13 GLOBAL NAVIGATION SATELLITE SYSTEMS—INTRODUCTION AND PRINCIPLES OF OPERATION

Asterisks (*) indicate problems that have partial answers given in Appendix G.

13.1 What are the two new civilian codes being added to the modernized satellites?

From Section 13.3: "The modernized satellites include a second civilian code on the L2 signal called the L2C. This code has both a civilian moderate (CM) and civilian long (CL) version."

13.2 How are satellites identified?

See Section 13.2: "The individual satellites are normally identified by their *PseudoRandom Noise* (PRN) number, (described below), but can also be identified by their satellite vehicle number (SVN) or orbital position."

13.3 What is the frequency of the *L*5 signal and its relationship to the fundamental frequency of the satellite clock?

From Section 13.3: "L5 will be broadcast at a frequency of 1176.45 MHz." From Table 13.1 its relationship to f_0 is $115f_0$.

13.4* Discuss the purpose of the pseudorandom noise codes.

See Section 13.2, paragraphs 3 thru 8. "The individual satellites are normally identified by their *PseudoRandom Noise* (PRN) number. The receiver simultaneously generates a duplicate PRN code. Matching the incoming satellite signal with the identical receiver-generated signal derives the time it takes for the signal to travel from satellite to receiver. This yields the signal delay that is converted to travel time. From the travel time, and the known signal velocity, the distance to the satellite can be computed."

13.5 Approximately how long does it take for the GPS satellite signal to reach a receiver on Earth?

From Section 13.3, paragraph 7: "Since the signal from the satellite transmitter must travel to the receiver, its reception will be delayed in relation to the signal generated by the receiver. This delay, which is approximately 0.07 sec, can be measured, and converted to a time difference."

13.6 Define perigee.

From Section 13.4.1, paragraph 1: "*Perigee* and *apogee* are points where the satellite is closest to, and farthest away from *G*, respectively, in its orbit."

13.7 Describe the content of the GPS broadcast message.

Handover word, Time of Week word, satellite clock bias, satellite positioning data (almanac and ephemeris), and ionospheric modeling data. This information is scattered throughout the chapter.

13.8 What is the purpose of anti-spoofing?

From Section 13.3, paragraph 6: "This encryption process is known as *anti-spoofing* (A-S). Its purpose is to deny access to the signal by potential enemies who could deliberately modify and retransmit it with the intention of "spoofing" unwary friendly users."

13.9 Describe the geocentric coordinate system.

From Section 13.4.1, paragraph 2: "This three-dimensional rectangular coordinate system has its origin at the mass center of the Earth. Its X_e axis passes through the Greenwich meridian in the plane of the equator, and its Z_e axis coincides with the *Conventional Terrestrial Pole* (CTP). Its Y_e axis lies in the plane of the equator and creates a right-handed coordinate system."

13.10 Define the terms "geodetic height," "geoid undulation," and "orthometric height." Include their relationship to each other.

See Section 13.4.3: $h = H + N$ where h is the geodetic height, H is the elevation/orthometric height, or N is the geoid undulation is the vertical distance between the ellipsoid and geoid.

13.11 Define PDOP, HDOP, and VDOP.

From Section 13.6.4:

- Positional dilution of precision: $\sqrt{\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2}$
- Horizontal dilution of precision: $\sqrt{\sigma_n^2 + \sigma_e^2}$
- Vertical dilution of precision: $\sqrt{\sigma_Z^2}$

13.12 What reference ellipsoid is used in the broadcast message of GPS?

From Section 13.4.1, footnote 3: WGS84

13.13 What is the primary purpose of the course/acquisition code?

From Section 13.3, paragraph 3: "This C/A code allows receivers to acquire the satellites as well as allowing receivers to determine their approximate positions."

13.14 What are the satellite orbital parameters?

From Section 13.4.2, paragraph 2: "To make the conversion from the satellite reference coordinate system to the geocentric system, four angular parameters are required, which define the relationship between the satellite's orbital coordinate system and key reference planes and lines on the Earth. As shown in Figure 13.5, these parameters are (1) the *inclination* angle, i (angle between the orbital plane and the Earth's equatorial plane), (2) the *argument of perigee*, ω (angle in the orbital plane from the equator to the line of apsides), (3) the *right ascension of the ascending node*, Ω (angle in the plane of the Earth's equator from the vernal equinox to the line of intersection between the orbital and equatorial planes), and (4) the *Greenwich hour angle of the vernal equinox*, GHA_γ (angle in the equatorial plane from the Greenwich meridian to the vernal equinox)."

13.15 What is single differencing?

From Section 13.5.1: Single differencing is the difference between two observations from one satellite to two receivers.

13.16 What is double differencing?

From Section 13.5.2: Double differencing is the difference between two single difference observations from two satellites.

