GLOBAL POSITIONING SYSTEM PRECISE POSITIONING SERVICE PERFORMANCE STANDARD

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

GPS
NAVSTAR
Global Positioning System

February 2007

Integrity - Service - Excellence

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NETWORKS AND INFORMATION
INTEGRATION

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FOREWORD

This document defines the levels of performance the U.S. Government makes available to authorized users of the Global Positioning System (GPS) Precise Positioning Service (PPS). It has been approved by the DoD Positioning, Navigation, and Timing Executive Committee. Please refer any questions or comments, in writing, to:

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SECTION 1.0 The GPS Precise Positioning Service

The Navstar Global Positioning System (GPS) is a space-based radionavigation system owned and operated by the United States. GPS has provided positioning, navigation, and timing services to military and civilian users on a continuous worldwide basis since first launch in 1978. An unlimited number of users with a civil or military GPS receiver can determine accurate time and location, in any weather, day or night, anywhere in the world.

The United States Air Force, as the Executive Agent for GPS, is responsible for the design, development, procurement, operation, sustainment, and modernization of the system. The Commander of United States Strategic Command (USSTRATCOM) exercises Combatant Command of GPS through the 14th Air Force (14 AF). 14 AF has day-to-day operational responsibilities for GPS, while its subordinate units, 50th Space Wing (50 SW) and the 2nd Space Operations Squadron (2 SOPS) maintain the health and status of the operational constellation at facilities located at Schriever Air Force Base, Colorado. The system is acquired and maintained by the Global Positioning Systems Wing (GPSW) at Space and Missile Systems Center, Los Angeles Air Force Base, California.

Relying on tracking and monitoring stations around the world, 2 SOPS crew members conduct 24-hour operations to monitor, control and ensure GPS performance and reliability meet or exceed the requirements of both military and civilian users.

GPS has grown into a global utility whose multi-use services are integral to U.S. and global security, economic growth, transportation safety, and are an essential element of the worldwide economic infrastructure. In an effort to ensure beneficial services are available to the greatest number of users without degrading security interests, two GPS services are provided. The Precise Positioning Service (PPS) is available primarily to the military of the United States and its allies for users properly equipped with PPS receivers. The Standard Positioning Service (SPS), as initially described in the *SPS Signal Specification*, was originally designed to provide civil users with a less accurate positioning capability than PPS, through a technique known as Selective Availability (SA).

In 2000, the U.S. Government recognized the increasing importance of the GPS to civil and commercial users and determined that global interests would be best served if deliberate degradation of accuracy for non-military signals was discontinued. The President announced that the practice of degrading the SPS via SA would be discontinued May 1, 2000. The *SPS Signal Specification* was rewritten to reflect this change in policy and became the *SPS Performance Standard, 4 October 2001.*

This first edition of the *PPS Performance Standard* establishes new unclassified performance standards that reflect SA being set to zero. It serves as a companion document to the *SPS Performance Standard,* for U.S. and allied military users of GPS who use the military capabilities provided by this “dual use” (PPS or SPS) system.

1.1 Purpose

This *PPS Performance Standard* (*PPS PS*) defines the levels of Signal In Space (SIS) performance to be provided by the DoD to the authorized PPS user community. It is established to provide a basis for certification of PPS receivers for use in aviation Instrument Flight Rules (IFR) and to establish a minimum performance level which the GPS constellation must sustain. As additional capabilities are realized on future GPS space, control and user segments, this standard will be updated. Its performance metrics and assumptions should therefore *not* be used as the sole basis for estimates of utility for future weapon systems. Performance standards described in this document lie between original design parameters and maximum constellation capability. The Commander, United States Strategic Command (USSTRATCOM) has ultimate responsibility to direct GPS constellation operations. USSTRATCOM directs operations to be conducted in a manner that balances system performance and operational tempo, and in this manner assures the most consistent and sustainable GPS performance to all users. The performance standards presented in this document are supported by operational procedures established under the authority of USSTRATCOM, and are tempered with technical and operational margin.

This *PPS PS* consists of a main body and three appendixes. The *PPS PS* provides an overview of the GPS program plus an overview of the PPS SIS and how it is used. It then provides the performance standards for the PPS SIS. It concludes with the relevant reference documents. The appendixes provide additional information that quantifies and illustrates PPS SIS performance. Provided below is a definition of each appendix's purpose.

- **Appendix A: PPS Signal-In-Space (SIS) Background Information.** This appendix provides further background information on the PPS SIS and its performance standards.

- **Appendix B: PPS Position, Velocity, and Time (PVT) Performance Expectations.** This appendix describes examples of how to translate the PPS SIS performance standards into end user position, velocity, and time (PVT) statistical performance expectations. These are only examples because the U.S. Government controls only a small portion of User Equipment (UE) development and usage policy. UE performance requirements are beyond the scope of this *PPS PS*.

- **Appendix C: Definitions.** This appendix provides a list of key terms, definitions, abbreviations and acronyms used in this *PPS PS*.

1.2 Scope

This *PPS PS* defines standards for the GPS PPS SIS performance. Section 3 specifies the performance standards for the PPS SIS from a global perspective, in terms of performance metrics the DoD uses to specify system performance. Appendix B describes the PVT performance an end user can expect to achieve using those same performance metrics. Authorized PPS users need to be aware that GPS is not optimized to support any specific user group, except potentially in time of conflict. The DoD reserves the right to optimize performance to support high priority military mission needs over an area of operations (AOO). See the *Concept of Operations for the Global Positioning System* ("*GPS CONOPS*") for additional details. Any such optimization will not degrade GPS PPS SIS performance beyond the standards defined in this *PPS PS* for areas outside the AOO.

This *PPS PS* employs standard definitions and relationships between the performance parameters such as availability, continuity, integrity, and accuracy. The standard definitions in this *PPS PS* represent the performance attributes of a space-based positioning and time transfer system. Refer to Appendix B for a more comprehensive discussion of the relationships between PPS SIS performance and end user PVT expectations.

This *PPS PS* only applies to the PPS SIS as it exists on the publication date of this document. This document does not address M-code, which is being broadcast by the latest Navstar satellites.

1.3 GPS PPS Definition

The United States Government defines the GPS Precise Positioning Service (PPS) as follows:

> *The PPS is a positioning and timing service provided by way of authorized access to ranging signals broadcast at the GPS L1 and L2 frequencies. The L1 frequency, transmitted by all Navstar satellites, contains a coarse/acquisition (C/A) code ranging signal, with a navigation data message, that is available for peaceful civil, commercial, and scientific use; and a precision (P) code ranging signal with a navigation data message, that is reserved for authorized use. The P-code will normally be cryptographically altered to become the Y-code. The Y-code will not be available to users that do not have valid cryptographic keys. Navstar satellites also transmit a second P- or Y- (P(Y)-) code ranging signal with a navigation data message at the L2 frequency. The navigation data message is identical across all codes and frequencies, but certain portions of the navigation data message will normally be cryptographically altered so as to not be available to users that do not have valid cryptographic keys.*
>
> *Authorized PPS users with valid cryptographic keys may access any available combination of frequencies, codes, and navigation data message as their individual mission needs or equipment limitations dictate. Therefore there are some authorized PPS users that only access the L1 frequency, some that only operate with the C/A-code ranging signals, and some that do not access the cryptographically altered portions of the navigation data message.*
>
> *Any planned disruption of the PPS in peacetime will be subject to a minimum of 48-hour advance notice provided by the DoD to the Coast Guard Navigation Information Center and the FAA Notice to Airmen (NOTAM) system (e.g., scheduled satellite maintenance). A disruption is defined as a period in which a satellite is not capable of providing the PPS SIS as defined in this Standard. Unplanned service disruptions resulting from satellite malfunctions or unscheduled maintenance will be announced by the Coast Guard and the FAA as they become known.*

1.4 Key Terms and Definitions

Terms and definitions which are key to understanding the scope of the GPS PPS SIS are provided in Appendix C. A list of abbreviations and acronyms is also provided in Appendix C.

1.5 Global Positioning System Overview

Sufficient information is provided below to promote a common understanding of the GPS baseline for the purposes of this document. The GPS baseline herein is comprised of two out of the three segments and two interfaces. The purpose of the two segments is to provide the two interfaces.

The two segments are known as the Space Segment and the Control Segment. The two interfaces they provide are the PPS SIS and the SPS SIS to the GPS user community.

The two GPS system segments are described below. The PPS SIS interface is described in Section 2 which follows. The SPS SIS interface is described in the *SPS Performance Standard* (*SPS PS*).

1.5.1 GPS Space Segment

The baseline Navstar satellite constellation nominally consists of 24, properly geometrically spaced operational satellites (Block II, IIA, IIR, and IIR-M), see Section 3.2. The PPS SIS from each block of these satellites meets or exceeds the performance standards in this *PPS PS*.

Each satellite broadcasts three pseudorandom noise (PRN) ranging codes: the precision (P) code, which is the principal NAV ranging code; the Y-code, used in place of the P-code whenever the anti-spoofing mode of operation is activated; and the coarse/acquisition (C/A) code which is used for acquisition of the P (or Y) code (denoted as P(Y)) and as a civil ranging signal. A navigation (NAV) message based upon data periodically uploaded from the Control Segment is provided by adding the NAV message data to both the 1.023 MHz C/A-code sequence and the 10.23 MHz P(Y)-code sequence. The satellite modulates the two resulting code-plus-data sequences onto a 1575.42 MHz L-band carrier (L1), and modulates just the 10.23 MHz code-plus-data sequence onto a 1227.6 MHz L-band carrier (L2); and then both modulated carriers are broadcast to the user community. The two broadcast carrier signals are referred to in this document as the PPS SIS. A subset of the PPS SIS, referred to in this document as the SPS SIS, comprises only the 1.023 MHz code-plus-data sequence on the 1575.42 MHz L-band carrier (L1). Collectively, the PPS SIS and the SPS SIS are known as the satellite's navigation signals (or navigation SIS). A block diagram illustrating the Block IIA satellites SIS generation process is provided in Figure 1.5-1.

The Block II, IIA, IIR, and IIR-M satellites are designed to provide reliable service over a 7.5- to 10-year design life, depending on the production version, through a combination of space qualified parts, multiple redundancies for critical subsystems, and internal diagnostic logic. The Block II, IIA, IIR, and IIR-M satellites require minimal interaction with the ground and allow all but a few maintenance activities to be conducted without interruption to the broadcast SIS. Periodic uploads of NAV message data are designed to cause no disruption to the SIS, although some satellites may experience a 6- to 24-second disruption during the upload.

1.5.2 GPS Control Segment

The Operational Control System (OCS) is comprised of four major components: a Master Control Station (MCS), Backup Master Control Station (BMCS), four ground antennas (GAs), and a network of globally-distributed monitor stations (MSs). An overview of the OCS is provided in Figure 1.5-2.

The MCS is located at Schriever Air Force Base, Colorado, and is the central control node for the GPS satellite constellation. Operations are maintained 24 hours a day, seven days a week throughout the year. The MCS is responsible for all aspects of constellation command and control, to include:

- Routine satellite bus and payload status monitoring
- Satellite maintenance and anomaly resolution
- Monitoring and management of PPS SIS performance in support of all performance standards
- NAV message data upload operations as required to sustain performance in accordance with accuracy and integrity performance standards
- Detecting and responding to PPS SIS failures

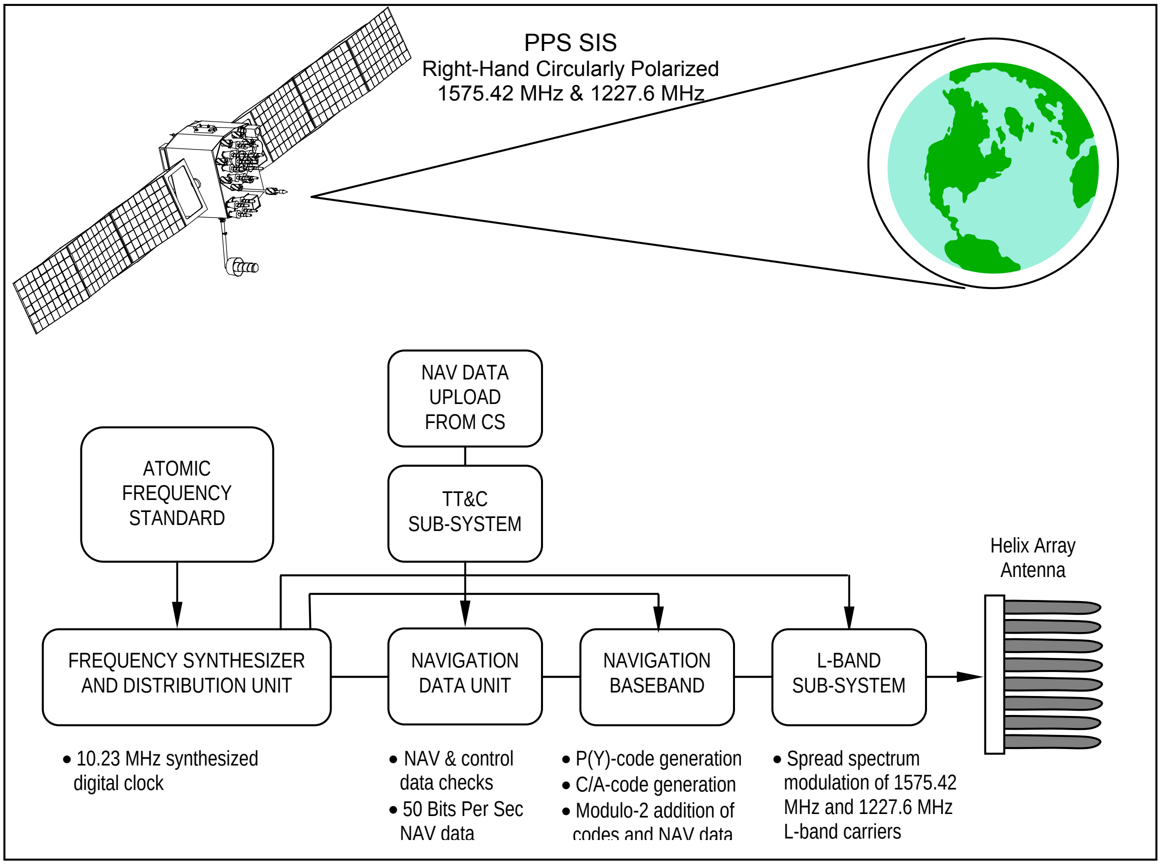

Figure 1.5-1. PPS SIS Generation and Transmission

In the event of a prolonged MCS outage, GPS operations can be moved to the BMCS. When required, personnel from the MCS deploy to the BMCS within 24 hours. The BMCS is operationally exercised approximately four times per year to ensure system capability.

The OCS's four GAs provide a near real-time telemetry, tracking, and command (TT&C) interface between the Navstar satellites and the MCS. The MSs provide near real-time satellite pseudorange measurement data and recovered NAV message data to the MCS and support continuous monitoring of constellation performance. The current OCS monitor stations provide 100% global coverage with the inclusion of National Geospatial-Intelligence Agency (NGA) stations. The OCS monitors the PPS SIS for all satellites in view of a MS in near-real time to ensure each PPS SIS meets the performance standards.

Navstar satellites automatically remove themselves from service whenever they experience any of a number of different kinds of on-board failures. This removal from service is accomplished by the satellite switching from broadcasting its normal navigation signals to instead broadcasting signals with non-standard PRN code sequences and/or default NAV message data. When a failure occurs that is not covered by the automatic removal capability, the OCS will respond to the failure by manually removing the satellite from service in a prompt manner, subject to MS visibility, GA visibility, and OCS equipment and communications reliability constraints. For details on both automatic and manual removal from service, see the PPS SIS integrity alarms listed in paragraph

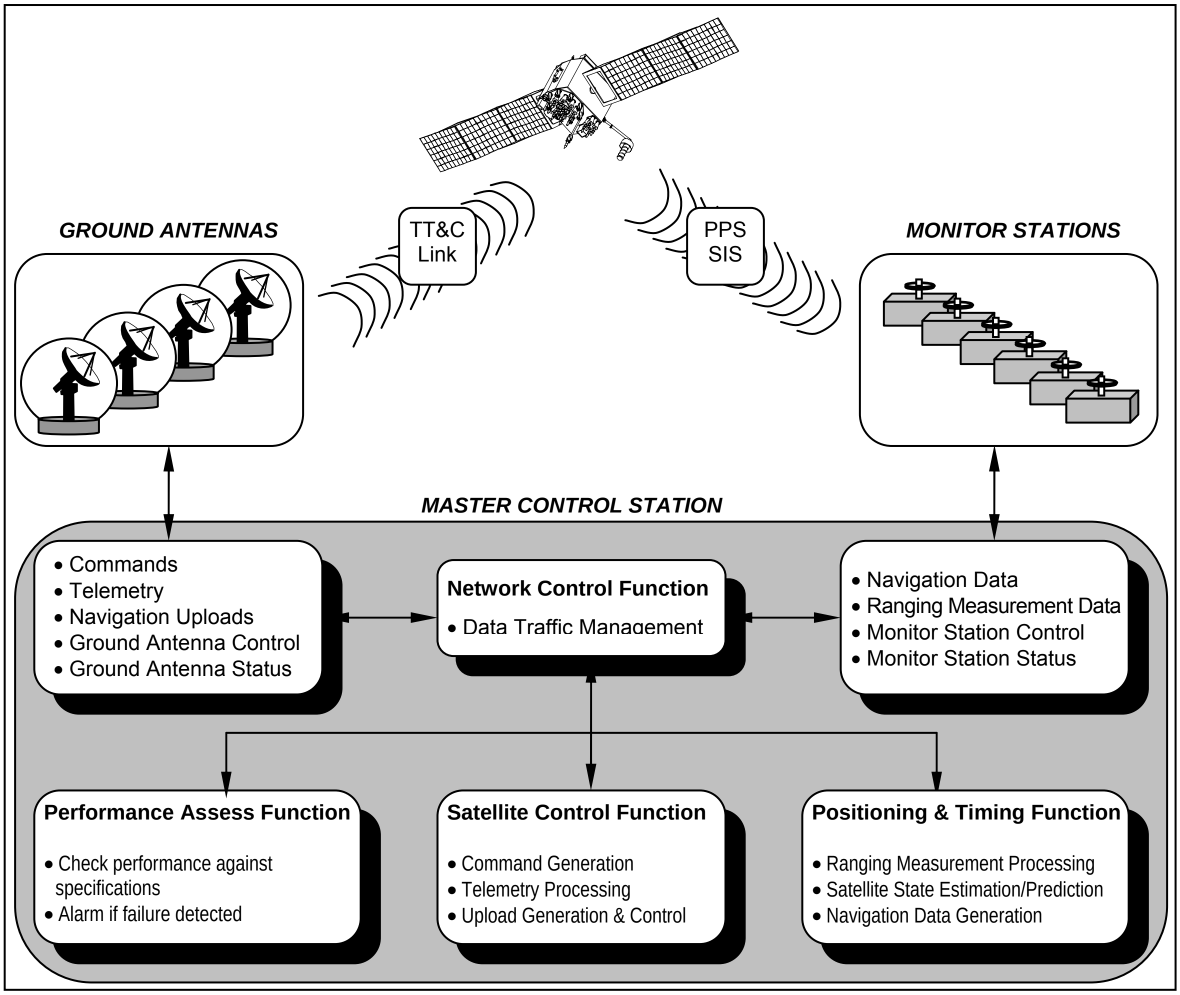

Figure 1.5-2. The GPS Operational Control System (OCS)

2.3.4 and the related PPS SIS integrity performance standards given in Section 3.5 and discussed in Section A.5.

When a MS is tracking a satellite's PPS SIS and the MCS is receiving the L- band measurements in near-real time, the MCS monitors the following PPS SIS metrics (among others) from that satellite:

a. pseudorange error, and

b. pseudorange rate error (i.e., the first time derivative of the pseudorange error, also known as the pseudorange "velocity" error).

The MCS does not directly monitor the pseudorange rate rate error (i.e., the second time derivative of the pseudorange error, more commonly known as the pseudorange "acceleration" error).

The pseudorange error and the pseudorange rate error for each PPS SIS are used internally by the MCS to determine how to manage each satellite to ensure its PPS SIS meets the performance standards (particularly the integrity standards). There are three primary options: (1) if the satellite's pseudorange error is small enough and growing slowly enough, then no action needs to be taken until the next regularly scheduled upload of NAV message data to that satellite; (2) if the satellite's pseudorange error is large enough or is growing quickly enough, then an unscheduled contingency upload may be performed to refresh the satellite's NAV message data and restore the accuracy/integrity of the PPS SIS; or (3) in extreme cases, if the satellite's pseudorange error is very large or is growing so rapidly that the satellite is at risk of exceeding its integrity tolerance, then the MCS may need to manually remove the satellite from service.

SECTION 2.0 PPS SIS Characteristics and Minimum Usage Assumptions

This section provides an overview of the PPS SIS interface characteristics and the assumptions made to arrive at the performance standards. The representative receiver characteristics are used to provide a framework for defining the PPS performance standards. They are not intended to impose any minimum requirements on receiver manufacturers or integrators, although they are necessary attributes to achieve the PPS performance described in this document. Receiver characteristics used in this standard are required in order to establish a frame of reference in which the PPS SIS performance can be described.

2.1 PPS SIS Interface Specification (IS) and Interface Control Document (ICD) Requirements

The PPS SIS shall comply with the technical requirements related to the interface between the Space Segment and the PPS receivers as established by IS-GPS-200, ICD-GPS-224, and ICD-GPS-225. See Section 4 for the specific references to the particular versions of these ISs/ICDs. In the event of conflict between the PPS SIS interface characteristics described in this document and the ISs/ICDs, defer to the ISs/ICDs.

2.2 Overview of PPS SIS Interface Characteristics

This section provides an overview of the PPS SIS interface characteristics. PPS SIS interface characteristics are allocated to two categories: (1) carrier and modulation radio frequency (RF) characteristics, and (2) the structure, protocols, and contents of the NAV message.

2.2.1 PPS SIS RF Characteristics

Navstar satellites transmit right-hand circularly polarized (RHCP) L-band signals at frequencies known as L1 at 1575.42 MHz and L2 at 1227.6 MHz as specified in IS-GPS-200. These signals are transmitted with enough power to ensure the minimum signal power levels of -158.5 dBW for L1 C/A-code, -161.5 dBW for L1 P(Y)-code, and -164.5 dBW for L2 P(Y)-code under the conditions defined in IS-GPS-200. The PPS SIS generation and transmission process is represented in Figure 1.5-1.

L1 consists of two carrier components which are in phase quadrature with each other. Each carrier component is bi-phase shift key (BPSK) modulated by a separate bit train. One bit train is the Modulo-2 sum of the P(Y)-code and NAV data, while the other is the Modulo-2 sum of the C/A-code and the NAV data. The L2 link is BPSK modulated by only one of those two bit trains; the bit train to be used for L2 modulation is selected by ground command. A third modulation mode is also selectable on the L2 channel by ground command: it uses the P(Y)-code without the NAV data as the modulating signal. For a particular Space Vehicle (SV), all transmitted signal elements (carriers, codes and data) are coherently derived from the same on-board frequency source. See IS-GPS-200 for the definition of the P-code and the C/A-code. See ICD-GPS-224 or ICD-GPS-225 for the definition of the Y-code.

2.2.2 GPS NAV Message Characteristics

Each Navstar satellite broadcasts NAV message data to support the GPS receiver's PVT determination process. Figure 2.2-1 provides an overview of the data contents and structure within the NAV message. The data includes information required to determine the following:

- Satellite time-of-transmission
- Satellite position
- Satellite health
- Satellite clock correction
- Ionospheric delay effects
- Time transfer to Coordinated Universal Time as kept by the U.S. Naval Observatory [UTC(USNO)]
- Constellation status

The same NAV message data is broadcast via the PPS SIS and the SPS SIS to all GPS receivers. PPS receivers are able to interpret and apply the entire NAV message. SPS receivers are not able to interpret or apply those parts of the NAV message reserved for PPS receiver use.

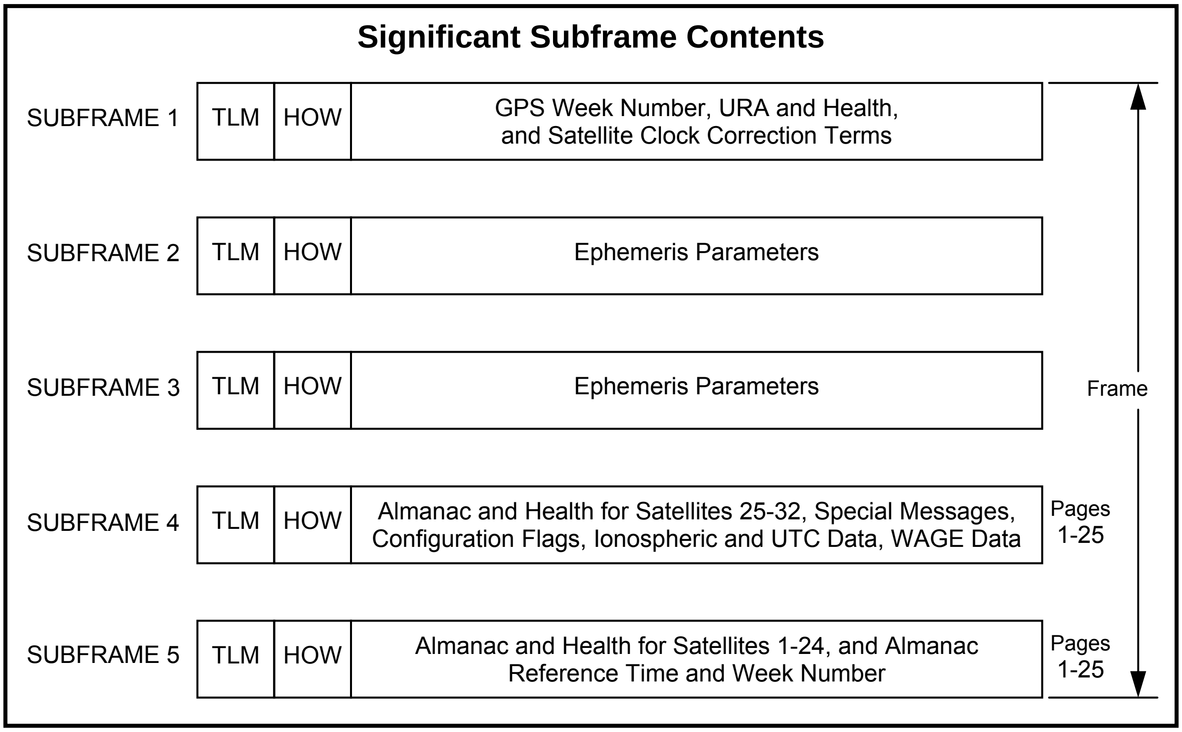

Figure 2.2-1. NAV Message Content and Format Overview

2.3 Overview of PPS SIS Performance Characteristics

The PPS SIS performance characteristics are described below.

