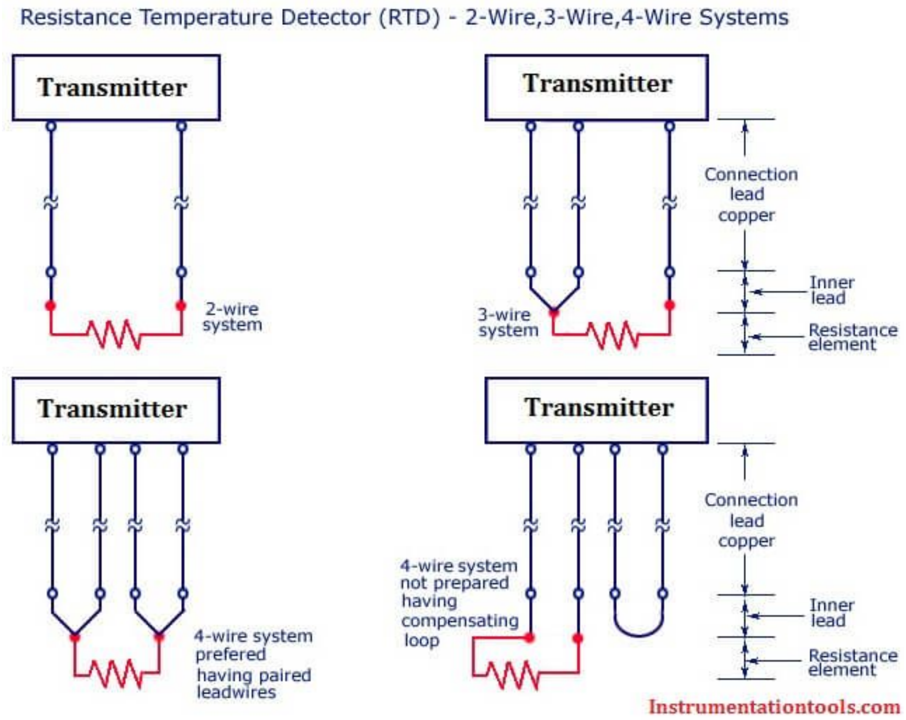
Images: Sterling Sensors, Omega, Rockz Automation

RTDs are resistance based devices with high stability, but low sensitivity





