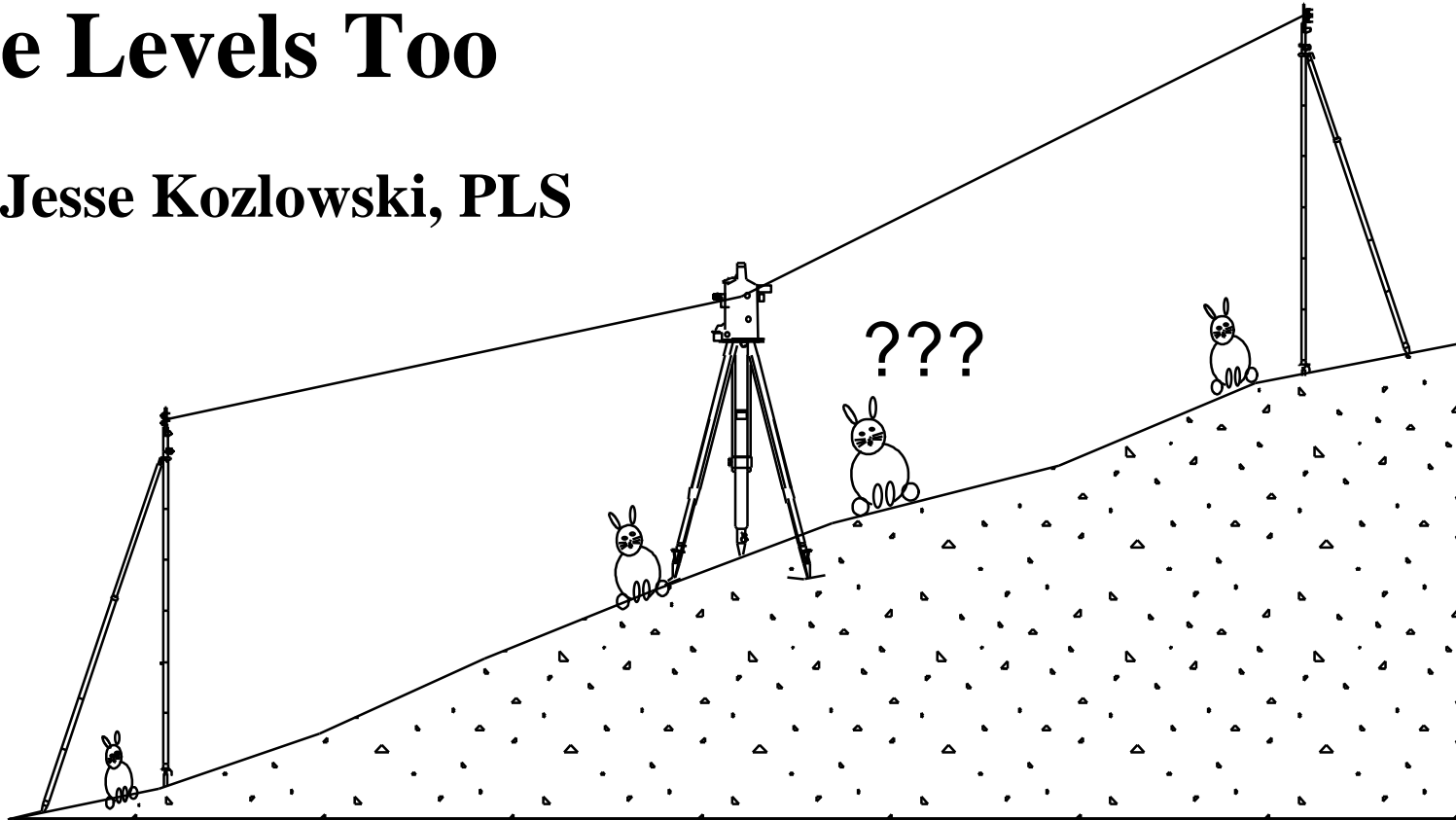


# Electronic Total Stations Are Levels Too

By Jesse Kozlowski, PLS



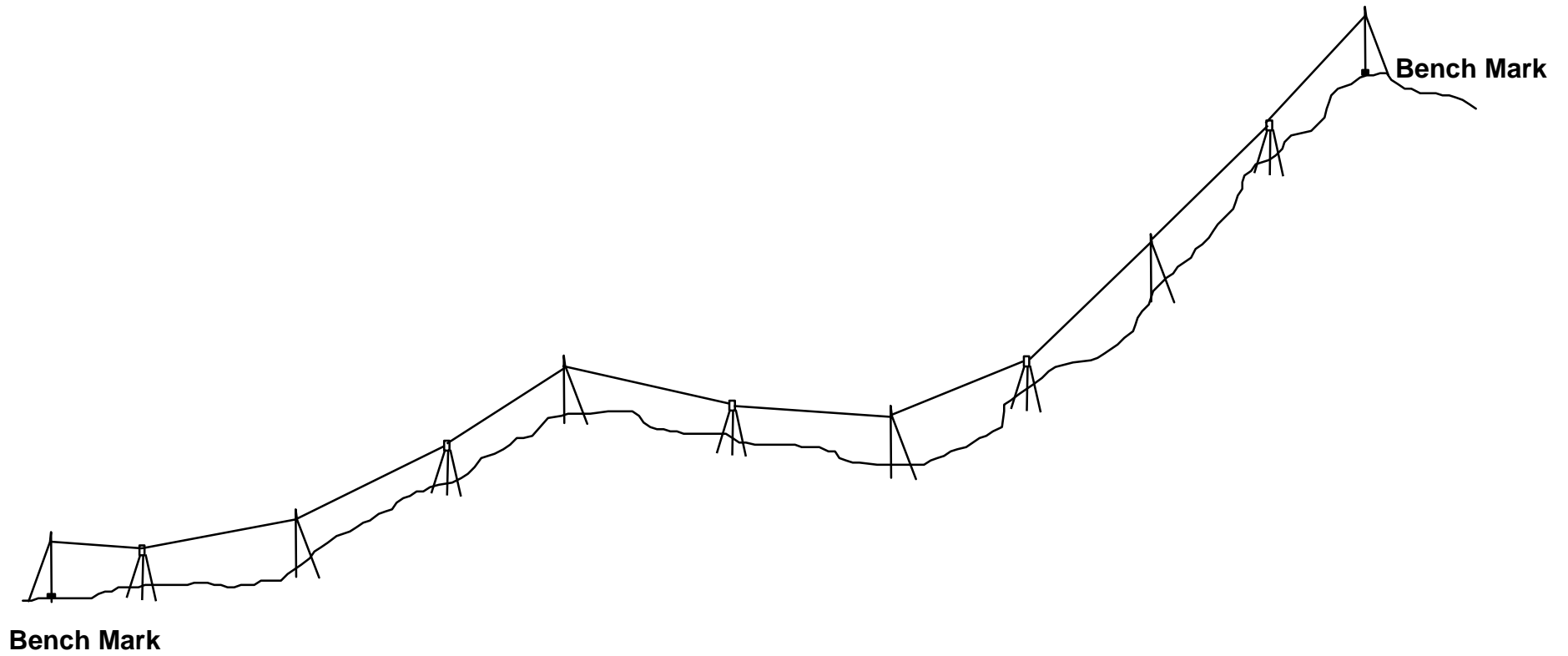
*Precise Trigonometric Leveling Using  
Modern Total Station Instruments*