2.3.1 PPS SIS Availability

The PPS SIS availability is the probability that the slots in the baseline constellation will be occupied by healthy Navstar satellites transmitting a usable PPS SIS. For this *PPS PS*, there are two components of availability as follows:

> **Per-Slot Availability.** The fraction of time that a slot in the baseline constellation will be occupied by a satellite that is healthy and transmitting a usable PPS SIS.
>
> **Baseline Constellation Availability.** The fraction of time that a specified number of slots in the baseline constellation are occupied by satellites that are healthy and transmitting a usable PPS SIS.

Note:

1. *For historical reasons, the term "operational satellite" applies to any Navstar satellite which appears in the current almanac data in subframe 5 or subframe 4 of the NAV message (see Figure 2.2-1). A satellite need not be healthy or transmitting a usable PPS SIS to be an "operational satellite", appearing in subframe 5 or subframe 4 is sufficient. The almanac data in subframes 5 and 4 includes all "operational satellites" regardless of their health or ability to transmit a usable PPS SIS.*

Not all Navstar satellites occupy a slot in the baseline constellation. Satellites that are not occupying a slot in the baseline constellation (whether in a baseline configuration or an expanded configuration) are considered "surplus" satellites. The PPS SIS from a surplus satellite is available if that satellite is healthy and transmitting a usable PPS SIS. The PPS SISs from surplus satellites do not count towards either the per-satellite availability or the baseline constellation availability.

Note:

1. *The term "spare satellite" has certain connotations which do not apply to a "surplus satellite." In the past, there were 3 spare satellites in the previous 18+3-satellite and 21+3-satellite constellation baselines. Each of the 3 spare satellites had a pre-defined slot and the operating plan was to launch a new satellite to fill those slots when they were unoccupied. In contrast, the current baseline is a 24-slot constellation, not a 24+3-slot constellation. Surplus satellites do not have pre-defined slots, and there are no a priori plans to replace surplus satellites when they fail. Surplus satellites may be "young" (recently launched) satellites waiting to move into an unoccupied slot, or they may be "old" (nearly worn out) satellites providing their last few months or years of navigation service before they finally expire.*

2.3.2 PPS SIS Health

The PPS SIS health is the status given by the real-time health-related information broadcast by each Navstar satellite as an integral part of the PPS SIS. The PPS SIS health is also sometimes referred to as "satellite health" or “space vehicle health” or “SV health”. For this standard, there are three possible PPS SIS health status indications as follows:

> **"Healthy".** The PPS SIS health is healthy when all of the following four conditions are present:
>
> (1) There is no PPS SIS alarm indication present, where the PPS SIS alarm indications are as defined in paragraph 2.3.4.

(2) The six-bit health status word given in subframe 1 of the NAV message is set to all zeros, i.e., binary 000000_2 (all NAV data are OK, all signals are OK).

(3) The User Range Accuracy (URA) alert flag transmitted as bit 18 of the HOW is set to 0.

(4) The transmitted PPS URA index "N"<15.

"Marginal". The PPS SIS health is marginal when the PPS SIS would otherwise have been defined as healthy except that one or more of the following three warning conditions is or are present:

(1) The Most Significant Bit (MSB) of the six-bit health status word given in subframe 1 of the NAV message is set to 0_2 and the 5 Least Significant Bits (LSBs) of the six-bit health status word in subframe 1 of the NAV message are set to anything other than 00000_2 (all signals are OK), 00010_2 (all signals dead), or 11100_2 (SV is temporarily out).

(2) The URA alert flag transmitted as bit 18 of the HOW is set to 1 and the PPS URA does not apply as defined in ICD-GPS-224 and ICD-GPS-225.

(3) The transmitted PPS URA index "N"=15.

"Unhealthy". The PPS SIS health is unhealthy when any one or more of the following four conditions is or are present:

(1) There is a PPS SIS alarm indication present, where the PPS SIS alarm indications are as defined in paragraph 2.3.4.

(2) The MSB of the six-bit health status word given in subframe 1 of the NAV message is set to 1_2 (some or all NAV data are bad).

(3) The 5 LSBs of the six-bit health status word in subframe 1 of the NAV message are set to 00010_2 (all signals dead) or 11100_2 (SV is temporarily out).

(4) The transmitted PPS SIS is unusable.

Notes:

1. *The PPS SIS is unhealthy when the MSB of the six-bit health status word in subframe 1 is set to* 1_2 *(some or all NAV data are bad) and/or the 5 LSBs of the six-bit health status word in subframe 1 are set to* 11111_2 *(more than one combination would be required to describe anomalies). The Control Segment frequently uses this particular combination to indicate a "dead" satellite.*

2. *Subframes 4 and 5 of the NAV message also contain information related to the health of all satellites in the constellation. This is not real-time information. It is more of a long-term average and may not correspond to the actual health of the transmitting satellite or other satellites in the constellation.*

2.3.3 PPS SIS Accuracy

The PPS SIS accuracy is described in two statistical ways; one way is as the 95th percentile (95%) PPS SIS user range error (URE) at a specified age of data (AOD), the other is as the 95% PPS SIS URE over all AODs. With either statistical expression, the PPS SIS accuracy is also known as the PPS SIS pseudorange accuracy. Other accuracy-related PPS SIS performance parameters include the PPS SIS pseudorange rate (velocity) accuracy defined as the 95% PPS SIS pseudorange rate error over all AODs and the PPS SIS pseudorange rate rate (acceleration) accuracy defined as the 95% PPS SIS pseudorange rate rate error over all AODs.

2.3.4 PPS SIS Integrity

The PPS SIS integrity is defined to be the trust which can be placed in the correctness of the information provided by the PPS SIS. PPS SIS integrity includes the ability of the PPS SIS to provide timely alerts to receivers when the PPS SIS should not be used for positioning or timing. For this *PPS PS*, there are four components of integrity as follows:

Probability of a Major Service Failure. The probability of a major service failure for the PPS SIS is defined to be the probability that the PPS SIS's instantaneous URE exceeds the SIS URE not-to-exceed (NTE) tolerance (i.e., misleading signal-in-space information [MSI]) without a timely alert being issued (i.e., unalerted MSI [UMSI]). Alerts generically include both alarms and warnings.

Time to Alert. The time to alert (TTA) for the PPS SIS is defined to be the time from the onset of MSI until an alert (alarm or warning) indication arrives at the receiver's antenna. Real-time alert information broadcast as part of the NAV message data is defined to arrive at the receiver's antenna at the end of the NAV message subframe which contains that particular piece of real-time alert information.

SIS URE NTE Tolerance. The PPS SIS URE NTE tolerance for a healthy PPS SIS is defined to be ±4.42 times the upper bound on the URA value corresponding to the URA index "N" currently broadcast by the satellite for the authorized user. The SIS URE NTE tolerance for a marginal PPS SIS is not defined in this *PPS PS*. There is no SIS URE NTE tolerance for an unhealthy PPS SIS.

Alarm Indications. An otherwise healthy PPS SIS or marginal PPS SIS becomes unhealthy when it is the subject of a PPS SIS alarm indication. For the PPS SIS alarm indications defined below, there is no PPS SIS URE NTE tolerance. The PPS SIS alarm indications are defined to include the following:

(1) The PPS SIS ceases transmission (e.g., no power or negligible power) or otherwise becomes unusable.

(2) The elimination of the standard P(Y)-code (and the corresponding elimination of the standard C/A-code).

(3) The substitution of non-standard P(Y)-code for the standard P(Y)-code (and the corresponding substitution of non-standard C/A-code for the standard C/A-code).

(4) The substitution of PRN P(Y)-code number 37 for the standard P(Y)-code (and the corresponding substitution of PRN C/A-code number 37 for the standard C/A-code).

(5) The failure of parity on 5 successive words of NAV data (3 seconds).

(6) The broadcast IODE does not match the 8 LSBs of the broadcast Index of Data Clock (IODC) (see ICD-GPS-224, ICD-GPS-225, or IS-GPS-200).

(7) The transmitted bits in subframe 1, 2, or 3 are all set to 0's or all set to 1's.

(8) Default NAV data is being transmitted in subframes 1, 2, or 3 (see ICD-GPS-224, ICD-GPS-225, or IS-GPS-200).

(9) The 8-bit preamble does not equal 10001011_2, decimal 139, or hexadecimal 8B.

Warning Indications. An otherwise healthy PPS SIS becomes marginal or unhealthy when it is the subject of a PPS SIS warning indication. PPS SIS warnings are typically provided in advance of the onset of MSI (i.e., preemptive warnings). The PPS SIS warning indications are defined in paragraph 2.3.2 above, plus:

(1) An appropriately inflated URA index "N" value (appropriately inflated to cover the expected large PPS SIS URE).

Notes:

1. *A PPS SIS alarm indication exists when the satellite is not usable because it is not transmitting the standard P(Y)-code (and standard C/A-code) modulation on the L-band carrier signals. As indicated above, specific PPS SIS alarm indications include the following: (a) when the L-band carrier signals have no modulation (i.e., unmodulated carrier signals), (b) when the L-band carrier signals are modulated by nonstandard P(Y)-code (and nonstandard C/A-code), and (c) when the L-band carrier signals are modulated by P(Y)-code number 37 (and C/A-code number 37). These PPS SIS alarm indications are specifically called out above because of their relatively high probability of occurrence.*

2. *The PPS SIS alarm indications related to the NAV message data are considered "weak" indications since PPS receivers do not necessarily continuously read each satellite's NAV message data either by design or by circumstance (e.g., radio-frequency interference [RFI] can prevent reading NAV message data). As a rule of thumb, these weak PPS SIS alarm indications are assumed to have a five minute lag time before PPS receivers take notice of them for alerting purposes.*

3. *See Appendix A, Section A.5 for additional background information on integrity.*

2.3.5 PPS SIS Continuity

The PPS SIS continuity for an available and healthy PPS SIS is the probability that the PPS SIS will continue to be available and healthy without unscheduled interruption over a specified time interval. Scheduled interruptions which are announced at least 48 hours in advance do not contribute to a loss of continuity. Scheduled PPS SIS interruptions are announced by way of the Control Segment issuing a "Notice Advisory to Navstar Users" (NANU). NANUs are similar to the "Notices to Airmen" (NOTAMs) issued regarding scheduled interruptions of ground-based air navigation aids. OCS internal procedures are to issue NANUs for scheduled interruptions at least 96 hours in advance.

2.3.6 PPS SIS UTC(USNO) Accuracy

The PPS UTC(USNO) accuracy for a healthy PPS SIS is defined to be the 95% error in the parameters (ref. 20.3.3.5.2.4 of IS-GPS-200) contained in that PPS SIS which relate GPS time to UTC(USNO).

2.4 Usage Assumptions for PPS Performance Standards

This *PPS PS* is conditioned upon certain assumptions regarding use of the PPS SIS. Those assumptions are as follows.

2.4.1 Authorized User

This *PPS PS* assumes an authorized user with a keyed GPS receiver. Specifically, the GPS receiver is assumed to contain current valid PPS keys and have the requisite hardware/software capabilities to be able to properly use those PPS keys.

This *PPS PS* assumes the keyed GPS receiver complies with the technical requirements related to the interface between the Space Segment and PPS receivers as established by IS-GPS-200, ICD-GPS-224, and ICD-GPS-225 as appropriate.

2.4.2 P(Y)-Code

This *PPS PS* assumes the GPS receiver is tracking and using the Y-code signals transmitted by the satellites for best PVT solution purposes. If a satellite is transmitting P-code signals instead of Y-code signals, then this *PPS PS* assumes the GPS receiver will track and use the P-code signals transmitted by that satellite for PVT solution purposes and will use other means to guard against spoofing. This *PPS PS* assumes certain keyed GPS receivers may track and use the C/A-code signals transmitted by the satellites rather than the P(Y)-code signals for operational reasons.

2.4.3 Dual- vs. Single-Frequency Operation

This *PPS PS* assumes a keyed GPS receiver, which has the hardware capability to track and use the P(Y)-code signals transmitted by the satellites on L1 and on L2, will track and use both signals for dual-frequency measurement-based ionospheric delay compensation purposes. This *PPS PS* assumes that a GPS receiver which only has the hardware capability to track and use the P(Y)-code signals transmitted by the satellites on L1 will track and use that signal for PVT solution purposes and the receiver will use the satellite-transmitted ionospheric parameters for single-frequency model-based ionospheric delay compensation purposes. This *PPS PS* further assumes that certain dual-frequency GPS receivers may only track and use the P(Y)-code signals transmitted by the satellites on L1 or on L2, and correspondingly use the satellite-transmitted ionospheric parameters for single-frequency model-based ionospheric delay compensation, for operational reasons.

Since Navstar satellites may suffer failures which prevent them from transmitting on both L1 and L2 (i.e., a satellite which transmits L1 only or L2 only), this *PPS PS* assumes a GPS receiver will track and use such an L1-only satellite or L2-only satellite as necessary for operational reasons. When a GPS receiver tracks and uses a particular L1-only satellite or L2-only satellite, this *PPS PS* assumes the GPS receiver will use the satellite-transmitted ionospheric parameters for single-frequency model-based ionospheric delay compensation of that particular satellite’s signals.

This *PPS PS* assumes a GPS receiver will take the inaccuracies of dual-frequency measurement-based ionospheric delay compensation and single-frequency model-based ionospheric delay compensation into account during operations.

2.4.4 PPS SIS Health

This *PPS PS* preferentially uses the term "PPS SIS health" to describe the status indicated by the real-time health-related information broadcast by each satellite as part of the PPS SIS. Occasionally, for consistency with prior usage, this *PPS PS* may also use the terms "satellite health" or "space vehicle health".

2.4.4.1 Limitations on PPS SIS Health

This *PPS PS* assumes a GPS receiver will only consider using a PPS SIS whose health status is indicated as healthy. This *PPS PS* explicitly assumes a GPS receiver will not use a PPS SIS whose health status is indicated as either marginal or unhealthy.

Notes:

1. *It is recognized that GPS receivers may gain operational benefit in certain situations by cautiously using a PPS SIS whose status is indicated as marginal. Such situations include periods of reduced satellite visibility due to terrain masking, body masking, abnormal receiving antenna orientation, or instances where an additional pseudorange measurement is needed for fault exclusion. Although potentially beneficial, use of a PPS SIS whose status is indicated as marginal is not recommended by this PPS PS. If an indicated-as-marginal PPS SIS is used, the reason for the marginal status should be ascertained and the impact on performance (accuracy, integrity, continuity) should be accounted for in that use.*

2. *It is further recognized that many GPS augmentation systems (e.g., maritime differential GPS (DGPS) services operating in accordance with the recommendations in RTCM Paper 194-93/SC104-STD) can override many parts of the real-time and non-real-time health-related information transmitted by each Navstar satellite. If a GPS augmentation system does override any of the health-related information transmitted by the satellites, that GPS augmentation system is explicitly responsible for any and all consequences of the override. Although potentially beneficial, overriding the health-related information transmitted by the satellites is not recommended by this PPS PS.*

2.4.4.2 Priority of PPS SIS Health Information

This *PPS PS* assumes a GPS receiver will prioritize the application of the real-time health-related information transmitted by each Navstar satellite ahead of the non-real-time health-related information transmitted by that Navstar satellite or any other Navstar satellite. The real-time health-related information is as described earlier in this *PPS PS*. The non-real-time health-related information is contained in words 3 through 10 of the various pages of subframe 4 and subframe 5 of the NAV data message as described in IS-GPS-200.

2.4.4.3 Timely Application of PPS SIS Health Information

This *PPS PS* assumes a GPS receiver will monitor, process, and apply the real-time health-related information transmitted by each Navstar satellite (including PPS SIS alert indications) each time the information is transmitted. For real-time health-related information broadcast as part of the NAV message data, the assumed time of application is 2.0 seconds after the end of the NAV message subframe which contains the particular piece of real-time health-related information.

Notes:

1. *Real-time alert information broadcast as part of the NAV message data is assumed to require an additional 2 seconds for application as opposed to real-time alert information not broadcast as part of the NAV message data.*

2. *As a general rule, the Control Segment will endeavor to operate the PPS SIS in such a manner to allow GPS receivers at least five minutes to receive, process, and apply the real-time health-related*

information before taking any action that could cause a large PPS SIS URE under normal operations and maintenance (O&M) conditions.

It is recognized that GPS receivers cannot always monitor the broadcast NAV message data since interruptions may be caused by temporary signal blockages, abnormal receiving antenna orientation, RFI (particularly jamming), and intermittent environmental effects. Although the GPS receiver is responsible for taking appropriate action when it cannot monitor, process, or apply the current real-time health-related information in the NAV message data, it is possible for the Control Segment to aid some GPS receivers by giving them some advance warning of impending PPS SIS health changes. This action will only be beneficial for PPS SIS integrity if the PPS SIS health changes from healthy to marginal, or from healthy to unhealthy. An example of such an in-advance warning would be setting the 5 LSBs of the six-bit health status word in subframe 1 to 11101_2 (SV will be temporarily out) for a period of time before setting the MSB of the six-bit health status word given in subframe 1 of the NAV message to 1_2 (some or all NAV data are bad) and/or setting the 5 LSBs of the six-bit health status word in subframe 1 to 11100_2 (SV is temporarily out).

Although providing warning of impending PPS SIS health changes in advance of scheduled O&M activities that are likely to cause a large PPS SIS URE would be beneficial for the PPS SIS integrity, it would be detrimental to the PPS SIS availability for many GPS receivers since those GPS receivers conservatively consider the PPS SIS to be unavailable at the time of the advance warning. Advance warnings are thus a trade off between benefiting PPS SIS integrity versus degrading PPS SIS availability. Making this trade off is within the purview of the Control Segment since other factors besides PPS SIS integrity and PPS SIS availability come into play. There are no constraints placed on this trade off by this *PPS PS*.

Note:

1. *The Control Segment does not currently provide advance warning of PPS SIS health changes by setting the 5 LSBs of the six-bit health status word in subframe 1 to 11101_2 (SV will be temporarily out). Advance warnings are provided, but they are commonly implemented by setting the MSB of the six-bit health status word in subframe 1 to 1_2 (some or all NAV data are bad) and setting the 5 LSBs of the six-bit health status word in subframe 1 to either 11100_2 (SV is temporarily out) or 11111_2 (more than one combination would be required to describe anomalies). These are conservative courses of action. The impact of these courses of action has already been factored into the PPS SIS availability standards.*

2.4.5 Excluded Errors

This *PPS PS* does not take into consideration any error source that is not under direct control of the Space Segment or Control Segment. Specifically excluded errors include those due to the effects of:

- Signal distortions caused by ionospheric and/or tropospheric scintillation
- Receiver dual-frequency ionospheric delay compensation
- Receiver tropospheric delay compensation
- Receiver noise (including received signal power and interference power) and resolution
- Receiver hardware/software faults
- Multipath and receiver multipath mitigation
- Operator error

SECTION 3.0 PPS SIS Performance Standards

This section establishes PPS SIS performance standards for GPS operations. The DoD is committed to operating GPS in accordance with these standards, in a manner consistent with system capabilities and subject to budgetary constraints. The DoD reserves the right to adjust GPS constellation management practices as necessary to support military and civil end users. One of the potential adjustments is an expansion of three of the baseline constellation slots, as described in Tables 3.2-1 and 3.2-2. The DoD also reserves the right to optimize performance to support high priority military mission needs over an AOO. See the *GPS CONOPS* for additional details. Any such optimization will not degrade the PPS SIS performance beyond the standards defined in this section for areas outside the AOO.

The PPS SIS performance is specified in terms of minimum performance standards for each performance parameter. Each standard includes a definition of conditions and constraints applicable to the provision of the specified service. Error contributions from the ionosphere, troposphere, receiver, multipath, or RFI are not included. PPS SIS performance characteristics associated with the standards are defined in the preceding section. Background information related to each performance standard is given in Appendix B of this *PPS PS*. Position solution performance estimates for users equipped with representative receivers, inclusive of ionosphere, troposphere, receiver noise error contributions, are provided in Appendix B of this *PPS PS* along with further discussion of the translation of these PPS SIS performance standards into end user PVT performance expectations.

3.1 Overview

PPS SIS performance standards do not include any element not under the direct control of the DoD. Any performance parameters not specified in this section are not considered to be part of the PPS SIS performance standards, nor do they represent a part of the minimum service being provided to the user community.

These PPS SIS performance standards do not directly represent the end performance users will experience. The standards provide a definition of the components of GPS performance that, when combined with a signal reception environment and assumptions concerning the GPS receiver, allow users to define for themselves the end performance they can expect for their particular application. The DoD recognizes that these metrics have little direct meaning to the average end user (e.g., pilot, navigator, driver), but they are absolutely essential for GPS receiver designers, system integrators, application engineers, infrastructure developers, space/control segment operators and maintainers, and usage regulators. In support of end users, Appendix B provides an expanded description of the position domain performance implied by the PPS SIS performance standards combined with the typical performance assumptions for a range of GPS receivers to give a sense of the operational characteristics that can be expected under a wide spectrum of operating conditions. Appendix B also gives examples of how to translate the expected pseudorange domain characteristics into end user PVT performance terms.

3.2 Baseline Constellation Definition

The GPS baseline constellation consists of 24 slots in six orbital planes with four slots per plane. Three of the 24 slots are expandable. The baseline operational satellites will occupy these slots. Any surplus operational satellites that exist on orbit will occupy other locations in the orbital planes. There are no a priori specified slots for surplus satellites.

The baseline satellites will be placed in the orbital slots defined by Table 3.2-1 and will be maintained relative to those slots in accordance with the reference orbit specifications and tolerances in Table 3.2-3. Slots for the 24-slot constellation are specified in terms of the Right Ascension of the Ascending Node (RAAN) and the Argument of Latitude for a defined epoch. The corresponding Groundtrack Equatorial Crossing (GEC) values (also known as the Geographic Longitude of the Ascending Node [GLAN] values) are also provided in Table 3.2-1. Tables 3.2-1 and 3.2-3 define the nominal, properly geometrically spaced, 24-slot baseline constellation for GPS.

Table 3.2-1. Baseline Orbit Slot Assignments as of the Defined Epoch

Slot	RAAN	Argument of Latitude	GEC (GLAN)
A1	272.847°	268.126°	127.85°
A2	272.847°	161.786°	74.68°
A3	272.847°	11.676°	179.63°
A4	272.847°	41.806°	14.69°
B1*	332.847°	80.956°	94.27°
B2	332.847°	173.336°	140.46°
B3	332.847°	309.976°	28.78°
B4	332.847°	204.376°	155.98°
C1	32.847°	111.876°	169.73°
C2	32.847°	11.796°	119.69°
C3	32.847°	339.666°	103.62°
C4	32.847°	241.556°	54.57°
D1	92.847°	135.226°	61.40°
D2*	92.847°	265.446°	126.51°
D3	92.847°	35.156°	11.37°
D4	92.847°	167.356°	77.47°
E1	152.847°	197.046°	152.31°
E2	152.847°	302.596°	25.09°
E3	152.847°	66.066°	86.82°
E4	152.847°	333.686°	40.63°
F1	212.847°	238.886°	53.23°
F2*	212.847°	345.226°	106.40°
F3	212.847°	105.206°	166.39°
F4	212.847°	135.346°	1.46°

Notes:

Epoch: 00:00:00 UTC, 1 July 1993
Greenwich Hour Angle: $18^h\ 36^m\ 14.4^s$
Referenced to FK5/J2000.00 Coordinates
Orbital Slot IDs are Arbitrarily Numbered
Orbital Slots Marked by an Asterisk are Expandable

Table 3.2-2. Expandable Orbit Slot Assignments as of the Defined Epoch

Expandable Slot		RAAN	Argument of Latitude	GEC (GLAN)
B1 Expands To:	**B1F**	332.847°	94.916°	101.25°
	B1A	332.847°	66.356°	86.97°
D2 Expands To:	**D2F**	92.847°	282.676°	135.13°
	D2A	92.847°	257.976°	122.78°
F2 Expands To:	**F2F**	212.847°	0.456°	114.02°
	F2A	212.847°	334.016°	100.80°

Each expandable slot may be occupied either by a single satellite in the baseline position defined in Table 3.2-1 or by a pair of satellites in the expanded positions defined in Table 3.2-2. The fore (F) and aft (A) positions in an expanded baseline slot are defined relative to the baseline slot in the direction of satellite motion. Together, Tables 3.2-1 and 3.2-2 define a total of 7 variations of the expanded constellation: 3 variations with 1 expanded slot, 3 variations with 2 expanded slots, and 1 variation with 3 expanded slots.

Note that the actual constellation RAAN values will change over each satellite's lifetime due to perturbation forces and variations in each unique orbit's nodal regression rate. The mean nodal regression rate is -0.04187 deg/day for an inclination of 55°. Maintenance of the GEC values and relative spacing of the slots are the controls employed to compensate for orbit plane drift and sustain constellation geometry at acceptable levels. It is also possible for the inclination to drift out of the operational range.

The orbital slots defined by Table 3.2-1 and Table 3.2-2 may be updated periodically based upon the epoch date or changing requirements for satellite replenishment.

Table 3.2-3. Reference Orbit Parameters

Reference Orbit Parameter	Nominal Value	Operational Range	Required Tolerance
Semi-Major Axis, km	26,559.7	Note 1	Note 2
Eccentricity	0.0	0.0 to 0.02	0.0 to 0.03
Inclination, deg	55.0	± 3	N/A
RAAN, deg	Note 3	± 180	N/A
Argument of Perigee, deg	0.0	± 180	N/A
Argument of Latitude at Epoch, deg	Note 3	± 180	Note 1

Note 1: The semi-major axis and orbital period will be adjusted to maintain the relative spacing of the satellite mean arguments of latitude to within ± 4 deg of the epoch values, with one year or more between orbit adjustments.

Note 2: The nominal value shown provides stationary ground tracks.

Note 3: See Tables 3.2-1 and 3.2-2.

3.3 PPS SIS Coverage

This section provides the PPS SIS coverage standards.

There are two components of PPS SIS coverage: (1) the per-satellite coverage, and (2) the baseline 24-slot constellation coverage. These two components are interrelated. The per-satellite coverage depends primarily on the satellite antenna subsystem design, the on-orbit satellite pointing accuracy, and the satellite altitude (where the allowed range of satellite altitudes is defined by baseline 24-slot constellation architecture). The baseline 24-slot constellation coverage depends primarily on the per-satellite coverage coupled with the baseline 24-slot constellation architecture.

Each component of PPS SIS coverage shall be as specified below.

3.3.1 Per-Satellite Coverage

Each healthy Navstar satellite transmits a PPS SIS which completely covers that portion of the surface of the Earth which is visible from the satellite's orbital position. The transmitted PPS SIS also completely covers the portion of the near-Earth region which extends from the surface of the Earth up to an altitude of 3,000 km above the surface of the Earth (i.e., the terrestrial service volume) which is visible from the satellite's orbital position (i.e., those portions of the resulting spherical shell surrounding the Earth which are not otherwise physically obscured by the Earth or by localized obstructions). These requirements apply at the worst-case satellite antenna pointing angle relative to the Earth.

The guaranteed minimum user-received PPS SIS power levels are for the terrestrial service volume as specified in IS-GPS-200. Although IS-GPS-200 uses a 5 degree elevation angle as the reference value for specifying the guaranteed minimum user-received PPS SIS power levels, the per-satellite coverage is not artificially restricted to just those locations where the Navstar satellite viewing angle is greater than or equal to 5 degrees above the local horizon.