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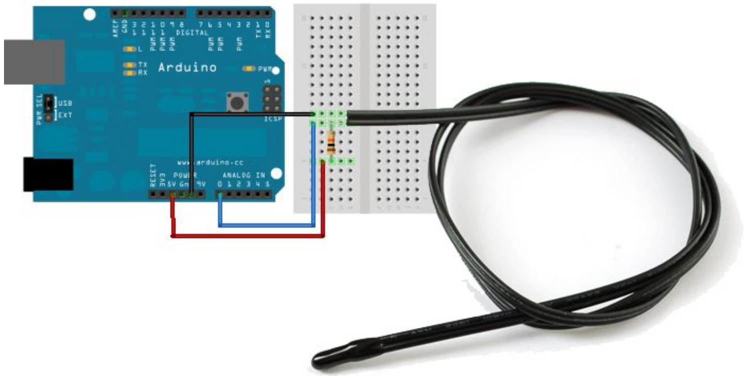
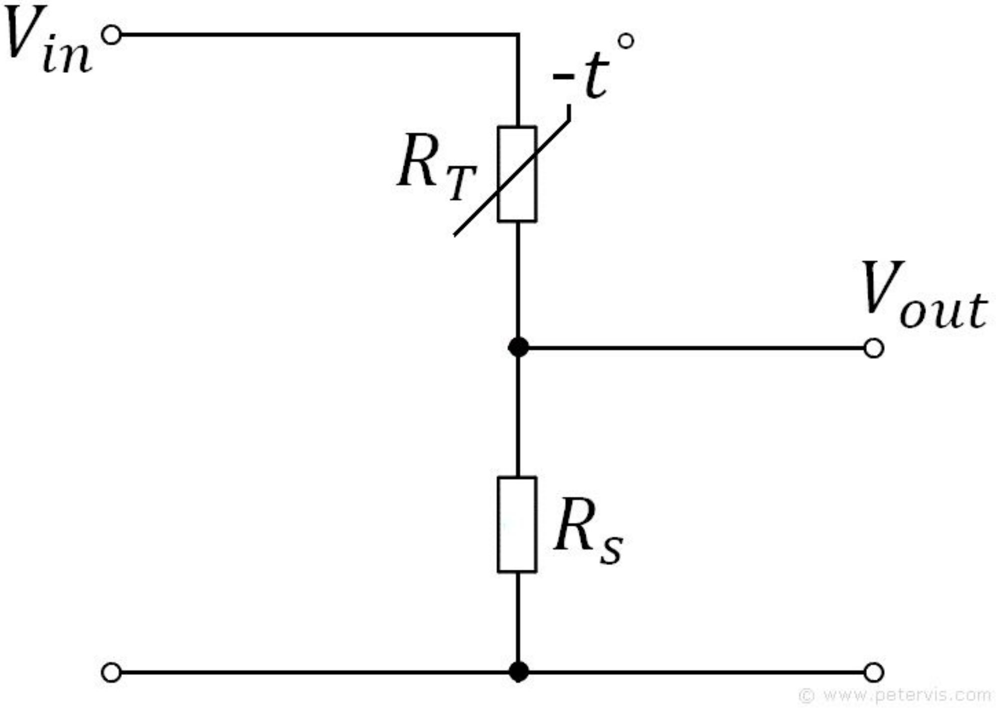
Images: DEWESoft

