Dial Gauge

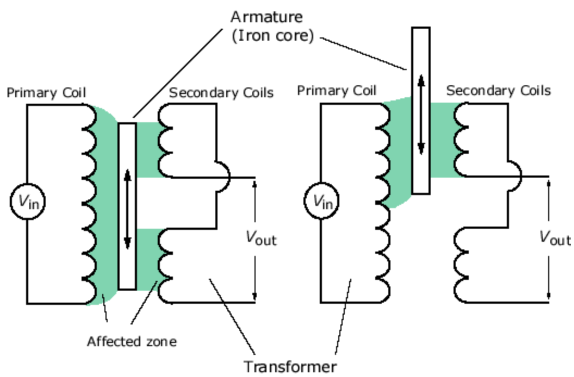
MEASURING SYSTEMS : SELECTED EXAMPLES

Displacement / distance: micrometer

Micrometer

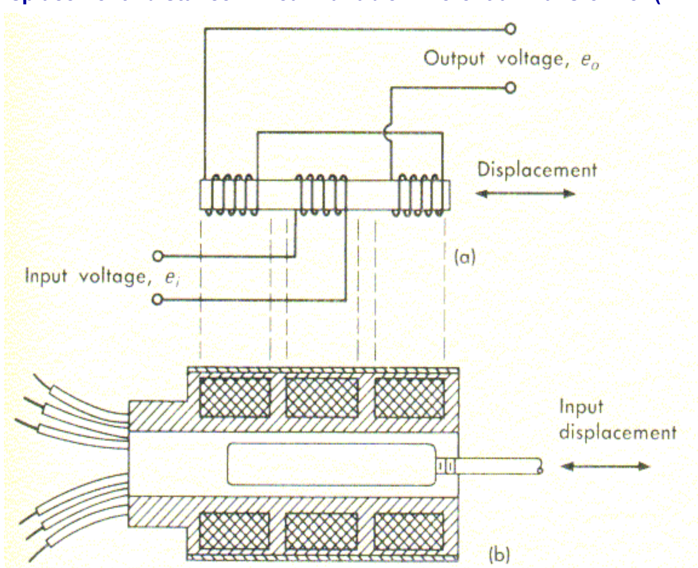
MEASURING SYSTEMS : SELECTED EXAMPLES

Displacement / distance: Linear Variable Differential Transformer (LVDT)



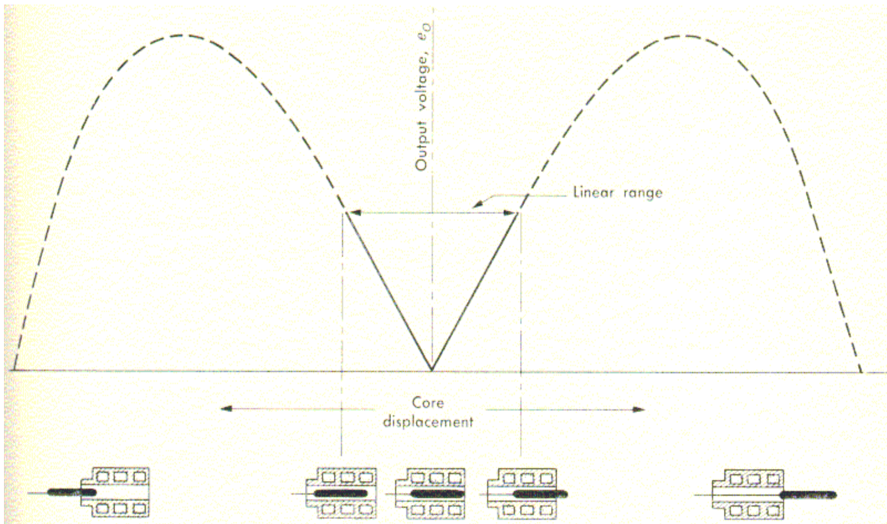
MEASURING SYSTEMS : SELECTED EXAMPLES

Displacement / distance: Linear Variable Differential Transformer (LVDT)



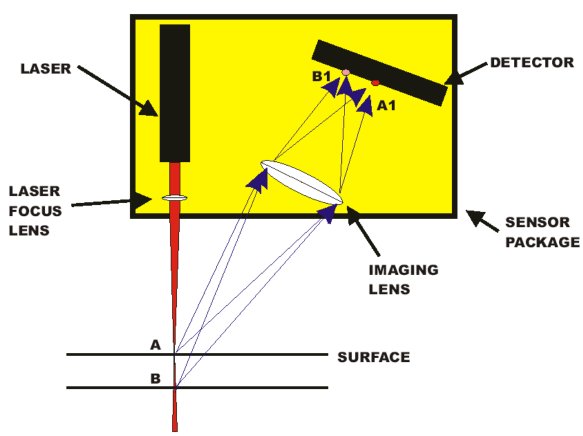
MEASURING SYSTEMS : SELECTED EXAMPLES

Displacement / distance: Linear Variable Differential Transformer (LVDT)



MEASURING SYSTEMS : SELECTED EXAMPLES

Displacement / distance: Laser (triangulation)



MEASURING SYSTEMS : SELECTED EXAMPLES

Displacement / distance: Laser (triangulation)

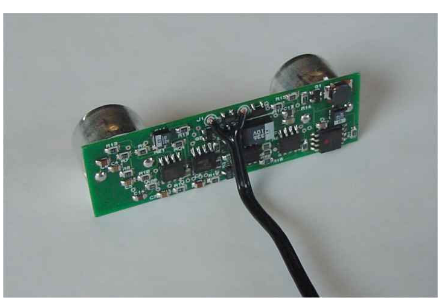
LK-2500 Series Specifications

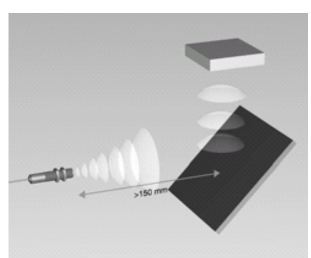
Model	Sensor Head	LK-501/503	
	Controller	LK-2501/2503	
Measurement Mode		Long range mode	High-precision mode
Reference distance		500 mm	350 mm
Measuring range		±250 mm	± 100 mm
Light Source		Red semiconductor Laser, wavelength: 690 nm	
Spot diameter		Approx. 0.3 mm dia. (at reference distance)	Approx. 0.7 mm dia. (at reference distance)
Linearity		±0.1% of FS	
Resolution		50 µm	10 µm
Sampling Cycle		1024 µs	
Other functions		Autozero, Alarm hold, Gain selection, Response speed selection, Span/Shift adjustment	
Power Supply		24 VDC ±10% Ripple (p-p): 10% max.	
Current Consumption		400 mA max.	
Material		Sensor head: Aluminum die-cast, Controller: Polycarbonate	
Weight (including cable)	Sensor head	Approx. 700 g	
	Controller	Approx. 515 g	

MEASURING SYSTEMS : SELECTED EXAMPLES

Displacement / distance: Time-of-flight distance sensors:

Ultrasonic (Sonar), Radio waves (Radar), Optical (Ladar),

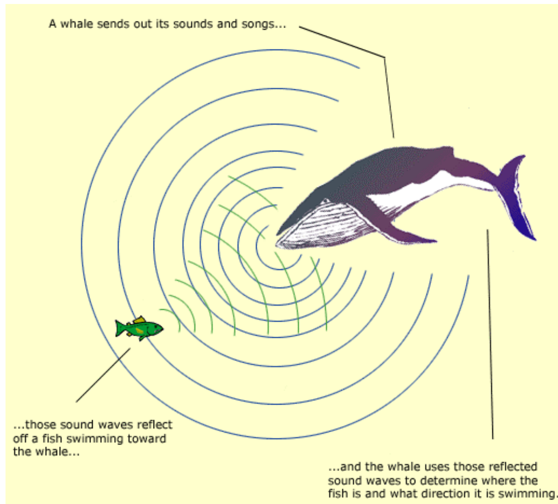




MEASURING SYSTEMS : SELECTED EXAMPLES

Displacement / distance: Time-of-flight distance sensors:

