M3: Linear measurements

Module 3: Linear measurements (4L): Taping; Optical distance measurement; Electronic distance measurement (EDM), classification and calibration; Errors in distance measurement and precautions.

- Types of linear measurements
- Accuracy in linear measurements
- Systematic errors in chaining/taping
- Optical Distance measurements
- Electronic distance measurements (EDM)
- Introduction: Electronic Distance Measuring Instrument (EDMI)
- Principle of EDMI
- Classification of EDMI (i) wavelength (ii) range (iii) accuracy (iv) integration
- Calibration of EDMI
- References

Linear measurements

Main methods
- Direct measurements
- Optical measurements
- Electronic measurements

- Direct measurements
  - Distance actually measured on the ground with chain, tape or any other instrument.
- Optical methods
  - Observations are done through telescope and calculations done for distances e.g. tacheometry and triangulation.
- Electronic methods
  - Using EDM relying on propagation reflection and reception of radio light waves e.g. tellurometer, navigator, lambda position fixing system.

Direct methods

(1) Pacing

(2) Passometer

(3) Pedometer

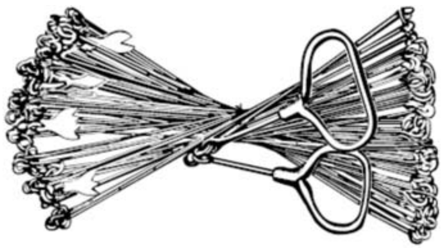
(4) Odometer and Speedometer

(5) Chain/tape

Methods	Instrument	Principle
Pacing	__________	Preliminary survey, length of average pace x no. of paces: accuracy 1: 100.
Passometer	Passometer	Watch like instrument, can be carried in pocket or attached to the leg. Registers the number of paces.
Pedometer	Pedometer	Similar to passometer but registers distances as calibrated against paces.
Odometer and speedometer	__________	Odometer records number of revolutions of wheel distance = number of revolutions x circumference.
Chaining	Chain/ tape	Measurement with chain and tape

Surveying chains

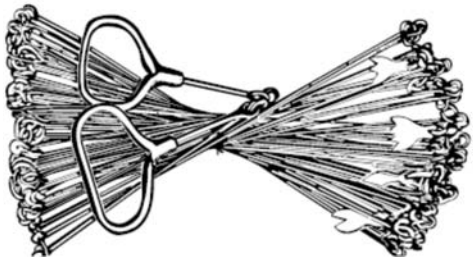
- Used if very high accuracy is not needed (now outdated)
- Comprise:
  - 5 m (25 links), 10 m (50 links), 20 m (100 links), 30 m (150 links) chains.
  - Links made of galvanized mild steel wires 4 mm diameter.
- Types of chains
  - Gunter's or surveyor's chain: 66 ft long with 100 links @ 0.6 ft.; 1 mile = 80 Gunter chain = 5280 ft.
  - Engineer's chain: 100 ft, 100 links @ 1 ft
  - Revenue chain: 33 ft, 16 links @ (2+1/16) ft, for cadastral works



Gunter's chain, Wolf and Ghilani

Configuration of Chain:

- Brass handles at ends for pulling and dragging with swivel joints.
- Link length is 200 mm for each link except the end link for which length of handle is included.
- Brass tallies or tags (markers) for reading fractional lengths. Configuration for
  - 5m chain – at every meter, with identical shapes at 1m & 4m, and 2m & 3m.
  - 10m chain – every meter and same configuration as 5m.
  - 20/30m chain – small brass rings at every meter length and tallies at every 5m.



Salient features of 30m chain

- Links provided in chain to know about intermediate distance in between chain length.
- At every one meter chain length, a brass ring is provided.

 Link provided at 3 m and 27 m

 Link provided at 6 m and 24 m

 Link provided at 9 m and 21 m

 Link provided at 12 m and 18 m

 Link provided at 15 m

Measuring tapes

Types depending on material used. These are:

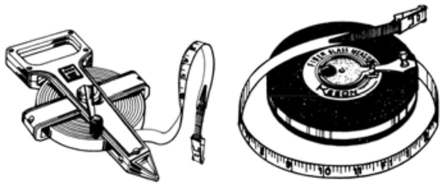
(a) Linen or plastic tapes

(b) Glass fiber

(c) Metallic

(d) Steel

(e) Invar



Fiberglass tapes
Open reel case and metal case

(1) Linen/ plastic

- Not very accurate, shrinkage, stretching twist and tangle easy.
- Available in lengths 10m, 20m, 25m, 30m; 10-15 mm wide.

(2) Fiberglass

- Quite flexible, strong and non-conductive.
- Do not stretch or shrink due to changes in temperature/moisture.

(3) Metallic

- Made of waterproof fabric or glass fiber in which metallic wires (generally copper wires, sometimes brass or bronze wires) are interwoven. Fabric used is generally painted or varnished. More durable than linen but not suitable for very accurate work.
- Available in 1 m, 2 m, 10 m, 20 m, 30 m, 50 m.

Problems

- Dampness which results in shrinkage
- Long usage makes it worn out and illegible

(4) Steel

Steel or stainless steel strip.

Available in 1m, 2m, 10, 15, 20, 30m , 50m lengths. Precision 1: 2000.

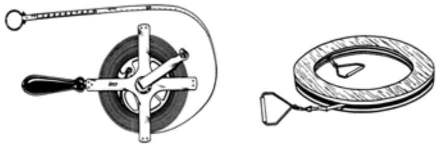
(5) Invar

- Alloy steel (64% steel and 36% nickel). It is a soft material hence should be handled carefully.
- Very low coefficient of thermal expansion.
- 6 mm wide, 20 m, 30 m and 60 m long.
- Exact length to be determined regularly because it changes due to creep and due to change in coefficient of expansion.

(6) Steel bands

Long and narrow strip of steel, used for measuring long distance accurately.

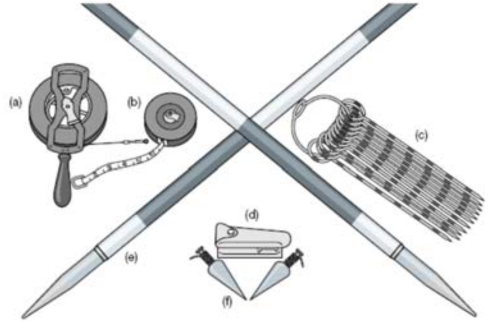
Width: 6 to 10 mm, Thickness: 0.2 to 0.6 mm, Length: 10 to 200 m, 30 to 50 m is common.



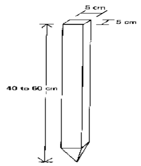
Steel tape open reel and invar tape in wooden case

Instrument for chaining/taping

- Tape (**a, b**)
- Arrows (chaining pins) (**c**)
- Simple clinometers/abney level (**d**)
- Ranging rods (**e**)
- Plumb bob (**f**)
- Offset rods
- Pegs
- Cross staff/ optical square and site square/double pentagonal prism (for measuring right angles



Abney level and clinometer



Ref: Wolf and Ghilani

Operations in chaining

Basic principle of chaining

- If points A and B are fixed, point C can also be fixed with respect to these by using ties and offsets.

- If length of sides in ΔABC is known, triangle can be plotted.
- Divide any area into framework of triangles (well conditioned nearly equilateral triangles).
- To locate details relative to this framework, measurements are made relative to the framework.
- Measurements with respect to chain line should be as short as possible. It should be never greater than the tape length (why?).
- Random errors α $L^{1/2}$, L is length of line.

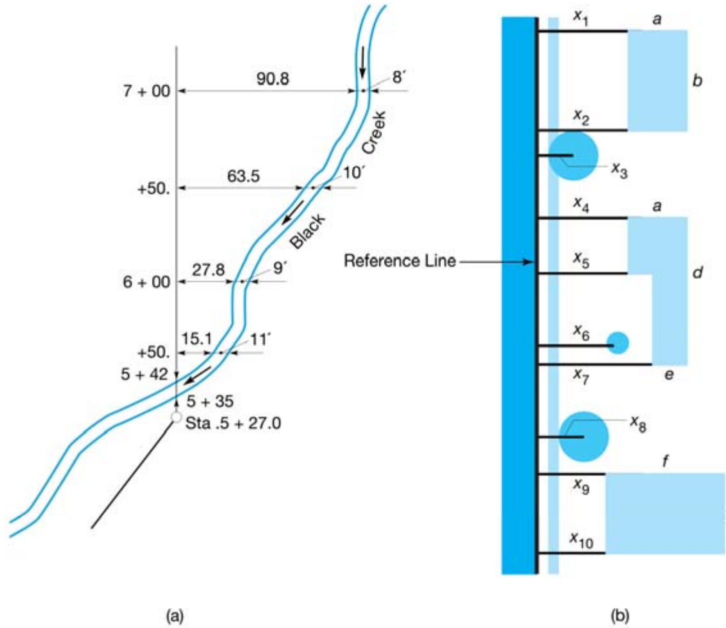


Figure 16–11 (a) Location of creek by perpendicular offsets from a reference line. (b) Locating objects by offsets from a reference line.

