Learning Objectives

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Learning objectives

1. Know the different methods of measuring distance.
2. Understand the general process of taping
3. Know how to make horizontal measurements on sloped ground
4. Understand the fundamental sources in taping
5. Understand how electromagnetic energy (i.e. light) can be used to make measurements
6. Understand the principles of electronic distance measurement (EDM)
7. List the common errors of using EDM

Homework Assignment

Do the following problems from the textbook:

6.1
6.2
6.4
6.5
6.7
6.9
6.10
6.15
6.20

Introduction

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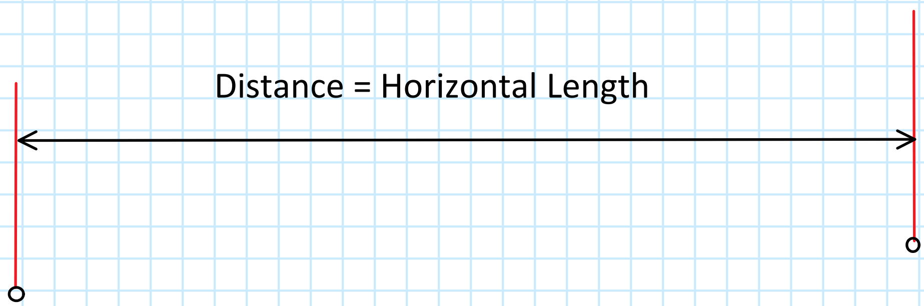
Distance Measurement

- Most fundamental is the most fundamental measurement
- For plane surveying, the distance between two points is a horizontal line.
- If the points are at different elevations, the distance is the horizontal length between vertical lines at the points



Methods of Measuring Distance

(1) pacing
(2) odometer readings
(3) optical range-finders
(4) tacheometry (stadia)
(5) subtense bars
(6) taping
(7) electronic distance measurement (EDM)
(8) satellite systems, and others.

From <https://online.vitalsource.com/#/books/9781292060675/cfi/149!/4/4@0:0.939>

Pacing

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[What is Pacing in Surveying? How to measure distance using pacing?](#)

Anime_Edu - Civil Engineering Videos

Pacing is the simplest and easiest method for measuring distance. Pacing is the process of walking the distance and counting the number of steps "paces" to cover the distance. The distance is determined by multiplying the number of steps taken between two points by one's pace factor. A person's pace factor is determined by pacing (walking) a measured distance, usually 300 to 500 ft, several times and determining the average length of pace (step). With practice it is possible to pace a distance with an error of less than 2 ft per 100 ft. To achieve that level of precision a person must learn to adopt a pacing step that is different from their normal walking step because many factors can cause variations in the length of a person's pace. Three of these are the roughness of the surface, the slope of the ground, and the type of vegetation. Care must be taken to ensure that a consistent pace factor is used.

From <https://www.progressivegardening.com/agricultural-engineering-2/pacing.html>

A student counted 92, 90, 92, 91, 93, and 91 paces in six trials of walking along a course of 200 ft known length on level ground. Then 85, 86, 86, and 84 paces were counted in walking four repetitions of an unknown distance AB. What is (a) the pace length and (b) the length of AB?

(a) pace length = 200(6)/(92+90+92+91+93+91) = **2.18 ft/pace**

(b) AB = (85+86+86+84)2.18/4 = **186 ft**

Pacing (cont.)

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Advantages

- Simple
- Low tech
- No equipment required

Disadvantages

- Topography affects accuracy
- Requires practice to achieve consistent pace
- Direction of pacing must be free of obstacles
- Only measures slope distance and not horizontal distance

Accuracy

≈ 2% of distance paced

Problem: An individual paces a 200.0 ft distance three times and counts 62, 60, and 64 paces. What is the person's pace factor (PF)?

Solution: To determine a pace factor, divide the measured distance by the average number of paces. The average number of steps (x) is:
and the pace factor is:

62 paces pace for 200 feet or 31 paces per 100 feet or 31 paces per 30 m

Once the pace factor is known, the length of an unknown distance can be determined

From <https://www.progressivegardening.com/agricultural-engineering-2/pacing.html>

Odometer

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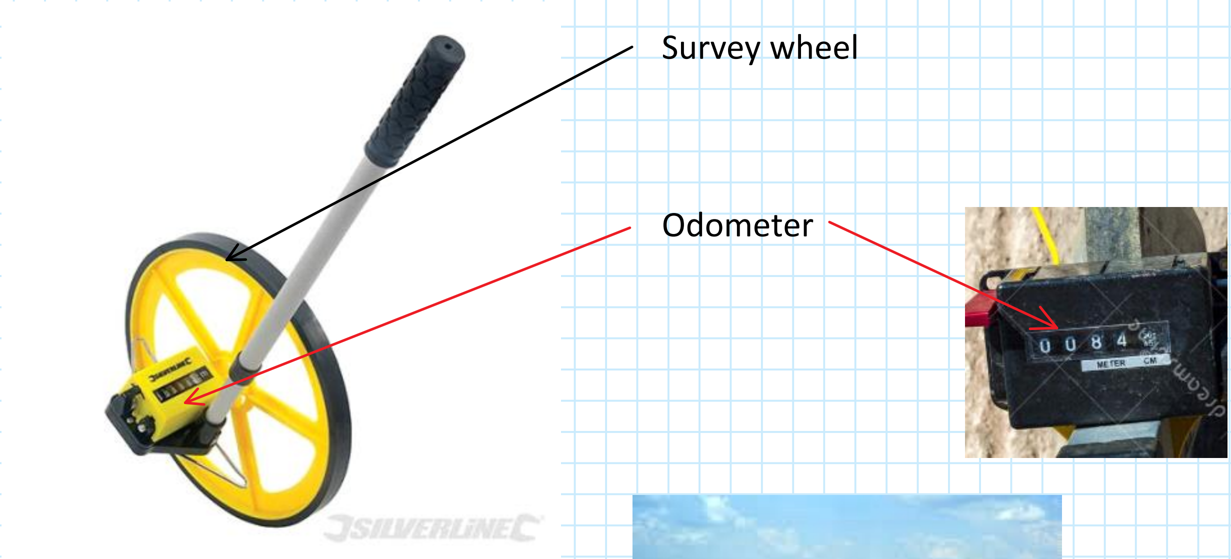

- An odometer is a mechanical revolution counter
- An odometer wheel uses the odometer to count the rotations of the wheel
- The gear ratio of the odometer provides the measurement in standard units (feet or meters)

Advantages

- Easy to use
- Low tech
- Low cost

Disadvantages

- Accuracy is influenced by surface conditions and topography
- Can only measure slope distance
- Direction of pacing must be free of obstacles

Accuracy

1% of distance measured

Optical Range Finders

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It can measure slope distance, inclination and azimuth; instantly calculate horizontal and vertical distances; and calculate 3D missing line values

From <https://www.gpsworld.com/laser-technology-offers-improved-rangefinder-with-compass/>

https://www.gpsworld.com/wp-content/uploads/2018/08/LTI-laser-rangefinder-360-PP.jpg

An accurate electronic compass integrated into the laser, continues to deliver added value for the modern measurement professional. Uses include forestry, utilities, construction and GIS mapping.

