I. Measurement Errors

A. Quality

1. Precision

2. Accuracy

3. Precision and Accuracy

4. Resolution

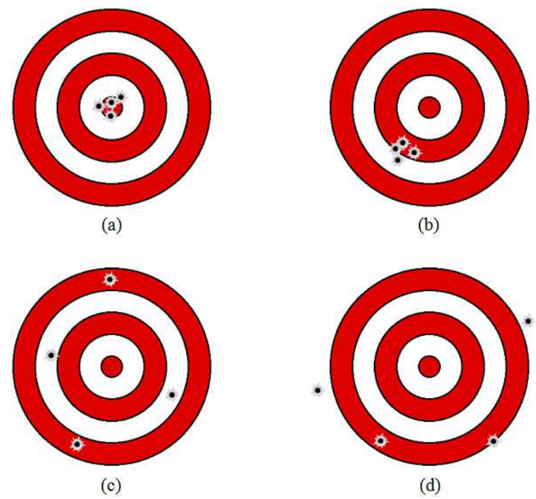


Figure 1: We Love Shootin' Stuff

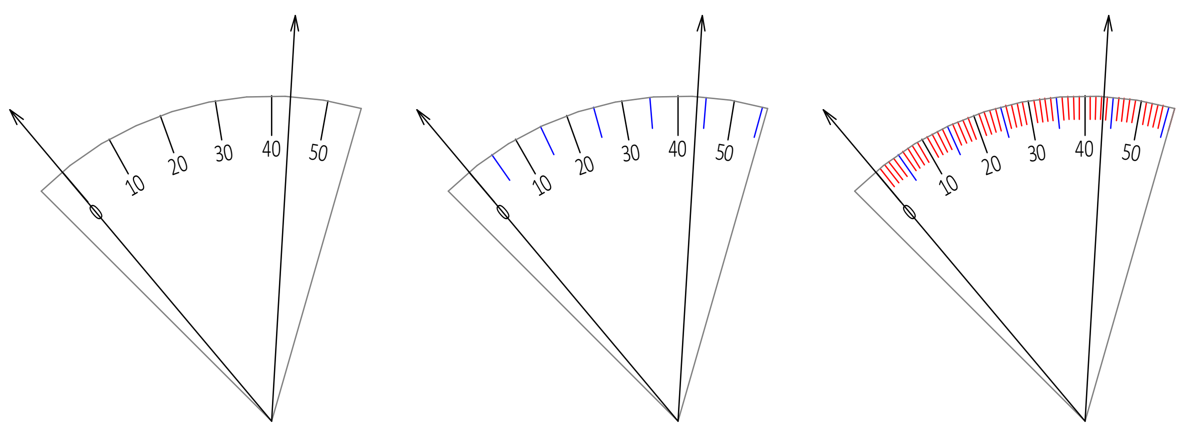


Figure 2: Measurement Resolution

B. Measurement Error Tenets

No measurement is exact.
Every measurement contains errors.
The true value of a measurement is never known.
The exact error present in a measurement is unknown.

C. Error Sources

Are where errors originate.

1. Natural

2. Instrumental

3. Personal

Figure 3: Into Each Life Some Rain Must Fall

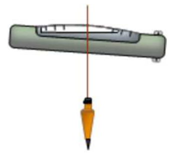


Figure 4: Bubble Run

Figure 5. Disheveled Level

D. Error Types

Are how errors behave.

1. Mistake

2. Systematic

3. Random

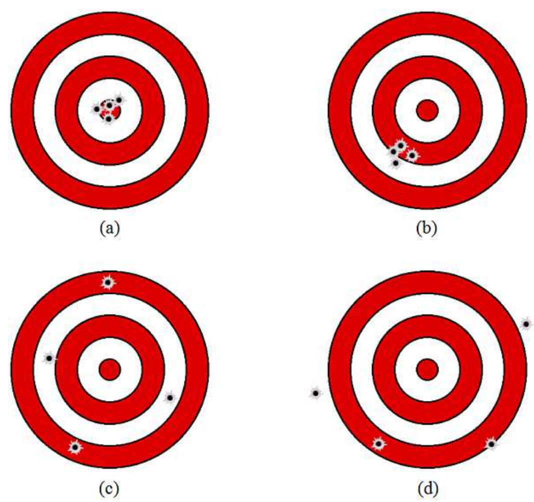


Figure 6. Errors Affecting Groupings

E. Minimizing

1. Mistake

2. Systematic

a. Adjustment

b. Computation

c. Procedure

3. Random

- Appropriate equipment
- Knowledgeable personnel
- Favorable conditions
- Repeat measurements

F. Random Errors

1. Behavior

Most probable value

$$MPV = \frac{\sum m}{n}$$

Eqn 1

Residual

$$v = MPV - m$$

Eqn 2

Least Squares

$$\sum(v^2) = \min$$

Eqn 3

Standard deviation

$$\sigma = \sqrt{\frac{\sum(v^2)}{n-1}}$$

Eqn 4

Precision indication

Std Error Of the Mean

$$E_{MPV} = \frac{\sigma}{\sqrt{n}}$$

Eqn 5

Accuracy indicator

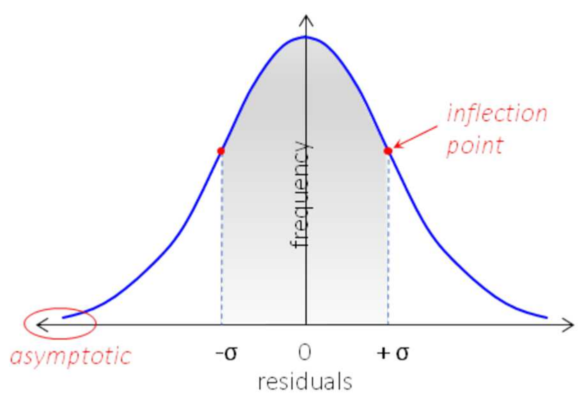


Figure 7: Normal Distribution Curve

2. Simple Error Propagation

a. Error of a Sum

$$E_{sum} = \sqrt{E_1^2 + E_2^2 + \cdots + E_n^2}$$

Eqn 6

b. Error of a Series

$$E_{series} = E\sqrt{n}$$

Eqn 7

If all the individual errors in a summations are the same, the Error of a Sum becomes the same as the Error of a Series.