Thermistors are inexpensive silicon resistance based devices that are fast, but can experience self heating



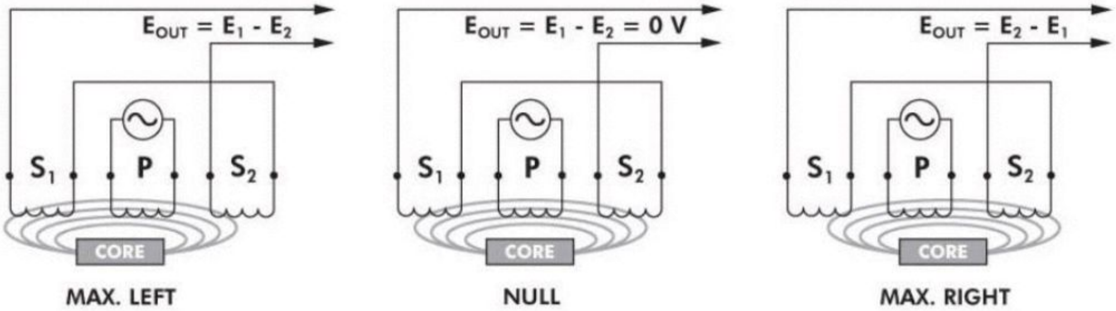


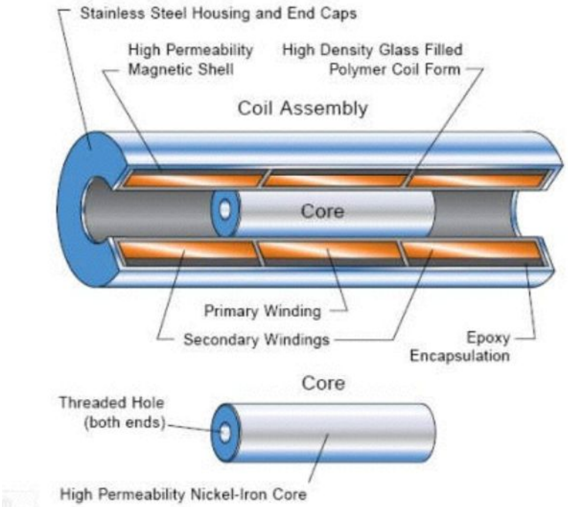
Images: Adafruit, Peter Vis

Position/Distance

- DCDTs/LVDTs
- Potentiometers
- Time of Flight
- Laser
- Inductive
- Capacitive

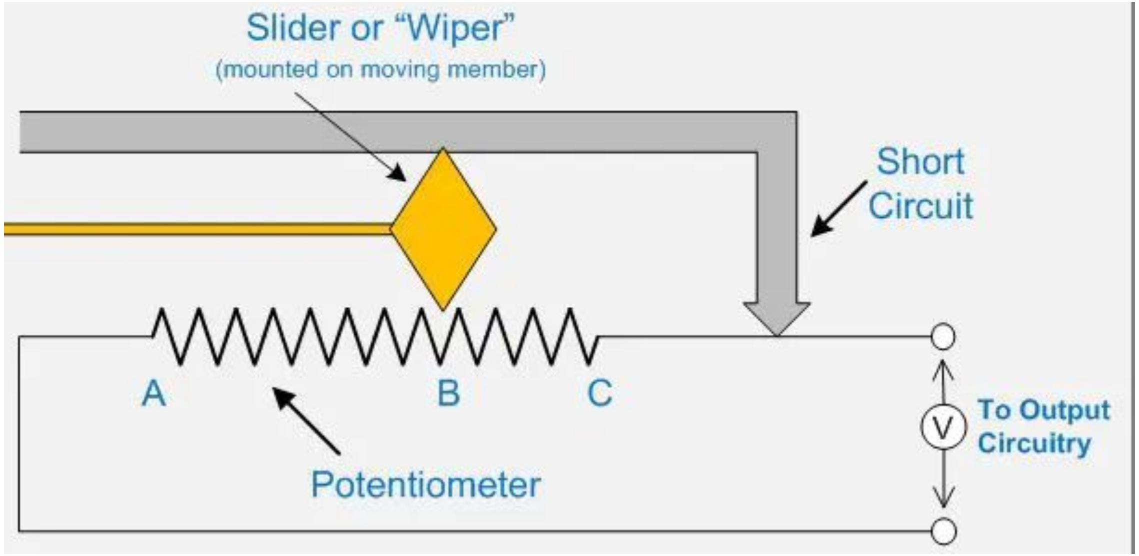
DCDTs and LVDTs are differential transformers, an expensive, but very good displacement sensors





Images: TE.com

Linear potentiometers can be slightly noisier and more thermally sensitive, but are inexpensive