In addition to its increased range and azimuth accuracy and Bluetooth-enabled communication, the TruPulse 360 features:

- Reflectorless technology that enables data capture to any surface type;
- advanced targeting modes to achieve accurate, repeatable results of the intended target;
- seven-power superior optics technology that displays all measured and calculated solutions; and
- Smart technology that recognizes adverse measurement conditions and prompts recalibration.

From <https://www.gpsworld.com/laser-technology-offers-improved-rangefinder-with-compass/>

Optical Range Finders (cont.)

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Percent Differences

Percent differences were calculated between the standard measurement and the test device measurement. The smaller the range of percent difference, the better. The smallest range of percent differences is met by the Impulse 200, followed closely by the Laser Atlanta Advantage.

Table 1—Rangefinder Data Reduction Results.

	Sonin 60	Power Disto	DME 70	Lytespeed 400	Impulse 200	Laser Atlanta Advtg.	Swarovski Optik RF-1	Ranging 400
Percent Inaccuracy								
Operator 1	11.62	0.36	4.32	1.43	0.35	0.21	1.22	3.28
Operator 2	9.76	1.36	4.55	1.47	0.43	0.20	1.15	3.65
Operator 3	11.11	0.73	3.01	1.51	0.31	0.19	1.40	4.59
All Operators	10.83	0.82	4.00	1.47	0.36	0.20	1.26	3.74
Percent Bias								
Operator 1	-11.59	0.12	-4.16	1.11	-0.32	-0.06	-1.15	3.58
Operator 2	-11.11	1.35	-4.48	1.13	-0.42	0.01	-1.00	-3.93
Operator 3	-11.11	1.17	-2.72	1.21	-0.26	-0.01	-1.14	-5.80
All Operators	-11.30	0.88	-3.79	1.15	-0.34	-0.02	-1.14	-2.16
Range of Percent Differences for all Operators								
Minimum	-13.0	-0.63	-8.9	-1.03	-0.95	-0.88	-3.79	-40
Maximum	-7.7	1.67	-1.0	5.98	0.30	0.94	0.68	13
Total Range	5.3	2.30	7.9	7.01	1.25	1.82	4.47	53

https://www.fs.fed.us/eng/pubs/html/98241307/98241307.html

Tacheometry (Stadia)

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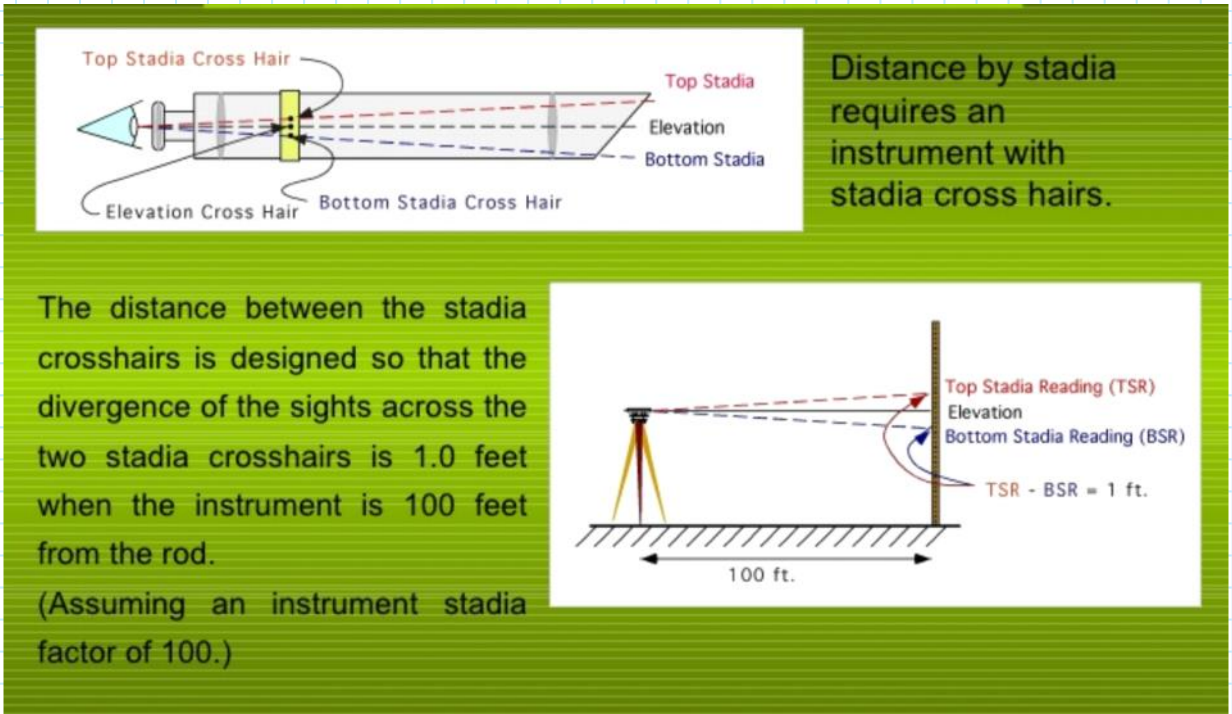

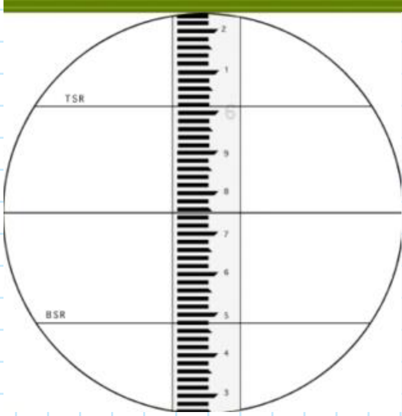

Accuracy

Distance	±10mm (less than 10m measurement) ±(0.1% x D) (10 to 50m measurement) ±(0.2% x D) (more than 50m measurement) (D: measured distance, unit: m)