II. Equipment

A. Basics

1. Bubbles & Axes

Axis of the bubble tube (ABT)
Vertical axis
Horizontal axis

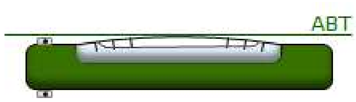


Figure 8: Bubble Tube

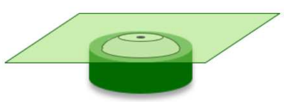


Figure 9: Circular Bubble

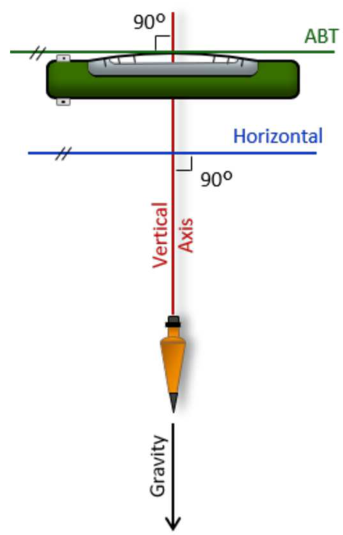


Figure 10: Relationships

2. Optics; Parallax

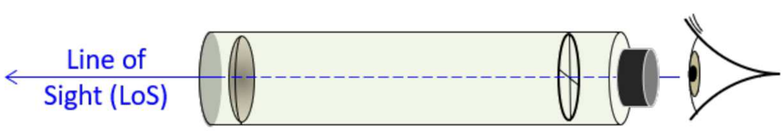


Figure 11: Line of Sight

3. Reversion principle

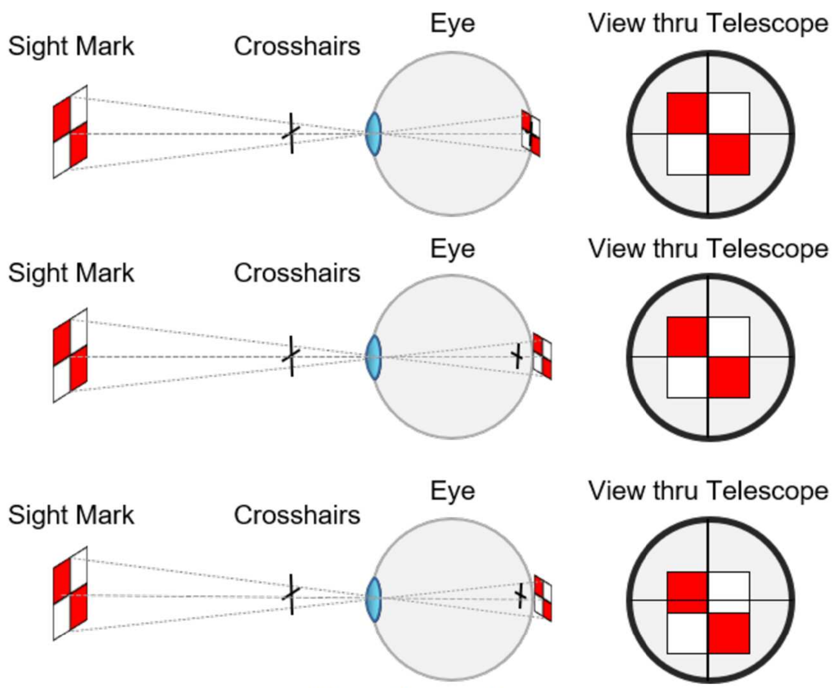


Figure 12: Parallax

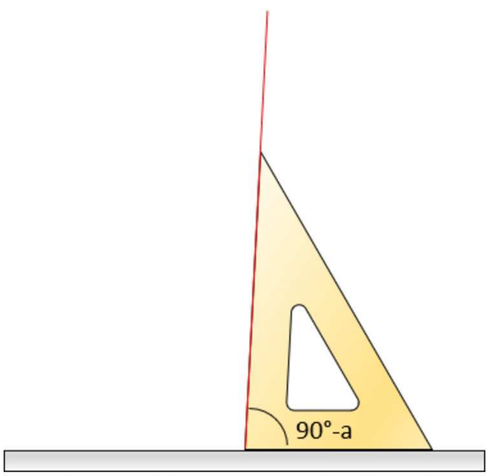


Figure 13: Reversion - Position 1

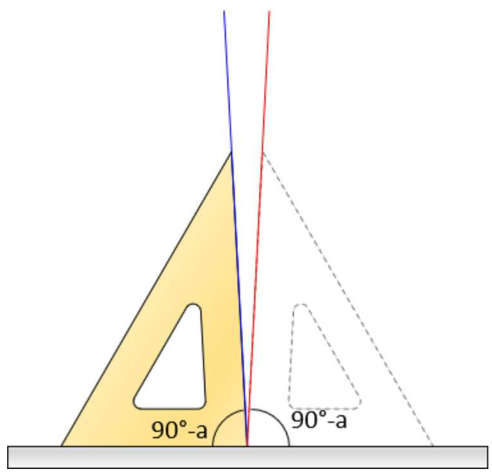


Figure 14: Reversion - Position 2

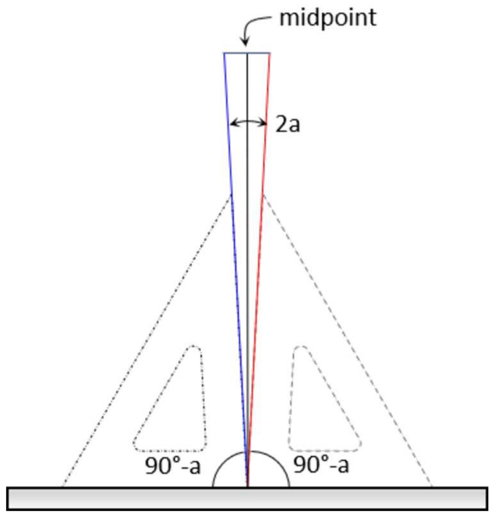


Figure 15: Reversion - Error Present

B. Automatic Level

1. Axes

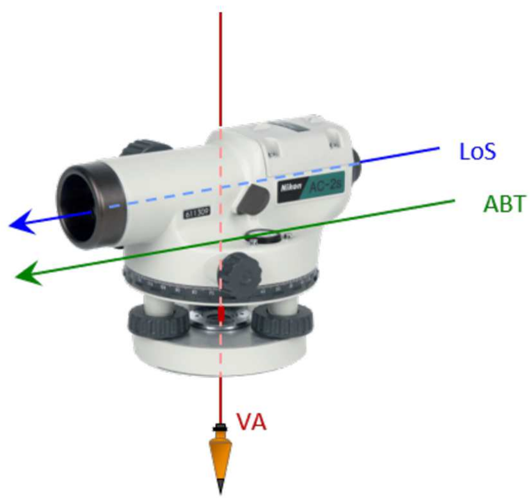


Figure 16: Level Axes

2. Natural Errors

Error	Type	Compensation
Wind	M S R	
Atmospheric distortion	M S R	

Error	Type	Compensation
Atmospheric refraction	M S R	Math: $R=-0.0033\times F^2=-0.093\times M^2$ *Eqn 8* F: 1000s ft; M: 1000s meters Procedure: Balance BS & FS distances Adjust: N/A