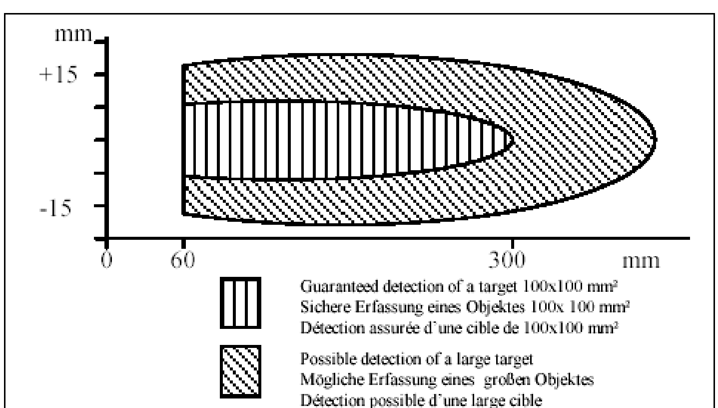
Ultrasonic (Sonar), Radio waves (Radar), Optical (Ladar),



MEASURING SYSTEMS : SELECTED EXAMPLES

Displacement / distance: Time-of-flight distance sensors:

Ultrasonic (Sonar), Radio waves (Radar), Optical (Ladar),



MEASURING SYSTEMS : SELECTED EXAMPLES

Displacement / distance: Time-of-flight distance sensors:

Ultrasonic (Sonar), Radio waves (Radar), Optical (Ladar),

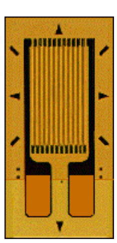
- Laser diode is pulsed every microsecond
- The reflection is detected by a photo diode

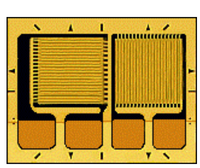
Animation courtesy Banner Engineering

MEASURING SYSTEMS : SELECTED EXAMPLES

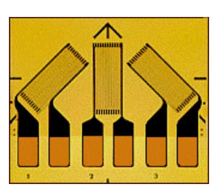
Strain: (resistance strain gauge)

- When the conductor (wire) is strained (extended), its cross-sectional area reduces and the total electrical resistance increases.
- The change in resistance is used to measure the strain of the material or component onto which the strain gauge is bonded.

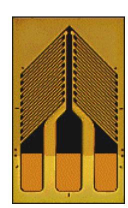




Bi-axial gauge



Tri-axial gauge (rosette) for Principal strains



Bi-axial gauge for normal or shear strains

MEASURING SYSTEMS : SELECTED EXAMPLES

Strain: (resistance strain gauge)

$$R = \rho\, L/A \quad \text{or} \quad R = \rho\, L/CD^2 \quad \square\ C=1 \quad O: C=\pi/4 \qquad (1)$$

When the conductor is strained, its geometry will change. Differentiating (1)

$$dR = CD^2(L\, d\rho + \rho\, dL) - 2C\, \rho LD\, dD\, /\, (CD^2)^2$$
$$= [(L\, d\rho + \rho\, dL) - 2\, \rho L\, dD/D]\, /\, CD^2 \qquad (2)$$

Dividing (2) by (1)

$$dR/R = dL/L \;-\; 2dD/D \;+\; d\rho/\rho \qquad (3)$$

Dividing by dL/L throughout:

$$(dR/R)\, /\, (dL/L) = 1 \;-\; 2(dD/D)/(dL/L) \;+\; (d\rho/\rho)/(dL/L) \qquad (4)$$

Since $dL/L = \varepsilon_a$ = axial strain, $dD/D = \varepsilon_L$ = lateral strain and ν = Poisson's Ratio = $(dD/D)/(dL/L)$, Eqn. (4) can be written to define the Gauge Factor, G:

$$G = (dR/R)/(dL/L) = (dR/R)/\, \varepsilon_a \quad \text{or} \quad \varepsilon_a = (dR/R)/G \qquad (5)$$

MEASURING SYSTEMS : SELECTED EXAMPLES

Force

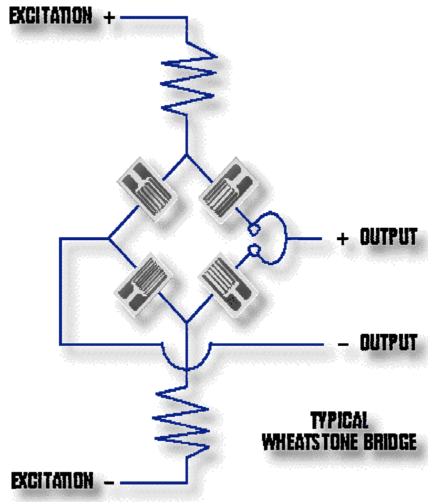
- Force and torque are often measured by bonding a number of strain gauges on a carefully designed component called a load cell. The load cell is usually manufactured using steel which has very linear (elastic) properties as well as having a high elastic modulus (low deformation under load).
- Load cells can be designed to measure a wide variety of forces such as compression, bending, tension, shear and torque.

Strain gauge type load cells

MEASURING SYSTEMS : SELECTED EXAMPLES

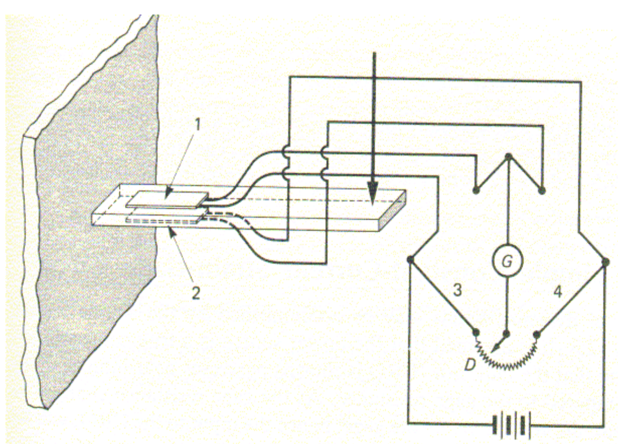
Strain: (resistance strain gauge)

The Wheatstone bridge



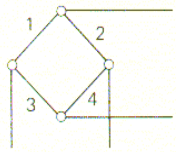
MEASURING SYSTEMS : SELECTED EXAMPLES

Strain gauge type load cells



MEASURING SYSTEMS : SELECTED EXAMPLES

Strain gauge type load cells



Requirement for null: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

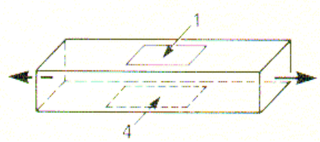
K = Bridge constant = $\frac{\text{Output of bridge}}{\text{Output of primary gage}}$

A — $K = 1$

Compensates for temperature if "dummy" gage is used in arm 2 or arm 3.

Does not compensate for bending.

B — $K = 2$

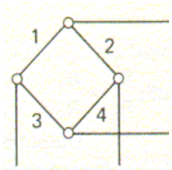


Compensates for bending.

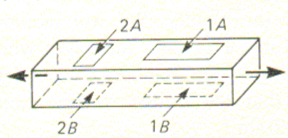
Two-arm bridge does not provide temperature compensation.
Four-arm bridge ("dummy" gages in arms 2 and 3) provides temperature compensation.

MEASURING SYSTEMS : SELECTED EXAMPLES

Strain gauge type load cells

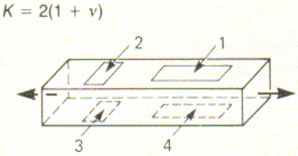


C — $K = 1 + \nu$



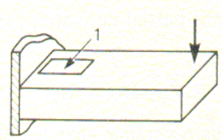
Two-arm bridge compensates for temperature and bending.

D — $K = 2(1 + \nu)$



Four-arm bridge compensates for temperature and bending.

