[ME 472]

Engineering Metrology & Quality Control

[CHAPTER 3]

Advanced Measurement Methods

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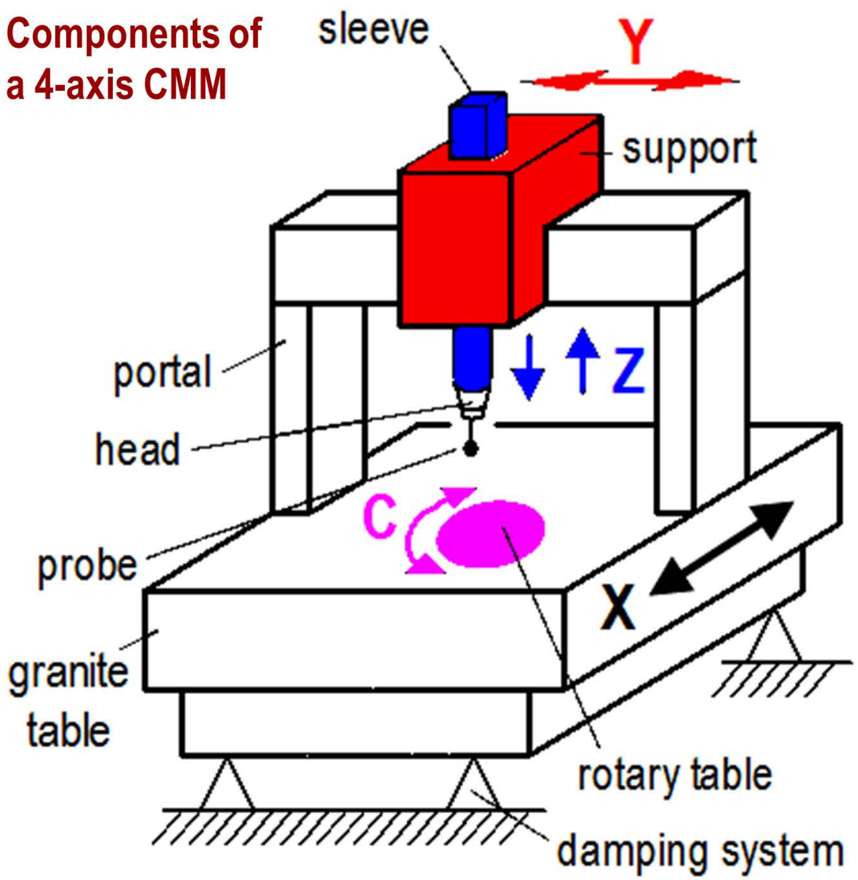
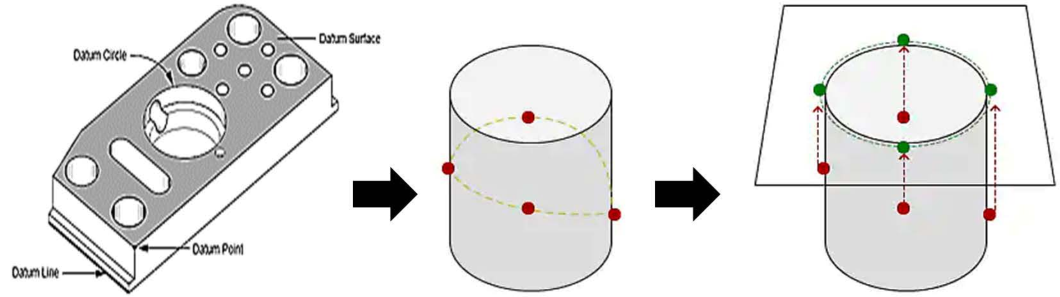
Mechanical Engineering Department

Coordinate Measuring Machine (CMM)

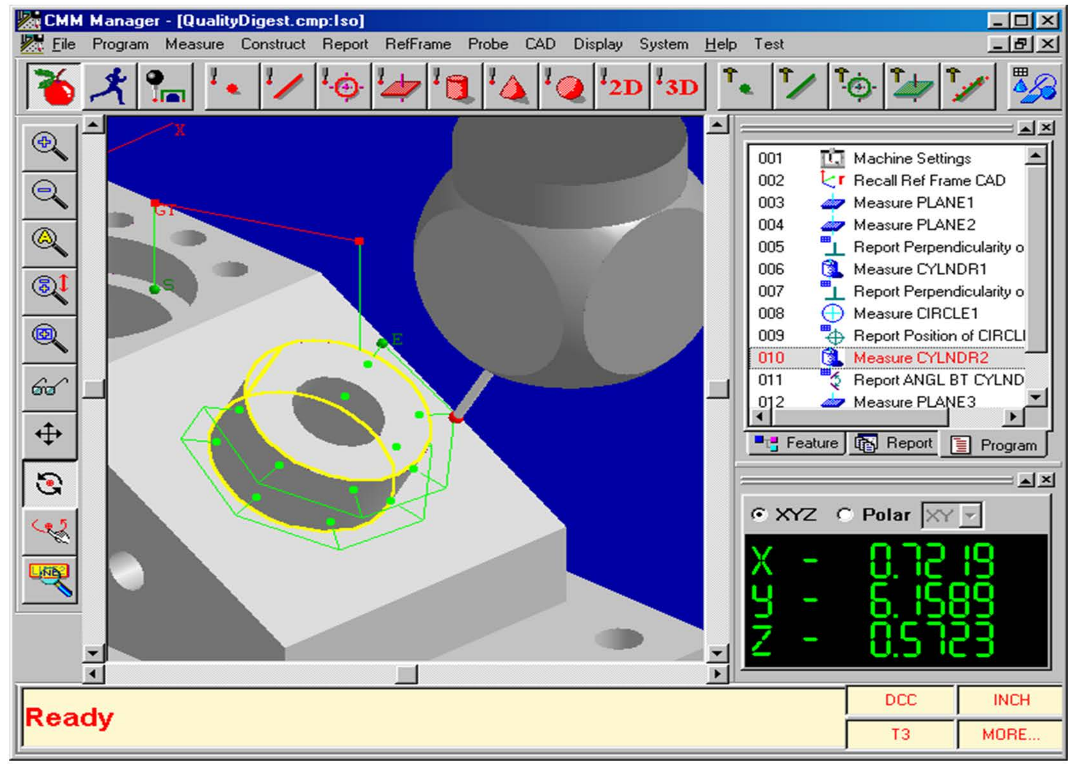
- Used for **precise & accurate measurements of 3D coordinates** of parts using small-head touching probes via movable axes.

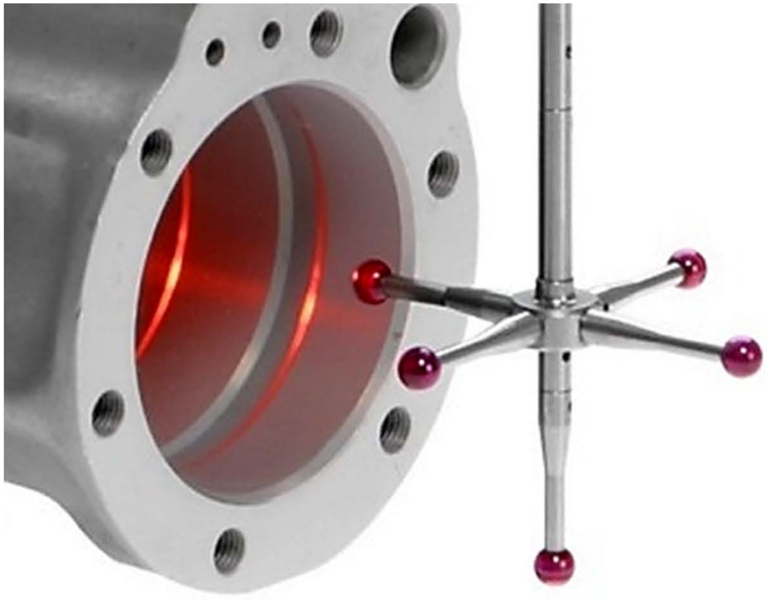
Components of a 4-axis CMM

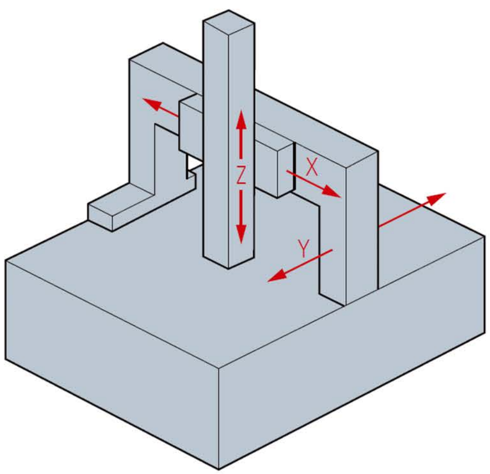




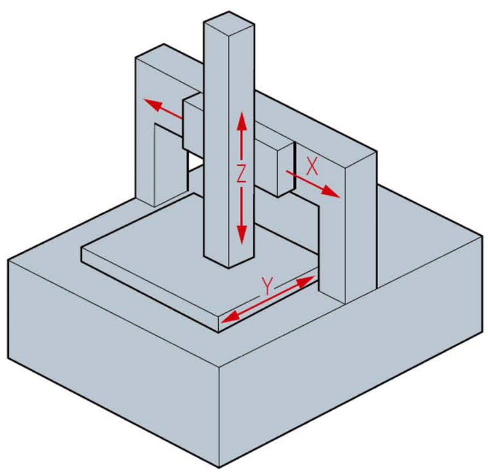
Defining Datums as Reference → Measured Points → Constructed Feature



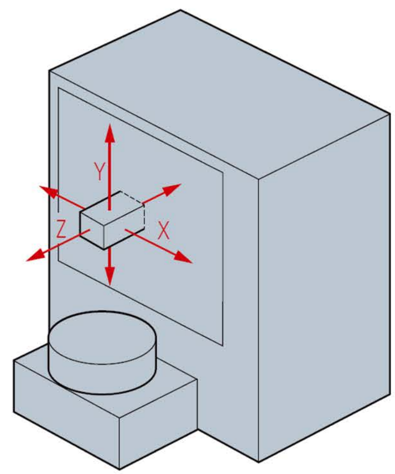




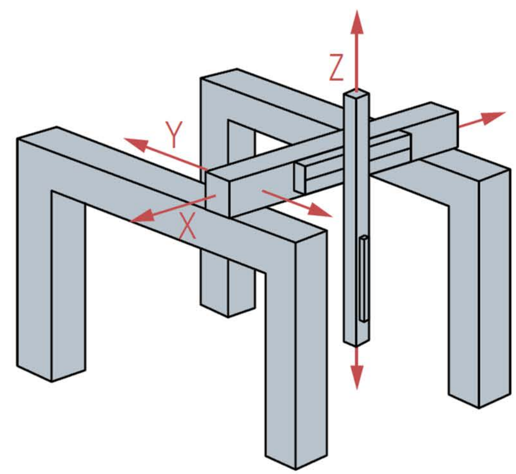
Bridge Type (Fixed Table)



Bridge Type (Moving Table)



