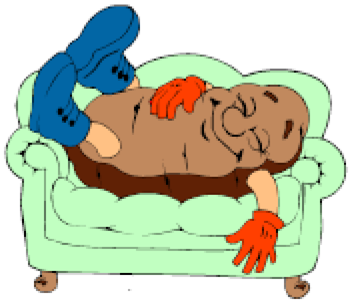
Test & Measurement Tutorial

Types Of Signals (Based on Rate Of Change)

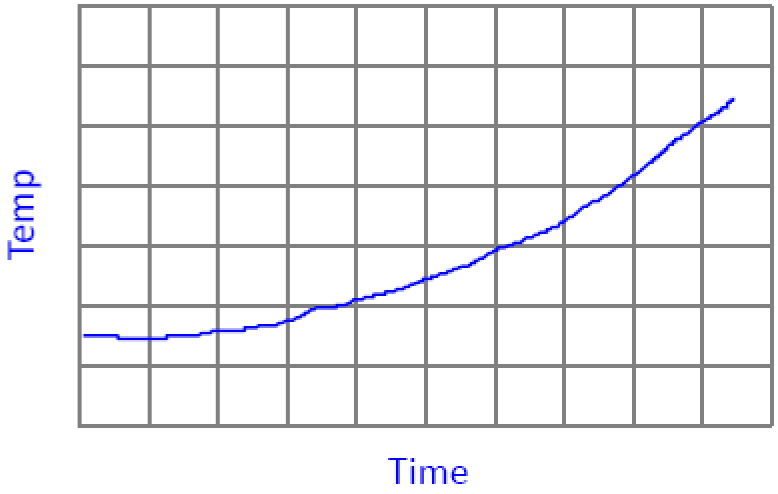
- **Static Signals**
  - Slowly changing values
  - Not simultaneously sampled
  - Multiplexing is generally allowed
- **Transient Signals**
  - High sample rate required
  - Typically time domain analysis
  - Simultaneous sampling
- **Dynamic Signals**
  - Often physical phenomena
  - What we FEEL and HEAR
  - Simultaneous sampling
  - Multiplexing difficult
  - Analysis on frequency content



Types Of Signals (Based on Rate Of Change)

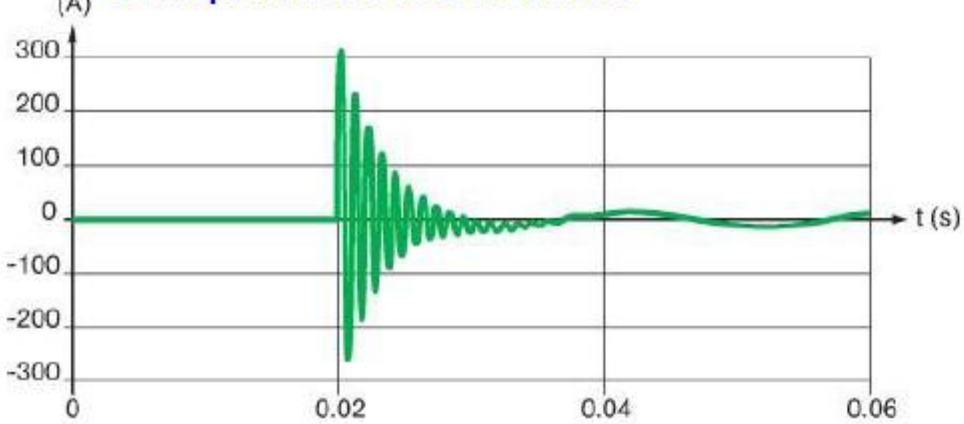
- **Static Signals**
  - Changing slowly over a long period in a non-repetitive fashion
  - Usually viewed in time domain
  - Generally requires sampling at <100 Sa/sec

Example: ***Motor Temp Test***



Types Of Signals (Based on Rate Of Change)

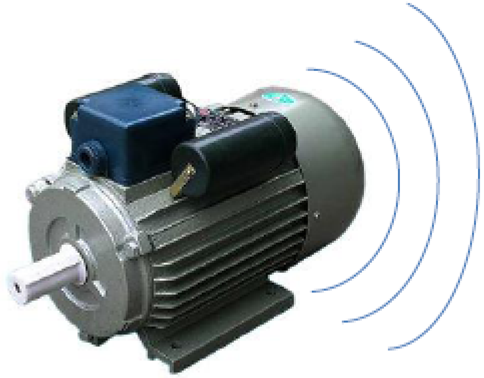
- Transient Signals
  - Changing rapidly over a short period in a non-repetitive fashion
  - Usually viewed in time domain
  - Sampling rates vary widely

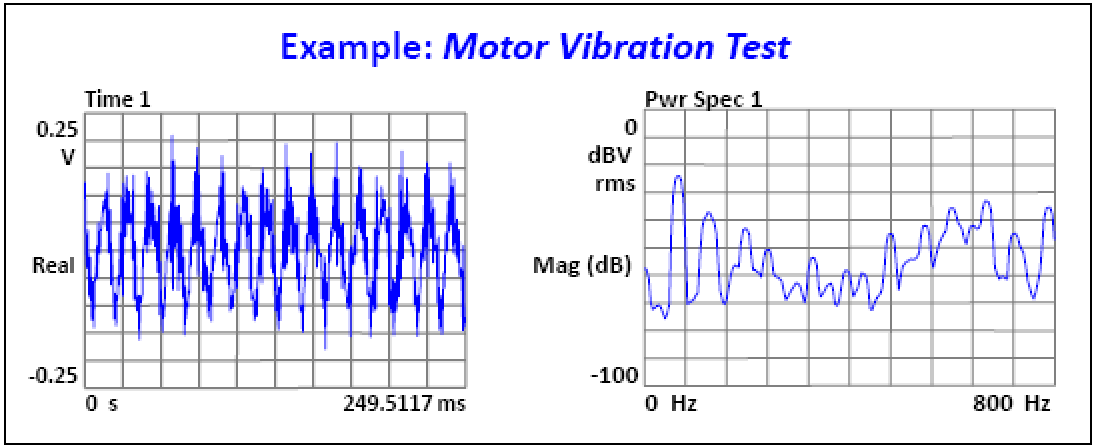


Torque of Fan
Drop test
Bomb blast

Types Of Signals (Based on Rate Of Change)

- Dynamic Signals
  - Rapidly changing time data (usually sound or vibration)
    - Combination of many frequencies
    - May be periodic, exponential or transient
  - Typically sampled at 1K-200KSa/sec
  - Usually viewed in frequency domain





Root Sum Squares (RSS)

Root Sum Squares (RSS): accuracy of a pressure transducer is calculated by taking the square root of non-linearity + hysteresis + non-repeatability.

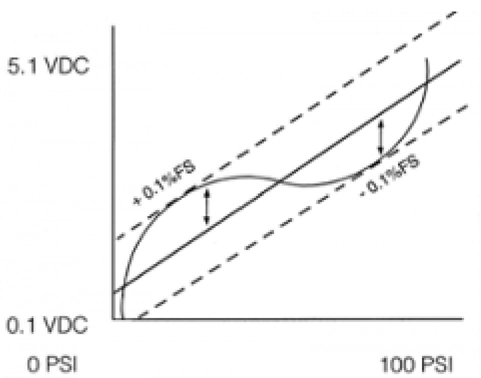
For Example:

[Non-Linearity: $(\pm0.1\%)^2 = 0.01\%$] + [Hysteresis: $(\pm0.05\%)^2 = 0.0025\%$] + [Non-Repeatability: $(\pm0.02\%)^2 = 0.0004\%$] = 0.0129%

$\sqrt{0.0129\%} = \pm0\ .11\%$ FS at constant temperature

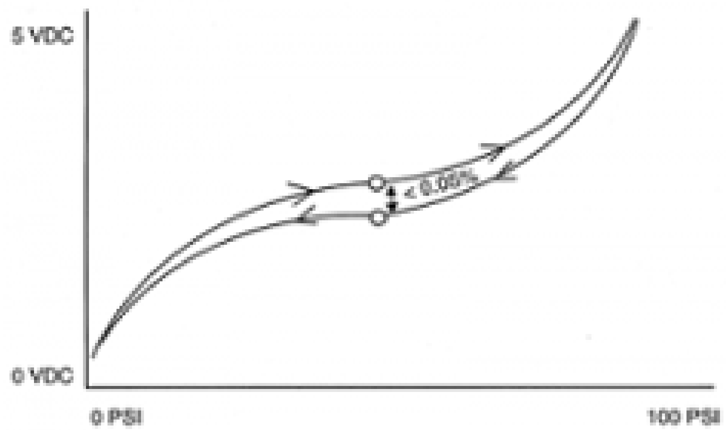
Non-Linearity

The relationship of a calibration curve to a specified straight line.



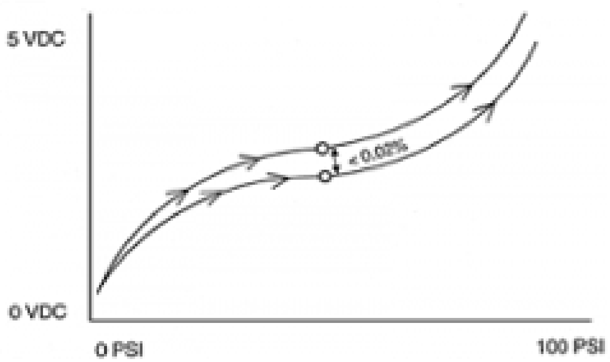
Hysteresis

The maximum difference in output at any pressure value within the specified range, when the value is approached with increasing and decreasing pressure.



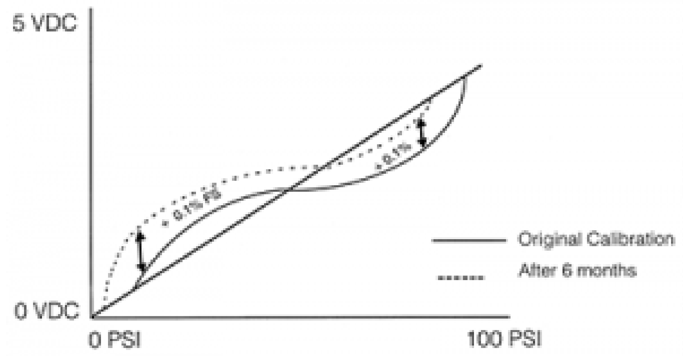
Non-Repeatability

The ability of a transducer to reproduce output readings when the same pressure value is applied to it consecutively, under the same conditions, and in the same direction.



Long-Term Stability

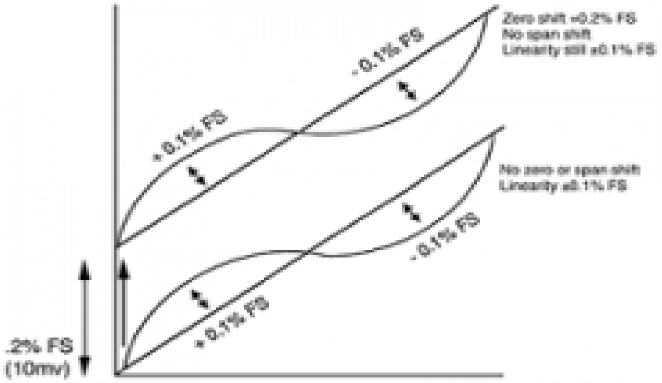
The ability of a transducer to reproduce output readings obtained during its original calibration at room conditions for a specified period of time.



Zero Offset

Zero output does not affect linearity or accuracy

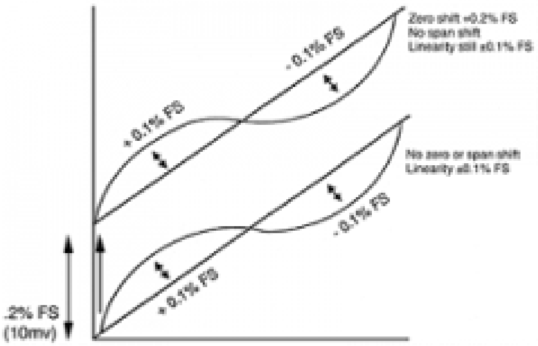
Zero output is factory set to within a certain % of full scale. Results in a shift up or down of the calibration curve.



Span Offset

Span output is factory set to within a certain % of full scale. Results in a change in the slope of the curve.

Does not affect linearity or accuracy.



Thermal Effects

The change in the zero and span output that occurs due to temperature changes.