E — $K = 1$

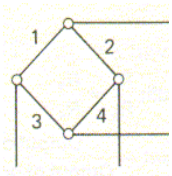


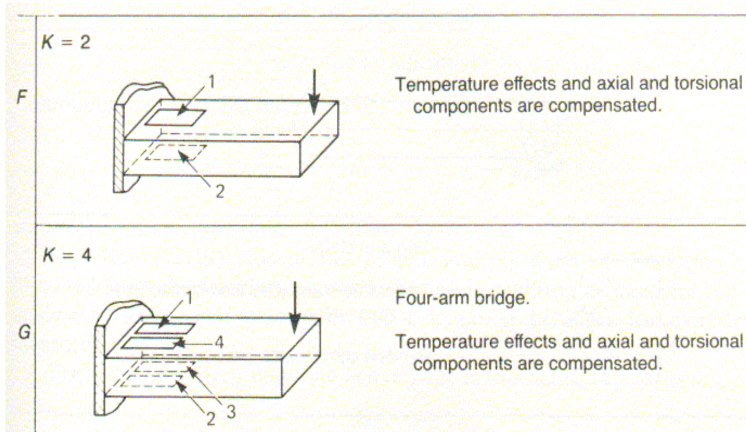
Temperature compensation accomplished when "dummy" gage is used in arm 2 or arm 3.

Bridge is also sensitive to axial and torsional components of loading.

MEASURING SYSTEMS : SELECTED EXAMPLES

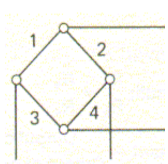
Strain gauge type load cells

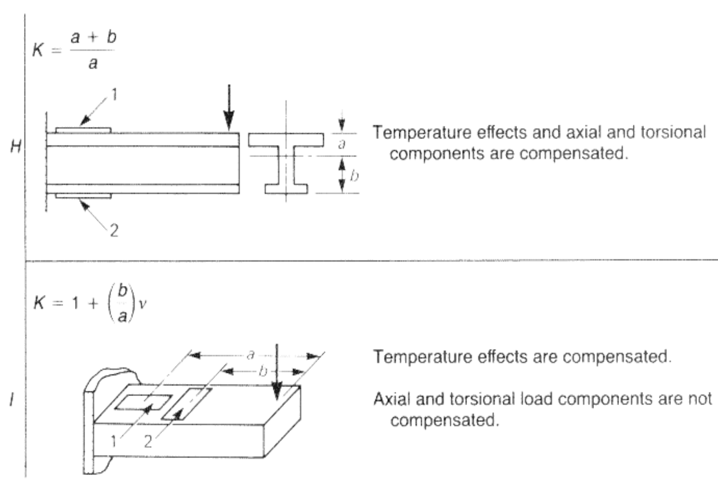




MEASURING SYSTEMS : SELECTED EXAMPLES

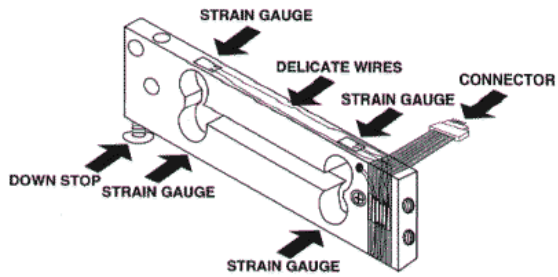
Strain gauge type load cells





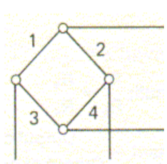
MEASURING SYSTEMS : SELECTED EXAMPLES

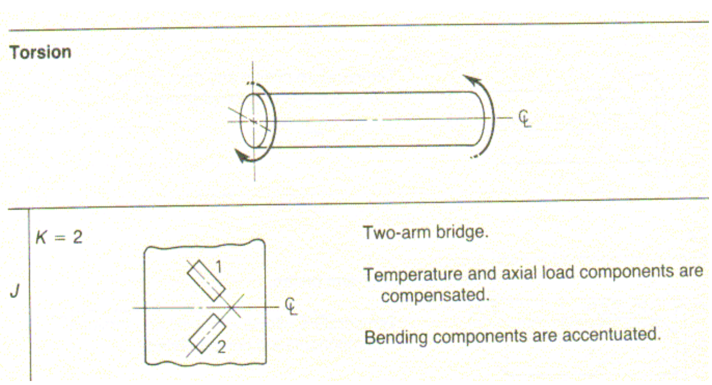
Strain gauge type load cells



MEASURING SYSTEMS : SELECTED EXAMPLES

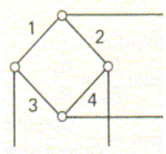
Strain gauge type load cells

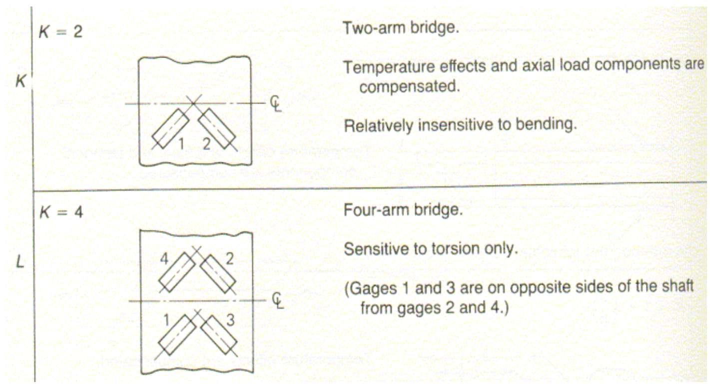




MEASURING SYSTEMS : SELECTED EXAMPLES

Strain gauge type load cells





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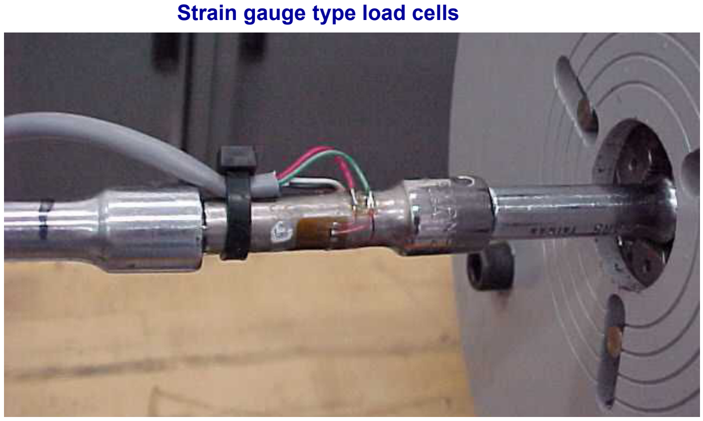
MEASURING SYSTEMS : SELECTED EXAMPLES

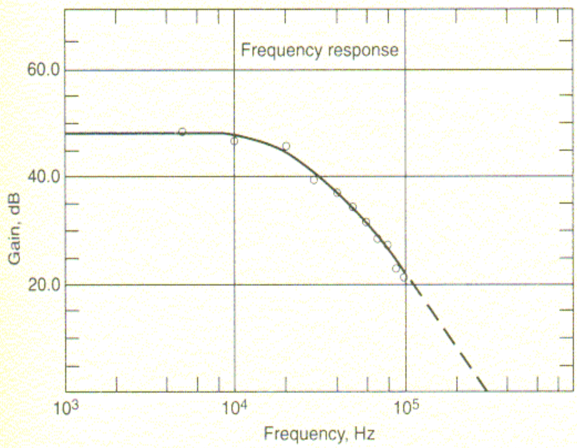
Strain gauge type load cells



MEASURING SYSTEMS : SELECTED EXAMPLES

Time response

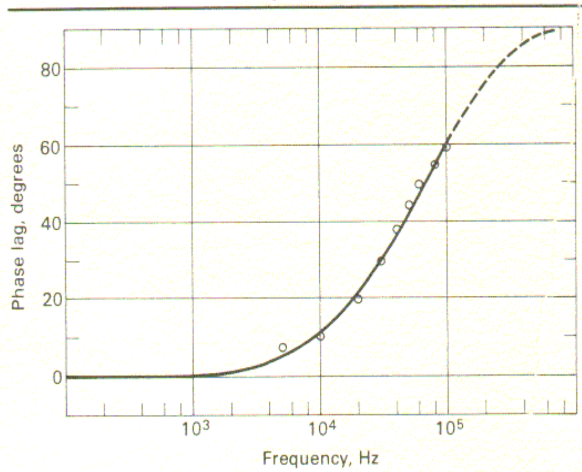
Figure 5.2 Frequency response curve for amplifier section of a commercially available strain-measuring system; e_i = 10 mV