The transmitted PPS SIS from each healthy Navstar satellite also covers the near-Earth region which extends from an altitude of 3,000 km above the surface of the Earth up to and including 36,000 km above the Earth's surface (i.e., the space service volume). The space service volume coverage is limited by physical obscuration by the Earth as well as by the transmitting satellite's antenna gain pattern and free-space path loss. The limits of coverage are determined by the received power contour surface of -182 dBW assuming a linear receiving antenna with a minimum gain that varies from +3 dBic at 3,000 km altitude to +7 dBic at 36,000 km altitude. There are no explicit per-satellite coverage standards for the space service volume.

3.3.2 Baseline Constellation Coverage

The baseline 24-slot constellation continuously covers the entire terrestrial service volume.

The baseline 24-slot constellation coverage for the space service volume varies significantly as a function of time and location within the space service volume. At certain times and locations, the baseline 24-slot constellation does not provide adequate coverage for instantaneous position solutions. Users operating at those times and locations are therefore limited to time-filtered position solutions propagated over time. There are no explicit constellation coverage standards for the space service volume.

3.4 PPS SIS Accuracy

This section provides the PPS SIS accuracy standards. The PPS SIS accuracy standards apply to the SIS portion of the GPS error budgets for the user equivalent range error (UERE).

There are four main aspects of PPS SIS accuracy. The standards for each of these aspects are given in this section. The four main aspects are:

1. The pseudorange accuracy (i.e., “User Range Error” or URE)
2. The time derivative of the URE (i.e., “User Range Rate Error” or URRE)
3. The second time derivative of URE (i.e., “User Range Rate Rate Error” or URRRE)
4. The UTC Offset Error (UTCOE)

The standards for each of the four main aspects of PPS SIS accuracy are different depending on the particular combination of the PPS SIS components and on the operational application and/or condition of utilization. Refer to Section A.4 in Appendix A for descriptions of the various PPS SIS components and their operational applications conditions of utilization. Different PPS SIS accuracy standards are given in this section for:

a. Dual-frequency P(Y)-code versus single-frequency P(Y)-code

b. Standard operation versus Wide Area GPS Enhancement (WAGE) operation using the broadcast NAV Message Correction Table (NMCT) data

c. Across all AODs versus at a specified AOD (i.e., either at zero AOD or at maximum AOD)

d. Normal operations versus extended operation (see paragraph A.4.3.2)

Regardless of PPS SIS component(s) or operational application/utilization, each of the four main aspects of PPS SIS accuracy are addressed in terms of a "global average" performance standard. In this case, "global average" means root-mean-square (rms) across the portion of the globe in view of the satellite over at least the ergodic period. All of the PPS SIS performance standards in this section are expressed at the 95% probability level in accordance with STANAG 4278.

Notes:

1. *The accuracy performance standards do not apply beyond the defined bounds of PPS SIS coverage (see Section 3.3).*
2. *The ergodic period contains the minimum number of samples such that the sample statistic is representative of the population statistic.*

3.4.1 PPS SIS URE Accuracy Standards

The PPS SIS URE accuracy shall be as specified in Table 3.4-1.

Table 3.4-1. PPS SIS URE Accuracy Standards

SIS Accuracy Standard	Conditions and Constraints
Dual-Frequency P(Y)-Code: • $\leq$ 5.9 m 95% Global Average URE during Normal Operations over all AODs • $\leq$ 2.6 m 95% Global Average URE during Normal Operations at Zero AOD • $\leq$ 11.8 m 95% Global Average URE during Normal Operations at Any AOD	• For any satellite marked as healthy in the NAV message
Single-Frequency P(Y)-Code: • $\leq$ 6.3 m 95% Global Average URE during Normal Operations over all AODs • $\leq$ 5.4 m 95% Global Average URE during Normal Operations at Zero AOD • $\leq$ 12.6 m 95% Global Average URE during Normal Operations at Any AOD	• For any satellite marked as healthy in the NAV message • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1
Dual-Frequency P(Y)-Code with WAGE: • $\leq$ 4.4 m 95% Global Average URE during Normal Operations over all WAGE AODs	• For any satellite marked as healthy in the NAV message
Single-Frequency P(Y)-Code with WAGE: • $\leq$ 6.2 m 95% Global Average URE during Normal Operations over all WAGE AODs	• For any satellite marked as healthy in the NAV message • Neglecting single-frequency ionospheric delay model errors • Including group delay time correction (T_{GD}) errors at L1
Dual- or Single-Frequency P(Y)-Code regardless of WAGE: • $\leq$ 388 m 95% Global Average URE during Extended Operations after 14 Days without Upload	• For any satellite marked as healthy in the NAV message

Notes:

1. *For dual-frequency P(Y)-code URE, the $\leq$ 11.8 m 95% at any AOD performance standard is equivalent to the $\leq$ 5.9 m 95% over all AODs performance standard.*
2. *For single-frequency P(Y)-code URE, see Appendix A for information on how to factor in the single-frequency ionospheric delay model errors for L1 or for L2.*
3. *For single-frequency P(Y)-code URE at L2, see Appendix A for information on how to factor in the group delay time correction (T_{GD}) errors at L2.*

4. *The "over all AODs" performance standards are the ones which are the most directly representative of the URE experienced by PPS receivers. See Appendix A for further information.*

3.4.2 PPS SIS URRE Accuracy Standards

The PPS SIS URRE accuracy shall be as specified in Table 3.4-2.

Table 3.4-2. PPS SIS URRE Accuracy Standards

SIS Accuracy Standard	Conditions and Constraints
Dual- or Single-Frequency P(Y)-Code: • ≤ 0.006 m/sec 95% Global Average URRE over any 3-second interval during Normal Operations at Any AOD	• For any satellite marked as healthy in the NAV message • Neglecting all perceived pseudorange rate errors attributable to pseudorange step changes caused by NAV message data cutovers (including NMCT cutovers) • Neglecting any single-frequency ionospheric delay model errors

Notes:

1. *The normal operations performance standards are consistent with a Block II/IIA clock stability of* $1x10^{-11}$ *at a tau of 3 seconds for either Rubidium clocks or Cesium clocks. However, more recent GPS Blocks exhibit significantly improved clock stability. Therefore this PPS PS is based upon a very conservative clock stability assumption.*

2. *Root-sum-squaring the SIS-caused URRE with the receiver-caused pseudorange rate error, and neglecting any correlated components, the combined pseudorange rate error perceived by the GPS receiver is known as the User Equivalent Range Rate Error (UERRE).*

3. *WAGE has no impact on the PPS SIS URRE accuracy standard.*

3.4.3 PPS SIS URRRE Accuracy Standards

The PPS SIS URRRE accuracy shall be as specified in Table 3.4-3.

Table 3.4-3. PPS SIS URRRE Accuracy Standards

SIS Accuracy Standard	Conditions and Constraints
Dual- or Single-Frequency P(Y)-Code: • ≤ 0.002 m/sec/sec 95% Global Average URRRE over any 3-second interval during Normal Operations at Any AOD	• For any satellite marked as healthy in the NAV message • Neglecting all perceived pseudorange acceleration errors attributable to pseudorange step changes caused by NAV message data cutovers (including NMCT cutovers) • Neglecting any single-frequency ionospheric delay model errors

Notes:

1. *The normal operations performance standards are consistent with a Block II/IIA clock stability of 1×10^{-11} at a tau of 3 seconds for either Rubidium clocks or Cesium clocks.*

2. *Root-sum squaring the SIS-caused URRE with the receiver-caused pseudorange acceleration error, and neglecting any correlated components, the combined pseudorange acceleration error perceived by the GPS receiver is known as the User Equivalent Range Rate Rate Error (UERRRE).*

3. *WAGE has no impact on the PPS SIS URRRE accuracy standard.*

3.4.4 PPS SIS UTCOE Accuracy Standards

The PPS SIS UTCOE accuracy shall be as specified in Table 3.4-4.

Table 3.4-4. PPS SIS UTCOE Accuracy Standards

SIS Accuracy Standard	Conditions and Constraints
Dual- or Single-Frequency P(Y)-Code: • ≤ 40 nsec 95% Global Average UTCOE during Normal Operations at Any AOD	• For any satellite marked as healthy in the NAV message

Notes:

1. *This is the accuracy of the UTC(USNO) offset data in the broadcast navigation message portion of the PPS SIS which relates GPS time (as maintained by the Control Segment) to UTC (as maintained by the U.S. Naval Observatory).*

2. *Root-sum squaring the UTCOE with a receiver's solution accuracy for GPS time gives the total UTC accuracy for that receiver. See Appendix B for further information.*

3. *WAGE has no impact on the PPS SIS UTCOE accuracy standard.*

3.5 PPS SIS Integrity

This section provides the PPS SIS integrity standards. For a positioning/timing system, integrity is defined as the trust which can be placed in the correctness of the positioning/timing information provided by the system. Integrity includes the ability of that system to provide timely alerts when it should not be used for positioning/timing. See Appendix A, Section A.5 for further definition.

The PPS SIS integrity standards given in the following tables apply to the PPS SIS from all healthy satellites regardless of whether they are occupying positions in the baseline 24-slot constellation or not. These PPS SIS integrity standards therefore apply equally to the PPS SIS from healthy baseline/expanded satellites and from healthy surplus satellites.

A timely alert is defined to be an alert provided at the GPS receiver antenna no later than 8 seconds after an instantaneous error exceeds the relevant NTE tolerance for any alert method except SatZap and non-standard Y-code (NSY)/non-standard C/A-code (NSC) (assumes 2 seconds for the GPS receiver response time). For SatZap and NSY/NSC, a timely alert is defined to be an alert provided at the GPS receiver antenna no later than 10 seconds after an instantaneous error exceeds the relevant NTE tolerance.

3.5.1 PPS SIS Instantaneous URE Integrity Standards

The PPS SIS instantaneous URE integrity shall be as specified in Table 3.5-1.

Table 3.5-1. PPS SIS Instantaneous URE Integrity Standards

SIS Integrity Standard	Conditions and Constraints
Dual- or Single-Frequency P(Y)-Code: • $\leq 1\text{x}10^{-5}$ Probability Over Any Hour of the maximum PPS SIS Instantaneous URE Exceeding the NTE Tolerance Without a Timely Alert during Normal Operations	• Applies to any satellite marked as healthy in the NAV message measured over any one-year interval • PPS SIS URE NTE tolerance defined to be ±4.42 times the upper bound on the URA value corresponding to the URA index "N" currently broadcast by the satellite for the authorized user • Given that the maximum PPS SIS instantaneous URE did not exceed the NTE tolerance at the start of the hour • Neglecting any single-frequency ionospheric delay model errors

Notes:

1. *Maximum instantaneous URE integrity with WAGE is not addressed. There is no PPS SIS URE NTE tolerance defined for WAGE. WAGE is intended to enhance PPS SIS accuracy, not integrity.*
2. *The probability of a single PPS SIS failure causing multiple integrity losses is negligible.*

For the maximum possible 32 satellites in the broadcast almanac (healthy baseline/expanded satellites plus healthy surplus satellites), the corresponding average annual number of PPS SIS instantaneous URE integrity losses is 3. Assuming each of these 3 losses of PPS SIS integrity lasts for no more than 6 hours, the equivalent worst-case probability of users experiencing hazardously misleading information (HMI) is 18 hours divided by 8760 hours or 0.002.

Notes:

1. *In 1 year, 32 continuously healthy satellites each transmitting a usable PPS SIS will accumulate a total of approximately 2.8x10^{+5} hours of operation. For a probability of 1x10^{-5}/hour of maintaining integrity, the expected number of losses of PPS SIS integrity in 1 year across the entire constellation is approximately 3.*
2. *The worst-case probability of a user experiencing HMI assumes that each of the 3 losses of PPS SIS integrity results in HMI for 6 hours and that the worst-case user is unlucky enough to be using each of the 3 satellites during the full duration of each loss of PPS SIS integrity.*

3.5.2 PPS SIS Instantaneous URRE Integrity Standards

The PPS SIS instantaneous URRE (i.e., pseudorange rate error) integrity shall be as specified in Table 3.5-2.

Table 3.5-2. PPS SIS Instantaneous URRE Integrity Standards

SIS Integrity Standard	Conditions and Constraints
Dual- or Single-Frequency P(Y)-Code: • No Integrity Performance Specified	• A future version of this *PPS PS* may establish a standard

Notes:

1. *Although there is no PPS SIS URRE NTE tolerance defined for dual-frequency P(Y)-code, a high-probability (6-sigma) upper bound on the PPS SIS instantaneous URRE which is typically used for design purposes is 0.02 m/sec over any 3-second interval during normal operations at any AOD. This is consistent with a Block II/IIA clock stability of 1x10^{-11} at a tau of 3 seconds for either Rubidium clocks or Cesium clocks.*
2. *Short-term fluctuations in the ionosphere can produce very large PPS SIS instantaneous URREs for single-frequency P(Y)-code operations.*
3. *Instantaneous URREs due to upload data cutovers (including NMCT cutovers) and data set pageovers last for less than 10 seconds.*

3.5.3 PPS SIS Instantaneous URRRE Integrity Standards

The PPS SIS instantaneous URRRE (i.e., pseudorange acceleration error) integrity shall be as specified in Table 3.5-3.

Table 3.5-3. PPS SIS Instantaneous URRRE Integrity Standards

SIS Integrity Standard	Conditions and Constraints
Dual- or Single-Frequency P(Y)-Code: • No Integrity Performance Specified	• A future version of this *PPS PS* may establish a standard

Notes:

1. *Although there is no PPS SIS URRRE NTE tolerance defined for dual-frequency P(Y)-code, a high-probability upper bound on the PPS SIS instantaneous URRRE which is typically used for design*

purposes is 0.007 m/sec/sec over any 3-second interval during normal operations at any AOD. This is consistent with a Block II/IIA clock stability of 1x10^{-11} *at a tau of 3 seconds for either Rubidium clocks or Cesium clocks.*

2. *Short-term fluctuations in the ionosphere can produce extremely large PPS SIS instantaneous URRREs for single-frequency P(Y)-code operations.*

3. *Instantaneous URRREs due to upload data cutovers (including NMCT cutovers) and data set pageovers last for less than 10 seconds.*

3.5.4 PPS SIS Instantaneous UTCOE Integrity Standards

The PPS SIS instantaneous UTCOE (i.e., UTC(USNO) offset error) integrity shall be as specified in Table 3.5-4.

Table 3.5-4. PPS SIS Instantaneous UTCOE Integrity Standards

SIS Integrity Standard	Conditions and Constraints
Dual- or Single-Frequency P(Y)-Code: • No Integrity Performance Specified	• A future version of this *PPS PS* may establish a standard

Notes:

1. *This is the integrity of the UTC(USNO) offset data in the broadcast navigation message portion of the PPS SIS which relates GPS time (as maintained by the Control Segment) to UTC (as maintained by the U.S. Naval Observatory).*

2. *Adding the UTCOE to a receiver's solution error for GPS time gives the total UTC error for that receiver. See Appendix B for further information.*

3. *WAGE has no impact on the PPS SIS UTCOE integrity standard.*

3.6 PPS SIS Continuity

This section provides the PPS SIS continuity standards. The PPS SIS continuity for an available and healthy PPS SIS is the probability that the PPS SIS will continue to be available and healthy without unscheduled interruption over a specified time interval.

The PPS SIS continuity standards only apply to an available and healthy PPS SIS that has not been scheduled for an interruption in advance. Scheduled interruptions which are announced at least 48 hours in advance do not constitute a loss of continuity.

3.6.1 PPS SIS Continuity Standards – Unscheduled Interruptions

The PPS SIS continuity shall be as specified in Table 3.6-1 for the composite of all unscheduled interruptions in service (long-term [LT] hard failures, short term [ST] hard failures, and soft failures; see Section A.6).

Table 3.6-1. PPS SIS Unscheduled Interruptions Continuity Standards

SIS Continuity Standard	Conditions and Constraints
Unscheduled Interruptions: • $\geq$ 0.9998 Probability Over Any Hour of Not Losing the PPS SIS Availability from a Slot Due to Unscheduled Interruption	• Calculated as an average over all slots in the 24-slot constellation measured over a 7.5 year interval • Given that the PPS SIS is available from the slot at the start of the hour

3.6.2 PPS SIS Continuity Standards – Scheduled Interruptions

The PPS SIS continuity shall be as specified in Table 3.6-2 for the composite of all scheduled interruptions in service (end-of-life [EOL] failures and satellite O&M activity interruptions; see Section A.6).

Table 3.6-2. PPS SIS Scheduled Interruptions Continuity Standards

SIS Continuity Standard	Conditions and Constraints
Scheduled Interruptions: • No Performance Specified	• A future version of this *PPS PS* may establish a standard • Calculated as an average over all slots in the 24-slot constellation measured over a 7.5 year interval • Given that the PPS SIS is available at the start of the hour • Scheduled interruptions announced by NANU issued at least 48 hours in advance do not contribute to a loss of continuity

Note:

1. *Table 3.6-2 is effectively a placeholder for a future standard that defines the level of rigor the Control Segment must maintain in issuing the NANUs.*

3.7 PPS SIS Availability

This section provides the PPS SIS availability standards.

There are two components of PPS SIS availability: (1) the per-slot availability, and (2) the baseline constellation availability. These two components are related. The per-slot availability depends primarily on the satellite design and the Control Segment procedures for on-orbit maintenance and failure response. The baseline constellation availability depends primarily on the per-slot availability coupled with the satellite launch policies and satellite disposal criteria.

Each component of PPS SIS availability shall be as specified below.

This section also provides the operational satellite body count standard.

3.7.1 PPS SIS Per-Slot Availability Standards

The PPS SIS per-slot availability shall be as specified in Table 3.7-1 for slots in either the baseline configuration or the expanded configuration.

Table 3.7-1. PPS SIS Per-Slot Availability Standards

SIS Availability Standard	Conditions and Constraints
• ≥ 0.957 Probability that a Slot in the Baseline Configuration will be Occupied by a Healthy Navstar Satellite Broadcasting a Useable PPS SIS • ≥ 0.957 Probability that a Slot in the Expanded Configuration will be Occupied by a pair of Healthy Navstar Satellites Each Broadcasting a Useable PPS SIS	• Calculated as an average over all slots in the 24-slot constellation measured over a 7.5 year interval

Notes:

1. *The PPS SIS availability standards given in Tables 3.7-1 apply to the PPS SIS from all slots in the 24-slot constellation.*
2. *Expanded slot availability includes occupancy by a pair of satellites in an equivalent-or-better non-standard configuration. See Section A.7 in Appendix A for example equivalent-or-better non-standard configurations.*
3. *The loss of availability caused by an expanded slot which has lost one of its pair of satellites can be remedied by either replacing the lost satellite or by returning the slot back to its baseline configuration. See Section A.7 in Appendix A for further information.*
4. *These PPS SIS availability standards do not apply to healthy surplus satellites not occupying a slot in the 24-slot constellation.*
5. *The PPS SIS per-slot availability measurement interval must be substantially longer than the mean time between per-slot interruptions and the mean time to restore per-slot availability.*

3.7.2 PPS SIS Baseline Constellation Availability Standards

The PPS SIS baseline constellation availability shall be as specified in Table 3.7-2 for the ensemble of all 24 slots in either the baseline configuration or the expanded configuration.

Table 3.7-2. PPS SIS Constellation Availability Standards

SIS Availability Standard	Conditions and Constraints
• ≥ 0.98 Probability that at least 21 Slots out of the 24 Slots will be Occupied Either by a Healthy Navstar Satellite Broadcasting a Useable PPS SIS in the Baseline Slot Configuration or by a Pair of Healthy Navstar Satellites Each Broadcasting a Useable PPS SIS in the Expanded Slot Configuration • ≥ 0.99999 Probability that at least 20 Slots out of the 24 Slots will be Occupied Either by a Healthy Navstar Satellite Broadcasting a Useable PPS SIS in the Baseline Slot Configuration or by a Pair of Healthy Navstar Satellites Each Broadcasting a Useable PPS SIS in the Expanded Slot Configuration	• Calculated as an average over all slots in the 24-slot constellation measured over a 1 year interval

Notes:

1. *So long as at least 21 slots out of the 24 slots are occupied either by a healthy Navstar satellite broadcasting a useable PPS SIS in the baseline slot configuration or by a pair of healthy Navstar satellites each broadcasting a useable PPS SIS in the expanded slot configuration, the all-in-view position dilution of precision (PDOP) with a mask angle of 5 degrees will be 6 or less for: a) 98% of the global average over any sidereal day, and b) 88% at the worst site over any sidereal day. See Appendix A for further information.*

2. *Expandable baseline slots occupied by a pair of healthy satellites in the expanded configuration can provide more robust constellation availability to enhance the overall PPS SIS performance. However, since there are no standards given in this PPS PS for the probabilities of the expandable baseline slots being in their expanded configurations and occupied by pairs of healthy satellites, no credit can be taken for them relative to the baseline 24-slot constellation availability with all slots in their baseline configuration.*

3. *The PPS SIS constellation availability measurement interval must be substantially longer than the mean time between constellation interruptions and the mean time to restore constellation availability.*

3.7.3 Operational Satellite Body-Count Standards

The total number of operational satellites in the constellation shall be as specified in Table 3.7-3.

Table 3.7-3. Operational Satellite Body-Count Standards

Satellite Body Count Standard	Conditions and Constraints
• ≥ 0.95 Probability that the Constellation will Have at least 24 Operational Satellites Regardless of Whether Those Operational Satellites are Located in Slots or Not	• Applies to the total number of operational satellites in the constellation (averaged over any day); where any satellite which appears in the transmitted navigation message almanac is defined to be an operational satellite regardless of whether that satellite is currently healthy and broadcasting a useable PPS SIS or not

SECTION 4.0 References

This section identifies the Government documents and non-Government documents referenced in this *PPS PS*.

4.1 Government Documents

SPECIFICATIONS:

Federal

4 October 2001	*Global Positioning System Standard Positioning Service Performance Standard, 3rd Edition*

Military

None

Program

SS-GPS-300G 5 August 2005	*System Specification for the Navstar Global Positioning System*

Other Government Activity

NIMA TR8350.2 3 January 2000	*Department of Defense* *World Geodetic System 1984* *Its Definition and Relationship with Local Geodetic Systems*

STANDARDS:

Federal

TSO-C129 10 December 1992	Technical Standard Order (TSO), *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)*
TSO-C129a 20 February 1996	Technical Standard Order (TSO), *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)*
TSO-C145a 19 September 2002	Technical Standard Order (TSO), *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)*

Military

MSO-C129a 30 August 2002	Military Standard Order (MSO), *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS) / Precise Positioning Service (PPS)*

MSO-C145 10 April 2003	Military Standard Order (MSO), *Airborne Navigation Sensors Using the Global Positioning System (GPS) / Precise Positioning Service (PPS) for Area Navigation (RNAV) in Required Navigation Performance (RNP) Airspace; RNP-20 RNAV through RNP-3 RNAV*
STANAG 4278 Edition 3, 17 August 1993	NATO Standardization Agreement (STANAG), *Method of Expressing Navigation Accuracy*
STANAG 4294 Ratification Edition 1 6 November 1991	NATO Standardization Agreement (STANAG), *Navstar Global Positioning System (GPS) System Characteristics*
STANAG 4294 Part I, Edition 2 5 December 1997	NATO Standardization Agreement (STANAG), *Navstar Global Positioning System (GPS) System Characteristics*
STANAG 4294 Part II, Edition 2 5 December 1997	NATO Standardization Agreement (STANAG), *Navstar Global Positioning System (GPS) Summary of Performance Requirements*
STANAG 4392 Edition 1 14 November 1995	NATO Standardization Agreement (STANAG), *A Data Interchange Format for Navstar Global Positioning System (GPS)*
STANAG 4572 Edition 1 Current Draft	NATO Standardization Agreement (STANAG), *Open System Architecture Interface to Enable Laboratory Test of Integrated Global Positioning System / Inertial Navigation Equipment*

<u>Program</u>

IS-GPS-200 Current Revision	*Navstar GPS Space Segment / Navigation User Interfaces*
ICD-GPS-224 (S) Current Revision	*Navstar GPS Selective Availability and Anti-Spoof Receiver Design Requirements (U)*
ICD-GPS-225 (S) Current Revision	*Navstar GPS Selective Availability and Anti-Spoof Host Application Equipment Design Requirements for Precise Positioning Service Security Module (U)*

Other Government Activity

N 8110.60 2 February 1997	Federal Aviation Administration Notice *GPS as a Primary Means of Navigation in Remote/ Oceanic Operations*

OTHER PUBLICATIONS:

Manuals

None

Regulations

None

Plans

DoD-4650.5 5 January 2006	*2005 Federal Radionavigation Plan* (Additionally numbered as DOT-VNTSC-RITA-05-12)
DOD-4650.5 19 March 2002	*2001 Federal Radionavigation Systems* (Additionally numbered as DOT-VNTSC-RSPA-01-3.1)
CJSCI 6130.01C 31 March 2003	*2000 CJCS Master Positioning, Navigation, and Timing Plan*

Miscellaneous

USAF 003-78 22 January 1990	*System Operational Requirements Document (SORD)* *Navstar Global Positioning System*
AFSPC/ACC 003-92-I/II/III (S) 18 February 2000	*Final Operational Requirements Document (ORD)* *Global Positioning System (GPS) (U)*
MNS 003-92 29 January 1993	Air Force Space Command *Mission Need Statement (MNS) for Improved Worldwide Navigational Positioning System*
28 December 2001	Headquarters Air Force Space Command *Concept of Operations for the Global Positioning System* (Also known as the "*GPS CONOPS*")
Tech Report No. 96 February 1962	U.S. Air Force Aeronautical Chart and Information Center, *Principles of Error Theory and Cartographic Applications*
AC 90-96 20 March 1998	Federal Aviation Administration Advisory Circular (AC) *Approval of U.S. Operators and Aircraft to Operate Under Instrument Flight Rules (IFR) in European Airspace Designated for Basic Area Navigation ((BRNAV/RNP-5)*

TOR S3-G-89-01 23 March 1989	Technical Operating Report (TOR) *Navstar Global Positioning System Standardized Accuracy Definitions and Relationships*

4.2 Non-Government Documents

SPECIFICATIONS:

None

STANDARDS:

RTCA/DO-229C 28 November 2001	RTCA Document, Special Committee 159 *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*
RTCA/DO-236A 13 September 2000	RTCA Document, Special Committee 181 *Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation*
RTCA/DO-245 28 September 1998	RTCA Document, Special Committee 159 *Minimum Aviation Performance Standards for the Local Area Augmentation System (LAAS)*
RTCM Paper 136-2001/SC104-STD August 2001	RTCM Document, Special Committee 104 *RTCM Recommended Standards for Differential Navstar GPS Service, Version 2.3*

OTHER PUBLICATIONS:

None

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GLOBAL POSITIONING SYSTEM PRECISE POSITIONING SERVICE PERFORMANCE STANDARD

APPENDIX A

PPS SIGNAL-IN-SPACE (SIS) BACKGROUND INFORMATION

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

February 2007

Integrity - Service - Excellence

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List of Tables

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SECTION A.1 Introduction

A.1.1 Scope

This appendix provides further background information on the PPS SIS and its performance standards. The performance standards given in Section 3 of this *PPS PS*, along with the referenced ICDs, comprise a full and complete description of the PPS SIS interface provided to the User Segment's PPS receivers. The background information in this appendix serves to place those standards into context and explain the rationale behind them.