Images: Control Products, TE

Time of flight sensors are a non-contact method than can be very economical

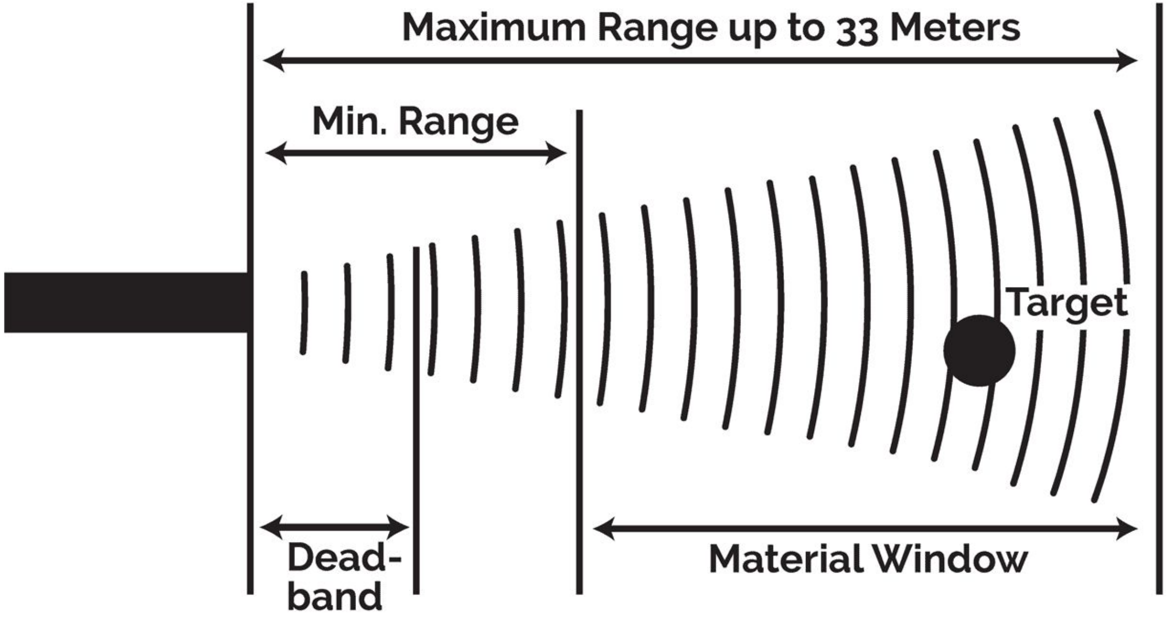


Image: Senex

Laser distance sensors are very precise, but expensive

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Image: Tuck Corp.

Inductive eddy current sensors are great for conductive non-contact measurements

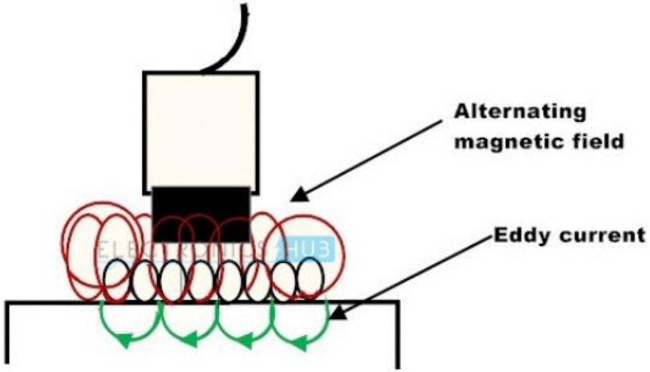

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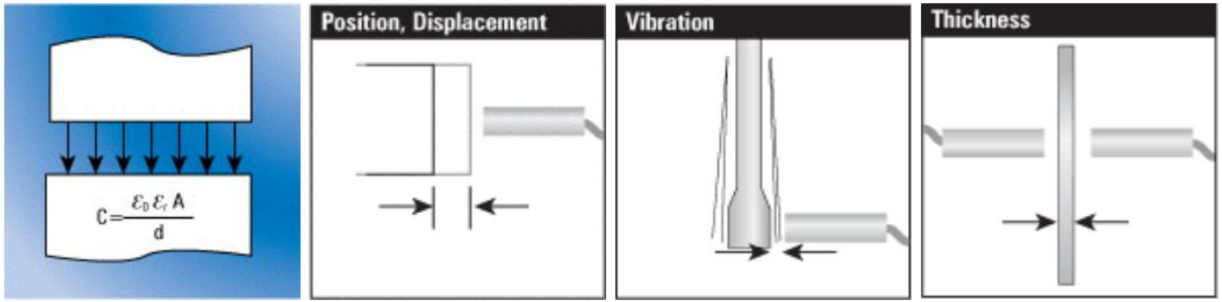
Image: Electronics Hub, Lion Precision