Sokkia SDL 30 User's Manual

Taping (Chaining)

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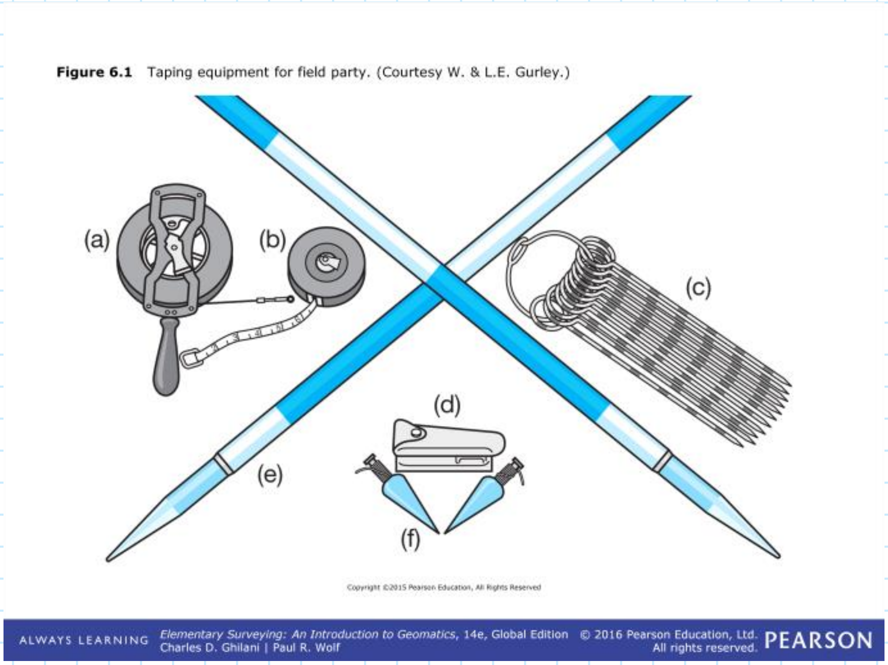

a) Survey steel tape and reel
b) Cloth tape
c) Chaining pins
d) Range poles
e) Hand level
f) Plumb bob

Taping (cont.)

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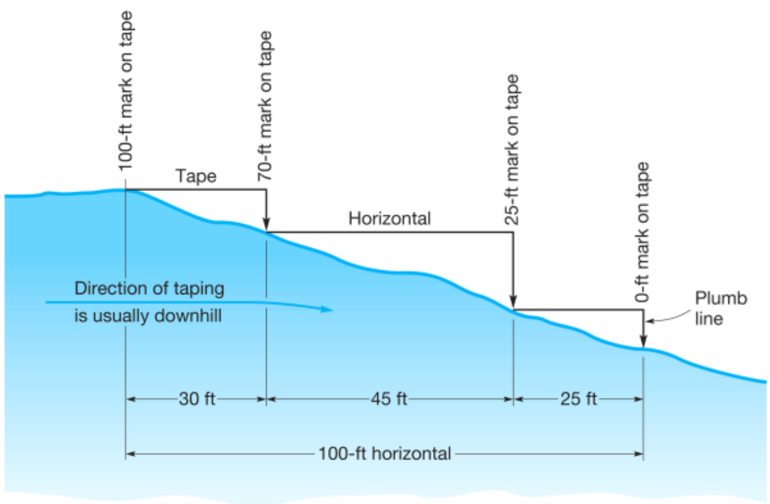
Figure 6.4 Procedure for breaking tape (when tape is not in box or on reel).



[Measuring & Distance 1]

surveyingmod

Taping Procedure

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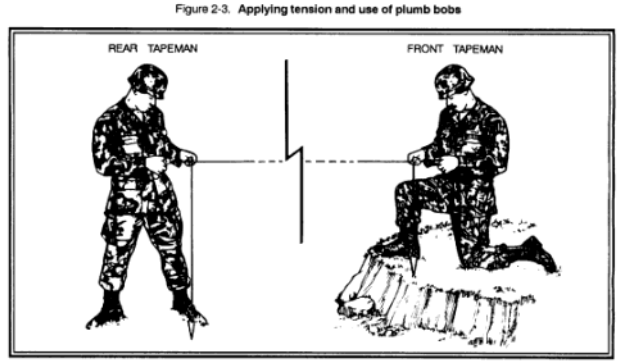
Lining In

Using range poles, the line to be measured should be marked at both ends, and at intermediate points where necessary, to ensure unobstructed sight lines. Taping requires a minimum of two people, a forward tape person and a rear tape person. The forward tape person is lined in by the rear tape person. Directions are given by vocal or hand signals.

Applying Tension

The rear tape person holding the 100-ft end of a tape over the first (rear) point lines in while the forward tape person, holding the zero end of the tape. For accurate results, the tape must be straight and the two ends held at the same elevation. A specified tension, generally between 10 and 25 lb, is applied. To maintain a steady pull, tape persons wrap the leather thong at the tape's end around one hand, keep fore- arms against their bodies, and face at right angles to the line. In this position, they are off the line of sight. Also, the body need only be tilted to hold, decrease, or increase the pull. Good communication between forward and rear tape persons will avoid jerking the tape, save time, and produce better results.

Figure 2-3. Applying tension and use of plumb bobs



Plumbing

Weeds, brush, obstacles, and surface irregularities may make it undesirable to lay a tape on the ground. In those cases, the tape is held above ground in a horizontal position. Placing the plumb-bob string over the proper tape graduation and securing it with one thumb, mark each end point on the tape. The rear tape person continues to hold a plumb bob over the fixed point, while the forward tape person marks the length. In measuring a distance shorter than a full tape length, the forward tape- person moves the plumb-bob string to a point on the tape over the ground mark.

From <https://online.vitalsource.com/#/books/9781292060675/cfi/154!/4/4@0.00:0.00>

Taping Procedure (cont.)

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Marking Tape Lengths

When the tape has been lined in properly, tension has been applied, and the rear tape person is over the point, "stick" is called out. The forward tape person then places a pin exactly opposite the zero mark of the tape and calls "stuck." The marked point is checked by repeating the measurement until certainty of its correct location is assured. After checking the measurement, the forward tape person signals that the point is OK, the rear tape person pulls up the rear pin, and they move ahead. The forward tape person drags the tape pacing roughly 100 ft and stops. The rear tape person calls "tape" to notify the forward tape person that they have gone 100 ft just before the 100-ft end reaches the pin that has been set. The process of measuring 100-ft lengths is repeated until a partial tape length is needed at the end of the line.