A.1.2 Limitations

Nothing in this appendix shall be deemed to change, modify, or alter the performance standards in Section 3 of this *PPS PS*. The background information in this appendix is for reference purposes only.

SECTION A.2 Constellation

A.2.1 Relationship with Section 3.2

Section 3.2 contains the PPS SIS performance standards for the Navstar satellite constellation. The orbital slots defined in Section 3.2 are the nominal originating locations for the PPS SIS. For convenience, this section further describes those nominal PPS SIS originating locations in a manner equivalent to the almanac data sets defined by IS-GPS-200 which may be more familiar to some readers.

A.2.2 Baseline Constellation Configuration

The baseline 24-slot constellation defined by Tables 3.2-1 and 3.2-3 can be expressed in an "almanac type" representation using parameters and units equivalent to those in IS-GPS-200 – see Table A.2-1. (Recognize that IS-GPS-200 uses semicircles rather than degrees, meters^{½} rather than meters, and includes clock offset parameters which are not shown in Table A.2-1).

Table A.2-1. Baseline Constellation Almanac, at Epoch of 00:00:00 on 1 Jul 93

Slot ID	e (unit less)	δ_i (degrees)	OMEGADOT (deg/sec)	A (meters)	OMEGA$_0$ (degrees)	ω (degrees)	M$_0$ (degrees)
A1	0.000	1.000	-4.4874E-7	26,559,710	357.734	0.000	268.126
A2	0.000	1.000	-4.4874E-7	26,559,710	357.734	0.000	161.786
A3	0.000	1.000	-4.4874E-7	26,559,710	357.734	0.000	11.676
A4	0.000	1.000	-4.4874E-7	26,559,710	357.734	0.000	41.806
B1	0.000	1.000	-4.4874E-7	26,559,710	57.734	0.000	80.956
B2	0.000	1.000	-4.4874E-7	26,559,710	57.734	0.000	173.336
B3	0.000	1.000	-4.4874E-7	26,559,710	57.734	0.000	309.976
B4	0.000	1.000	-4.4874E-7	26,559,710	57.734	0.000	204.376
C1	0.000	1.000	-4.4874E-7	26,559,710	117.734	0.000	111.876
C2	0.000	1.000	-4.4874E-7	26,559,710	117.734	0.000	11.796
C3	0.000	1.000	-4.4874E-7	26,559,710	117.734	0.000	339.666
C4	0.000	1.000	-4.4874E-7	26,559,710	117.734	0.000	241.556
D1	0.000	1.000	-4.4874E-7	26,559,710	177.734	0.000	135.226
D2	0.000	1.000	-4.4874E-7	26,559,710	177.734	0.000	265.446
D3	0.000	1.000	-4.4874E-7	26,559,710	177.734	0.000	35.156
D4	0.000	1.000	-4.4874E-7	26,559,710	177.734	0.000	167.356
E1	0.000	1.000	-4.4874E-7	26,559,710	237.734	0.000	197.046
E2	0.000	1.000	-4.4874E-7	26,559,710	237.734	0.000	302.596
E3	0.000	1.000	-4.4874E-7	26,559,710	237.734	0.000	66.066
E4	0.000	1.000	-4.4874E-7	26,559,710	237.734	0.000	333.686
F1	0.000	1.000	-4.4874E-7	26,559,710	297.734	0.000	238.886
F2	0.000	1.000	-4.4874E-7	26,559,710	297.734	0.000	345.226
F3	0.000	1.000	-4.4874E-7	26,559,710	297.734	0.000	105.206
F4	0.000	1.000	-4.4874E-7	26,559,710	297.734	0.000	135.346

Notes:

e = Eccentricity
δ_i = Delta-inclination relative to a nominal value of 0.30 semi-circles (54 degrees)
OMEGADOT = Rate of Right Ascension
A = Semi-major axis
OMEGA$_0$ = Geographic Longitude of the Ascending Node at the Weekly Epoch
ω = Argument of perigee
M$_0$ = Mean anomaly at the reference time

A.2.3 Expanded Constellation Configuration

Table A.2-2 provides the equivalent "almanac type" representation for when all of the expandable slots are in their expanded configuration in accordance with Tables 3.2-1, 3.2-2, and 3.2-3. Note that each expandable slot may individually be in its non-expanded configuration or in its expanded configuration. There is no linkage between the expandable slots.

Table A.2-2. Expanded Baseline Constellation Almanac, at Epoch of 00:00:00 on 1 Jul 93

Slot ID	e (unit less)	δ_i (degrees)	OMEGADOT (deg/sec)	A (meters)	OMEGA$_0$ (degrees)	ω (degrees)	M$_0$ (degrees)
A1	0.000	1.000	-4.4874E-7	26,559,710	357.734	0.000	268.126
A2	0.000	1.000	-4.4874E-7	26,559,710	357.734	0.000	161.786
A3	0.000	1.000	-4.4874E-7	26,559,710	357.734	0.000	11.676
A4	0.000	1.000	-4.4874E-7	26,559,710	357.734	0.000	41.806
B1F	0.000	1.000	-4.4874E-7	26,559,710	57.734	0.000	94.916
B1A	0.000	1.000	-4.4874E-7	26,559,710	57.734	0.000	66.356
B2	0.000	1.000	-4.4874E-7	26,559,710	57.734	0.000	173.336
B3	0.000	1.000	-4.4874E-7	26,559,710	57.734	0.000	309.976
B4	0.000	1.000	-4.4874E-7	26,559,710	57.734	0.000	204.376
C1	0.000	1.000	-4.4874E-7	26,559,710	117.734	0.000	111.876
C2	0.000	1.000	-4.4874E-7	26,559,710	117.734	0.000	11.796
C3	0.000	1.000	-4.4874E-7	26,559,710	117.734	0.000	339.666
C4	0.000	1.000	-4.4874E-7	26,559,710	117.734	0.000	241.556
D1	0.000	1.000	-4.4874E-7	26,559,710	177.734	0.000	135.226
D2F	0.000	1.000	-4.4874E-7	26,559,710	177.734	0.000	282.676
D2A	0.000	1.000	-4.4874E-7	26,559,710	177.734	0.000	257.976
D3	0.000	1.000	-4.4874E-7	26,559,710	177.734	0.000	35.156
D4	0.000	1.000	-4.4874E-7	26,559,710	177.734	0.000	167.356
E1	0.000	1.000	-4.4874E-7	26,559,710	237.734	0.000	197.046
E2	0.000	1.000	-4.4874E-7	26,559,710	237.734	0.000	302.596
E3	0.000	1.000	-4.4874E-7	26,559,710	237.734	0.000	66.066
E4	0.000	1.000	-4.4874E-7	26,559,710	237.734	0.000	333.686
F1	0.000	1.000	-4.4874E-7	26,559,710	297.734	0.000	238.886
F2F	0.000	1.000	-4.4874E-7	26,559,710	297.734	0.000	0.456
F2A	0.000	1.000	-4.4874E-7	26,559,710	297.734	0.000	334.016
F3	0.000	1.000	-4.4874E-7	26,559,710	297.734	0.000	105.206
F4	0.000	1.000	-4.4874E-7	26,559,710	297.734	0.000	135.346

SECTION A.3 Coverage

A.3.1 Relationship with Section 3.3

Section 3.3 contains the PPS SIS performance standards for coverage from each Navstar satellite and from the Navstar satellite constellation. This section provides further information relative to both aspects of the PPS SIS coverage.

A.3.2 Per-Satellite Coverage

A.3.2.1 Satellite Footprint

The portion of the surface of the Earth which is visible from a satellite's orbital position is known as the satellite's "footprint". See Figure A.3-1.

The footprint of each Navstar satellite occupying a slot in the baseline 24-slot constellation covers approximately 38% of the Earth's surface. The use of artificial mask angles will reduce the satellite's effective footprint. With a 5-degree mask angle, a Navstar satellite's effective footprint is reduced to slightly more than one-third of the Earth's surface (33.9%).

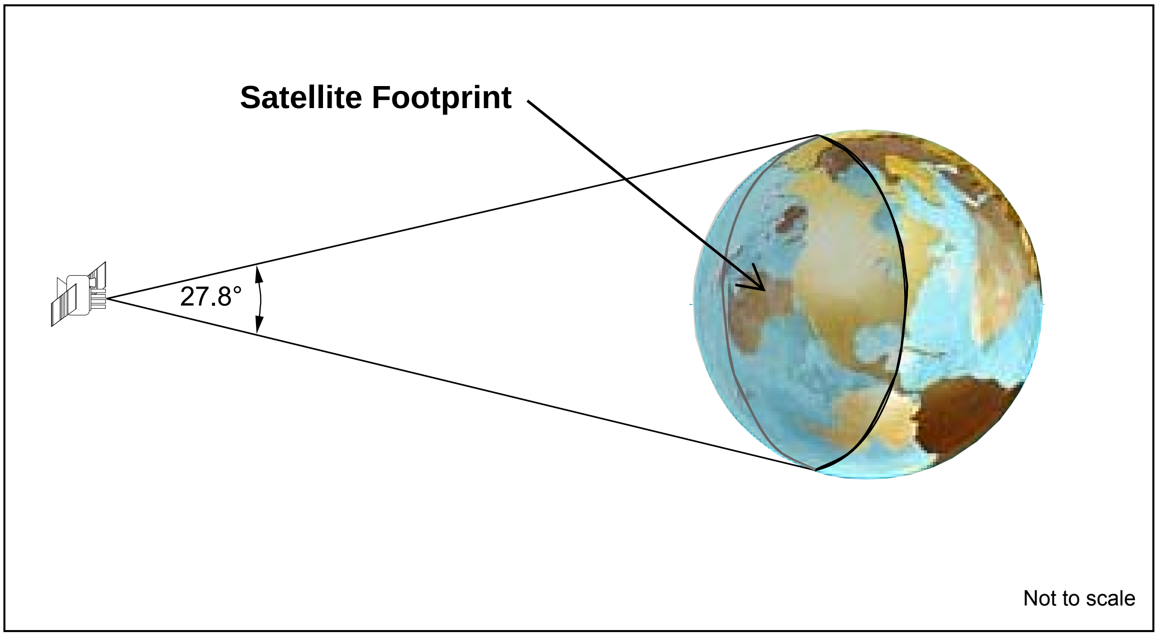


Figure A.3-1. Illustration of Satellite Footprint

A.3.2.2 Mask Angles

The 5 degree elevation angle used in IS-GPS-200 for specifying the guaranteed minimum user-received power level should not be interpreted as specifying, recommending, or suggesting a particular GPS receiver mask angle. The GPS receiver mask angle (if any) should be determined as a function of the IS-GPS-200 guaranteed minimum user-received power levels, the PPS SIS frequencies used, the GPS receiver antenna gain patterns at each frequency, the GPS receiver front-end sensitivity at each frequency, the particular types of mission(s) to be accomplished, and related factors. Some common GPS receiver mask angles are 15 degrees, 10 degrees, 7.5 degrees, 5 degrees, 2 degrees, and 0 degrees. Some GPS receivers have no mask angle. Most older military GPS receivers have a variable mask angle.

A.3.3 Baseline Constellation Coverage

A.3.3.1 Seamless Coverage

The coverage of a "global positioning system" should obviously be global and seamless. The same is not necessarily true for a "global navigation satellite system" (GNSS) which incorporates wide area or local area augmentations. The PPS SIS constellation coverage is seamless.

A.3.3.2 Terrestrial Service Volume

The near-Earth region extending from the surface of the Earth up to an altitude of 3,000 km above the surface of the Earth is also known as the "terrestrial service volume". See Figure A.3-2.

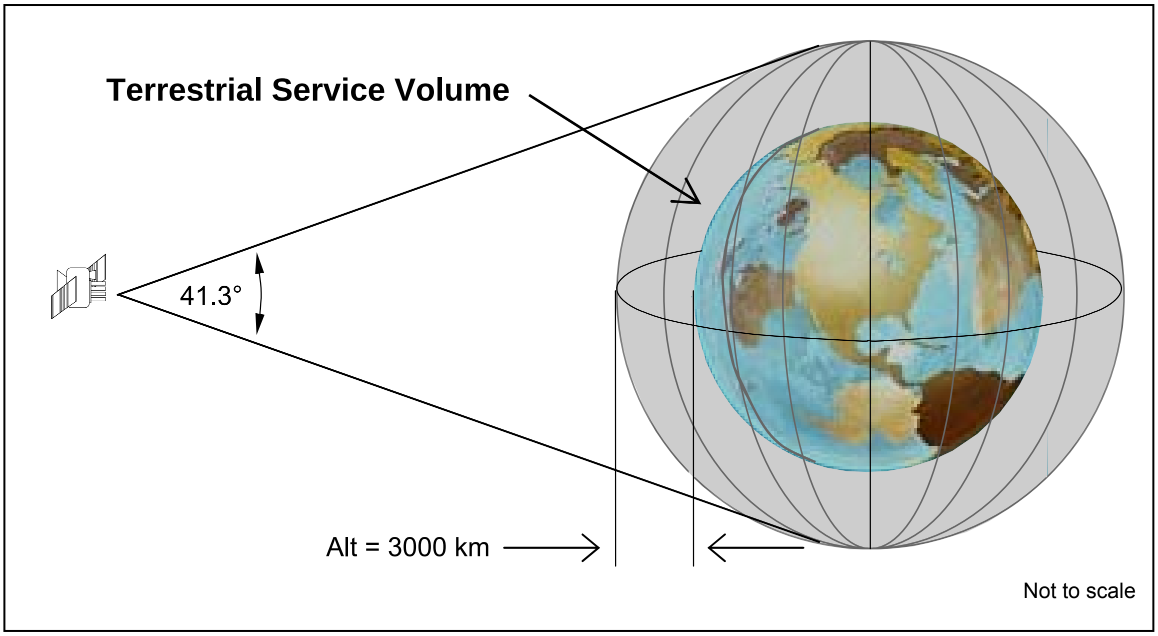


Figure A.3-2. Illustration of Terrestrial Service Volume

A.3.3.3 Space Service Volume

The spherical shell extending from the outer surface of the terrestrial service volume up to an altitude of 36,000 km above the surface of the Earth (approximately the geosynchronous orbit altitude) is known as the "space service volume". There are no explicit constellation coverage standards for the space service volume.

SECTION A.4 Accuracy

A.4.1 Relationship with Section 3.4

Section 3.4 contains the PPS SIS performance standards for accuracy. This section provides background information relative to the PPS SIS accuracy performance standards.

A.4.2 Component Dependency

The GPS UERE budgets, and the corresponding PPS SIS accuracy standards, vary as a function of the particular PPS SIS components being used. There are many different types of PPS receivers that use different PPS SIS components or combinations of PPS SIS components. There are few PPS receivers that always use only one specific PPS SIS component or combination of components; most PPS receivers use different components or combinations of components as a function of operating mode. For example, many PPS receivers will start out using C/A-code for a period of time before they transition to using P(Y)-code. Other PPS receivers have a mode where they will only use Y-code and some have a mode where they will only use C/A-code. Higher-end PPS receivers commonly use both the L1 and L2 signals. Some of the most common PPS receivers have no ability to use the L2 signal and therefore only use the L1 signal. Certain PPS receivers read and apply the Wide Area GPS Enhancement (WAGE) NAV Message Correction Table (NMCT) data while others do not. The typical PPS SIS component variations used by PPS receivers include the following:

a. Using P(Y)-code, or using C/A-code

b. Using L1 and L2 for dual-frequency ionospheric delay compensation, or using L1 only, or using L2 only

c. Not applying WAGE NMCT data, or applying WAGE NMCT data

The PPS SIS component accuracies are specified in Section 3.4.

A.4.3 Time Dependency

A.4.3.1 Graceful Degradation

In addition to varying as a function of the particular PPS SIS components being used, the GPS UERE budgets and corresponding PPS SIS accuracy standards vary as a function of time. The accuracy variation over time will be significant if the Control Segment is unable to upload fresh NAV message data to the satellites in the constellation. Such a condition could occur as the result of total loss of the Control Segment due to a natural or man-made disaster, or it could occur on a per-satellite basis if a satellite were to become unable to accept and process the uploaded data. In either case, the UERE will degrade gracefully over time as illustrated in Figure A.4-1.

A.4.3.2 Normal Operations vs. Extended Operations

When the satellites are being uploaded on a routine basis, the PPS SIS accuracy standards which apply are for the normal operations mode. During normal operations, each satellite in the constellation is uploaded at least once per day. Additional (contingency) uploads may be necessary for certain satellites as described in the following section. The normal operations mode is shown at the far left-hand side of Figure A.4-1. The PPS SIS indicates when the satellite is in the normal operations mode by way of the fit interval flag being set to "0" (zero) in accordance with IS-GPS-200. When the fit interval flag is set to "1" (one), the satellite is operating in the extended operations mode. Special PPS SIS accuracy standards apply for the extended operations mode. See IS-GPS-200 for further details on the fit interval flag.

Note:

1. *Three uploads per day is a worst-case assumption for the normal operations period. One upload per day is a best-case assumption. Many satellites typically only require one upload per day.*

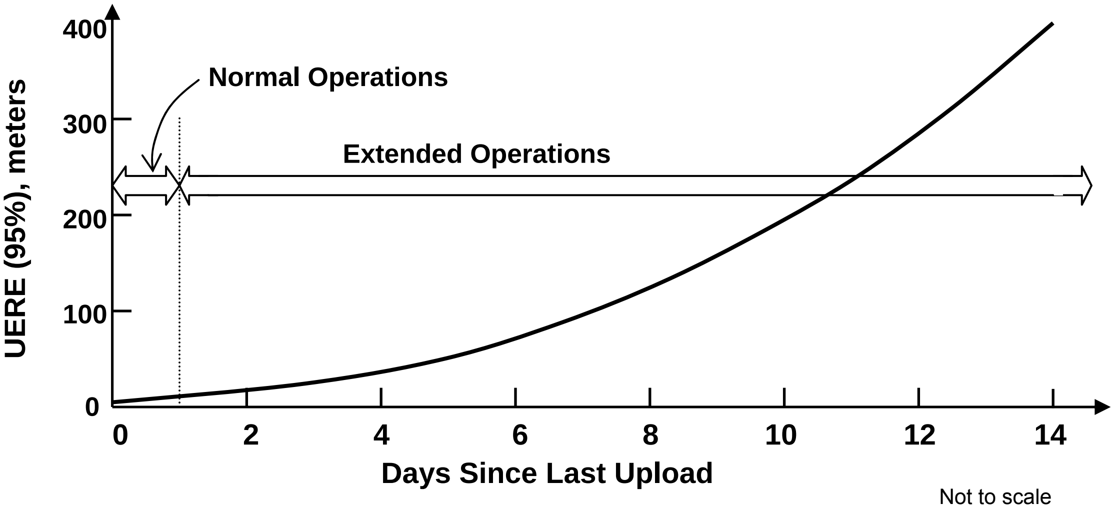


Figure A.4-1. UERE Graceful Degradation

The extended operations period is shown at the center and right-hand side of Figure A.4-1. A different set of PPS SIS accuracy standards applies when a satellite is operating in the extended operations mode. All Navstar satellites will provide a useable PPS SIS for at least 14 days in the extended operations mode (i.e., at least 14 days after the last upload of fresh NAV message data from the Control Segment). Most Navstar satellites will continue to provide a useable PPS SIS for even longer than 14 days. See IS-GPS-200 for further details on the capability of different types of Navstar satellites to continue in the extended operations mode beyond 14 days.

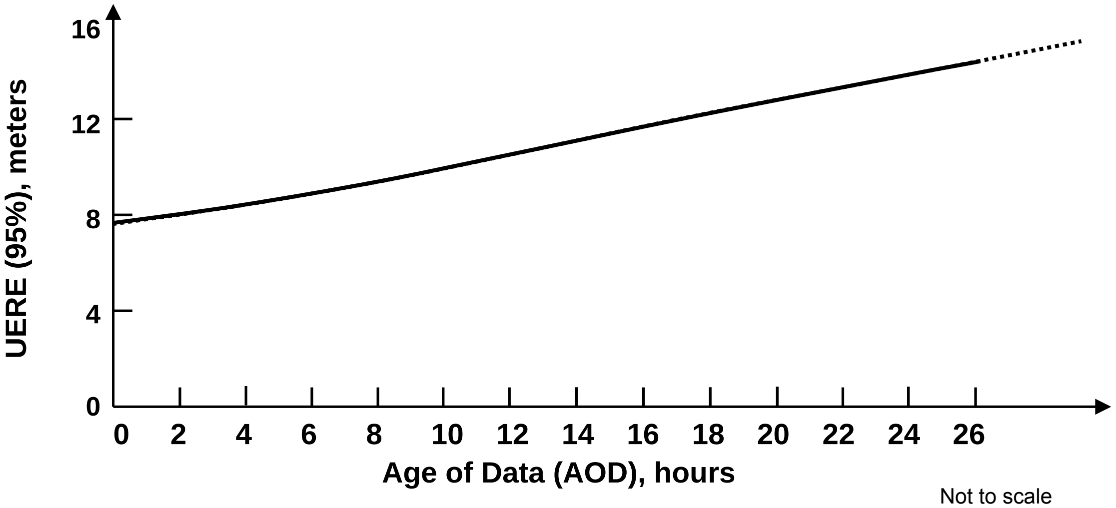
A.4.3.3 Variations During Normal Operations

During the normal operations period without WAGE, the GPS UERE and PPS SIS accuracy vary as a function of the time since upload in the same general manner as shown in Figure A.4-1, but with the maximum time since last upload for each satellite limited to no more than about a day. The smallest UERE and best SIS accuracy will generally occur immediately after an upload of fresh NAV message data to a satellite, while the largest UERE and worst SIS accuracy will usually be with the stalest NAV message data just prior to the next upload to that satellite.

The metric used to characterize whether the NAV message data being transmitted by a satellite is fresh or stale is the age of data (AOD), where the AOD is the elapsed time since the Control Segment generated the satellite clock/ephemeris prediction used to create the NAV message data upload. The AOD is approximately equal to the time since last upload plus the time it took the Control Segment to create the NAV message data and upload it to the satellite.

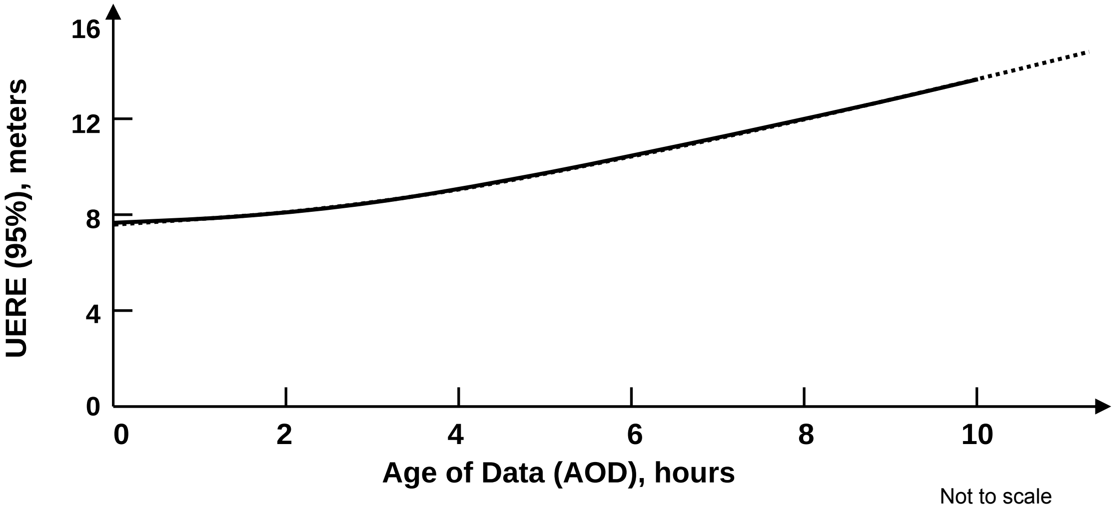
For normal operations without WAGE, the GPS UERE budget and the traditional PPS SIS accuracy specifications apply at each AOD. Because the largest UERE and worst SIS accuracy usually occur with the stalest NAV message data, the UERE budget and traditional PPS SIS accuracy specifications are taken as applying at the maximum AOD.

Figure A.4-2 shows close-up views of the normal operations period without WAGE. The horizontal axes are given in terms of the AOD. In a best-case one-upload-per-day scenario for a satellite with a very stable clock (Figure A.4-2a), the maximum AOD is assumed to be 26 hours based on: (a) 1 hour to create the NAV message data and upload it to satellite, (b) 24 hours mean time between uploads, and (c) 1 hour schedule variation for the subsequent upload. In a worst-case three-upload-per-day scenario for a satellite with a less stable clock (Figure A.4-2b), the maximum AOD is assumed to be 10 hours based on: (a) 1 hour to create the NAV message data and upload it to satellite, (b) 8 hours mean time between uploads, and (c) 1 hour schedule variation for the subsequent upload.