Thermal Zero Shift: < +/- 0.004%/°F (0.0072%/°C)
Thermal Span Shift: < +/-0.003%/°F (0.0054%/°C)

Example: Temp Range -10°F to +130°F (-23°C to +55°C)
Max temp. change from 70°F (21°C) = 80°F (44°C)

80°F X .004%/°F = .32% FS DZ/DT
or 44°C X .0072%/°C = .32% FS DZ/DT

80°F X .003%/°F = .24% FS DS/DT
or 44°C X .0054%/°C = .24% FS DS/DT

Sensors & Actuators

- Sensors / Transducers
  - Converts a physical quantity into electrical quantity
  - Not necessarily be linear
  - Some sensors need excitation (which is mostly sensor dependent)
- Actuators
  - Converts an electrical signal into physical parameter
  - May require additional power amplifier

Parameter	Sensor	Actuator
Temperature	Thermocouple	Heater
Acoustic	Microphone	Speaker
Vibration	Accelerometer	Shaker
Motion	Encoder	Motor

Temperature sensors

- Most common types of sensors
  - Contact type
    - Thermocouple
    - RTD
    - Thermistor
    - Semiconductor

    (Thermocouple, RTD, Thermistor) : Serviced by VTI Instruments
  - Non-Contact type (Pyro / Infrared) : Serviced by LAND Instruments

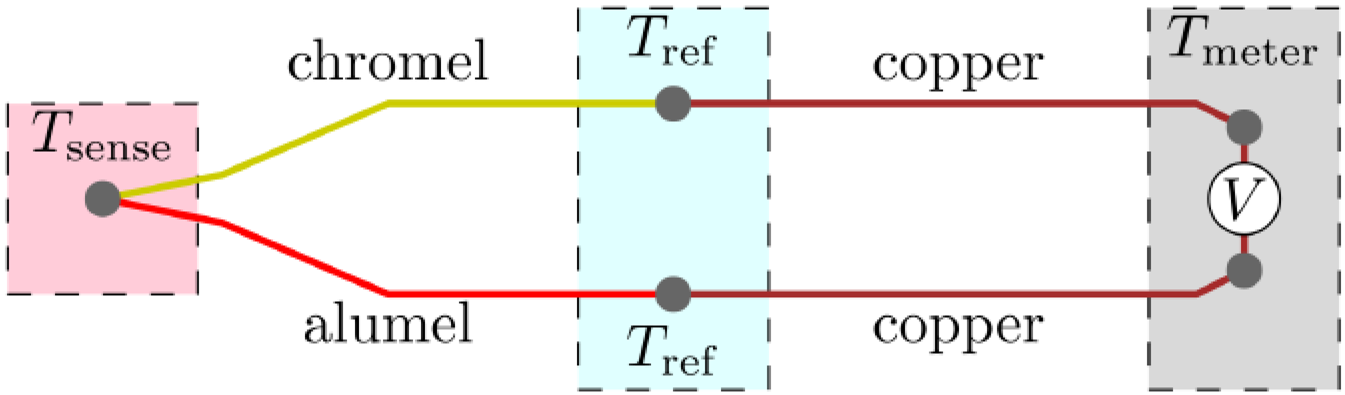
Thermocouple

RTD

Thermistor

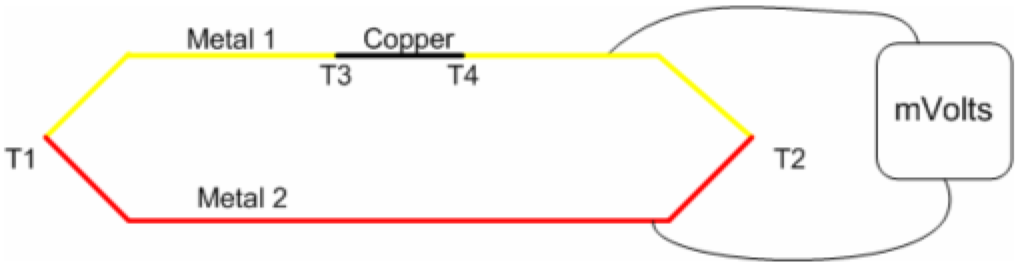
Thermocouples

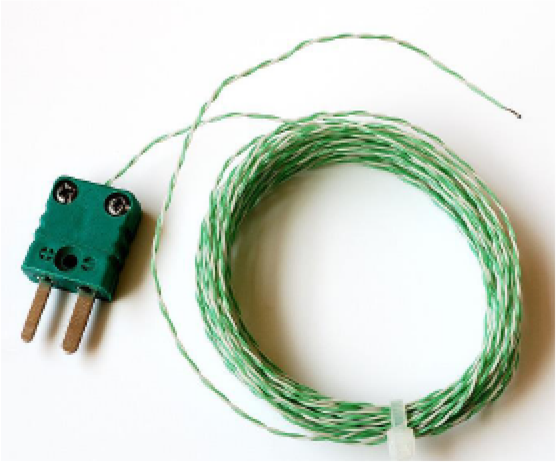
- Simply a pair of two dissimilar metals, whose ends are kept at different temperatures
- Voltage generated by TC will be dependent on "difference" between $T_{sense} - T_{ref}$ (and not based on absolute temperature).
- Cold junction should be kept at known temperature (Ice bath) or the temperature of cold junction itself should be measured



Thermocouples

- Voltage output will be very low (few hundred micro volt), and hence requires sensitive instrumentation
- Requires no excitation – Just a 2 wire voltage measurement ckt
- Polarized connectivity: Connections can't be reversed
- Extra lead wires must be made of same TC metals, to avoid junctions. Also called as compensating cable





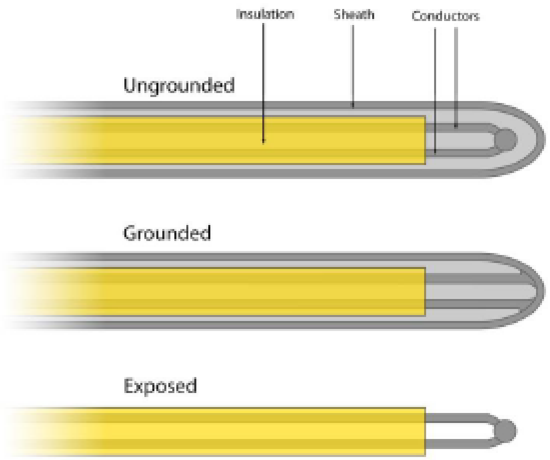
Thermocouples

- Standard thermocouple types and their curves are standardized as per IEC or ANSI
- Simple look-up table type interpolation, or complex inverse curve fitting functions may be used for Engg Unit conversion.

TYPE	Temperature	Positve Leg	Negative Leg	Color Code
TYPE B	0 to 1700°C	Platinum-30% Rhodium	Platinum-6% Rhodium	Gray & Red
TYPE E	-100 to 1000°C	Chromel	Constantan	Purple & Red
TYPE J	0 to 750°C	Iron	Constantan	White & Red
TYPE K	-100 to 1300°C	Chromel	Alumel	Yellow & Red
TYPE N	-230 to 1300°C	Nicrosil	Nisil	Orange & Red
TYPE R	0 to 1600°C	Platinum-13% Rhodium	Platinum	Black & Red
TYPE S	0 to 1600°C	Platinum-10% Rhodium	Platinum	Black & Red
TYPE T	-200 to 350°C	Copper	Constantan	Blue & Red

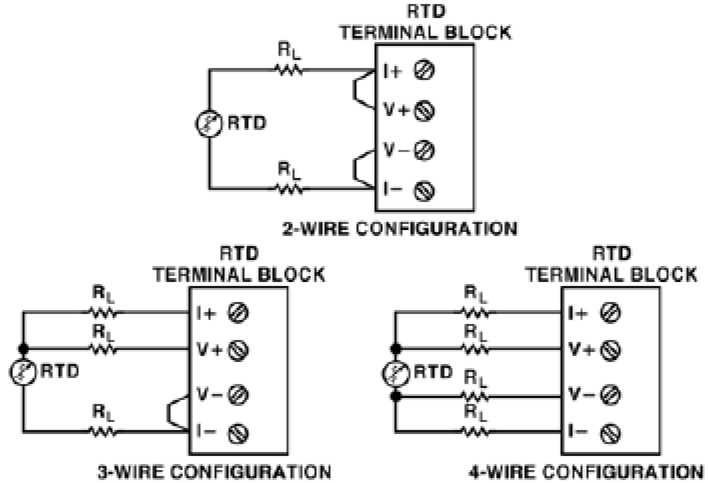
Thermocouples

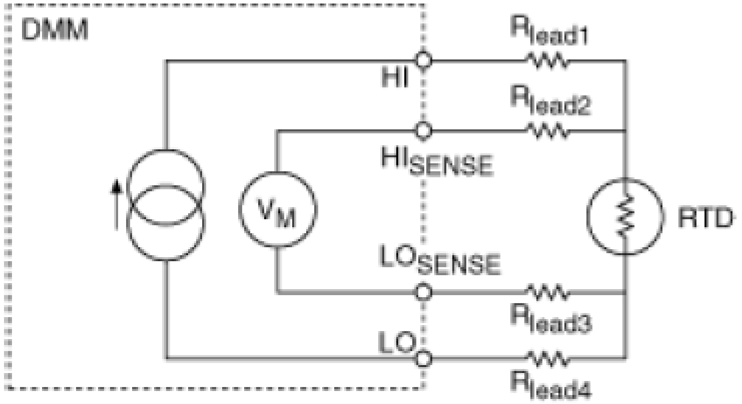
- Standard thermocouple types and their curves are standardized as per IEC or ANSI
- Simple look-up table type interpolation, or complex inverse curve fitting functions may be used for Engg Unit conversion.
- Typical DAQ characteristics
  - Slow to medium speed sampling (≤ 1000 Sa/sec/ch)
  - Medium resolution (≤ 16 bit)
  - Higher gain & low drift
  - Open thermocouple detection
  - Good calibration
  - Isolation (in some cases)
- Example: (K Type TC) : 40µV ≈ 1°C



RTDs

- Simply a resistor whose resistance will change based on temperature
- Resistance will increase with temperature (but not linearly)
- Although main element is always 2 wire, it will be connected as 3 or 4 wire method, to improve accuracy (eliminates lead wire errors)
- Non-directional & non-polar (can interchange terminals)





RTDs

- Resistance to Temperature conversions are done based on **callendar van-dusen coefficients** for given type of RTD
- Different standardization agencies have different precision of constant's value

$$R_T = R_0\left[1 + AT + BT^2 + CT^3(T-100)\right]$$

R_0 = nominal resistance of RTD (resistance at 0 °C)
T = temperature in °C
$A = \alpha[1 + (\delta/100)]$
$B = -\alpha\delta/1 \times 10^4$
$C = -\alpha\beta/1 \times 10^8)$

RTD Type	Standard	α	β	δ	R_0
PT100	ITS-90	0.003850	0.10863	1.49990	100 Ω
D100	ITS-90	0.003920	0.10630	1.49710	100 Ω
F100	ITS-90	0.003900	0.11000	1.49589	100 Ω
PT385	IPTS-68	0.003850	0.11100	1.50700	385 Ω
PT3916	IPTS-68	0.003916	0.11600	1.50594	3916 Ω

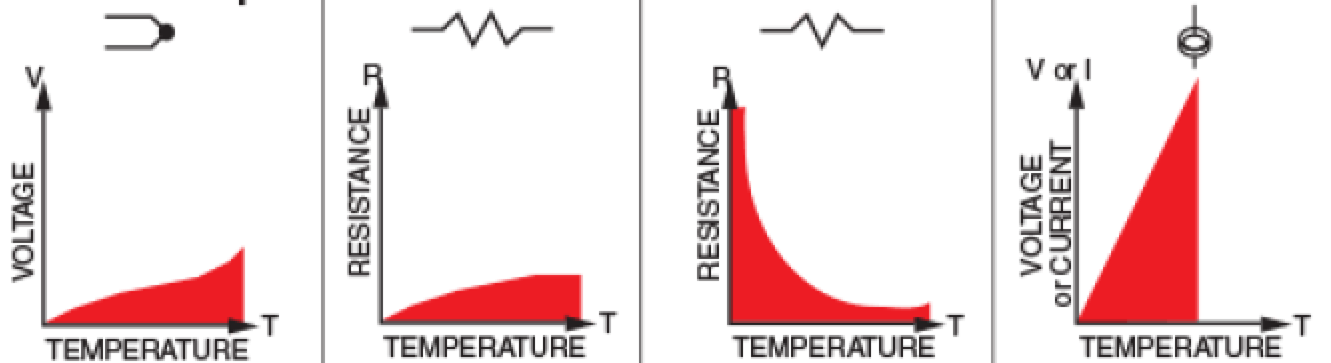
RTDs

- Requires excitation (usually few mA of constant current)
- Any resistance measurement device (like DMM) can be used to interface (assuming EU conversion is done externally)
- Typical DAQ characteristics
  - Slow speed sampling (≤ 10 Sa/sec/ch)
  - Medium to High resolution (≥ 16 bit)
  - Support for 4 wire technique with built-in current source
  - Good calibration
  - Isolation (in some cases)
  - Pulsed excitation sources (in some cases)
- Example: Pt-100 Type RTD: $0.3\Omega \approx 1^{\circ}C$

Thermistors

- Similar to RTDs, whose resistance is a function of temperature
- Resistance will decrease with increase in temperature
- High output but limited temperature range
- Typically used in 2 wire mode, as lead wire resistance % error is less
- Excitation required (few 10s of µA, to avoid self heating)
- Usually stable and requires no calibration
- Typical DAQ characteristics
  - Slow speed sampling (≤ 10 Sa/sec/ch)
  - Medium to High resolution (≥ 16 bit)
  - Uses Steinhart-Hart equation and coefficients for EU conversion
- Usual thermistor types: 2.252 kΩ, 5 kΩ, and 10 kΩ

Comparison Of Various Sensors



	Thermocouple	RTD	Thermistor	I. C. Sensor
Advantages	Self-powered Simple Rugged Inexpensive Wide variety Wide temperature range	Most stable Most accurate More linear than thermocouple	High output Fast Two-wire ohms measurement	Most linear Highest output Inexpensive
Disadvantages	Non-linear Low voltage Reference required Least stable Least sensitive	Expensive Current source required Small Δ R Low absolute resistance Self-heating	Non-linear Limited temperature range Fragile Current source required Self-heating	T<200°C Power supply required Slow Self-heating Limited configurations

Solid-state based relays are not recommended for RTD based applications

Dual Temperature and Pressure Transducers

Standard Features:

- Ranges to 20000 PSI
- Stainless Steel Construction
- Probes from 1” to 4”
- Operates with fluids or gases

Optional Features

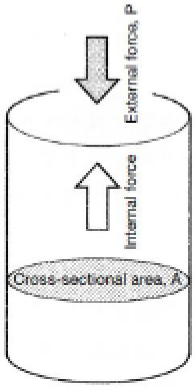
- Probe Length Greater Than 4”
- Alternative pressure ports
- Alternative electrical terminations
- Alternative materials of construction
- Temperature probe from -320°F to +750°F

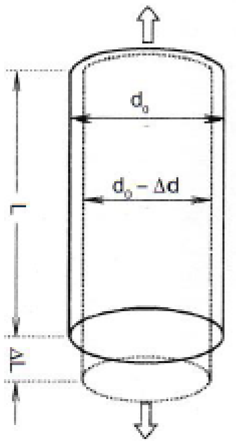
Benefits:

- Accuracy %FSO* 0.10%.
- Long term stability
- Low sensitivity to shock and vibration
- Wide compensated temperature range
- Excellent response to transient pressures and infinite resolution

Stain Gauge

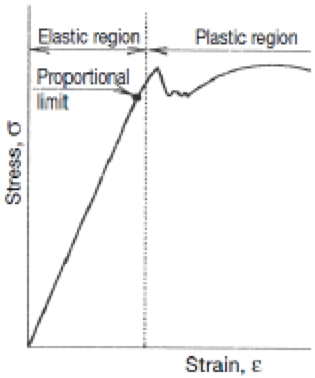
- Stress is the force an object generates inside by responding to an applied external force, P.
- The repelling force is called internal force and the internal force divided by the cross-sectional area of the object (a column in this example) is called stress, which is expressed as a unit of Pa (Pascal) or N/m2.
- Since external force = internal force, stress, σ (sigma), is equal to P/cross section area.
- Since stress can't be measured directly, in most cases, an indirect parameter (strain) will be measured
- Strain, ε = $\frac{\Delta L\ (differential\ change\ in\ length)}{L\ (Original\ length)}$





Stain Gauge

- Strain has no unit, but has direction (Vector).
- Since ε value is so small, it is often measured in μm/m (or simply called as με, Micro Strain)
- The strain developed in the same direction of force application is called longitudinal strain (ε_1)
- Strain will be present in orthogonal direction is called lateral strain ($\varepsilon 2 = \frac{-\Delta d}{d}$)
- Poisson's ratio is the ratio of lateral strain to longitudinal strain. It is fixed for given material (~0.3)
- Relationship between stress & strain is determined experimentally, and fixed for given material type. Young's modulus, $E = \frac{\sigma}{\varepsilon}$



Stain Gauge

- So, if we can measure change in length, strain can me calculated, using which stress can be calculated, using which load can be calculated (assuming that the properties of material are well known)
- Methods to detect change in length
  - Contact type
    - Bonded strain gage based
    - Fibre optic based
    - Vibrating wire based
  - Non contact type
    - Camera based
    - Lasers based

Stain Gauge

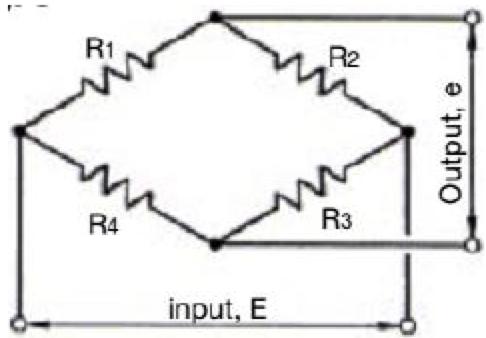
- When a strain gage elongates:

its resistance will change (ΔR), as compared to its original resistance (R)

- The ratio of change in resistance will be proportional to strain that the element is undergoing. $\frac{\Delta R}{R} = K.\varepsilon$
- K is known as gage factor, and depends on the type of material that strain gage element is made of. Typical value ~ 2
- Standard base resistance of strain gages are: 120Ω, 350Ω, 700Ω, 1kΩ
- Change in resistance will be usually very small, since strain itself is an invisible infinitesimal phenomenon
  - Example: 240mΩ change in a 120Ω element (having nominal gage factor of 2), is equivalent to 1000 $\mu\varepsilon$
- Hence signal conditioning should be precise and accurate

Wheatstone bridge formations

- Typical Ohmmeter / DMM can't reliably measure m/µ ohm level changes.
- Wheatstone bridge is an electric circuit suitable for detection of minute "changes" in resistance.
  - Input to the bridge is constant voltage, E
  - Output of the bridge is also voltage (proportional to ΔR), e
  - The bridge is called "balanced" when its output is zero. This happens only when $R_1 * R_3 = R_2 * R_4$
  - When a small change happens in one arm (say R1) of the bridge, the output will emerge (which is proportional to change in R1, and other bridge elements)



$$e = \frac{1}{4} \times \frac{\Delta R}{R} \times E$$

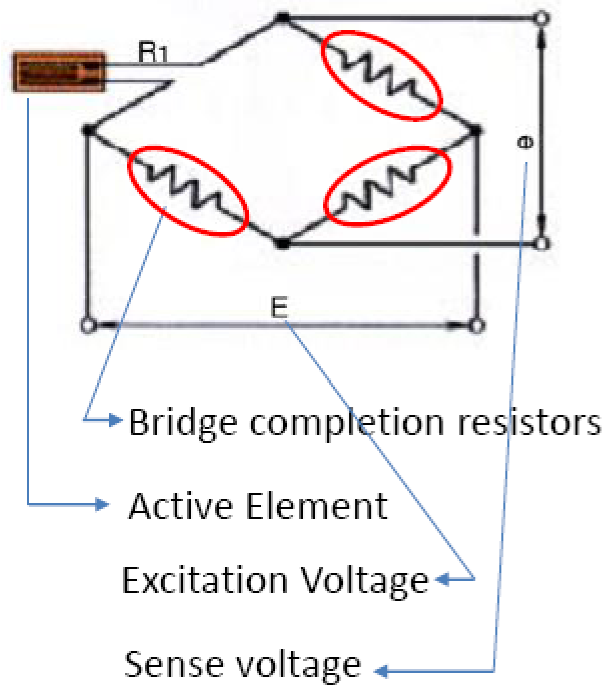
$$e = \frac{1}{4} \times K.\varepsilon \times E$$

$$\varepsilon = \frac{e}{K.E} \times 4$$

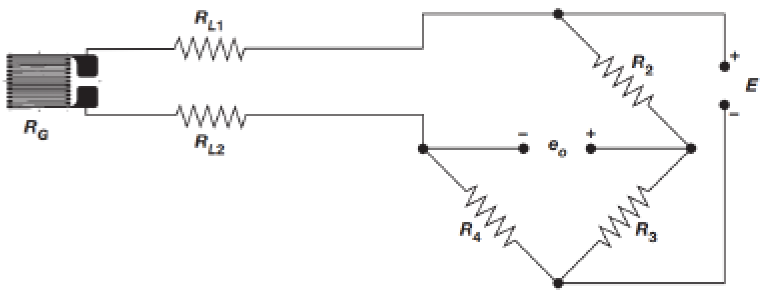
Stain Gauge

Wheatstone bridge formations

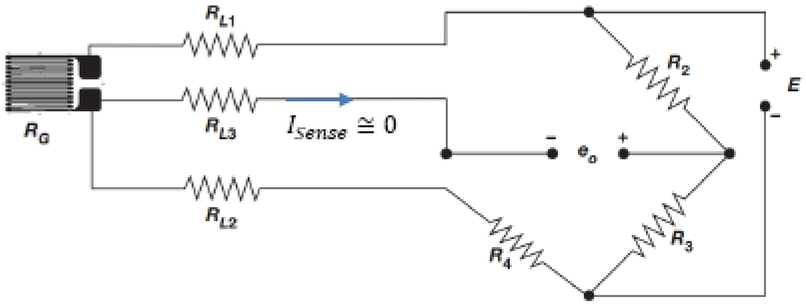
- Quarter Bridge:
  - One active element per bridge
  - Cost effective
  - Less sensitive than Half and Full bridge configurations
  - Temperature and other parameters will affect reading & stability of bridge
  - Most commonly used configuration
  - Lead wires could affect the reading as their resistance can also change due to temperature, stress, ageing etc.



- Quarter Bridge: 3 wire connection
  - Lead wire resistance (from strain gage) will also form a part of Wheatstone bridge, and hence could affect the reading. If this change is constant, it could be Offsetted / Tared-off / Balanced
  - Lead wire resistance can also change due to ambient temperature, stress, ageing etc.
  - Assumes $R_{L1}=R_{L2}=R_{L3}$, and Current passing through $R_{L3}=0$



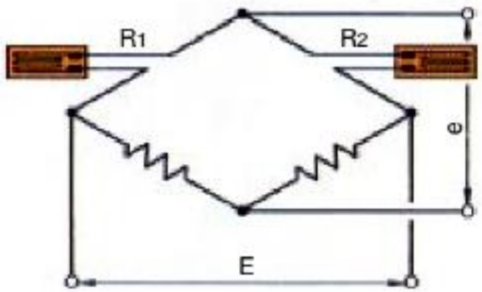
Two wire gage



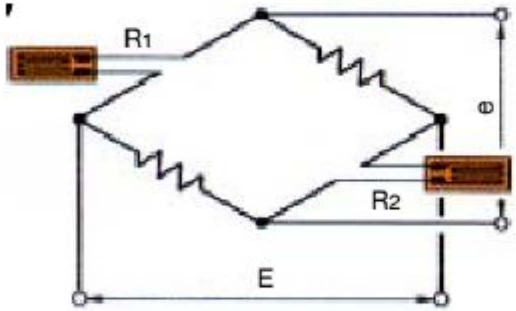
Three wire gage

Stain Gauge

- Half Bridge:
  - Two active element per bridge
  - Can be used to, either
    - Negate each other (or)
    - Temperature Compensation (or)
    - Double the sensitivity
  - More sensitive than Quarter bridge
  - Less sensitive than Full bridge
  - Less commonly used configuration
  - Lead wires could affect the reading as their resistance can also change due to temperature, stress, ageing etc.



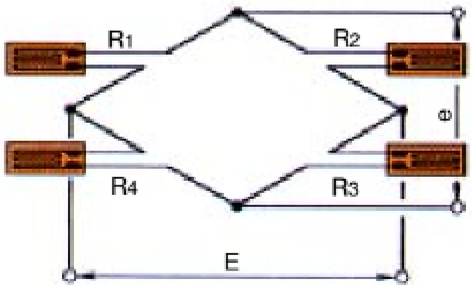
$$e = \frac{1}{4} K (\varepsilon_1 - \varepsilon_2) E$$



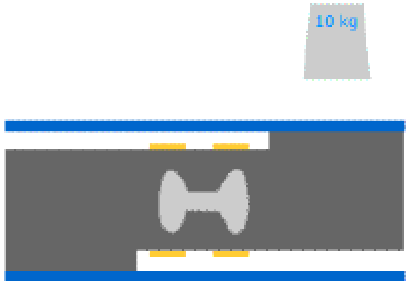
$$e = \frac{1}{4} K (\varepsilon_1 + \varepsilon_3) E$$

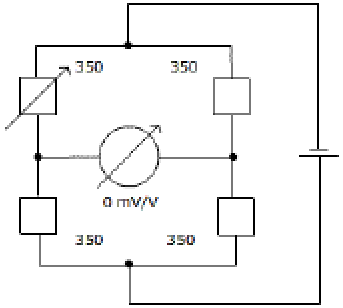
Stain Gauge

- Full Bridge:
  - Four active element per bridge
  - Typically used in Load cells, pressure transducers etc
  - More sensitive than Half & Quarter bridge configurations
  - Don't need any external bridge completion elements
  - Bridge arms can be of any value; what matters is mV/V sensitivity
  - Typically used in 6 wire configuration (2 for sense, 2 for excitation, and 2 for excitation voltage read back)



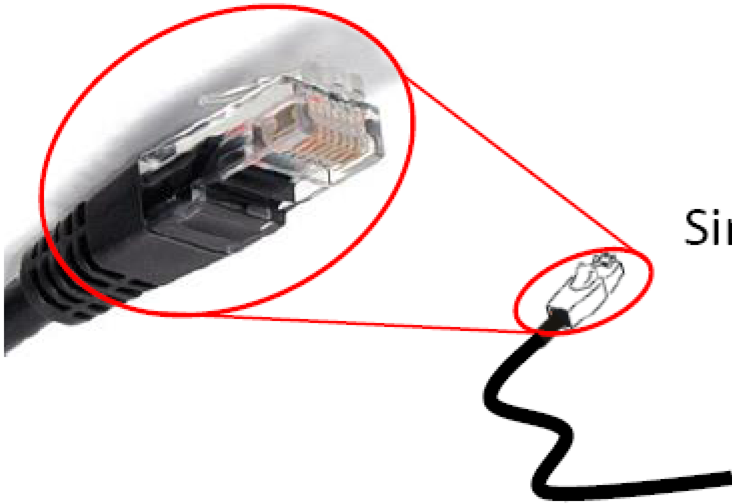
$$e = \frac{1}{4} \cdot K\,(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)\,E$$



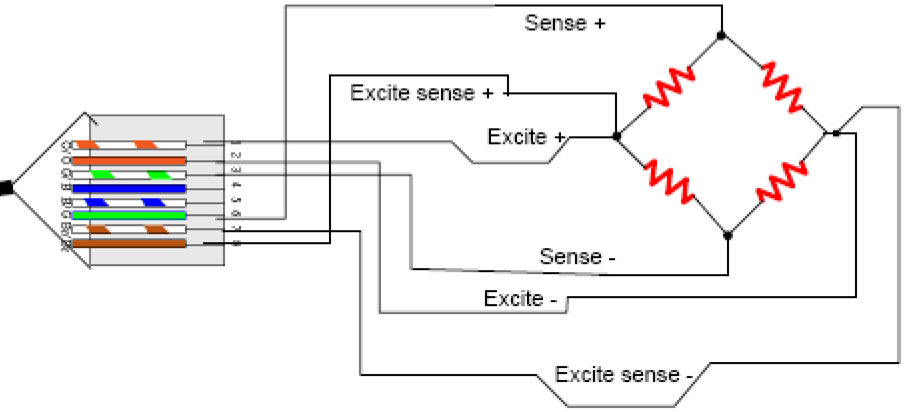


Wheatstone bridge formations

- Full Bridge 6 wire connection:
  - "Excitation +" and "Excitation Sense +" terminals can be interchanged
  - "Excitation -" and "Excitation Sense -" terminals can be interchanged