# Acknowledgments:

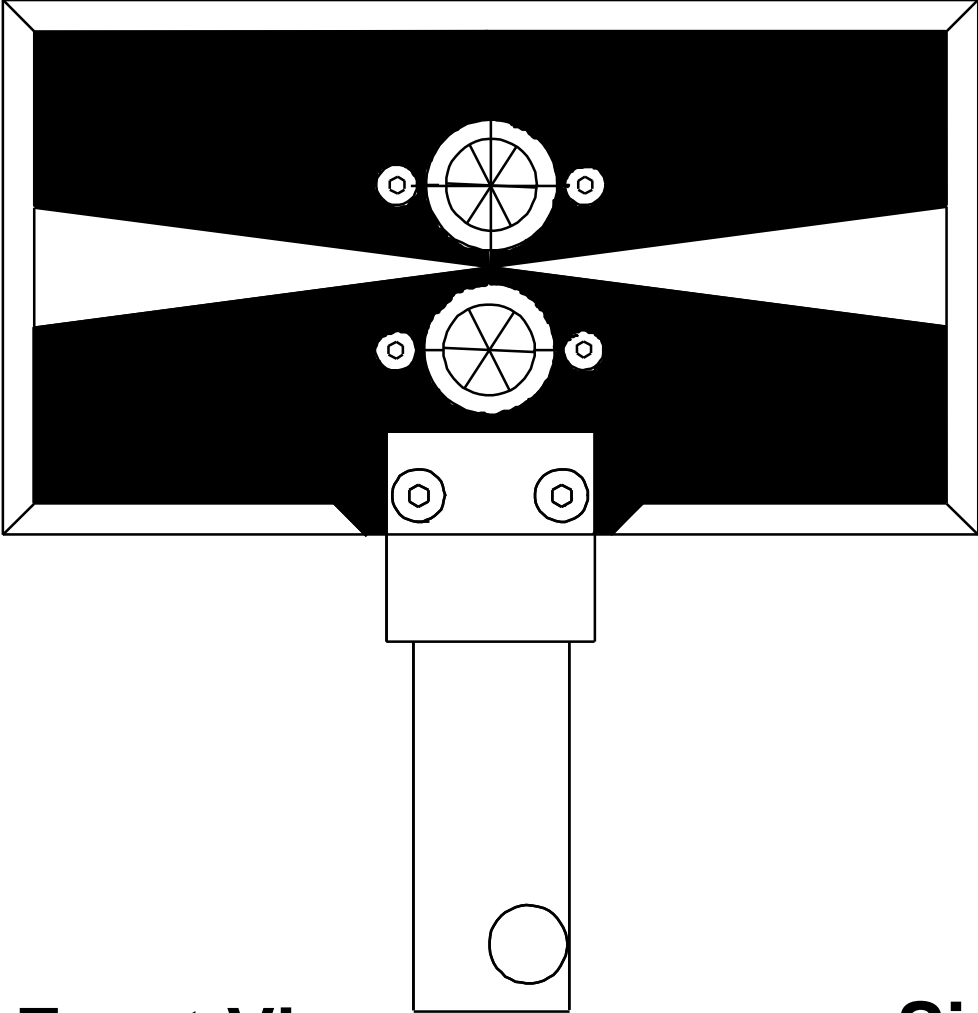
**Charlie C. Glover – The authority on Precise Trig Leveling. I learned this method from Charlie when he was a Geodetic Technician with the National Geodetic Survey working at the Instrumentation and Methodologies Branch located in Corbin, Virginia.**

**Orland (Audie) W. Murray – Audie is a Geodetic Technician with the National Geodetic Survey working at the Instrumentation and Methodologies Branch located in Corbin, Virginia. He created all of the diagrams in AutoCAD to scale. These were imported into this MS Power Point as DXF files and then re-worked.**

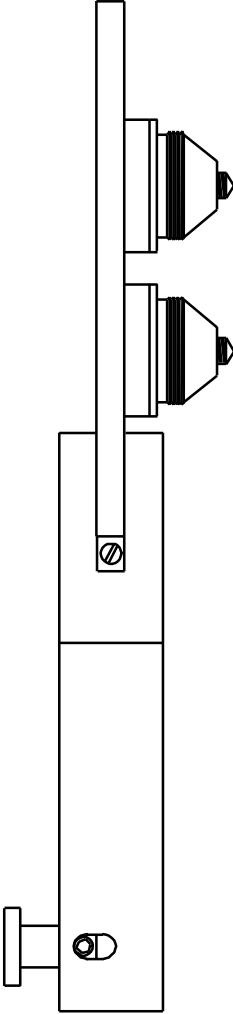
# Trigonometric Leveling



# Trigonometric Leveling Target

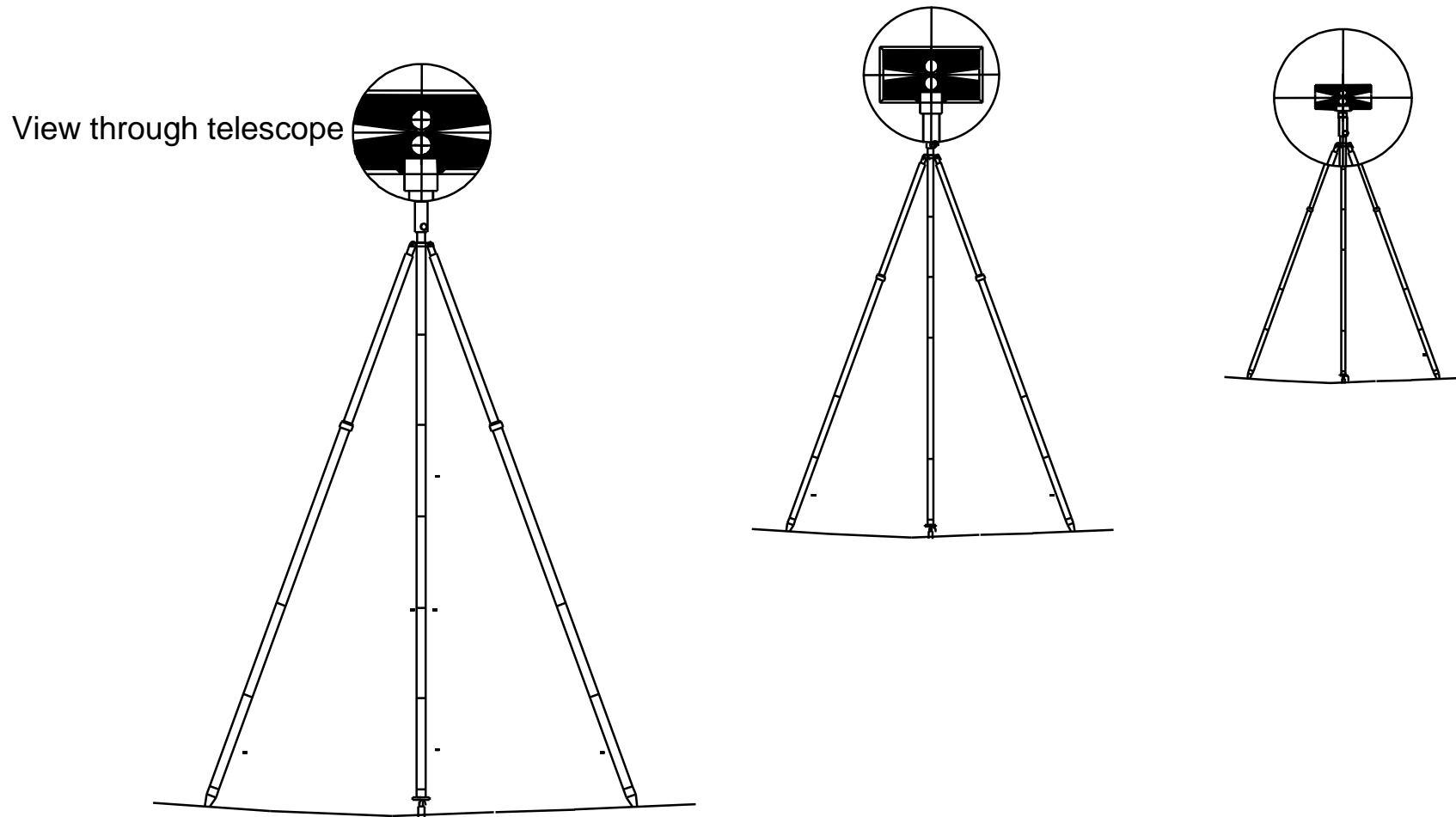


**Front View**



**Side View**

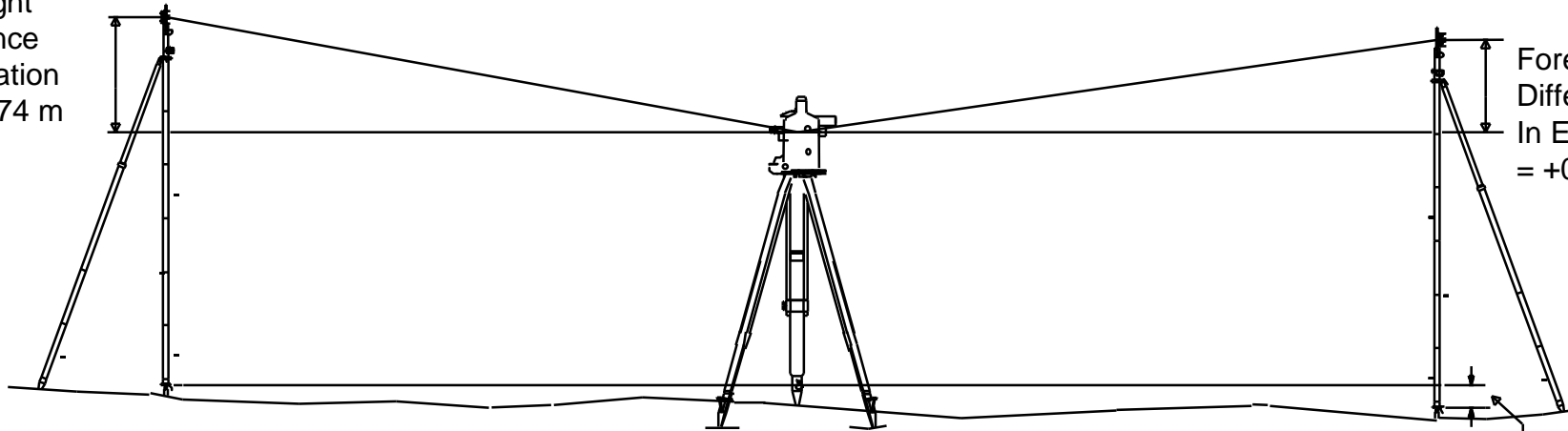
# Trig-Target Views At Various Distances



