1. In Table 2.1, “Orbital Radius (mi)” should be replaced by “Orbital radius (mi)” with a lower case “r”.

2. Equation 3.19 should be replaced by:

$$\Phi_{BPSK,\scriptscriptstyle (\nu)}(f) = T_c \sin^2 \left( \pi f T_c \right)$$

(3.19)

3. Equation 3.26 should be replaced by:

$$\Phi_{\scriptscriptstyle BOC,\scriptscriptstyle (f, f_0)}(f) = \begin{cases} 
\frac{1}{f_c} \sin^2 \left( \frac{\pi f}{f_c} \right) \tan^2 \left( \frac{\pi f}{2 f_c} \right), & k_{\scriptscriptstyle BOC} \text{ even} \\
\frac{1}{f_c} \cos^3 \left( \frac{\pi f}{f_c} \right) \tan^2 \left( \frac{\pi f}{2 f_c} \right), & k_{\scriptscriptstyle BOC} \text{ odd} 
\end{cases}$$

(3.26)

4. Equation (4.9) should be replaced by:

$$P_R = EIRP - L_{ex} - L_{ant} + 27.56 - 20 \log_{10} \left( f \right) - 20 \log_{10} \left( r_{t2r} \right) + 10 \log_{10} \left( G_T \right)$$

(4.9)

5. Equation (4.17) should be replaced by:

$$L = 0.2 f_{\text{MHz}}^{0.3} d_{\text{foliage}}^{0.6} \text{ (dB)}$$

(4.17)

6. Equation (4.19) should be replaced by:

$$L = 15.6 \times f^{-0.009} \times d_{\text{foliage}}^{0.26}$$

(4.19)

7. Figure 4-9 should be replaced with the version in Appendix A.

8. The first complete sentence after equation (4.19) should be replaced by:

Reference 9 provides test results showing that the model (4.17) is more accurate, but still has an error of 6.5 dB RMS.
9. In the second to last paragraph of Section 5.3, the sentence should read “even though as precorrelation bandwidths approach infinity zero, the input SNR C/(βrN0) approaches zero.”

10. In Table 7.2, “Correction” should be “correction”

11. In Table 7.7, the entry −158.5 dBW should have an asterisk added: −158.5 dBW*

Table 7.7 should then have the same kind of note underneath that Table 7.9 does. The note should read:

*The value is −160.0 dBW for Block IIR-M and IIF satellites, but is planned to be −158.5 dBW for GPS III and all subsequent satellites.

12. In Table 7.9, the following entry for Spreading codes is not correct:

Pilot component: Length 767250-bit L2CL code, duration 1.5 seconds
Data component: Length 10230-bit L2CM code, duration 20 msec

It should be replaced by

Pilot component: Length 10230-bit I5 code, duration 1 msec
Data component: Length 10230-bit Q5 code, duration 1 msec

13. The first paragraph in 8.2 should be clarified as follows.

As a wide area differential system, described in more detail in Chapter 23, an SBAS uses a network of ground reference stations, precisely surveyed, to collect measurements from the satellite signals being augmented [7]. Ground reference stations currently receive GPS L1 and L2 signals: the C/A code signal as well as P(Y) code signal on L1 and L2. The P(Y) code signal is received without use of the spreading code bits using codeless or semicodeless techniques [8]. As portrayed in Figure 8.1, the ground reference stations’ measurements are communicated, via a terrestrial communications network or satcom network, to one or more master stations that use the dual-frequency ionospheric measurements to compute a grid of ionospheric corrections. In addition, the master stations evaluate the discrepancies between measurements and the known locations of the ground reference station antennas to compute corrections to the satellites’ ephemeris broadcasts and clocks. The master stations also determine each signal’s integrity (whether the signal’s RF and data message characteristics are within specification, data message contents are valid, and pseudorange errors are correctable), and the measurement quality available from the signal. The master stations then construct augmentation messages containing ionospheric corrections and (for each individual signal from each satellite) ephemeris and clock corrections, integrity, and measurement quality indicators, and modulate these messages onto a signal passed to an uplink station for transmission to a transponder on a geostationary satellite. The uplink signal is transmitted at higher carrier frequencies than L band, with C band, K band, and Ku band being commonly used. The GEO transponder translates the signal at the uplink carrier frequency to the desired L band carrier frequency, amplifies the signal, and broadcasts it from an earth-coverage
antenna. This simple transponder operation, consisting of a frequency shift and amplification, is often called “bent pipe” operation. It is conceivable that some future SBAS satellites might use signal-generating payloads rather than bent-pipe operation.