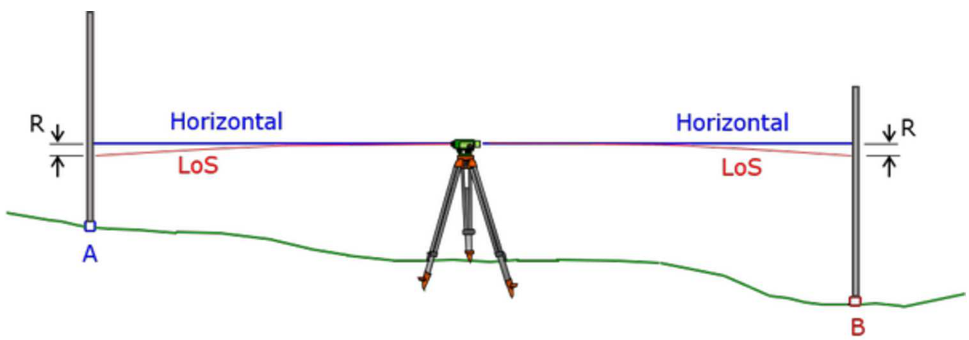


Figure 17: Refraction

Error	Type	Compensation
Curvature	M S R	Math: $C=0.0239\times F^2=0.667\times M^2$ *Eqn 9* F: 1000s ft; M: 1000s meters Procedure: Balance BS & FS distances Adjust: N/A

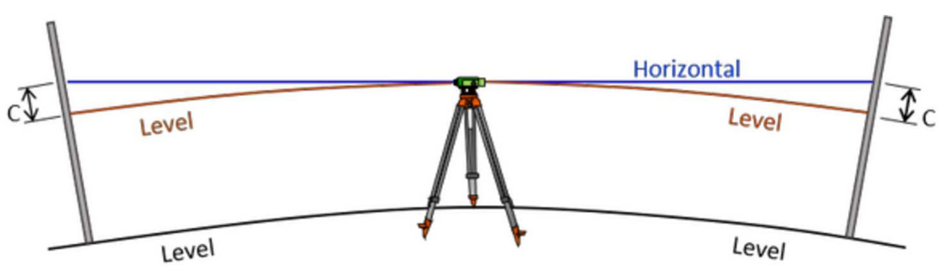


Figure 18: Curvature

3. Instrumental Errors

Error	Type	Compensation
Compensator	M S R	Math: N/A

Error	Type	Compensation
		Procedure: N/A
		Adjust: N/A

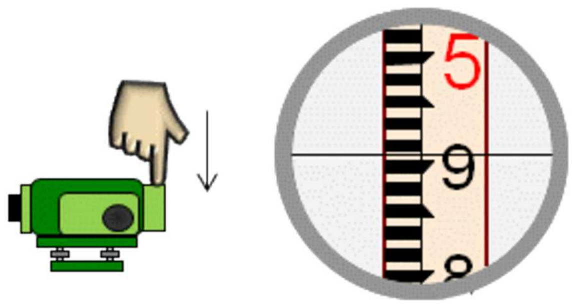


Figure 19: Compensator Check

Error	Type	Compensation
Crosshairs	M S R	Math: N/A
		Procedure: Read with center of crosshairs.
		Adjust: Rotate reticule.

Procedure:

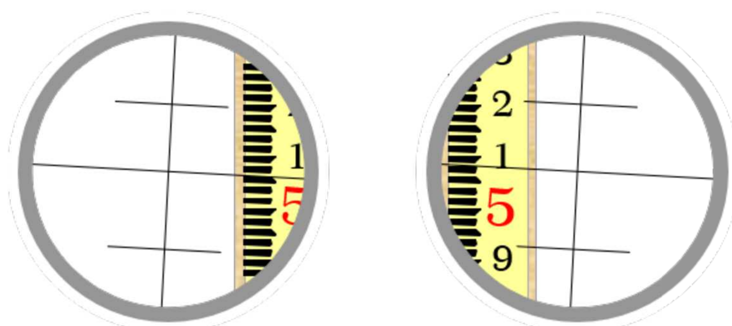


Figure 20: Crosshairs

Error	Type	Compensation
Collimation	M S R	Math: Perform collimation test to determine correction. Apply correction to each BS and FS.
		Procedure: Balance BS and FS distances.
		Adjust: Perform collimation test to determine correction. Shift reticule up/down to apply correction.