Ref: Wolf and Ghilani

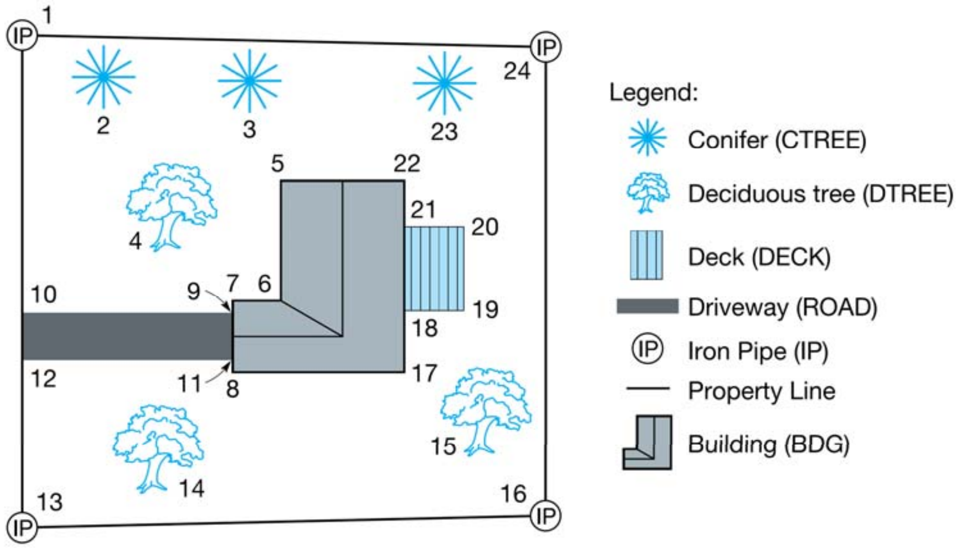


Figure 16–16 Field sketch for problems 16–19 and 16–20.

Ref: Wolf and Ghilani

- **Reconnaissance**: To establish **stations** using ranging rods or pegs.
- **Backbone line:** Accuracy of work enhanced if framework of triangles is founded on a **backbone line** run through the site to be surveyed. At least one long **backbone line** upon which triangles may be formed.
- **Check lines:** (Additional chain lines) crossing existing triangles should be incorporated where necessary to check on measurements to ensure that errors do not go undetected.
- As few lines as necessary should be used, and steep, uneven slopes are avoided.
- **Well conditioned triangles:** ($30^o < \theta < 120^o$) to give clean intersection and check lines should be provided for all independent figures.
- Avoid chain lines without offsets unless they are check lines and keep offsets short as far as possible.

Booking the survey

- Use **field book**, with each page ruled up the center with a single colored line or two such lines about 15mm apart to represent chain lines.
- Make a sketch showing locations of stations and chain lines after reconnaissance.
- Take enough measurements, generally ties from nearby easily recognizable features, and note enough information to enable easy location of stations.
- Take bearing from true/ magnetic north of at least one of the lines.
- Begin each line at the bottom of the fresh page.
- Take plenty of room and make no attempt to scale bookings.
- Exaggerate any small irregularity capable for plotting.
- Book systematically, proceed one side up the chain then the other starting with the site with more details (hence more offsets).

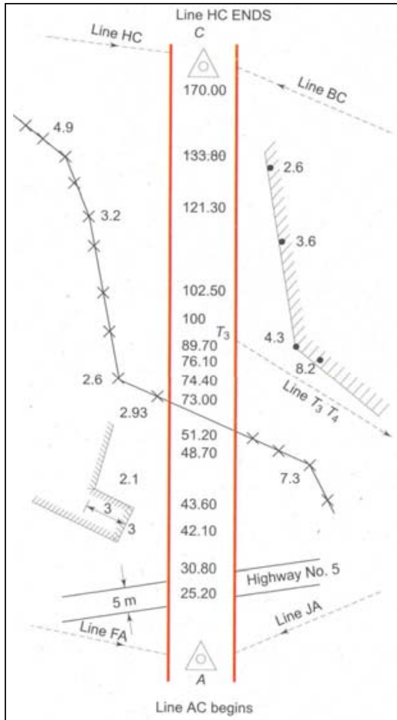


Fig. 5.3 A page from a field book

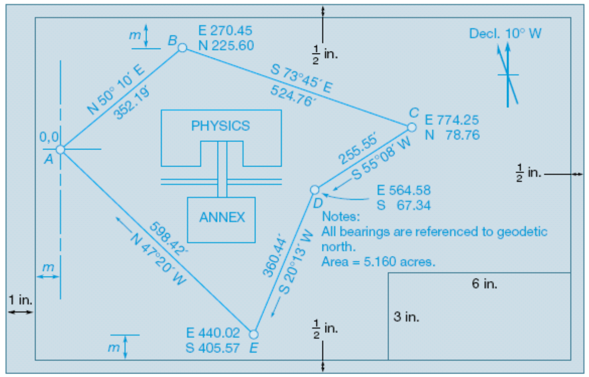


Figure 17–2 Map layout.

Ref: Wolf and Ghilani

Precision in taping

- Relative precision: 1: 1000
- Normally chain lines are measured to nearest 20 mm and offsets to nearest 50 mm. Accuracy obtained also depends on plotting scale.
  - A good draftsman can plot within 0.5 mm (plotting accuracy). Therefore, if scale 1: 500 then 0.5 mm = 0.25 m on ground.
- But since it may be needed to plot at higher scale, therefore accuracy up to 10 mm or 0.01 m should be taken. This can be achieved using tapes.
- Link can be estimated to 0.1 link which can be facilitated by laying down a 0.2 m metal scale along side the relevant link.

Relative precision in chaining

S. No.	Methods	Precision	Purpose
1.	Pacing, pedometer, etc.	1/100 – 1/200	Reconnaissance and rough survey
2.	Chaining	1/250 – 1/1000	Chain traverse, compass or ordinary traverse
3.	Steel tape	1/2000 – 1/20,000	Precise traverse and ordinary triangulation
4.	Invar tape	1/20,000 – 1/100,000	Base line measurement in ordinary triangulation

Office work in taping

- Check should be carried out.
- Check line lengths can be calculated using appropriate formulae and compared with the measured length.
- 2H pencils – drawing framework.
- 1H pencils – Details.
- Water proof Indian ink.

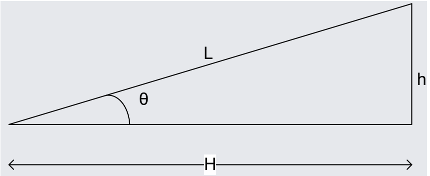
Errors in chaining/taping

Errors	Mistakes	Random	Systematic
• Erroneous length of chain or tape • Bad ranging • Careless holding and marking • Bad straightening • Non horizontality • Sag in chain • Temperature variation • Variation in pull • Personal mistakes	• Adding or dropping full tape length • Reading numbers incorrectly (68 or 89) • Calling numbers incorrectly • Adding a foot or decimeter	• Plumbing and uncertainty in marking tape ends • Uncertainty in – applying tension – marking tape ends with tape fully supported – reading temperature – recording elevation difference or slope angle	• Slope • Erroneous tape length • Temperature • Tension • Sag • Misalignment • Reduction to MSL

Systematic errors in taping

(a) Slope/inclination correction (C_I)

- Since survey measurements are shown on plan therefore slope measurements need to be converted to horizontal equivalents.



$$C_I = L - \sqrt{L^2 - h^2}$$

$$= L - L\left(1 - h^2/2L^2 - h^4/8L^4 - - - - -\right)$$

$$= \frac{h^2}{2L} + \frac{h^4}{8L^3}$$

$$C_I \approx \frac{h^2}{2L} \quad \text{(If } h < 3\text{m in a length of 20 m , } h^4/8L^3 \text{ is small)}$$

$$C_I = L - L\cos\theta$$

(b) Correction to erroneous tape Length C_L

- Needed if absolute length or true length of tape is not equal to nominal/designated length.
- Correction per tape length: $C_l = l' - l$;

  l = nominal length

  l' = actual length
- Correction is positive if $l' > l$, negative if $l' < l$
- Total correction in measured distance L (= C_L)

$$C_L = (l' - l) \times \frac{L}{l} = C_l \times \frac{L}{l}$$

(c) Correction for pull C_P

- Required if pull in field is different from standard pull.
- If field pull > standard pull; then actual length of tape is > nominal length, therefore correction is positive.

$$C_p = \frac{(P - P_o)L}{AE} \qquad \text{Sign of } C_p \text{ depends on values of } P \text{ and } P_o$$

P = Actual Pull (N)

P_o = Standard pull (N)

L = Measured length

A = Cross - section of tape

E = Young's Modulus

(d) Correction to temperature C_T

- Needed if tape temperature is different from temperature at which it was standardized.
- Usual calibration temperature is 20°C or 27°C.

$$C_T = \alpha \times (T - T_o)L$$

α = coefficient of linear expansion

T = mean temperature

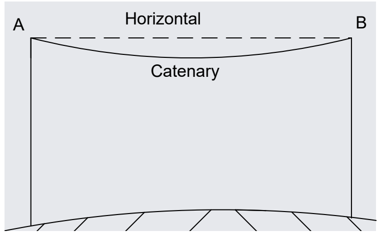
T_o = standard temperature

For Steel Tape $\alpha = 1.16 \times 10^{-5}$ per °C

For invar tape $\alpha = 1.16 \times 10^{-6}$ to 3.87×10^{-7} per °C (1/10 to 1/30 of steel tape)

(e) Sag Correction C_S

- Tape supported at ends take shape of a catenary.
- Simplification: Curve is assumed to be a parabola instead of actual catenary.
- Sag correction is always negative.



$$C_s = -\frac{l_1 (w \,.\, l_1)^2}{24P^2} = -\frac{w^2 \,.\, l_1^3}{24P^2} = -\frac{l_1 \,.\, W_1^2}{24P^2}$$

w = weight per unit length (N/m)

P = applied pull (N)

l_1 = length of tape suspended between supports (m)

W_1 = total weight of tape between supports ($w.l_1$) (N)

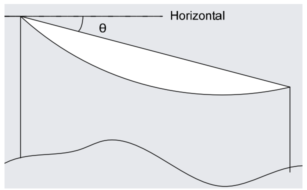
- If l = total length of tape which is supported in n bays of equal length. Then, length of one bay is l_1:

$$l_1 = \frac{l}{n}$$

- Assuming that both ends of tape are at the same level, total sag correction for n bays

$$\begin{aligned} C_s(n \text{ bays}) &= -n\frac{l_1 (w \,.\, l_1)^2}{24P^2} \\ &= -n\frac{(l/n)(w\,.l/n)^2}{24P^2}; \quad (\because l_1 = l/n) \\ &= -\frac{l.(wl)^2}{24n^2P^2} \end{aligned}$$

- If both ends of tape are NOT at the same level, total sag correction for n bays



$$C_s^{'}(n \text{ bays}) = C_s \cos^2\theta \left(1 \pm \frac{wl_1}{P}\sin\theta\right)$$

+ve sign: if tension P applied at higher level

-ve sign: if tension P applied at lower end

θ = slope angle between end supports

- For steel tape, formula approximated as

$$C_s^{'}(n \text{ bays}) = C_s \cos^2\theta$$

C_s = Ordinary sag correction for zero slope

Normal tension

- It is the theoretical pull at which the pull correction is numerically equal to the sag correction.