# Trigonometric Leveling

## Level Ground

Backsight  
Difference  
In Elevation  
= + 1.174 m



Foresight  
Difference  
In Elevation  
= +0.752 m

Difference In Elevation (DE)  
Backsight (BS) To Foresight (FS)  
 $DE = FS - BS$   
 $= + 0.752 - (+1.174)$   
 $= - 0.422 \text{ meters}$

# Observation Procedure

## Pointings - 2 Sets of D&R ZA

1 Direct on Backsite

2 Swing Alidade

3 Direct on Foresite

4 Plunge Scope

5 Reverse on Foresite

6 Swing Alidade

7 Reverse on Backsite

*That completes one set of*

*Direct and Reverse Pointings*

8 Re-point on Backsite in Reverse

9 Swing Alidade

10 Reverse on Foresite

11 Plunge Scope

12 Direct on Foresight

13 Swing Alidade

14 Direct on Backsite

## What Gets Recorded?

**Vertical Distances to the millimeter or tenth of a millimeter.**

**Be sure to record the algebraic sign!!!**

**Slope Distances to the nearest decimeter just to keep track of the distance traveled.**

**Make sure that all the necessary corrections are being applied!!!**

**Temperature**

**Pressure**

**PPM**

**EDM Constant**

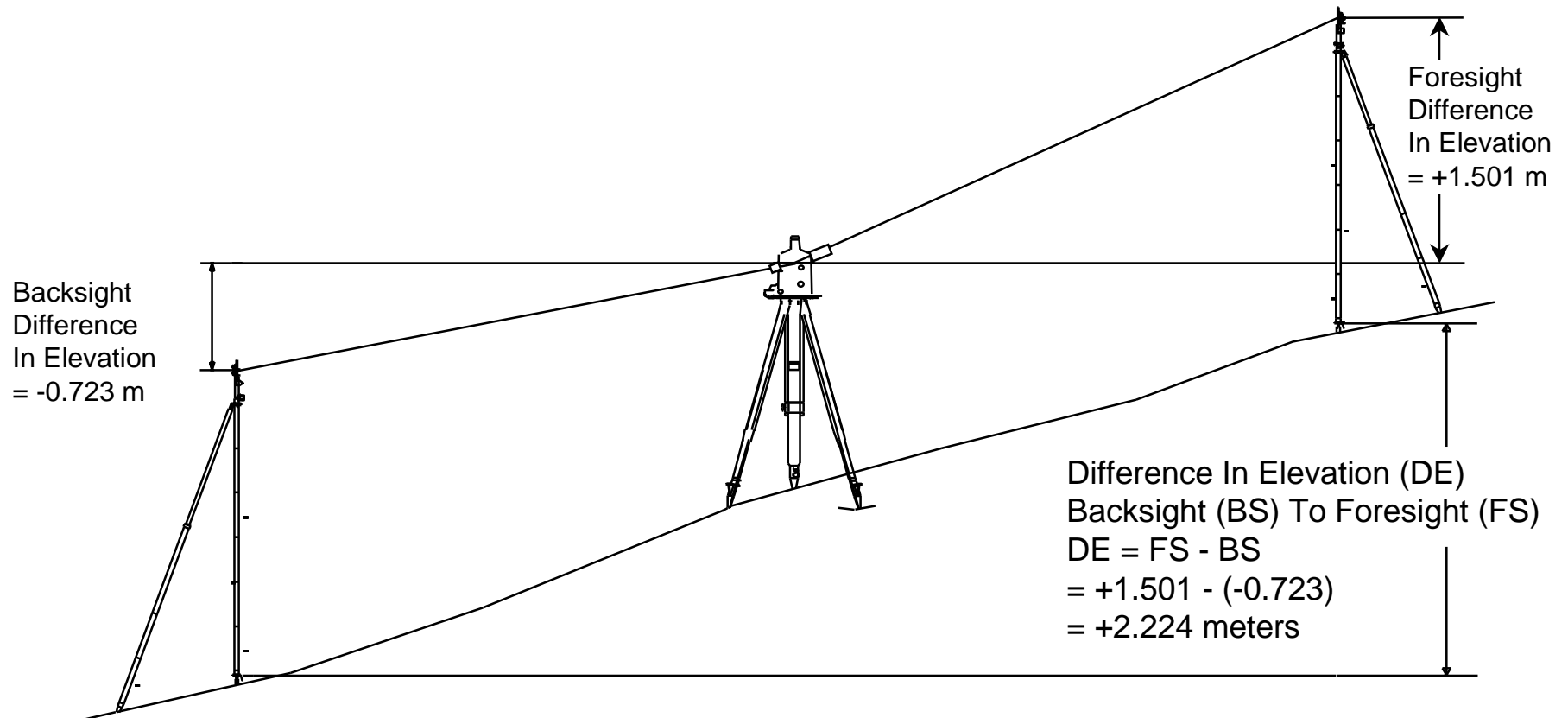
**Reflector Constant**

**Curvature and Refraction**

**A Data Collector with a Trig Leveling Routine would be great!!!!**

# Trigonometric Leveling

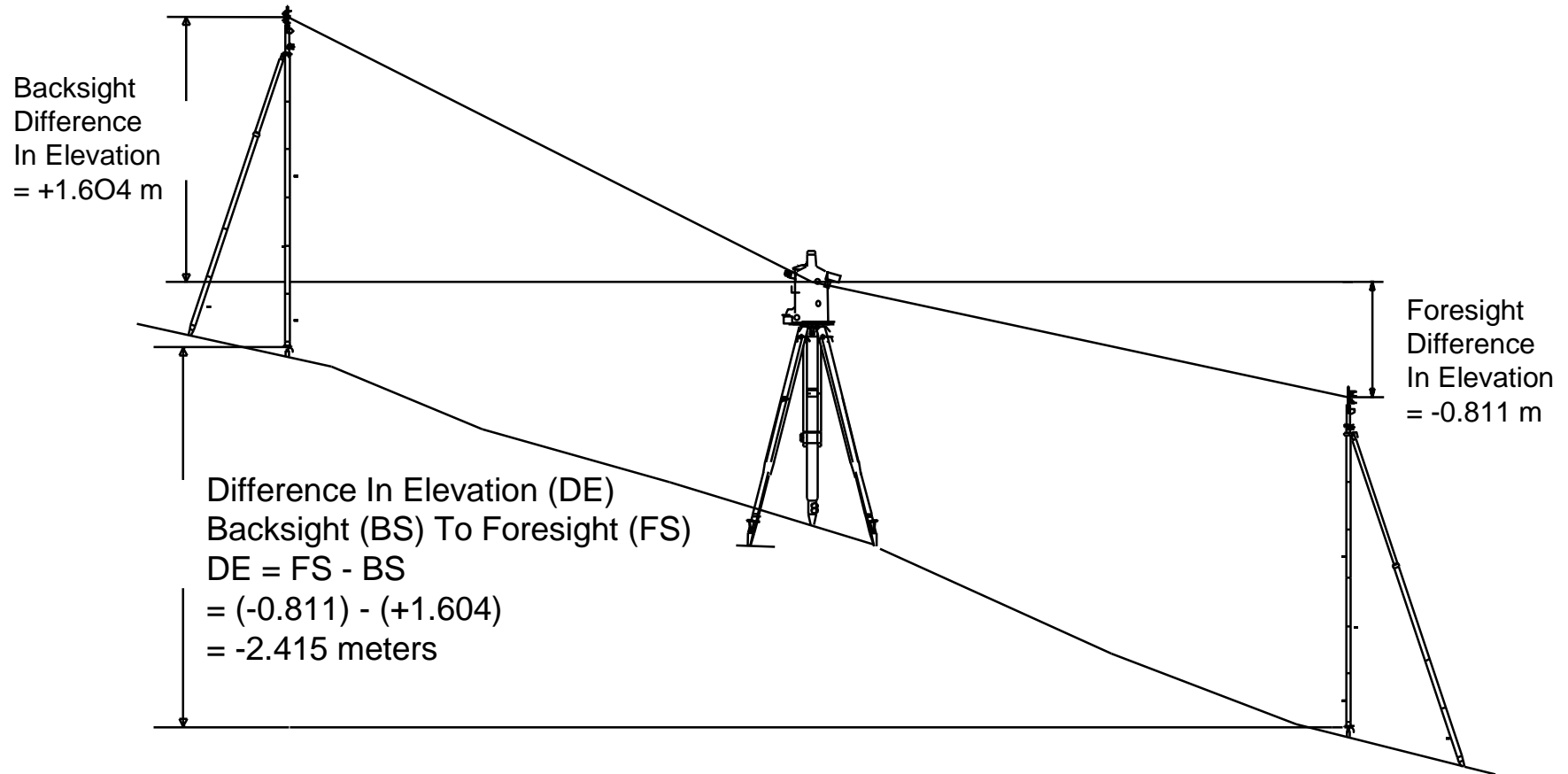