Error	Type	Compensation

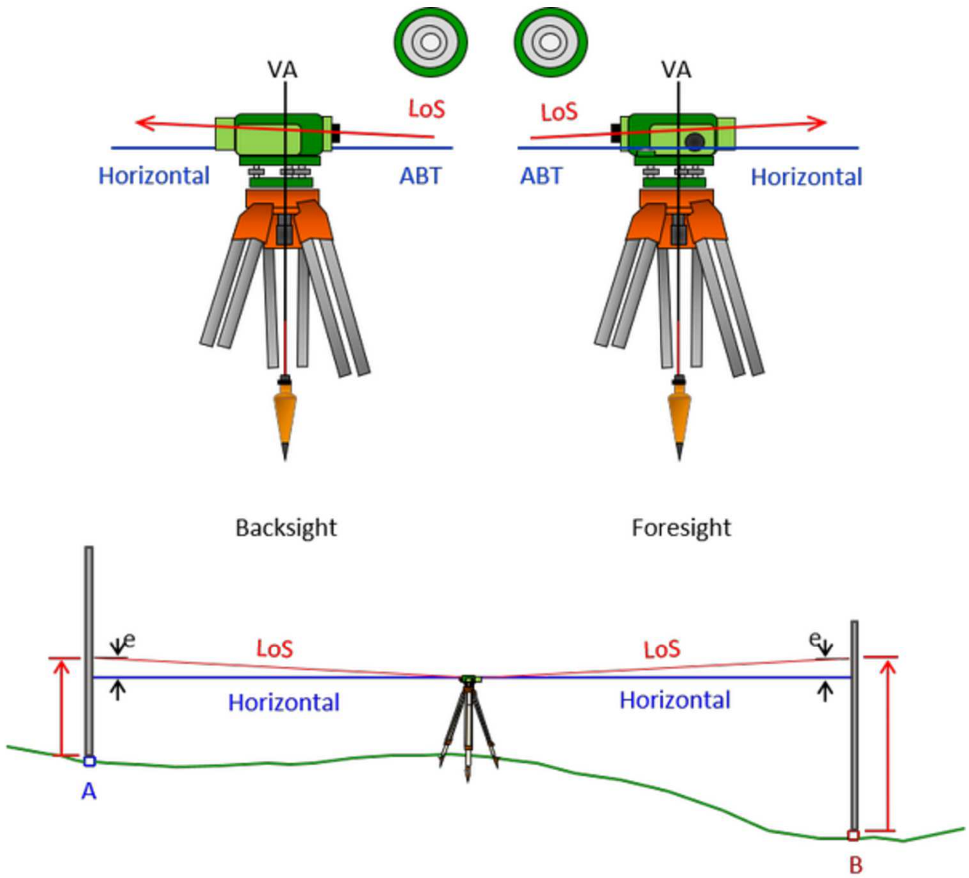


Figure 21: Collimation

4. Personal Errors

Error	Type	Compensation
Set up	M S R	
Parallax	M S R	
Field notes	M S R	
Computations	M S R	
Rod Reading	M S R	

Error	Type	Compensation

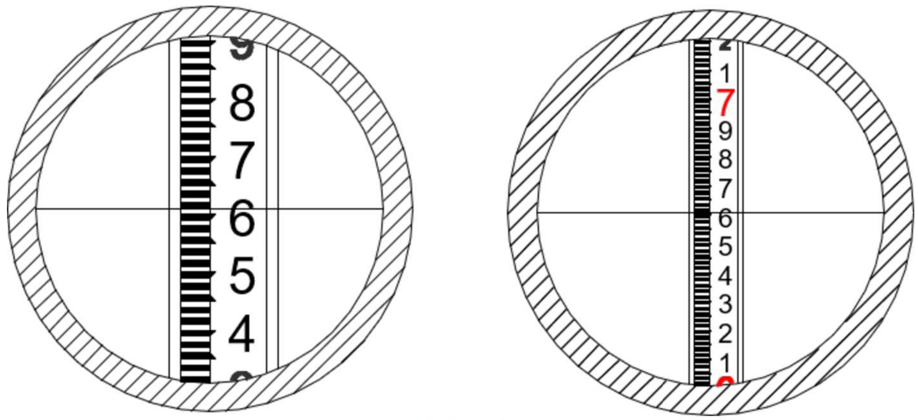


Figure 22: Reading Error

Rod not vertical	M S R	Procedure: Rock the rod or use rod bubble.

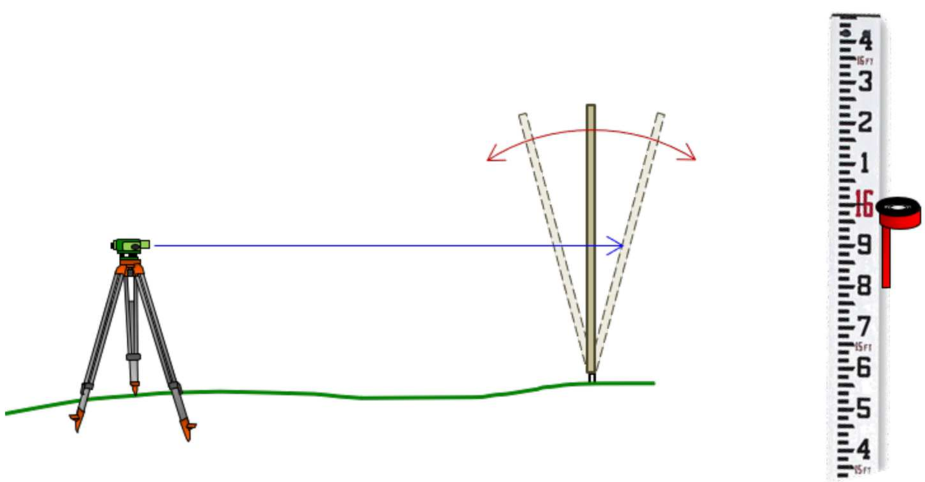


Figure 23: Plumbing Rod

Rod not fully extended	M S R	

5. Random Error Propagation

$$Elev_B = Elev_A + BS_A - FS_B$$

Eqn 10

Error of a sum

$$E_B = \sqrt{E_{BS}^2 + E_{FS}^2}$$

Eqn 11

Example: Figure 24 shows a level circuit running from BM Sam to BM Phil. The tripod icons indicate instrument set ups. The numbers at each set up are the expected BS and FS errors.

