Laser Instruments

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Laser Interferometry

- *Laser based distance measurement is done using interferometric principles.*
- *Displacement measurements using optical interferometry was developed by Michelson (1882)*
- *To measure changes in speed of light in different directions with respect to motion of earth in space.*
- *Maximum displacement measured is only few centimeters.*
- *Limitation due to:*
  - *Low intensity of light*
  - *Poor coherence*

Laser Interferometry Cntd..

- Lasers have made interferometry to develop into a fast, highly accurate and versatile technique for measuring very small displacements of order of few nanometers.
- Interferometric measurements are highly accurate compared to pulsed echo techniques or beam modulation telemetry methods.
- Laser based interferometers use frequency stabilized laser(He-Ne) to measure displacements of few ten meters.
- Wide line width blurs interference fringes as distance increases beyond few centimeters.
- Unstabilized laser have bandwidth of about 10^9Hz and frequency stabilized laser used to measure larger distance upto several tens of meters in temperature controlled single mode condition.

Basic Michelson interferometer

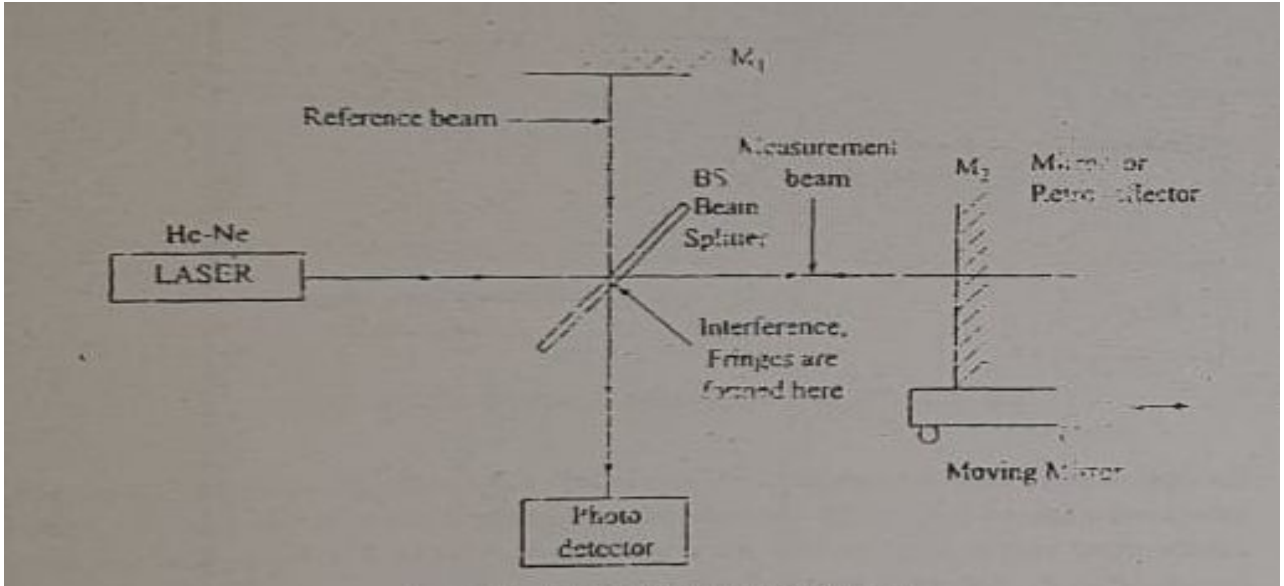
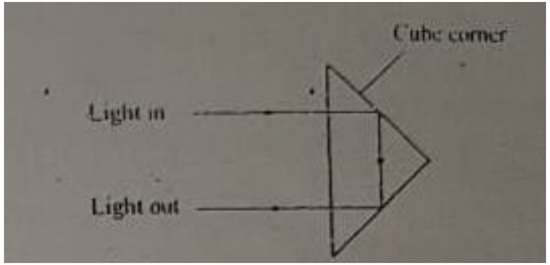


Fig. 4.1 Basic Michelson interferometer.

Basic Michelson interferometer explanation

- *He-Ne laser beam falls on beam splitter(BS).*
- *BS reflects half of the beam in one direction(reference beam) and other half transmits (measurement beam).*
- *These 2 beams are reflected by mirrors- M1(stationary mirror): reference arm and M2 (moving mirror).*
- *Often mirrors are replaced by cube corner (retro) reflectors.*



Basic Michelson interferometer explanation

- *Two reflected beams recombine at beam splitter(BS) to form interference pattern which is viewed by observer and sensed by photodetector.*
- *The fringe pattern is related to path lengths travelled by 2 beams before they recombine.*
- *Suppose the detector is viewing a bright fringe, when M2 is in particular position.*
- *If M2 now moves by distance=λ/4 of laser wavelength, round trip distance with measurement λ/2 and fringe pattern will be seen dark.*
- *Distance measurement consists of counting number of fringes varies as M2 moves.*

Contd..

- *Each complete fringe responds to phase variation of* 2π *radians.*
- *The phase variation* δ *is given by:*

$$\delta = 4\pi\Delta x/\lambda$$

λ = *Laser wavelength*

Δx = *measured distance M2 moved*

Therefore interferometric method has high precision, Δx *measure with accuracy of* λ*.*

- $\Delta x_{max} = c/\Delta v$

$C = 3x10^8$ *m/s*

Δv = *line width*

- *Frequency stabilized laser with small line width to measure larger*

Contd..