## Leveling Up Hill





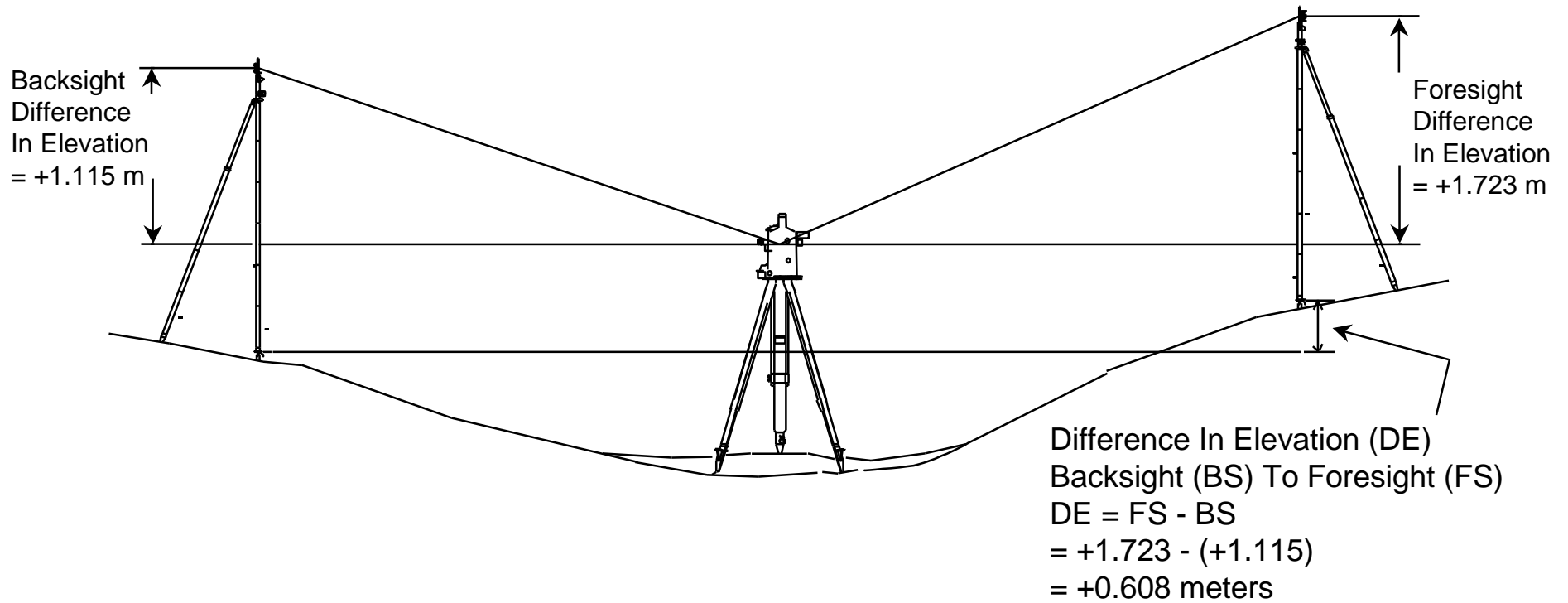
# Trigonometric Leveling

## Leveling Down Hill



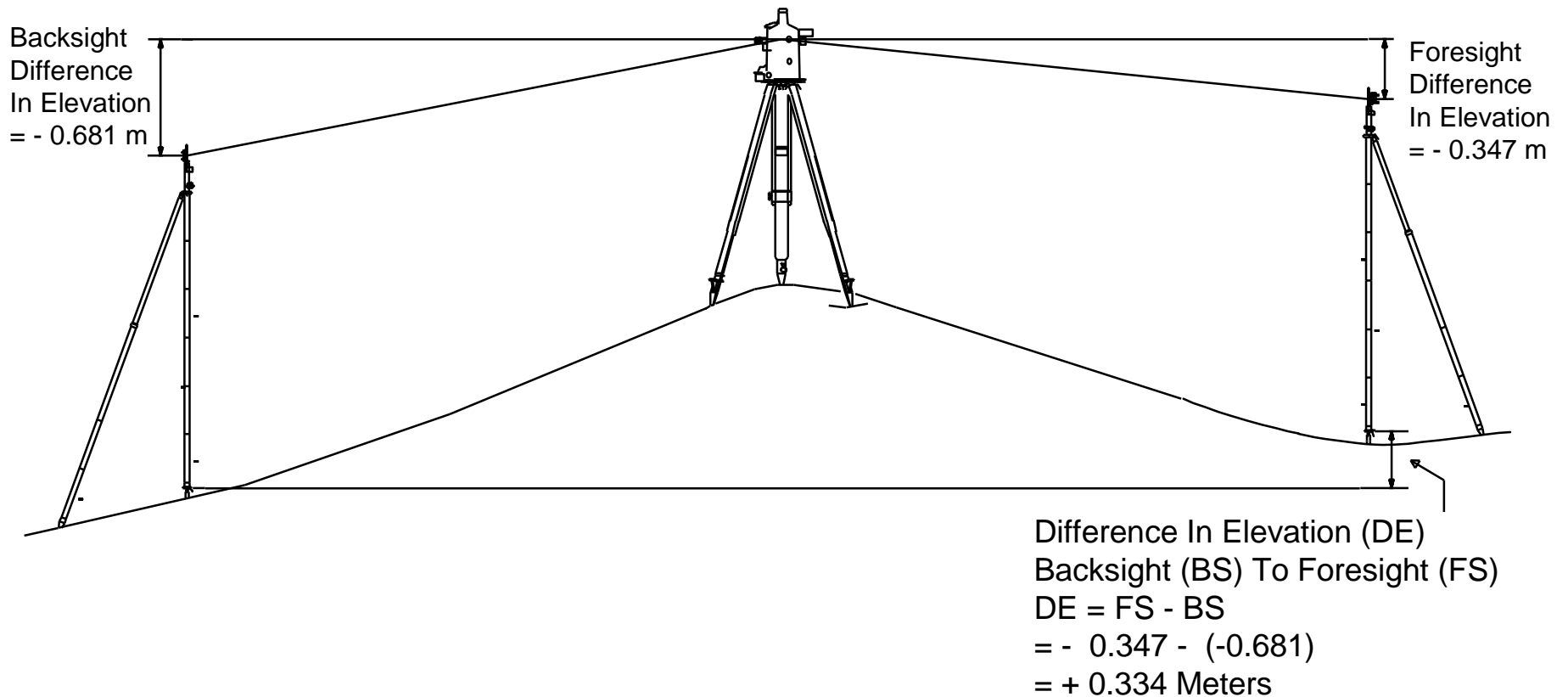
# Trigonometric Leveling

## Leveling Down and Up Hill



# Trigonometric Leveling

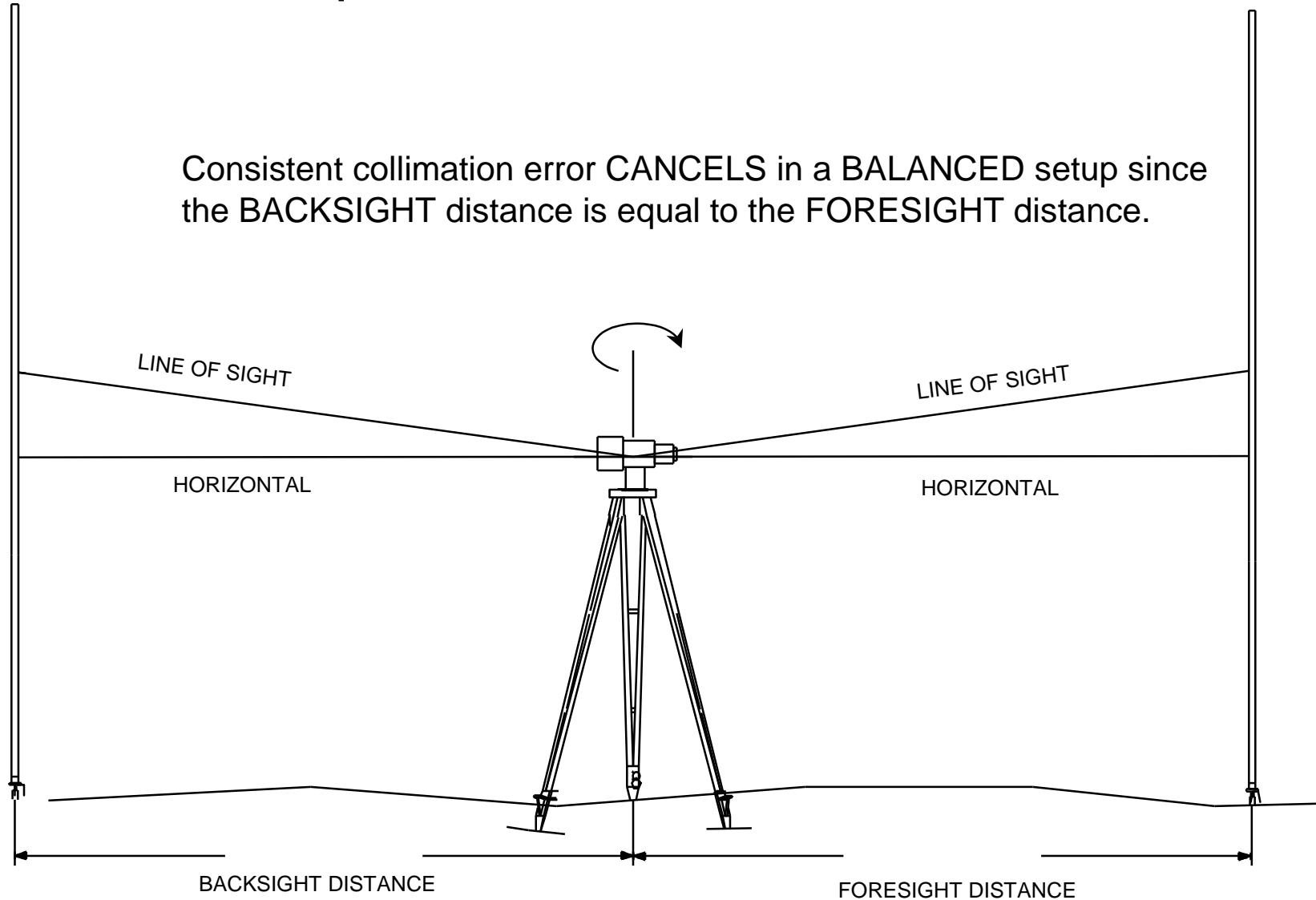
## Leveling Up and Down Hill



# Conventional Differential Leveling

## Balanced Setup

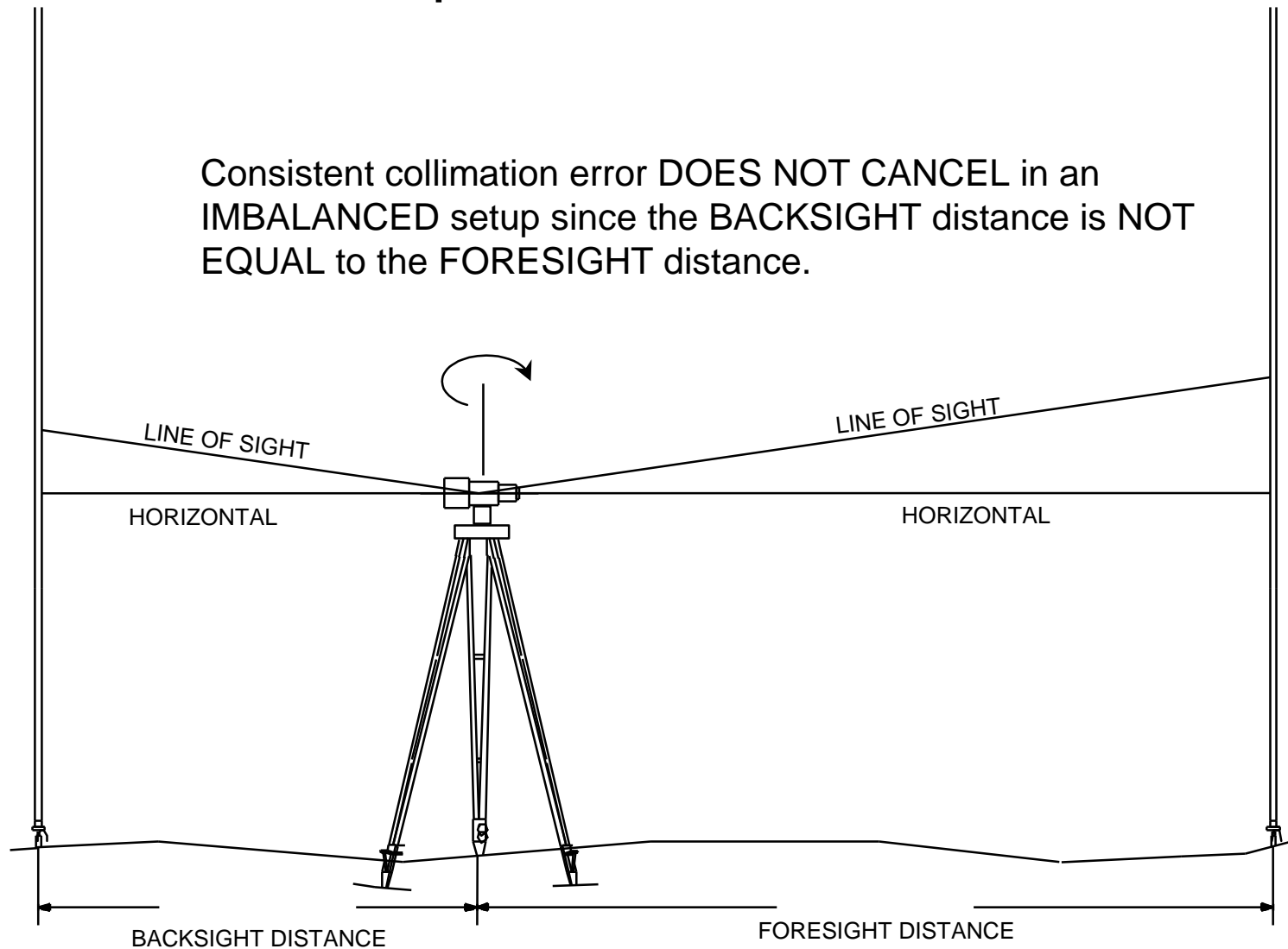
Consistent collimation error CANCELS in a BALANCED setup since the BACKSIGHT distance is equal to the FORESIGHT distance.