Horizontal-Arm Type



Gantry / Floor Type

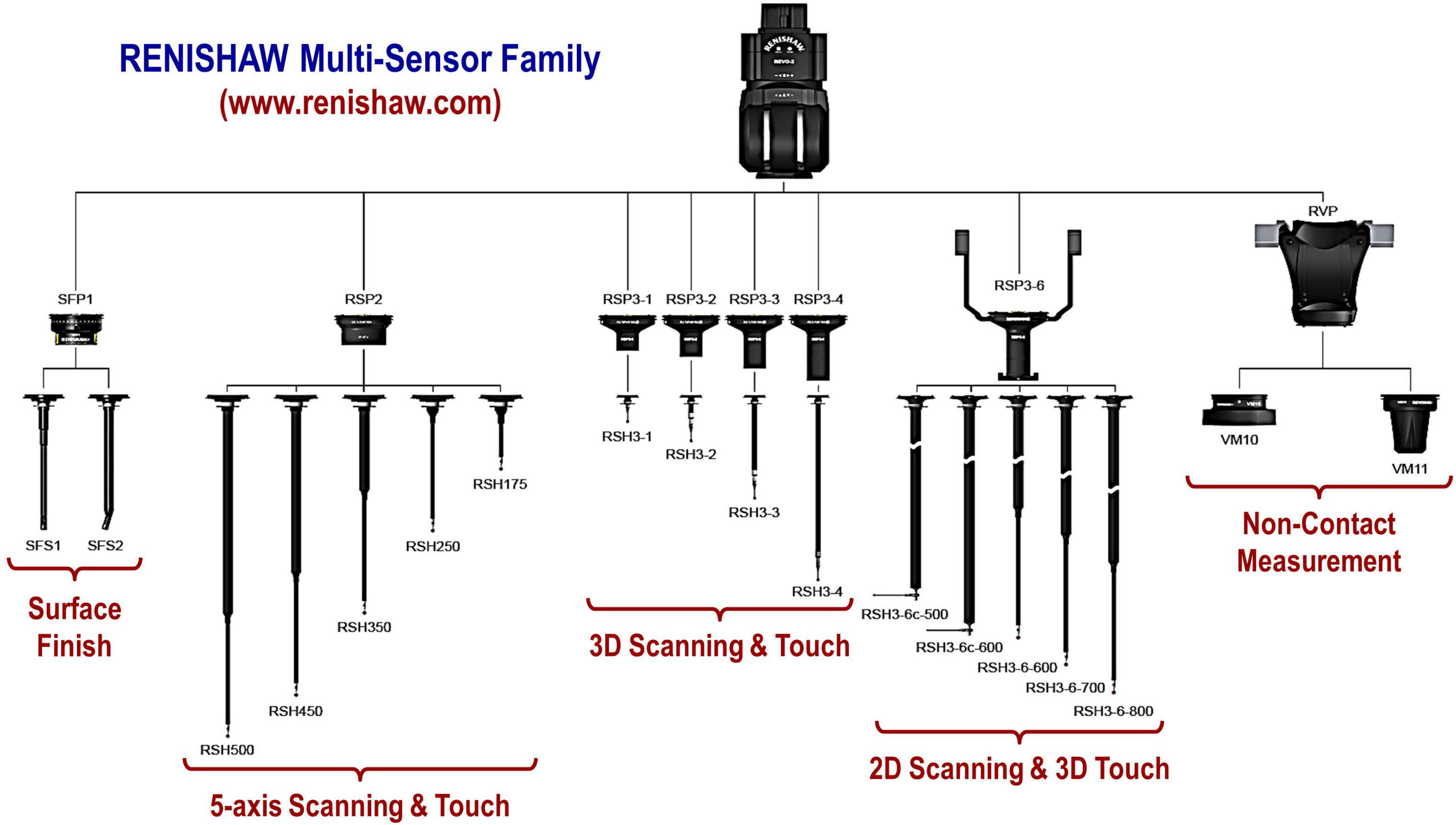
RENISHAW Measurement Systems
(www.renishaw.com)

REVO-2 Dynamic Measuring Head
(5-axis touch & scan probe system)

RVP Vision Probe
(5-axis non-contact measurement)

RUP1 Ultrasonic Probe
(Thickness measurement of 1-20 mm)

RENISHAW Multi-Sensor Family
(www.renishaw.com)



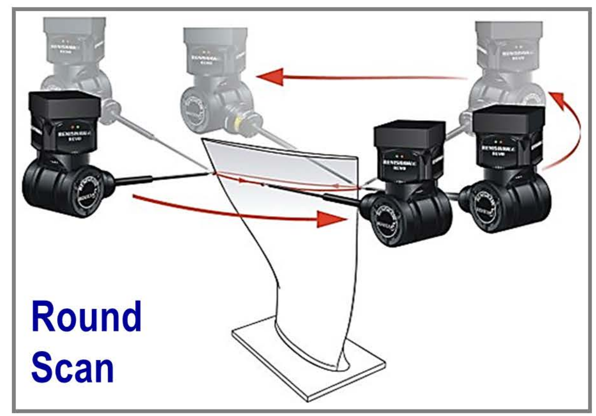

Helix Scan


Gasket Scan


Sharp-Edge
Sweep Scan

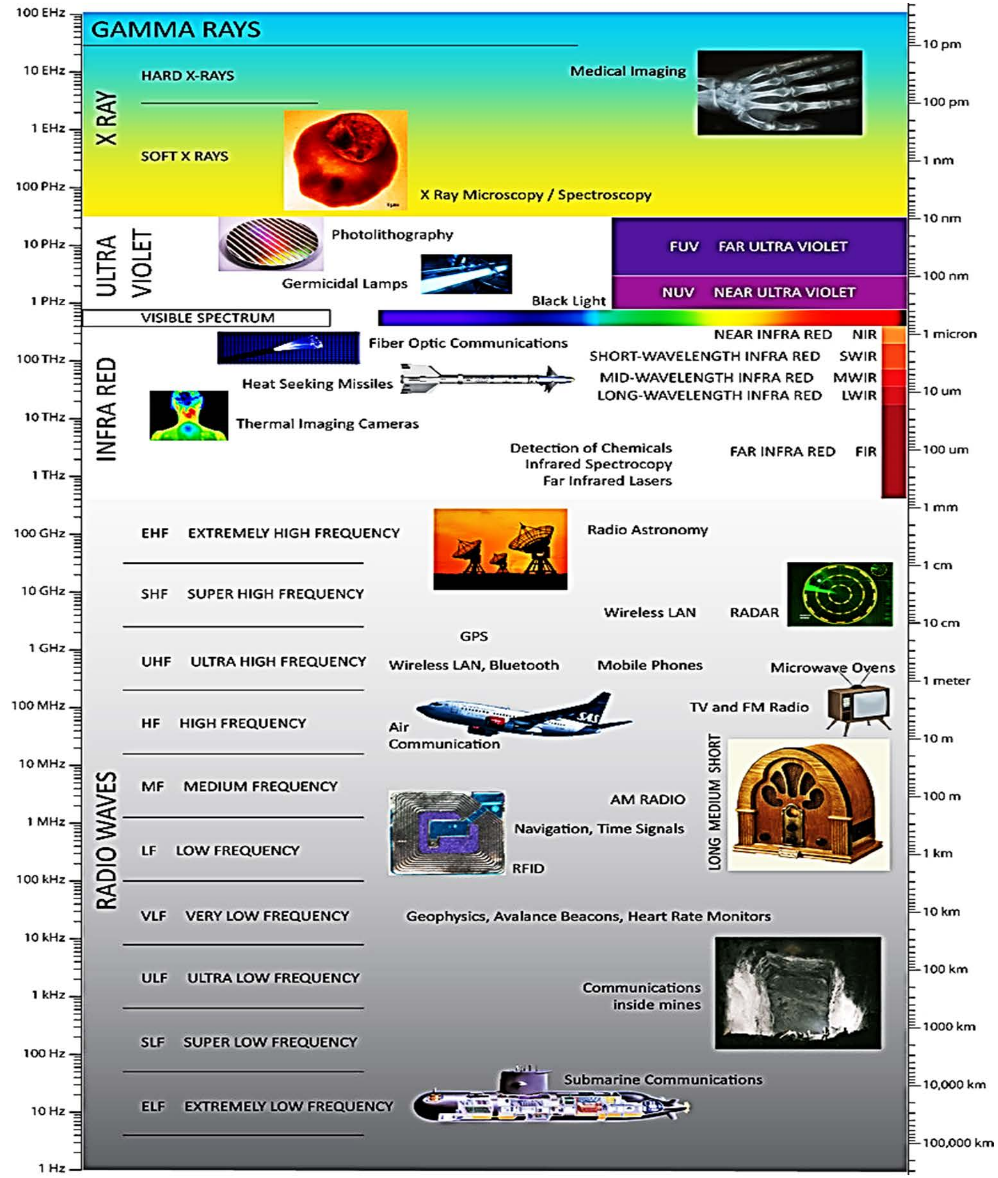

Rapid HeadTouches


Sweep Scan


Round
Scan

Measurement using Light

- **ElectroMagnetic Radiation (EMR)** consists of self-propagating electromagnetic waves (such as light).
- EMR has **electrical & magnetic field components**, oscillating in phases that are perpendicular to each other and to the direction of propagation of wave.
- EMR behaves as particles (**photons**) having certain **frequency & wavelength**.
- **ElectroMagnetic Spectrum (EMS)** has the range of all electromagnetic frequencies.
- Frequencies are grouped by their use (such as radio waves, visible light, x-rays, microwaves, etc.)
- The chart shows EMS range with common uses for different parts of the spectrum. Frequency is shown on the left, wavelength is on the right.

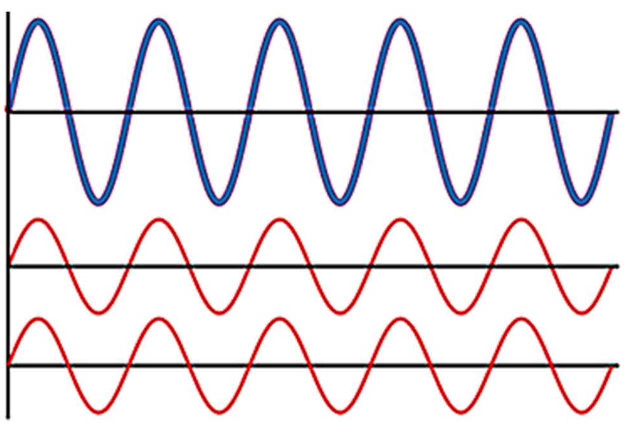


Interferometry

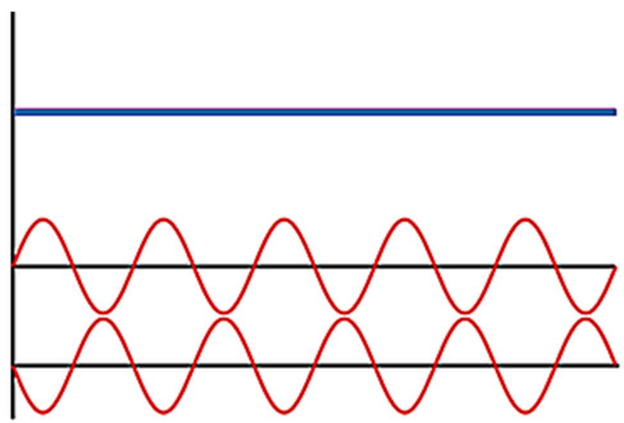
- The technique of **superimposing (i.e. interfering) waves** to detect differences between them.
- Applied in variety of fields including **astronomy**, **seismology**, **oceanography**, **optical metrology**, **quantum mechanics**, and **plasma physics**.
- In metrology, it is used **to determine shape and transmission properties of surfaces**.

Interference of Waves

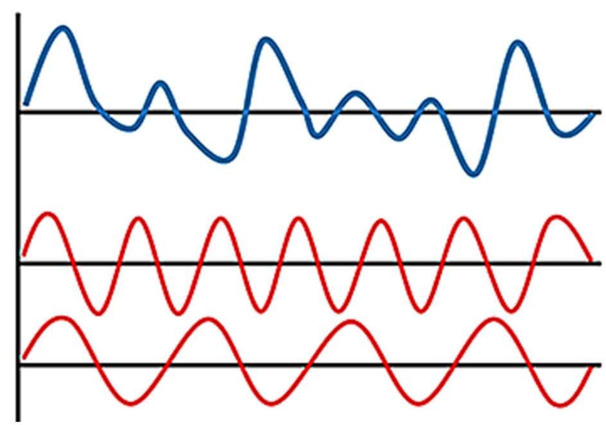
- Whenever two (or more) light waves come together at the same time and place, interference occurs.
- **Constructive interference: The waves are in phase** (i.e. their crests coincide), thus a single wave having higher crest (i.e. larger amplitude) is formed.
- **Destructive interference: Waves are out of phase** (i.e. their crests are shifted), the amount of interference depends on amplitudes and frequencies of the waves.