MEASURING SYSTEMS : SELECTED EXAMPLES

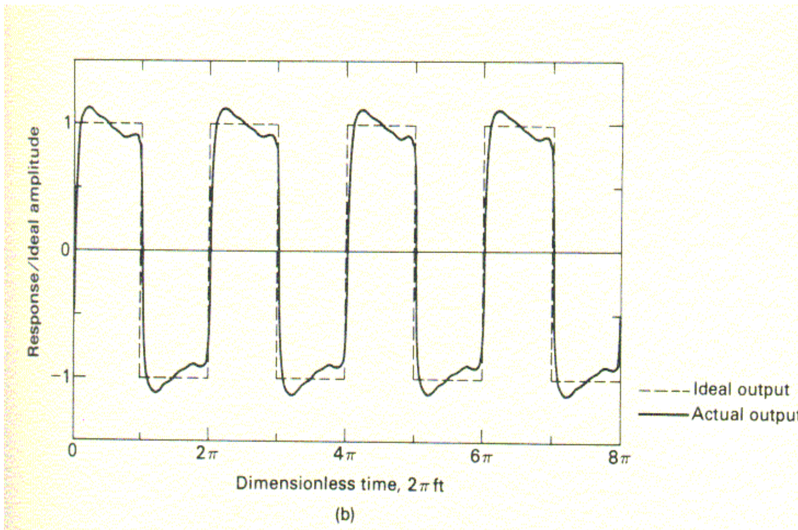
Time response

Figure 5.3 Phase lag versus frequency (phase response) for the same amplifier used in Fig. 5.2



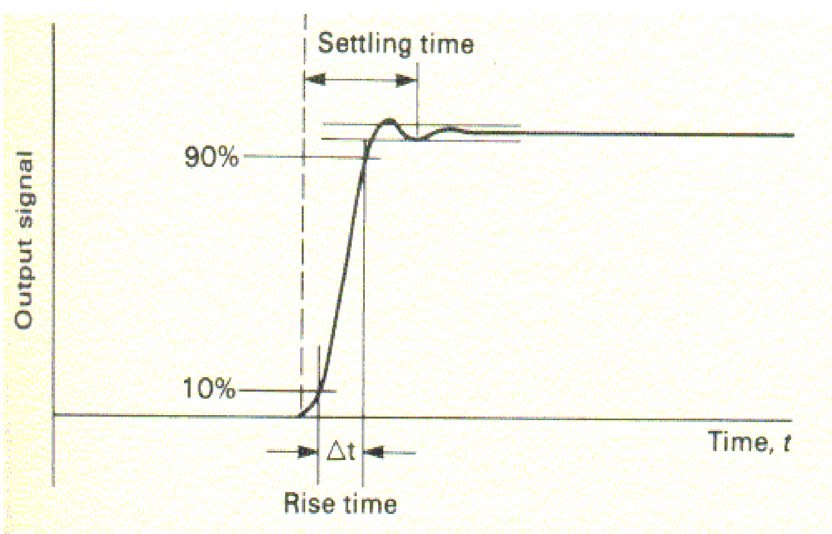
MEASURING SYSTEMS : SELECTED EXAMPLES

Time response



MEASURING SYSTEMS : SELECTED EXAMPLES

Time response



MEASURING SYSTEMS : SELECTED EXAMPLES

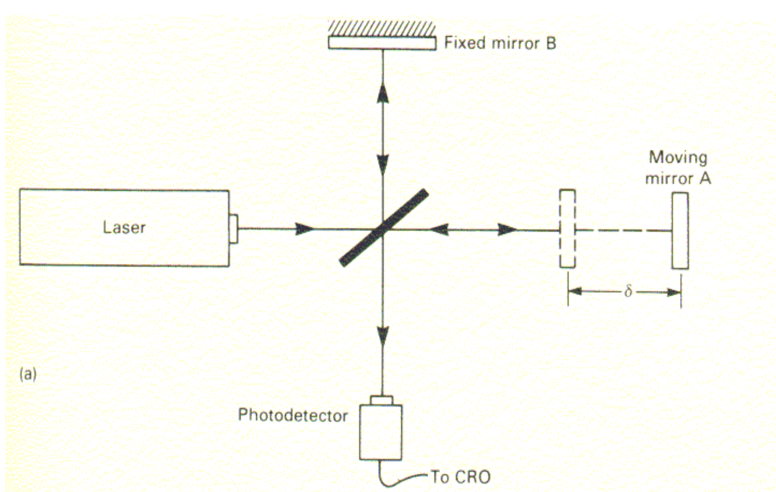
Temperature

- Thermocouples are based on the principle that when two dissimilar metals are joined a predictable voltage will be generated that relates to the difference in temperature between the measuring junction and the reference junction (connection to the measuring device).

- RTDs are wire wound and thin film devices that work on the physical principle of the temperature coefficient of electrical resistance of metals. They are nearly linear over a wide range of temperatures and can be made small enough to have response times of a fraction of a second. They require an electrical current to produce a voltage drop across the sensor that can be then measured by a calibrated read-out device.

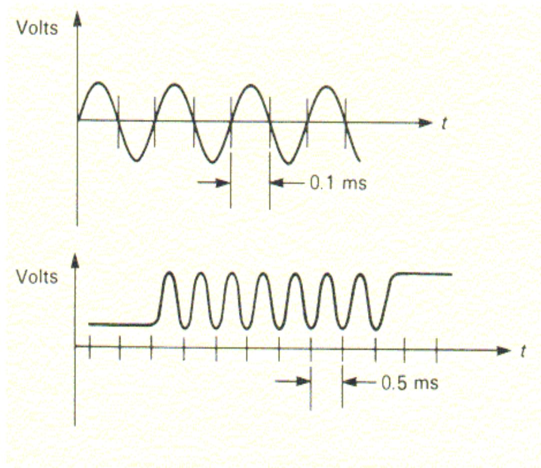
MEASURING SYSTEMS : SELECTED EXAMPLES

Velocity: Interferometry (Michelson interferometer)