# Conventional Differential Leveling

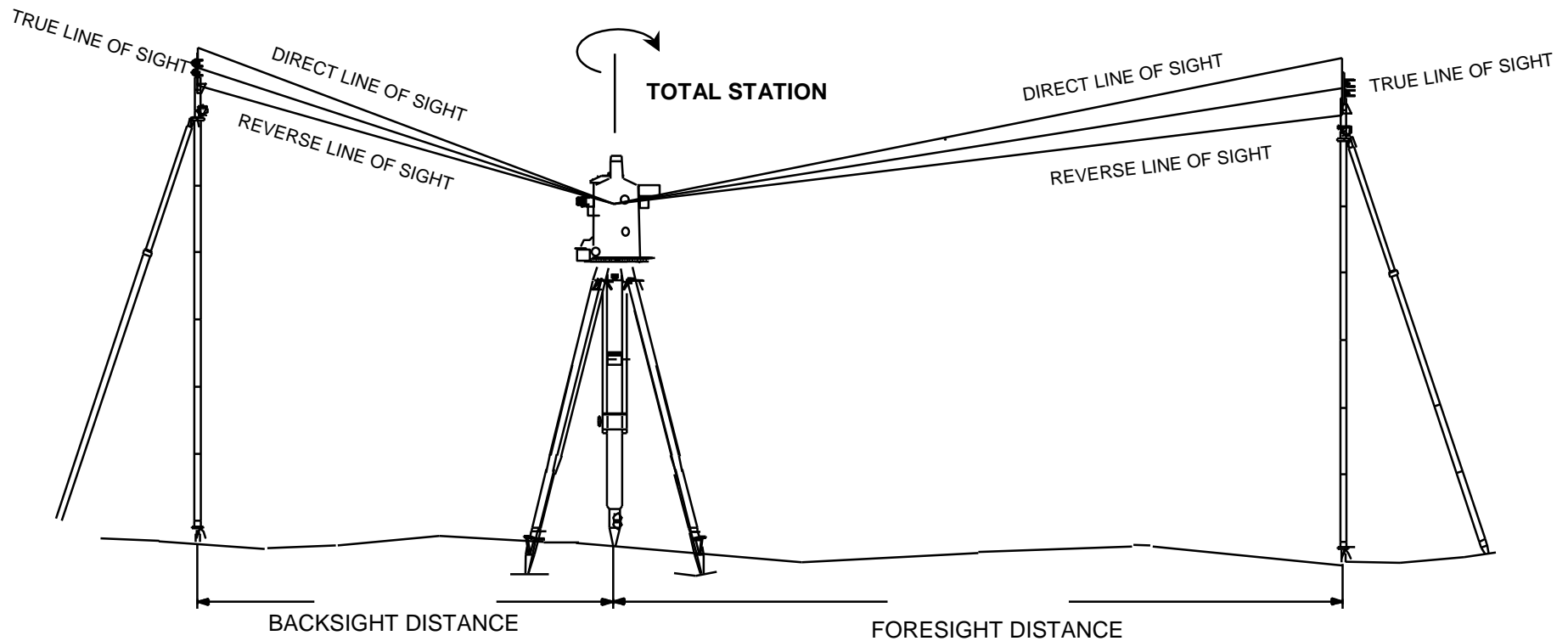
## Imbalanced Setup

Consistent collimation error DOES NOT CANCEL in an IMBALANCED setup since the BACKSIGHT distance is NOT EQUAL to the FORESIGHT distance.



# Trigonometric Leveling

## Imbalanced Setup

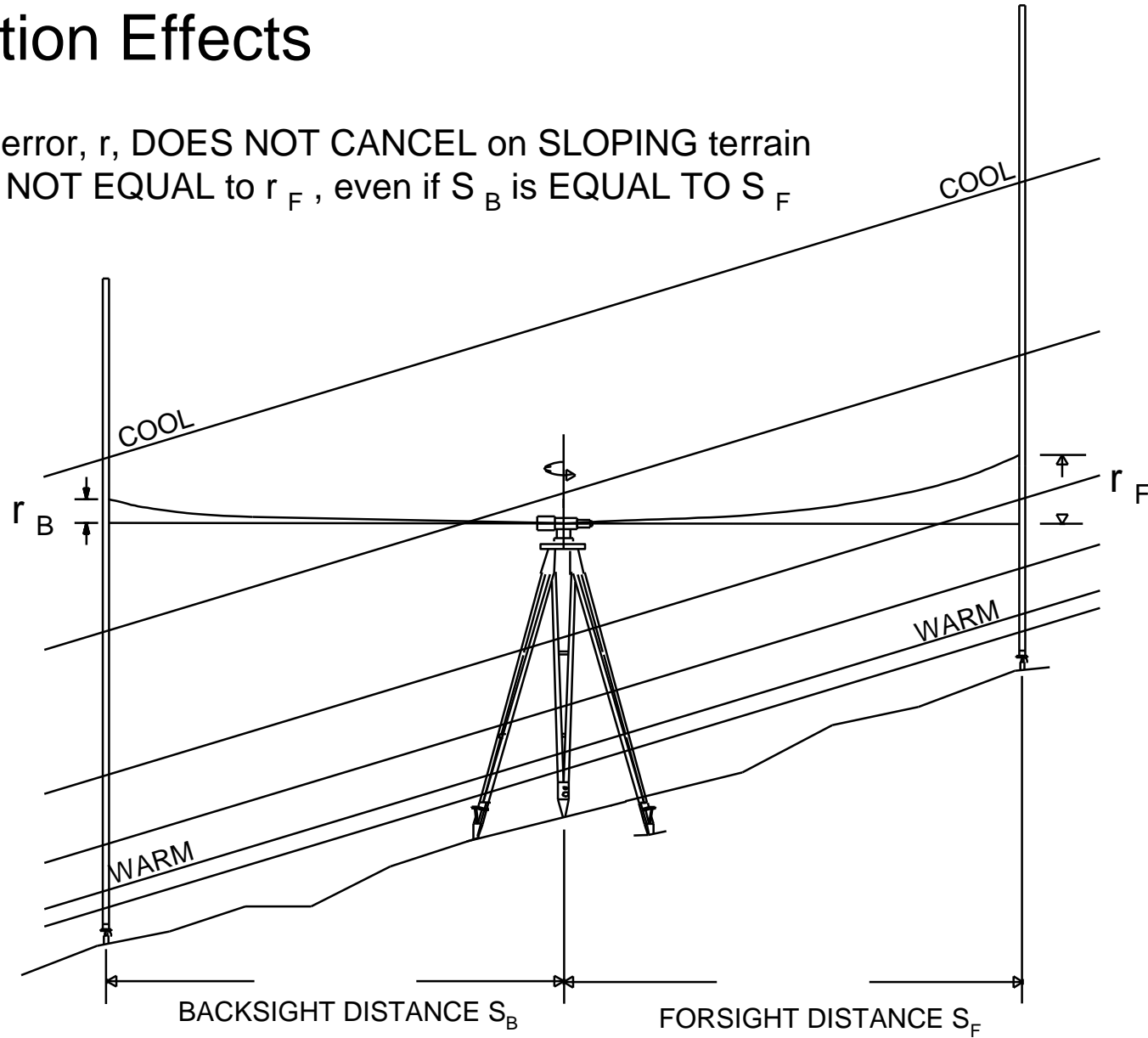


**Collimation ERROR CANCELS in a BALANCED or IMBALANCED SETUP in TRIGONOMETRIC LEVELING**

# Conventional Differential Leveling

## Refraction Effects

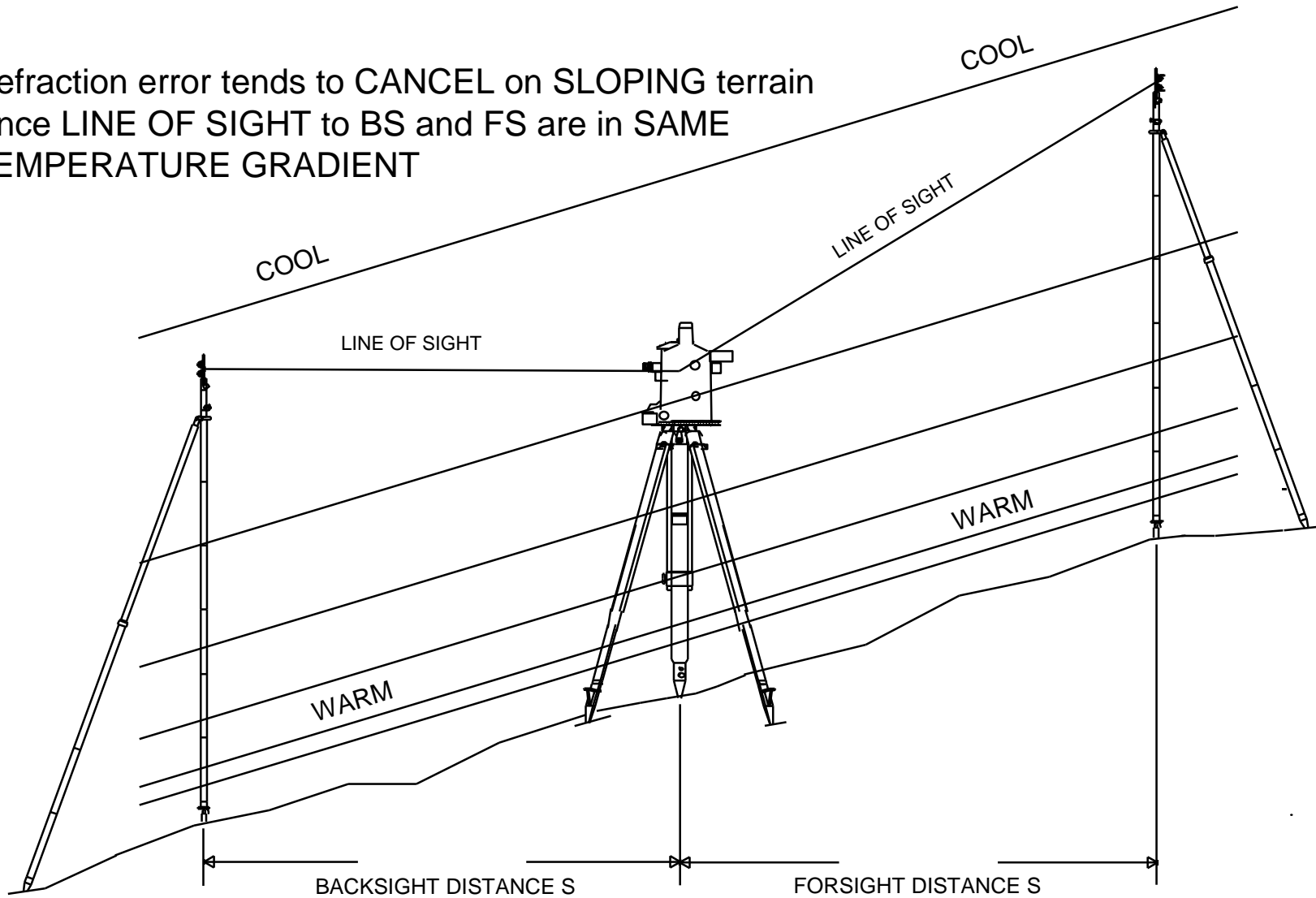
Refraction error,  $r$ , DOES NOT CANCEL on SLOPING terrain since  $r_B$  is NOT EQUAL to  $r_F$ , even if  $S_B$  is EQUAL TO  $S_F$