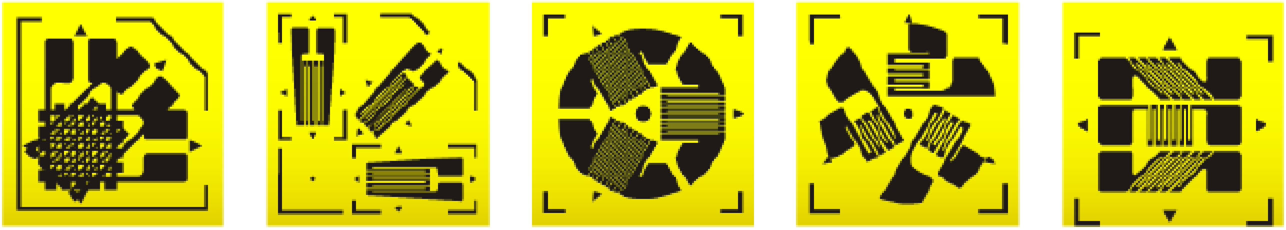


Simple & inexpensive RJ45 connectivity



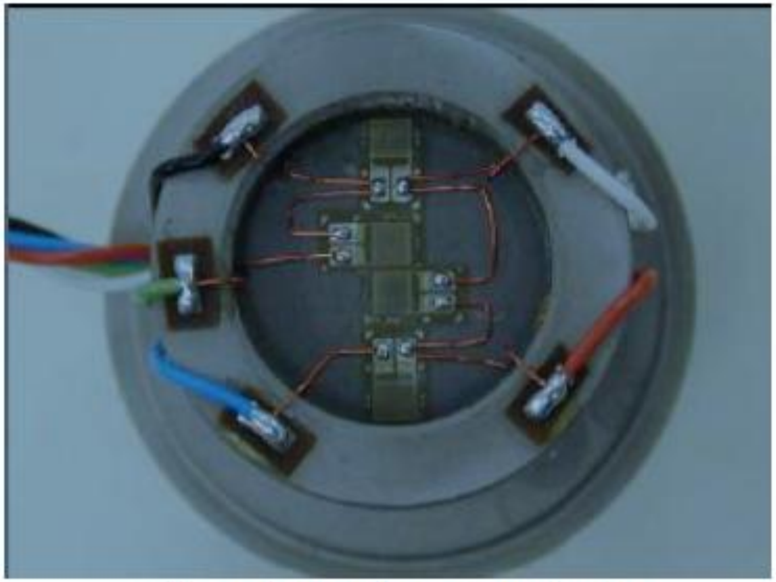
Stain Gauge

- Rosettes:
  - Strain is vector quantity
  - If strain in few directions is known, it can be mathematically resolved for other directions
  - Rosettes are simply 2 or more pre-arranged strain gages in a pattern
  - Each strain gage can be an active element of Wheatstone bridge
  - Sophisticated software can automatically resolve, principle stress etc
  - Stress analysis is different topic than strain measurement



Foil Bonded Strain Technology

Stellar uses foil bonded strain sensing technology for our all of our pressure and load sensors.



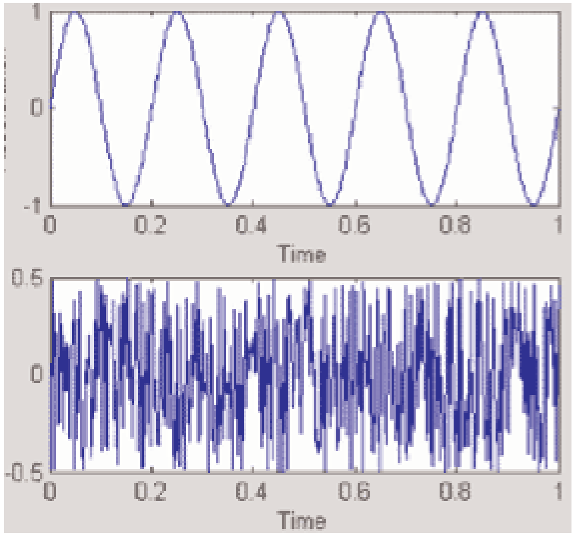
Stellar Foil Bonded Strain Technology

The foil bonded strain gage technology employed in our designs has generations of design pedigree, resulting in a sensing technology that is known in industry for being high-precision, rugged, reliable, shock resistant, and stable over temperature and time with low sensitivity to vibration.

Vibration

Vibration

- Structural Vibration:
  - Repetitive motion
  - Unwanted as it causes fatigue and degrades structural performance
  - If possible, identify the source and eliminate it. If not reduce the affects of it, by any means
- Basic terminology of Structural Vibration
  - Free vibration (natural response of structure to some impact)
  - Forced vibration (based on source of excitation)
  - Sinusoidal vibration
  - Random vibration
  - Rotating imbalance

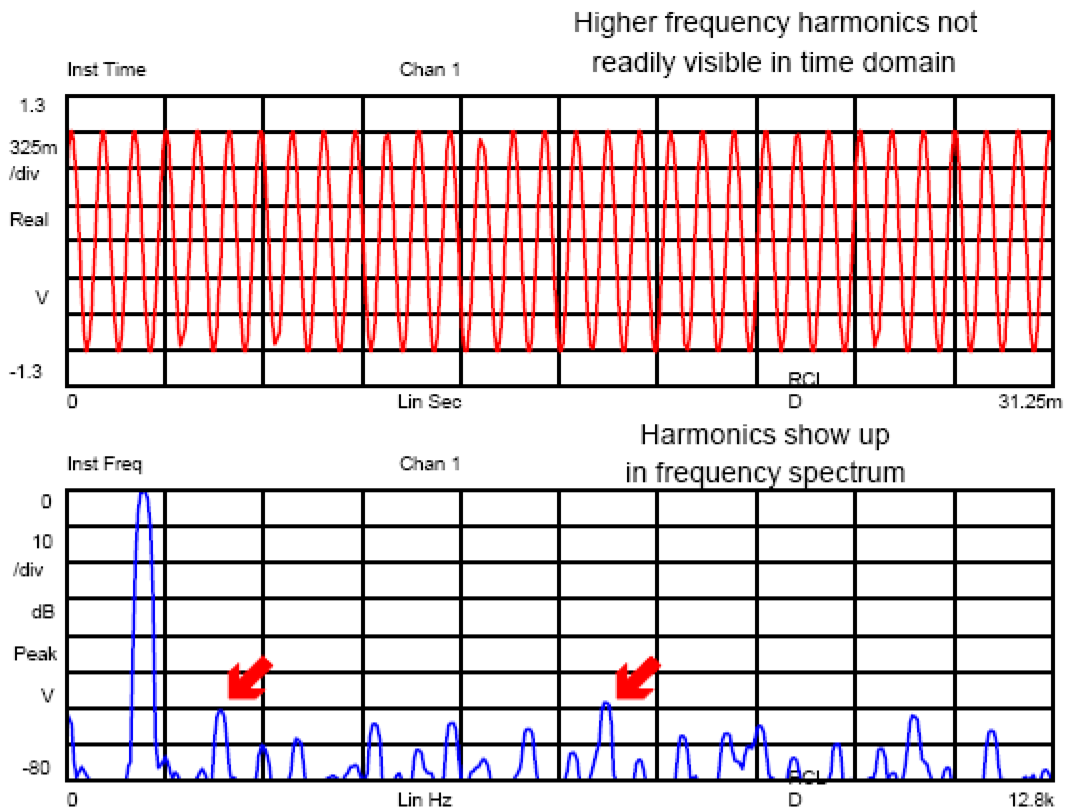


Tuning fork

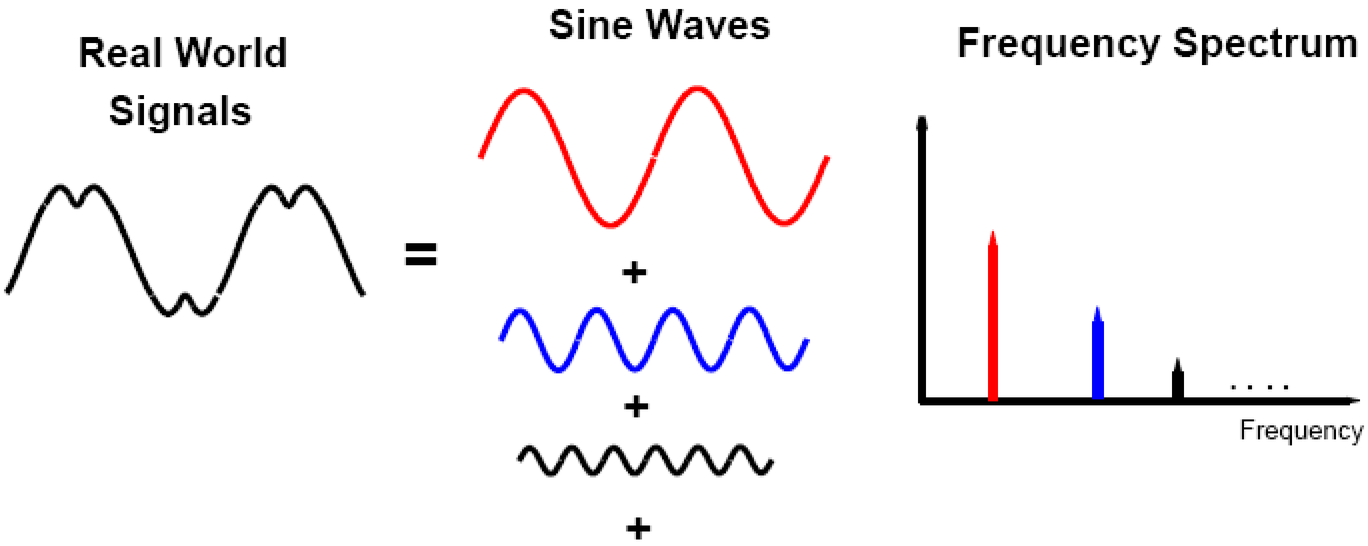
Pendulum

Car mirror

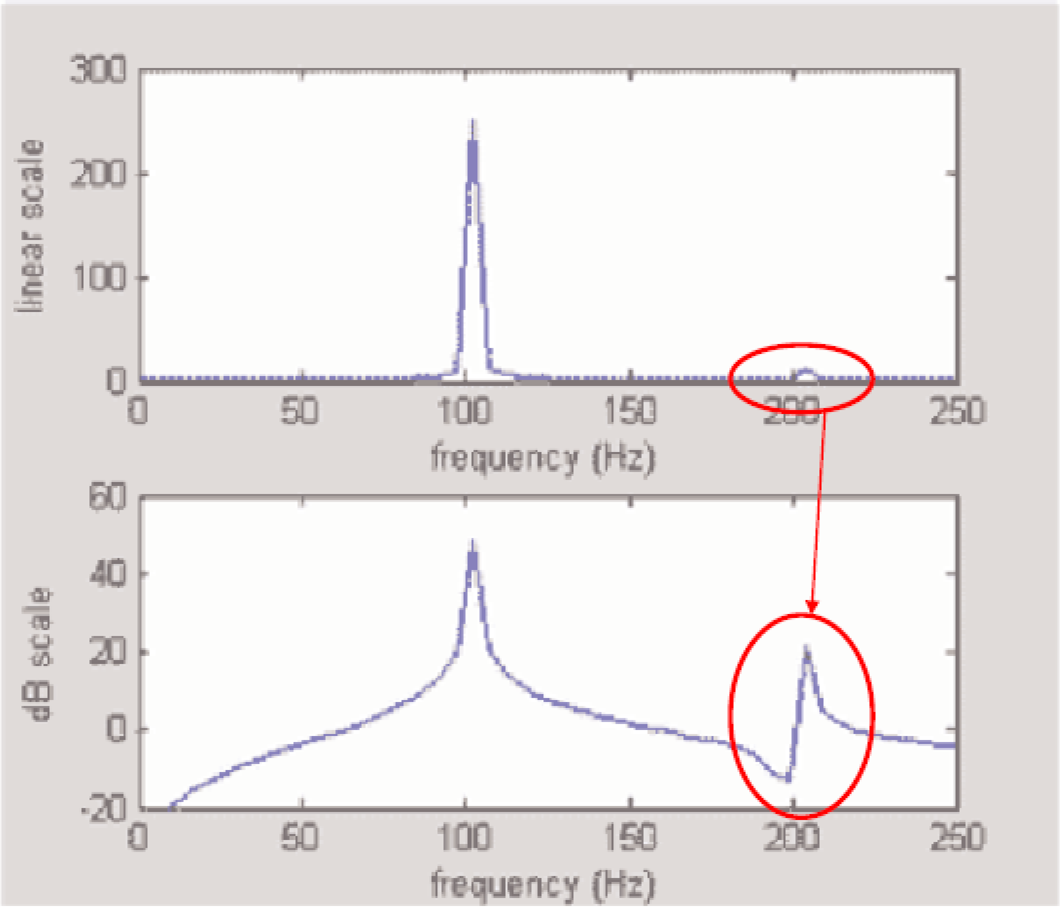
- Time Domain & Frequency Domain analysis
  - Its easy to measure & visualize in time domain (Time Vs Amplitude)
  - But....its easy to mathematically process data in frequency domain



- **Fourier Transform**
  - The mathematical way to represent any given (time domain) waveform into a sum of pure sine waves
  - Even a square wave can be represented as sum of sine waves
  - Uses windowing to avoid artefacts of sampling & triggering