Not to scale

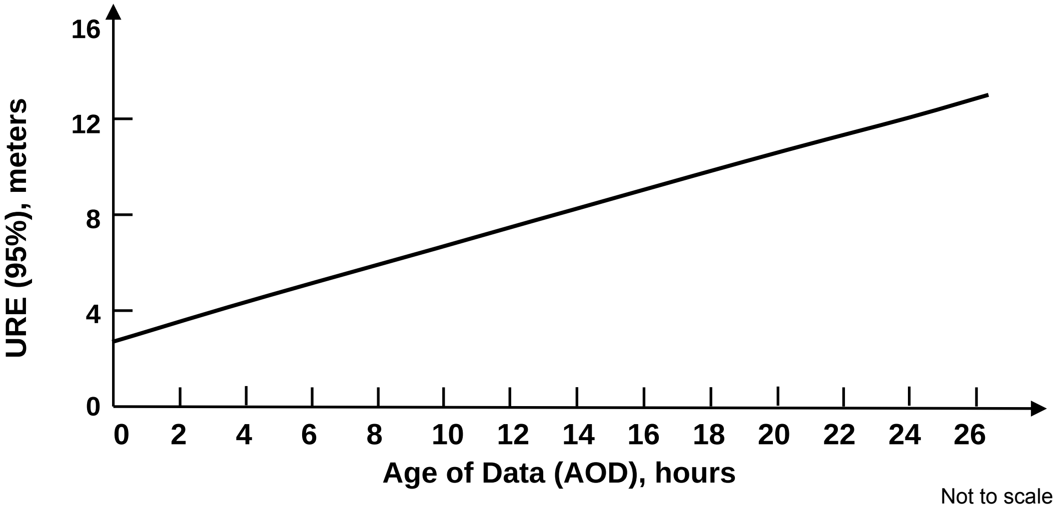
Figure A.4-2a. UERE as a Function of AOD, One-Upload-Per-Day Scenario



Not to scale

Figure A.4-2b. UERE as a Function of AOD, Three-Uploads-Per-Day Scenario

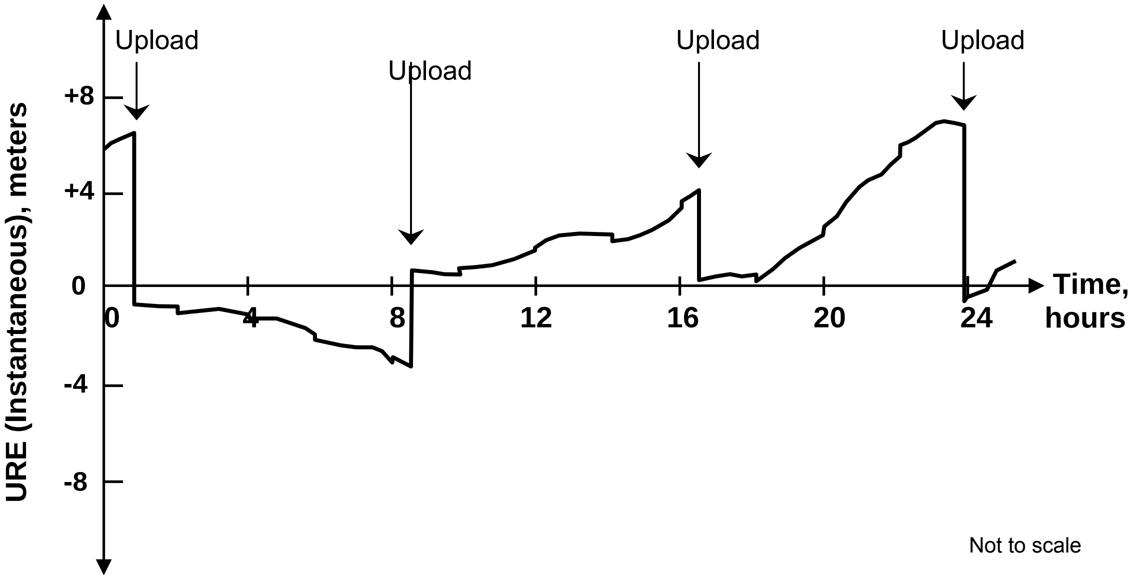
Recognize that a large portion of the UERE in Figure A.4-2a (and in Figure A.4-2b) does not vary as a function of the AOD. The dominant component which does not vary is the PPS receiver's contribution to the UERE (known as the user equipment error or UEE). Factoring out the PPS receiver's UEE leaves just the PPS SIS contribution to the UERE (i.e., the PPS SIS URE). As shown in Figure A.4-3, the PPS SIS URE exhibits a stronger dependence on the AOD than the PPS UERE shown in Figure A.4-2a.



Not to scale

Figure A.4-3. Statistical PPS SIS URE as a Function of AOD, One-Upload-Per-Day Scenario

Figure A.4-3, like the preceding figures, is a statistical plot. It shows the cumulative PPS SIS URE-as-a-function-of-AOD results over many uploads (e.g., all uploads to a satellite over the course of a year in a one-upload-per-day scenario). Figure A.4-4 shows a representative example of four uploads performed over a day to a single satellite in a three-upload-per-day scenario. Unlike the preceding figures, Figure A.4-4 shows the instantaneous URE as a function of time rather than the cumulative statistical URE as a function of the AOD.



Not to scale

Figure A.4-4. Instantaneous PPS SIS URE as a Function of Time

Note:

1. *The instantaneous URE can be positive or negative as shown in Figure A.4-4. The statistical URE is always unsigned (illustrated as positive) as shown in Figures A.4-1 through A.4-3.*

In Figure A.4-4, the uploads are shown as occurring at approximately 00:42, 08:28, 16:29, and 23:57. Each upload is characterized by the instantaneous PPS SIS URE resetting to near zero as a result of the satellite starting to broadcast the fresh NAV message which has just been uploaded. The transition from the stale old NAV message data to the fresh new NAV message data is known as an "upload cutover". In addition to the large discontinuities at the upload cutovers, Figure A.4-4 also shows much smaller discontinuities occurring at the 2-hour boundaries (slightly exaggerated for clarity). These smaller discontinuities are the result of the satellite switching from broadcasting one 2-hour data set to the next 2-hour data set from the same upload. Even though sequential 2-hour data sets come from the same upload, minor differences in clock/ephemeris curve fitting introduce small discontinuities between data sets (i.e., between curve fits). The transition from one 2-hour data set to the next 2-hour data set is known as a "data set cutover". See IS-GPS-200 for further details on upload cutovers and data set cutovers.

During normal operations with WAGE, the resulting GPS UERE and PPS SIS accuracy vary as a function of the age of the NMCT data being used. The accuracy of the NMCT data is subject to the same AOD effects as the regular NAV message data for a single satellite. The smallest UERE and best SIS accuracy will generally occur with freshly uploaded NMCT data, while the largest UERE and worst SIS accuracy will usually be just prior to expiration of the NMCT data. For normal operations with WAGE, the GPS UERE budget and the PPS SIS accuracy standards apply over all WAGE AODs.

A.4.3.4 Accuracy at Time of Upload

As shown in the preceding figures, uploads of fresh NAV message data reset the instantaneous PPS SIS URE to near zero, but they do not always reset the instantaneous PPS SIS URE to exactly zero. There are three main types of errors which prevent fresh NAV message data from being 100% accurate at the time of the upload. In descending order of impact on upload accuracy, the three types of limiting errors are:

a. The first error type is the result of the inability of the Control Segment to perfectly determine a satellite's clock offset from GPS time and its location in orbit at every instant in time. This is often called the zero age of data (ZAOD) error. The MCS uses a Kalman filter to process the PPS SIS tracking data supplied by the MSs and generates estimates for the satellite clock/ephemeris parameters in near real time. Because Kalman filters do not react instantaneously to unpredictable changes, and because there are only a limited number of MSs providing PPS SIS tracking measurements, the near real time estimated clock/ephemeris parameters in the MCS are always slightly inaccurate. The ZAOD errors tend to be lower when more MSs are tracking a satellite, and they tend to be larger when a satellite's clock or orbit are changing in an unpredictable manner. Inaccurately estimated clock/ephemeris parameters from the Control Segment's Kalman filter map directly into the upload based on those parameters.

b. The second error type is the result of there only being a limited number of data bits in the NAV message data to represent a satellite's predicted clock and ephemeris. This is known as the curve fit error. The two "curves" which have the fitting error are: (1) the quadratic curve specified in IS-GPS-200 for representing a satellite's predicted clock offset from GPS time, and (2) the quasi-Keplerian curve specified in IS-GPS-200 for representing a satellite's predicted ephemeris. This is the same error which is responsible for the small discontinuities occurring at the 2-hour boundaries shown in Figure A.4-4. See IS-GPS-200 for further details on curve fit errors.

c. The third error type is the result of the delay between the time that the Control Segment's Kalman filter generates its estimates of the satellite clock/ephemeris parameters and the time that the satellite starts transmitting new NAV message data from an upload based on those Kalman filter estimates. The AOD starts counting at the time the Kalman filter generates the satellite clock/ephemeris parameters, not at the time of the upload. Because of the delay, new NAV message data already has a significant non-zero AOD when a satellite starts transmitting it.

A.4.4 Contingency Uploads

The Control Segment has some ability to manage the PPS SIS contribution to the overall UERE. The Control Segment can do this by monitoring the current instantaneous PPS SIS URE from each satellite and performing a "contingency upload" if the URE starts to become large relative to the allocated Space/Control portions of the UERE budget. Done consistently, this puts an effective bound on the maximum PPS SIS URE. This *PPS PS* contains no requirement for the Control Segment to perform contingency uploads nor does it give any PPS SIS URE threshold for prompting a contingency upload. The contingency upload threshold (CUT), if any, is under the purview of the Control Segment. The only PPS SIS accuracy-related requirements on the Control Segment for uploading are: (1) uploading each satellite a minimum of approximately once per day, and (2) satisfying the requirements of Tables 3.4-1 through 3.4-4.

A.4.5 UERE Budgets

For reference, the GPS UERE budgets for PPS receivers using various PPS SIS components without WAGE at zero AOD, at maximum AOD in normal operations, and at 14.5 day AOD in extended operations, are shown in Table A.4-1 and Table A.4-2. The breakouts of the individual segment components of the UERE budgets shown in these tables are given for illustration purposes only. The actual PPS SIS accuracy standards are given in Table 3.4-1.

The corresponding GPS UERE budgets with WAGE at zero WAGE AOD and at a WAGE AOD of 2 hours are shown in Table A.4-3 and Table A.4-4. The global average WAGE AOD is 2 hours assuming satellites are uploaded once per day in random order. The breakouts of the individual segment components of the UERE budgets shown in these tables are given for illustration purposes only. The actual PPS SIS accuracy standards with WAGE are given in Table 3.4-1.

Recognize that those portions of the GPS UERE budgets related to the PPS receivers are shown strictly for illustration purposes only. The actual PPS receiver UEE contributions to the overall GPS UERE budgets will vary significantly as a function of PPS receiver performance under different environmental conditions.

Notes:

1. *The mix of satellite clocks requiring different numbers of uploads per day to meet the PPS SIS accuracy standards in Table 3.4-1 will be controlled such that the PPS SIS accuracy standards will be met with no more than 50 uploads per day for up to 27 satellites supported.*

Table A.4-1. Dual-Frequency P(Y)-Code UERE Budget Without WAGE

Segment	Error Source	UERE Contribution (95%) w/o WAGE (meters)		
		Zero AOD	Max. AOD in Normal Operation	14.5 Day AOD
Space	Clock Stability	0.0	8.9	257
	Group Delay Stability	0.0	0.6	0.6
	Diff'l Group Delay Stability	0.0	2.0	2.0
	Satellite Acceleration Uncertainty	0.0	2.0	204
	Other Space Segment Errors	1.0	1.0	1.0
Control	Clock/Ephemeris Estimation	2.0	2.0	2.0
	Clock/Ephemeris Prediction	0.0	6.7	206
	Clock/Ephemeris Curve Fit	0.8	0.8	1.2
	Iono Delay Model Terms	N/A	N/A	N/A
	Group Delay Time Correction	N/A	N/A	N/A
	Other Control Segment Errors	1.0	1.0	1.0
User*	Ionospheric Delay Compensation	4.5	4.5	4.5
	Tropospheric Delay Compensation	3.9	3.9	3.9
	Receiver Noise and Resolution	2.9	2.9	2.9
	Multipath	2.4	2.4	2.4
	Other User Segment Errors	1.0	1.0	1.0
95% System UERE (PPS)		7.5	13.8	388
* For illustration only, actual PPS receiver performance varies significantly -- see Table B.2-1				

Table A.4-2. L1 Single-Frequency P(Y)-Code UERE Budget Without WAGE

Segment	Error Source	UERE Contribution (95%) w/o WAGE (meters)		
		Zero AOD	Max. AOD in Normal Operation	14.5 Day AOD
Space	Clock Stability	0.0	8.9	257
	Group Delay Stability	1.6	1.6	1.6
	Diff'l Group Delay Stability	0.0	0.0	0.0
	Satellite Acceleration Uncertainty	0.0	2.0	204
	Other Space Segment Errors	1.0	1.0	1.0
Control	Clock/Ephemeris Estimation	2.0	2.0	2.0
	Clock/Ephemeris Prediction	0.0	6.7	206
	Clock/Ephemeris Curve Fit	0.8	0.8	1.2
	Iono Delay Model Terms	9.8-19.6	9.8-19.6	9.8-19.6
	Group Delay Time Correction	4.5	4.5	4.5
	Other Control Segment Errors	1.0	1.0	1.0
User*	Ionospheric Delay Compensation	N/A	N/A	N/A
	Tropospheric Delay Compensation	3.9	3.9	3.9
	Receiver Noise and Resolution	2.9	2.9	2.9
	Multipath	2.4	2.4	2.4
	Other User Segment Errors	1.0	1.0	1.0
95% System UERE (PPS)		12.5-21.1	16.8-23.9	388
* For illustration only, actual PPS receiver performance varies significantly -- see Table B.2-1				

Table A.4-3. Dual-Frequency P(Y)-Code UERE Budget With WAGE

		UERE Contribution (95%) w/ WAGE (meters)		
Segment	Error Source	Zero WAGE AOD	2 Hour WAGE AOD	14.5 Day WAGE AOD
Space	Clock Stability	8.9	8.9	N/A
	Group Delay Stability	0.6	0.6	N/A
	Diff'l Group Delay Stability	2.0	2.0	N/A
	Satellite Acceleration Uncertainty	2.0	2.0	N/A
	Other Space Segment Errors	1.0	1.0	N/A
Control	Clock/Ephemeris Estimation	2.0	2.0	N/A
	Clock/Ephemeris Prediction	6.7	6.7	N/A
	Clock/Ephemeris Curve Fit	0.8	0.8	N/A
	Iono Delay Model Terms	N/A	N/A	N/A
	Group Delay Time Correction	N/A	N/A	N/A
	Other Control Segment Errors	1.0	1.0	N/A
WAGE	SIS Error Reduction from NMCT	-11.5	-11.3	N/A
User*	Ionospheric Delay Compensation	4.5	4.5	4.5
	Tropospheric Delay Compensation	3.9	3.9	3.9
	Receiver Noise and Resolution	2.9	2.9	2.9
	Multipath	2.4	2.4	2.4
	Other User Segment Errors	1.0	1.0	1.0
95% System UERE (PPS)		7.5	7.9	N/A
* For illustration only, actual PPS receiver performance varies significantly -- see Table B.2-1				

Table A.4-4. L1 Single-Frequency P(Y)-Code UERE Budget With WAGE

		UERE Contribution (95%) w/ WAGE (meters)		
Segment	Error Source	Zero WAGE AOD	2 hour WAGE AOD	14.5 Day WAGE AOD
Space	Clock Stability	8.9	8.9	N/A
	Group Delay Stability	1.6	1.6	N/A
	Diff'l Group Delay Stability	0.0	0.0	N/A
	Satellite Acceleration Uncertainty	2.0	2.0	N/A
	Other Space Segment Errors	1.0	1.0	N/A
Control	Clock/Ephemeris Estimation	2.0	2.0	N/A
	Clock/Ephemeris Prediction	6.7	6.7	N/A
	Clock/Ephemeris Curve Fit	0.8	0.8	N/A
	Iono Delay Model Terms	9.8-19.6	9.8-19.6	N/A
	Group Delay Time Correction	4.5	4.5	N/A
	Other Control Segment Errors	1.0	1.0	N/A
WAGE	SIS Error Reduction from NMCT	-11.5	-11.3	N/A
User*	Ionospheric Delay Compensation	N/A	N/A	N/A
	Tropospheric Delay Compensation	3.9	3.9	3.9
	Receiver Noise and Resolution	2.9	2.9	2.9
	Multipath	2.4	2.4	2.4
	Other User Segment Errors	1.0	1.0	1.0
95% System UERE (PPS)		12.5-21.1	12.5-21.1	N/A
* For illustration only, actual PPS receiver performance varies significantly -- see Table B.2-1				

2. *The normal operations UERE budgets are consistent with a Block II/IIA clock stability of 5x10^{-13} at a tau of 10^{4} seconds for either Rubidium clocks or Cesium clocks and an average of three uploads per day per satellite assuming an average maximum AOD of 8.5 hours. Under a three-uploads-per-day scenario, the actual average maximum AOD is on the order of 10 hours.*

3. *The normal operations UERE budgets are conservative with a Block IIR clock stability of 6x10^{-14} at a tau of 10^{5} seconds for a Rubidium clock and an average of one upload per day per satellite assuming an average maximum AOD of 26 hours.*

4. *The extended operations UERE budgets are consistent with an "average" Block II/IIA clock stability of 3.5x10^{-13} at a tau of 10^{4} seconds (i.e., average between a Rubidium clock and a Cesium clock) and an AOD of 14.5 days.*

5. *14 days after the Control Segment ceases uploading satellites with fresh NAV message data under the system-wide graceful degradation scenario, the average AOD across all satellites in the constellation will be 14.5 days assuming an average of one upload per day per satellite before the Control Segment ceased uploading satellites. The extended operations URE standards apply across the entire constellation 14 days after the Control Segment ceased uploading satellites.*

6. *For satellite NAV message data at zero AOD (i.e., at the time the Control Segment generates the satellite's clock/ephemeris prediction), the WAGE NMCT correction for that satellite is defined to be zero. See IS-GPS-200 for details.*

7. *In Tables A.4-3 and A.4-4, WAGE performance is shown relative to the UERE budget for a satellite at maximum AOD during normal operation. Fresher NMCT data (i.e., at a lower WAGE AOD) provides better accuracy. WAGE NMCT data is not valid during extended operations (e.g., at a WAGE AOD of 14.5 days). See IS-GPS-200 for details on the maximum WAGE AOD at which the NMCT data is still valid.*

9. *Actual single-frequency ionospheric delay model errors depend on the point in the 11-year sunspot cycle, the geomagnetic location, the local solar time of day, and the local satellite elevation angle. Due to this variability, the single-frequency URE, URRE, and URRRE standards do not include the single-frequency ionospheric delay model errors. Tables A.4-2 and A.4-4 illustrate the typical method for including the single-frequency ionospheric delay model errors at L1. See paragraph A.4.9 for additional information.*

10. *The user contributions to the UERE budget illustrate mid-1980s vintage PPS receiving equipment under a stressed RFI environment. See Appendix B for additional information on different PPS receivers and environments.*

11. *All statistical values are expressed at the 95% probability level in accordance with STANAG 4278.*

A.4.6 URE Over All AODs

The PPS SIS portions of the preceding UERE budgets without WAGE describe the PPS SIS accuracy at various specified AODs. During the normal operations period, the statistical PPS SIS URE at the maximum AOD (i.e., any AOD) has traditionally been taken as being the URE seen by PPS receivers for system accuracy computations. Although valid under worst-case conditions, PPS receivers are very unlikely to encounter a condition where all satellites being used are simultaneously at their maximum AOD. Instead, the general-case condition for a PPS receiver is for the satellites being used to have a range of AODs. Some satellites will have large AODs, some satellites will have small AODs, and some satellites will have AODs in the middle. Under this general-case condition, using the PPS SIS URE at the maximum AOD will result in overly conservative system accuracy computations.

To avoid over-conservatism for the normal operations period, a different PPS SIS URE statistic is used. This is the PPS SIS URE over all AODs which occur during the normal operations period. The PPS SIS URE over all AODs applies to individual satellites over time as well as to the ensemble of satellites used by a PPS receiver over time. The PPS SIS URE over all AODs should be used in system accuracy computations.

Notes:

1. *Due to the shape of the PPS SIS URE curve as a function of AOD (e.g., see Figure A.4-3), the PPS SIS URE over all AODs is not equal to the PPS SIS URE at the average AOD.*
2. *The PPS SIS URE over all AODs is the expected PPS SIS URE at a random point in time over a long series of uploads (i.e., at a random AOD).*

A.4.7 URE Time Derivative Accuracies

There are two time derivatives of the PPS SIS instantaneous URE (instantaneous pseudorange error) addressed in this *PPS PS*. The first time derivative of the PPS SIS instantaneous pseudorange error is the PPS SIS instantaneous pseudorange rate error; also known as the instantaneous pseudorange velocity error or instantaneous user range rate error (URRE). The second time derivative of the PPS SIS instantaneous pseudorange error is the PPS SIS instantaneous pseudorange rate rate error; more commonly known as the instantaneous pseudorange acceleration error or instantaneous user range rate rate error (URRRE).

The inter-relationship of the time derivatives with the PPS SIS instantaneous URE is shown in the three panels of Figure A.4-5. Figure A.4-5(a) is a repeat of Figure A.4-4. Because the instantaneous pseudorange rate error is the rate of change of the instantaneous URE, the instantaneous URRE is simply the slope of the instantaneous URE. For example; just before the first upload, the slope of the instantaneous URE is steep and positive -- hence the instantaneous URRE is large and positive. This large and positive instantaneous URRE is shown in Figure A.4-5(b). One derivative further, the instantaneous pseudorange rate rate error is the rate of change of the rate of change of the instantaneous URE, or equivalently the rate of change (the slope) of the instantaneous URRE. For the example in Figure A.4-5(a); right after the first upload, the slope of the instantaneous URE starts out at zero and gradually becomes negative over time -- these changing slopes are the instantaneous URRE over time as shown in Figure A.4-5(b) -- and the changing slopes of the instantaneous URRE over time are the instantaneous URRRE over time as shown in Figure A.4-5(c).

Just as the behavior of the instantaneous URE over time is specified in terms of a statistical URE, the behavior of the instantaneous pseudorange rate error over time is specified in terms of a statistical URRE and the behavior of the instantaneous pseudorange rate rate error over time is specified in terms of a statistical URRRE. Also like the URE values, the URRE and URRRE values are expressed as 95th percentile accuracies over time, where measurement point is at any AOD for the normal operations scenario and at 14 days after the Control Segment ceases uploading in the extended operations scenario.

The infinite spikes in the instantaneous URRE and instantaneous URRRE values shown in Figures A.4-5b and A.4-5c deserves special mention. Whenever a step change occurs in the instantaneous URE in Figure A.4-5a -- due to a discontinuity caused by either an upload cutover or a data set cutover -- there is a corresponding spike in the instantaneous URRE. These spikes occur because the step change in the instantaneous URE at the cutover happens over an infinitesimally short time and the resulting "slope" of the instantaneous URE at the step change is infinite. The same principle also causes spikes in the instantaneous URRRE whenever a step change in the instantaneous URRE occurs at a cutover. These spikes in the instantaneous URRE and instantaneous URRRE are infinitely large in size, but only last for an infinitesimally short duration. These spikes are not included in the statistical URRE 95% and URRRE 95% values.

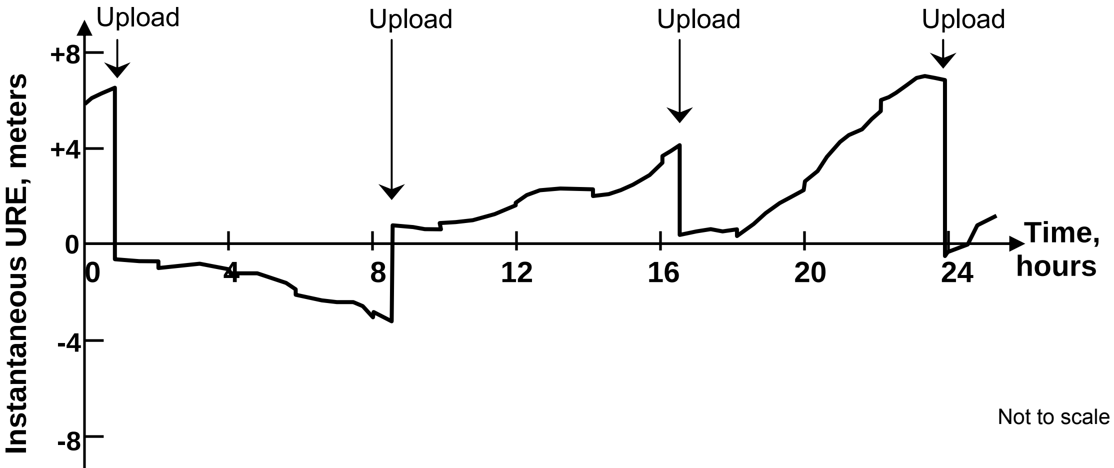


Figure A.4-5a. Instantaneous PPS SIS URE as a Function of Time

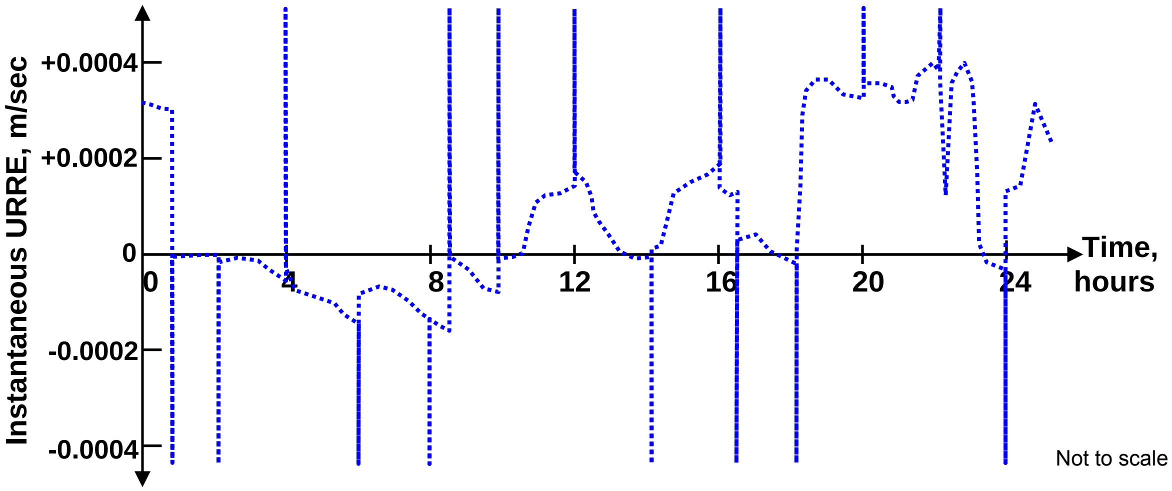


Figure A.4-5b. Instantaneous PPS SIS URRE as a Function of Time

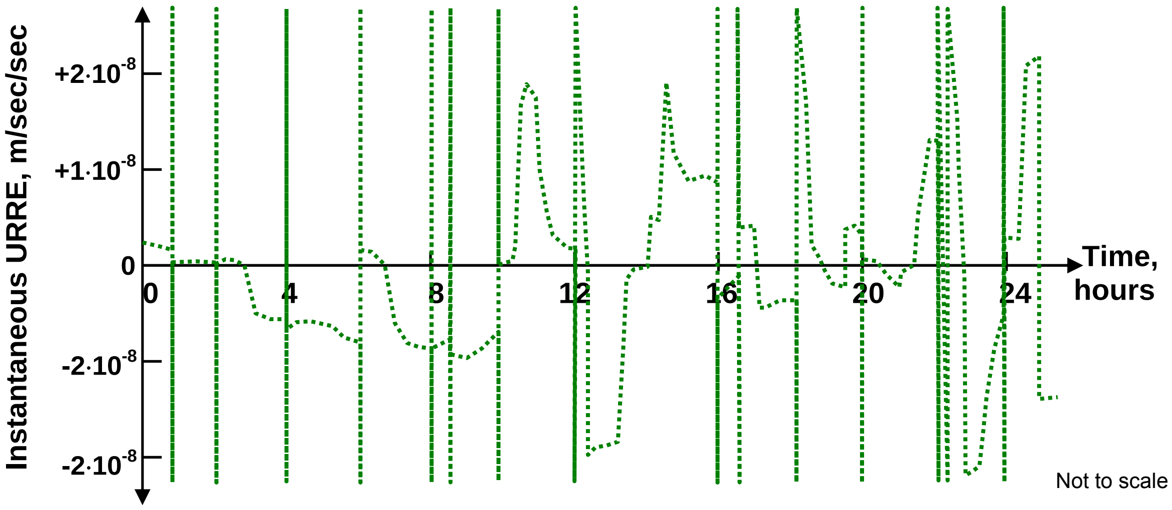


Figure A.4-5c. Instantaneous PPS SIS URRRE as a Function of Time

A.4.8 UTC(USNO) Offset Accuracy

The PPS SIS NAV message contains offset data for relating GPS time to UTC(USNO). The same offset data applies equally to both the PPS and the SPS. During normal operations, the accuracy of this offset data during the transmission interval is such that the UTC offset error (UTCOE) in relating GPS time (as maintained by the Control Segment) to UTC (as maintained by the U.S. Naval Observatory) is within 40 nanoseconds 95% (20 nanoseconds 1-sigma). See IS-GPS-200 for additional details regarding the UTC(USNO) offset data.