Constructive Interference



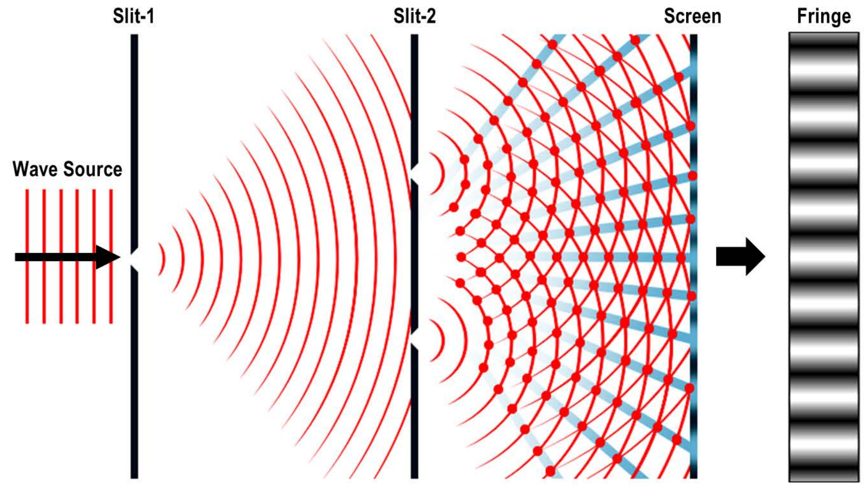
Destructive Interference



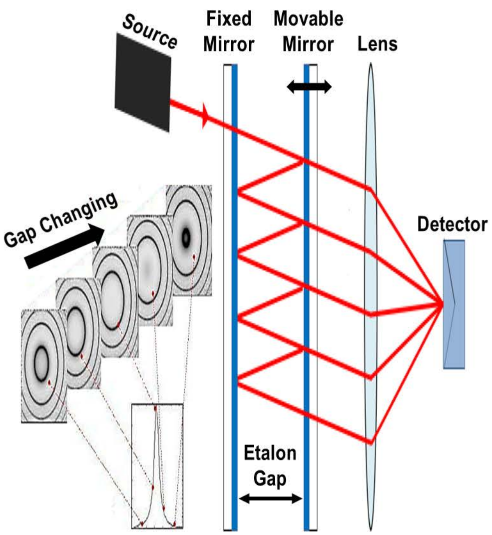
Mixed Interference

Classification of Interferometers

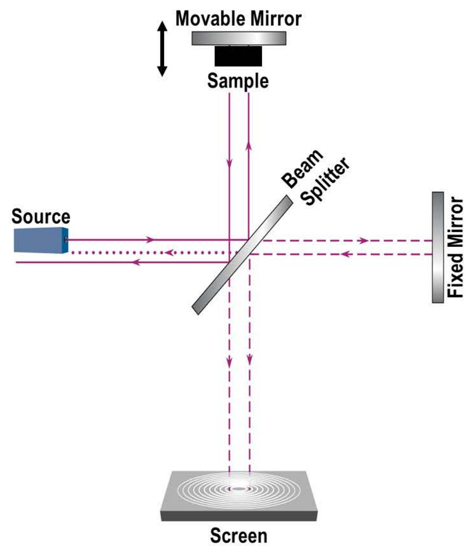
- **Division of Wavefront:** light beam is divided by passages (slits) through apertures that are placed side-by-side
  Llyod's Mirror, **Young's Double Split**, **Fresnel's Biprism**
- **Division of Amplitude:** light beam is divided by splitters (partially-reflecting plates) into beams of reduced amplitudes
  Michelson, **Mach-Zehnder**, **Sagnac**, **Fabry-Perot**, etc.



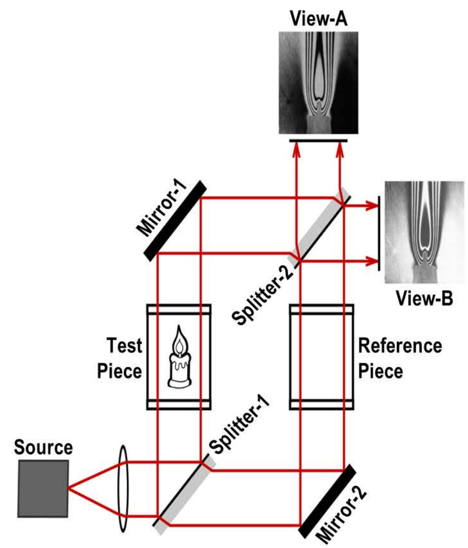
Young's Double Slit



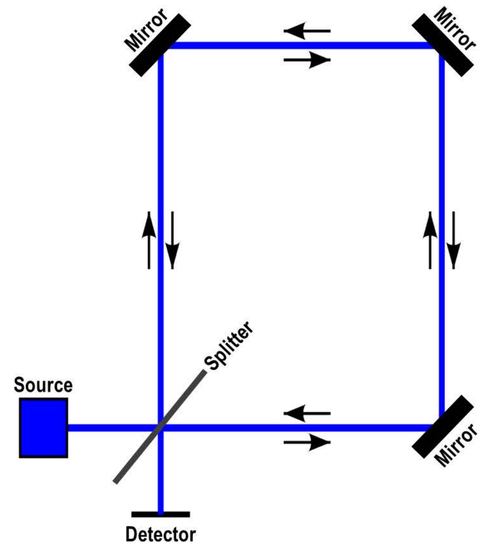
Fabry-Perot



Michelson



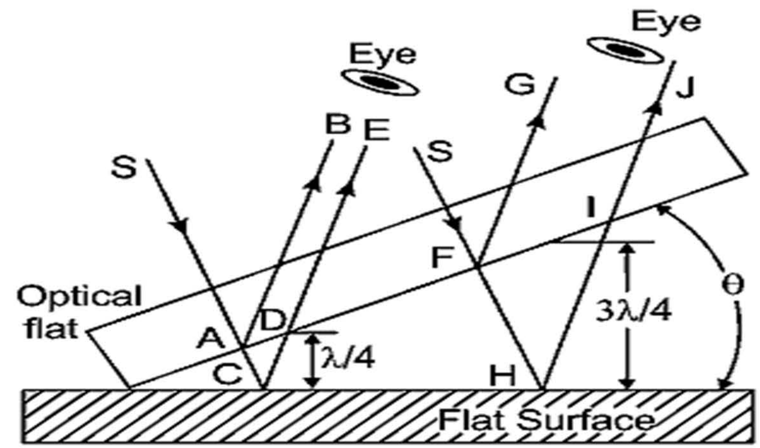
Mach-Zehnder



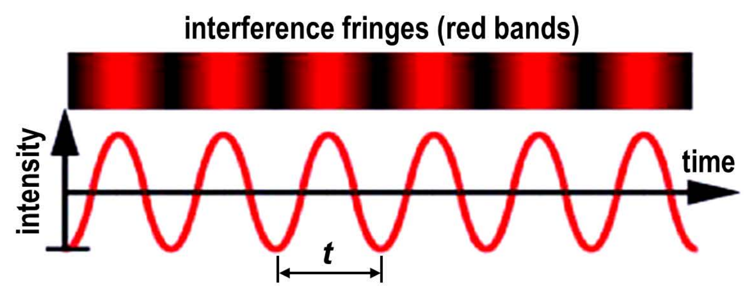
Sagnac

Checking Flatness of Surface by Interferometry

- The setup of interferometry includes a monochromatic light source and an optical flat (a disc of stress-free glass or quartz with highly polished two plane faces flat and parallel).
- The optical flat is placed on the part surface with small angle (**θ**), the light beam from source (**S**) is projected onto the optical flat, and the reflected light beams are seen at eye.
- At point **A**, the light ray is partially reflected to the eye (along **AB**) and partially transmitted & reflected to the eye (along **CDE**).
- Thus, two reflected components are collected & recombined by the eye (the lengths of travelled paths differ by the amount **ACD**).
- When the lengths of consecutive reflections (**CDE** & **HIJ**) differ by the amount of **half-wavelength** (i.e. **λ/2**, which is the wavelength of original light ray from source), then **the surface perfectly flat**.
- Therefore, the part surface will be seen as **pattern of dark bands (fringes)**, which are straight for the case of a flat surface.



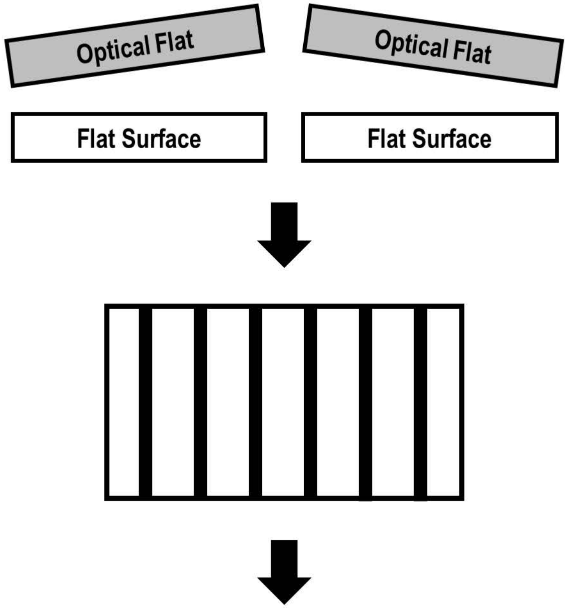
$$\left.\begin{aligned} AC = DC &= \frac{\lambda}{4} \\ FH = HI &= 3\,\frac{\lambda}{4} \end{aligned}\right\} AC - FH = \frac{\lambda}{2}$$



$$\sin\theta = (\lambda/2)\, t$$

Fringe Analysis: Straight Pattern

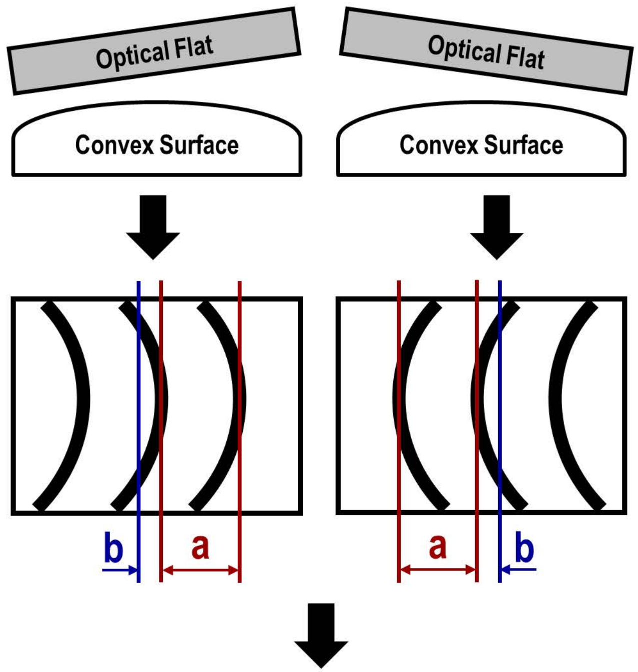
- Indicates **perfectly flat surface**.
- Assume: **λ** = 0.6328 μm
- Then: flatness = 0.3164 μm



$$\text{Flatness} = (\lambda/2)$$

Fringe Analysis: Curved Pattern

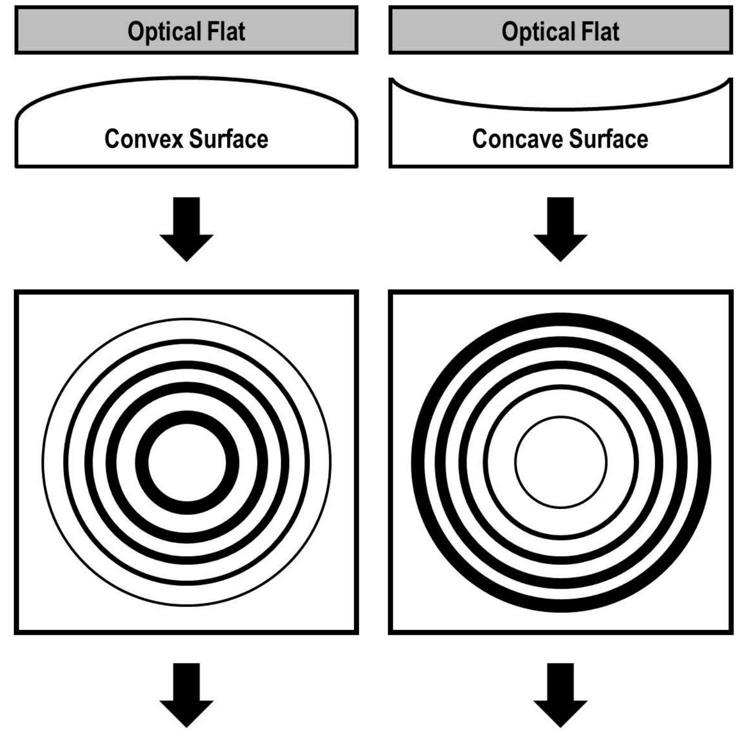
- Indicates **convex / concave surface**.
- **Red lines** drawn tangent to center of two adjacent fringes. **Blue line** drawn by the centroid of a single fringe.
- Assume: **a** = 5.02 μm & **b** = 1.24 μm
- Then: flatness = 0.078 μm