What is the expected circuit misclosure?

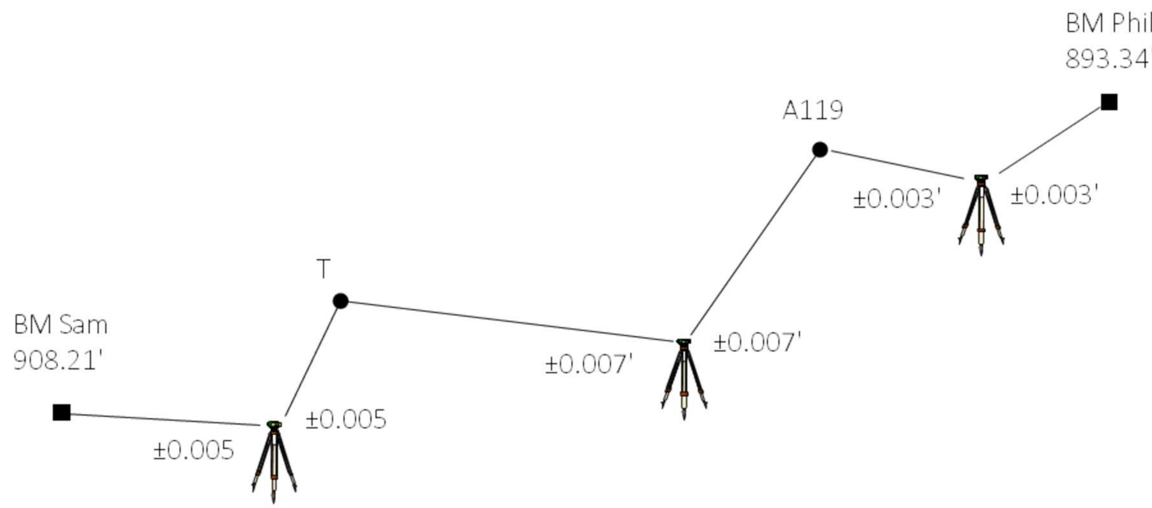


Figure 24: Example Level Circuit

C. Total Station Instrument (TSI)

1. Axes

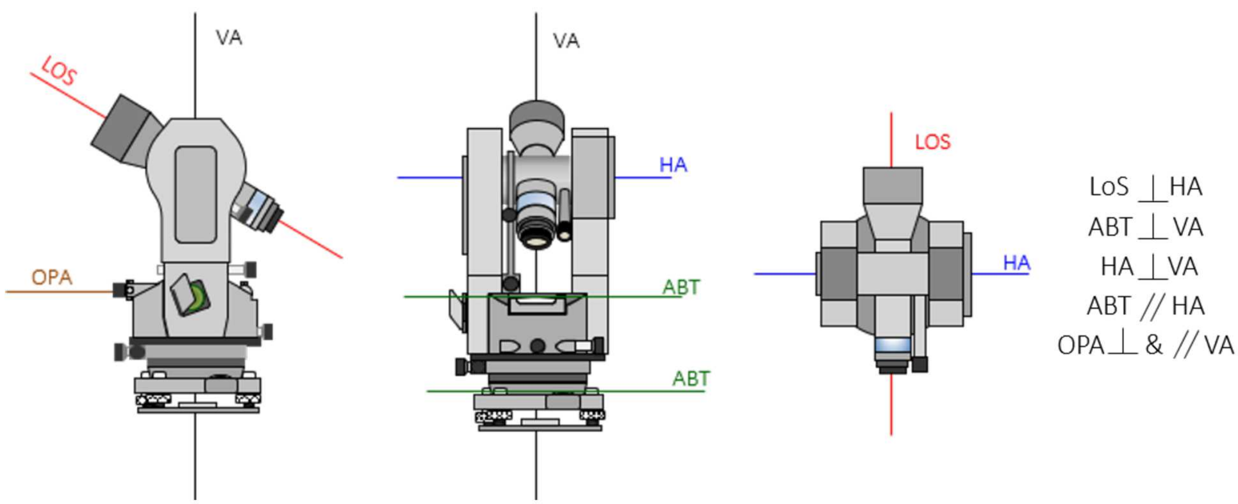


Figure 25: Axes and Relationships

HA - Horizontal axis
OPA - Optical plummet axis

2. Natural Errors

Error	Type	Compensation
Wind	M S R	
Atmospheric distortion		

Error	Type			Compensation	
▪ General	M	S	R		
▪ Distance meas	M	S	R	Math:	Compute and apply ppm correction
				Procedure:	N/A
				Adjust:	N/A

$$ppm = 278.96 - \frac{10.5 \times P}{1 + 0.002175 \times T}$$

Eqn 12

$$D = D' \times \left(1 + \frac{ppm}{1,000,000}\right)$$

Eqn 13

Refraction and curvature	M	S	R	Math:	Compute and apply correction
				Procedure:	N/A
				Adjust	N/A