# Trigonometric Leveling

## Refraction Effects

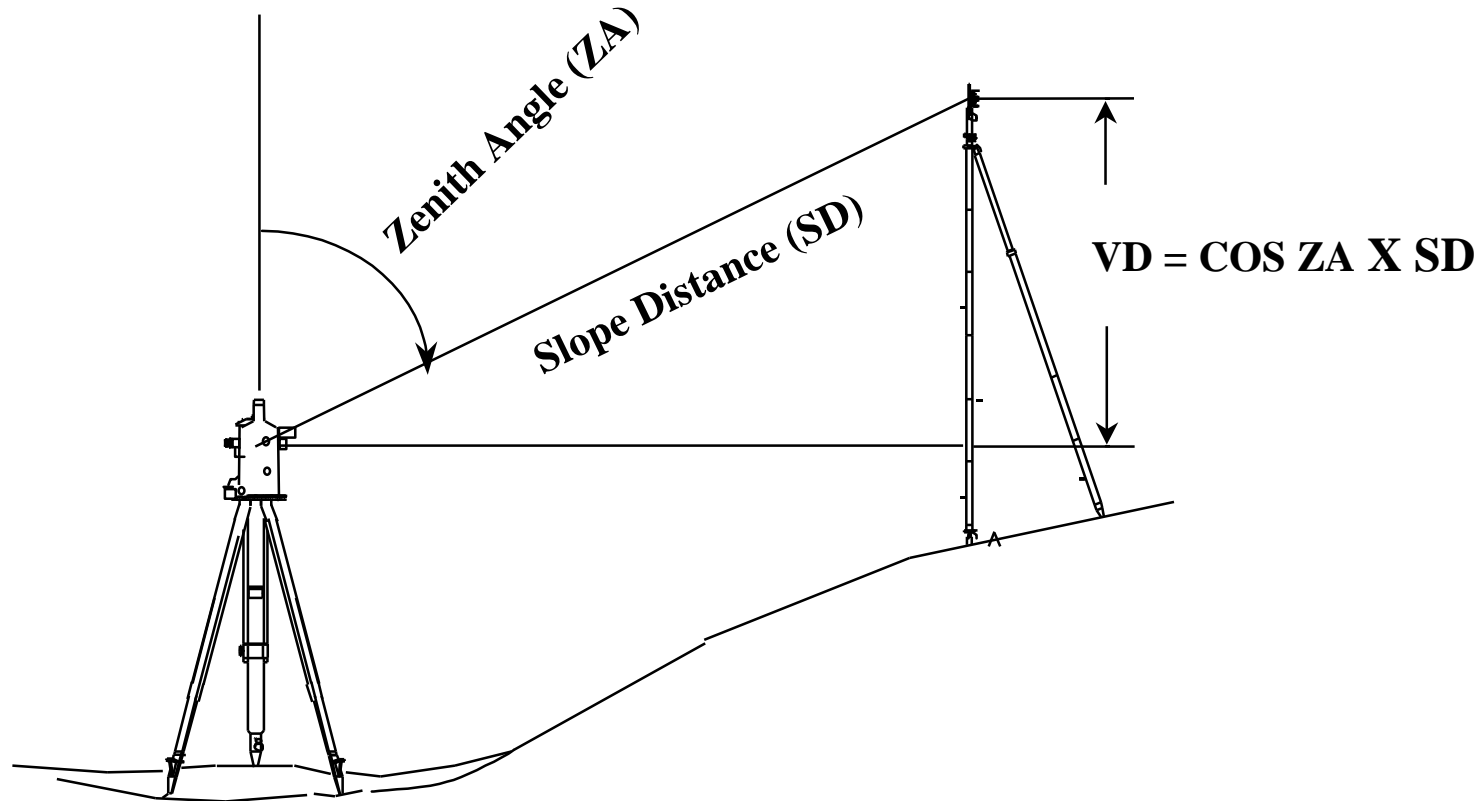
Refraction error tends to CANCEL on SLOPING terrain  
since LINE OF SIGHT to BS and FS are in SAME  
TEMPERATURE GRADIENT





# How Far?

That primarily depends on the precision of the vertical circle.



# 1mm EDM and 0.5 Second Total Station

## Zenith Angle

|     | 89   | 88   | 87   | 86   | 85   | 84   | 83   | 82   | 81   | 80   | 79   | 78   | 77   | 76   | 75   |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 10  | 0.03 | 0.04 | 0.06 | 0.07 | 0.09 | 0.11 | 0.12 | 0.14 | 0.16 | 0.18 | 0.19 | 0.21 | 0.23 | 0.24 | 0.26 |
| 20  | 0.05 | 0.06 | 0.07 | 0.08 | 0.10 | 0.12 | 0.13 | 0.15 | 0.16 | 0.18 | 0.20 | 0.21 | 0.23 | 0.25 | 0.26 |
| 30  | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 | 0.13 | 0.14 | 0.16 | 0.17 | 0.19 | 0.20 | 0.22 | 0.24 | 0.25 | 0.27 |
| 40  | 0.10 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.16 | 0.17 | 0.18 | 0.20 | 0.21 | 0.23 | 0.24 | 0.26 | 0.28 |
| 50  | 0.12 | 0.13 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.20 | 0.21 | 0.22 | 0.24 | 0.25 | 0.27 | 0.28 |
| 60  | 0.15 | 0.15 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 | 0.23 | 0.24 | 0.25 | 0.27 | 0.28 | 0.29 |
| 70  | 0.17 | 0.17 | 0.18 | 0.18 | 0.19 | 0.20 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.27 | 0.28 | 0.29 | 0.31 |
| 80  | 0.19 | 0.20 | 0.20 | 0.21 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.31 | 0.32 |
| 90  | 0.22 | 0.22 | 0.22 | 0.23 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.30 | 0.31 | 0.32 | 0.33 |
| 100 | 0.24 | 0.24 | 0.25 | 0.25 | 0.26 | 0.26 | 0.27 | 0.28 | 0.29 | 0.30 | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 |
| 110 | 0.27 | 0.27 | 0.27 | 0.27 | 0.28 | 0.29 | 0.29 | 0.30 | 0.31 | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 | 0.37 |
| 120 | 0.29 | 0.29 | 0.30 | 0.30 | 0.30 | 0.31 | 0.31 | 0.32 | 0.33 | 0.33 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 |
| 130 | 0.32 | 0.32 | 0.32 | 0.32 | 0.33 | 0.33 | 0.34 | 0.34 | 0.35 | 0.36 | 0.36 | 0.37 | 0.38 | 0.39 | 0.40 |
| 140 | 0.34 | 0.34 | 0.34 | 0.35 | 0.35 | 0.35 | 0.36 | 0.36 | 0.37 | 0.38 | 0.38 | 0.39 | 0.40 | 0.41 | 0.42 |
| 150 | 0.36 | 0.37 | 0.37 | 0.37 | 0.37 | 0.38 | 0.38 | 0.39 | 0.39 | 0.40 | 0.40 | 0.41 | 0.42 | 0.43 | 0.44 |
| 160 | 0.39 | 0.39 | 0.39 | 0.39 | 0.40 | 0.40 | 0.40 | 0.41 | 0.41 | 0.42 | 0.43 | 0.43 | 0.44 | 0.45 | 0.46 |
| 170 | 0.41 | 0.41 | 0.41 | 0.42 | 0.42 | 0.42 | 0.43 | 0.43 | 0.44 | 0.44 | 0.45 | 0.45 | 0.46 | 0.47 | 0.47 |
| 180 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.45 | 0.45 | 0.45 | 0.46 | 0.46 | 0.47 | 0.47 | 0.48 | 0.49 | 0.49 |
| 190 | 0.46 | 0.46 | 0.46 | 0.46 | 0.47 | 0.47 | 0.47 | 0.48 | 0.48 | 0.49 | 0.49 | 0.50 | 0.50 | 0.51 | 0.51 |
| 200 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.50 | 0.50 | 0.50 | 0.51 | 0.51 | 0.52 | 0.52 | 0.53 | 0.54 |