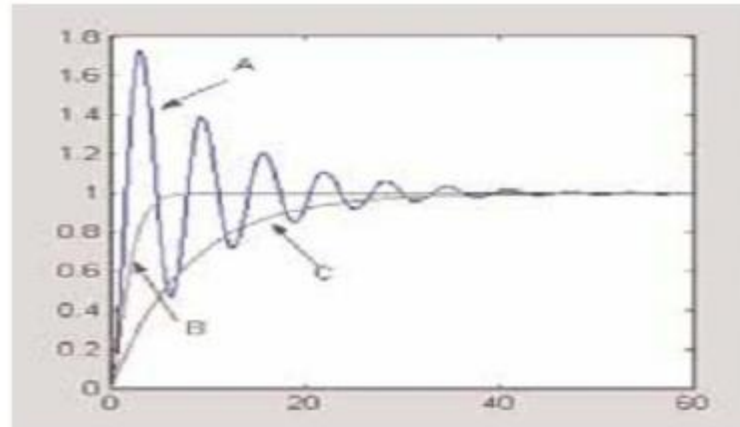


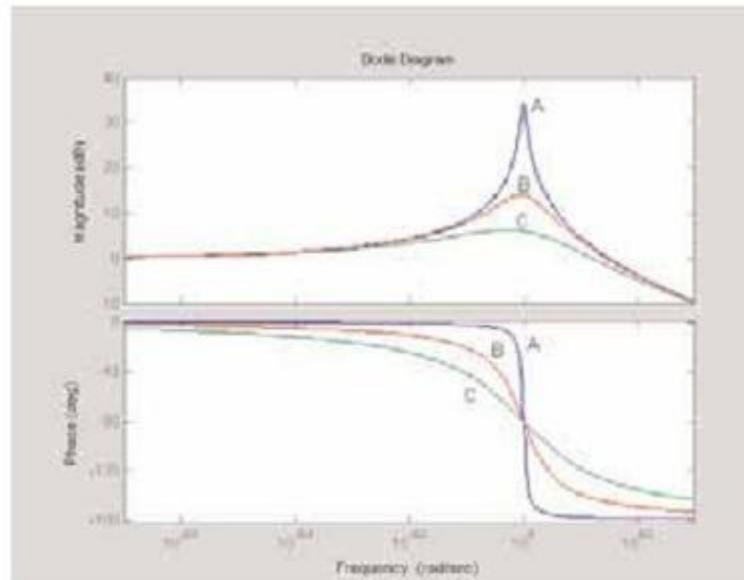
- **dB scale**
  - Unit-less
  - Zero dB must be defined
  - Helps in visualizing small signals in the presence of large quantity
  - Human response is exponential
  - Easy to add & subtract

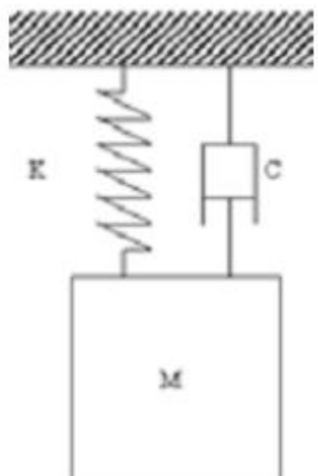


Vibration

- **Structural Vibration**
  - Single degree of freedom (SDOF)
    - Hypothetical & easy
    - Various damping levels
    - Goal is to achieve critical damping
    - Bode plot: Phase & resonance frequency

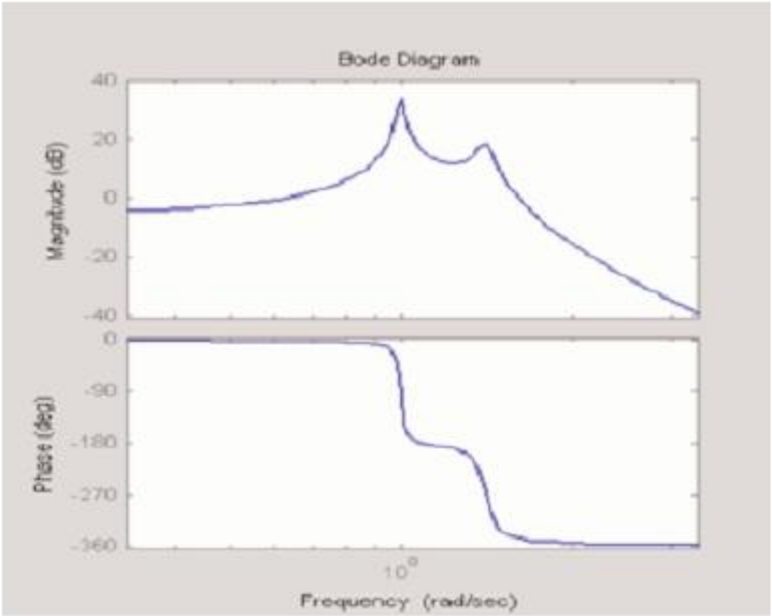


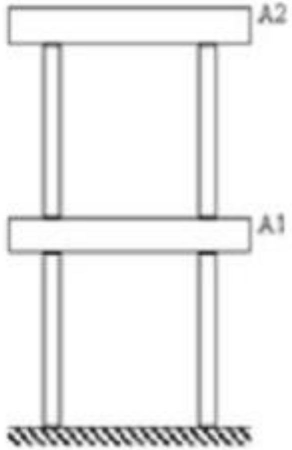


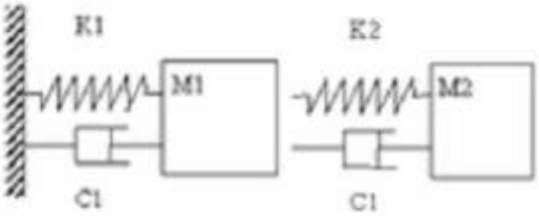


Vibration

- **Structural Vibration**
  - Multi degree of freedom (MDOF)
    - Close to practical
    - Multiple SDOF levels, superimposed
    - Goal is to understand

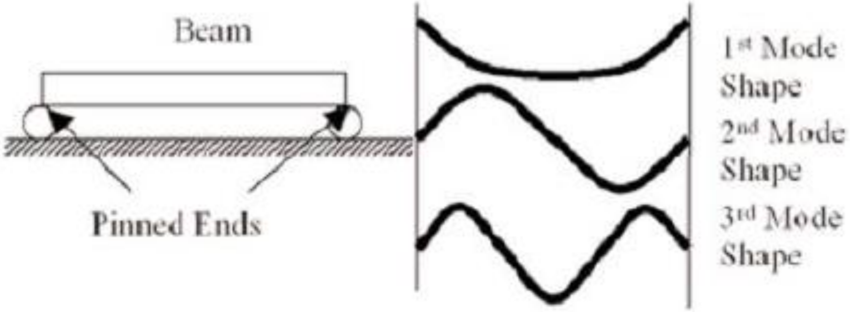


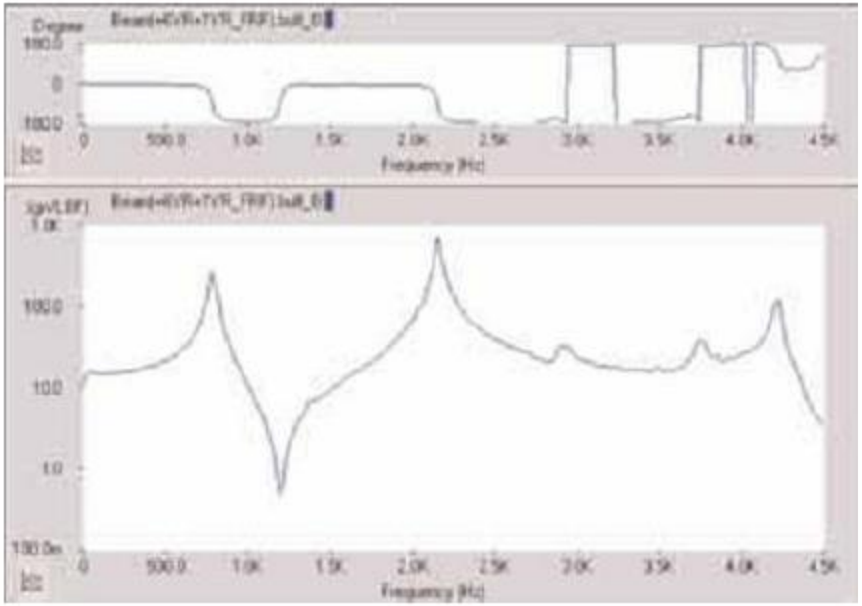




Vibration

- Continuous structure
  - Example: Beam
  - Mass is distributed all over
  - Will have multiple different resonance frequencies
  - Higher frequencies will have lesser affect, since they are damped by structure itself, just like low pass filter
  - Mode shapes: What happens, when you sweep excitation freq

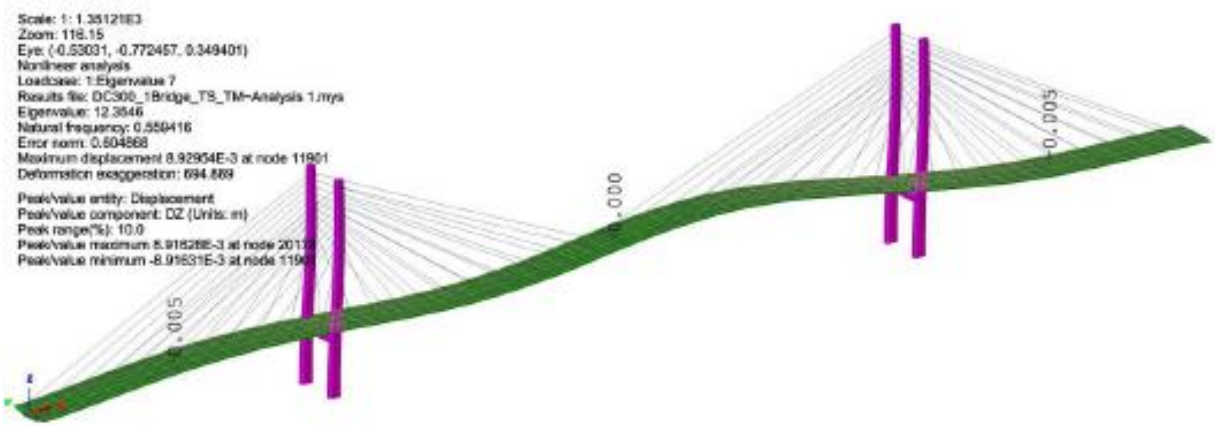


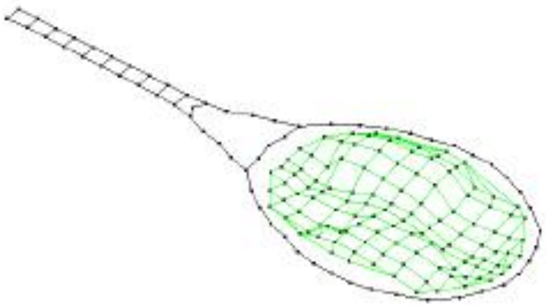


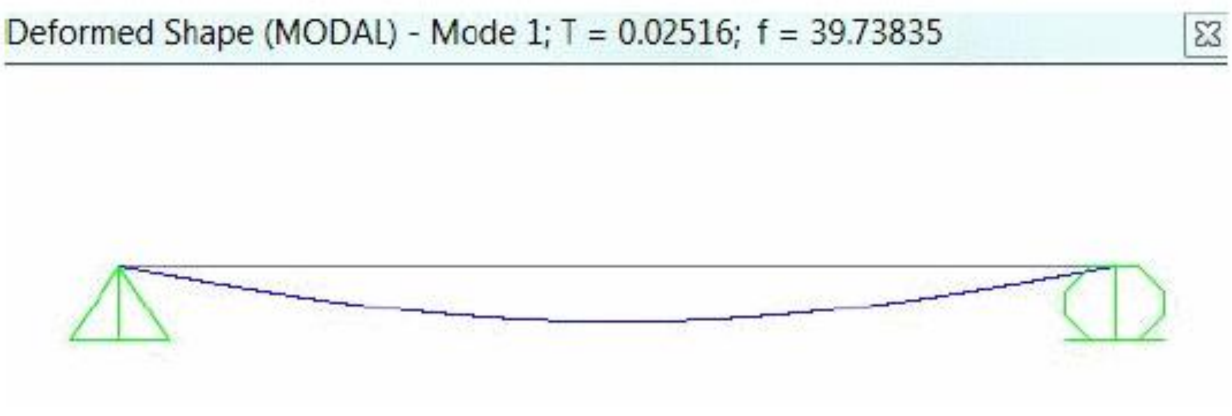
Vibration

- Goal: Improve quality of machines, and improve human comfort
- Why it is important?
  - Because you have problems you can't solve any other way
  - They quantify what we hear and feel
  - You need high quality data for making engineering decisions
  - Wide variety of measurements from the same data
- Major DSA Applications
  - Acoustic Analysis
  - Rotating Machinery Analysis
  - Control System Analysis
  - **Structural Analysis**
  - General Purpose Electronic Test

- Mode shapes


Zoom: 118.15
Eye: (-0.53031, -0.772457, 0.349401)
Nonlinear analysis
Eigenvalue: 12.3546
Deformation exaggeration: 694.889
Peak/value entity: Displacement
Peak/value component: DZ (Units: m)
Peak range(%): 10.0
0.005
0.000
-0.005



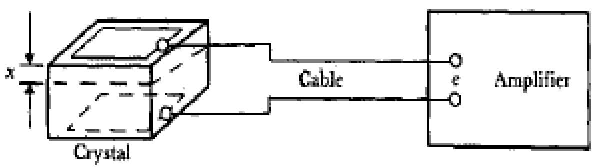

Deformed Shape (MODAL) - Mode 1; T = 0.02516; f = 39.73835

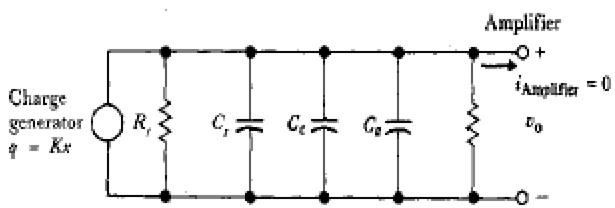
How To Measure Vibration

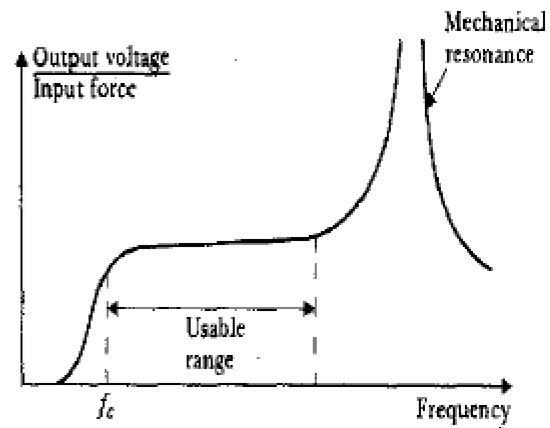
- Fundamentals
  - Force = Mass X Acceleration
  - Change of position = Displacement
  - Rate of change ($\frac{dy}{dx}$)of displacement = Velocity (angular / linear)
  - Rate of change of Velocity = Acceleration
  - Units of acceleration (m^2/s)
  - 1G = 9.81 m^2/s
  - If we can measure "G" level some how, we can integrate this over time to get velocity / speed, and integrate it again over time to get total displacement
  - So the question is how to measure "G" level?