Reading the Tape

There are two common styles of graduations on 100-ft surveyor's tapes. It is necessary to identify the type being used before starting work to avoid making one-foot mistakes repeatedly.

Recording the Distance

Accurate fieldwork may be canceled by careless recording. After the partial tape length is obtained at the end of a line, the rear tape person determines the number of full 100-ft tape lengths by counting the pins collected from the original set of 11. Since long distances are measured electronically today, tapes are never used for long distances. Although taping procedures may appear to be relatively simple, high precision is difficult to achieve. Taping is a skill that can best be taught and learned by field demonstrations and practice.

Slope Measurements

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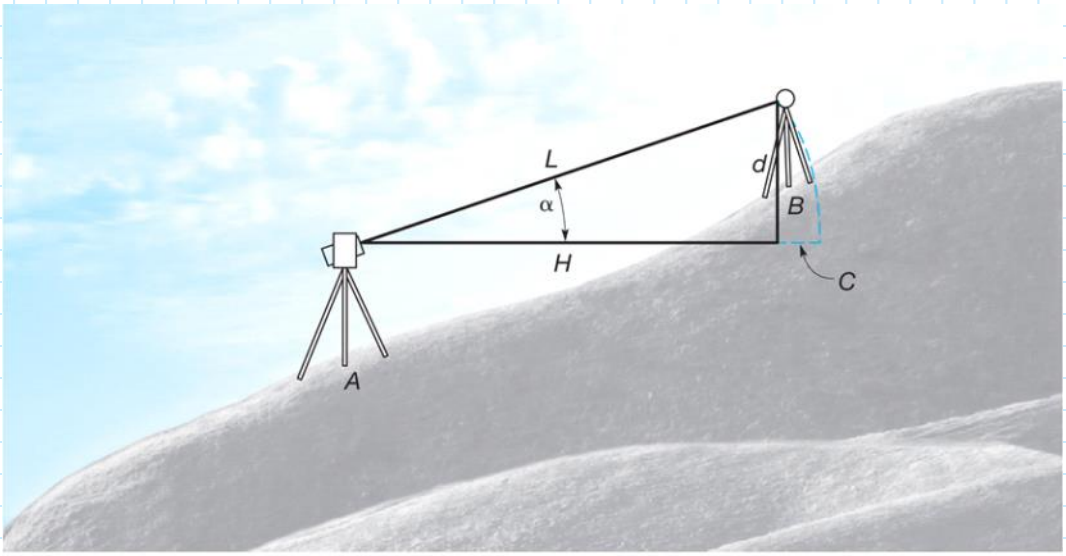
In measuring the distance between two points on a steep slope, rather than break tape every few feet, it may be desirable to tape along the slope and compute the horizontal component.



$H = L \cos \alpha$

$H = (L^2 - d^2)^{0.5}$

For the following data, compute the horizontal distance for a recorded slope distance AB, L = 104.93

(a) AB = 104.93 ft, slope angle = 2°13′46″ $H = 104.93 \cos 2°13'46''$ = **<u>104.85 ft</u>**

(b) AB = 86.793 m, difference in elevation A to B = −2.499 m.

$H = \sqrt{86.793^2 - 2.499^2} = 86.757$ m

Sources of Error in Taping

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There are three fundamental sources of error in taping:

1. **Instrumental errors.** A tape may differ in actual length from its nominal graduated length because of a defect in manufacture or repair, or as a result of kinks.

2. **Natural errors.** The horizontal distance between end graduations of a tape varies because of the effects of temperature, wind, and weight of the tape itself.

3. **Personal errors.** Tape persons setting pins, reading the tape, or manipulating the equipment.

From <https://online.vitalsource.com/#/books/9781292060675/cfi/159!/4/4@0.00:0.00>

Taping Errors (cont.)

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Standardization of Tapes

100-ft steel tape

- 68 deg F. (20 deg. C)
- Fully supported (lying on flat surface)
  - 12-lb pull (tension) (5.4 kg)
- Supported on ends only
  - 20-lb pull (tension) (9.1 kg)

Incorrect Tape Length

Incorrect length of a tape can be one of the most important errors. Tape manufacturers do not guarantee steel tapes to be exactly their graduated nominal length—for example, 100.00 ft—nor do they provide a standardization certificate unless requested and paid for as an extra. The true length is obtained by comparing it with a standard tape or distance.

An error, caused by incorrect length of a tape, occurs each time the tape is used. If the true length, known by standardization, is not exactly equal to its nominal value of 100.00 ft recorded for every full length, the correction can be determined as

$$C_L = \left(\frac{l - l'}{l'}\right)L$$

where C_L is the correction to be applied to the measured (recorded) length of a line to obtain the true length, l the actual tape length, l' the nominal tape length, and L the measured (recorded) length of line. Units for the terms this equation can be in either feet or meters.

Example

A 30-m tape was measured and found to have a true length of 30.002 m length. Calculate the tape length correction factor, C_L, for this tape if the measured distance is 102.353 m.

C_L = ((30.002-30)/30)*102.353=0.0068

True length = 102.353+0.0068=102.3598 ≈ 102.360 m

Taping Error (cont.)

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Temperature Other Than Standard

Steel tapes are standardized for 68°F (20°C) in the United States. A temperature higher or lower than this value causes a change in length that must be considered. The coefficient of thermal expansion and contraction of steel used in ordinary tapes is approximately 0.00000645 per unit length per degree Fahrenheit, and 0.0000116 per unit length per degree Celsius. For any tape, the correction for temperature can be computed as

$$C_T = k(T_1 - T)L$$

where C_T is the correction in the length of a line caused by nonstandard temperature, k the coefficient of thermal expansion and contraction of the tape, T_1 the tape temperature at the time of measurement, T the tape temperature when it has standard length, and L the observed (recorded) length of line. The correction C_T will have the same units as L, which can be either feet or meters. Errors caused by temperature change may be practically eliminated by either (a) measuring temperature and making corrections according to Equation (6.4), or (b) using an Invar tape.

What difference in temperature from standard, if neglected in use of a steel tape, will cause an error of 1 part in 10,000?

15.5° F or **8.6° C**

$$1 = 0.00000645(\Delta T)10000 \qquad 1 = 0.0000116(\Delta T)10{,}000$$

$$\Delta T = \frac{1}{0.00000645(10000)} = 15.5° \text{ F} \quad \text{or} \quad \Delta T = \frac{1}{0.0000116(10000)} = 8.6° \text{ C}$$

Taping Errors (cont.)