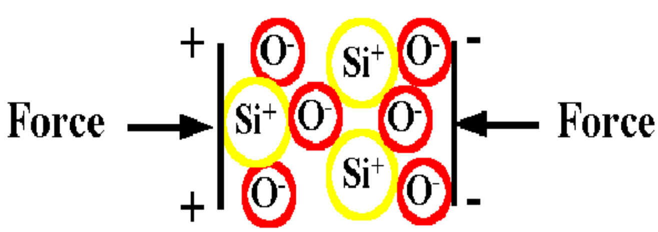
MEASURING SYSTEMS : SELECTED EXAMPLES

Velocity: Interferometry



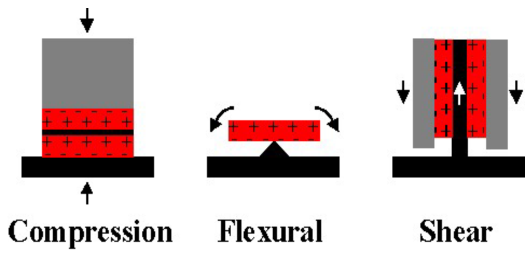
MEASURING SYSTEMS : SELECTED EXAMPLES

Piezoelectric sensors



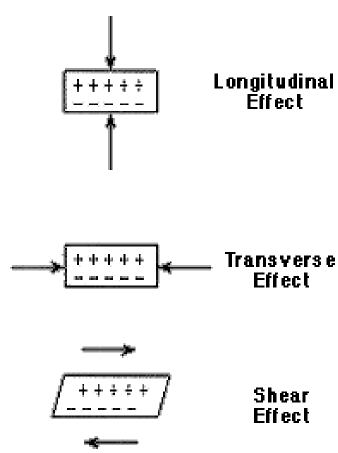
MEASURING SYSTEMS : SELECTED EXAMPLES

Piezoelectric sensors

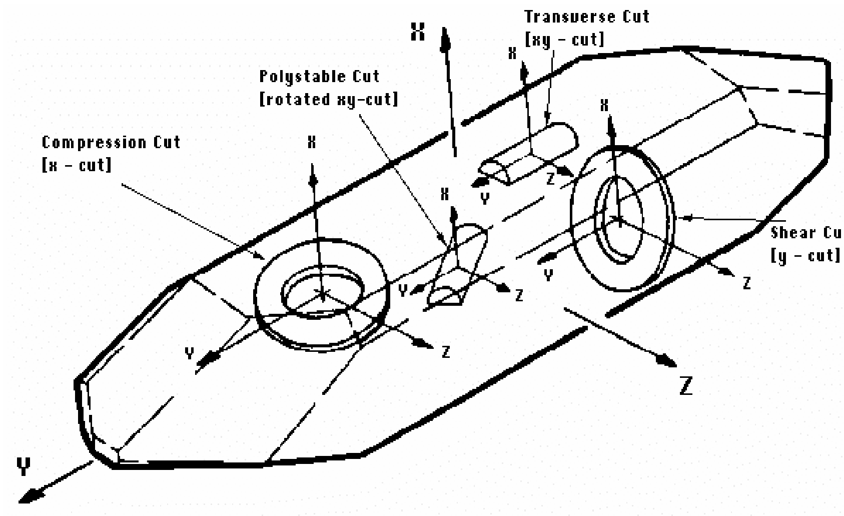


MEASURING SYSTEMS : SELECTED EXAMPLES

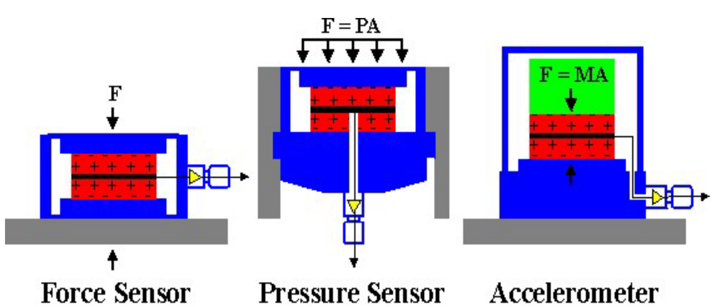
Piezoelectric sensors



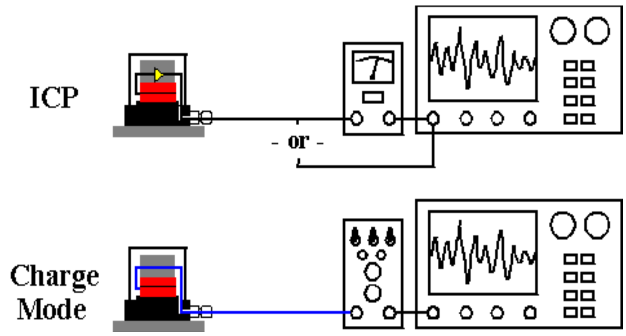
MEASURING SYSTEMS : SELECTED EXAMPLES
Piezoelectric sensors



MEASURING SYSTEMS : SELECTED EXAMPLES
Piezoelectric sensors



MEASURING SYSTEMS : SELECTED EXAMPLES
Piezoelectric sensors

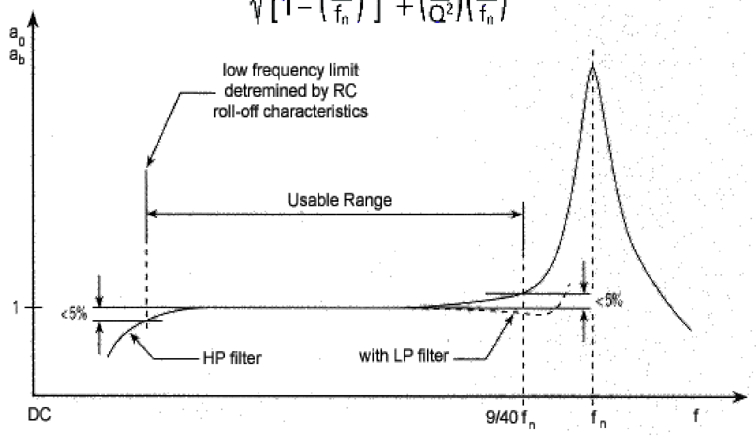


MEASURING SYSTEMS : SELECTED EXAMPLES
Piezoelectric sensors
Accelerometer performance:

- Sensitivity (Pc/g or V/g)
- Range
- Resolution
- Transverse sensitivity
- Amplitude linearity
- Frequency response or frequency range

MEASURING SYSTEMS : SELECTED EXAMPLES
Piezoelectric sensors
Accelerometer performance:

$$\frac{a_o}{a_b} \cong \frac{1}{\sqrt{\left[1-\left(\frac{f}{f_n}\right)^2\right]^2+\left(\frac{1}{Q^2}\right)\left(\frac{f}{f_n}\right)^2}}$$



MEASURING SYSTEMS : SELECTED EXAMPLES
Piezoelectric sensors
Environmental effects:

- Temperature – may affect sensitivity, natural frequency and damping. Effects sometimes characterised by manufacturer.
- Humidity – mainly affects high impedance transducers.
- Acoustic noise.
- Strain sensitivity – may generate spurious signals when the case is strained or distorted (ie. badly mounted)

MEASURING SYSTEMS : SELECTED EXAMPLES
Piezoelectric sensors
Accelerometer mounting:

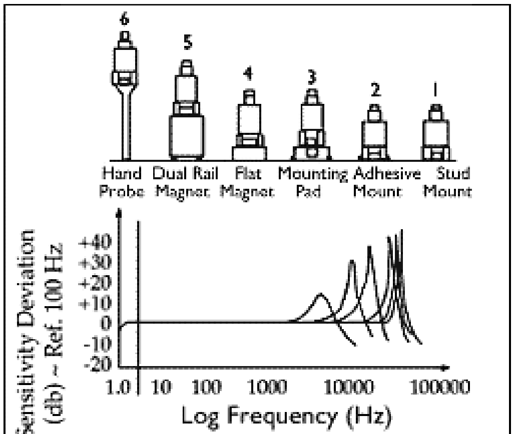


Fig. 6 - Mounted Resonance Change

MEASURING SYSTEMS : SELECTED EXAMPLES
Piezoelectric sensors
Accelerometer mass loading:

The vibrational characteristics of a structure can be altered by adding mass to that structure. An accelerometer that is too heavy, with respect to the test structure, will affect the vibrational behaviour of the structure and give erroneous measurements. Care must be used when selecting an accelerometer and mounting hardware to avoid the effects of mass loading.