$$\text{Flatness} = (\lambda/2)\ (b/a)$$

Fringe Analysis: Circular Pattern

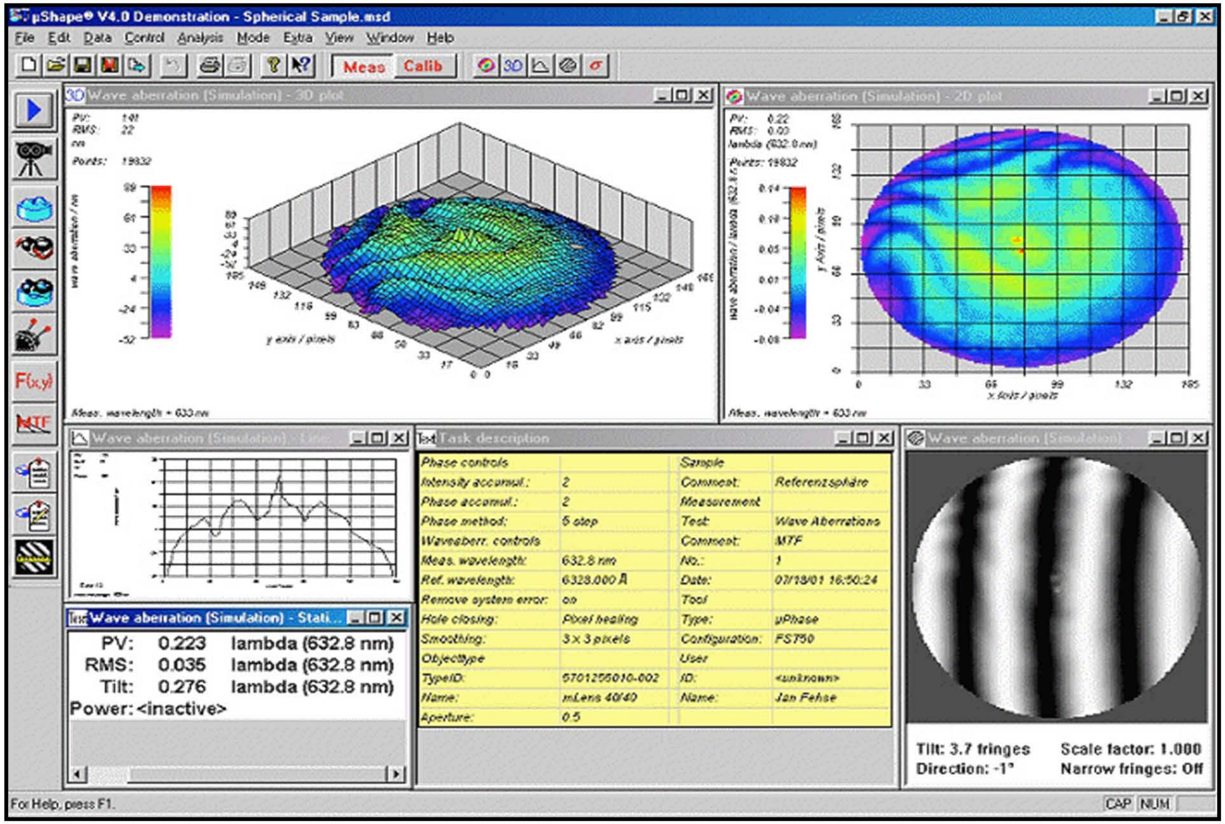
- Indicates **convex or concave surface**.
- The total distance between peak & valley (i.e. **height or depth of surface**) is calculated.
- Assume: no. of fringes (full circles) = 5
- Then: height or depth = 1.582 μm

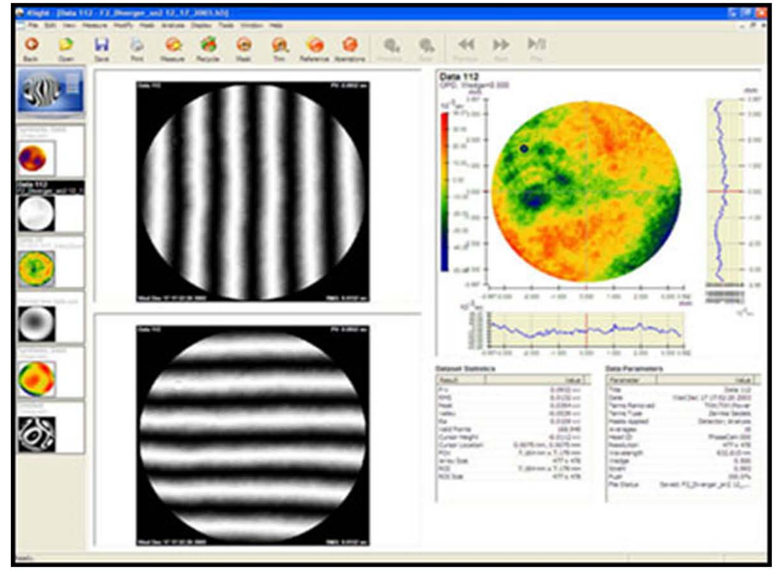


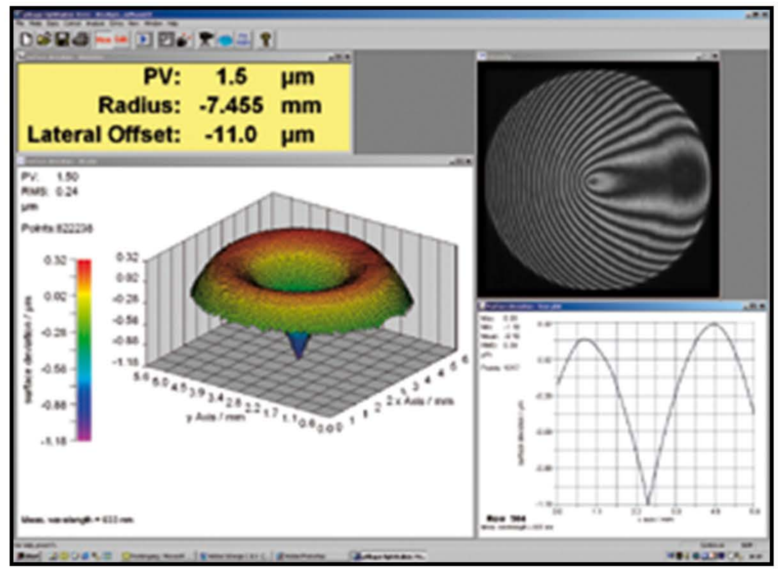
$$\text{Height} = (\lambda/2)\ (\#) \qquad \text{Depth} = (\lambda/2)\ (\#)$$

Fringe Analysis Software

- Special-purpose software are required for accurate & precise analysis of **complex fringe patterns**.
- They are used for analysis of surface topography to determine **flatness**, **waviness**, **roughness**, etc.