14. Figure 16.1 had some typos. The corrected graphic is provided in Appendix B to this document.

15. Figure 17.7 is missing some curves. The correct graphic is provided in Appendix C to this document.

16. Equation (19.17) needs to be corrected. The correct equation is

\[
\sigma_{\text{CELP}}^2 \approx \frac{B_s}{\left( \frac{\zeta C}{N_0} \right) \left[ \int_{-\beta/2}^{\beta/2} \tilde{f}(f) \sin(\pi f \Delta) df \right]^2} \\
\times \left[ \int_{-\beta/2}^{\beta/2} \tilde{f}(f) \sin^2(\pi f \Delta) df + \frac{1}{N_0} \int_{-\beta/2}^{\beta/2} \tilde{f}(f) \tilde{f}(f) \sin^2(\pi f \Delta) df \right] \left( s^2 \right) 
\]

16. Figure 18.7 had incorrect labels. The corrected figure is in Appendix D.

17. Figures 18.14, 18.15, 18.17 had incorrect labels. The corrected figures are in Appendix E.

18. Section 20.5 is revised in Appendix F to clarify the distinction between line of sight velocity and receiver velocity.

19. In the appendix, the section title **A.4 STOCHASTIC PROCESSES** should be replaced by

**A.4 STOCHASTIC PROCESSES**

20. The paragraph preceding A.8 should read:

If \( R \), the covariance matrix of the measurements, is an invertible \( m \times m \) matrix, the previous result can be generalized to minimize the weighted mean-squared error \( (Ax - b)^H R^{-1} (Ax - b) \). The **weighted least-squares (WLS)** solution is \([6] x_{\text{WLS}} = \left( A^H R^{-1} A \right)^{-1} A^H R^{-1} b \) which reverts to the OLS solution when \( R = I \).
Appendix A. Corrected Figure 4.9

![Graph showing the relationship between Loss (dB) and d_foliage (m) with two lines for 1575.42 MHz and 1176.45 MHz. The graph ranges from 0 to 70 dB on the y-axis and 0 to 400 m on the x-axis.](image-url)
Initial Synchronization Processing

- Frequency Adjustment
- Tracking Correlators
- Smoothing & Carrier NCO
- Replica Generator
- Smoothing & Code NCO
- Discriminator & Filter for Code
- Discriminator & Filter for Carrier

*Replicated for Each Receiver Channel*
Appendix C. Corrected Figure 17.7

The graph shows the parameter estimate errors over time for different models:
- First Order
- Second Order, SC
- Second Order, SJD

The x-axis represents the time (number of loop updates), and the y-axis represents the parameter estimate error. The graph illustrates how these errors change over time for each model, with the error decreasing as the time increases.
Appendix D. Revised Figure 18.7

Loop Bandwidth, 5 Hz

Loop Bandwidth, 20 Hz

RMS Frequency Tracking Error (Hz)

\( (C/N_0)_{\text{eff}} \) (dB-Hz)

T=0.002
T=0.005
T=0.02

T=0.002
T=0.005
T=0.02
Appendix E. Revised Figures 18.14, 18.15, 18.17

\[ \lambda (C/N_0)_{\text{eff}} \text{ (dB-Hz)} \]

- Probability of Bit Error
- \( T_b = 0.004 \)
- \( T_b = 0.008 \)
- \( T_b = 0.02 \)
\( \lambda (C/N_0)_{\text{eff}} \) (dB-Hz)

Probability of Bit Error

\( T_b = 0.004 \quad T_b = 0.008 \quad T_b = 0.002 \)
Appendix F. Revised Section 20.5 to clarify distinction between line of sight velocity and receiver velocity

20.5 Velocity Calculation

In general, satnav enables a PVT solution, but the earlier discussion has addressed only position and time. This section completes the discussion of obtaining a PVT solution when position and time offset have already been determined using the approach in Section 20.3 or Section 20.4. Subsection 20.5.1 describes an algorithm based on delta pseudoranges, while subsection 20.5.2 describes an algorithm based on delta-ranges or pseudorange rates.