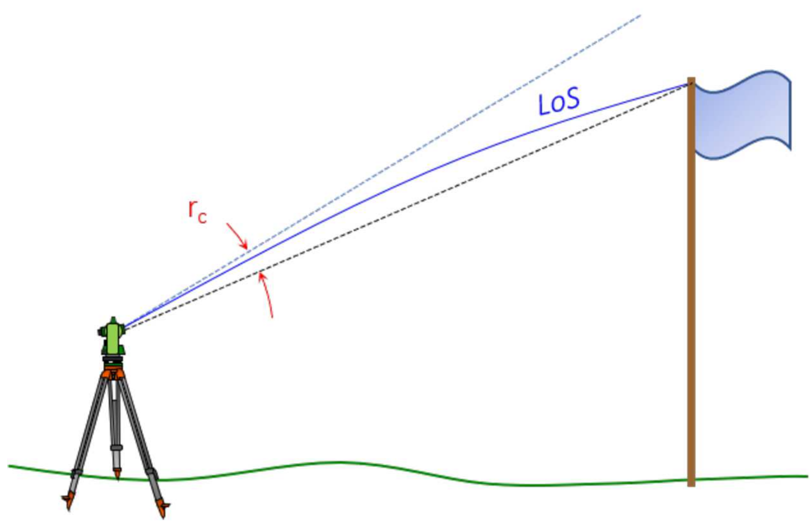


Figure 26: Refraction

Error	Type	Compensation

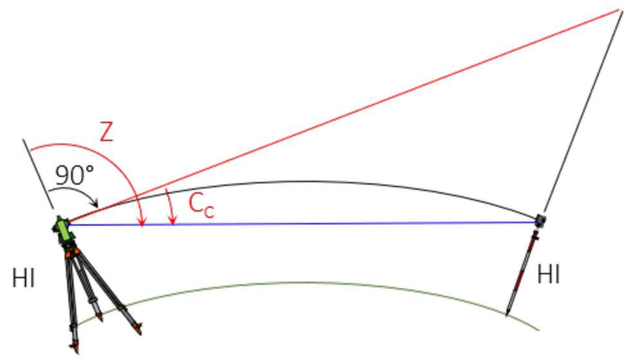


Figure 27: Curvature

$$H = S \times \sin(Z) - \left[\frac{S^2 \times \sin(2 \times Z) \times \left(1 - \frac{k}{2}\right)}{2 \times R}\right]$$

Eqn 14

$$V = S \times \cos(Z) + \left[\frac{S^2 \times \sin^2(Z) \times (1 - k)}{2 \times R}\right]$$

Eqn 15

3. Instrumental Errors

Error	Type			Compensation	
ABT $\not\perp$ VA					
▪ Circular bubble	M	S	R	Math:	N/A
				Procedure:	Circular bubble is used for rough leveling; use bubble tube for accurate leveling.
				Adjust:	Level the inst using the bubble tube, then adjust the circular bubble to center.
▪ Bubble tube	M	S	R	Math:	N/A
				Adjust:	Level inst by reversion.
				Procedure:	Level inst by reversion; adjust bubble to center.

Error	Type	Compensation

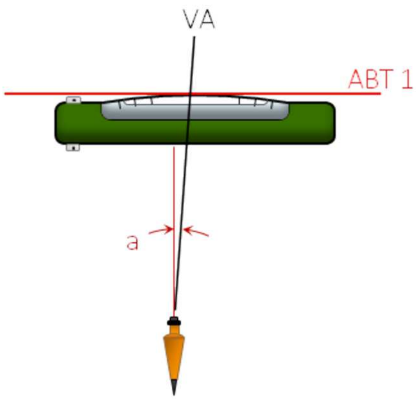


Figure 28 First Position

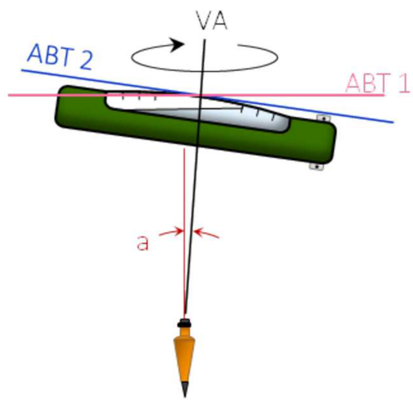


Figure 29: Reversed Position

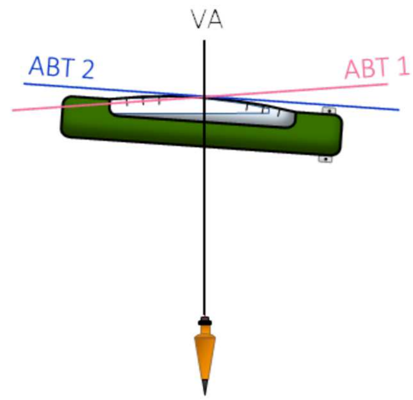


Figure 30: Leveled Instrument

OPA M S R

Math: N/A

Procedure: Method (1) Center instrument using reversion.
Method (2) Use plumb bob to center instrument.

Adjust: Method (1) Center instrument using reversion; adjust plummet mark to ground point.
Method (2) Use plumb bob to center instrument; adjust plummet mark to ground point.

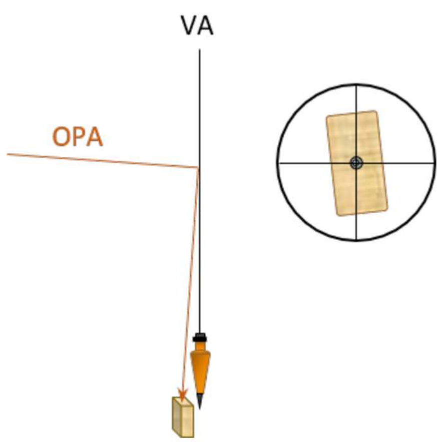


Figure 31: Maladjusted OPA

Overhead views

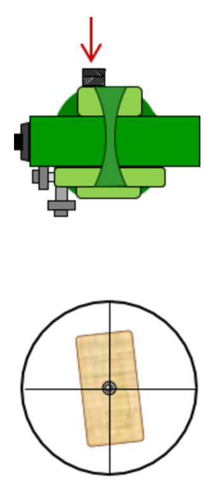


Figure 32: First Position

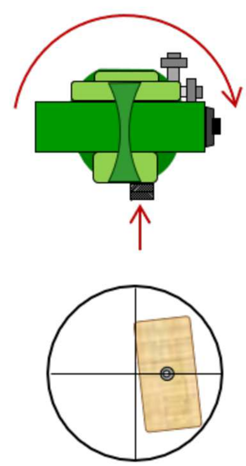


Figure 33: Reverse Position

Error	Type	Compensation

Figure 34: Actual Location

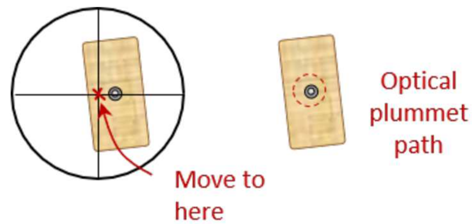


Figure 35: Adjusting Position

LoS $\not\perp$ HA M S R

Math: N/A

Procedure: Extend line by double-centering

Adjust: Use double centering to set correct point; adjust reticule horizontally to point.