Vibration Transducers

- Accelerometers
  - Typically based on Piezoelectric effect (when some crystals deform, they generate charge which is proportional to rate of deformation of shape)
  - Output “charge” is proportional to amount of acceleration it is subjected to
  - Output is linear only for a given frequency range

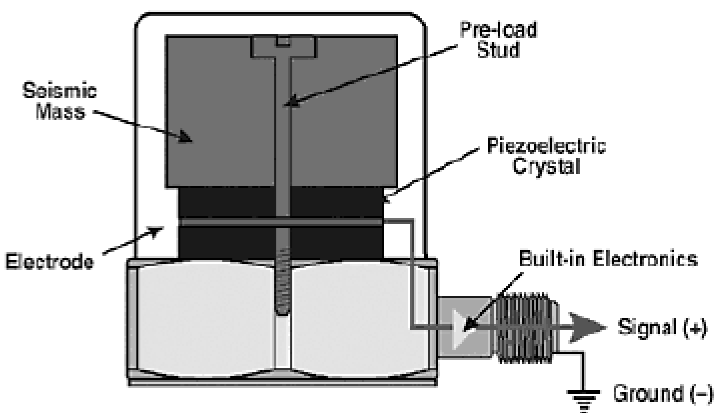


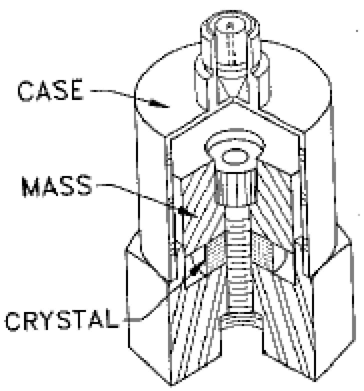




Vibration Transducers

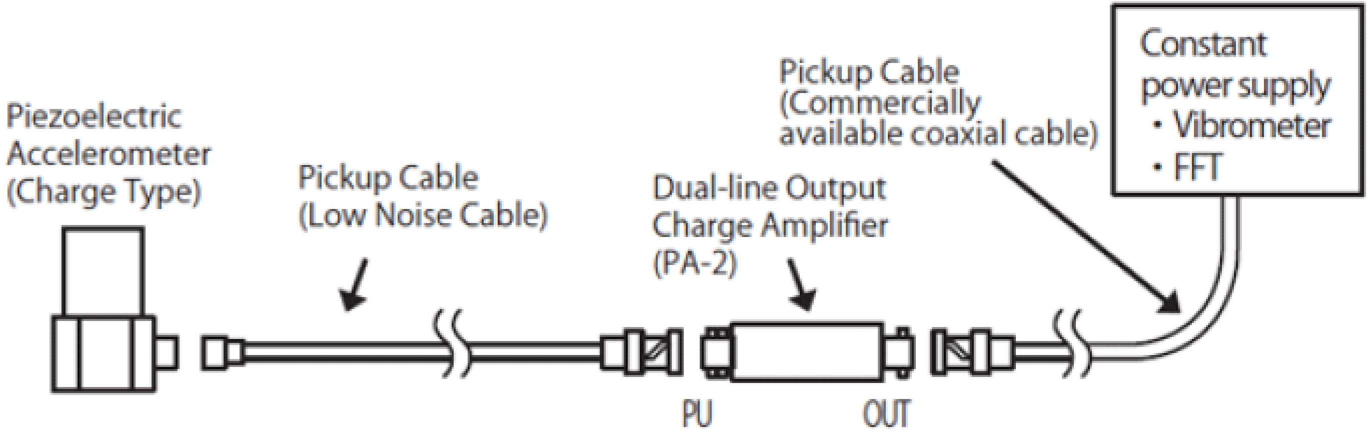
- Accelerometer types (also microphone types)
  - Piezoelectric type / Charge output type
  - IEPE Type / ICP type
  - Semiconductor / MEMS type





Vibration Transducers

- Piezoelectric type / Charge output type
  - Most basic type
  - Can be used up to very high temperatures
  - Low weight, hence no structural modifications
  - Output requires ‘charge to voltage’ converter; commonly known as charge amplifier / pre-amplifier / in-line amplifier



Vibration Transducers

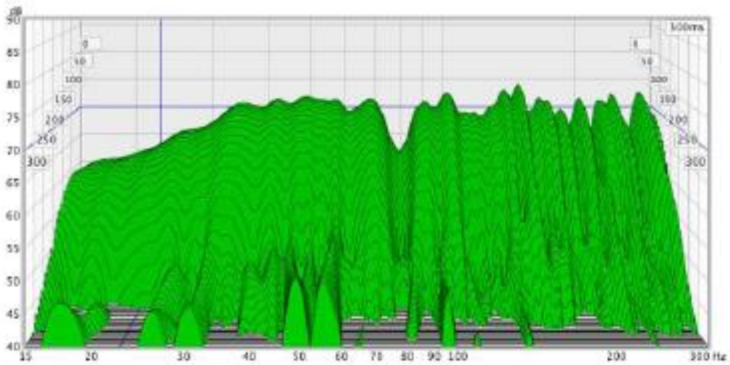
- ICP / IEPE type
  - Most common type of accelerometer
  - Includes the electronics, such that output is voltage
  - Requires excitation: Constant current source
  - Output voltage is superimposed on excitation lines itself
  - Only two wires are needed to interface (SMA, BNC etc., connectors)
  - Voltage must be extracted from these lines and amplified by the signal conditioner
  - Current levels of 2mA to 20mA is most common
  - Uni-axial & Tri-axial are also available

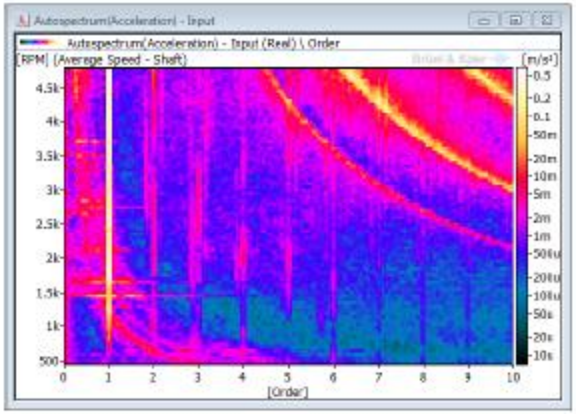
Vibration Transducers

- Semiconductor / MEMS type
  - Latest type of accelerometer
  - Very rugged (virtually indestructible)
  - Low cost, due to bulk production
  - Output is voltage proportional to instantaneous / RMS value of “G”
  - Typically 3 or 4 wires are needed to interface (SMA, BNC etc., connectors)
  - Can detect very very low frequencies
  - Excitation is common voltage levels, for example: 24V

Vibration Transducers

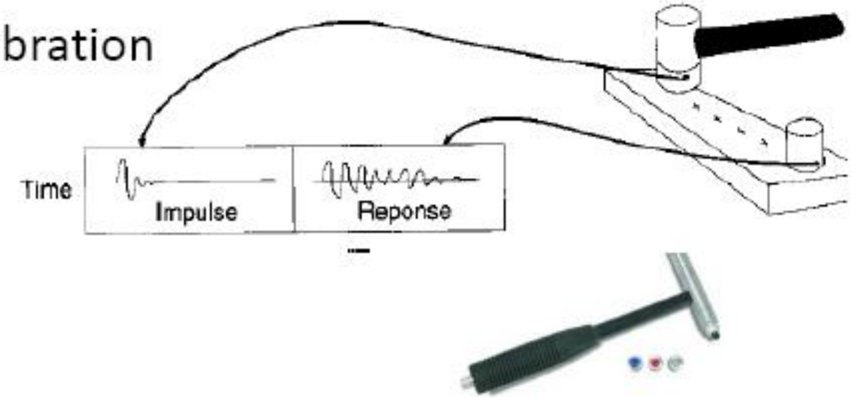
- **Rotational measurements**
  - Also known as order measurements
  - Vibration is measured as a function of RPM
  - Example: Shaft vibration of electric generator, car engine etc
  - In addition to measuring the level of vibration, if is important to understand at what RPM those measurements were made
  - Uses a “tacho-meter” which generates pulses when it revolves
  - A counter will interface with tacho-meter, and derives the RPM of the shaft (based on pre-configured settings)
  - Uses Order analysis to calculate special diagrams, like waterfall diagram, autospectrum etc

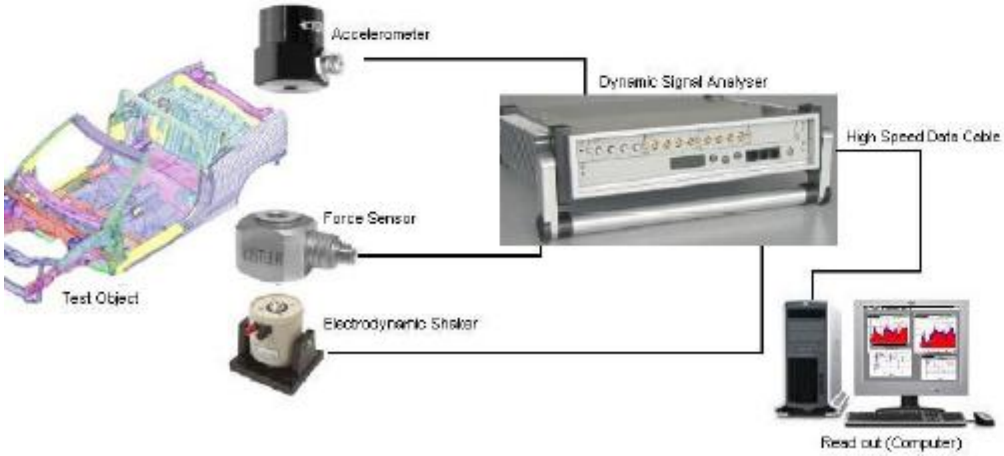




Vibration Generators

- Does opposite of detecting vibration
- Two most common types
  - Impact hammer
  - Electro-dynamic shaker
  - Shaker/Slip tables