Notes:

1. *The accuracy of the UTC(USNO) offset data may degrade if the Control Segment is unable to upload fresh data to the satellites. During extended operations, it is expected that alternate sources of UTC are no longer available, and that the relative accuracy of the UTC(USNO) offset data will be sufficient for most users.*

2. *The UTC(USNO) offset data is intended to be applied by the GPS receiver, or by the user, after the GPS receiver has solved for its own offset from GPS time. The GPS receiver is not required to compute a position solution for the UTC(USNO) offset data to be useful, only a time solution is needed.*

3. *The Control Segment is not required to update it's estimate of the UTC (USNO) offset data prior to each upload. As such, the same UTC(USNO) offset data is commonly broadcast by several satellites simultaneously. Depending on the Control Segment's UTC(USNO) offset estimate update schedule, it is possible for all satellites to be broadcasting the same UTC(USNO) offset data.*

A.4.9 Single-Frequency Ionospheric Delay Model Errors

The accuracy of the single-frequency ionospheric delay model is better than 50%. Typical global average single-frequency ionospheric delay model errors for L1 vary from 9.8 m to 19.6 m 95% for benign and disturbed ionospheric conditions respectively (see STANAG 4294). Ionospheric delay model errors for L1 can be as severe as ±100 m or more in some solar conditions, at some latitudes, at some elevation angles, at some times of day. The largest errors are usually seen when solar storms occur during or shortly after a maximum in the 11-year sunspot cycle, within ±15 degrees of the geomagnetic equator, near the horizon, during the local afternoon. The smallest errors are usually seen when the sun is quiet during a minimum in the 11-year sunspot cycle, at the geomagnetic mid-latitudes, at zenith, during the local night. The influence of the local time of day on the single-frequency ionospheric delay model accuracy is particularly strong. Regardless of the 11-year sunspot cycle phase or geomagnetic latitude, the ionospheric delay model errors for L1 at zenith between local midnight and local dawn are commonly less than ±1 m.

Tables A.4-2 and A.4-4 illustrate the typical method for including the single-frequency ionospheric delay model errors in the Control Segment contribution to the L1 PPS SIS URE. Single-frequency ionospheric delay model errors for L2 may be similarly factored into the Control Segment contribution to the L2 PPS SIS URE by multiplying the L1 values with the scaling factor $\gamma_{12} = (154/120)^2$.

A.4.10 Single-Frequency Group Delay Time Correction (T_{GD}) Errors

As described in IS-GPS-200, the group delay time correction (T_{GD}) is broadcast in the NAV message for the benefit of single-frequency GPS receivers. Errors in the broadcast T_{GD} value affect the URE experienced by single-frequency GPS receivers which apply that T_{GD} value.

Tables A.4-2 and A.4-4 illustrate the typical method for including T_{GD} errors in the Control Segment contribution to the L1 PPS SIS URE. T_{GD} errors for L2 may be similarly factored into the Control Segment contribution to the L2 PPS SIS URE by multiplying the L1 value with the scaling factor $\gamma_{12} = (154/120)^2$.

A.4.11 Spatial Dependency

As described earlier in this Section, the GPS UERE budgets and the PPS SIS accuracy standards vary as a function of the particular PPS SIS components and as a function of the elapsed time since upload. The UERE budgets and SIS accuracy standards do not vary as a function of the spatial “look angles” relative to the Navstar satellites. The UERE budgets and accuracy standards apply equally at every point within the satellite’s coverage footprint.

In reality, however, the PPS SIS URE does vary significantly across each satellite’s coverage. The source of this spatial dependency are errors in the satellite orbit. Satellite orbit errors are primarily due to either: (a) unpredictable satellite accelerations, or (b) inaccurate ephemeris data uploads. The distinction between these sources of satellite orbit errors is manifested in the UERE budgets of Tables A.4-1 through A.4-4. Unpredictable satellite accelerations are satellite specific, and the Space Segment has a UERE budget allocation for them in Tables A.4-1 through A.4-4. Inaccurate ephemeris data uploads are due to a mix of estimation/prediction errors plus curve fit limitations, and the Control Segment has UERE budget allocations for each of them in Tables A.4-1 through A.4-4. There are also secondary causes of satellite orbit errors, such as mis-orientation of the lever arm from the satellite center of mass to the broadcast antenna phase center. These secondary causes of satellite orbit errors are also in the UERE budgets of Tables A.4-1 through A.4-4 under the “other segment errors” lines for the Space Segment and for the Control Segment.

The SIS URE’s spatial dependency on satellite orbit errors is partially explained in Figure A.4-6. This figure shows a horizontal orbit error “H” (also known as a tangential orbit error) resulting from some combination of Space/Control Segment errors. In Figure A.4-6, the horizontal orbit error vector is oriented due north, with the satellite actually being located further south than the location indicated by the broadcast ephemeris data (the sense of the error vector is “indicated minus truth”).

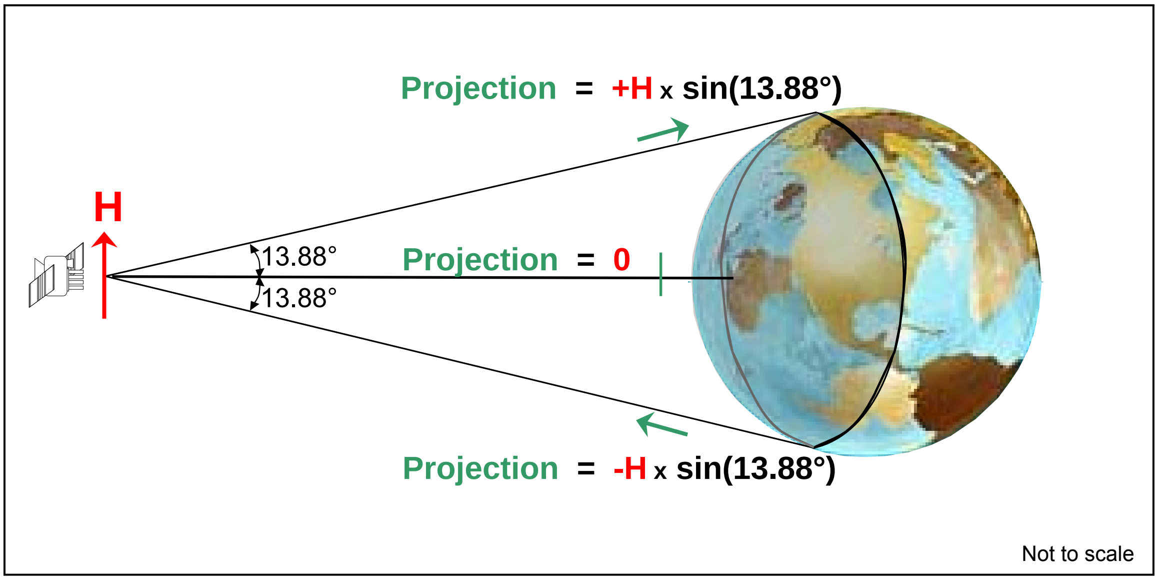


Figure A.4-6. Illustration of Spatial Dependency - Horizontal Orbit Error

An observer located at the edge of the satellite's coverage footprint due north of the sub-satellite point will perceive a *positive* instantaneous URE because the satellite's true location is further away from the observer than the location indicated by the broadcast ephemeris data. An observer located at the edge of the satellite's coverage footprint due south of the sub-satellite point will perceive a *negative* instantaneous URE because the satellite's true location is closer than the location indicated by the broadcast ephemeris data. And an observer located at center of the satellite's coverage footprint exactly at the sub-satellite point will perceive *zero* instantaneous URE because the satellite's true location is just as far away as the location indicated by the broadcast ephemeris data.

This sinusoidal variation of the instantaneous URE across the coverage footprint depending on the look angle projection is characteristic of horizontal orbit errors. In the customary radial-alongtrack-crosstrack (RAC) orbital coordinate system, the alongtrack (A) and crosstrack (C) orbital errors are the two orthogonal horizontal error components and each has the same sinusoidal characteristic in it's impact on the instantaneous URE. Over a satellite's coverage footprint on the Earth's surface, their maximum impact on the instantaneous URE is ±0.240 x A and ±0.240 x C. Across the coverage footprint on the Earth's surface at a 2° mask, their root-mean-square (rms) effect on the URE is 0.141 x A and 0.141 x C. At the edge of the terrestrial service volume (0° mask, 3,000 km above a mean Earth radius of 6,371 km), their maximum impact on the instantaneous URE is ±0.353 x A and ±0.353 x C.

The second part of URE's spatial dependency on satellite orbit errors is explained in Figure A.4-7. This figure shows a radial orbit error ("R") resulting from a combination of Space/Control Segment errors. In Figure A.4-7, the radial orbit error vector is oriented towards the Earth, with the satellite actually being located further away from the Earth than the location indicated by the broadcast ephemeris data.

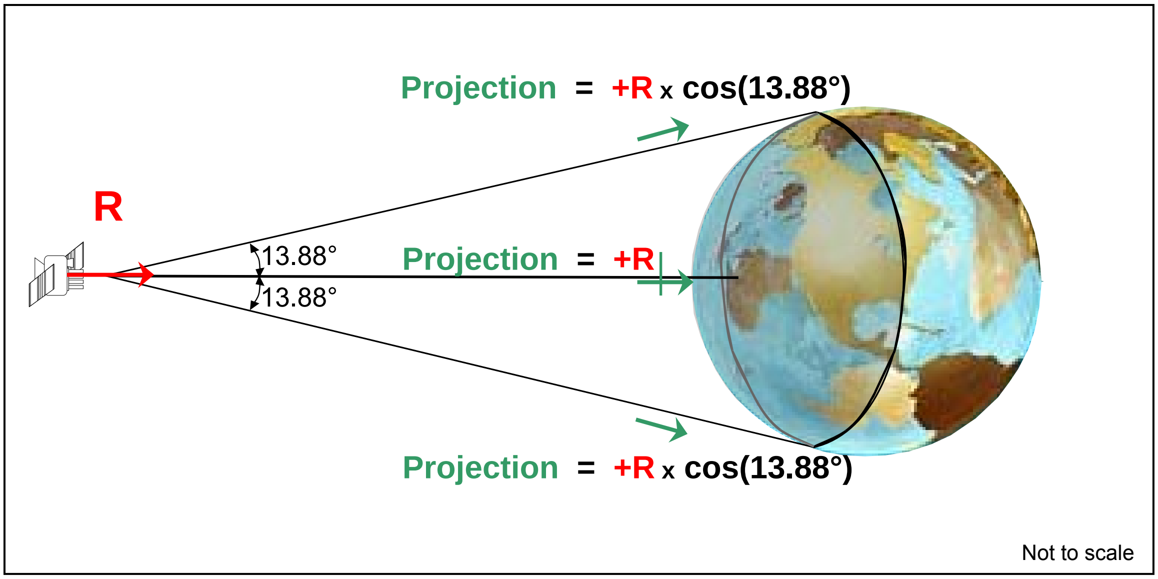


Figure A.4-7. Illustration of Spatial Dependency - Radial Orbit Error

An observer located anywhere within the satellite's coverage footprint (north, south, east, west, or centered) will perceive a *positive* instantaneous URE because the satellite's true location is always further away from the observer than the location indicated by the broadcast ephemeris data. The URE spatial dependency for radial (R) orbital errors is cosinusoidal rather than sinusoidal as for the horizontal orbital errors. The impact of an R orbital error on the instantaneous URE does not change algebraic signs at the sub-satellite point as does the impact of A or C orbital errors.

Over the coverage footprint on the Earth's surface, the maximum impact on the instantaneous URE of a radial error is 1.000 x R and the minimum impact is 0.971 x R. Across the coverage footprint on the Earth's surface at a 2° mask, the rms effect on the URE is 0.980 x R. At the edge of the terrestrial service volume (0° mask, 3,000 km above a mean Earth radius of 6,371 km), the minimum impact on the instantaneous URE is 0.936 x R.

PPS SIS timing errors (satellite clock, inter-signal delays, group delays, etc.) do not cause the URE to vary across a satellite's coverage. PPS SIS timing errors are omni-directional. They affect the URE equally at every point within the satellite's coverage.

As described in Section 3.4, the PPS SIS accuracy performance standards are addressed in terms of a "global average URE" where "global average URE" means the rms URE across the portion of the globe in view of the satellite. There are two generally accepted methods for computing the global average URE for a satellite at a particular instant in time. Those two methods are:

1. Brute Force RMS. The instantaneous URE values can be evaluated at a large number of spatial points spread evenly across the satellite's coverage, and the global average URE value can then be computed as the rms of the instantaneous URE value at each of those spatial points.

2. Piecewise RMS. The satellite's alongtrack, crosstrack, and radial orbit error components, plus it's total PPS SIS timing error can be used piecewise in the following equation:

   $$\text{Global Average URE} = ((c\text{x}T)^2+(0.980\text{x}R)^2+(0.141\text{x}A)^2+(0.141\text{x}C)^2-1.960\text{x}c\text{x}T\text{x}R)^{1/2} \qquad \text{(A-1)}$$

   where

   c = speed of light
   T = total Timing error
   R = Radial orbit error
   A = Alongtrack orbit error
   C = Crosstrack orbit error

   and where the final term in the equation accounts for the correlation (possibly significant) between the total timing error and the radial orbit error.

SECTION A.5 Integrity

A.5.1 Relationship with Section 3.5

Section 3.5 contains the PPS SIS performance standards for integrity. This section provides background information relative to the PPS SIS integrity performance standards.

A.5.2 URA Relationship to Integrity

One of the axioms of information theory is that all data is useful provided one knows how much weight to give to the data. This axiom applies well to data from the PPS SIS. Some Navstar satellites inherently provide more accurate data on average than other Navstar satellites do. One should logically place more weight on the data from the inherently more accurate satellites than on data from inherently less accurate satellites.

The PPS URA index, "N", included in each Navstar satellite's broadcast NAV message describes the satellite's expected accuracy (i.e., 1-sigma bounds on the expected URE). The relationship between the broadcast PPS URA index and the bounds on the expected URE are given in ICD-GPS-224 and ICD-GPS-225 and are repeated in Table A.5-1 below for convenience. Note that this table is equivalent to the look-up table in IS-GPS-200.

Table A.5-1. PPS URA Index to Expected URE Relationship

PPS URA Index "N"	Typical Expected URE, 1-sigma	Numerical URA Value, Representing the Bounds on the Expected URE, 1-sigma		
0	2.0 m	0.00 m	< URA ≤	2.40 m
1	2.8 m	2.40 m	< URA ≤	3.40 m
2	4.0 m	3.40 m	< URA ≤	4.85 m
3	5.7 m	4.85 m	< URA ≤	6.85 m
4	8.0 m	6.85 m	< URA ≤	9.65 m
5	11.3 m	9.65 m	< URA ≤	13.65 m
6	16.0 m	13.65 m	< URA ≤	24.00 m
7	32.0 m	24.00 m	< URA ≤	48.00 m
8	64.0 m	48.00 m	< URA ≤	96.00 m
9	128.0 m	96.00 m	< URA ≤	192.00 m
10	256.0 m	192.00 m	< URA ≤	384.00 m
11	512.0 m	384.00 m	< URA ≤	768.00 m
12	1024.0 m	768.00 m	< URA ≤	1536.00 m
13	2048.0 m	1536.00 m	< URA ≤	3072.00 m
14	4096.0 m	3072.00 m	< URA ≤	6144.00 m
15	No Expectation Provided	6144.00 m	< URA	Use at own risk

Notes:

1. *The PPS URA Index, Typical URE, and URA Value include all PPS SIS error components except for those specific to single-frequency operation and to WAGE.*

2. *If the PPS URA were completely reliable, then the PPS SIS would have full integrity with regards to all PPS SIS error components except for those specific to single-frequency operation and to WAGE. For instance, say that: (1) all of the satellites except one always broadcast a PPS URA index of 3*

and the actual PPS URE for those satellites always follows a normal distribution with a 1-sigma dispersion of 5.7 meters, and (2) one satellite always broadcasts a PPS URA index of 7 and the actual PPS URE for that satellite always follows a normal distribution with a 1-sigma dispersion of 32.0 meters. Each PPS SIS has full integrity in this case because the user (i.e., the PPS receiver) can decide whether the satellite which always broadcasts a PPS URA index of 7 should be used for navigation in the context of the particular mission to be accomplished. As a general rule, most modern PPS receivers would still use the satellite broadcasting a PPS URA index of 7, but they would deweight it by a factor of about 6 relative to the satellites broadcasting a PPS URA index of 3.

A.5.3 URA-Derived Integrity Tolerance

The broadcast URA index in the PPS SIS is used to determine the user's (the PPS receiver's) expectation for the PPS URE. For dual-frequency PPS receivers, the URA index can be used directly as a pointer into the look-up table given in ICD-GPS-224/-225/200. For single-frequency PPS receivers, the resulting URE expectation must be augmented with the estimated URE contribution due to the single-frequency ionospheric delay model term inaccuracy. Either way, the PPS receiver knows exactly what to expect regarding the PPS URE from that satellite: a random variable which will follow a normal distribution over the long term with zero mean and a 1-sigma dispersion equal to the computed URA value.

A normal distribution has no outer bounds per se. As can be seen in Table A.5-2, the probability of exceeding a given outer bound drops off as the outer bound increases to ever larger values; but it never becomes absolutely zero no matter how far out the bounds are placed.

Table A.5-2. Normal Distribution Bounds vs. Probability of Exceeding Those Bounds

Normal Distribution Bounds	Probability of Exceeding Those Bounds
± 1-sigma	0.317310508
± 2-sigma	0.045500264
± 3-sigma	0.002699796
± 4-sigma	0.000063342
± 5-sigma	0.000000573
± 6-sigma	0.000000002

For PPS SIS integrity definition purposes, outer bounds have been established at ±4.42-sigma. The corresponding probability of exceeding these bounds for a normal distribution is 0.00001 (i.e., 1×10^{-5}). These outer bounds constitute the not-to-exceed (NTE) PPS SIS URE tolerance for integrity. A PPS SIS URE exceeding the NTE tolerance is defined to be misleading signal-in-space information (MSI). MSI may or may not be a loss of PPS SIS integrity depending on whether a timely alert is issued.

Note:

1. *These outer bounds are consistent with the outer bounds used by civil users subject to SA. SA was the dominant SPS SIS error with an a priori assumed 1-sigma dispersion of 33 m. For these civil users, ±150 m outer bounds were established for SPS SIS integrity purposes by rounding the product of 33 m multiplied by 4.42.*
2. *PPS SIS MSI may cause some PPS receivers to output hazardously misleading information (HMI). The factors which determine if PPS SIS MSI will cause HMI or not include: whether the affected PPS SIS is being used in the position solution, the relative geometry of the set of satellites being used in the position solution, whether the PPS receiver performs any autonomous integrity monitoring to*

detect the occurrence of MSI and/or exclude an affected PPS SIS in a timely manner (see Appendix B for further information), and the user's particular tolerance for error in the current application.

A.5.4 Nature of PPS SIS URE

Neglecting failures and ignoring Control Segment intervention, the PPS SIS URE from healthy satellites can reasonably be assumed to follow a normal distribution over the long term with zero mean. Under this assumption, the PPS URA would be a fully satisfactory means of providing PPS SIS integrity. Unfortunately, GPS failures do occur and many of them can impact the PPS SIS URE enough to cause the PPS URE to exceed the PPS SIS URE NTE tolerance. Fortunately, the Control Segment monitors the PPS SIS URE and is able to intervene when such a "soft" GPS failure has occurred. (As used in this *PPS PS*, a soft GPS failure is a failure where the PPS SIS is still usable but the URE is impacted enough to pose a potential risk to integrity. A hard GPS failure is a failure where the PPS SIS is no longer usable and therefore poses no risk to integrity.)

A.5.4.1 Integrity Failure Modes and Effects

GPS failures which impact the PPS SIS, can occur in the Navstar satellites, the Control Segment, or in the information supplied to the Control Segment by an external source. The soft failure modes which pose a potential integrity risk are listed in Table A.5-3 along with the representative type of effect on the URE. The various types of URE effects are illustrated in Figure A.5-1. Table A.5-3 also identifies whether these potential integrity failure modes have a related symptom which is detectable by a PPS receiver.

Table A.5-3. Potential Integrity Failure Modes

System/ Segment	Failure Mode	Representative Effect on URE	Spatially Dependent	Receiver Detectable
Satellite	Momentum Dump (Thruster Firing)	Step/Ramp/Sinusoid	Yes	No
	Loss of L1 or L2	Sinusoid	No	Yes
	L1 and L2 Power Reduction	Noise	No	Yes
	Incorrect PRN	Varies	Some	Yes
	Clock Frequency Shift or Instability	Ramp	No	No
	NAV Message Data Garbled	Varies	Some	Yes
	PRN Code Generation Errors	Step	No	Some
	Frequency Synthesizer Upsets	Step	No	No
	Out-Gassing	Step/Ramp/Sinusoid	Yes	No
Control	Delayed/Missed Upload	Ramp	Some	No
	Bad Upload: Bad Clock/Ephemeris	Step, Ramp, or Sinusoid	Some	No
	Bad Upload: Wrong/Irrelevant Data	Varies	Some	Most
	Operational Error: Health Settings	Step, Ramp, or Sinusoid	Some	No
	Operational Error: Data Content	Step or Sinusoid	Some	No
	GA Induced Errors	Varies	No	Yes
	MS Induced Errors	Step, Ramp, or Sinusoid	Some	No
Input Data	Bad PPS Key Information	Varies	Some	Yes
	Bad Earth Orientation Predictions	Ramp or Sinusoid	Yes	No
	Bad Solar Flux Observations	Sinusoid	Yes	No
	Bad UTC(USNO) Offset Data	Other	No	No

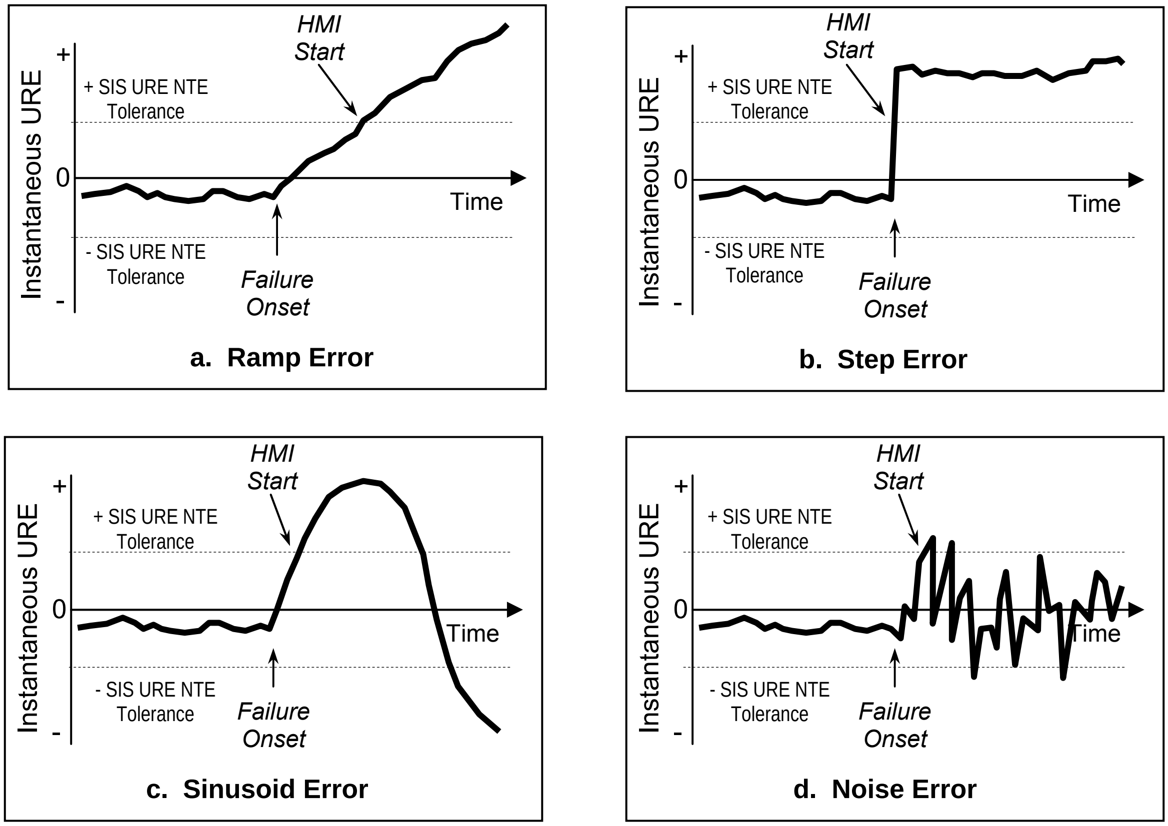


Figure A.5-1. Types of URE Effects

For the potential integrity failure modes which are detectable by a PPS receiver, most of them are accompanied by a PPS SIS alarm or warning indication which is what is actually detected by the PPS receiver. The PPS SIS alarm indications include, but are not limited to, the following:

(1) The apparent cessation of PPS SIS transmission (can also be symptomatic of a hard failure or Control Segment intervention actions).

(2) The elimination the standard P(Y)-code and the corresponding elimination of the standard C/A-code (can also be symptomatic of a hard failure or Control Segment intervention actions).

(3) The substitution of non-standard P(Y)-code for the standard P(Y)-code and the corresponding substitution of non-standard C/A-code for the standard C/A-code (an action taken by the satellite when it autonomously detects certain failures that could compromise the URA).

(4) The substitution of pseudorandom noise (PRN) P(Y)-code number 37 for the standard P(Y)-code and the corresponding substitution of PRN C/A-code number 37 for the standard C/A-code (indicative of Control Segment intervention).

(5) The failure of parity on 5 successive words of NAV data (can be symptomatic of a "bad upload: wrong/irrelevant data" failure).

(6) The broadcast Index of Data Ephemeris (IODE) does not match the 8 LSBs of the broadcast IODC data (can also be symptomatic of a "bad upload: wrong/irrelevant data" failure).

(7) All transmitted bits in subframes 1, 2, or 3 are set to 0's or to 1's (can be symptomatic of a "bad upload: wrong/irrelevant data" failure).

(8) Default NAV data is being transmitted in subframes 1, 2, or 3 (an action taken by the satellite when it autonomously detects certain failures that could compromise the URA).

(9) The preamble does not equal 10001011_2, or 139_{10}, or $8B_{16}$ (can be indicative of a failure in the satellite navigation data unit or in the navigation baseband unit).