Capacitive sensors are very fast and high resolution sensors



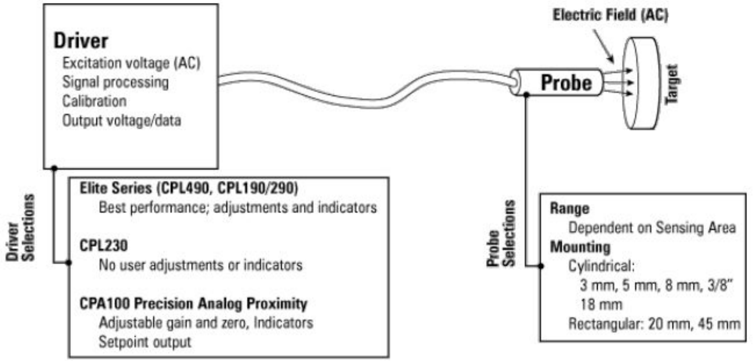


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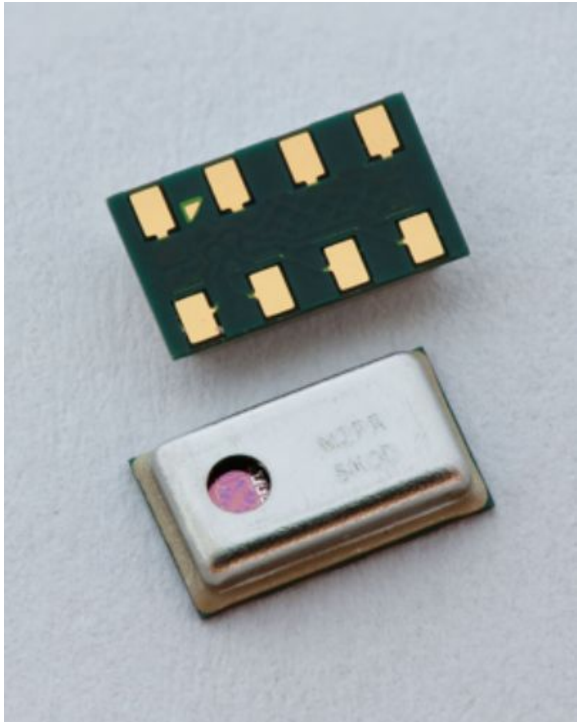
Image: Lion Precision

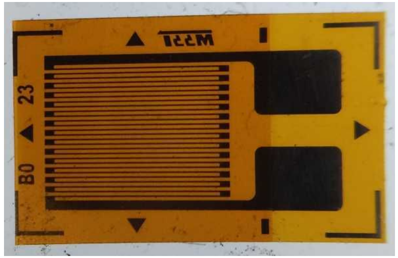
Pressure transducers are generally strain based, but come in multiple reference point variations



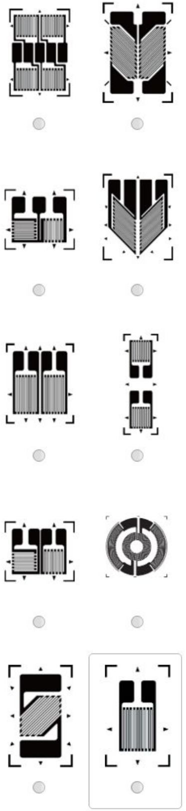
- Absolute
- Gage
- Vacuum
- Differential
- Sealed

Image: WikiPedia

Strain is measured with strain gauges and forms the basis for many other sensing technologies



$$\mathrm{GF} = \frac{\frac{\Delta R}{R}}{\epsilon}$$



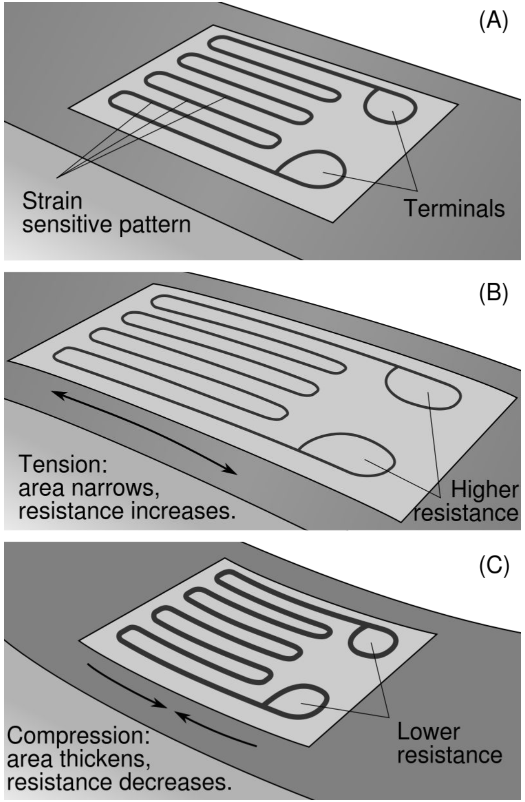
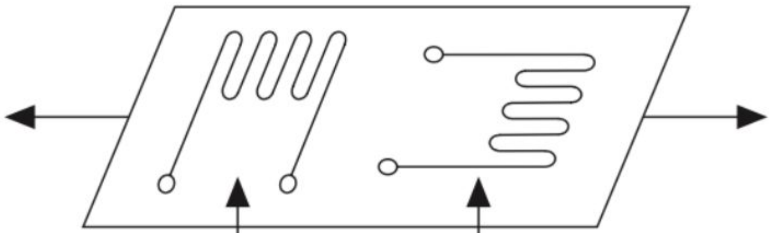


