6 DISTANCE MEASUREMENT

Asterisks $^{(*)}$ indicate problems that have partial answers given in Appendix G.

6.1 What distance in travel corresponds to 1 μsec of time for electromagnetic energy?

<u>0.299792 m</u> = 299,792,458(0.000001)

6.2* 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) = **<u>2.18 ft/pace</u>**

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

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

<u>15.5° F</u> or **<u>8.6° C</u>**

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

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

6.4 An add tape of 101 ft is incorrectly recorded as 100 ft for a 200-ft distance. What is the correct distance?

<u>202 ft</u>;

6.5* List five types of common errors in taping. (See Section 6.14)

6.6 List the proper procedures taping a horizontal distance of about 84 ft down a 4% slope.

See Section 6.12 and 6.13.

6.7 For the following data, compute the horizontal distance for a recorded slope distance AB,

(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.

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

6.8* 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

6.9 List the possible errors that can occur when measuring a distance with an EDM.

See Section 6.24

6.10 Briefly describe how a distance can be measured by the method of phase comparison.

See Section 6.18

6.11 Describe why the sight line for electronic distance measurement should be at least 0.5 m off the surface of the pavement along its entire line of sight.

Due to the fact that index of refraction will be significantly different near surface due a microclimate that lies immediately above the surface.

6.12* Assume the speed of electromagnetic energy through the atmosphere is 299,784,458 m/sec for measurements with an EDM instrument. What time lag in the equipment will produce an error of 800 m in a measured distance?

<u>0.0027 msec or 2.7 μsec</u>; $t=\dfrac{800}{299{,}784{,}458}=0.0000027$ sec

6.13 What is the length of the partial wavelength for electromagnetic energy with a frequency of the 14.9989 MHz and a phase shift of 156°?

<u>8.661 m</u>; $\lambda=\dfrac{299{,}784{,}458}{14.9989\times10^6}\dfrac{156°}{360}=8.661$ m

6.14 What "actual" wavelength results from transmitting electromagnetic energy through an atmosphere having an index of refraction of 1.0043, if the frequency is:

(a)* 29.988 MHz; **<u>19.903 m</u>**; $\lambda=\dfrac{299{,}792{,}458/1.0043}{14.9989\times10^6}=19.903245$ m

(b) 14.989 MHz; **<u>199.020 m</u>**; $\lambda=\dfrac{299{,}792{,}458/1.0043}{1.49989\times10^6}=199.0205$ m

6.15 Using the speed of electromagnetic energy given in Problem 6.12, what distance corresponds to each microsecond of time?

<u>299.8 m</u>; $D=299{,}784{,}458\left(10^{-6}\right)=299.8$ m

6.16 To calibrate an EDM instrument, distances AC, AB, and BC along a straight line were observed as 90.158 m, 30.164 m, and 60.025 m, respectively. What is the system measurement constant for this equipment? Compute the length of each segment corrected for the constant.

<u>0.031 m</u>; From Equation (6.16): $K=90.158-30.164-60.025=0.031$ m

6.17 Which causes a greater error in a line measured with an EDM instrument: **(a)** A disregarded 10° C temperature variation from standard or **(b)** a neglected atmospheric pressure difference from standard of 50 mm of mercury?

(a) Pressure; From Figure 6.16, a 10° C difference in temperature will cause a 10 ppm error in the distance whereas a 50 mm of Hg difference in pressure will cause about an 18 ppm error in the distance. So the pressure difference will cause the largest error.

6.18* In Figure 6.14, h_e, h_r, elev$_A$, elev$_B$ and the measured slope length L were 5.56, 6.00, 603.45, 589.06, and 408.65 ft, respectively. Calculate the horizontal length between A and B.

<u>408.41 ft</u>; From Equation (6.13) $d = (603.45 + 5.56) - (589.06 + 6.00) = 13.95$ ft

By Equation (6.2): $H = \sqrt{408.65^2 - 13.95^2} = 408.41$ ft

6.19 Similar to Problem 6.18, except that the values were 1.489, 1.502, 126.897, 142.681, and 206.782 m, respectively.

<u>206.178 m</u>; From Equation (6.13) $d = (1.489+126.897) - (1.502+142.681) = -15.797$ m

By Equation (6.2): $H = \sqrt{206.782^2 - 15.797^2} = 206.1777$ m

6.20 In Figure 6.14, h_e, h_r, z, and the measured slope length L were 5.53 ft, 6.00 ft, $93°20'06''$ and 489.65 ft, respectively. Calculate the horizontal length between A and B if a total station measures the distance.

<u>488.82 ft</u>; $H = 489.65 \sin(93°20'06'') = 488.821$ ft

6.21* Similar to Problem 6.20, except that the values were 1.45 m, 1.55 m, $96°05'33''$ and 1663.254 m, respectively.

<u>1653.860 m</u>; $H = 1663.254 \sin(96°05'33'') = 1653.8597$ m

6.22 What is the actual wavelength and velocity of a near-infrared beam $(\lambda = 0.901\ \mu\text{m})$ of light modulated at a frequency of 330 MHz through an atmosphere with a dry bulb temperature, T, of 26° C, a relative humidity, h, of 75%, and an atmospheric pressure of 893 hPa?