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Inconsistent Pull

When a steel tape is pulled with a tension greater than its standard pull (the tension at which it was calibrated), the tape will stretch and become longer than its standard length. Conversely, if less than standard pull is used, the tape will be shorter than its standard length. The modulus of elasticity of the tape regulates the amount that it stretches. The correction for pull can be computed and applied using the following formula

$$C_P = (P_1 - P)\frac{L}{AE}$$

where C_P is the total elongation in tape length due to pull, in feet; P_1 the pull applied to the tape at the time of the observation, in pounds; P the standard pull for the tape in pounds; A the cross-sectional area of the tape in square inches; E the modulus of line. An average value of E is 29,000,000lb/in^2 for the kind of steel typically used in tapes. In the metric system, to produce the correction C_P in meters, comparable units of P and P_1 are kilograms, L is meters, A is square centimeters, and E is kilograms per square centimeter. An average value of E for steel in these units is approximately 2,000,000 kg/cm^2. The cross-sectional area of a steel tape can be obtained from the manufacturer, by measuring its width and thickness with calipers, or by dividing the (490 lb/ft^2), and multiplying by 144 to convert square feet to square inches.

From <https://online.vitalsource.com/#/books/9781292060675/cfi/160!/4/4@0:45.3>

Taping Errors (cont.)

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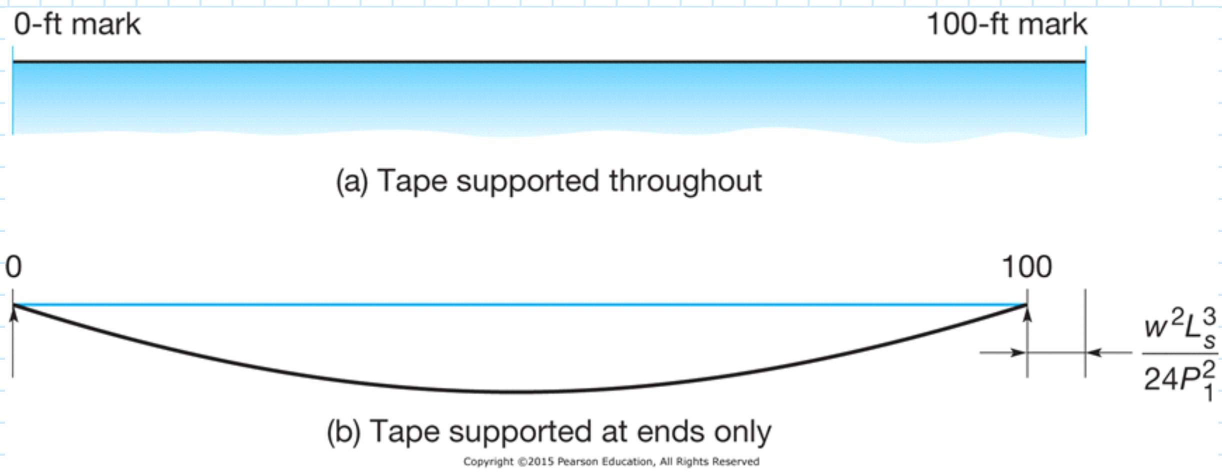
<u>Sag</u>



A steel tape not supported along its entire length sags in the form of a catenary, a good example being the cable between two power poles. Because of sag, the horizontal distance (chord length) is less than the graduated distance between tape ends, as illustrated in Figure 6.6. Sag can be reduced by applying greater tension, but not eliminated unless the tape is supported throughout. The following formula is used to compute the sag correction:

$$C_S = -\frac{w^2L_S^3}{24P_1^2}$$

where in the English system C_S, is the correction for sag (difference between length of curved tape and straight line from one support to the next), in feet; L_S the unsupported length of the tape, in feet; w the weight of the tape per foot of length, in pounds; and P_1 the pull on the tape, in pounds. Metric system units for this equation are kg/m for w, kg for P_1, and meters for C_S and L_S.

The effects of errors caused by sag can be eliminated by (a) supporting the tape at short intervals or throughout, or (b) by computing a sag correction for each unsupported segment and applying the total to the recorded length according to the above equation. It is important to recognize that this equation is nonlinear and thus must be applied to each unsupported section of the tape. It is incorrect to apply it to the overall length of a line unless the line was observed in one section.

Taping Errors (cont.)

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Tape Not Horizontal or Off-Line

Corrections for errors caused by a tape being inclined in the vertical plane are computed in the same manner as corrections for errors resulting from it being off-line in the horizontal plane. Corrected lengths can be determined by Equation (6.2), where in the vertical plane d is the difference in elevation between the tape ends, and in the horizontal plane, d is the amount where one end of the tape is off-line. In either case, L is the length of tape involved in the measurement.

$$H = (L^2 - d^2)^{0.5}$$

Improper Plumbing

Practice and steady nerves are necessary to hold a plumb bob still long enough to mark a point. The plumb bob will sway, even in calm weather. On very gradual slopes and on smooth surfaces such as pavements, inexperienced tape persons obtain better results by laying the tape on the ground instead of plumbing. Experienced tape persons plumb most measurements. Errors caused by improper plumbing are random, since they may make distances either too long or too short. However, the errors would be systematic when taping directly against or in the direction of a strong wind. Heavier plumb bobs and touching the plumb bob on the ground, or steadying it with one foot, decreases its swing. Practice in plumbing will reduce errors.

Faulty Marking

Chaining pins should be set perpendicular to the taped line but inclined 45° to the ground. This position permits plumbing to the point where the pin enters the ground without interference from the loop. Brush, stones, and grass or weeds deflect a chaining pin and may increase the effect of incorrect marking. Errors from these sources tend to be random and are kept small by carefully locating a point, then checking it.

From <https://online.vitalsource.com/#/books/9781292060675/cfi/162!/4/4@0:40.5>

Taping Errors (cont.)

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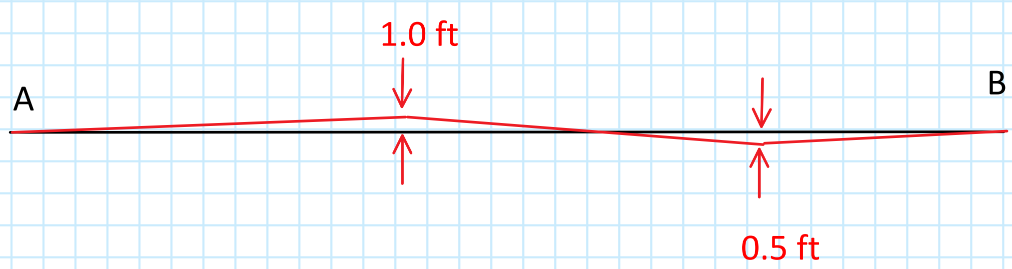
$$H = (L^2 - d^2)^{0.5}$$

Example

When measuring a distance AB, the first taping pin was placed 1.0 ft to the right of line AB and the second pin was set 0.5 ft left of line AB. The recorded distance was 236.89 ft. Calculate the corrected distance. (Assume three taped segments, the first two 100 ft each.)