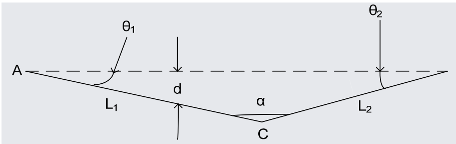
$$\frac{(P_n - P_o)\, l_1}{AE} = \frac{l_1 W_1^2}{24P_n^2}$$

$$P_n = \frac{0.204 W_1 \sqrt{AE}}{\sqrt{P_n - P_o}}$$

- Above equation can be solved by trial and error.

(f) Correction due to misalignment C_M

- If survey line is not accurately ranged out, then measured distance is always greater than the correct distance.



$$C_M = (L_1 \cos\theta_1 + L_2 \cos\theta_2) - (L_1 + L_2)$$
$$= -[L_1(1-\cos\theta_1) + L_2(1-\cos\theta_2)]$$
$$\alpha = 180^o - (\theta_1 + \theta_1)$$

- If end station is not visible (A, B), then locate another station C and measure angle α. Then

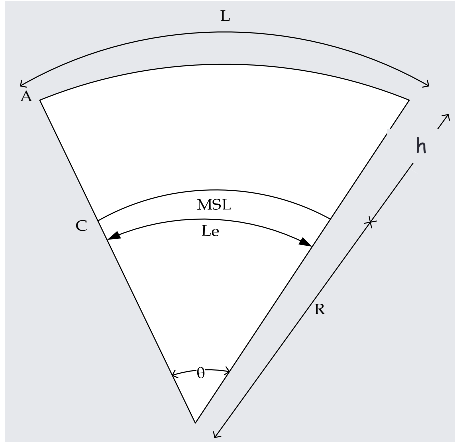
$$C_M = AB - (L_1 + L_2)$$
$$= \sqrt{\left(L_1^2 + L_2^2 - 2.L_1.L_2 \cos\alpha\right)} - (L_1 + L_2)$$

- If angles are not measured, but distance d is measured, then

$$C_M = \left[\sqrt{L_1^2 - d^2} + \sqrt{L_2^2 - d^2}\right] - (L_1 + L_2)$$
$$\approx -\left(\frac{d^2}{2L_1} + \frac{d^2}{2L_2}\right)$$

(g) Reduction of length to MSL

- If observation have to be reduced to a common level (say MSL)



$$L = (R + h)\theta$$
$$L_e = R\theta$$
$$\theta = \frac{L}{(R + h)} = \frac{L_e}{R}$$
$$L_e = L \times \left(\frac{R}{(R + h)}\right)$$
$$C_h = (L_e - L) = L \times \left(\frac{R}{(R + h)}\right) - L$$
$$C_h = -\left(\frac{L \times h}{R + h}\right)$$
$$C_h = -\left(\frac{L \times h}{R}\right) \quad \text{For very small } h$$

Summary of systematic/random errors

S. No.	Correction	Source	Type	Sign	Formula
1.	Standardization	Instrumental	Systematic	±	$\frac{l'-l}{l}L$
2.	Temperature	Natural	Systematic	±	$\alpha\,(T - T_o)*L$
3.	Pull	Personal	Systematic	±	$\frac{P-Po}{AE}L$
4.	Sag	Natural, personal	Systematic	-	$W^2 l^3/(24P^2)$
5.	Slope	Natural	Systematic	-	$\frac{h*h}{2L}$
6.	Alignment	Personal	Systematic	-	$\frac{d*d}{2L}$
7.	Plumbing, marking, interpolation variation in temperature and pull	Personal	Random	±	———

Comparison of methods of measuring distance (Anderson and Mikhail)

Method	Relative precision*	Use	Instruments required
Pacing odometer or mileage recorder	1/100	Reconnaissance, small-scale mapping, checking tape measurement, quantity surveys.	Pedometer, odometer
Tacheometry Stadia	1/300-1/1000	Location of details for topographic mapping, rough traverse, checking more accurate measurements	Level rod or stadia board, calibrated optical line of sight with stand
Distance wedge	1/5,000-1/10,000	Traverse for land surveys, control of route and topographic surveys and construction work	Horizontal graduated rod and support; Calibrated optical line of sight equipped with a distance wedge
Subtense bar	1/1000-1/9000	Hydrographic surveys, traverse	Calibrated subtense bar and tripod; 1″theodolite
Ordinary taping	1/3000-1/5000	Traverse for land surveys, and for control of route and topographic surveys and construction	Steel tape, chaining pins, plumb bobs
Precise taping	1/10,000-1/30,000	Traverses for city surveys, base lines for triangulation of low accuracy, and construction surveys requiring high accuracy	Calibrated steel tape, thermometer, tension handle, hand level, plumb bobs
Photogrammetry	Up to 1/50,000	Location of detail for topographic mapping, second- and third-order ground control surveys	Stereoplotters, mono and stereo comparators, electronic computer
Inertial systems	Up to 1/50,000	Rapid, reconnaissance surveying: large area surveys, second-and third-order ground control surveys	Inertial positioning system
Base-line taping	1/100,000-1/1,000,000	First-, second-, and third-order triangulation for large areas, city surveys, long bridges, and tunnels	Calibrated steel tape, thermometers, tension handle, taping supports, level, level rod
EDM	1 mm + 2 ppm	Traverse, triangulation, and trilateration for control surveys of all types and for construction surveys	EDM equipment

* Relative precision is ratio of allowed standard deviation to the distance measured

Random errors in taping (Anderson and Mikhail)

Designation	Source	Governing conditions and causes	Estimated value per tape length
σ_v	Plumbing to mark tape ends	Rugged terrain, breaking tape frequently	0.05 - 0.10 ft (15 - 30 mm)
σ_m	Marking tape ends with tape fully supported	Tape graduated to hundredths of ft or mm	0.01 ft (3 mm)
σ_p	Applying tension	Change in sag correction due to variations in tension of ±2 lb or 0.9 kg from standard tension	
σ_h	Determining elevation difference or slope angle (assume a maximum 6 percent slope)	If $h = \pm 0.8$ ft (±0.25 m) If $\theta = \pm 0^0 28'$	0.50 ft (15 mm)
σ_d	Standardization	Field tapes compared to standardized tape kept in office	0.005 ft (1.5 mm)

Optical distance measurements

- Determines horizontal distance to points with the help of readings on the upper and lower (stadia) wires on the reticle.
- Principle: In similar triangles, corresponding sides are proportional.
- Figure depicts a telescope with a simple lens, light rays from points *A* and *B* pass through lens center and form a pair of similar triangles *AmB* and *amb*.
- *AB(=I)* is rod intercept (stadia interval), and *i* is spacing between stadia wires.

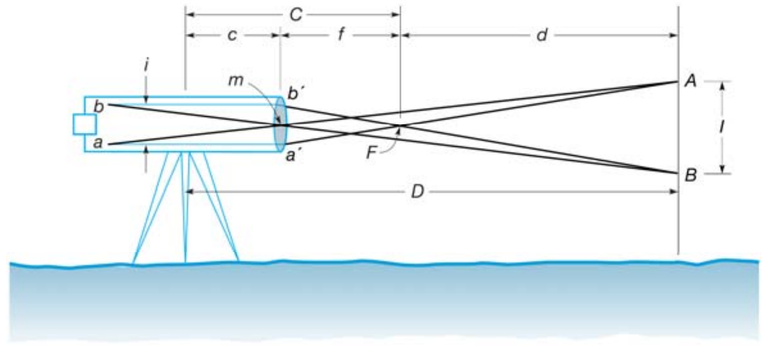
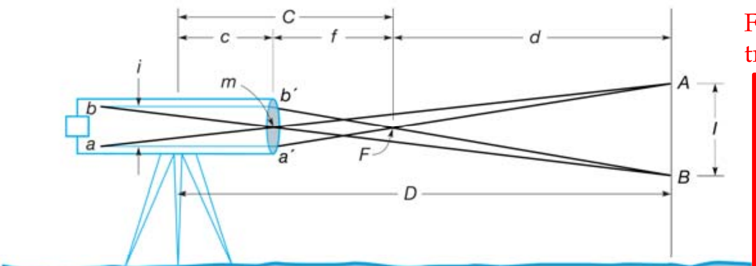


Figure 16–7 Principle of stadia.

f	Focal length of lens (a constant for any particular compound objective lens)
i	Spacing between stadia wires (*ab*)
f/i	Stadia interval factor usually 100 and denoted by *K*
I	Rod intercept (AB), also called stadia interval
c	Distance from instrument center (vertical axis) to objective lens center (varies slightly when focusing the objective lens for different sight lengths but is generally considered to be a constant)
C	Stadia constant (*c* + *f*)
d	Distance from the focal point *F* in front of telescope to face of rod
D	Distance from instrument center to rod face = *C* + *d*



Above drawing correctly shows relationships and aids in deriving the stadia equation for a simplified type of external focusing telescope (now obsolete).