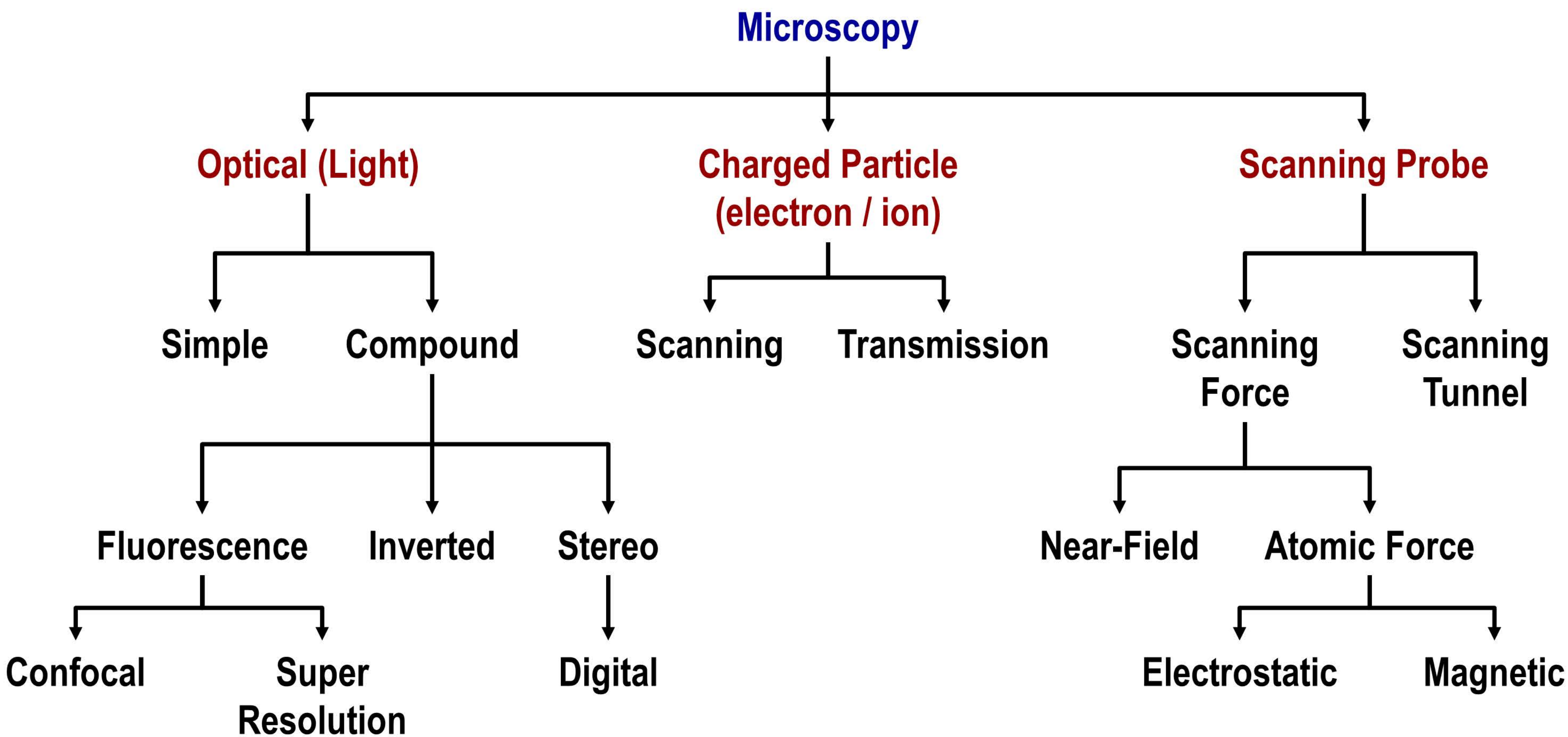






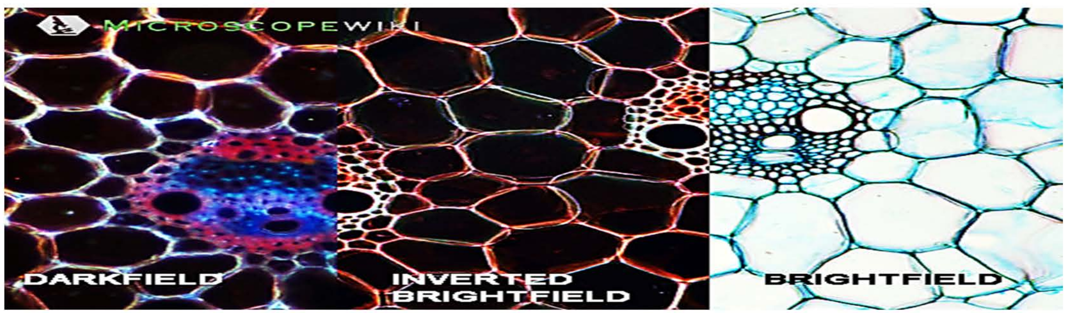
Microscopy

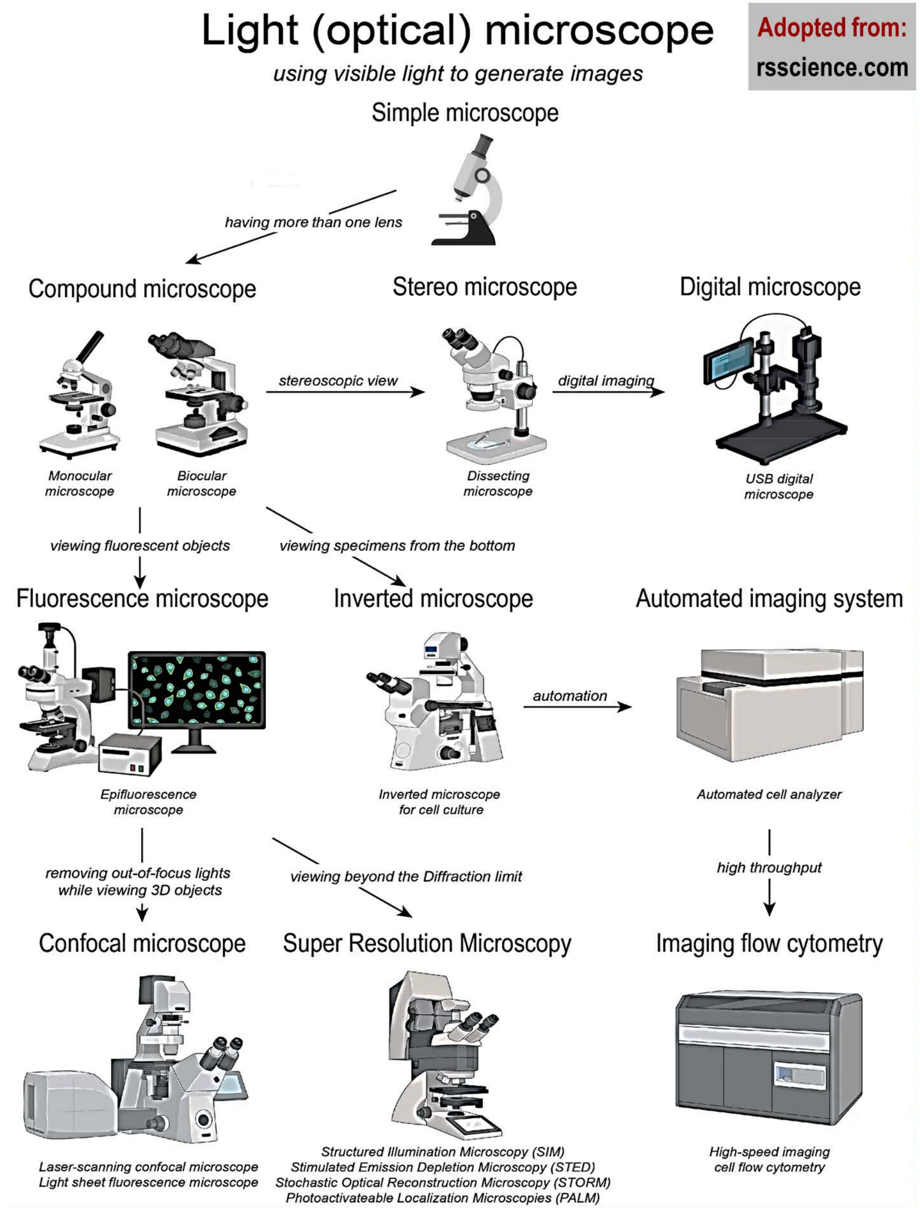
- The technical field of using microscopes to view desired portion of objects that **cannot be seen with naked eye**.
- Classified depending upon working principle, image resolution & precision, feature detection, and so on.



Optical (Light) Microscopy

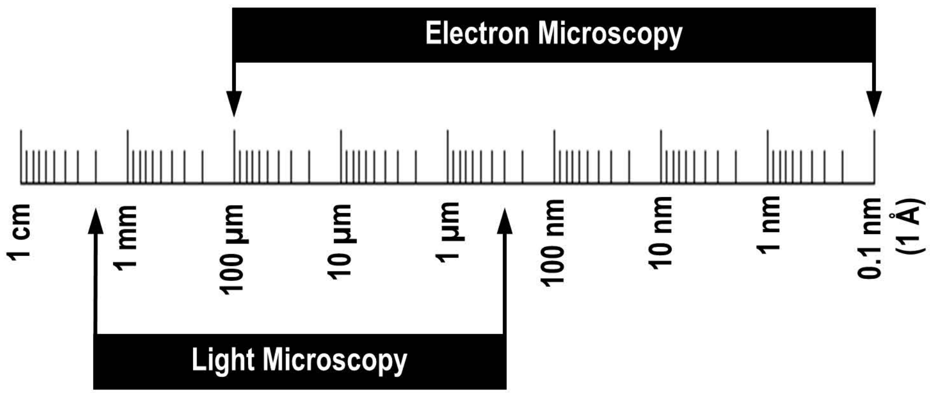
- **Use of visible light** transmitted through or reflected from the object via lens (or multiple lenses) for magnified view.
- Classification according to **lens**:
  - **Simple:** a single lens
  - **Compound:** multiple lenses
- Classification according to **eyepiece**:
  - **Monocular:** look through single eyepiece
  - **Binocular:** look through two eyepieces
  - **Trinocular:** binocular head plus third ocular (possible installation of a camera)
- Classification according to **background lightening**:
  - **Bright Field:** dark image against bright background
  - **Dark Field:** bright image against dark background

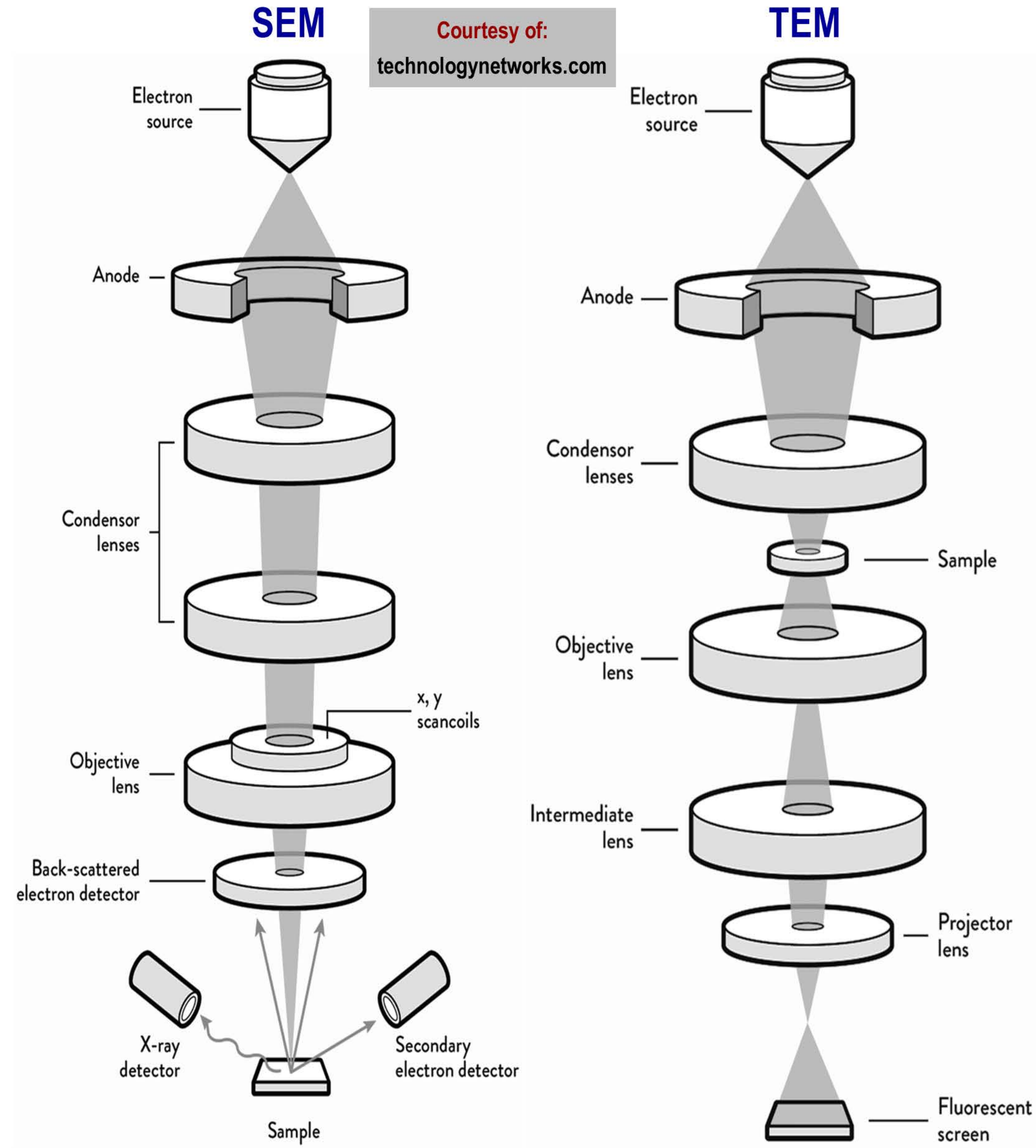




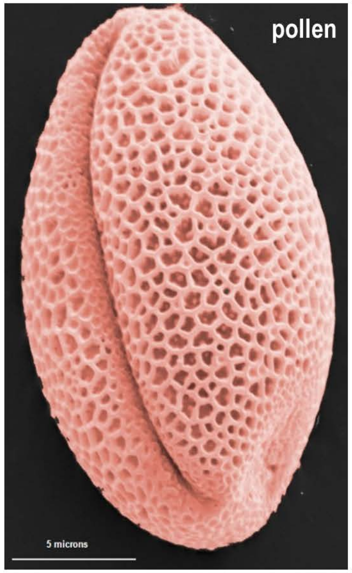
Electron Microscopy

- Sample is **bombarded by accelerating the beam of electrons**, and the details of sample's surface and/or internal characteristics are revealed.
- **Much higher resolutions** than light microscopy with visualization of spots down to **0.1 nm (1Å)**.
- Two common types:
  - **Scanning Electron Microscopy (SEM):** visualizing the surface characteristics of objects
  - **Transmission Electron Microscopy (TEM):** analyzing the inner structure of objects