MEASURING SYSTEMS : SELECTED EXAMPLES

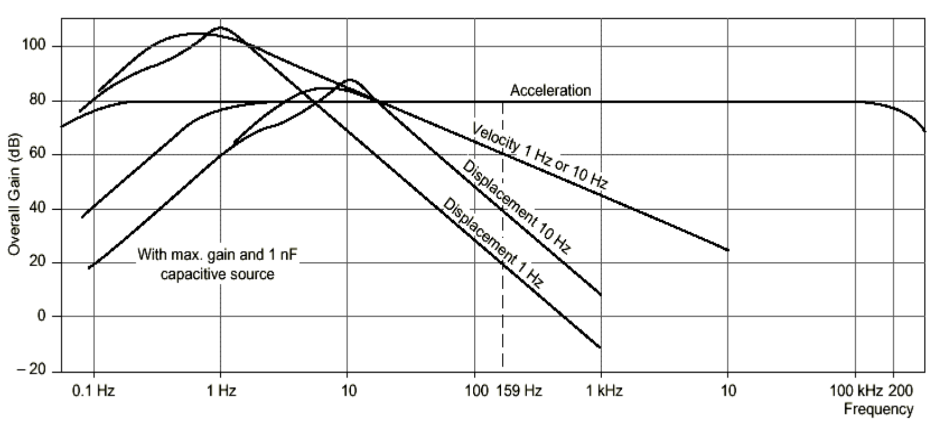
Piezoelectric sensors

Charge amplifiers

MEASURING SYSTEMS : SELECTED EXAMPLES

Piezoelectric sensors

Frequency Response:



MEASURING SYSTEMS : SELECTED EXAMPLES
(Ref: Mechanical Measurements 5th ed. Beckwith, Marangoni & Leinhard)

Instrument type	Measurand	Method	Typical hardware
Potentiometer	Displacement	Electrical Resistance	DC power supply - voltage divider (metre - ohms - volt)
LVDT	Displacement	Inductance	AC excitation signal (Modulator) & Demodulator (metre - henry - volt)
Ultrasonic	Displacement	Time of flight	Ultrasonic generator, ultrasonic microphone & Clock (metre - second - volt)
Laser - Triangulation	Displacement	Geometrical variations	Laser light source & photodiode array (metre - count - volt)
Optical encoder	Displacement	Optical masking	Optical source, counter (metre - count s- pulses)
Laser - Interferometer	Displacement / velocity	Optical interference	Laser light source, optical splitters, photodiode, frequency counter / converter. (metre - count/rate - volt)

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MEASURING SYSTEMS : SELECTED EXAMPLES
(Ref: Mechanical Measurements 5th ed. Beckwith, Marangoni & Leinhard)

Instrument type	Measurand	Method	Typical hardware
Accelerometer	Acceleration	Piezoelectric effect	Charge amplifier (g -coulomb - volt)
Pressure sensor	Fluid pressure	Piezoelectric effect	Charge amplifier (Pascal - coulomb - volt)
Force sensor	Dynamic force	Piezoelectric effect	Charge amplifier (Newton - coulomb - volt)
Pressure sensor	Fluid pressure	Capacitive (distance)	Capacitance bridge - modulator/demodulator (metre - Farad - volt)
Water surface elevatuion (waves)	Surface elevation (displacement)	Change in permitivity -capacitance	Capacitance bridge - modulator/demodulator (metre - Farad - volt)
Load cell	Force	Component strain (dimentional change)	Resistance bridge (newton - metre - ohm - volt)

MEASURING SYSTEMS : SELECTED EXAMPLES
(Ref: Mechanical Measurements 5th ed. Beckwith, Marangoni & Leinhard)

Instrument type	Measurand	Method	Typical hardware
Thermocouple	Temperature	Seedbeck effect (emf across different metals)	Amplifier / lineariser (C - microvolt - volt)
RTD (Resistance Temperature Detector)	Temperature	Thermo-resistive effect	Weathstone bridge & amplifier (C -ohm - volt)
Semiconductor-Junction Temperature sensors	Temperature	Semiconductor junction	Integrated circuit (C - volt)
Fluid flow rate	Flow rate	Obstruction effect : pressure drop across venturi, flow nozzle, orifice plate	(m^3/s - pascal -volt)
Fluid flow rate	Flow rate	Turbine speed	Pulse / frequency counter (m^3/s - hertz -volt)
Fluid flow rate	Flow rate	Magnetic induction (Faraday's law)	(m^3/s - gauss -volt)
Fluid flow rate	Flow rate	Vortex shedding frequency	Pulse / frequency counter (m^3/s - hertz -volt)

DIGITAL SAMPLING - DIGITISATION

- Digital sampling is mainly used in data acquisition systems
- The analogue electric signal (usually volts) produced by the measuring system is converted to digital format (numbers / digits)
- This is carried out within **digital** computers and **digital** microprocessor-based systems
- These are known as analogue-to-digital converters (A/D or ADC)

DIGITAL SAMPLING - DIGITISATION

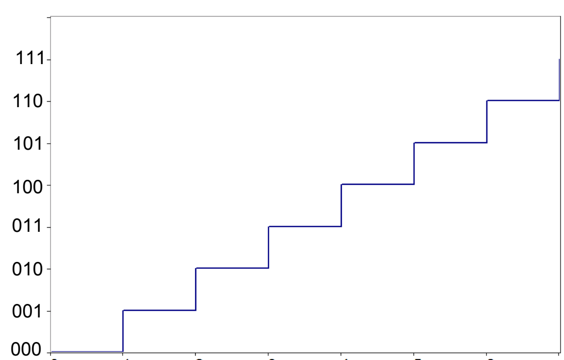
Main reasons for using digital sampling systems:

- Unlike analogue recording systems enable the recorded data to be analysed and manipulated
- ADC's can operate at great speeds (MHz) and can therefore be used to capture rapid changes in the measured quantity (sound – up to 20 kHz, mechanical impacts, pyrotechnic loads – up to 100's kHz)
- ADC's can be **programmed** to capture data automatically at very long intervals (eg: tides, or based on the process level (triggered systems)
- Information is stored permanently
- Information can be accessed remotely
- Information can be used as part of a control system
- Digital circuits use relatively low power, low voltages → safer

DIGITAL SAMPLING - DIGITISATION

Analogue-to-Digital conversion:

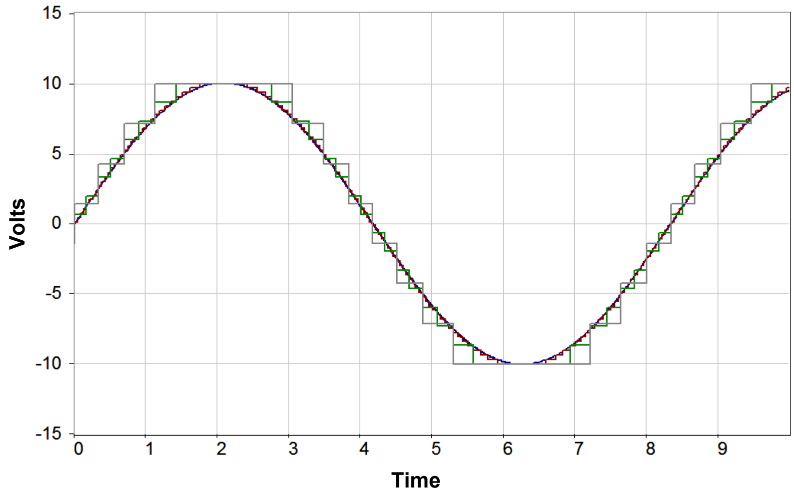
- Digital processors (computers) operate with transistors which are essentially binary switches: **ON / OFF**
- The vast majority of ADCs convert the analogue signal into Bits (Binary Units)
- For example a 3-bit converter provides 2^3 or 8 divisions
- Each division is similar to the divisions on a ruler.



Decimal	3-bit Binary
0	0 0 0
1	0 0 1
2	0 1 0
3	0 1 1
4	1 0 0
5	1 0 1
6	1 1 0
7	1 1 1

DIGITAL SAMPLING - DIGITISATION

Analogue-to-Digital conversion:



DIGITAL SAMPLING - DIGITISATION

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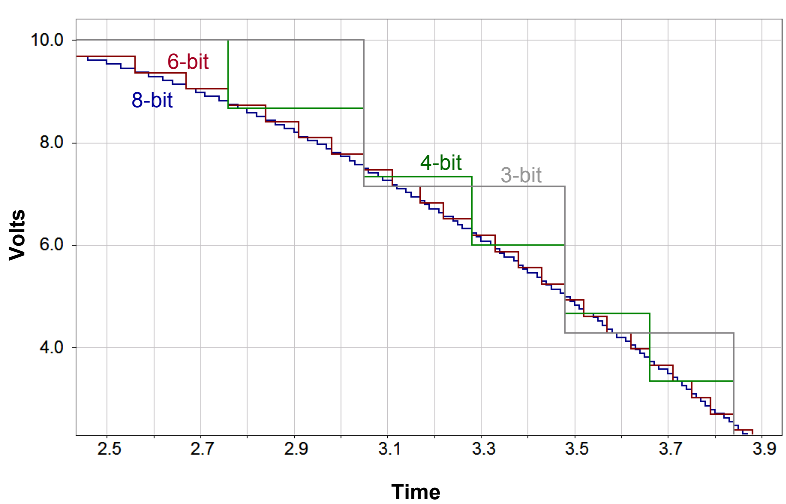