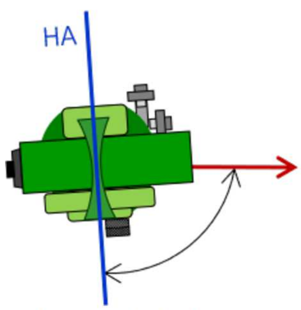


Figure 36: Maladjusted LoS

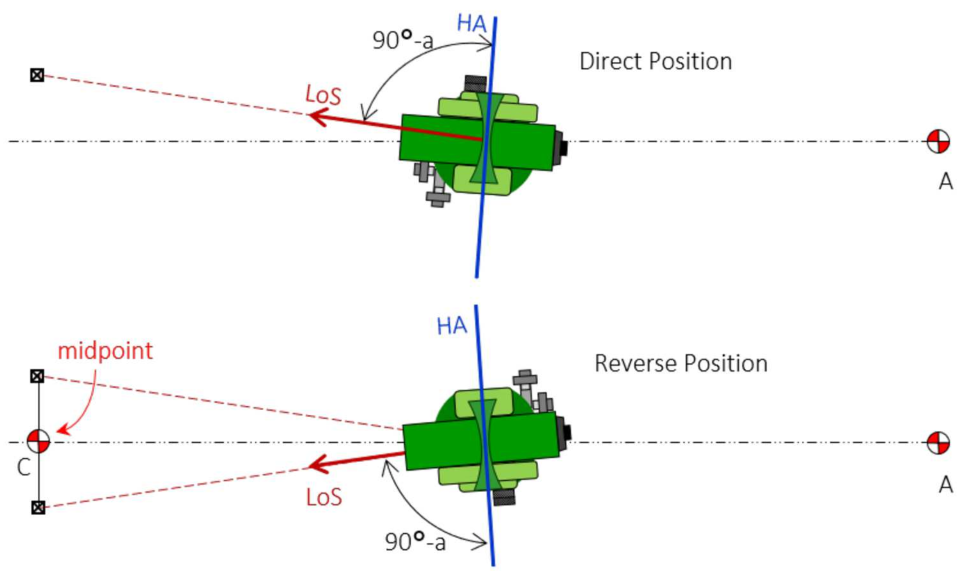


Figure 37: Double Centering

HA $\not\perp$ VA M S R

Math: N/A

Procedure: Measure angles direct and reverse; take average.

Adjust: Most modern total stations have dual axis compenstation to accomodate some maladjustment.

Error	Type	Compensation

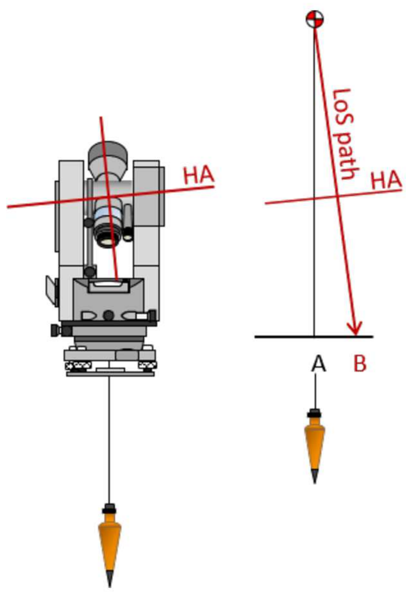


Figure 38: Direct

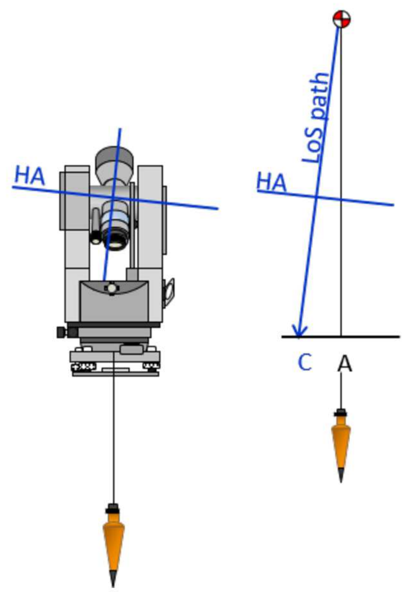


Figure 39: Reverse

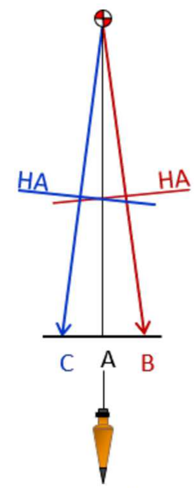


Figure 40: Average

Error	Type	Compensation	
Combined constant (distances)	M S R	Math:	Manually correct distances.
		Procedure:	Set constant in instrument.
		Adjust:	N/A