Figure 16–7 Principle of stadia.

From similar triangles

$$\frac{d}{f} = \frac{I}{i}$$

$$d = \left(\frac{f}{i}\right) \times I = KI$$

$$\underbrace{d + C}_{D} = KI + C$$

$$D = KI + C$$

- Objective lens of an **internal focusing telescope** (now used in surveying instruments) remains fixed in position, while a movable negative-focusing lens between the objective lens and the plane of the crosshairs changes directions of the light rays. As a result, the stadia constant (*C*) is so small that it can be assumed equal to zero and drops out of Equation. Thus the equation for distance on a horizontal stadia sight reduces to

$$\boxed{D = KI}$$

- Fixed stadia lines in theodolites, transits, levels, and alidades are generally spaced by instrument manufacturers to make the stadia interval factor equal to 100.
- Stadia constant should be determined the first time an instrument is used, although the manufacturer's specific value posted inside the carrying case will not change unless the crosshairs, reticle, or lenses are replaced or adjusted.

Inclined sight

- Instrument set over point *M* and rod held at O. With middle crosshair set on point *R* to make *RO* equal to height of instrument *EM* = h_i, vertical angle (angle of inclination) is α.
- In stadia work, height of instrument h_i is defined as the height of the line of sight above the point occupied.

L: slope length *ER*

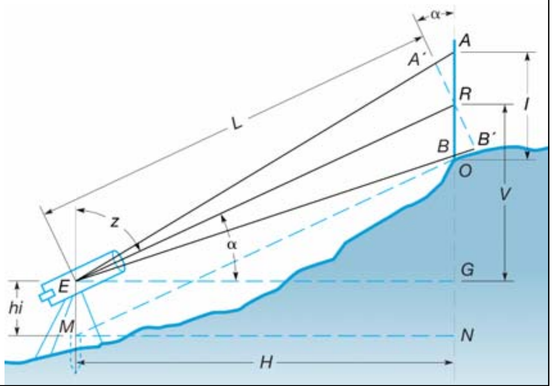
H: horizontal distance *EG* = *MN*

V: vertical distance *RG* = *ON*

$$H = L\cos\alpha$$
$$V = L\sin\alpha$$

If rod could be held normal to line of sight at O, reading A′B′ = I′ would be obtained. Hence

$$L = KI'$$



- Since it is not practical to hold the rod at an inclination angle α, it is plumbed and reading *AB*, or *I*, taken. For small angle at *R* on most sights, it is sufficiently accurate to consider angle *AA'R* as a right angle. Therefore:

$$I' = I\cos\alpha$$
$$L = KI\cos\alpha$$

- Substituting $$H = KI\cos^2\alpha$$
- If zenith angles are read rather than vertical angles, then horizontal distance is given by

$$H = KI\sin^2 z$$
$$z = 90 - \alpha$$

- For vertical distance

$$V = KI\cos\alpha\,\sin\alpha$$
$$V = KI\,\cos z\,\sin z$$

- Elevation of point O is give as $$Ele_O = Ele_M + h_i + V - R$$

Electronic distance measurements: EDMIs

(a) Introduction

- 1943 first geodetic distance meter - electro optical device by Bergstrand "Geodimeter"
- 1957 first microwave EDM - using phase measurement principle by Wadley "Tellurometer"
- Late 1960's HeNe lasers introduced to EDM
- 1970 first electronic tacheometer "total station" Zeiss Reg ELTA 14
- Purpose:
  - measurement of baselines for geodetic networks
  - measurement of baselines for precise engineering surveys
  - high accuracy
    - precision 1/1000000 to 1/500000
    - methods slow and labour intensive

- Evolved from techniques used for determination of velocity of light, which itself is dependent upon measurement of distance and time. Hence, there is no inherent improvement in absolute accuracy by EDMIs.
- Mainly functional advantage:
  - precise linear measurement can be used for longer base lines
  - field operations can be simplified
  - trilateration can replace or augment triangulation.
- Early instruments were large, heavy, complicated and expensive. Improvements in technology have given lighter, simpler, and less expensive instruments with good integrated software.
- Used with:
  - theodolites (both digital and optical) or
  - as an independent unit.

(b) Principle of EDMI

- A modulated EM beam from one transmitter at the master station sent to a reflector at the remote station and received back at the master station.

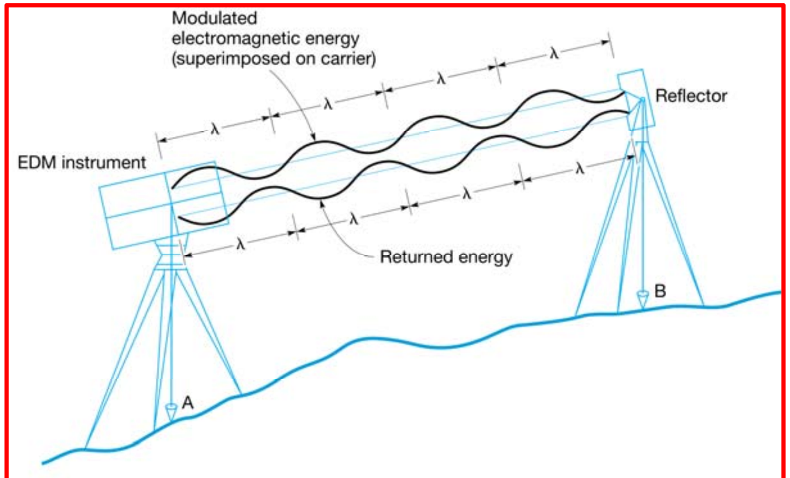


Figure 6–9 Generalized EDM procedure.

- Instrument measures slope distance between transmitter and receiver by modulating the continuous carrier wave at different frequencies, and then measuring the phase difference at the master station between the outgoing and the incoming signals.
- Modulation: Process of superimposing one wave on the carrier so as to vary certain characteristics of carrier.
- In EDM, modulation signal is used for actual measurement. Carrier signal need not be at precisely determined frequency. However, it should be an accurately controlled signal.
- This establishes following relationship for a double distance (2D):

$$2D = m\lambda + \frac{\phi}{2\pi}\lambda + k$$

m	unknown number of complete wavelengths (ambiguity) contained within double distance
ϕ	measured phase difference
λ	modulation wavelength
k	constant

- Multiple modulation frequencies are used to evaluate m

(c) Classification of EDMI

- EDMI can be classified on the basis of four parameters (Schoffield, 2001, Kavanagh, 2003):

  (i) wavelength used

  (ii) working range

  (iii) achievable accuracy

  (iv) degree of integration with a theodolite

(i) On the basis of wavelength

Current EDMIs use following types of wavelengths (Schoffield, 2001):

(i) Electro-optical systems:

(a) Infra red light

(b) Laser light

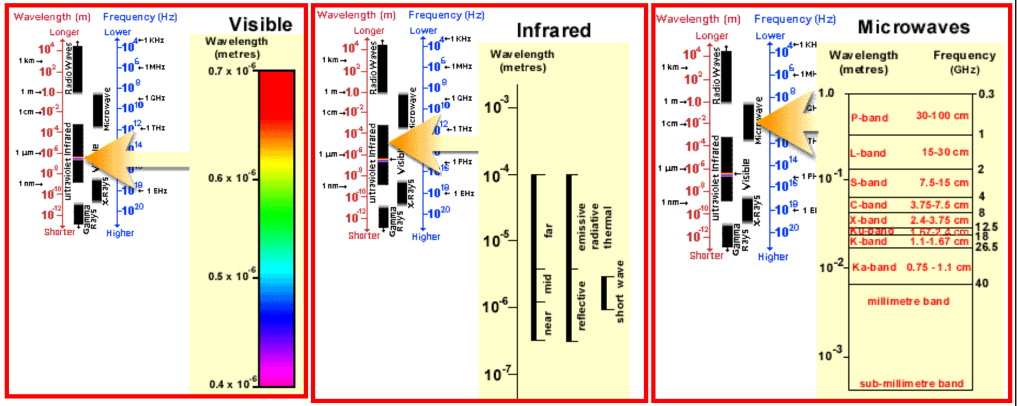
(ii) Electronic systems

(c) Microwaves

Wavelength

Electro-optical	Microwave
laser, infra red	3 to 35 GHz 1.0 to 806mm

Important portions of frequency spectrum



Electro-optical systems

- Infra red based system
  - Allow use of optical corner reflectors but need optically clear path between two stations.
  - Use transmitter at one end of line and a reflecting prism or target at the other end.
- Laser based system
  - Use transmitter at one end of line and may or may not use a reflecting prism or target at the other end.
  - Reflectorless laser instruments for short distances (100 m to 350 m) and use light reflected off the feature to be measured (say a wall).