236.87 ft

A-Pin1: $\sqrt{100^2 - 1^2} = 99.995$ ft ; Pin1-Pin2: $\sqrt{100^2 - (1+0.5)^2} = 99.989$ ft

Pin1-B: $\sqrt{36.89^2 - 0.5^2} = 36.887$ ft ; $AB = 99.995 + 99.989 + 36.887 = 236.870$ ft

Taping Errors (cont.)

Improper Plumbing

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From <https://online.vitalsource.com/#/books/9781292060675/cfi/162!/4/4@0:40.5>

Summary of Errors

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Table 6.1 Summary of Errors

Error Type	Error Source*	Systematic (S) or Random (R)	Departure from Normal to Produce 0.01-ft Error for 100-ft Tape
Tape length	I	S	0.01 ft
Temperature	N	S or R	15°F
Pull	P	S or R	15 lb
Sag	N, P	S	0.6 ft at center for 100-ft tape standardized by support throughout
Alignment	P	S	1.4 ft at one end of 100-ft tape, or 0.7 ft at midpoint
Tape not level	P	S	1.4-ft elevation difference between ends of 100-ft tape
Plumbing	P	R	0.01 ft
Marking	P	R	0.01 ft
Interpolation	P	R	0.01 ft

*I, instrumental; N, natural; P, personal.

EDM Principles

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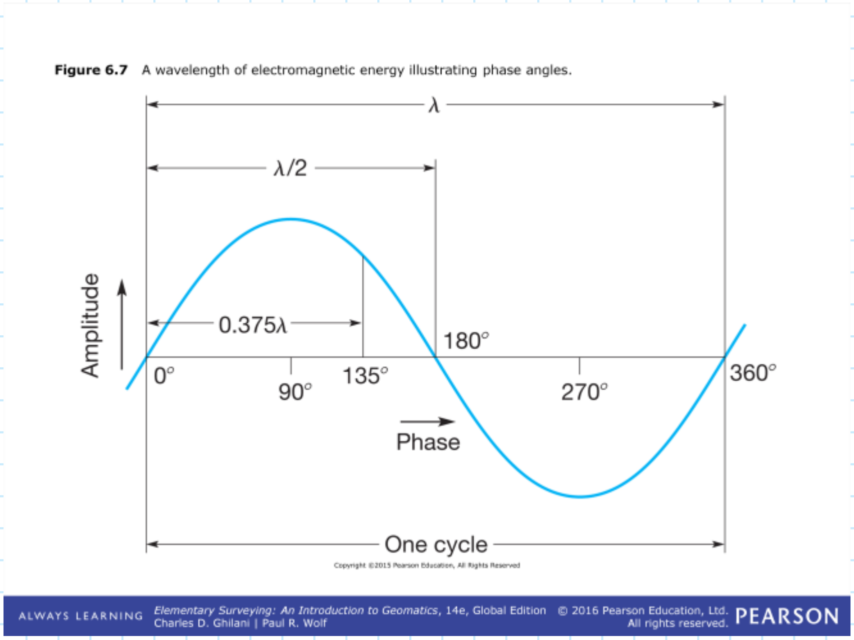
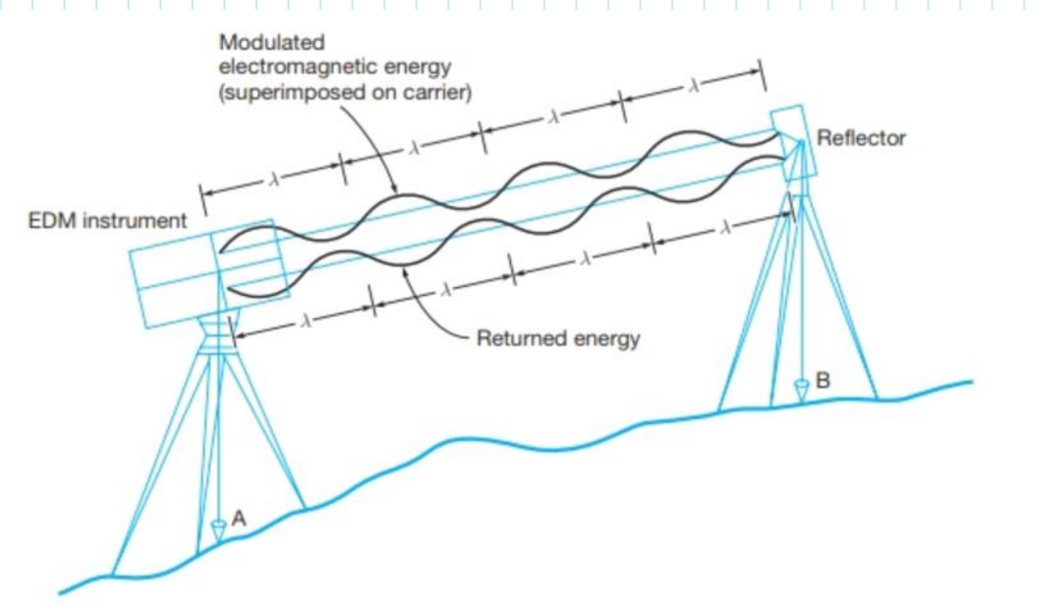


Figure 6.7 A wavelength of electromagnetic energy illustrating phase angles.

The instrument transmits a carrier signal of electromagnetic energy to station B. A reference frequency of a precisely regulated wavelength has been superimposed or modulated onto the carrier. A reflector at B returns the signal to the receiver, so its travel path is double the slope distance AB. In the figure, the modulated electromagnetic energy is represented by a series of sine waves, each having wavelength λ. The unit at A determines the number of wavelengths in the double path, multiplied by the wavelength in feet or meters, and divided by 2 to obtain distance AB.

From <https://online.vitalsource.com/#/books/9781292060675/cfi/167!/4/4@0:35.8>



EDM Principles (cont.)