20.5.1. Using Delta Pseudoranges for Velocity Calculation

If receiver dynamics are modest and the receiver produces position updates frequently, the line of sight velocity to each satellite can be estimated using sequential pseudorange updates. From (20.15), denote here explicitly the time at which the pseudorange estimate is made by $T_{k} = T_{k-1} + \Delta T$. The delta pseudorange estimate is the difference between two sequential pseudorange estimates,

$$
\hat{\Delta} \rho_k \left[ nT \right] = \hat{\rho}_{k} \left[ (n+1)T \right] - \hat{\rho}_{k} \left[ nT \right] + c \left( \hat{D}_{k} \left[ (n+1)T \right] - \hat{D}_{k} \left[ nT \right] \right)
$$

Observe that if the uncorrected pseudorange (20.3) is used instead, as long as $T$ is small enough that the tropospheric error, clock offset, and ionospheric error are approximately the same for the sequential updates, these errors cancel in the delta pseudorange. However, computing the delta pseudorange magnifies the pseudorange error due to jitter, since the variance of $\hat{D}_{k} \left[ (n+1)T \right] - \hat{D}_{k} \left[ nT \right]$ is the sum of the variances of $\hat{D}_{k} \left[ (n+1)T \right]$ and $\hat{D}_{k} \left[ nT \right]$, when they are uncorrelated.

The already-estimated receiver position and time offset are used to obtain estimated direction vectors

$$
\hat{u}_k = \begin{bmatrix} \hat{x}_k \bar{x}_k \\ \hat{y}_k \bar{y}_k \\ \hat{z}_k \bar{z}_k \\ \end{bmatrix}^T \text{ and the estimated velocity geometry matrix}
\hat{G} = \begin{bmatrix} (\hat{u}_1)^T \\ (\hat{u}_2)^T \\ \vdots \\ (\hat{u}_K)^T \end{bmatrix}^T.
$$

The receiver velocity vector is then estimated from the OLS solution [10]

$$
\begin{bmatrix} \dot{x}_r \\ \dot{y}_r \\ \dot{z}_r \\ \end{bmatrix} = \hat{G}^+ \begin{bmatrix} \hat{\Delta} \rho_k \left[ (n+1)T \right] - \hat{\rho}_{k} \left[ nT \right] \\ \hat{\Delta} \rho_k \left[ (n+1)T \right] - \hat{\rho}_{k} \left[ nT \right] \\ \vdots \\ \hat{\Delta} \rho_k \left[ (n+1)T \right] - \hat{\rho}_{k} \left[ nT \right] \end{bmatrix} + \hat{G} \begin{bmatrix} \dot{x}_1 \\ \dot{y}_1 \\ \dot{z}_1 \\ \dot{x}_2 \\ \dot{y}_2 \\ \dot{z}_2 \\ \vdots \\ \dot{x}_K \\ \dot{y}_K \\ \dot{z}_K \end{bmatrix}
$$

where all quantities are in ECEF coordinates. The first term on the right hand side is the line of sight velocity vectors, while the right hand term removes the satellite velocities projected onto the lines of sight, leaving the receiver velocity. Note that (20.27) has important similarities and differences with the SPP equations (20.21). In both cases, each row of the geometry matrix contains a direction vector.
between the receiver and $k$th satellite, but in the calculation for velocity using delta pseudoranges, there is no fourth column. For velocity calculation, the direction vectors are known since position has already been determined, so there is no need for an iterative solution as there was in (20.21). Further, there are only three unknowns, so as few as three measurements are needed, unless a unique satellite geometry causes the rank of the resulting measurement matrix to be less than 3. A matrix inverse is used if measurements from only three satellites are available, and a WLS equivalent can be used if there are measurements from more than three satellites, and the measurement covariance matrix is known. While this delta pseudorange approach has the advantage of only having three unknowns to solve for, it has the disadvantage of using pseudorange measurements. Not only are these pseudorange measurements far noisier than phase measurements, but the differencing further increases the error.