Image: dsfs

Strain gauges can be arranged in a variety of ways to measure different components of strain

Image: dsfs

We often use dummy gauges (not bonded or bonded in an unstrained direction) to compensate for temperature



$$\frac{\Delta R}{R} = \mathrm{GF}\epsilon + \alpha \Delta T$$

Image: National Instruments

Great care should be taken with the bridge circuit design

Image: dsfs

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

Bonding, placement, wiring, resistance testing, and more are required and each with a lot of odd sensitivities

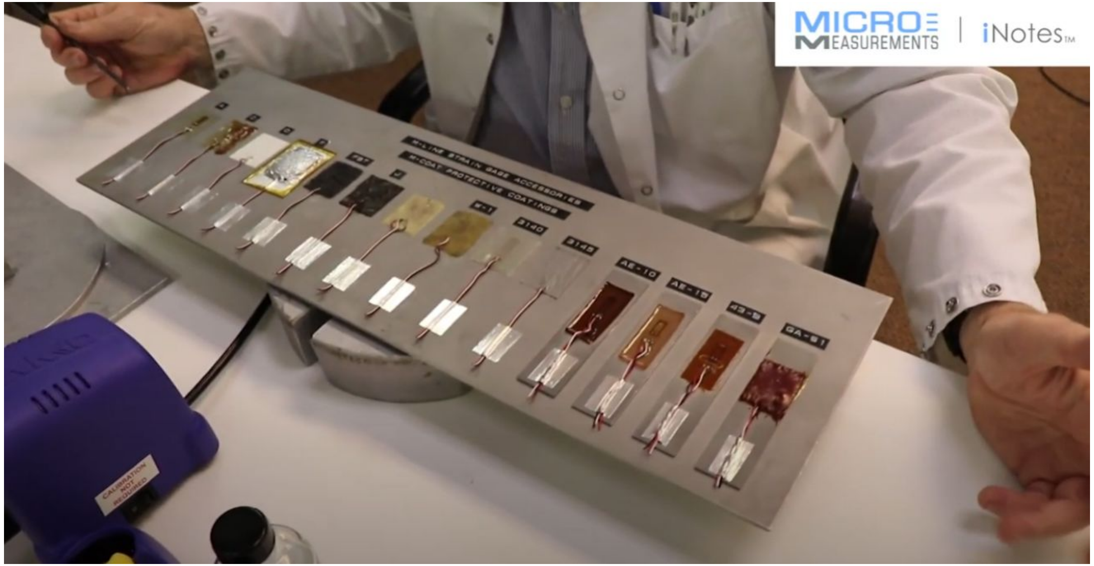


Image: Micromeasurements

Encoders are a great tool for rotary (or what can be translated to rotary) motion