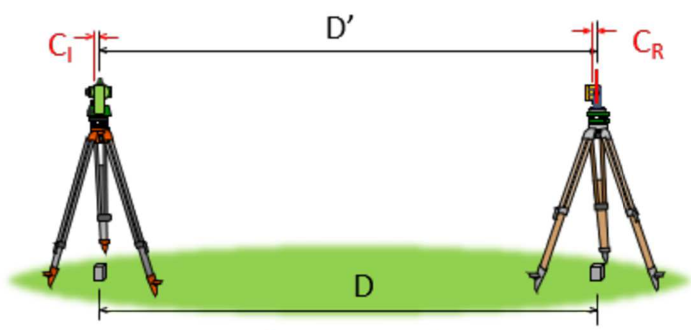


Figure 41: Combined Constant

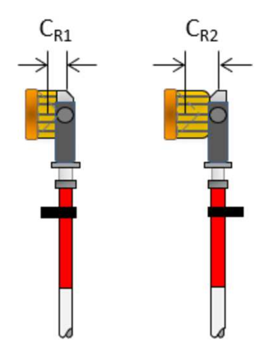
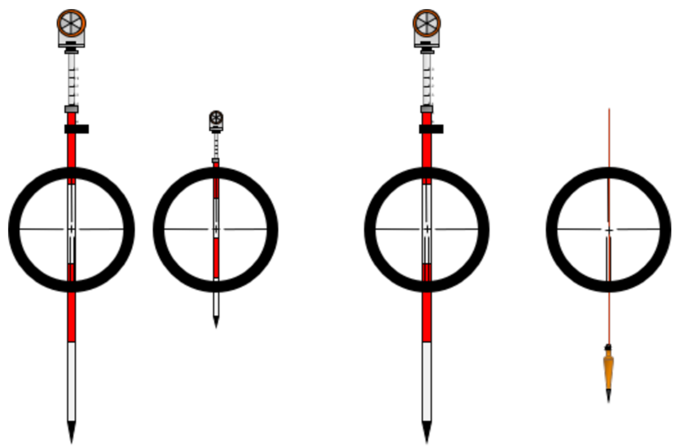


Figure 42: Reflector Offsets

4. Personal Errors

Error	Type	Compensation
Set up		
▪ Instrument	M S R	
▪ Target(s)	M S R	
Parallax		

Error	Type	Compensation
▪ Telescope	M S R	
▪ Optical plummet	M S R	
Pointing	M S R	 *Figure 43: Pointing Errors*
Notes	M S R	
Temp & press determination	M S R	

5. Random Error Propagation

a. Distance measurement

Manufacturer Stated Accuracy (MSA) and setup centering errors.

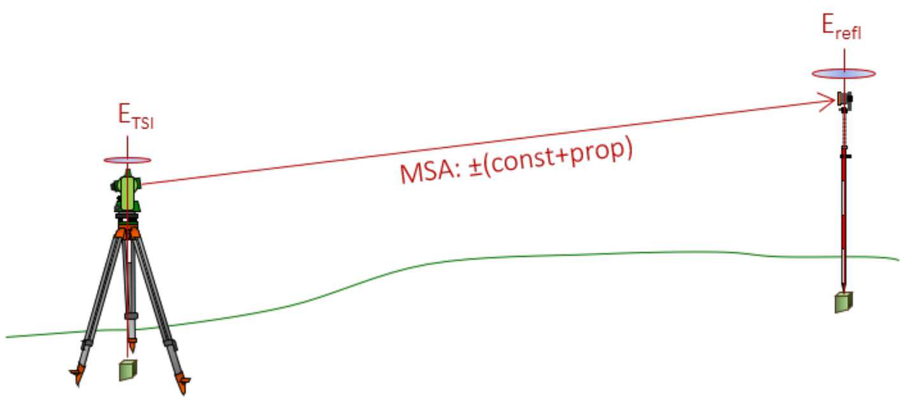


Figure 44: Distance Error

Error of a sum.

$$E_{Dist} = \sqrt{E_{TSI}^2 + E_{const}^2 + E_{prop}^2 + E_{refl}^2}$$

Eqn 16

E_{Dist}	Expected distance error
E_{TSI}	TSI centering error
E_{const}	MSA constant
E_{prop}	MSA proportional contribution
E_{refl}	Reflector centering error

Example

Measured 600.00 ft distance, instrument MSA ±(2 mm+2 ppm); 0.005 ft instrument centering error, reflector on pole has 0.01 ft centering error.

Distance error?

b. Angle measurement

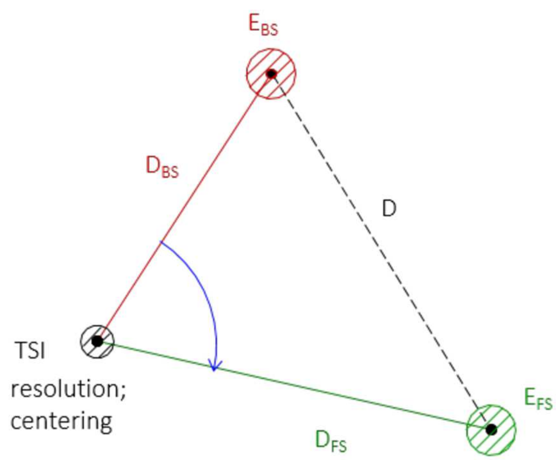


Figure 45. Horizontal Angle Error

TSI Point and Read

$$E_{pr} = \frac{2 \times E_{DIN}}{\sqrt{n}}$$

Eqn 17

TSI Centering

$$E_{tsi} = \frac{D \times E_i}{D_{BS} D_{FS} \sqrt{2}} \times \frac{206{,}264.8 \text{ sec}}{\text{radian}}$$

Eqn 18

Targent Centering

$$E_t = \sqrt{\left(\frac{E_{BS}}{D_{BS}}\right)^2 + \left(\frac{E_{FS}}{D_{FS}}\right)^2} \times \frac{206{,}264.8 \text{ sec}}{\text{radian}}$$

Eqn 19

Angle Error

$$E_{ang} = \sqrt{E_{pr}^2 + E_{tsi}^2 + E_t^2}$$

Eqn 20

E_{DIN}	Instrument DIN angle specification
n	Number of repetitions
E_{BS}, E_{FS}	BS & FS centering errors

Example:

A TSI with DIN spec of 2 sec; ; centering error: ±0.005 ft

BS & FS centering errors: ±0.005 ft & ±0.01 ft;

BS & FS dists: 176 ft & 243 ft.

Angle was measured 2 D/R to get 123°30'10"

What is the expected error in the angle?