Electronic system

Microwave

- Receiver/transmitter at both ends of measured line.
- Used for hydrographic surveys normally up to 50 km, though of late hydrographic EDMIs have generally been replaced by GPS.
- Can be used in adverse weather conditions (such as fog and rain) unlike infrared and laser systems. But varying humidity over measurement length may result in lower accuracy.
- Undesirable reflections and signal leakage from transmitter to the receiver requires the use of another transmitter at the remote or slave station. The slave station is operated at different carrier frequency in order to separate two signals and adds to weight of equipment.
- Multipath effects at microwave frequency also add to distance error which can be reduced by taking series of measurements using different frequency.

(ii) On the basis of range

- Long range
  - radio wave equipment for ranges up to 100 km
- Medium range
  - microwave equipment with frequency modulation for ranges up to 25 km
- Short range
  - electro-optical equipment using amplitude modulated infra-red or visible light for ranges up to 5 km, use multiple prisms to enhance range.

(iii) On the basis of accuracy

- EDM distance equation can be written:

$$D = m\frac{\lambda}{2} + u + k \qquad (1)$$

m = whole number of wavelengths in measurements (assumed errorless)
u = fractional part of half wavelength ($\lambda/2$) obtained by measuring phase difference
k = zero correction (includes instrument and reflector conastant)

$$\lambda = \frac{c}{nf} \qquad (2)$$

- Assuming that errors in λ, u and k are independent, using law of propagation of variance to eqns (1) and (2)

$$\sigma_D^2 = \left(\frac{m}{2}\right)^2 \sigma_\lambda^2 + \sigma_u^2 + \sigma_k^2 \qquad (3)$$

$$\sigma_\lambda^2 = \lambda^2\left[\left(\frac{\sigma_c}{c}\right)^2 + \left(\frac{\sigma_n}{n}\right)^2 + \left(\frac{\sigma_f}{f}\right)^2\right] \qquad (4)$$

- Combining equation (3) and (4)

$$\sigma_D^2 = \left(\frac{m\lambda}{2}\right)^2\left[\left(\frac{\sigma_c}{c}\right)^2 + \left(\frac{\sigma_n}{n}\right)^2 + \left(\frac{\sigma_f}{f}\right)^2\right] + \sigma_u^2 + \sigma_k^2 \qquad (5)$$

- Approximating D ≅ m(λ/2), we can write

$$\sigma_D^2 = D^2\left[\left(\frac{\sigma_c}{c}\right)^2 + \left(\frac{\sigma_n}{n}\right)^2 + \left(\frac{\sigma_f}{f}\right)^2\right] + \sigma_u^2 + \sigma_k^2 \qquad (6)$$

- Letting

$$a = \sqrt{\sigma_u^2 + \sigma_k^2} \text{ and } b = \sqrt{\left[\left(\frac{\sigma_c}{c}\right)^2 + \left(\frac{\sigma_n}{n}\right)^2 + \left(\frac{\sigma_f}{f}\right)^2\right]}$$

$$\sigma_D = \sqrt{a^2 + b^2 D^2} \qquad (7)$$

Accuracy of EDMI is stated in terms of ±(a mm + b ppm):

(a) indicative of constant instruments error

(b) indicative of measuring error proportional to measured distance

- **Part (a): Constant instrument error:** It is independent of the length of the line measured and arises due to errors in phase measurements (u) and zero error (k); both are independent of distance; a is more significant for short distances.
- **Part (b): Distance related error:** It is due to error in modulation frequency (f), the velocity of light (c) and the group refractive index (n_g) and are functions of distance; b is more significant for long distances. Expressed as relative accuracies in parts per million (ppm)
- Expressed as (Schoffield, 2001):

$$a = \sqrt{\sigma_u^2 + \sigma_k^2}$$

$$b = \sqrt{(\sigma_c/c)^2 + (\sigma_f/f)^2 + (\sigma_n/n)^2}$$

- Where σ indicates standard error. Most EDMI have accuracy levels from ±(3 mm + 1 ppm) to ±(10 mm + 10 ppm).

Classification on the basis of accuracy

Accuracy

Instruments with a standard deviation of one observation

greater than ±(5mm +5ppm)	equal or smaller than ±(5mm +5ppm)	of about ±(5mm +1ppm)	equal or smaller than ±(1mm +2ppm)	equal or smaller than ±(0.2mm +0.2ppm)
pulse distance meters passive or moving targets	short range meters general surveying practice	long range meters eg AGA Geodimeter Model 8	precision meters includes some infra red	high precision laser eg Terrameter LDM-2

(iv) On the basis of integration with theodolites

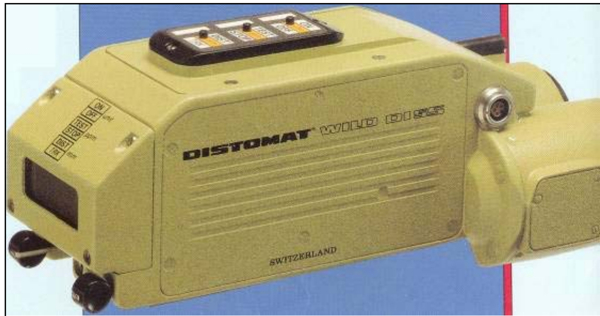
Degree of integration with theodolites

Full electronic tacheometers	Modular electronic tacheometers
Semi-electronic tacheometers	Telescope mounted EDM
Theodolite mounted EDM	Separate EDM instruments

Selected electronic distance measuring instruments (Anderson and Mikhail, 1998)

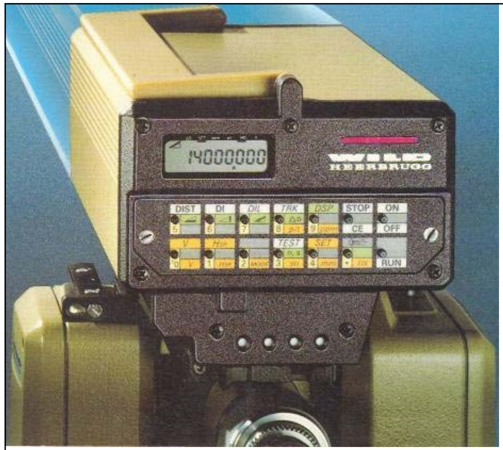
Instrument	Manufacturer	Emission source	Range (m) (Single Prism)	Accuracy (mean square error)
Short range				
DI1001	Leica	Infrared	1-800	±(5 mm + 5 ppm)
RED Mini 2	sokkia	Infrared	800	±(5 mm + 3 ppm)
DM-H1	Topcon	Infrared	0.15-800	±(1 mm + 2 ppm)
DM-A5	Topcon	Infrared	0.15-800	±(5 mm + 3 ppm)
ND20/21	Nikon	Infrared	N/A-700/1000	±(5 mm + 5 ppm)
MD-14 / MD-20	Pentax	Infrared	1-1,000/1,600	±(5 mm + 5 ppm)
MA200	Navigation Electronics	Infrared	1,600	±(0.25 mm + 0.5 ppm)
ND-26	Nikon	Infrared	N/A-2,000	±(5 mm + 5 ppm)
DI1600	Leica	Infrared	1-3,000	±(3 mm + 5 ppm)
Intermediate Range				
Geodimeter 220	Geotronics	Infrared	0.2-2,300	±(5 mm + 3 ppm)
DM-S2 / DM-S3L	Topcon	Infrared	0.15-2,400	±(5 mm + 3 ppm)
DI2002	Leica	Infrared	1-2,500	±(1 mm + 1 ppm)
RED 2A / RED 2L	Sokkia	Infrared	2,000/3,800	±(5 mm + 5 ppm)
Leica / Kern ME5000	Leica	Laser	20-5,000	±(0.2 mm + 0.2 ppm)
DIOR 3002S	Leica	Infrared	0-6,000 No Prism, 300	±(3.5 mm + 0.2 ppm)
RED 2LV	Sokkia	Infrared	6,000	±(5 mm + 5 ppm)
Eldi 10	Zeiss	Infrared	0.2-7,000	±(5 mm + 3 ppm)
Pulsar 50	Geo-Fennel	Infrared	2-8,000	±(5 mm + 5 ppm)
DI 3000S	Leica	Infrared	1-9,000	±(3 mm + 1 ppm)
Criterion 100	Laser Technology	Laser	1.5-8,000 No Prism, 457	±(90 mm + 50 ppm)
Long Range				
Pro Survey 1000	Laser Atlanta	Laser	1-10,000 No Prism, 850	± 100 mm ± 100 mm
Atlas 2000	Laser Atlanta	Laser	1-10,000 No Prism 1,500	± 100 mm ± 100 mm
Geodimeter	Geotronics	Infrared	0.2-14,000	±(5 mm + 1 ppm)
MRA 7	Navigation	Microwave	10-50,000	±(15 mm + 3 ppm)