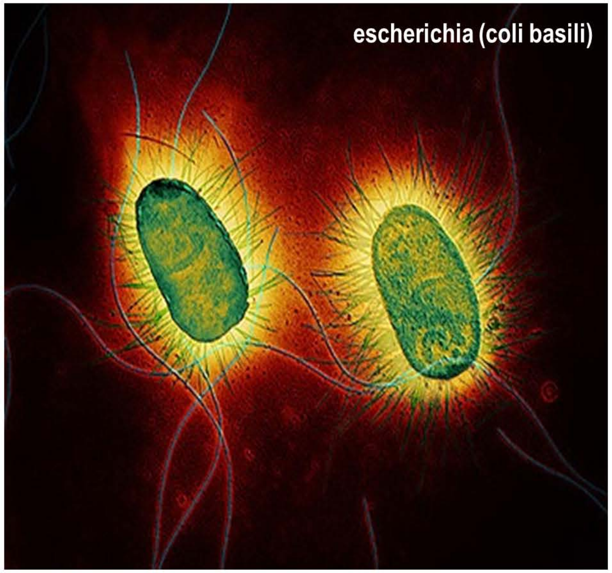


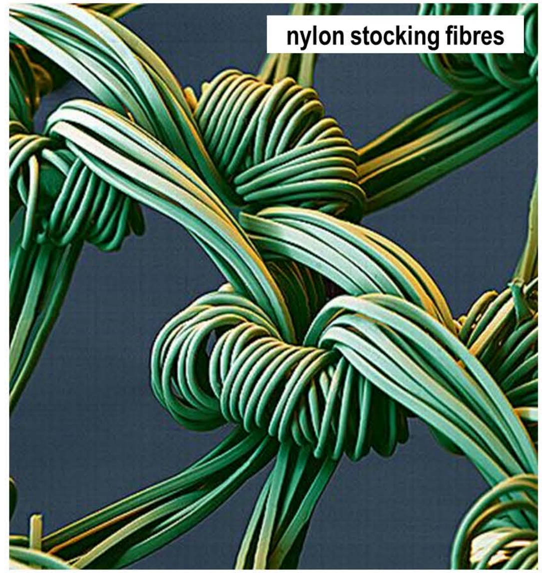


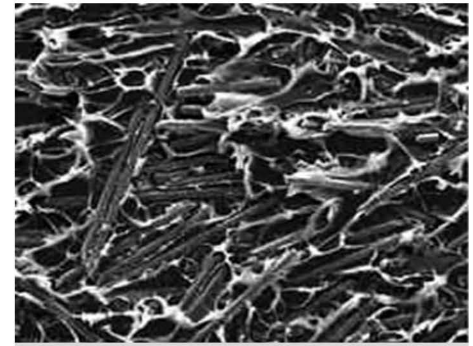
Courtesy of: technologynetworks.com

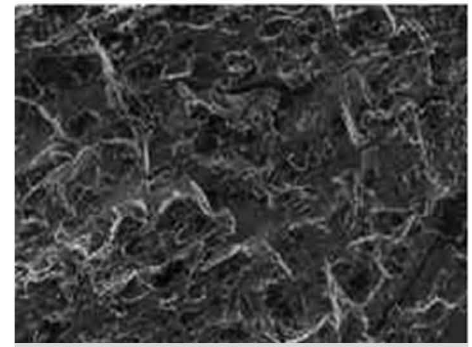


pollen

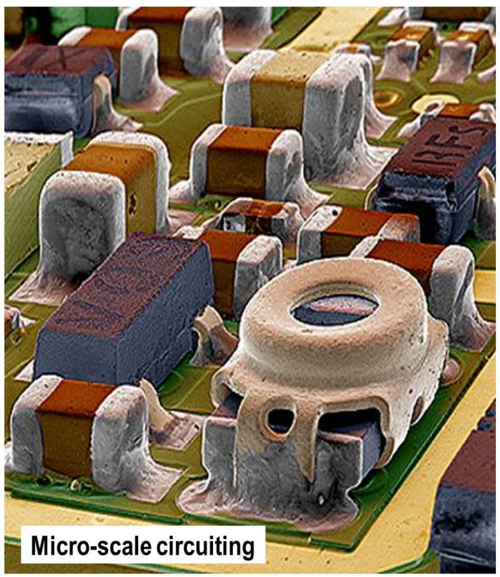

escherichia (coli basili)


nylon stocking fibres


ductile-forced fracture in reinforced plastic


stress-corrosion cracking in brass


laser-burned hole in steel


Micro-scale circuiting

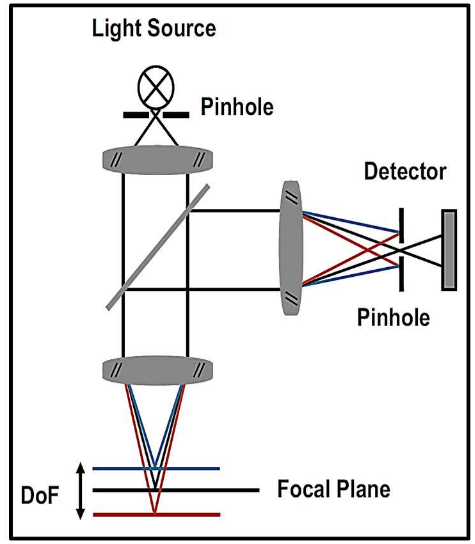

uranium waste bacteria


witherite (barium carbonate crystal)

3D Microscopy: Confocal Microscopes

- The cure for problem of **Depth of Field (DoF)** in classical microscopy so that providing **higher vertical resolution**.
- This is accomplished by means of a modified optical path.
- Recently, the laser has been used as light source in **Laser Scanning Confocal Microscope (LSCM)**.

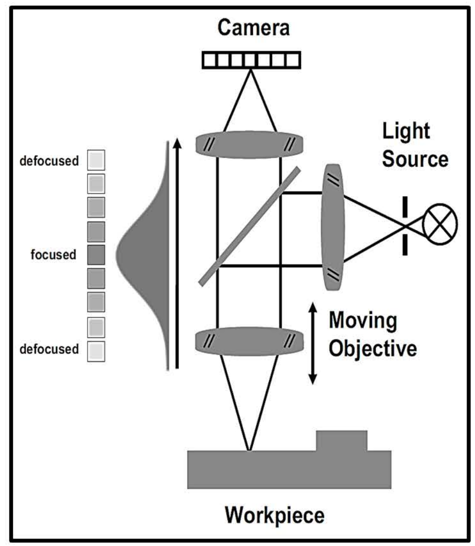
Photo: Olympus LEXT OLS5000 (www.olympus-ims.com/en/metrology/ols5000)



3D Microscopy: Variable-Depth Focal Microscopes

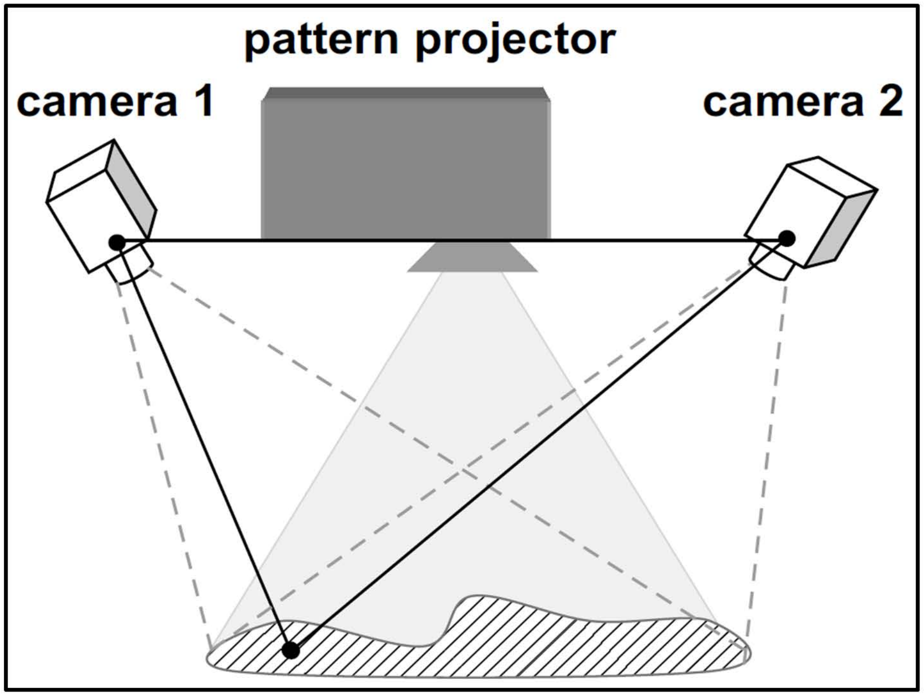
- **Focal Depth Variation (FDV)** achived by vertical scanning of the surface with **Through-Focus Scanning Optical Microscope (TSOM)**.
- This is accomplished using highly sophisticated software to calculate **the best focus** from continuously recorded data, which enables reconstruction of **3D surface topography**.

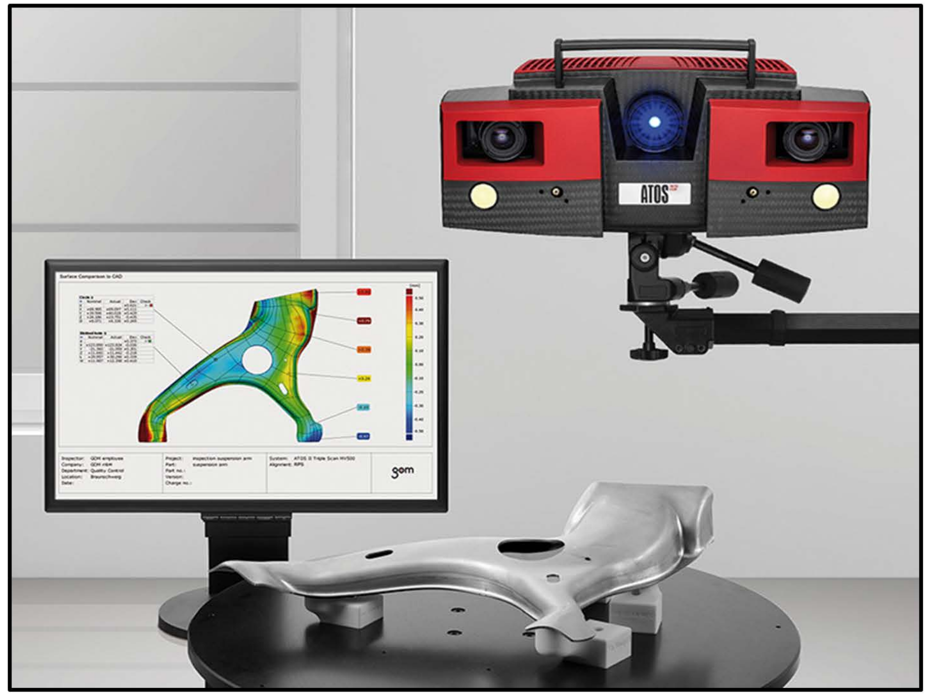
Photo: Alicona InfiniteFocus (www.alicona.com/en/products/infinitefocus)



3D Scanning Systems

- Used for **3D fringe projection of complex surfaces** (particularly free-form surfaces).
- Consist of two digital cameras and a pattern (fringe) projector enclosed at a fixed angle.
- Light waves with shifted patterns of parallel sinusoidal stripes are projected onto the surface. If the surface is not plane flat, then the patterns get distorted. Both cameras record an image of the distorted fringe pattern, and hence **the surface topography** could be constructed.

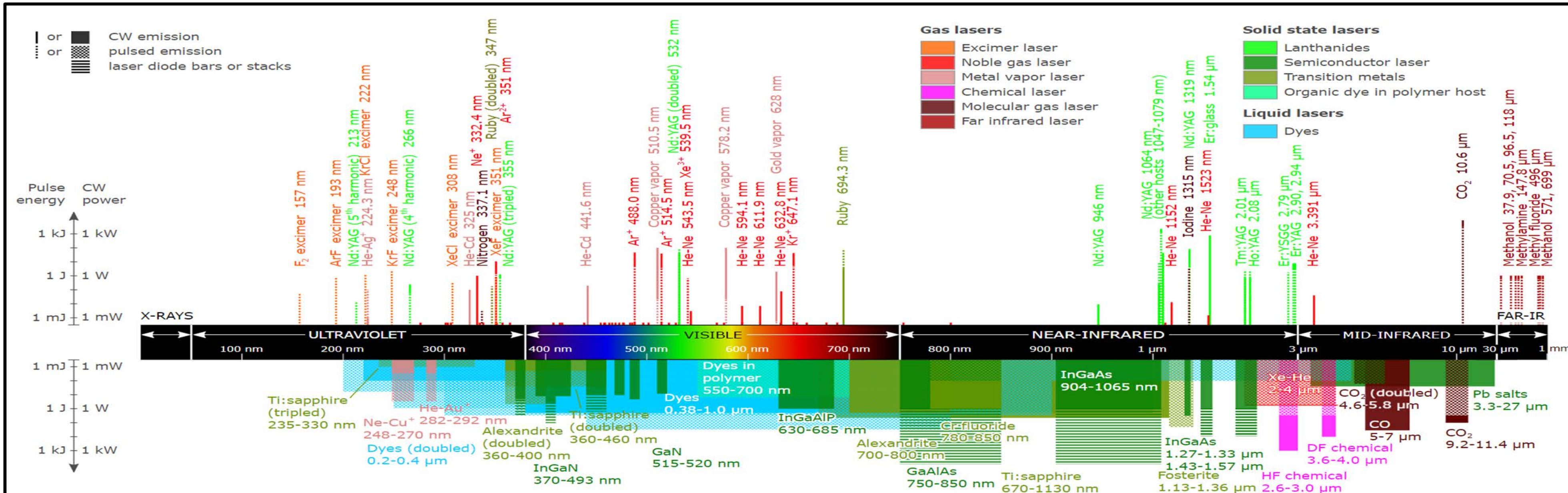




More information: www.gom.com/metrology-systems/atos.html

Measurement using Laser

- **LASER** is an acronym for "**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation"
- It is a device that **emits light (electromagnetic radiation)** through a process of **optical amplification** based on **the stimulated emission of photons**.
- Different types of laser are **used for research and industrial purposes** (metal cutting, welding, dynamic alignment/positioning, dimensional measurements, nondestructive testing, lithography, medical treatments, military applications, and so on).