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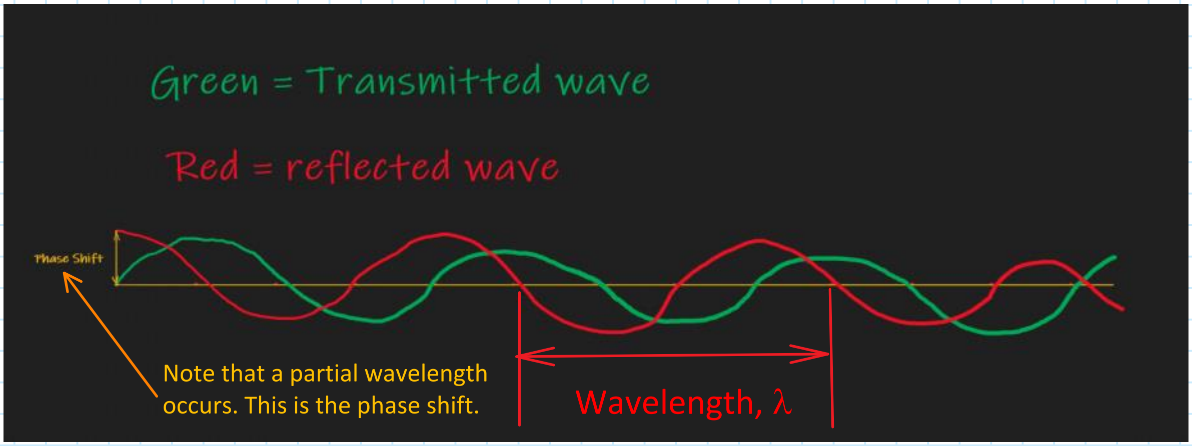
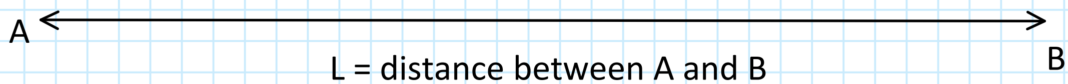
<u>Measuring the Phase Difference</u>





L = distance between A and B

$L = (n\lambda + p)/2$

n = number of full wavelengths
λ = wavelength
p =length of fractional part

Example:

What is the <u>length of the phase shift</u> for electromagnetic energy with a frequency of 14.9989 MHz and a phase shift of 156 deg.

$\lambda = (v/f)p$

where v = velocity of wave propagation (299,784,458 m/s) (in vacuum)
f = frequency of wave (cycles per second (called Hertz)) Hz
p =length of the fractional part

For n = 9 cycles
λ = 20.000 m (precise)
p = 115.7/360*20=6.4278 m
L = (9*20+6.428)/2=93.214 m

EDM Principles - Electro-Optical EDM

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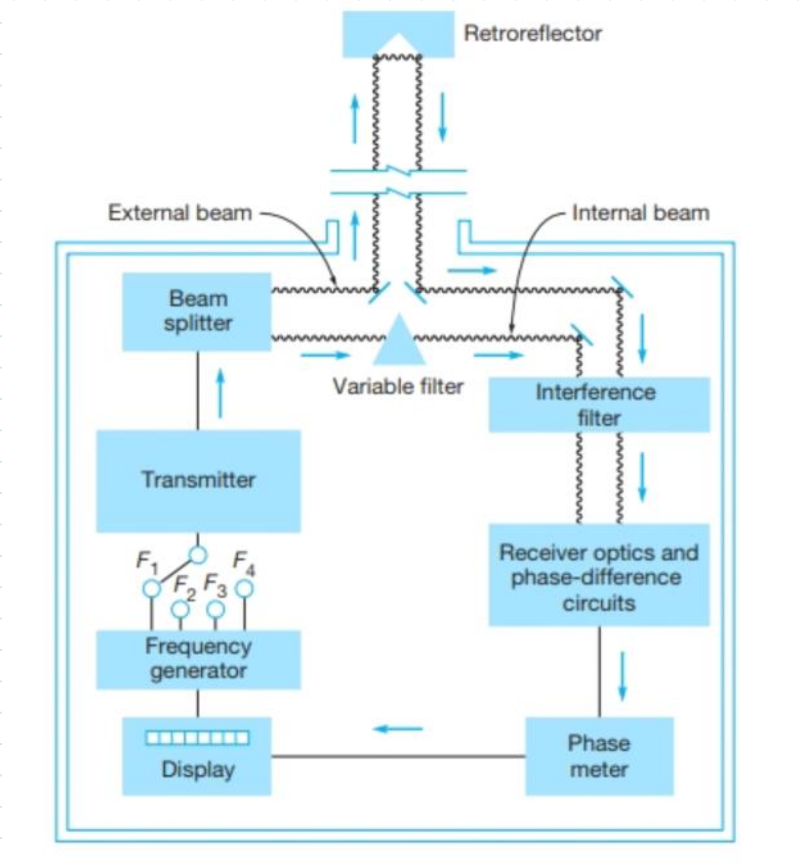

<u>Measuring Distance Based on Number of wavelengths and phase angle</u>

<u>Example</u>

An electro-optical EDM transmits a signal at 14.9989 MHz and signal is returned with 40 cycles and a phase shift of 232.992 degrees. What is the distance to the object?

L = (nλ + p)/2
n = number of cycles
p = phase shift
λ = (see previous page)

f = 14.9989e6=1.4999E7 Hz
λ = (v/f) = 299784458/1.4999E7=19.987 m
p = 19.987*232.992/360=12.9356

2L = 40*19.987+12.9356=812.4156
L = 812.4156/2=406.2078 m

EDM Principles - Time-Pulsed laser EDM

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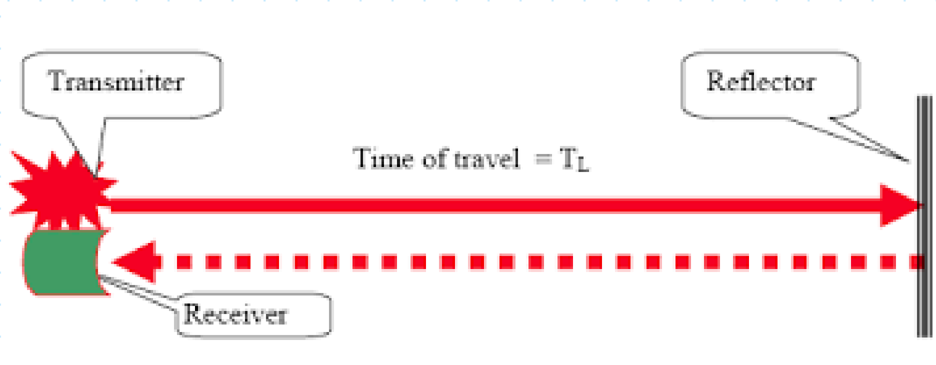
Laser Distance Measurement



<u>Measuring Distance Based on Returned Signal Time</u>

<u>Example</u>

An laser EDM transmits a signal at 14.9989 MHz and signal is returned in 2.71e-6 seconds. What is the distance to the object?