Different Types of EDMI



Wild Distomat D15S

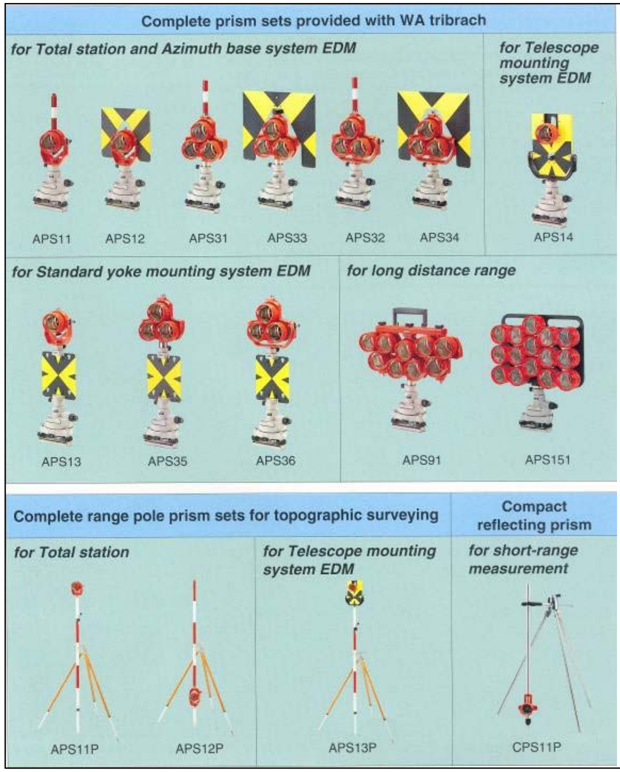
Wild Distomat D15S mounted on different types of theodolites



Wild Distomat D13000 Infrared EDM

Different types of Nikon EDMI with mounting on theodolite

Sokkia Red line EDM



Different types of prism targets used with Sokkia EDM

Methods used in EDMIs

Two approaches:

- Timed pulse techniques: Used in variety of radar instruments.
- Measurements of a phase difference Many infra red instruments

- Pulse methods are heavy weight equipment (cannot be classed as lightweight portable instruments), need more power but have advantage over phase difference methods (used over long distances)

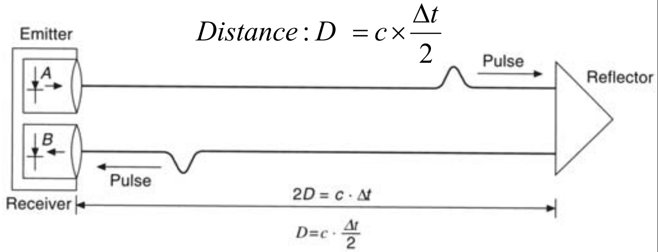
(i) Pulse techniques

- Use very precise measurement of time usually expressed in units of nanoseconds (1×10^{-9} s), which a wave takes to travel from one station to another. A short, intensive pulse radiation is transmitted to a reflector target, which is immediately transmitted back to receiver.

Application areas:

- satellite laser ranging
- lunar laser ranging
- military laser rangefinders
- pulsed distance meters for surveying
- airborne laser terrain profiler
- laser airborne depth sounder

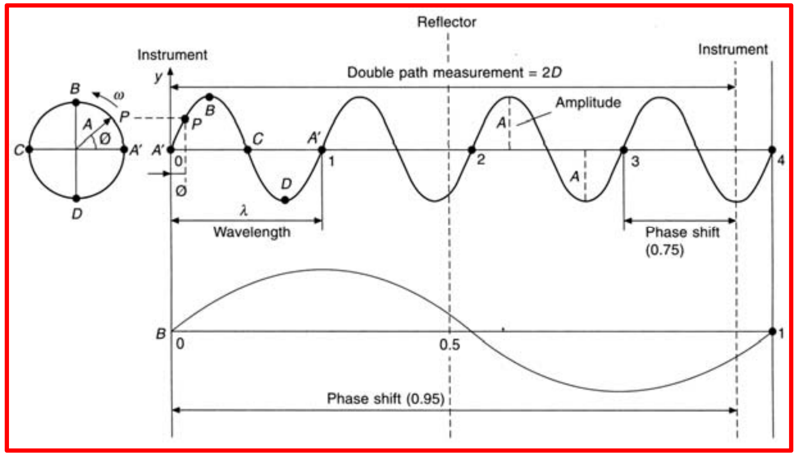
$$Distance: D = c \times \frac{\Delta t}{2}$$



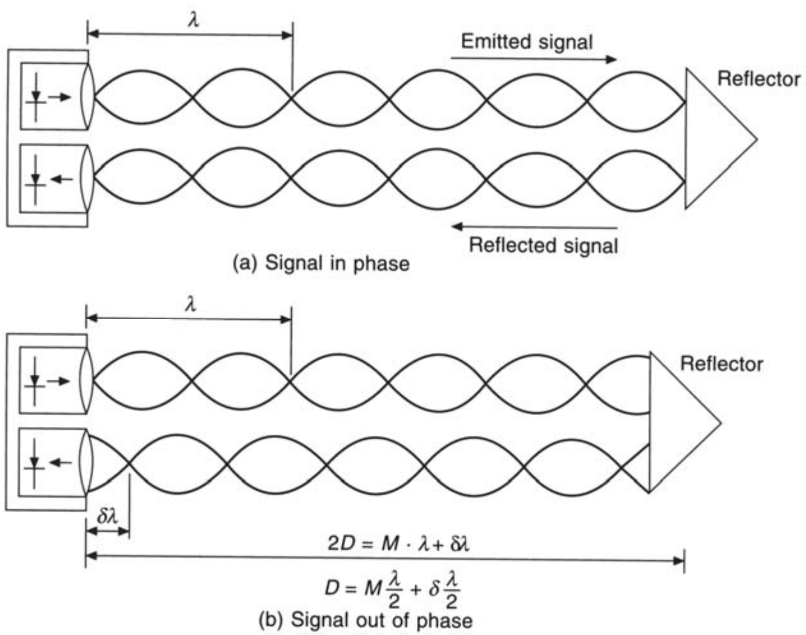
Pulse based measurement (Schoffield and Breach, 2007)

(ii) Phase difference techniques

- Used by majority of EDMI; Instrument measures amount $\delta\lambda$ by which reflected signal is out of phase with the emitted signal.
- For a given complete cycle of EM wave, the phase difference can be expressed both in terms of angular (degrees) and linear (fraction of wavelengths) units.



Principle of phase measurement (Schoffield, 2007)



Principle of phase measurement (Schofield, 2002)

Measurement with EDMI

- Distance measured: $D = n \times (\lambda/2) + d/2$
  - Integer no. of half wavelength + half the phase difference values
  - $d/2$ measured fairly accurately by phase discriminator
  - n has to be estimated by multiple wavelengths.

Principle of measurement (Benton and Taetz, 1991):

- Say distance = 2429.382 m is to be measured & say modulated λ = 20 m, $\lambda/2$ = 10 m
- $2D$ = 2 x 2429.382 = 4858.764 (for both way measurements since phase is measured at master station only)
- Instrument will measure phase difference (n x 20 + phase) = 4858.764 – 4840 = 18.764 m, Hence, $d/2$ = 18.764/2 = 9.382 m
- Hence, single frequency will measure only 9.382 m plus some any multiple of 10 m i.e. 9.382 or 19.382, or 29.382 and so on up to a maximum range of EDM.
- Hence, determination of ***n*** is crucial to get correct distance.

Methods to measure n

(a) Decade modulation approach (Old approach):

- Use as many as 4 modulation wavelengths λ_1, λ_2, λ_3, λ_4 that differed from one another by a factor of 10.
- Using a precise, crystal controlled oscillator that produced a primary λ = 20 m, and primary half wavelength (also called the effective wavelength) = 10 m.
- Effective wavelength is half the true wavelength. If true wavelength is λ_T, then effective wavelength $\lambda_E = (\lambda_T/2)$. λ_E is usually short, 10 m being the common value.
- By synchronization produce other frequency such that

λ_2 = 200m $\lambda_2/2$ = 100m

λ_3 = 2000m $\lambda_3/2$ = 1000m

λ_4 = 20000m $\lambda_4/2$ = 10000m

Example:

From previous example, for measuring D = 2429.382m, 2D = 4858.764m

- With λ_1, distance would be measured as d = Mod $(2D, \lambda_1)$ = 18.764 m.
- Hence, $d/2$ = 18.764 /2 = 9.382 m (assuming 4 right digits are retained).
- With λ_2 , EDM would measure phase difference to the same number of significant digits as the first one.
- Therefore, measured phase difference can be calculated as (d = Mod $(2D, \lambda_2)$ = 58.764).
- Hence, $d/2$ = 58.764/2 or half phase difference = 29.38 m (4 significant digits)
- Instrument will ignore last three digits of 29.38 and will insert 2 before the precisely measured value of phase i.e. 29.382 m (tens of meter of digits = 2).

- In next step, λ_3 = 2000m. Hence, d = Mod $(2D, \lambda_3)$ = 858.764. Hence, $d/2$ = 858.764/2 (with 4 significant digits) = 429.4 m (hundreds of meters of digits = 4
- In next step, λ_4 = 20000m. Hence, d = Mod $(2D, \lambda_4)$ = 4858 (4 significant digits). Hence, $d/2$ = 4858/2 = 2429 m (thousand of meter of digits = 2)
- Assembling thousands, hundreds and tens digits in order and adding in initial at d/2 value given a measurement reading of 2429.382 m.