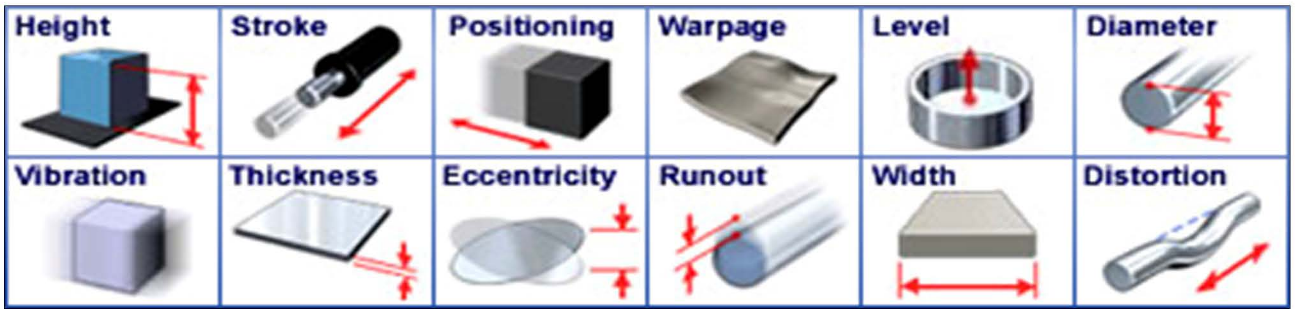


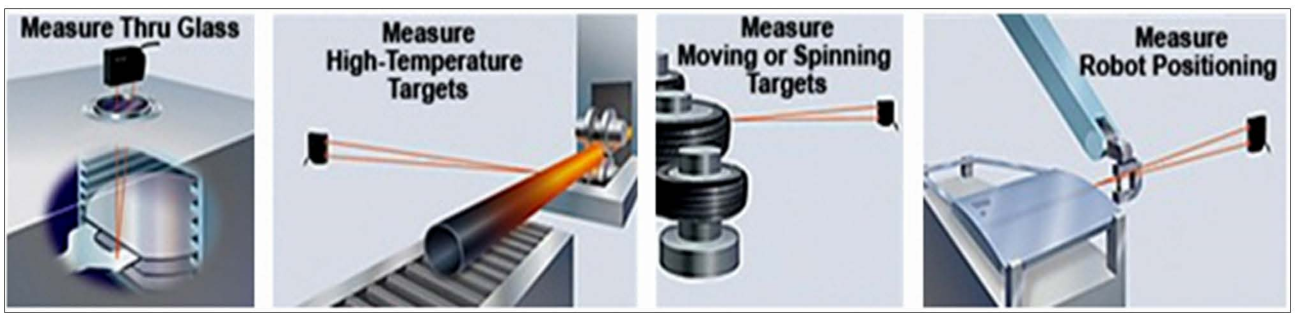
Courtesy of: wikimedia.org

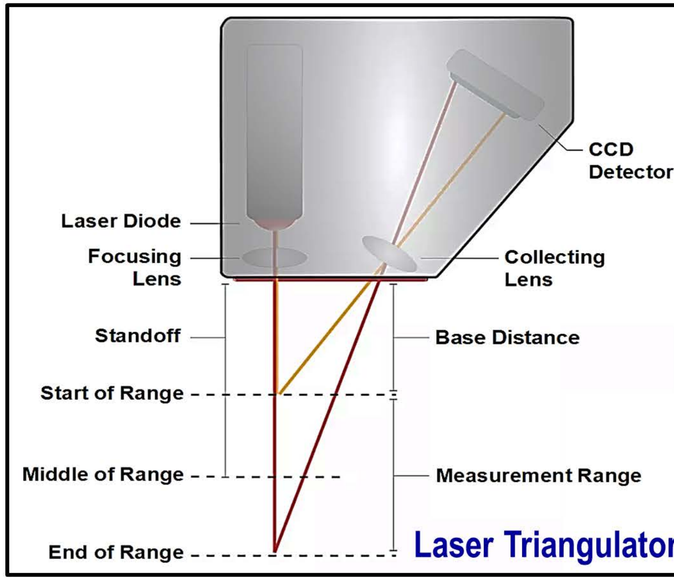
Laser Probes

- **Laser Triangulator:** uses high-speed & high-efficiency non-contact laser probe to perform complex profile measurements.
- **Laser Scanner:** takes range measurements over the entire path (rather than measuring single point) for scanning of a region.
- So, they can be used for **measurement of distance and/or surface topography** within certain measurement ranges.

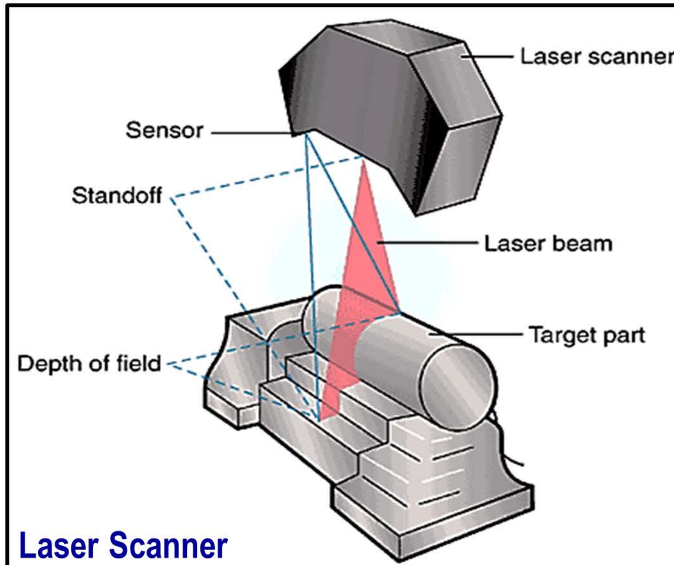
More information: keyence.com







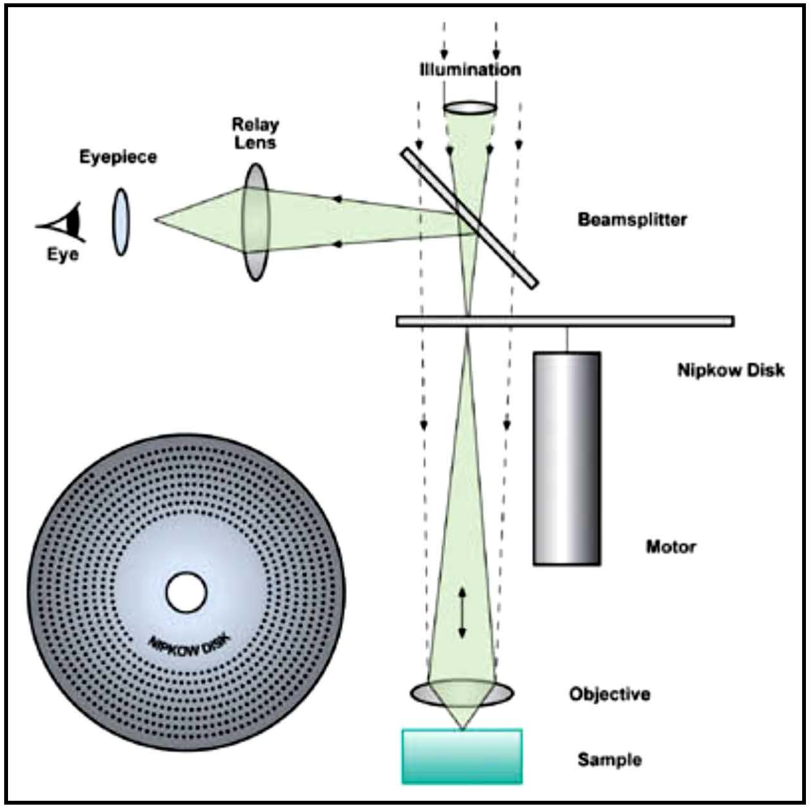
Laser Triangulator



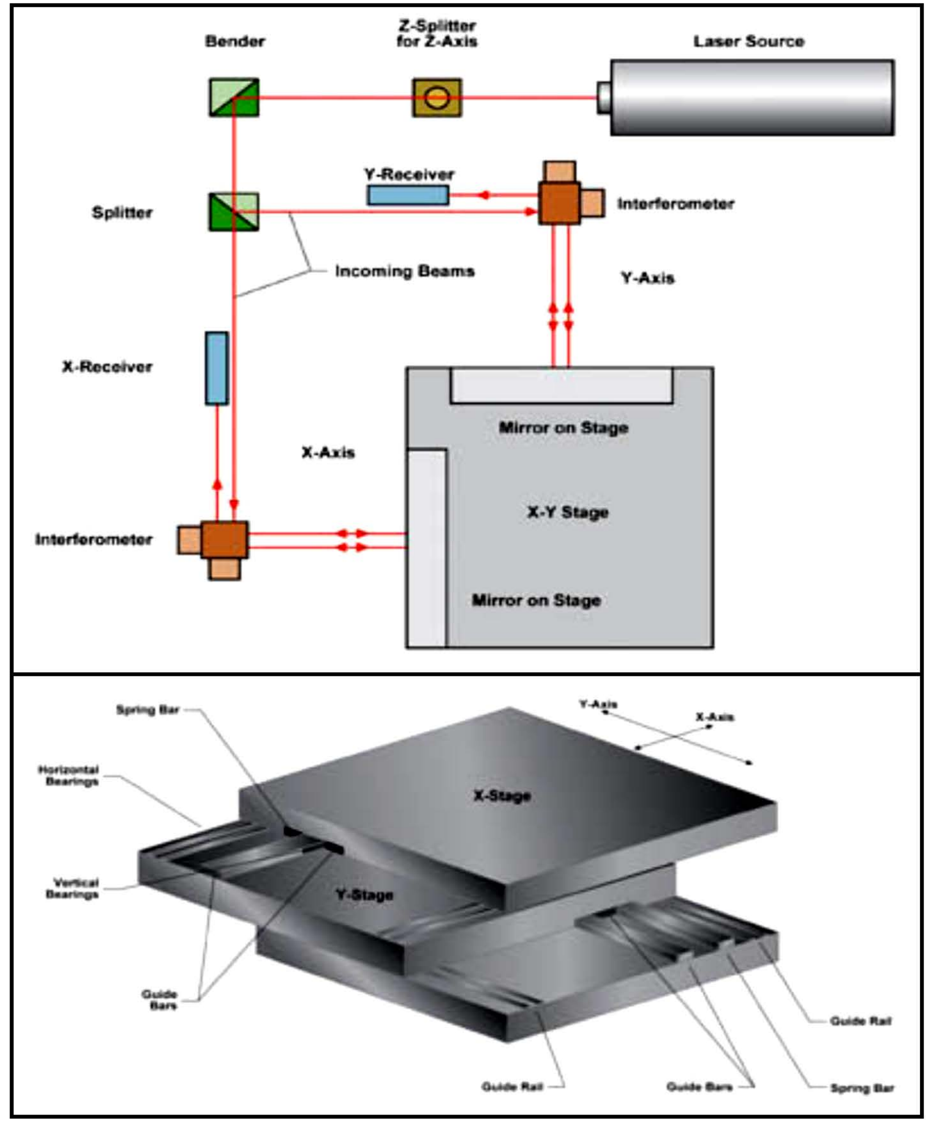
Laser Scanner

Laser Interferometers

- Provide advanced measurement systems for **vision, positioning, movement**.
- **Higher precision, accuracy, speed** as compared to common optical interferometers.