Obtaining the system of equations (20.27) involves a number of assumptions and approximations that must be recognized. Implicit to the development is that the rates of change of satellite system clock offset and receiver clock offset are negligible. Otherwise, these quantities must be accounted for, increasing the order of the system of equations. Further, the receiver’s position must be close to constant. All of these assumptions and approximations best apply when $T$ is small, but this is the case when pseudorange jitter most degrades the solution.

20.5.2. Using Delta-Ranges or Pseudorange Rates for Velocity Calculation

In this case, the receiver position has already been determined using an approach consistent with Section 20.3 or Section 20.4. Carrier tracking produces estimates of the Doppler shift from each satellite, biased by any frequency offset in the receiver’s oscillator. As described in Section 18.1, an FLL provides an estimate of the $k$th satellite’s received frequency translated carrier frequency over some time interval $T$, denoted \( \hat{f}_{m}(k) \). Then the delta range over a time interval $T$ is

\[
\Delta \hat{r}_{m}(k) = \frac{c}{\lambda_{0}} \left( \hat{f}_{m}(k) + f_{\Delta} - f_{0} \right) T / \left( \hat{f}_{m}(k) + f_{\Delta} \right),
\]

where $f_{0}$ is the wavelength of the carrier frequency. Generally, the receiver’s oscillator is biased from the true frequency, so that the estimated frequency of arrival $\hat{f}_{m}(k) + f_{\Delta}$ is biased by $f_{r}$. The biased estimate of the average line of sight velocity, or pseudovelocity, to the satellite over time interval $T$ is then the delta range divided by $T$, or \( \hat{v}^{(k)} = c \left( \hat{f}_{m}(k) + f_{\Delta} - f_{0} \right) / \left( \hat{f}_{m}(k) + f_{\Delta} \right) \).

Alternatively, if a Costas loop or PLL is used, the receiver can count the number of carrier cycles $N_{\theta}^{(k)}$ over a time interval $T$, (where $N_{\theta}^{(k)}$ need not be an integer) producing an alternative estimate of the received frequency

\[
N_{\theta}^{(k)} = \left( \hat{f}_{m}(k) - f_{0} \right) T.
\]

The pseudorange rate is then \( c N_{\theta}^{(k)} / \left( T \left( \hat{f}_{m}(k) + f_{\Delta} \right) \right) \), which also is biased by $f_{r}$. In this case, the biased estimate of line of sight velocity, or pseudovelocity, to the $k$th satellite is \( \hat{v}^{(k)} = c (N_{\theta} / T + f_{\Delta}) / \left( \hat{f}_{m}(k) + f_{\Delta} \right) \).

With either pseudovelocity estimate, the resulting estimates of receiver velocity and oscillator frequency bias are found using the estimated geometry matrix.
by computing

$$\hat{\mathbf{u}} = \begin{bmatrix} (\hat{u}_1)^T & 1 \\ (\hat{u}_2)^T & 1 \\ \vdots & 1 \\ (\hat{u}_K)^T & 1 \end{bmatrix}$$

The expression (20.28) can be solved directly for the velocity vector and frequency offset using the same approaches (matrix inverse if $K = 4$ and the matrix is invertible, and for $K > 4$ either the OLS or WLS solutions) as for SPP, but without any need for iterations. Compared to using delta pseudoranges described in subsection 20.5.1, the disadvantage of using delta ranges is the need for an additional measurement. However, using delta ranges employs much higher accuracy measurements (typically FLL measurements have an order of magnitude smaller variance than delta pseudoranges, and phase measurements have two orders of magnitude smaller variances than delta pseudoranges), providing more accurate estimates of receiver velocity. Further, using delta ranges does not assume the receiver is stationary, so is more generally applicable. It should be clear that, unlike the solution approach described in subsection 20.3.3 for SPP, neither of these approaches for finding velocity needs an iterative solution.