Wavelength	Resolved Distance
10	xxx9.382
100	xx29.382
1000	x429.382
10000	2429.382

New approach to measure n

- It uses just two slightly different wavelengths.
- If wavelengths were close enough:
  - the number of whole wavelengths from EDM to reflector and back would be the same for two wavelengths (or at most different by one whole wavelength)
  - but the phase difference would be significantly different (for two wavelengths).

$$\boxed{\begin{gathered} n\times\lambda_1 + d_1 = n\times\lambda_2 + d_2 \\ n = \frac{(d_1 - d_2)}{(\lambda_2 - \lambda_1)} \end{gathered}}$$

For λ_1 and λ_2 (round trip distribution)

- λ_1 and λ_2 precisely established
- d_1 and d_2 precisely measured
- Since maximum phase difference d can be any value between 0-λ. Hence, maximum range of $(d_1 - d_2)$ must also be equal to numerical value of λ.
- Hypothetical maximum value of $n = \lambda_1/(\lambda_2 - \lambda_1)$

Example

- For two frequency modulation, Primary λ_1 = 40 m, Secondary λ_2 = 40.16 m
- Hence, $\lambda_2 - \lambda_1$ = 0.16 m. Hence, largest value of n to be determined as

$$n_{max} = \lambda_1/(\lambda_2 - \lambda_1) = 40/0.16 = 250$$

- Hence, maximum measurable round trip distance

$$n_{max} \times \lambda_1 = 250 \times 40 = 10000 \text{ m}$$

- Hence, one way maximum measurable distance = 5 km, which is somewhat higher than most EDMs.
- Maximum measurable distance is a function of
  - power output of carrier
  - efficiency of reflector array
- The design wavelength difference should be small enough to permit maximum n values to accommodate EDMs maximum range.

- If measured distance were such that n from second wavelength were one less than from primary. It can be written as

$$2D = (n-1)\,\lambda_2 + d_2 = n\lambda_1 + d_1$$

$$n(\lambda_2 - \lambda_1) = (d_1 - d_2) + \lambda_2$$

$$n = \frac{(d_1 - d_2) + \lambda_2}{(\lambda_2 - \lambda_1)}$$

Important features of EDMs

- Precision of EDM is determined by measure of phase (Φ).
  - Some instruments resolve it by 1% of phase, some to 0.1% or better.
  - Now days phase difference is not measured at the operating frequencies. It is rather transformed to corresponding difference at much lower frequency improving measurement of phase difference such that resolution to one thousandth part of cycle is also possible.

- Lower frequency signals:
  - provide greater range but require large transmitter
  - affected by atmosphere
  - less accurate for EDM than those using higher frequency
  - useful for marine and air navigation and for much hydrographic work where long range is vital and accuracy requirements are comparatively low; permanent and semi-permanent transmitters are appropriate.
- For practical field measurement in engineering, higher frequency is more useful as
  - instrument can be made small and transportable and propagation through air more stable.
  - but at these frequencies it is much difficult to measure phase difference- wavelengths are so small that it is practically difficult to directly use the waves themselves.
  - Problem can be alleviated by modulating the carrier with another wave.

Example

- For two wavelengths λ_A and λ_B, where $\lambda_A > \lambda_B$; wavelength difference (λ_A - λ_B) has frequency = difference of f_A - f_B
- Difference in phase between two wavelength is always equal to the phase of the given difference frequency.
- Thus measuring two-phase delays consequent to traveling over double distance is equivalent to traveling over double distance and taking this phase difference and measuring the phase of wave with frequency which is difference of two.

Example:

- Let us say we are measuring 200m with λ_A = 40m, λ_E = 50m.
- Hence, $f_E = (4/5)f_A$; $(f_A - f_E) = f_A/5$; λ_{E-A}= 200m
- Say at any distance, a phase difference of 1.54π is observed on subtraction, a double distance of $1.54\pi \times 200/2\pi = 154$ is involved.

(d) Components of EDMI

EDMI components:

- Radiation source for carrier signal
- Modulation signals and modulator
- Signal transmitter and signal receiver
- Beam splitter
- Reflector
- Filter
- Amplifier
- Phase discriminator
- Display unit

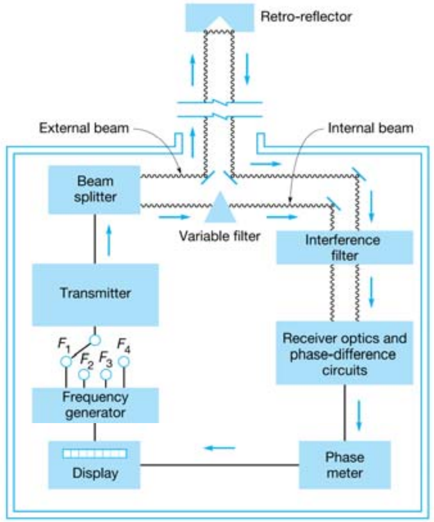


Figure 6–11 Generalized block diagram illustrating operation of electro-optical EDM instrument.

Components of EDMI (Wolf and Ghilani, 2002)

(e) Operations with EDMI

- Measurement with EDMI involves four basic steps:

  (a) Set up (b) Aim (c) Measure (d) Record

(a) Setting up: EDMI is centered over a station by means or tribrach or by mounting over a compatible theodolite. Reflector prisms are set over the remote station either on tribrach or on a prism pole. Observations related to height or instrument and prism are recorded. These are usually kept the same to avoid any additional correction.

- Aiming: EDMI is aimed at prisms by using sighting devices or theodolite telescope. Slow motion screws are used to intersect the prism centre. Some kind of electronic sound signal helps the user to indicate the status of centering.
- Measurement: The operator presses the measure button to record the slope distance which is displayed on LCD panel which can be recorded manually or automatically. All meteorological parameters are also recorded.

Special Features of Modern Short range EDMI

- on-board application of first velocity correction
- computation of horizontal distance and height difference
- tracking mode
- audio signal
- automatic data recording
- computer assisted surveying
- setting out aids
- pointing aids
- Range of EDM

$$R_y = (y/a)^{0.5} e^{-zR_y}$$

R_y = Range of distance measured with y prisms
a = Instrument specific parameter
z = Attenuation coefficient
y = Number of prisms used

Error sources in EDMI

Fundamental distance measured by EDMI can be put into the following generalized form:

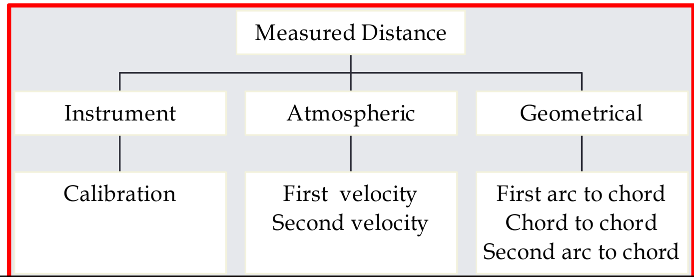
$$D = m\left(\frac{\lambda}{2}\right) + \frac{\phi}{2\pi}\left(\frac{\lambda}{2}\right) + (K_1 + K_2 + K_3)$$

$$D = m\left(\frac{V_o}{2n_g f}\right) + \frac{\phi}{2\pi}\left(\frac{V_o}{2n_g f}\right) + (K_1 + K_2 + K_3)$$

m integer ambiguity
λ wavelength of modulation wave
ϕ measured phase difference
n_g group refractive index
Vo velocity of EMR in vacuum
K_1 scale error
K_2 zero error
K_3 cyclic error

Measurement with EDMI has following error sources which have to be accounted for while reporting the distance (Kennie and Petrie, 1990):

- Gross errors
  - Reading
  - Recording
- Systematic errors
  - Additive constant
  - Scale
  - Cyclic
- Random errors
  - centring
  - pointing



(i) Instrument operation errors

- Precise centering needed at master and slave station,
- Precise pointing/sighting of reflector
- Entry of correct values of prevailing atmospheric conditions.

(ii) Atmospheric errors

- Incorrect meteorological conditions (temperature, pressure, humidity, etc.)
- Can be removed by applying an appropriate atmospheric correction model that takes care of differential meteorological parameters from the standard one.

(iii) Instrument error

Systematic errors with three components:

- scale error
- zero error
- cyclic error

Corrections in EDMI

Three types of corrections required to reduce measured distance ($D = V \times t$) to corrected distance:

(a) Calibration or standardization

(b) Velocity correction

(c) Geometric correction

(i) Calibration or standardization

- Takes care of scale, zero, and cyclic errors and should be applied periodically to account for aging and wear and tear of equipment.

(ii) Velocity correction: Applied to account for atmospheric effects since:

- signal is not traveling in vacuum but some medium which reduces the speed of EMR.
- waves follow a curved rather than a straight line path between the transmitter and receiver.

(iii) Geometric correction

- To reduce measured distance (corrected for refractive index) to the equivalent distance on spheroid.

(i) Calibration or standardization

Reasons to calibrate

- *Quality control*
  - significance of corrections with respect to the work required of the instrument
  - whether the instrument is working within the manufacturer's specifications
  - whether the instrument requires a service
  - whether any systematic errors exist
- *Improvement of accuracy*
  - applying corrections to measured values improves the accuracy
- *legal metrology*

Calibration results in

- determination of instrument constants (IC) and associated precision
- baseline calibration (rigorous, mathematical) - errors computed simultaneously
- field calibration (practical) - order of computations important

- An EDMI can be tested and calibrated for all errors one at time, or simultaneously using a baseline
- An easy method is to determine each error by a series of tests which should be performed in the following order:
  1) Determine the degree of cyclic error
  2) Determine the value of the additive constant
  3) Measure known distances to find the scale error

(a) Cyclic error (K_3)

- It varies with distance and also termed
  - period errors
  - resolver errors
  - non-linearity errors
- Function of the internal phase measurement of an EDM and results from internal electronic contamination between transmitter and receiver circuitry. Phase measurement error is caused by:
  - electrical coupling between the reference signal and the measurement signal
  - optical crosstalk between transmitter and receiver optics in EDMI
  - sinusoidal curve over the measurement unit length
- Their effect is minimized by the manufacturer by electrical isolation and shielding of instrument components.