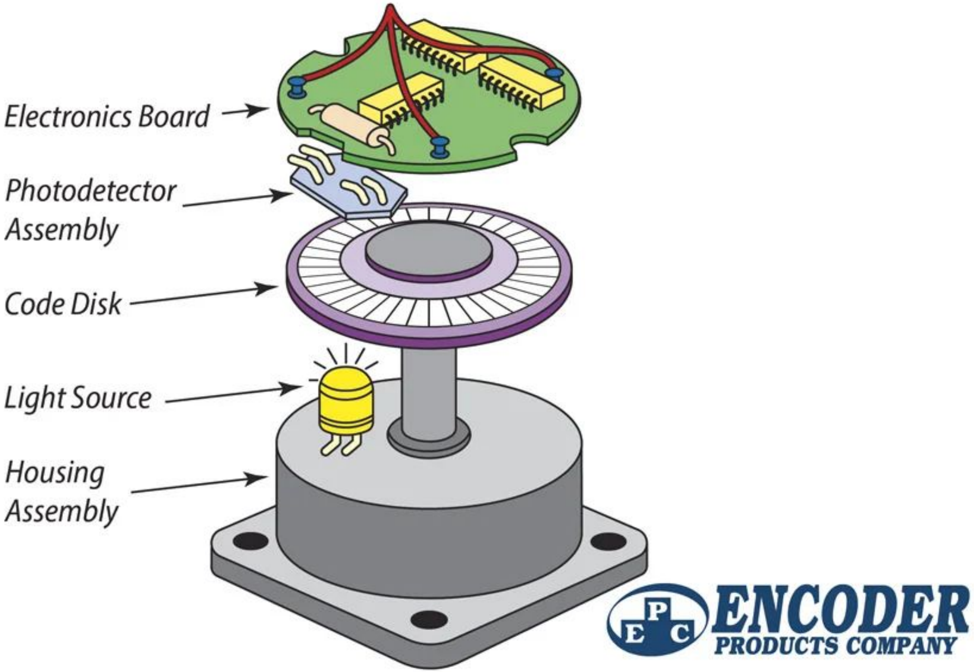
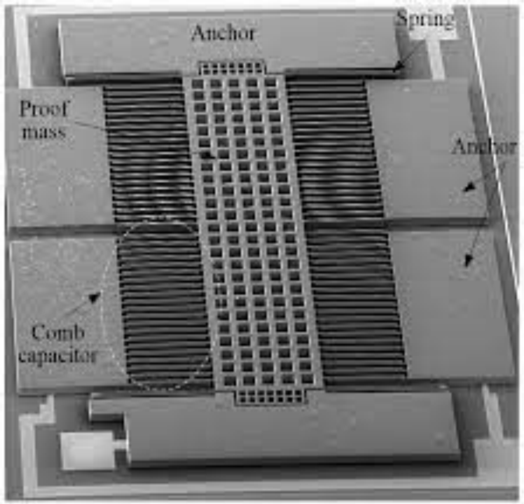
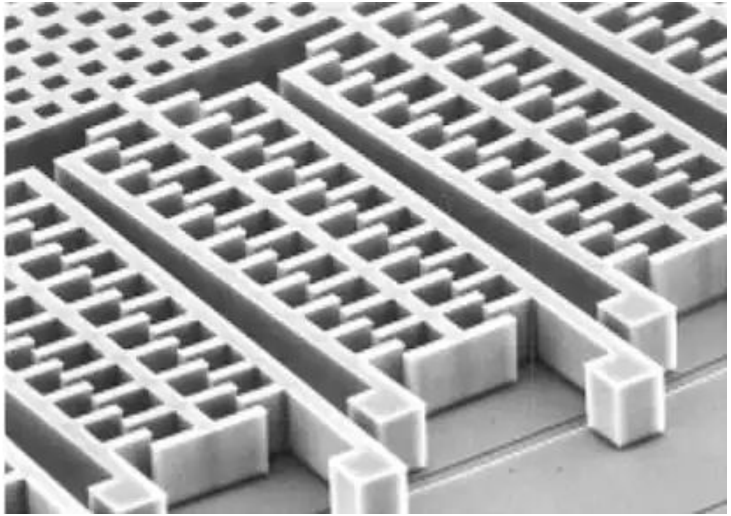
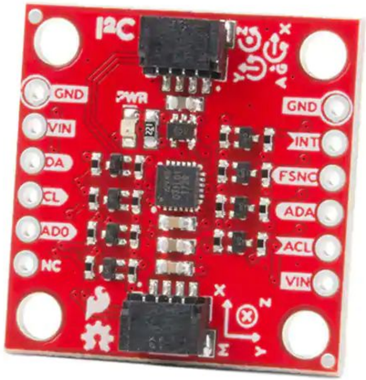