A.5.4.2 Control Segment Monitoring and Intervention

One of the Control Segment's major functions is monitoring and assessing the PPS SIS performance. If the Control Segment determines that a failure has occurred which will adversely affect the PPS SIS performance, the Control Segment will intervene to prevent, or at least minimize, the impact of the failure on the PPS SIS performance.

When a soft failure effect on the PPS SIS URE is small, or when rare normal fault-free performance excursions occur, the typical Control Segment intervention is to perform a contingency upload (see paragraph A.4.4) to the affected satellite. Contingency uploads serve both to prevent an integrity fault from occurring and to maintain PPS SIS accuracy.

Note:

1. *During fault-free operation, the PPS SIS URE is assumed to follow a normal distribution with zero mean. Large PPS SIS URE values are expected to occur during fault-free operations but they should be rare (see Table A.5.2).*

When the soft failure effect on the PPS SIS URE is large, the typical Control Segment intervention is to send a SatZap command to the affected satellite. The SatZap command results in the satellite immediately switching its assigned PRN code identity to PRN code 37 (i.e., the satellite starts transmitting P(Y)-code number 37 and C/A-code number 37). This terminates the usable PPS SIS from the SatZapped satellite. (PRN codes in the range of 36 to 33 are reserved for other uses outside the scope of this *PPS PS*.) An equivalent intervention would be commanding the satellite to switch to transmitting non-standard codes in lieu of the normal PRN codes; but this is not typical practice at this time. Compared to performing a contingency upload, SatZap is a much quicker method of intervening -- but it necessarily renders the PPS SIS unusable.

Until recently, the Control Segment was not able to monitor each satellite's PPS SIS 100% of the time due to MS limitations (e.g., geographic locations, equipment reliability, and communication line reliability). This shortfall has been corrected by the Accuracy Improvement Initiative (AII). The Control Segment is still not able to upload or command each satellite due to GA limitations however (not corrected by AII). Although very unlikely, this *PPS PS* assumes it is possible for a PPS SIS integrity fault to persist for up to 6 hours before the Control Segment is able to intervene. This intervention delay is comparable to an average satellite in-view time of $6^2/_3$ hours. This conservative assumption will be reevaluated following the incorporation of the remaining AII monitoring stations.

Note:

1. *The $6^2/_3$ hour average in-view time (along with the 6 hour maximum intervention delay) also applies to PPS SIS UREs that are large, but not so large as to result in an integrity fault or MSI. For receiver autonomous integrity monitoring (RAIM) purposes, the average in-view time can be conservatively assumed as the effective correlation time for "large, but not too large" PPS SIS UREs.*

A.5.4.3 Control Segment Preemptive Actions

One of the Control Segment's other major functions is conducting on-orbit O&M of the Navstar satellites. Most satellite O&M are scheduled in advance. Certain types of O&M activities are quite likely to cause a large PPS SIS URE (e.g., station keeping maneuvers and atomic clock maintenance). In order to prevent a large PPS SIS URE from compromising the URA-derived NTE tolerance and thereby causing a PPS SIS MSI, the Control Segment will take preemptive action to warn PPS receivers to not use the PPS SIS from the affected satellite. The preemptive PPS SIS warning indications include, but are not limited to, causing the satellite to broadcast the following:

(1) An appropriately inflated URA index "N" value (appropriately inflated to cover the expected large PPS SIS URE).

(2) The 6-bit health status word in subframe 1 with the MSB equal to 1_2 and/or the 5 LSBs equal to anything other than 00000_2 (a typical "do not use" indication is with the MSB equal to 1_2 (some or all NAV data are bad) and the 5 LSBs equal to 11100_2 (SV is temporarily out)).

(3) A URA index "N"=15 (default action which may be taken by the Control Segment when a reliable URA cannot be computed).

(4) The transmitted bit 18 of the HOW set to 1_2 (may or may not constitute a preemptive PPS SIS warning, see ICD-GPS-224 or ICD-GPS-225).

To be preemptive, a PPS SIS warning indication must be broadcast to GPS receivers in advance of the potential integrity fault. So long as the last bit of the NAV message subframe which contains the particular PPS SIS warning indication is received before the NTE tolerance is breached, no integrity fault will occur because the PPS SIS has provided a timely warning that it should not be used. The Control Segment may take one or more of the above preemptive actions, or other preemptive actions (e.g., SatZap) in advance of conducting the O&M that can cause the large PPS SIS URE. The fact that a preemptive action or actions occurs early with respect to the NTE tolerance being breached has no adverse impact on PPS SIS integrity. There is no "false alarm" requirement to constrain how early the Control Segment can take preemptive actions. The impact of "too early" preemptive actions, or preemptive actions which occur when the subsequent O&M is cancelled or not completed, is the resulting adverse effect on PPS SIS availability.

Notes:

1. *As described in paragraph 2.4.4.3, the Control Segment endeavors to operate the PPS SIS in such a manner to allow GPS receivers at least five minutes to receive, process, and apply the real-time health-related information in the NAV message before taking any O&M actions that could cause a large PPS SIS URE under normal conditions.*

2. *NANUs are another form of preemptive warning. However, NANUs are not considered as a warning for integrity purposes. The PPS SIS alarm and warning indications received in real time by an operating GPS receiver always take precedence over the NANU information received off-line by an*

end user. However, NANUs are considered as an adequate warning for continuity purposes (see Section 3.6).

A.5.4.4 Satellite On-Board Monitoring and Intervention

The Navstar satellites are able to autonomously perform a substantial amount of on-board monitoring for those subsystems which affect the PPS SIS performance. If a satellite determines that a malfunction has occurred which may adversely affect the PPS SIS performance, an internal alarm will be generated and the satellite will intervene to minimize the impact of that failure on the PPS SIS performance. If the detected malfunction affects the satellite's reference frequency or other critical subsystem, the satellite will provide an integrity alert by switching its broadcast P(Y)-code signals to non-standard Y- (NSY) code and its broadcast C/A-code signal to non-standard C/A- (NSC) code. If the detected malfunction affects the satellite's NAV data generation subsystem, the satellite will provide an integrity alert by switching its broadcast NAV message to default data (alternating 1s and 0s with invalid parity). In general, the Block II, IIA, IIR, and IIR-M satellites will switch to broadcasting NSY and NSC codes or default NAV data within 6 seconds of detecting a fault which can impact PPS SIS integrity.

Many of malfunctions detected by the satellite on-board monitoring are transient either because the conditions which cause them only exist for a short while or because the satellite will autonomously correct the malfunction. If the on-board monitoring determines the detected malfunction is no longer present, the satellite will return to broadcasting normal P(Y)- and C/A-codes or normal NAV data as appropriate. Typical recovery times range from 6 to 24 seconds.

Notes:

1. *When a satellite switches over to broadcasting NSY and NSC codes in lieu of normal P(Y)- and C/A-codes, GPS receivers which are currently tracking the satellite signals lose track of the satellite signals at the time of the switchover. GPS receivers which are currently attempting to acquire the satellite signals are unable to acquire the satellite signals.*

2. *When a satellite switches over to broadcasting default NAV data in lieu of normal NAV data, GPS receivers are assumed to continue tracking the satellite signals through the switchover even though the GPS receiver is assumed to intentionally not use any of the default NAV data. GPS receivers which are currently attempting to acquire the satellite signals are assumed to be able to acquire the satellite signals but will not intentionally use any of the default NAV data.*

3. *Satellite malfunctions that are not detected by the satellite may require Control Segment intervention to protect the user (see paragraph A.5.4.2). Control Segment intervention is usually required to return a satellite to healthy status broadcasting a usable PPS SIS.*

A.5.5 Timely Alert Considerations

The definition of integrity used in this document requires a "timely alert" to be provided when the PPS SIS should not be used for positioning. Based on operational needs, a threshold of 10 seconds after a breach of the PPS SIS URE NTE tolerance has been established for an alarm or warning to be issued in order to be considered timely. Alarms and warnings are collectively called "alerts". This 10 second threshold applies to alerts issued to the end user of the PPS receiver, and so includes both the time allocated to the PPS SIS and the time allocated to the PPS receiver. For the PPS SIS, the allocated time (known as the "time to alert" or TTA) is 8 seconds for all alert indications except for SatZap and NSY/NSC codes. SatZap and NSY/NSC codes are allocated the full 10 seconds. If a PPS alert indication is transmitted within 8 seconds of an integrity fault occurring, then -- by definition -- the PPS SIS has converted the MSI into "alerted misleading signal-in-space information" (AMSI) because a timely alert has been provided. On the other hand, if a PPS alert indication is not transmitted within 8 seconds of an integrity fault occurring, then the PPS SIS is defined to have provided "unalerted misleading signal-in-space information" (UMSI). UMSI constitutes a loss of PPS SIS integrity while AMSI is not a loss of integrity since the alert is timely. Breaches of the relevant NTE tolerance for less than the overall TTA of 10 seconds do not require a timely alert.

Preemptive actions taken by the Control Segment (as described in paragraph A.5.4.3) are fully satisfactory as alerts for integrity purposes. To be timely, the last bit of the NAV message subframe which contains the particular PPS SIS warning indication must be present at the receiving antenna within 8 seconds of the NTE tolerance being breached. Preemptive Control Segment actions are taken well in advance of scheduled O&M activities that are likely to cause a large PPS SIS URE (e.g., station keeping maneuvers and atomic clock maintenance). The fact that Control Segment preemptive actions occur early (e.g., 5 minutes or more) with respect to the NTE tolerance being breached has no adverse impact on PPS SIS integrity.

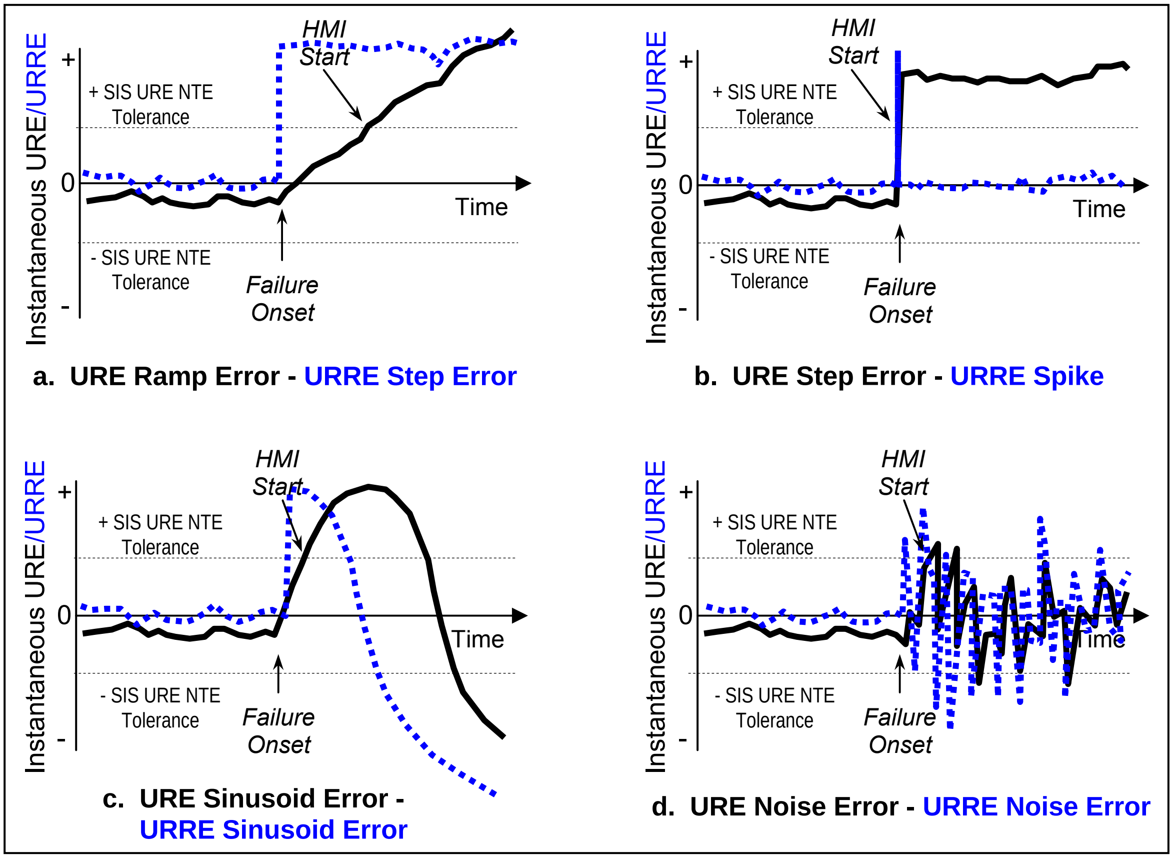
A.5.6 Nature of PPS SIS URE Time Derivatives

GPS receivers provide end users with velocity information in addition to position and time information. This is evident in the fact that the outputs of a GPS receiver are commonly referred to as PVT (i.e., position, velocity, and time). The accuracy and integrity of the GPS receiver's velocity output depends in large part on the accuracy and integrity of the SIS velocity. The SIS velocity errors are called the "first time derivatives of the URE", "pseudorange rate errors", or URRE. GPS receivers generally do not output acceleration information. SIS acceleration errors -- more properly the "second time derivatives of the URE", "pseudorange acceleration errors", or URRRE -- are important primarily for their effect on the integrity of the GPS receiver's output PVT information and for the limitations they impose on augmentations like differential GPS (DGPS) and inertial aiding.

A.5.6.1 URE Time Derivative Illustrations for Integrity

A typical large pseudorange rate error was illustrated by Figure A.5-1(a) given earlier for a URE ramp error effect. Figure A.5-1(a) showed the instantaneous URE being well behaved before the start of the failure, then ramping off rapidly after the failure onset at a relatively constant rate. Since the instantaneous URRE is the slope of the instantaneous URE, the ramp error for the instantaneous URE thus represents a step error for the instantaneous URRE as shown in Figure A.5-2(a). This type of instantaneous URE ramp error -- or instantaneous URRE step error -- is the integrity failure paradigm for testing RAIM algorithms in GPS receivers (see Appendix B for information on RAIM). The URRE step used for RAIM testing is 5 m/sec. Although fine for test purposes, it is not a representative failure magnitude for the actual PPS SIS.

Figure A.5-2(b) shows an instantaneous URE step error with a constant (near zero) instantaneous URRE on both sides of instantaneous URE step error. This sort of instantaneous URE step error is a much larger version of the URE step changes which are seen at NAV message data transitions after an upload cutover and the smaller URE step changes which are seen at the NAV message data set cutovers every two hours (see Figure A.4-4). While none of these instantaneous URE step changes necessarily involves a finite-duration instantaneous URRE to get from one instantaneous URE to the other, an instantaneous URRE will be perceived if the simple difference between two instantaneous UREs which straddle the step change is computed and divided by the difference in time separating the two instantaneous UREs. In the limit, as the time difference between two instantaneous UREs becomes smaller and smaller, this perception will converge to an infinitely large instantaneous URRE occurring over an infinitely short duration.



a. URE Ramp Error - URRE Step Error

b. URE Step Error - URRE Spike

c. URE Sinusoid Error - URRE Sinusoid Error

d. URE Noise Error - URRE Noise Error

Figure A.5-2. Types of URE/URRE Effects

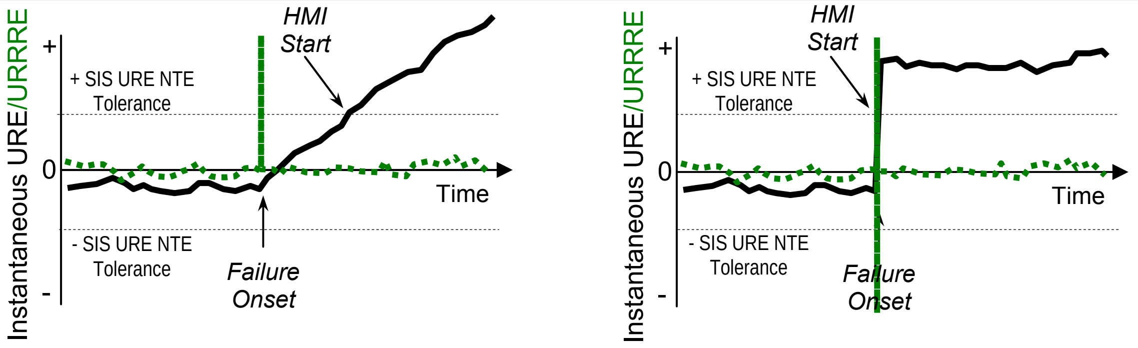
Another typical URRE error arises from an instantaneous URE sinusoid error effect as illustrated by Figure A.5-2(c). After the failure occurs in this figure, the instantaneous URE is at first positive, then it gradually becomes zero at the maximum positive URE, then it becomes negative, and then it starts to become zero again. This is a fairly common type of instantaneous URE. It is seen when ephemeris errors are mapped along the line-of-sight to a GPS receiver over the full in-view period. The peak URE magnitudes of these pseudorange rate errors are usually only about half of the URE budget. Because the instantaneous URRE is the time derivative of the instantaneous URE, the instantaneous URRE associated with a sinusoidal instantaneous URE is also a sinusoid, but offset in phase by a quarter period (i.e., the time derivative of a sine wave is a cosine wave).

Depending on the particular time scale involved, there may or may not be noise-like instantaneous URREs associated with the instantaneous URE noise error like those shown in Figure A.5-2(d). If the instantaneous URE noise time scale is very long, then there will be instantaneous URREs whose characteristics are equivalent to many successive ramp errors with random magnitudes and durations. If the time scale is very short, then there will only be instantaneous URREs with infinitely large magnitudes occurring over infinitely short durations.

A.5.6.2 URE Second Time Derivative Illustrations

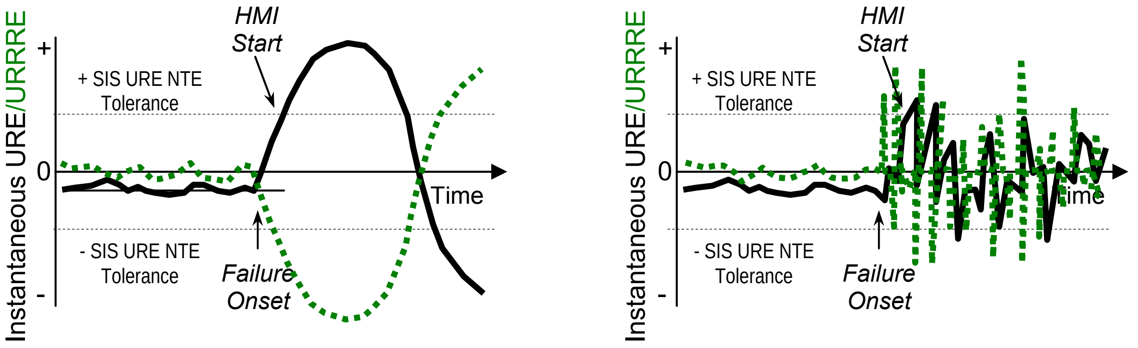
Figure A.5-2(a) showed a step change in the instantaneous URRE where the instantaneous URRE is near zero before the instantaneous URE ramp starts and jumps up to a near-constant positive instantaneous URRE value immediately afterwards. Just as there does not need to be a finite-duration instantaneous URRE when an instantaneous URE step change occurs to get from one instantaneous URE to the next, there does not need to be a finite-duration instantaneous URRRE when a URRE step change occurs to get from one instantaneous URRE to the next. The rationale is analogous to that given in the preceding section regarding the URE step change in Figure A.5-2(b). Some GPS receivers may perceive an instantaneous URRRE when an instantaneous URE ramp error occurs if they simply compute the difference between two instantaneous UREs which straddle the start of the ramp error and divide by the difference in time separating the two instantaneous UREs; but there really is no finite-duration instantaneous URRRE for the "sharp" ramp error, only an infinitely narrow instantaneous URRRE spike as shown in Figure A.5-3(a). A "dull" instantaneous URE ramp error, however, may have a large finite-duration instantaneous URRRE -- particularly if the magnitude of the ramp error starts out small but grows over time.

Figure A.5-3(b) shows a double-headed infinitely narrow instantaneous URRRE spike occurring at the time of the instantaneous step change in the URE. The reason for the double-headed URRRE spike is intuitive if one imagines the instantaneous URE step change being caused by the URRE spike shown in A.5-2(b). The positive portion of the URRRE spike occurs when the URRE spike starts and the negative portion occurs when the URRE spike ends. Since the URRE spike is infinitely narrow, the two portion of the URRRE spike overlap and result in what appears to be a double-headed spike.



a. URE Ramp Error - URRRE Spike Error

b. URE Step Error - URRRE Double Spike Error



c. URE Sinusoid Error - URRRE Sinusoid Error

d. URE Noise Error - URRRE Noise Error

Figure A.5-3. Types of URE/URRRE Effects

Figure A.5-3(c) illustrates the most common form of instantaneous URRRE. Just as the most common form of instantaneous URRE has a sinusoidal effect because it is the first time derivative of an instantaneous URE with a sinusoidal effect, the most common form of instantaneous URRRE has a sinusoidal effect because it is the second time derivative of a sinusoidal URE.

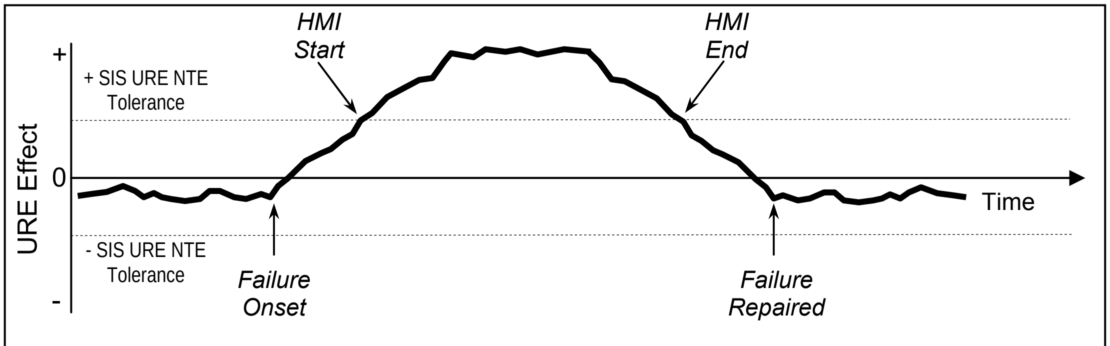
Note:

1. *The first time derivative of a sine wave is a cosine wave, and the second time derivative of a sine wave is an inverted sine wave.*

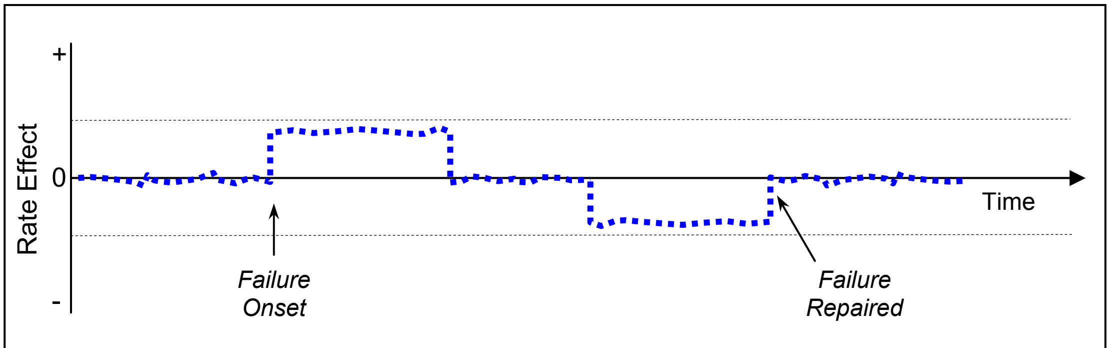
Like Figure A.5-2(d), Figure A.5-3(d) shows instantaneous URRREs with a noise effect. This need not be the case, however, depending on the particular instantaneous URE noise time scale.

A.5.6.3 Combinations of URE Time Derivatives

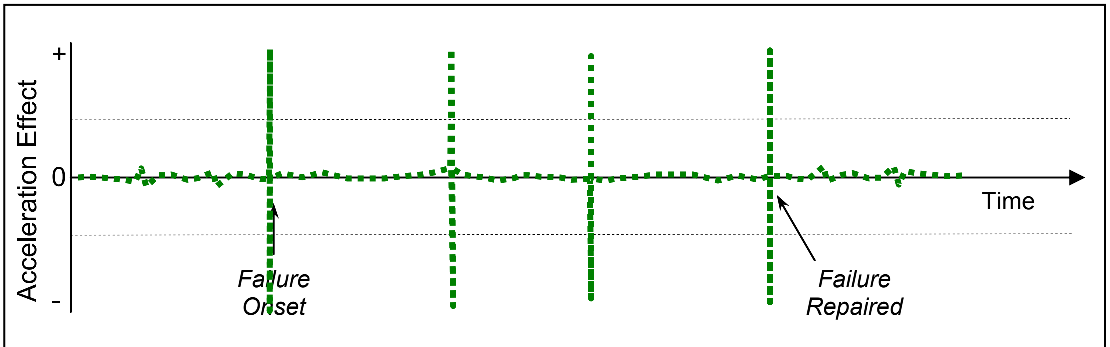
Many potential integrity faults manifest themselves via a combination of instantaneous URE time derivatives. A typical example is shown in Figure A.5-4. This is an example where the Navstar satellite first causes the failure and then autonomously repairs it. Figure A.5-4(a) shows a pair of offsetting instantaneous URE ramp failures (equal magnitudes but opposite signs) separated by a short period of constant large instantaneous URE. Recognize the intervening period does not constitute an instantaneous URE step error although it appears similar. Figure A.5-4(b) shows this same example in the first time derivative domain. This figure clearly shows the pair of instantaneous URE ramp failures as equal but opposite sign instantaneous URRE step changes. Because the second time derivative of an instantaneous URE ramp failure is zero (i.e., no instantaneous URRRE), Figure A.5-2(c) shows a constant instantaneous URRRE of zero except for the four double-headed instantaneous URRRE spikes which occur at the start and finish of each instantaneous URE ramp failure.



a. Pseudorange (URE) Domain



b. Pseudorange Rate (URRE) Domain



c. Pseudorange Acceleration (URRRE) Domain

Figure A.5-4. Combined URE Time Derivative Examples

SECTION A.6 Continuity

A.6.1 Relationship with Section 3.6

Section 3.6 contains the PPS SIS performance standards for continuity. This section provides background information relative to the PPS SIS continuity performance standards.

A.6.2 Various Types of Failures and the Impacts on Continuity

A.6.2.1 Hard Failures

Navstar satellites can suffer failures that result in the cessation of PPS SIS transmissions. Such failures are known as "hard failures". The cessation of PPS SIS transmissions need not be sudden as a result of the hard failure, it can be gradual (e.g., a steady drop in transmitted PPS SIS power would be a gradual cessation). Some hard failures result in an immediate cessation of PPS SIS transmissions, while others result in a delayed cessation (e.g., if a Navstar satellite fails such that it can no longer accept new uploads of NAV message data, it will gracefully degrade in the extended operations mode for at least 14 days until the PPS SIS becomes unavailable). Many different types of hard failures are possible.