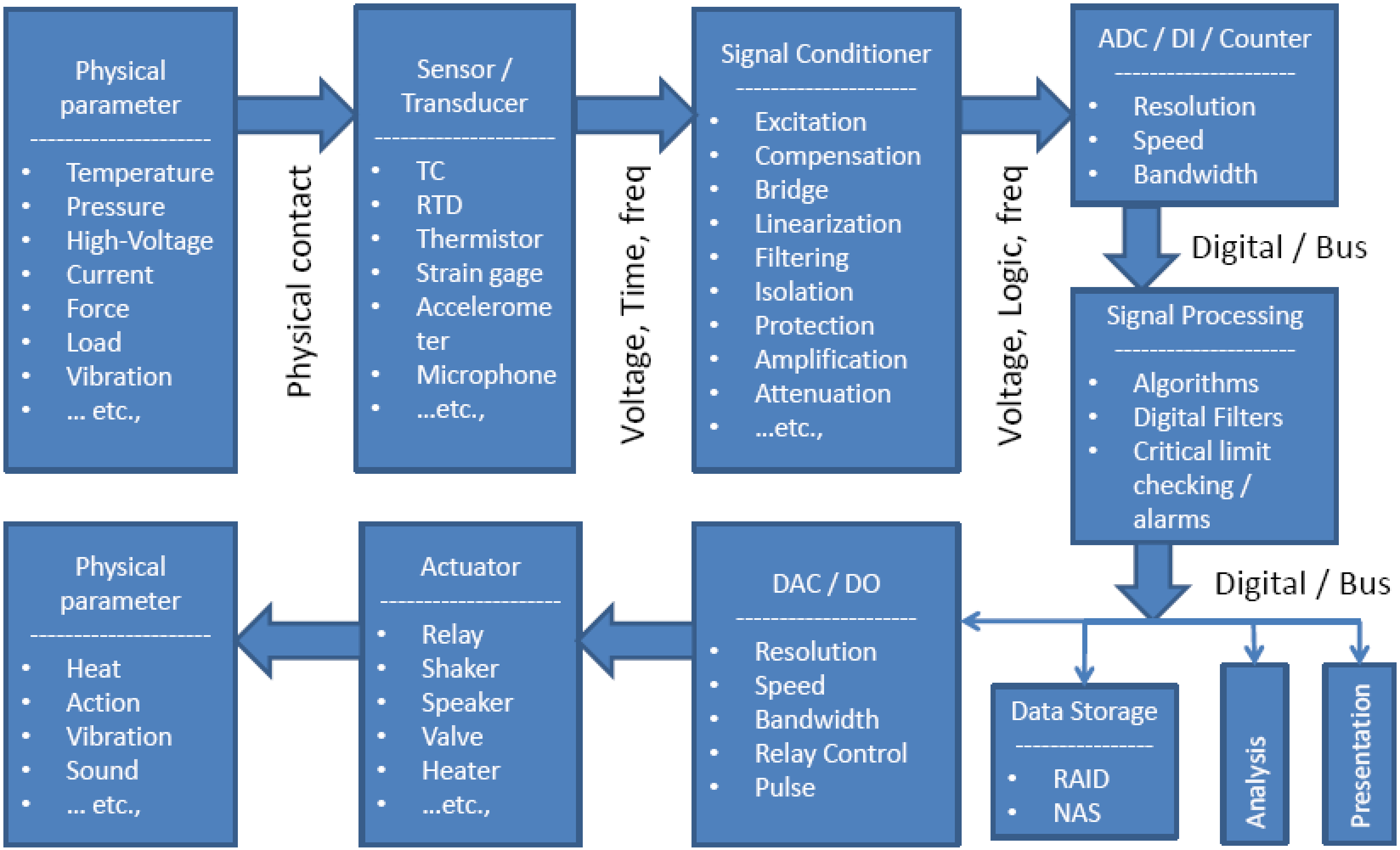




Acoustic Transducers

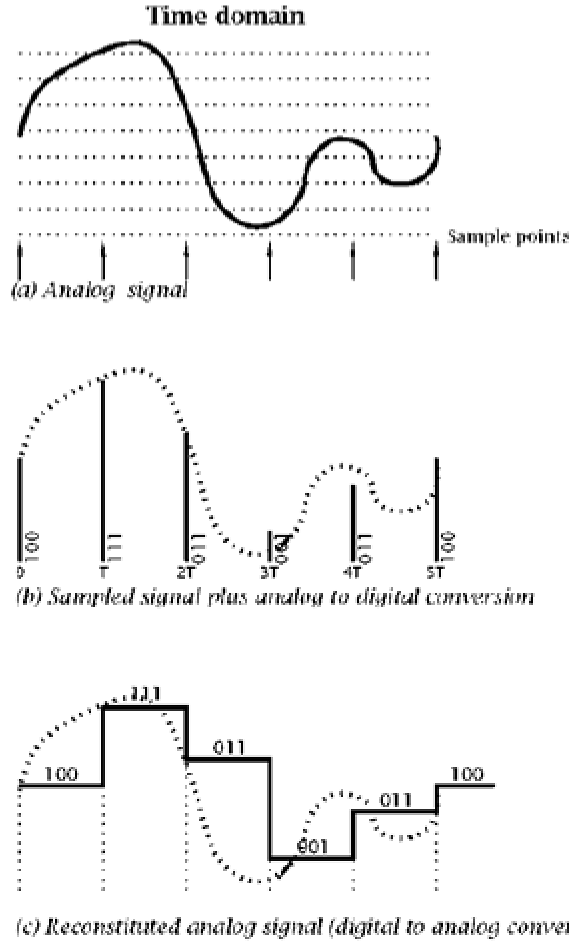
- Similar to vibration in all respects
- Microphones are used in place of accelerometers
  - Types are all type, and same with the output also
- Speakers / Horns are used as exciters, instead of shakers
- Measurement instrumentation is same as that of vibration
  - The input channels which can accept an accelerometer can also accept microphones
- Microphones, which can be used underwater, are called as Hydrophones (Used in SONAR & other applications)
- Processing software, visualization graphs etc., are different
- Typical goal is to quantify the quality, and identify the source of noise

DAQ


Physical parameter
Temperature
Pressure
High-Voltage
Current
Force
Load
Vibration
... etc.,
Physical contact
Sensor / Transducer
TC
RTD
Thermistor
Strain gage
Accelerometer
Microphone
...etc.,
Voltage, Time, freq
Signal Conditioner
Excitation
Compensation
Bridge
Linearization
Filtering
Isolation
Protection
Amplification
Attenuation
...etc.,
Voltage, Logic, freq
ADC / DI / Counter
Resolution
Speed
Bandwidth
Digital / Bus
Signal Processing
Algorithms
Digital Filters
Critical limit checking / alarms
Digital / Bus
Data Storage
RAID
NAS
Analysis
Presentation
DAC / DO
Resolution
Speed
Bandwidth
Relay Control
Pulse
Actuator
Relay
Shaker
Speaker
Valve
Heater
...etc.,
Physical parameter
Heat
Action
Vibration
Sound
... etc.,

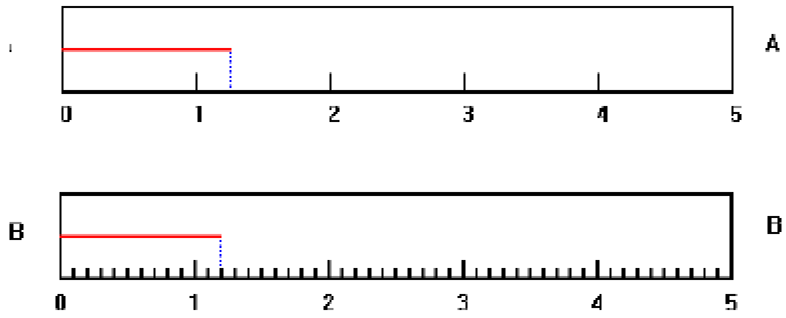
Building Blocks & Jargons of ADC

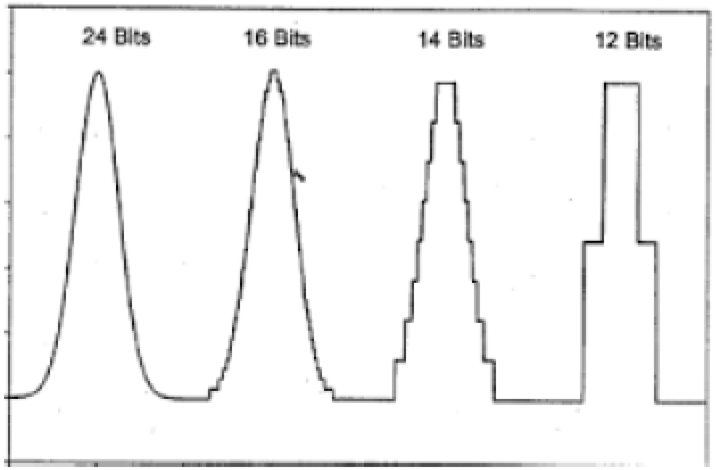
- Analog to Digital Converter (ADC)
  - A piece of hardware responsible for converting analog voltage input into discrete digital equivalent code (which can be understood by computer), at fixed intervals of time
  - There are different architectures of ADC (SAR, Sigma-Delta, etc.)
  - Quality of ADC can be characterized by resolution, Sampling speed and Accuracy
  - Sampling introduces unwanted artefacts like Noise & bandwidth limiting etc., which are unavoidable in the process of digitization



- **Resolution** – 8 Bit, 16bit, 24bit … etc
  – Higher the number of bits, better for the resolution

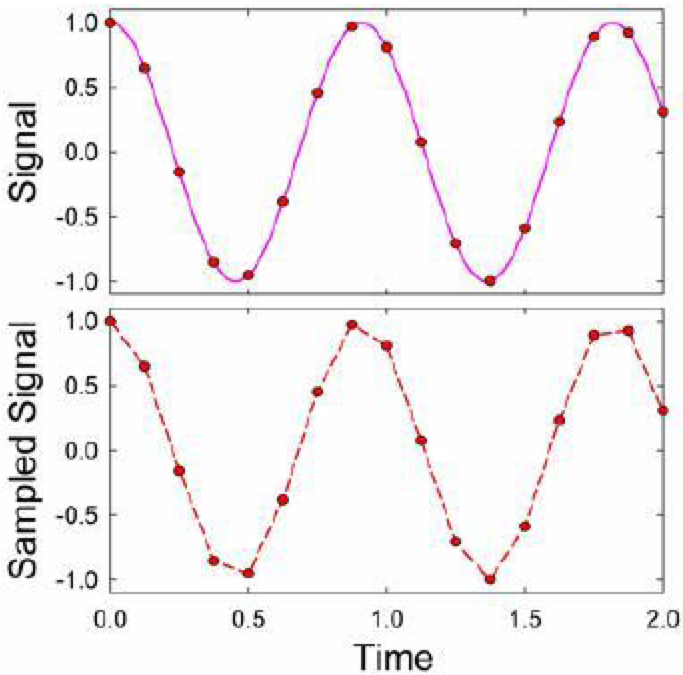
- Example: Measure the length of red line

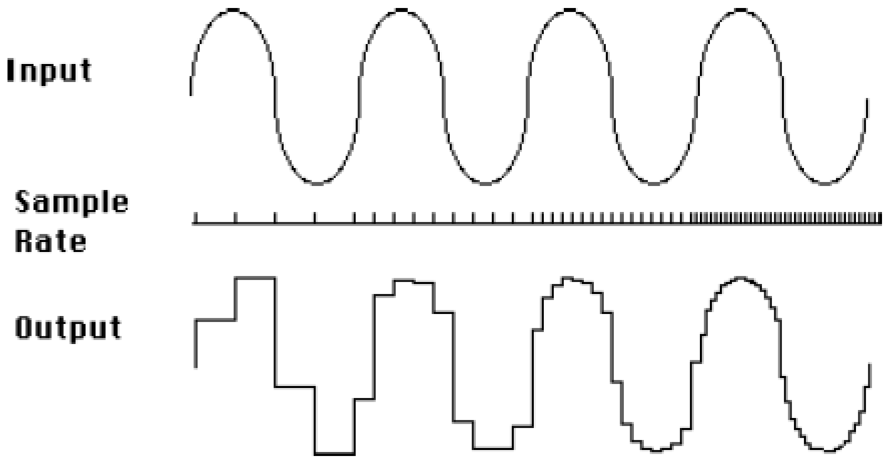




Building Blocks & Jargons of ADC

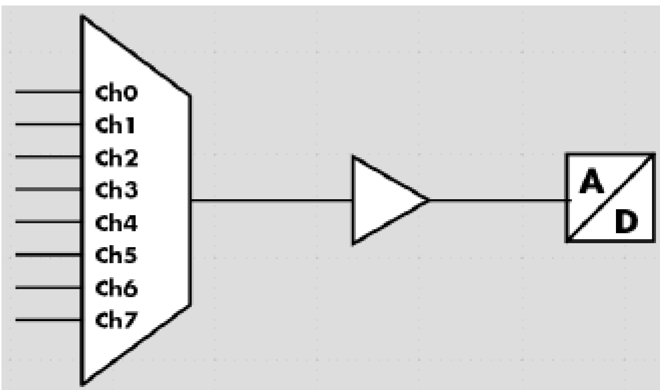
- **Sampling speed**:
  - Faster the sampling, the better it is to reconstruct

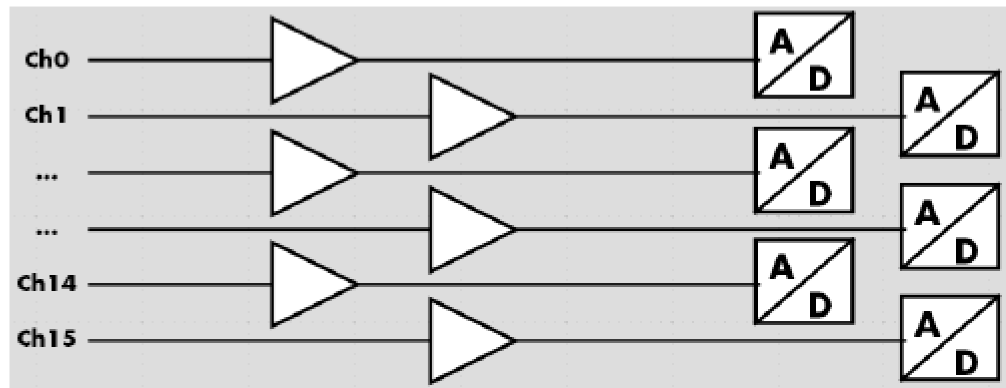




Building Blocks & Jargons of ADC

- Sampling speed:
  - All ADCs does sampling (which can be multiplexed also)

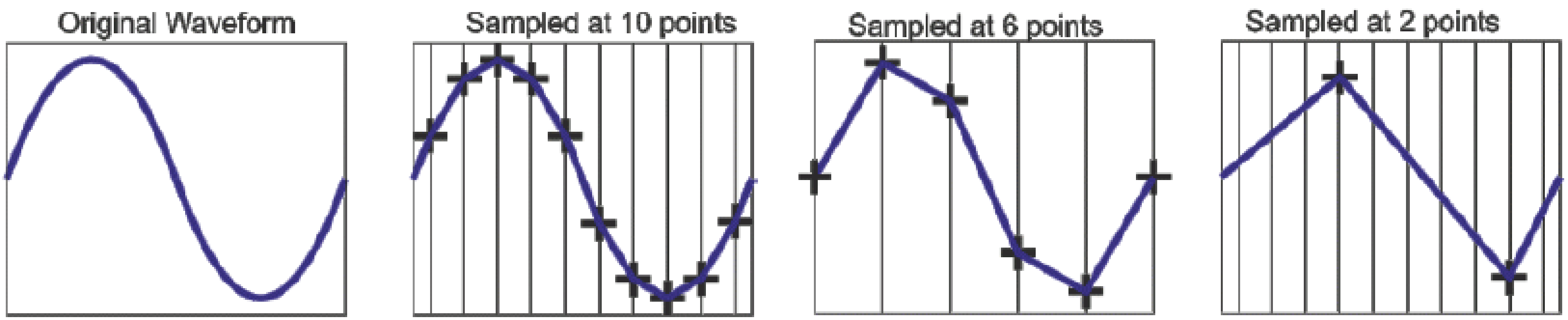




- Multiplexed sampling is economical
- ADC's sampling rate is shred by channels
- Phase information is lost
- Preferred for slow varying signals

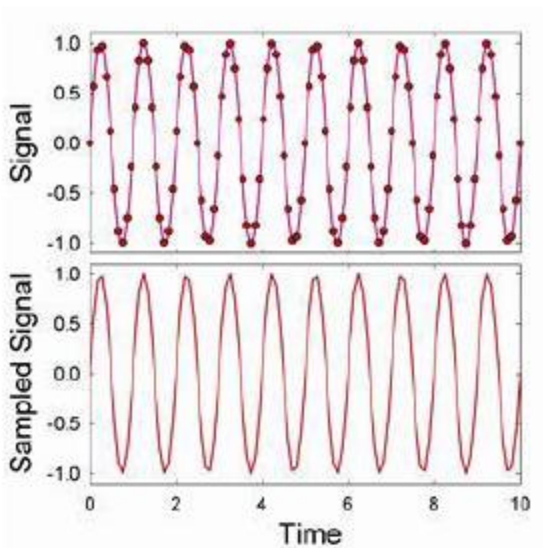
- Simultaneous sampling is costly (as more number of ADCs were used
- Retains phase information (synchronous)
- Preferred architecture for dynamic signals like strain, vibration and acoustics

- Nyquist – Shannon sampling Theorem:
  - A signal can only be represented by samples taken at more than twice the maximum frequency in the signal.
  - In other words, the sampling rate / frequency, should be at least twice that of frequency component of interest of incoming signal

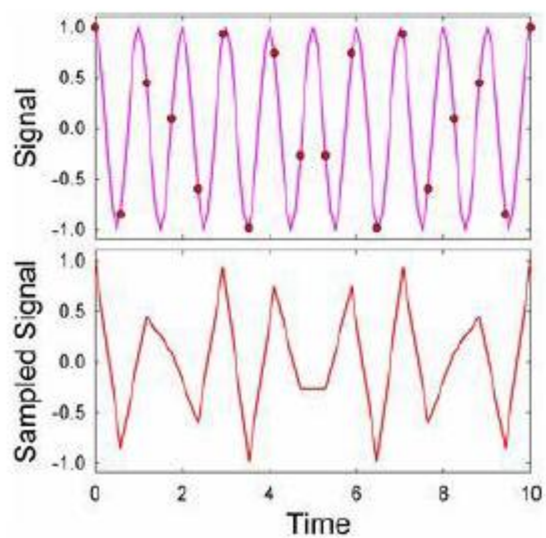


- Note: This theorem does not guarantee the wave shape & amplitude preservation. It will only guarantee that the frequency of the sample-reconstructed waveform will be same as input
- Pure sine wave waveform shape we can expect from a mechanical quantity (like torque, force, etc.,)?