2L = v*Δt
2L = 299784458*2.71e-6 = 812.4159 m
L = 812.4159/2=406.208 m

EDM - Topcon GM Series 50

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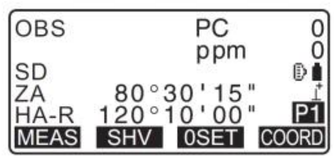
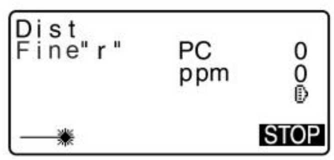
Topcon GM Series 50 Total Station Theodolite

1. Sight the target.

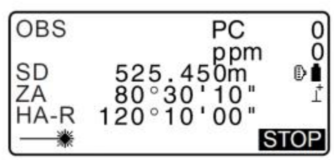
2. In the first page of OBS mode, press **[MEAS]** to start distance measurement.



When measurement starts, EDM information (distance mode, prism constant correction value, atmospheric correction factor) is represented by a flashing light.



A short beep sounds, and the measured distance data (SD), vertical angle (ZA), and horizontal angle (HA-R) are displayed.



3. Press **[STOP]** to quit distance measurement.

Distance unit	m/ft/inch (selectable)
Accuracy (D: measurement distance; Unit: mm) (Under normal atmospheric conditions[*1])	
(Using prism)[*3]	
Fine measurement:	(1.5 + 2 ppm X D) mm[*9 *11] ←
Rapid measurement:	(5 + 2 ppm X D) mm
(Using reflective sheet target)[*4]	
Fine measurement:	(2 + 2 ppm X D) mm
Rapid measurement:	(5 + 2 ppm X D) mm
(Reflectorless (White))[*6]	
Fine measurement:	(2 + 2 ppm X D) mm (0.3 to 200 m)[*10] ←
	(5 + 10 ppm X D) mm (over 200 to 350 m) ←
	(10 + 10 ppm X D) mm (over 350 to 500 m) ←

EDM Possible Errors

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Errors

Personal errors include inaccurate setups of EDM instruments and reflectors over stations, faulty measurements of instrument and reflector heights [needed for computing horizontal lengths (see Section 6.23)], and errors in determining atmospheric pressures and temperatures. These errors are largely random. They can be minimized by exercising utmost care and by using good-quality barometers and thermometers.

From <https://online.vitalsource.com/#/books/9781292060675/cfi/176!/4/4@0:8.84>

Correction for temperature, pressure and humidity

For each 1°C change in temperature, a 1 ppm error in the distance measurement will occur. As a rule, the current temperature and pressure should be set at the time of the measurement. However, it is often practical to set the temperature and pressure three or four times per day: morning, midmorning, noon, and midafternoon. At a minimum, the temperature and pressure should be set twice a day; once in the morning and at noon. However, a lower-accuracy survey will result.

$v = c/n$

v = actual speed of propagation in atmosphere

c = speed of wave propagation in vacuum = 299,792,458 m/s

n = atmospheric index of refraction

EDM Possible Errors (cont.)

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Temperature, atmospheric pressure, and relative humidity all have an effect on the index of refraction. Because a light source emits light composed of many wavelengths, and since each wavelength has a different index of refraction, this group of waves has a *group index of refraction*. The value for the group refractivity N_g in *standard air*[3] for EDM is

$$N_g = (n_g - 1)10^6 = 287.6155 + \frac{4.88660}{\lambda^2} + \frac{0.06800}{\lambda^4} \qquad (6.9)$$

where λ is the wavelength of the light expressed in micrometers (μm) and n_g is the group refractive index. The wavelengths of light sources commonly used in EDMs, are 0.6328 μm for red laser and 0.900 to 0.930 μm for infrared.

The actual group refractive index n_a for atmosphere at the time of observation due to variations in temperature, pressure, and humidity can be computed as

$$n_a = 1 + \left(\frac{273.15}{1013.25} \cdot \frac{N_g P}{t + 273.15} - \frac{11.27\, e}{t + 273.15}\right)10^{-6} \qquad (6.10)$$

where e is the partial water vapor pressure in hectopascal[4] (hPa) as defined by the temperature and relative humidity at the time of the measurement, P the pressure in hPa, and t the dry bulb temperature in °C. The partial water vapor pressure, e, can be computed with sufficient accuracy for normal operating conditions as

$$e = E \cdot h/100 \qquad (6.11)$$

where $E = 10^{[7.5t/(237.3 + t) + 0.7858]}$ and h is the relative humidity in percent.

[3] A standard air is defined with the following conditions: 0.0375% carbon dioxide, temperature of 0°C, pressure of 760 mm of mercury, and 0% humidity.

[4] 1 Atmosphere = 101.325 kPa = 1013.25 hPa = 760 torr = 760 mm Hg.

EDM Possible Errors (cont.)

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Example 6.1

What is the actual wavelength and velocity of a near-infrared beam ($\lambda = 0.915\ \mu m$) of light modulated at a frequency of 320 MHz through an atmosphere with a (dry) temperature t of 34°C, relative humidity h of 56%, and an atmospheric pressure of 1041.25 hPa?

Solution

By Equation (6.9)

$$N_g = 287.6155 + \frac{4.88660}{(0.915)^2} + \frac{0.06800}{(0.915)^4} = 293.5491746$$

By Equation (6.11)

$$a = \frac{7.5\,(34)}{(237.3 + 34)} + 0.7858 = 1.7257$$

$$E = 10^a = 53.174$$

$$e = Eh = 53.174(56/100) = 29.7774$$

By Equation (6.10)

$$n_a = 1 + \left(\frac{273.15}{1013.25} \cdot \frac{293.5492 \times 1041.25}{34 + 273.15} - \frac{11.27 \times 29.7774}{34 + 273.15}\right)10^{-6}$$

$$= 1 + (268.268660 - 1.092597)10^{-6}$$

$$= 1.0002672$$

By Equation (6.8)

$$V = 299{,}792{,}458/1.0002672 = 299{,}712{,}382 \text{ m/sec}$$

Rearranging Equation (6.7) yields an actual wavelength of

$$\lambda = 299{,}712{,}382/320{,}000{,}000 = 0.9366012 \text{ m}$$

Blank

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