DIGITAL SAMPLING - DIGITISATION

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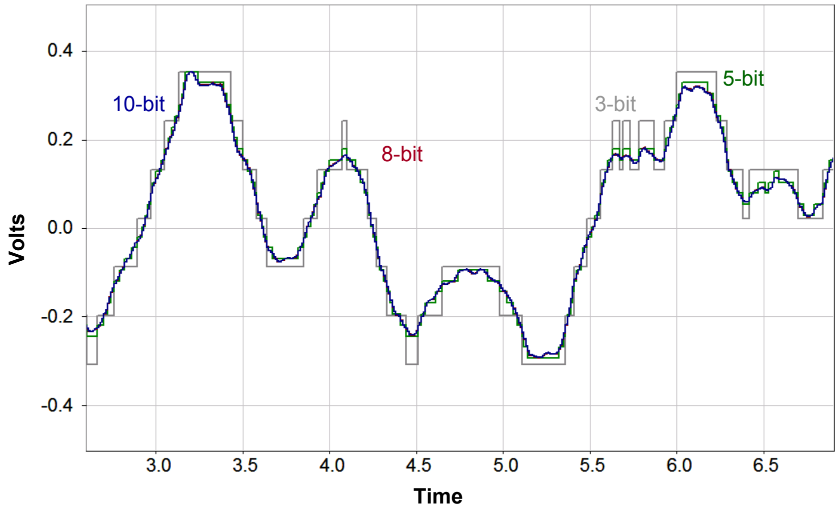
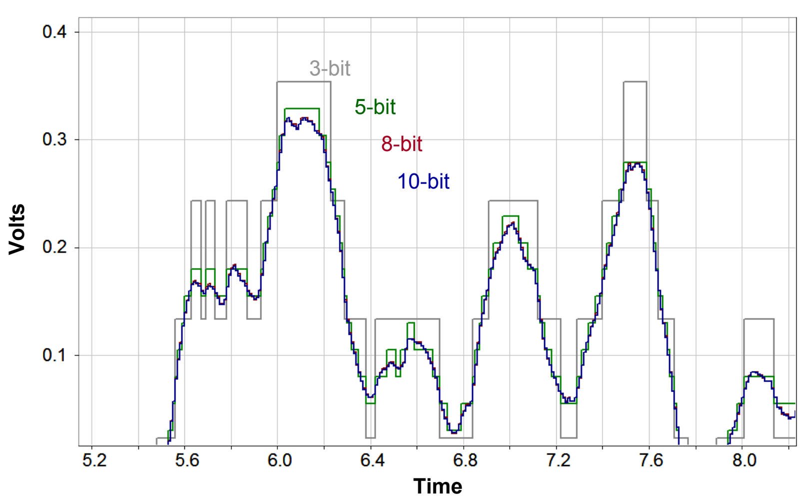


DIGITAL SAMPLING - DIGITISATION

Analogue-to-Digital conversion:



DIGITAL SAMPLING - DIGITISATION

Analogue-to-Digital conversion:

- Most modern ADC operate with at least 12-bit (2^{12} = 4096) conversion and up to 24-bit (2^{24} = 16777216)
- The resolution of the ADC, ε_v, is determined by:

$$\varepsilon_v = \frac{\Delta V_{fs}}{2^n}$$

where ΔV_{fs} *is the full – scale voltage range*
and n is the number of bits of the ADC

- For example, a 12 Bit ADC with a voltage range of ± 10 Volts has a resolution of 20/4096 = 4.88 mV

DIGITAL SAMPLING - DIGITISATION

Dynamic Range:

- The dynamic range of ADC are often specified in dB.
- For bi-polar ADC (measures positive & negative signals) the dynamic range is:
  Dynamic range = 20 log (2^r/2)
  Eg. 12 bit conversion: 20 log (2^{12}/2) = 20 log 4096/2 = 66 dB
  Eg. 16 bit conversion: 20 log (2^{16}/2) = 20 log 65536/2 = 90 dB
- For bi-polar ADC (measures positive & negative signals) the dynamic range is:
  Dynamic range = 20 log (2^r)
  Eg. 12 bit conversion: 20 log (2^{12}) = 20 log 4096= 72 dB

- **Conversion of DV to voltage :**
- **Various forms of conversion**

$$Voltage = \frac{DV - 2048}{2048} 10 \quad \text{or}$$

$$Voltage = \frac{20}{4096} DV - 10 \quad \text{or}$$

$$Voltage = \frac{Span}{2^{resolution}} DV + \text{lowest voltage}$$

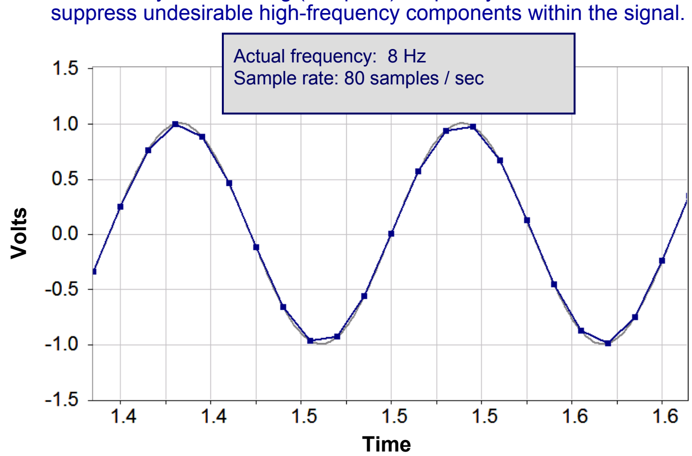
$$Voltage = \frac{\left(\frac{Span}{2^{resolution}} DV + \text{lowest voltage} \right)}{gain}$$

DIGITAL SAMPLING – DIGITISATION

Dadisp ShannonRandom Dadisp ShannonSine

Sampling frequency (rate):

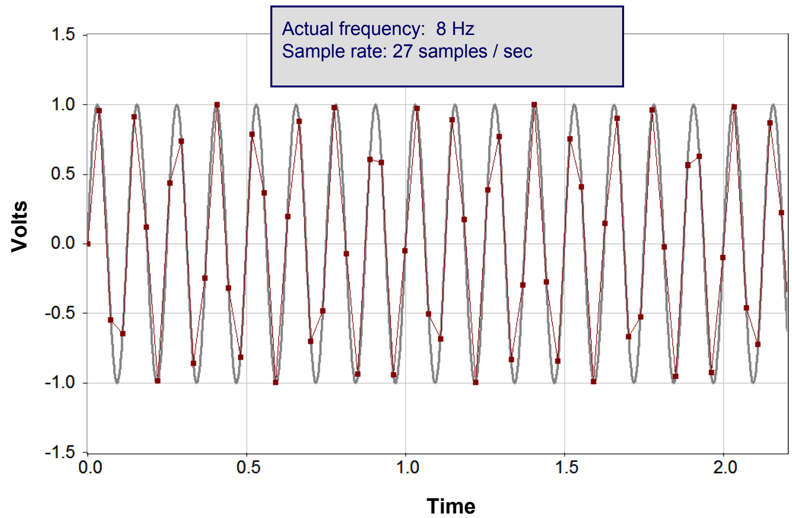
- To obtain an accurate estimate of the process in the time domain, the sampling frequency should besignificantly greater (12 times or more) than the maximum frequency of the signal.
- Alternatively, anti-aliasing (low-pass) frequency filters can be used to suppress undesirable high-frequency components within the signal.



DIGITAL SAMPLING – DIGITISATION

Sampling frequency (rate):

- The sampling frequency can be reduced without loosing information regarding the frequency, amplitude and phase of the signal.