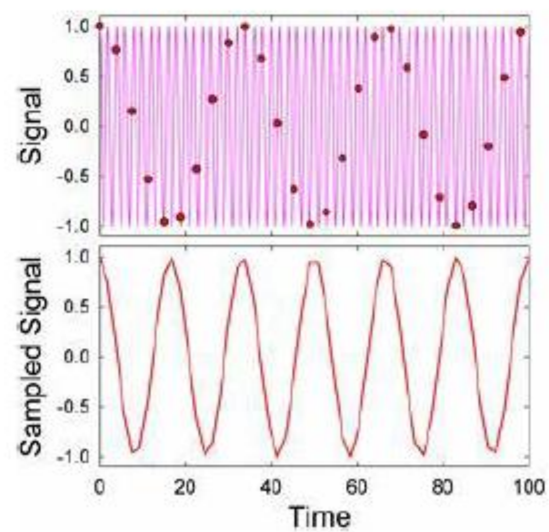
- Aliasing:
  - What happens, when you disobey Nyquist theorem, knowingly or unknowingly
  - Push higher frequency input (which is higher than half of ADC sampling frequency), into an ADC



1Hz Signal, 10Hz Sampling
GOOD



1Hz Signal, 1.7Hz Sampling
BAD



1Hz Signal, 0.53 Hz Sampling
Looks good but...GARBAGE

ADC - Aliasing & How to overcome

- Sample it at right frequency … (if you can)
- We are measuring something because we don't know about it. How do we know the frequency of "unknown signal"??
- Limit the input signal's frequency using "Anti-aliasing filter" which is set at less than half of sampling rate of ADC.
- Anti-alias filter (which is essentially a low pass filter) must be analog type, since it should be placed before ADC. (all digital filters will come after digitization)
- Over sample the signal by about 5 times (or more), which helps cover the transition band of AAF, and also reduces noise
- Input frequency not always means fundamental frequency of signal, but could also cover its harmonics etc.

Amplifier…and why you need it

- It is similar to magnifier glass.
- You need it, because
  - Your ADC’s input range is limited (±10V)
  - You want to utilize the full resolution of ADC
- Too less amplification factor:
  - Your would not utilize ADC’s full capability
  - Noise may dominate your signal at its weaker portions
- Too high amplification factor:
  - Your signal will be clipped by ADC (as it exceeds headroom)
  - Gain will vary and subjected to temperature changes
  - Introduces non-linearity

Building Blocks & Jargons of ADC

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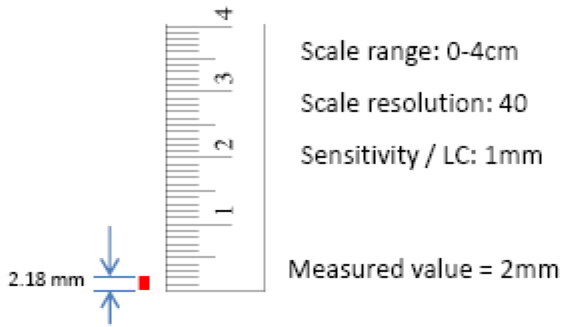
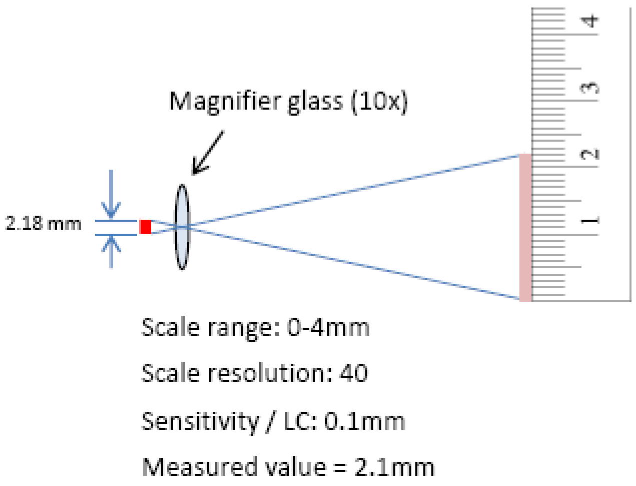




Building Blocks & Jargons of ADC

- Amplifiers can't have infinite number of ranges. Usually it will be x2, x5, x10, x20, x50, x100, x1000 etc
- Types of amplifiers / DAQ inputs:
  - Differential : 2 terminals per each ch (Ch1+, Ch1-, GND)
    - Absolute difference between + and – inputs will be amplified, irrespective of common mode level
    - Immune to common mode noise has high CMRR
  - Single ended (SE): 1 terminals per each ch (Ch1, Ch2, Ch3, … GND)
    - Level of input from common GND will be amplified, which is inclusive of common mode level
    - Shares a common ground with all channels
    - Prone to ground loop related errors
  - Pseudo Differential : Somewhere in between SE & Differential

Signal Conditioning Jargons

- **Excitation:** A means to provide power to the sensor / transducer, to enable its functioning. It could be either voltage, current or charge. Ability to provide excitation by the signal conditioner itself, will remove the need to have external electronics, and better control

- **Compensation:** Outputs of some sensors (like thermocouple) must be compensated for external factors like ambient temperature. A good signal conditioner must take care of this internally, and provide an output which is directly proportional to input

Signal Conditioning Jargons

- **Bridge Completion:** Some sensors will need a Wheatstone bridge circuit be to formed around them, in order to function. Some signal conditioners will have all necessary arms of Wheatstone bridge, such that user don't have to add any external electronic components / select jumpers

- **Linearization:** Outputs of some sensors (like thermocouple) may not be linear with respect to its physical inputs. The signal conditioner for such sensors should have the capability to perform an inverse curve fitting capability, such that the output from signal conditioner is linear w.r.t. physical input of the sensor

Signal Conditioning Jargons

- **Filtering:**
  - Filters will help remove unwanted signals, which are mixed in the input signal. These unwanted signals (including noise) may be a due to physical parameter itself, or due to any external interferences.
  - **Analog Filters** are made out of real physical passive R,L, C Components, and sometimes active Op-Amp circuits.
    - Size gets larger with the order of filter
    - Not effective at lower frequency ranges due to slow roll-off
    - Gets costly with the complexity of design
    - Limited flexibility in selection of frequencies, filter type etc
    - Performance can get affected due to component ageing, temperature drift etc.

Signal Conditioning Jargons

- **Filtering:**
  - **Digital Filters** process the digitized signal information, either in a micro-processor, DSP or in software
    - Linear phase response & constant group delay
    - Filter type, cut-off frequency, order, etc can be changed easily though software (since they are just algorithms)
    - Unaffected by environmental factors
    - Bandwidth is inferior to that of analog filters
    - Needs much longer time to design, develop and validate the digital sequences & algorithms

- No single filter will fit the needs to all applications.
- Flexibility of filters make the DAQ system more versatile

- Filters are used to eliminate power line noise (50Hz) from static measurements (like thermocouple based temperature measurement)

Building Blocks of DAQ

- **Isolation:**
  - Some signals may be prone to have their ground signals floating at high voltages, such that they can't be tied to DAQ system ground (Else a ground loop will form)
  - Some signals may have higher common mode voltages, may be by application itself (Current shunt, Embedded sensors in motor winding, Fuel cell stack / Battery measurements
- Isolation provides an additional layer of protection (safety)
- Not all isolation schemes are equal
  - Channel to ground, Channel to Channel, Input to Output etc
- Isolation increases the cost of amplifier
- Isolation sometimes increase the noise, due to usage of DC-DC converters

Building Blocks of DAQ

- **Digital to Analog converter**:
  - Converts discrete digital code into an equivalent analog voltage
  - Needed, when some generation of voltage, current etc is involved (for example, closed loop control, stimulus, simulation etc.,)
  - Outputs can be voltage or current,
  - Different types of update mechanisms, characterize its type
    - Simple output / DAC: Updates single point up on software command
    - Function Generator: Generates smooth waveform shapes (sine, triangular, square, saw-tooth etc, and user need not to define each data point on the wave shape
    - Arbitrary Waveform Generator (AWG):   Generates a sweep of data outputs which are previously stored in memory, at higher & consistent clock rates than general DAC (used for custom signal simulation)

Building Blocks of DAQ

- **Counter / Timer:**
  - Measures (counts) the number of input events (discrete)
  - Functions of counter:
    - Object counting
    - Relative time period measurement
    - Frequency measurement
    - RPM / speed measurement
    - Linear / Angular displacement measurement using angular encoder
  - Inputs are mostly digital, but analog channels (with level detection logic) can also be used, in case if the input signals are sinusoidal or discrete signal with lot of noise
  - Merit depends on number of bits, input types, oscillator source quality, and buffer memory architecture

INNOVATE ELECTRONICS

Programming Tools

A programming **tool** or **software** development **tool** is a computer **program** that **software** developers use to create, debug, maintain, or otherwise support other **programs** and applications.

Testing modules like NI TestStand

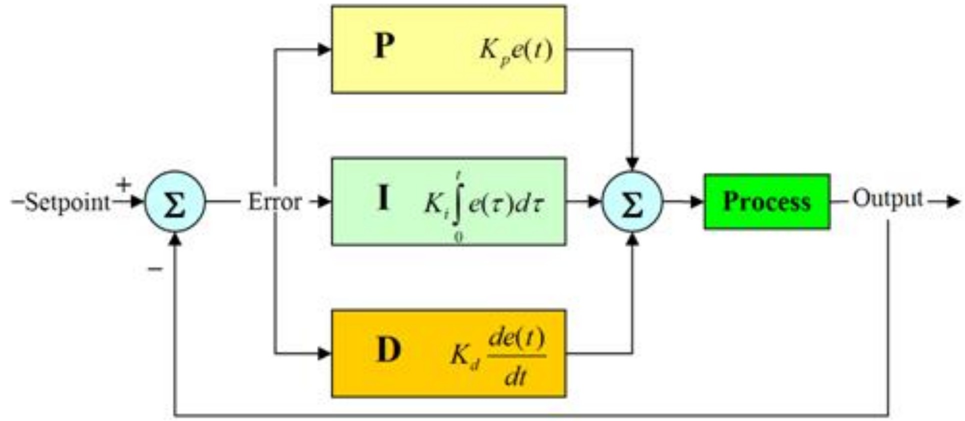
Program Languages

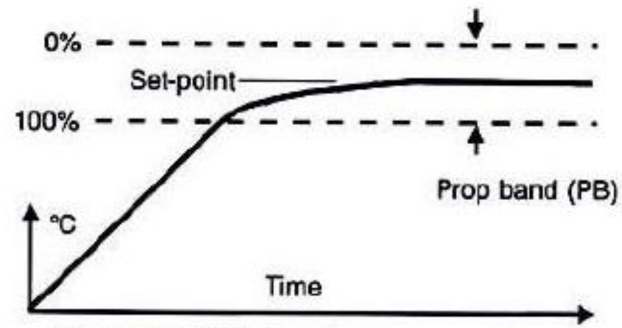
A **programming language** is a formal constructed **language** designed to communicate instructions to a machine, particularly a computer. **Programming languages** can be used to create programs to control the behavior of a machine or to express algorithms.

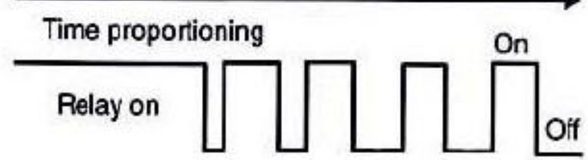
Example:

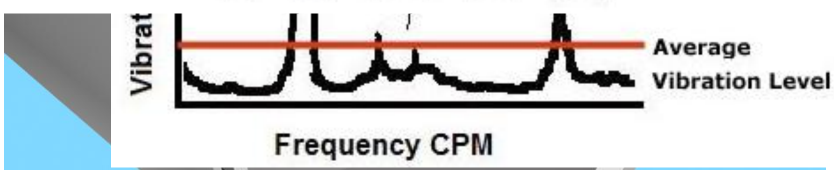
C, C++, Pascal, Java, VB, LabView, Keysight VEE so on..

Product Range









- Temperature
- Pressure
- Strain/Stress
- Force/Load /Thrust
- Displacement
- Flow / RPM
- Acoustics
- Shock/Vibration
- Data Logging & Closed loop c

Thank You