Image: EPC

MEMS has slowly been taking over many traditional applications, but the technology is certainly not fully mature







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Images: MDPI, Digikey

MEMS has slowly been taking over many traditional applications, but the technology is certainly not fully mature

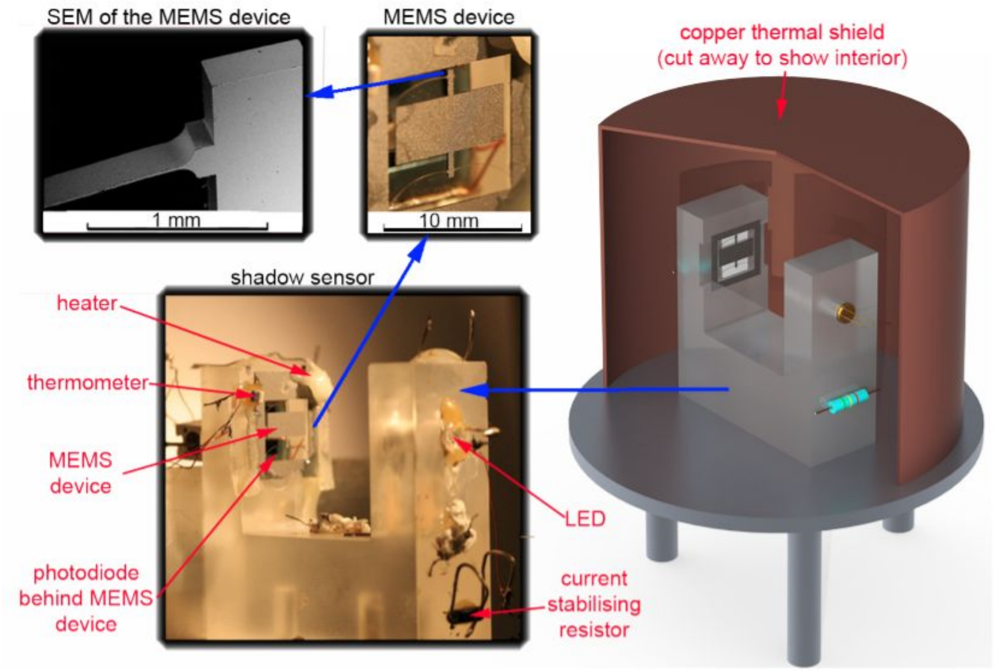
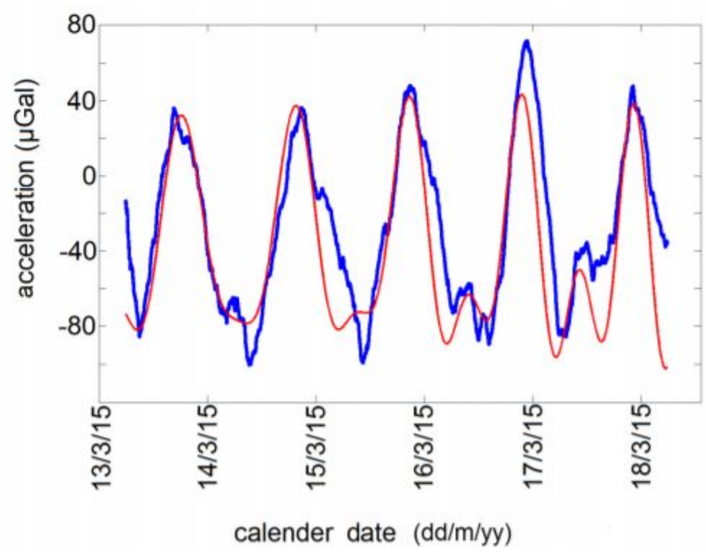


Figure 2



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Actuators come in many, many varieties and we're not going to focus on them more than to mention a few of the common ones

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Image: Teknic, ServoCity, Amazon