Expected Accuracy (mm)

# 1mm EDM and 1.0 Second Total Station

## Zenith Angle

|     | 89   | 88   | 87   | 86   | 85   | 84   | 83   | 82   | 81   | 80   | 79   | 78   | 77   | 76   | 75   |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 10  | 0.05 | 0.06 | 0.07 | 0.08 | 0.10 | 0.12 | 0.13 | 0.15 | 0.16 | 0.18 | 0.20 | 0.21 | 0.23 | 0.25 | 0.26 |
| 20  | 0.10 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.16 | 0.17 | 0.18 | 0.20 | 0.21 | 0.23 | 0.24 | 0.26 | 0.28 |
| 30  | 0.15 | 0.15 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 | 0.23 | 0.24 | 0.25 | 0.27 | 0.28 | 0.29 |
| 40  | 0.19 | 0.20 | 0.20 | 0.21 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.26 | 0.27 | 0.28 | 0.29 | 0.31 | 0.32 |
| 50  | 0.24 | 0.24 | 0.25 | 0.25 | 0.26 | 0.26 | 0.27 | 0.28 | 0.29 | 0.30 | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 |
| 60  | 0.29 | 0.29 | 0.30 | 0.30 | 0.30 | 0.31 | 0.31 | 0.32 | 0.33 | 0.33 | 0.34 | 0.35 | 0.36 | 0.37 | 0.38 |
| 70  | 0.34 | 0.34 | 0.34 | 0.35 | 0.35 | 0.35 | 0.36 | 0.36 | 0.37 | 0.38 | 0.38 | 0.39 | 0.40 | 0.41 | 0.42 |
| 80  | 0.39 | 0.39 | 0.39 | 0.39 | 0.40 | 0.40 | 0.40 | 0.41 | 0.41 | 0.42 | 0.43 | 0.43 | 0.44 | 0.45 | 0.46 |
| 90  | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.45 | 0.45 | 0.45 | 0.46 | 0.46 | 0.47 | 0.47 | 0.48 | 0.49 | 0.49 |
| 100 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.49 | 0.50 | 0.50 | 0.50 | 0.51 | 0.51 | 0.52 | 0.52 | 0.53 | 0.54 |
| 110 | 0.53 | 0.53 | 0.54 | 0.54 | 0.54 | 0.54 | 0.54 | 0.55 | 0.55 | 0.55 | 0.56 | 0.56 | 0.57 | 0.57 | 0.58 |
| 120 | 0.58 | 0.58 | 0.58 | 0.58 | 0.59 | 0.59 | 0.59 | 0.59 | 0.60 | 0.60 | 0.60 | 0.61 | 0.61 | 0.61 | 0.62 |
| 130 | 0.63 | 0.63 | 0.63 | 0.63 | 0.63 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.65 | 0.65 | 0.65 | 0.66 | 0.66 |
| 140 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.69 | 0.69 | 0.69 | 0.69 | 0.70 | 0.70 | 0.70 | 0.70 |
| 150 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.73 | 0.74 | 0.74 | 0.74 | 0.74 | 0.74 | 0.75 | 0.75 |
| 160 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.79 | 0.79 | 0.79 | 0.79 |
| 170 | 0.82 | 0.82 | 0.82 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.84 | 0.84 |
| 180 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 |
| 190 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.93 | 0.93 | 0.93 |
| 200 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |

Expected Accuracy (mm)

# 2mm EDM and 3.0 Second Total Station

## Zenith Angle

|     | 89   | 88   | 87   | 86   | 85   | 84   | 83   | 82   | 81   | 80   | 79   | 78   | 77   | 76   | 75   |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 10  | 0.15 | 0.16 | 0.18 | 0.20 | 0.23 | 0.25 | 0.28 | 0.31 | 0.34 | 0.38 | 0.41 | 0.44 | 0.47 | 0.50 | 0.54 |
| 20  | 0.29 | 0.30 | 0.31 | 0.32 | 0.34 | 0.36 | 0.38 | 0.40 | 0.42 | 0.45 | 0.48 | 0.50 | 0.53 | 0.56 | 0.59 |
| 30  | 0.44 | 0.44 | 0.45 | 0.46 | 0.47 | 0.48 | 0.50 | 0.51 | 0.53 | 0.55 | 0.57 | 0.60 | 0.62 | 0.64 | 0.67 |
| 40  | 0.58 | 0.59 | 0.59 | 0.60 | 0.61 | 0.62 | 0.63 | 0.64 | 0.65 | 0.67 | 0.69 | 0.70 | 0.72 | 0.74 | 0.76 |
| 50  | 0.73 | 0.73 | 0.73 | 0.74 | 0.75 | 0.75 | 0.76 | 0.77 | 0.78 | 0.80 | 0.81 | 0.82 | 0.84 | 0.86 | 0.87 |
| 60  | 0.87 | 0.87 | 0.88 | 0.88 | 0.89 | 0.89 | 0.90 | 0.91 | 0.92 | 0.93 | 0.94 | 0.95 | 0.96 | 0.98 | 0.99 |
| 70  | 1.02 | 1.02 | 1.02 | 1.03 | 1.03 | 1.03 | 1.04 | 1.05 | 1.05 | 1.06 | 1.07 | 1.08 | 1.09 | 1.10 | 1.11 |
| 80  | 1.16 | 1.16 | 1.17 | 1.17 | 1.17 | 1.18 | 1.18 | 1.19 | 1.19 | 1.20 | 1.20 | 1.21 | 1.22 | 1.23 | 1.24 |
| 90  | 1.31 | 1.31 | 1.31 | 1.31 | 1.32 | 1.32 | 1.32 | 1.33 | 1.33 | 1.34 | 1.34 | 1.35 | 1.35 | 1.36 | 1.37 |
| 100 | 1.45 | 1.46 | 1.46 | 1.46 | 1.46 | 1.46 | 1.46 | 1.47 | 1.47 | 1.47 | 1.48 | 1.48 | 1.49 | 1.49 | 1.50 |
| 110 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | 1.61 | 1.61 | 1.61 | 1.61 | 1.62 | 1.62 | 1.62 | 1.63 | 1.63 |
| 120 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 |
| 130 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.90 | 1.90 | 1.90 | 1.90 |
| 140 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.04 | 2.03 | 2.03 | 2.03 | 2.03 |
| 150 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.17 | 2.17 | 2.17 | 2.17 |
| 160 | 2.33 | 2.33 | 2.33 | 2.33 | 2.32 | 2.32 | 2.32 | 2.32 | 2.32 | 2.32 | 2.32 | 2.32 | 2.31 | 2.31 | 2.31 |
| 170 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.46 | 2.46 | 2.46 | 2.46 | 2.45 | 2.45 | 2.45 | 2.44 |
| 180 | 2.62 | 2.62 | 2.62 | 2.62 | 2.61 | 2.61 | 2.61 | 2.61 | 2.60 | 2.60 | 2.60 | 2.59 | 2.59 | 2.59 | 2.58 |
| 190 | 2.76 | 2.76 | 2.76 | 2.76 | 2.76 | 2.76 | 2.75 | 2.75 | 2.75 | 2.74 | 2.74 | 2.73 | 2.73 | 2.72 | 2.72 |
| 200 | 2.91 | 2.91 | 2.91 | 2.91 | 2.90 | 2.90 | 2.90 | 2.89 | 2.89 | 2.89 | 2.88 | 2.88 | 2.87 | 2.86 | 2.86 |

Expected Accuracy (mm)