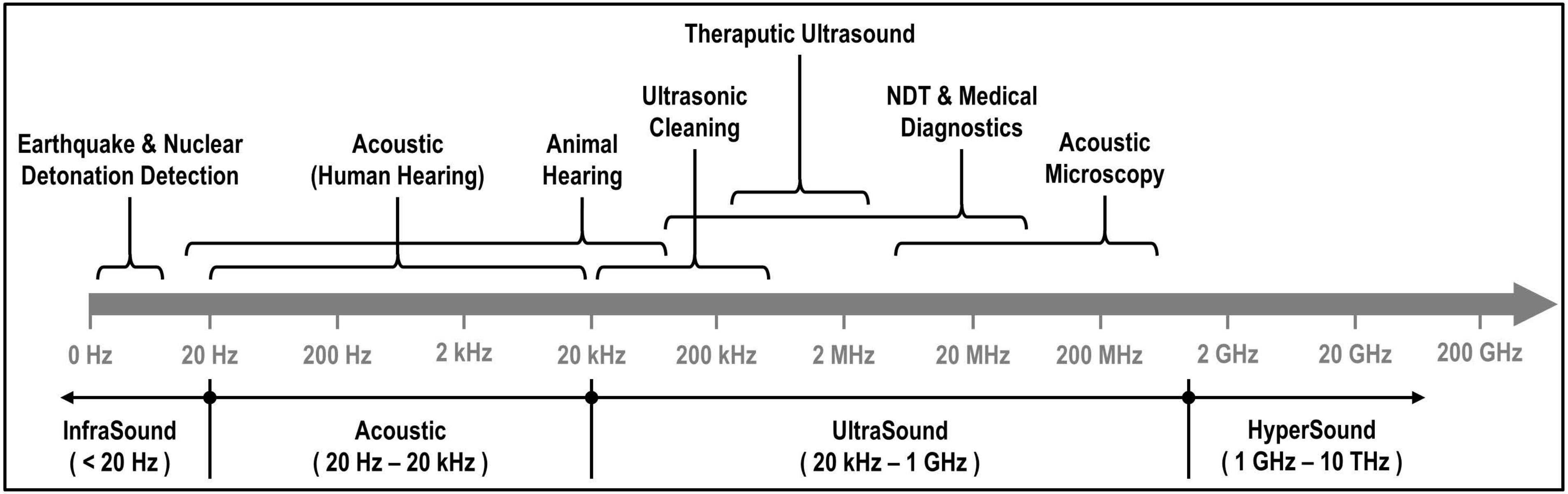
Laser Interferometer for Enhanced Vision



Laser Interferometer for Precise Positioning

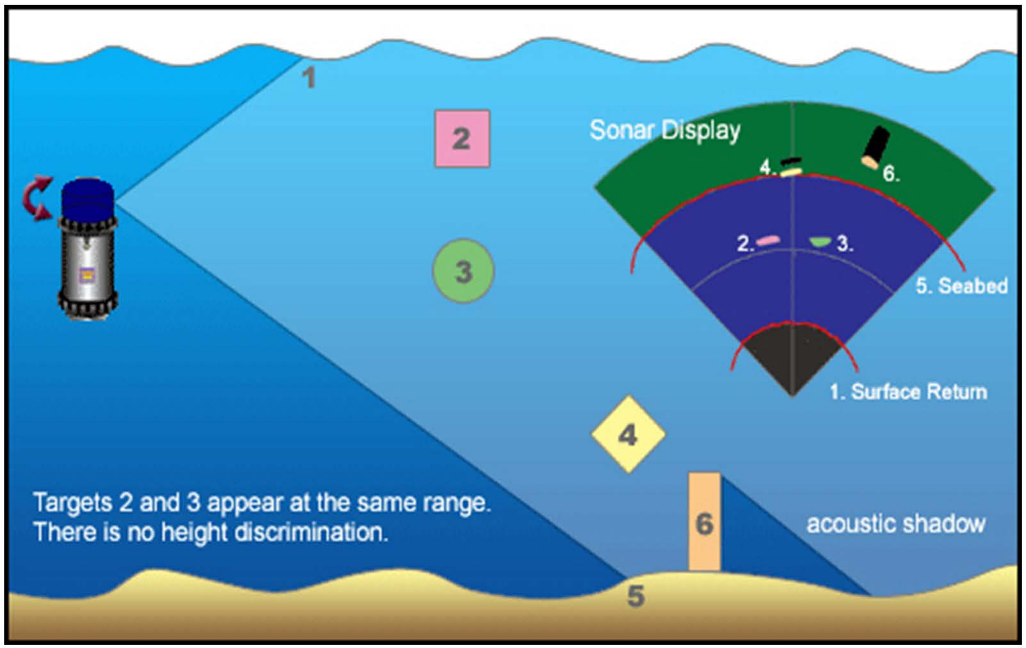
Measurement using Sound

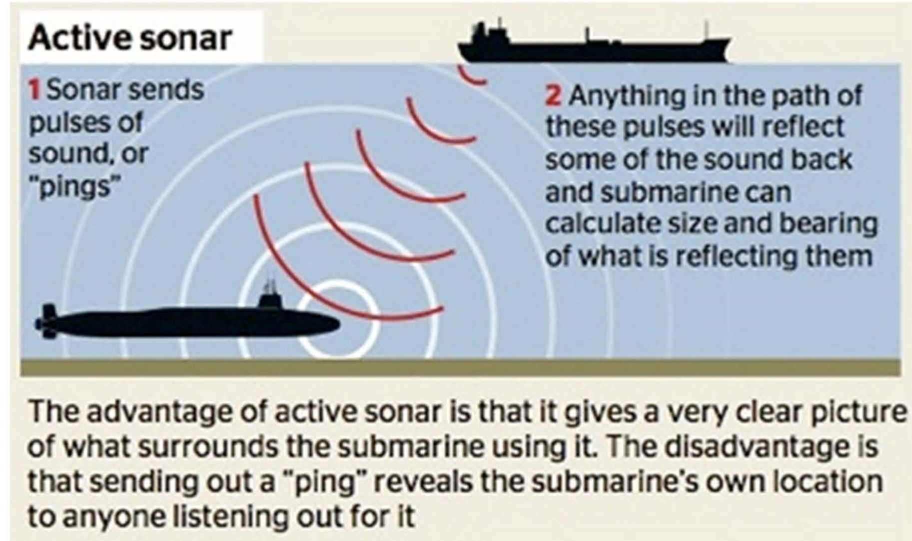
- Sound is **a sequence of waves of pressure** propagating through a compressible media (air, water, solids, etc.)
- During propagation, waves are **reflected**, **refracted** or **attenuated** by the medium.
- Sound waves are classified into specific ranges according to **their frequencies**:
  - **Infrasound:** has the frequency of less than 20 Hz (the limit of human hearing)
  - **Acoustic:** is the range of human hearing (the range of audible sound)
  - **Ultrasound:** has the frequency of greater than 20 kHz (not audible by human)
- From **metrology viewpoint**, sounds waves with certain frequencies & amplitudes are used in many applications (such as underwater, seismology, medical, NDT, infrasound, ultrasonic inspection, and so on).

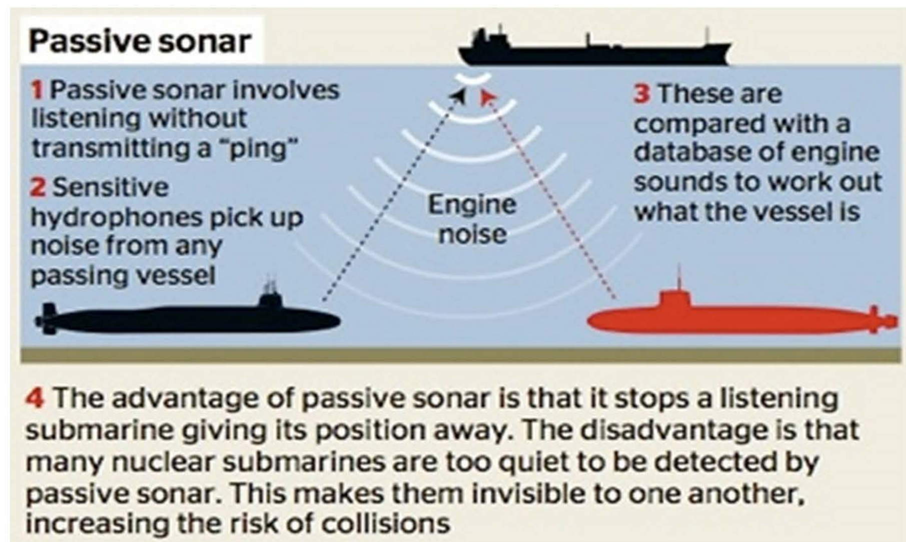


SONAR Measurement

- **SONAR** stands for "**SO**und **NA**vigation and **R**anging"
- The technique using underwater sound propagation to **navigate, communicate or detect the objects**.
- There are two SONAR systems:
  - **Active SONAR:** deploys & recevies its own signal
  - **Passive SONAR:** just listening any signal

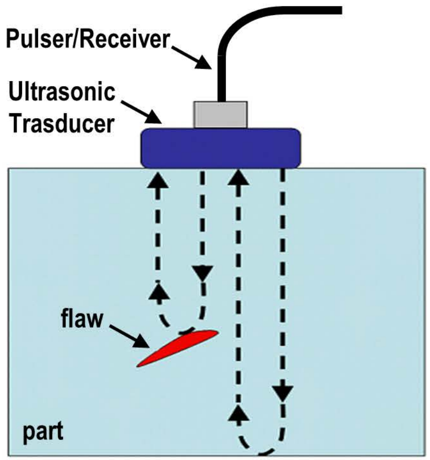


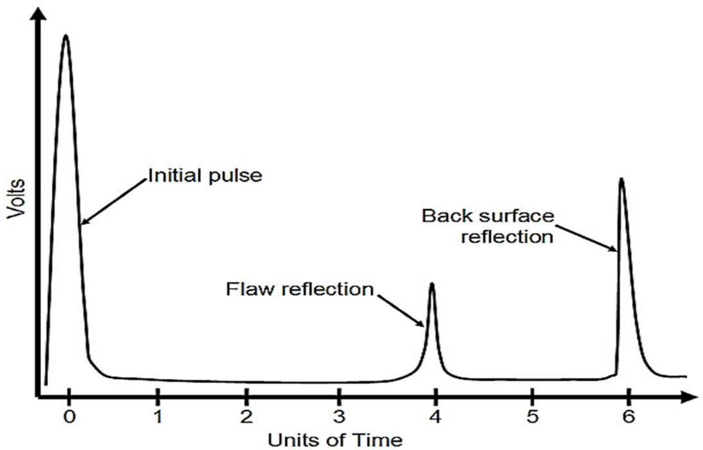


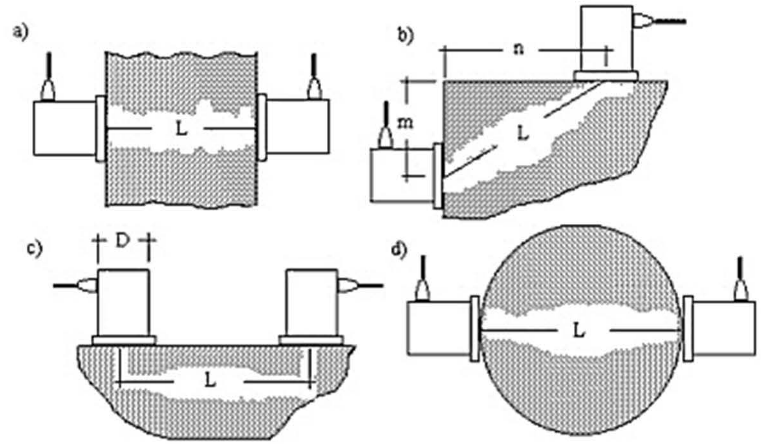


Ultrasonic Testing

- Uses high-frequency sound energy to conduct flaw detection, dimensional inspection, material characterization, and more.
- The testing setup consists of: **a pulser/receiver**, **a transducer**, **a display software/device**.
- Pulser/receiver produces high voltage electrical pulses. Driven by pulser, the transducer generates high-frequency ultrasonic energy, which propagates through the part in form of waves.
- If there is discontinuity (crack/flaw) in the wave path, some part of energy is reflected back from flaw surface. **Voltage signals of reflecting energy reveals location & size of the flaw.**







Typical schemes
a) one-axis through testing b) angle testing
c) one-surface testing d) curve surface testing