13.17 List and describe the ephemerides.

From Section 13.6.3, paragraph 2: "One of three updated post-survey ephemerides are available: (1) ultra-rapid ephemeris, (2) the *rapid ephemeris*, and (3) the *precise ephemeris*. The ultra-rapid ephemeris is available twice a day; the rapid ephemeris is available within two days after the survey; the precise ephemeris (the most accurate of the three) is available two weeks after the survey. The ultra-rapid and rapid ephemerides are sufficient for most surveying applications."

13.18 What are the major sources of error in a GPS pseudorange?

From Section 13.6, paragraph 1: "Some of the larger errors include (1) satellite and receiver clock biases and (2) ionospheric and tropospheric refraction. Other errors in satellite surveying work stem from (a) satellite ephemeris errors, (b) multipathing, (c) instrument miscentering, (d) antenna height measurements, and (e) satellite geometry."

13.19 If the HDOP during a survey is 1.15 and the UERE is estimated to be 1.65 m, what is the 95 percent horizontal point-positioning error?

±3.7 m; 1.15(1.65)1.96

13.20* In Problem 13.19, if the VDOP is 3.5, what is the 95% point-positioning error in geodetic height?

±11.3 m; 3.5(1.65)1.96

For Problems 13.21 through 13.26 use the WGS84 ellipsoidal parameters.

13.21* What are the geocentric coordinates in meters of a station in meters that has a latitude of 49°27'32.20144" N longitude of 122°46'53.56027" W and height of 303.436 m.

From WolfPack: (**−2,249,118.734, −3,492,419.151, 4,824,120.725**)

R_N = 6,372,357.535 m

13.22 Same as Problem 13.21 except with geodetic coordinates of 41° 46'29.83749" N, longitude of 75°54'02.92846" W and height of 335.204 m?

From WolfPack: **(−1,160,501.219, −4,620,426.650, 4,227,218.696)**

R_N = 6,363,780.101 m

13.23 Same as Problem 13.21 except with geodetic coordinates of 29°07'22.20376" N longitude of 105°32'42.29475" W and height of 1003.093 m?

From WolfPack: (−**1,494,643.637, −5,373,090.242, 3,086,289.873**)

R_N = 6,383,199.726 m

13.24* What are the geodetic coordinates in meters of a station with geocentric coordinates of (136,153.995, −4,859,278.535, 4,115,642.695)?

From WolfPack: (**40°26'29.65168" N, 88°23'42.09876" W, 182.974 m**)

13.25 Same as Problem 13.24, except with geocentric coordinates in meters are (−1,155,636.309, −5,266,793.426, 3,395,499.990)?

From WolfPack: (**32°22'23.45671" N, 102°22'32.45125" W, 86.098 m**)

13.26 Same as Problem 13.24, except with geocentric coordinates in meters are (1,427,663.093, −4,505,627.131, 4,269,188.048)?

From WolfPack: (**42°16'54.58310" S, 72°25'06.80760" W, 553.106 m**)

13.27 The GNSS determined height of a station is 288.038 m. The geoid undulation at the point is −32.456 m.

320.494 m by Equation (13.8): H = h − N

13.28* The GNSS determined height of a station is 84.097 m. The geoid undulation at the point is −30.025 m. What is the elevation of the point?

114.122 m by Equation (13.8) : H = h − N

13.29 Same as Problem 13.28, except the height is 464.684 m and the geoid undulation is −28.968 m.

493.652 m by Equation (13.8): H = h − N

13.30* The orthometric height of a point is 124.886 m. The geoid undulation of the point is −28.998 m. What is the geodetic height of the point?

<u>95.888 m</u> by Equation (13.8): H = h − N

13.31 Same as Problem 13.30, except the elevation is 1086.904 m, and the geoid undulation is −22.232 m.

<u>1109.136 m</u> by Equation (13.8): H = h − N

13.32 The GNSS observed height of two stations is 124.685 m and 89.969 m, and their orthometric heights are 153.104 m and 118.386 m, respectively. These stations have model-derived geoid undulations of −28.454 m and −28.457 m, respectively. What is the orthometric height of a station with a GNSS measured height of 105.968 m and a model-derived geoid undulation of −28.446 m?

134.376 m

N_{GPS}	ΔN
124.685 − 153.104 = −28.419	−28.419 + 28.454 = 0.035
89.969 − 118.386 = −28.417	−28.417 + 28.457 = 0.040

Avg ΔN = 0.0375 m   H = 105.968 −(−28.446 + 0.0375) = **134.376 m**

13.33 Why are satellites at an elevation below 10° from the horizon eliminated from the positioning solution?

From Section 13.6.2, last paragraph: To minimize the errors caused by refraction.

13.34 Find at least two Internet sites that describe how GPS works. Summarize the contents of each site.

Responses will vary.