Test for cyclic error

- A number of distances need to be measured within the unit length of the instrument
- Find out unit length of instrument (from manual e.g. 10 m)
- Set out 10 or 11 marks at one tenth the unit length of the instrument between marks.
- Level wall ideal
- Tape measure set out at 1 m, 2 m, 3 m, etc. to 10 m
- Set prism on first mark
- Set EDMI up about 70 to 100 m from wall in a straight line with the marks. Measure to the marks ensuring that the prism is set in exactly the same position each time
- Note measured position and tape mark
- Calculate the difference between the measured distance and the tape measure
- Atmospheric errors can be ignored if measurement taken over a short time
- Insignificant over short distances
- Graphical or rigorous solution

Rueger, 1996

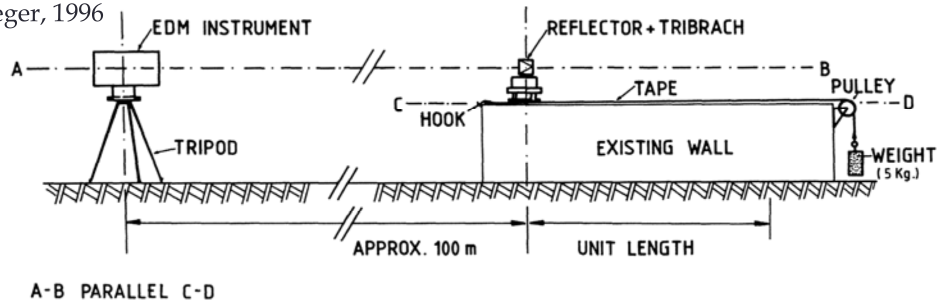
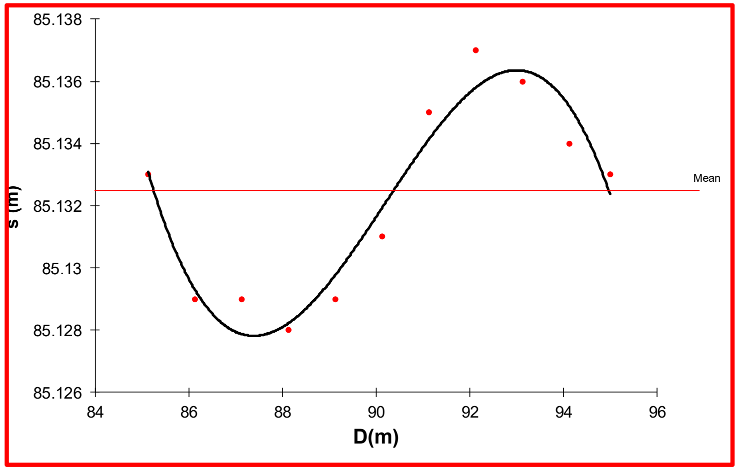


Fig. 13.1. Longitudinal section through a cyclic error testline. The pulley and 5 kg weight ensure proper tension at changing temperatures. The unit length is equivalent to half of the modulation wavelength. The axis of the EDM beam ($A-B$) must be parallel in three dimensions to the axis of the tape ($C-D$)

Measured Distance (D)	Tape Mark (m)	Dist minus Tape mark (s)
85.133	0	85.133
86.129	1	85.129
87.129	2	85.129
88.128	3	85.128
89.129	4	85.129
90.131	5	85.131
91.135	6	85.135
92.137	7	85.137
93.136	8	85.136
94.134	9	85.134
	mean (s)	85.1321



- Curve will repeat every 10 m
- Plot a value for 95 m same as 85 m
- Maximum cyclic error about 4mm, large should be only 1-2 mm
- Correction for cyclic error is the difference between the estimated cyclic error curve and the mean distance, can be written in terms of an equation and applied
- EDM should be checked regularly for cyclic error, if it gets too large eg 5 mm, instrument should be serviced.

(b) Zero error (K_2)

- Independent of distance measured.
- Also termed: additive constant error, index error, or reflector/prism offset error.
- Cause: Internal measurement centers of the instrument/reflector do not coincide with the physical centers of the instrument/reflector.
- It consists of two components:
  - First component: Due to non-coincidence of the physical centre of the instrument which is plumbed over the survey station with the position within the instrument to which measurements are made.
  - Second component: Similar interpretation for reflector which absorbs changes in velocity of light while moving from air to reflector glass prism and light path itself through the reflector.

Prism reflectors

Figure 6–12 Triple retro-reflector. (Courtesy Topcon America Corp.)

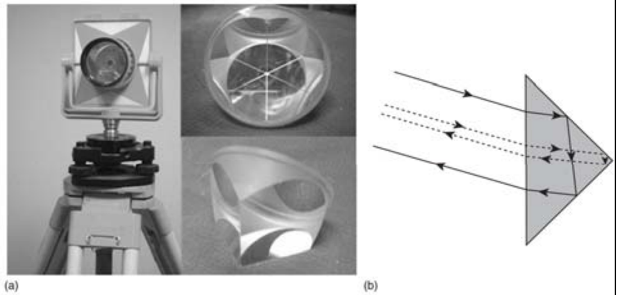
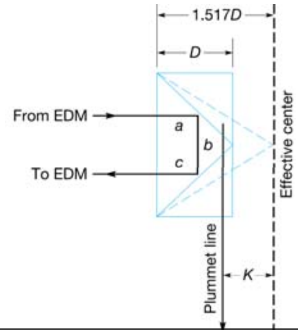


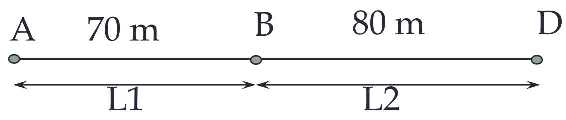
Fig. 4.21 *(a) Corner cube prism. (b) Rays of light through a corner cube prism*



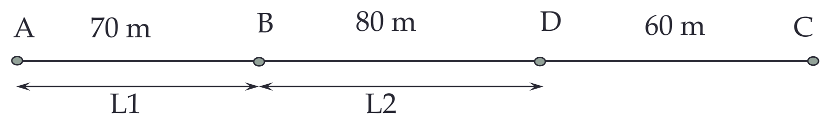
D is prism depth

Test for additive constant error

- A simple test is to measure all three distances (AB, BD, AD) between three points which lie in a straight line
- Minimum distance 50 m and distances between pegs are multiples of 10 m
- Distances between the pegs are unequal
- By keeping distances in multiples of 10m the error remains the same or near the same.



- By keeping distances short the effect of scale is minimised
- Greater number of setups greater the redundancy
- 3 points minimum
- Measure AB (L1): AB = L1 + e
- Measure BD (L2) BD = L2 + e
- Measure AD: AD = L1 + L2 + e
- All three distances contain the constant error. Hence,
- AB + BD = AD $\Rightarrow$ L1 + K_1 + L2 + K_1 = AD + K_1
- Difference is additive constant K_1



- Distances between pegs multiples of 10 m
- Distances > 50 m overcome phase inhomogeneities

Example: Measured Horizontal distances corrected for atmospheric effects are

- AB = 103.260 (L1); AD = 189.364; BD = 86.081 (L2)

These also need to be corrected for cyclic errors as in the previous example

AB = 103.260 - 0.004 = 103.256 (L1)

AD = 189.364 + 0.000 = 189.364

BD = 86.078 + 0.003 = 86.081 (L2)

Zero constant error = (103.256 + 86.081) - 189.364 = -0.027 m

Check:

(103.256 + .027) + (86.081 + .027) = (189.364 + .027)

(c) Scale error (K_1)

- It describes errors that are linearly proportional to the length of line measured.
- Causes:
  - (a) variations in modulation frequency of EDM,
  - (b) non-homogeneous emission/reception patterns from emitting and receiving diodes (phase inhomogeneities)
  - (c) unmodelled variations in atmospheric conditions which affect velocity of propagation
  - (d) errors in the collection and use of atmospheric data. This includes use of uncalibrated thermometers/barometers, not taking atmospheric measurements in shade and incorrect entry of atmospheric correction into the EDM.

- Function of time and temperature
  - time short term: warm up time to achieve oscillator frequency
  - time long term: age of the oscillator, deteriorates over time
- reduction by measurement of a baseline of known length
- Methods of correction:
  - direct method
  - indirect method

Direct method

- if we measure a line of known length then the scale error of the EDM can be calculated
- use a line with two stations, a few hundred metres apart

- baseline has to be greater than 500 m to discern scale correction e.g. 2 mm
- plumbing of instrument and reflector critical, 1 mm error gives 2 ppm in a 500 m baseline
- zero and cyclic errors need to be known as distance is measured directly

$$\text{scale correction } (\text{in } ppm) = \left[\frac{Dist_{known} - Dist_{measured}}{Dist_{known}}\right] \times 10^6 = n\ ppm$$

$$\text{Corrected distance} = Dist_{measured} + n\ ppm \times Dist_{measured}$$

Example

- True distance of baseline = 423.185 m
- After correcting for atmosphere, cyclic, constant and reducing to the horizontal
  - distance = 423.194 m
  - Hence, scale error = [(423.185 - 423.194)/423.185] x 10^6 = -21.27 ppm
- in terms of correction to a measured distance

  = 423.197 - [21.27 * (423.197/1000)] = 423.206 m
- It should be verified by measuring a number of distances over the baseline

Indirect method

$$\boxed{\begin{array}{l}\text{scale correction in ppm} = \left[\dfrac{Dist_{known} - (IB_{measured} - IA_{measured})}{Dist_{known}}\right] \times 10^6 = n\ ppm \\ \text{Corrected distance} = Dist_{measured} + nppm \times Dist_{measured}\end{array}}$$

Errors eliminated due to differential process

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