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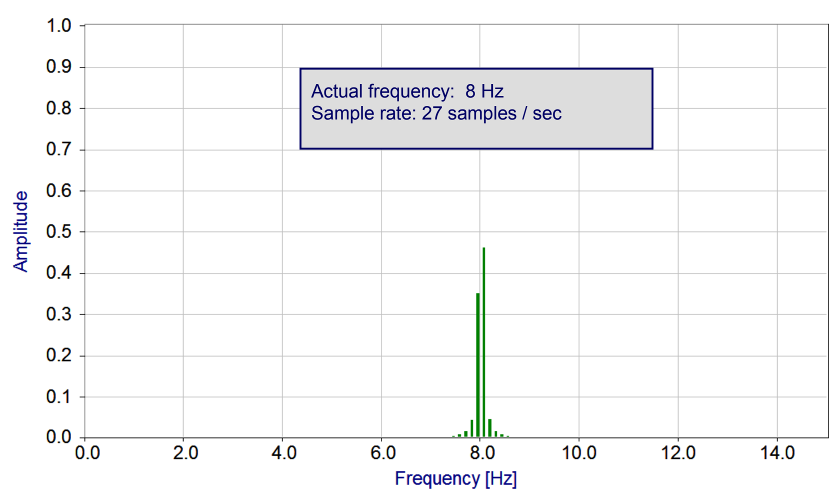
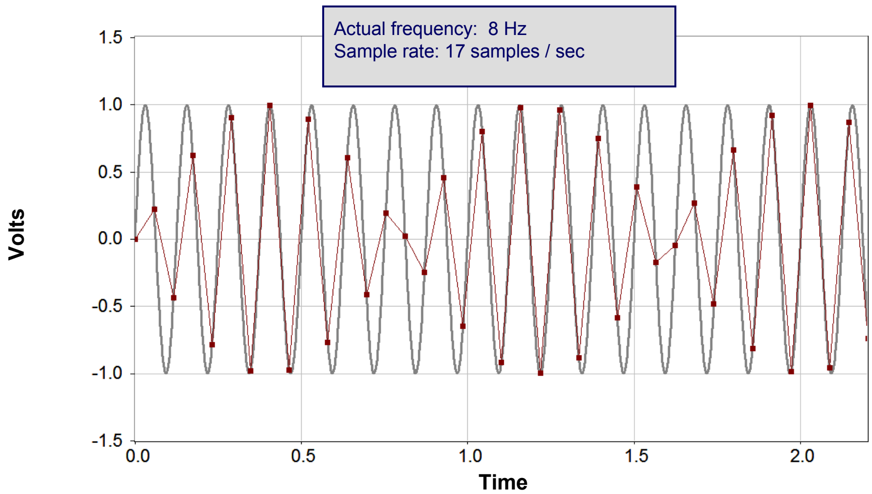


DIGITAL SAMPLING – DIGITISATION

Sampling frequency (rate):

- The sampling frequency can be as low as just over twice the maximum frequency component without loosing information regarding the frequency, amplitude and phase of the signal.



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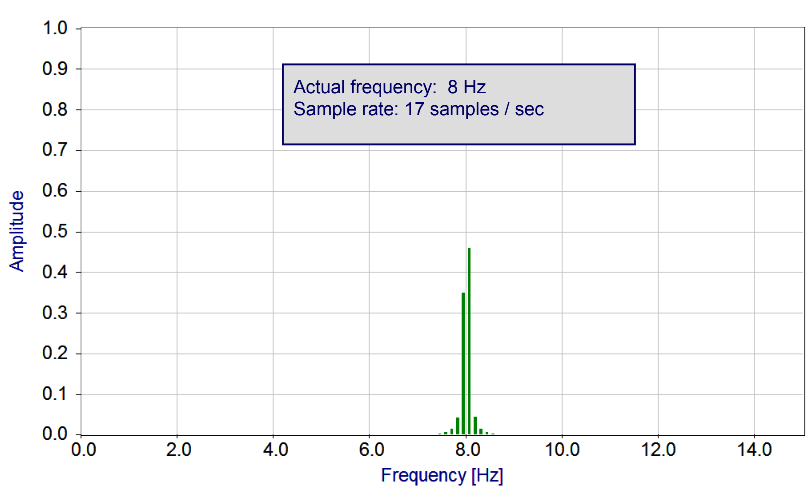
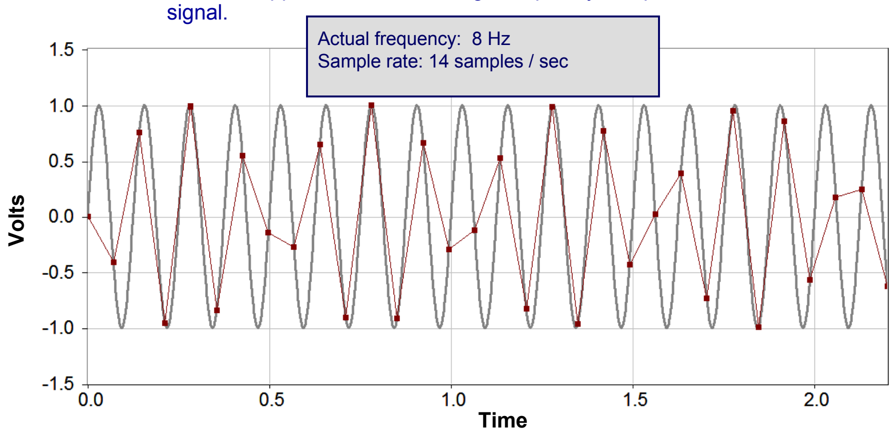


DIGITAL SAMPLING – DIGITISATION

Dadisp ShannonRandom Dadisp ShannonSine

Sampling frequency (rate):

- If the sampling frequency is reduced to or below the maximum frequency component, a ghost frequency component appears. This phenomenon is called Aliasing
- Aliasing can be prevented by using, anti-aliasing (low-pass) frequency filters to suppress undesirable high-frequency components within the signal.



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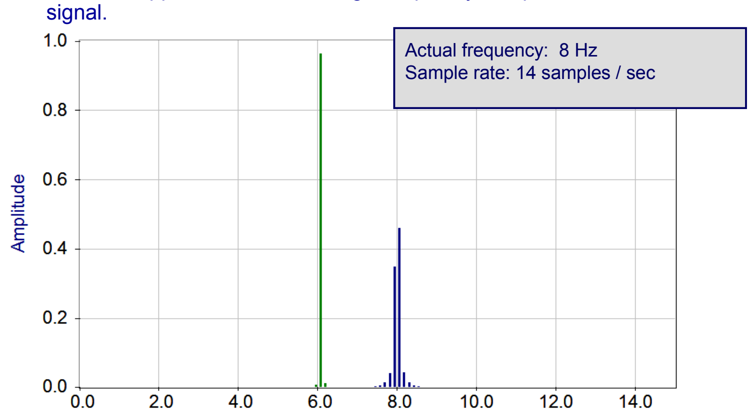

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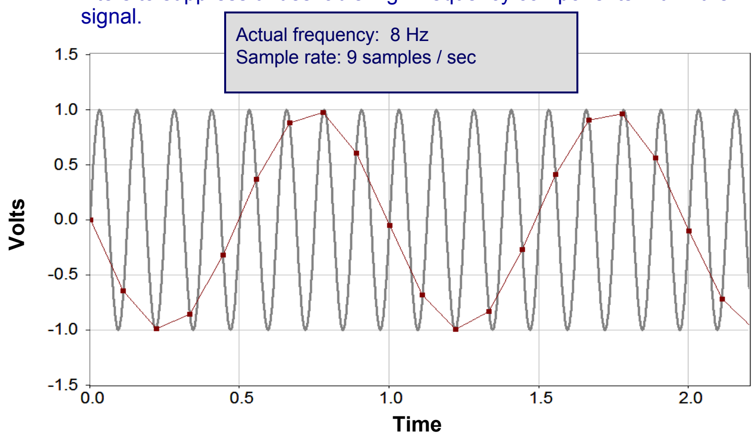

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