- *Distance measured by interferometer is optical path i.e refractive index of air medium.*
- *Optical distance is product of physical path and refractive index close to unity.*
- *High accuracy interferometric distance measurement have sensors for measurement of air temperature, pressure, humidity and micro-computer based correction for variable atmospheric parameters.*

Beam modulation telemetry

- The atmospheric conditions affect optical path results in inaccurate ranging.
- Larger distance cannot be measured by interferometer.
- So beam modulation telemetry is used to measure upto several tens of km.
- Laser beam is used as carrier wave with no distance information.
- Distance measuring RF is used as signal frequency to modulate laser beam.
- Modulation method used for either amplitude or polarization modulation using Pockel's cell.

Distance measurement by beam modulation telemetry

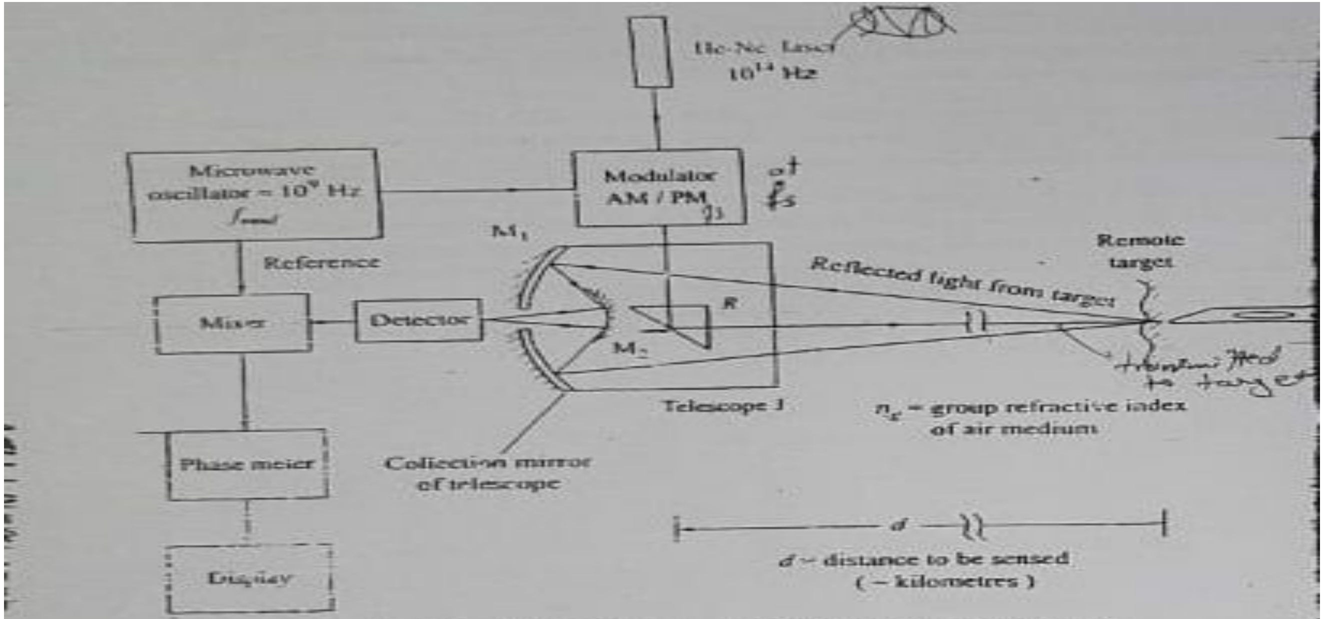


Fig. 4.5 Distance measurement by beam-modulation telemetry.

Distance measurement by beam modulation telemetry

- *CW laser beam from He-Ne laser/ laser diode is amplitude or polarization modulated at signal frequency fs.*
- *Distance is sensed by data modulated laser beam which is transmitted to the target.*
- *Retroreflector is used to transmit laser beam to target.*

Contd..

- *Light reflected from remote target is collected by cassegrain telescope. (use concave mirrors rather than convex lenses)*
- *M1 is collection concave mirror of telescope.*
- *M2 is concave mirror used to focus laser beam onto photo detector.*
- *Microwave data signal received at detector gets recovered from laser beam.*

Contd..

- *Range is determined by measuring phase angle Φr using phase meter between reference sine wave signal and received microwave sine wave data signal.*
- *The phase angle is related to time delay.*
- *Round trip transit time,*

$$t_r = \Phi_r / 2\pi f_{mod}$$

Φ_r *=phase angle between transmitted and received microwave sine waves*

fmod=microwave modulating signal frequency (laser carrier wave is getting modulated by fmod

Contd..

- *Phase difference is shown in diagram:*

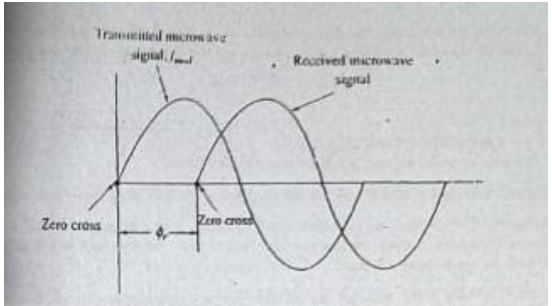


Fig. 4.4 Phase comparison measurement in CW, tone ranging.

- *Range is given by, R=*
- *Maximum unambiguous range results in phase delay in sine wave of 1 complete cycle.*
  - $R_u = c/2f_{mod}$

Contd..

- Total phase difference is given by,
  - $\Phi_r=(p+q)2\pi$

p= integer to be solved

q= fractional phase shift , less than 1

- Phase comparator gives measurement of q
- p value is obtained by repeating the measurement at another fs.
- $L=\Phi_r\lambda/4\pi\,\eta_g$

Accuracy of beam modulation ranging in limited by several factors:

- *Frequency of the tone (modulating frequency)*
- *Accuracy of phase movement loop*
- *Stability of the modulating(tone) oscillator*
- *Number of measurements that are averaged.*
- *Turbulence in the air path for laser beam.*
- *Variation of refractive index ηg of the air path.*