<u>0.908248 m</u>

$$N_g = 287.6155 + \frac{4.88660}{0.901^2} + \frac{0.06800}{0.901^4} = 293.73814$$

$$a = \frac{7.5(26)}{237.3+26} + 0.7858 = 1.5264001$$

$$E = 10^a = 33.604704$$

$$e = E\frac{75}{100} = 25.203528$$

$$n_a = 1 + \left(\frac{273.15}{1013.25}\frac{293.76587(893)}{26+273.15} - \frac{11.27e}{26+273.15}\right)10^{-6} = 1.0002354$$

$$V = \frac{299,792,458}{1.0002354} = 299,721,895 \text{ m/s}$$

$$\lambda = \frac{299,721,895}{330 \cdot 10^6} = 0.9082482 \text{ m}$$

6.23 What is the actual wavelength and velocity of a near-infrared beam $(\lambda = 0.922\ \mu\text{m})$ of light modulated at a frequency of 330 MHz through an atmosphere with a dry bulb temperature, T, of 16° C, a relative humidity, h, of 35%, and an atmospheric pressure of 812 hPa?

<u>0.9082606 m</u>

$$N_g = 287.6155 + \frac{4.88660}{0.922^2} + \frac{0.06800}{0.922^4} = 293.45797$$

$$a = \frac{7.5(16)}{237.3+16} + 0.7858 = 1.5264001$$

$$E = 10^a = 33.604704$$

$$e = E\frac{35}{100} = 11.761646$$

$$n_a = 1 + \left(\frac{273.15}{1013.25}\frac{293.76587(812)}{16+273.15} - \frac{11.27e}{16+273.15}\right)10^{-6} = 1.0002217$$

$$V = \frac{299,792,458}{1.0002217} = 299,726,009 \text{ m/s}$$

$$\lambda = \frac{299,722,006}{330 \cdot 10^6} = 0.9082606 \text{ m}$$

6.24 If the temperature and pressure at measurement time are 18°C and 760 mm Hg, what will be the error in electronic measurement of a line 3 km long if the temperature at the time of observing is recorded 10°C too high? Will the observed distance be too long or too short?

From Figure 6.16: ppm_T = 10 ppm; error = $10/10^6(3000)$ = 0.030 m, which is too short

6.25* The standard deviation of taping a 30 m distance is ±5 mm. What should it be for a 90-m distance?

<u>8.7 mm</u>; $5\sqrt{90/30} = 8.66$ mm

6.26 Determine the most probable length of a line *AB*, the standard deviation, and the 95% error of the measurement for the following series of taped observations made under the same conditions: 215.382, 215.381, 215.384, 215.374, 215.391, 215.382, 215.374, 215.382, 215.389, and 215.387 m.

215.383 ± 0.010 m = 215.383 ± 1.9599(0.00533) = 215.383 ± 0.0104 m

6.27 If an EDM instrument has a purported accuracy capability of ±(1.5 mm + 2 ppm), what error can be expected in a measured distance of **(a)** 25 m **(b)** 483.40 ft **(c)** 387.563 m? (Assume that the instrument and target miscentering errors are equal to zero.)

(a) **<u>±1.50 mm</u>**; $\sqrt{1.5^2 + \left[\dfrac{2(25000)}{10^6}\right]^2} = \pm 1.50 \text{ mm}$

(b) **<u>±0.005 ft</u>**; $\sqrt{1.5^2 + \left[\dfrac{2(483.40)}{1000000}\right]^2} = \pm 1.53 \text{ mm} = \pm 0.005 \text{ ft}$

(c) **<u>±4.2 mm</u>**; $\sqrt{1.5^2 + \left[\dfrac{2(387,563)}{1000000}\right]^2} = \pm 1.69 \text{ mm}$

6.28 The estimated error for both instrument and target miscentering errors is ±1.5 mm. For the EDM in Problem 6.27, what is the estimated error in the observed distances?

(a) **<u>±2.60 mm</u>**; $\sqrt{1.5^2 + 1.5^2 + 1.5^2 + \left[\dfrac{2(25000)}{10^6}\right]^2} = \pm 2.60 \text{ mm}$

(b) **<u>±0.009 ft</u>**; $\sqrt{1.5^2 + 1.5^2 + 1.5^2 + \left[\dfrac{2(483.40)}{1000000}\right]^2} = \pm 2.61 \text{ mm} = \pm 0.0086 \text{ ft}$

(c) **<u>±2.71 mm</u>**; $\sqrt{1.5^2 + 1.5^2 + 1.5^2 + \left[\dfrac{387,563}{1000000}\right]^2} = \pm 2.71 \text{ mm}$

6.29 If a certain EDM instrument has an accuracy capability of ±(2 mm + 2 ppm), what is the precision of measurements, in terms of parts-per-million, for line lengths of: **(a)** 20.000 m **(b)** 200.000 m **(c)** 2000.000 m? (Assume that the instrument and target miscentering errors are equal to zero.)

(a) **<u>100 ppm</u>**; *E* = ±2.00; ppm = (2.00/20,000)1,000,000 = 100.02 ppm

(b) **<u>10.2 ppm</u>**; *E* = ±10.2; ppm = (10.2/200,000)1,000,000 = 10.198 ppm

(c) **<u>2.24 ppm</u>**; *E* = ±4.47; ppm = (4.47/2,000,000)1,000,000 = 2.236 ppm

6.30 The estimated error for both instrument and target miscentering errors is ±1.5 mm. For the EDM and distances listed in Problem 6.29, what is the estimated error in each distance? What is the precision of the measurements in terms of part-per-million?

(a) **146 ppm**; $E = \pm 2.92$ mm; ppm = (2.92/20,000)1,000,000 = 145.79 ppm

(b) **14.7 ppm**; $E = \pm 2.94$ mm; ppm = (2.94/200,000)1,000,000 = 14.71 ppm

(c) **2.5 ppm**; $E = \pm 4.95$ mm; ppm = (4.95/2,000,000)1,000,000 = 2.47 ppm

6.31 Create a computational program that solves Problem 6.22. Response should vary.