Hard failures are subdivided into two main categories: (1) long-term failures, and (2) short-term failures. Long-term (LT) hard failures are basically those failures which result in an irrecoverable loss of the PPS SIS from the satellite. The normal remedy for LT hard failures is the lengthy process of launching a replacement satellite. In contrast, short-term (ST) hard failures result in only a temporary loss of PPS SIS from the satellite. The usual remedy for ST hard failures is the relatively rapid process of switching the satellite configuration over to using a redundant subsystem instead of the failed subsystem. All critical satellite subsystems have on-board redundancy.

Whether the hard failure of an otherwise healthy baseline satellite results in a loss of continuity or not depends on the Control Segment issuing a NANU in advance of the PPS SIS interruption. If the nature of the hard failure is such that the Control Segment issues the NANU at least 48 hours in advance of the interruption, then there is no loss of continuity. If the hard failure results in a sudden or rapid loss of the PPS SIS from the baseline satellite such that the Control Segment cannot issue a NANU at least 48 hours in advance, then there is a loss of continuity.

An alternate means of avoiding a loss of continuity exists in those situations where a second satellite occupies the same slot in the baseline 24-slot constellation (or occupies the same position in the case of an expanded slot configuration). So long as the second satellite does not cease its PPS SIS transmissions, the sudden or rapid loss of the PPS SIS in either of the two satellites occupying that slot does not cause a loss of continuity.

Notes:

1. *The "48 hour in advance" threshold exists for operational reasons related to air traffic control and flight planning (i.e., NOTAMs -- see DOD-4650.5). It is not based on any technical characteristics of the PPS SIS. Internally, the OCS uses a "96 hour in advance" threshold.*

2. *There are no PPS SIS continuity standards applicable to surplus satellites. This is true no matter where the surplus satellite is located. It is expected that most surplus satellites will exhibit lower continuity than baseline satellites since most surplus satellites will have been made surplus because the satellite is near the end of its useful life and is thus more prone to failures.*

A.6.2.2 Wear-Out Failures

Navstar satellites are subject to wear-out failures. Wear-out failures differ from hard failures in that wear-out failures are generally predictable (i.e., “schedulable”). Hard failures are generally not predictable. Wear-out failures are a characteristic of the satellite "end-of-life" (EOL) operating phase. They do not occur on recently launched satellites nor do they occur on satellites in the "middle age" operating phase. Wear-out failures are all ultimately LT failures, but it is frequently possible to prolong the usefulness of satellites in the EOL phase by the Control Segment expending substantial effort.

It is possible for a wear-out failure during the EOL phase to cause a loss of continuity, but this requires one of two unlikely errors on the part of the Control Segment. It is extremely improbable that the Control Segment would fail to predict the wear-out failure in advance. Much more probable, but still unlikely, the Control Segment could underestimate the effort needed to prolong the life of a satellite in the EOL phase. If the Control Segment chooses to prolong the life of an EOL satellite but later comes up short and cannot expend the necessary effort due to unforeseen circumstances, then -- unless a NANU was issued at least 48 hours before the shortfall -- a loss of continuity will occur.

Notes:

1. *The preferred means of avoiding the loss-of-continuity risk posed by a wear-out failure is to simply replace a baseline satellite when it reaches the EOL operating phase. This is not the required means of avoiding the loss-of-continuity risk however. The decision to replace a worn out baseline satellite or to instead attempt to prolong its life and accept the loss-of-continuity risk is made based on many factors including cost and Control Segment operator workload.*

2. *An alternate means of minimizing the loss-of-continuity risk posed by a wear-out failure is for the Control Segment to: (a) predict the future point in time where the wear-out failure will become severe enough to pose a non-trivial loss-of-continuity risk, (b) at least 48 hours (nominally 96 hours) in advance of that point in time issue a NANU warning that the satellite will become unavailable at that time, and (c) preemptively set the 6-bit health status word in subframe 1 to indicate the satellite is unhealthy at the planned time.*

A.6.2.3 Soft Failures

Section 3.5 addresses integrity failures. Integrity failures are known as "soft failures" in that while a failure has occurred, the PPS SIS continues to be available without an alert indication (alarm or warning) that the failure has occurred. Because the PPS SIS continues to be available to users, soft failures do not -- in and of themselves -- constitute a loss of continuity.

Although soft failures do not constitute a loss of continuity themselves, they can certainly trigger a loss of continuity. Certain soft failures are autonomously detectable on-board a Navstar satellite. If the satellite detects and reacts to that soft failure by transmitting a PPS alert, it is actually the PPS alert that makes the PPS SIS unavailable to users and thereby causes the loss of continuity. (Soft failures are not predictable, so there is no way to issue a NANU regarding them at least 48 hours in advance). The same principle applies when the Control Segment detects and reacts to a soft failure. The loss of continuity occurs when the Control Segment reaction causes the PPS SIS to become unavailable to users without a 48-hour advance warning. This principle is similar to the one which applies to fault detection alerts issued by the RAIM algorithm in a GPS receiver. A loss of continuity occurs if the fault cannot be excluded and a "do not use" alert is displayed to the user.

In the case of a loss of continuity triggered by a soft failure, the Control Segment will provide notification via a NANU as soon as possible after the event.

A.6.2.4 Satellite O&M Activities

Certain types of routine Navstar satellite O&M that are almost certain to cause a large PPS SIS URE (e.g., station keeping maneuvers and atomic clock maintenance) are not commonly referred to as failures. However, from a strict integrity perspective, most of them do result in MSI and could thus be correctly classified as a form of failure. These types of "O&M-induced failures" are unique compared to all other failures in that they are planned in advance by the Control Segment. Being planned, the Control Segment can prepare for them and can take preemptive actions to ensure that any MSI the O&M activity causes is AMSI (e.g., by performing an upload prior to the start of the O&M to set the 6-bit health status word in subframe 1 to indicate the satellite is unhealthy and thereby make the PPS SIS unavailable to users). Taking this preemptive action precludes UMSI and thus prevents any impact to PPS SIS integrity. Although the preemptive action of taking the satellite off-line before the O&M activity is good for PPS SIS integrity, it is not necessarily good for PPS SIS continuity since it is an interruption in service that could potentially lead to a loss of continuity.

Since these "O&M-induced interruptions in service" are normally planned well in advance, the Control Segment can also take further preemptive actions to prevent any impacts to PPS SIS continuity. The typical required preemptive action is issuing a NANU regarding the planned interruption at least 48 hours in advance of the start of the PPS SIS scheduled outage period. From a strict continuity perspective, a NANU only needs to be issued for a scheduled interruption affecting a baseline satellite that is not backed up by a second satellite in the orbital slot (or position in the case of an expanded slot configuration). However, due to prior convention and operational reliance on the NANUs, all scheduled interruptions currently require a NANU to be issued at least 48 hours in advance to avoid a loss of continuity. The Control Segment issues NANUs at least 96 hours in advance of scheduled outages.

The Control Segment can easily cause a loss of continuity of the PPS SIS by failing to issue the required NANU at least 48 hours in advance of the scheduled interruption in service. Such a loss of continuity is considered to be reasonably probable.

Note:

1. *Even though O&M-induced interruptions in service are normally short term, the duration of the loss of PPS SIS availability is not a determining factor for losing continuity. So long as the outages last longer than the TTA of 8 seconds for integrity (which O&M-induced interruptions do), the outages will all pose the same risk of a loss of continuity. Each loss of continuity counts as a single loss of continuity no matter if the loss lasts for one minute or it lasts for a thousand minutes. Although the duration of the interruption does not affect the PPS SIS continuity, it very much does affect the PPS SIS availability.*

A.6.3 Losses of Continuity

For the PPS SIS from a baseline satellite, continuity is lost any time there is an unscheduled loss of PPS SIS availability from that satellite (unscheduled defined from the user perspective relative to the 48-hour advance warning threshold). Consistent with paragraphs 2.3.4 and 2.3.5, the following PPS alert indications and PPS SIS "do not use" indications which are defined as ways to maintain integrity are also further defined as ways to lose continuity if they occur without at least 48 hours of advance warning:

- Apparent cessation of PPS SIS transmissions
- Loss of standard P(Y)-code and standard C/A-code
- Non-standard P(Y)-code and non-standard C/A-code
- P(Y)-code PRN number 37 and C/A-code PRN number 37
- Parity failure on 5 successive words of NAV data
- Broadcast IODE does not match 8 LSBs of broadcast IODC data
- All transmitted bits in subframe 1, 2, or 3 set to 0's or to 1's
- Default NAV data in subframes 1, 2, or 3
- Preamble not equal to 10001011_2, or 139_{10}, or $8B_{16}$
- 6-bit health status word in subframe 1 with the MSB equal to 1_2 and/or the 5 LSBs equal to anything other than 00000_2
- URA index "N"=15
- Bit 18 of the HOW set to 1_2 (may or may not be a loss of continuity, see ICD-GPS-224 or ICD-GPS-225)

A.6.4 Expected Frequencies for Losses of Continuity

The expected mean time between failure (MTBF), per-satellite, for the various types of failures defined in Section A.6.2 are as follows:

LT Hard Failures. The expected MTBF for LT hard failures is about twice the Navstar Block II/IIA satellite design life of 7.5 years (equals 15 years MTBF).

ST Hard Failures. The expected MTBF for ST hard failures is about one-fifteenth the Navstar Block II/IIA satellite design life of 7.5 years (equals 0.5 years MTBF).

EOL (Hard) Failures. The expected MTBF for EOL (hard) failures is about the same as the Navstar Block II/IIA satellite design life of 7.5 years (equals 7.5 years MTBF).

Soft Failures. The expected MTBF for soft failures is no greater than the MTBF for LT hard failures (equals 15 years MTBF or less).

Satellite O&M Activities. The expected "MTBF" for satellite O&M activities is no greater than the MTBF for ST hard failures (equals 0.5 years "MTBF" or less).

Ideally, there should be no losses of continuity associated with either EOL (hard) failures or satellite O&M activities since the interruptions are schedulable and the Control Segment can be arbitrarily rigorous about issuing the required NANUs 48 hours in advance. There is, however, no standard which defines the level of rigor the Control Segment must maintain in issuing the NANUs other than the internal "at least 96 hours in advance" threshold with unspecified probability of success. The worst case would obviously be no rigor whatsoever. Even though unrealistic, this does put an upper bound on the expected frequency of the losses of continuity. Comparing the 7.5 year MTBF for EOL (hard) failures against the 0.5 year "MTBF" for satellite O&M activities, it is obvious that the satellite O&M activities completely dominate the EOL (hard) failures. The resulting mean time between loss of continuity (MTBLOC) is thus 0.5 years increased by whatever level of rigor the Control Segment can maintain.

In contrast to the schedulable interruptions, there should be losses of continuity associated with all of the unschedulable interruptions due to LT hard failures, all ST hard failures, and most soft failures. All LT hard failures and all ST hard failures should have an associated loss of continuity since there is no way the Control Segment can issue NANUs 48 or 96 hours in advance for these failures. Most soft failures will also have an associated loss of continuity since they rapidly lead to a interruption in service and the Control Segment will not be able to issue a NANU 48 or 96 hours in advance. Some soft failures will not lead to a interruption in service however. Soft failures which the Control Segment resolves using contingency uploads do not involve an interruption in service. Like with the schedulable interruptions, the MTBF for one of the failure modes (ST hard failures) completely dominates the MTBFs for the other two failure modes in determining the composite MTBLOC.

A.6.5 Expandable Slot Continuity

The expandable slots defined in Tables 3.2-1, 3.2-2 and 3.2-3 are considered to lose continuity when either:

(1) The expandable slot is in the baseline configuration, and the satellite occupying the orbital position defined in Table 3.2-1 for the slot loses continuity.

(2) The expandable slot is in the expanded configuration, and either one of the pair of satellites occupying the orbital positions defined in Table 3.2-2 for the slot loses continuity.

SECTION A.7 Availability

A.7.1 Relationship with Section 3.7

Section 3.7 contains the PPS SIS performance standards for availability. This section provides background information relative to the PPS SIS availability performance standards.

The two components of PPS SIS availability (the per-slot availability and the baseline constellation availability) are interrelated. The per-slot availability depends primarily on the satellite design and the Control Segment procedures for on-orbit maintenance and failure response. The baseline constellation availability depends primarily on the per-slot availability coupled with the satellite launch policies and satellite disposal criteria.

A.7.2 Per-Slot Availability

A.7.2.1 Satellite Outage Categories

The various types of failures and interruptions defined in Section A.6 for continuity reasons can be categorized as a function of the typical outage duration and whether the Control Segment has any ability to schedule them in advance. The resulting four categories and the straightforward mapping of the outage reasons are:

1. Long Term Unscheduled (LTU) Outages
    - LT Hard Failures

2. Short Term Unscheduled (STU) Outages
    - ST Hard Failures
    - Soft Failures

3. Long Term Scheduled (LTS) Outages
    - EOL (Hard) Failures

4. Short Term Scheduled (STS) Outages
    - Satellite O&M Activities

A.7.2.2 Conservative Satellite/Slot Availability Model

The Navstar satellite/slot availability model for baseline slots is both simple and conservative. The assumed maximum life for the Navstar satellites addressed in this *PPS PS* is 7.5 years, which corresponds to the design life of the Block II/IIA satellites. Any satellite reaching this age is assumed to be at EOL and it is assumed it will be replaced. The replacement timeline is assumed to be schedulable. Each satellite is assumed to have an a priori probability of 0.6 for reaching EOL and a 0.4 probability of dying early due to an LT hard failure. For those satellites that die early, the assumed mean age at the LT hard failure is approximately 3.75 years.

Before the Navstar satellite dies or is replaced, the conservative model assumes ST hard failures and soft failures happen at random. The same is also true for satellite O&M activities.

When it is time to replace a failed Navstar satellite, the conservative model assumes the replacement process does not start until after either the LT hard failure occurs or after the satellite is disposed of during EOL operations.

Using the MTBF (MTBLOC) expectations given in Section A.6.4 in this appendix and average outage durations, the numerical satellite/slot availability model parameters are as summarized in Table A.7-1.

Table A.7-1. Per-Satellite/Slot Availability Model Parameters for Baseline Slots

Model Parameter	Model Value
Before the LT Hard Failure or EOL Disposal:	
Average Number of STU Outages	2.0 per year
Mean STU Outage Duration	36.0 hours
Average Number of STS Outages	2.0 per year
Mean STS Outage Duration	12.0 hours
For the LT Hard Failure or EOL Disposal:	
Mean time to LT Hard Failure or EOL Disposal	6.0 years
Mean time to replace after LT Hard Failure or EOL Disposal	0.2 years

Notes:

1. *The conservative satellite/slot availability model and the parameters in Table A.7-1 represent the simple "launch on need" (LON) strategy for constellation sustainment.*

2. *It can be assumed that the satellite/slot availability model and the parameters in Table A.7-1 will be conservative with respect to whatever Control Segment on-orbit maintenance and failure response procedures may be adopted by the DoD in the future. The satellite/slot availability model and parameters in Table A.7-1 are very conservative compared to the current "launch to sustain" (LTS) strategy established in the GPS CONOPS. (The LTS strategy is a combination of the LON and "launch on anticipated need" [LOAN] strategies.)*

3. *Table A.7-1 also applies to expandable slots in their baseline configuration.*

A.7.2.3 Satellite/Slot Availability Computation

Using the model parameters in Table A.7-1, the fraction of time that a baseline slot will be occupied by a satellite which is healthy and transmitting a usable PPS SIS is no less than 0.957 (95.7%) on a long-term average basis. The resulting fraction of time that a baseline satellite will either be unhealthy or transmitting an unusable PPS SIS (0.043) is the sum of the fraction of time that a baseline satellite will be unhealthy or transmitting an unusable PPS SIS with an advance warning having been given via NANU (e.g., "scheduled downtime" due to on-orbit O&M or disposal activities) plus the fraction of time that a baseline satellite will be unhealthy or transmitting an unusable PPS SIS with no advance warning having been given (i.e., "unscheduled downtime" due to an on-orbit failure).

A.7.2.4 Expandable Slot Availability

The expandable slots defined in Tables 3.2-1, 3.2-2 and 3.2-3 are considered to be available when either:

(1) The expandable slot is in the baseline configuration, and the orbital position defined in Table 3.2-1 for the slot is occupied by a satellite which is healthy and transmitting a usable PPS SIS.

(2) The expandable slot is in the expanded configuration, and the pair of orbital positions defined in Table 3.2-2 for the slot are both occupied by a satellite which is healthy and transmitting a usable PPS SIS.

(3) The expandable slot is in an equivalent-or-better non-standard configuration (see A.7.2.5), and the pair of non-standard orbital positions for the slot are both occupied by a satellite which is healthy and transmitting a usable PPS SIS.

There are no performance standards in this document related to how often an expandable slot can be or must be in its expanded configuration. Each expandable slot may therefore be in its baseline configuration anywhere from 100% of the time to 0% of the time.

A.7.2.5 Equivalent-or-Better Non-Standard Expanded Slot Configurations

The expandable slots defined in Tables 3.2-1, 3.2-2 and 3.2-3 can be filled by satellites in a non-standard configuration. Any non-standard configuration which provides equivalent-or-better performance than the nominal (non-expanded) slot is defined to be an acceptable alternative for either the nominal slot or the expanded slot.

The nominal and expanded configurations of an expandable slot can be graphically illustrated as shown in Figure A.7-1.

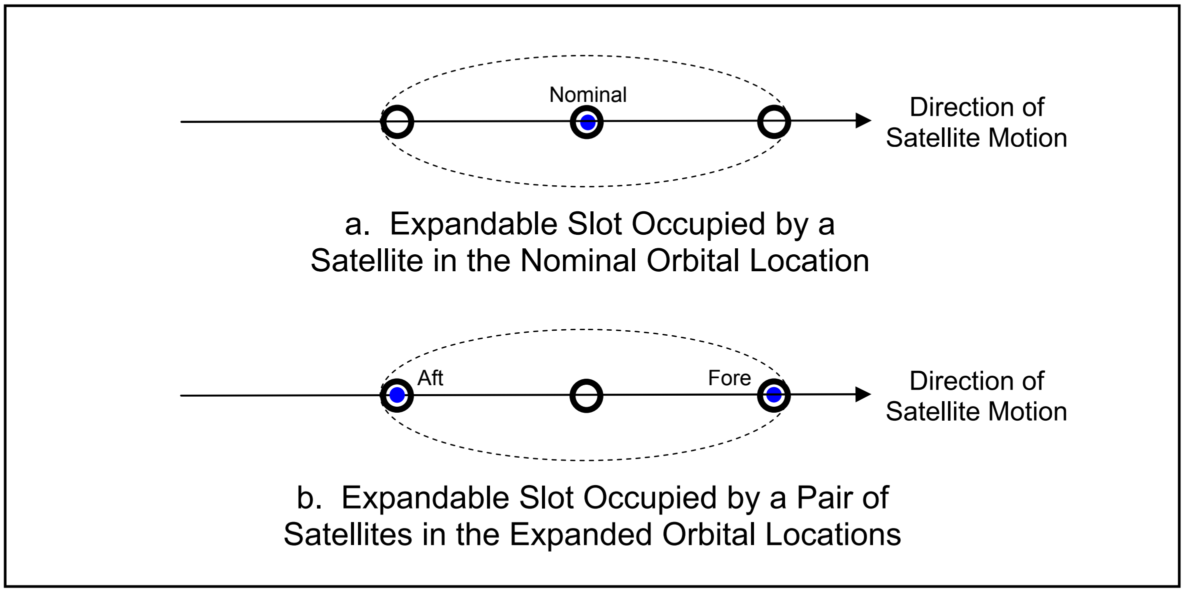
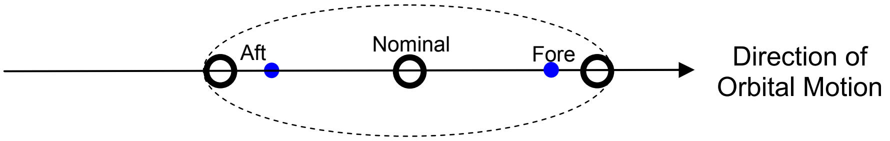


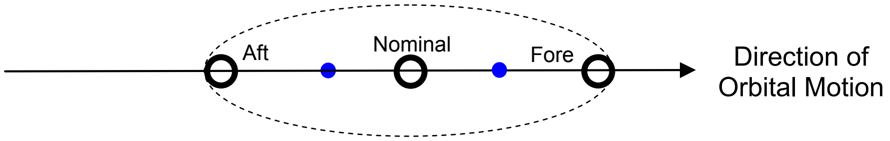
Figure A.7-1. Illustration of Nominal and Expanded Slot Configurations

Example non-standard configurations which provide equivalent-or-better performance than the nominal configuration are graphically illustrated in Figure A.7-2. Mirror images of the illustrated examples also provide equivalent-or-better performance.

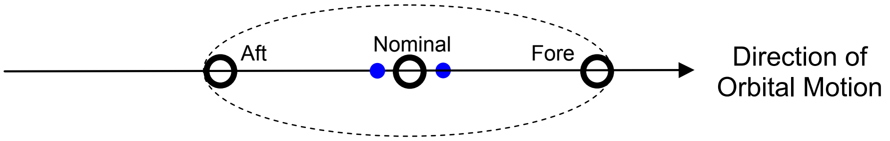
The two contracting-and-reallocating sequences shown on Sheet 2 of Figure A.7-2 are likely options for when one of the satellites in an expanded slot must be moved elsewhere in the orbital plane. The contract-then-reallocate sequence (h-i-j-k) and the simultaneous-contract-and-reallocate sequence (l-m-n) both maintain slot availability during the moves.



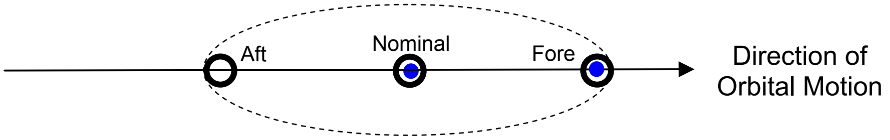
a. Condensed Slot - 1



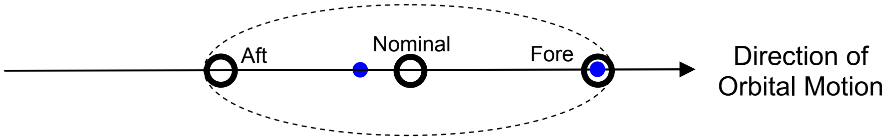
b. Condensed Slot - 2



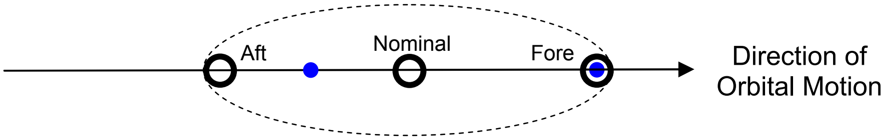
c. Condensed Slot - 3



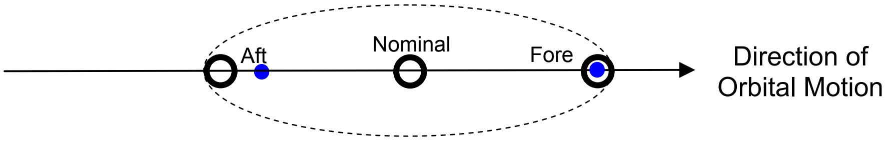
d. Expanding a Slot -1



e. Expanding a Slot - 2

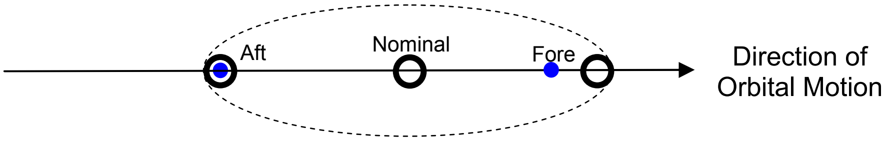


f. Expanding a Slot - 3

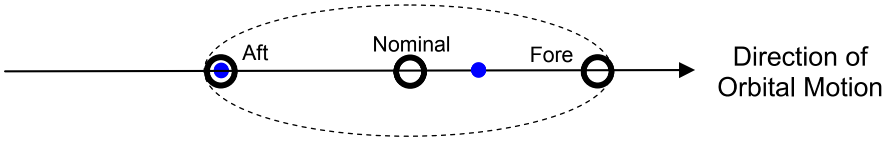


g. Expanding a Slot - 4

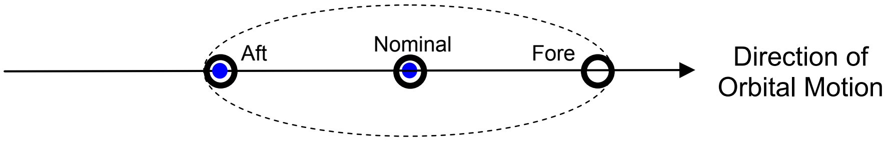
Figure A.7-2. Illustration of Equivalent-or-Better Non-Standard Configurations (1 of 2)



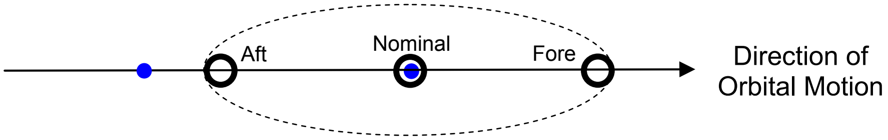
h. Contracting a Slot – 1



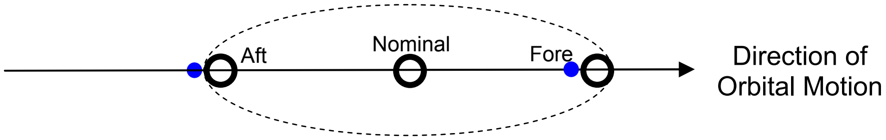
i. Contracting a Slot – 2



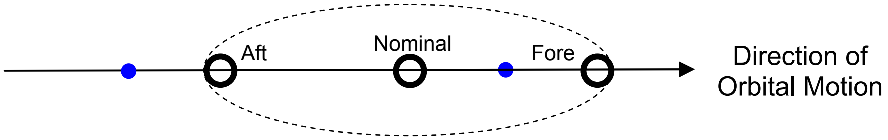
j. Contracted Slot – 3



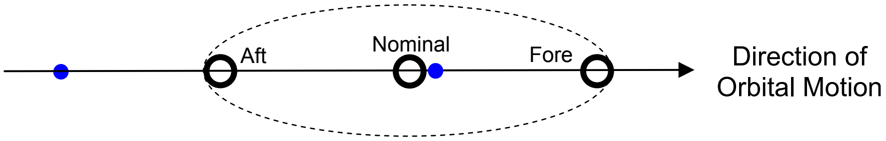
k. Reallocating from a Contracted Slot – 4



l. Simultaneously Contracting and Reallocating – 1



m. Simultaneously Contracting and Reallocating – 2



n. Simultaneously Contracting and Reallocating – 3

Figure A.7-2. Illustration of Equivalent-or-Better Non-Standard Configurations (2 of 2)

A.7.3 Baseline Constellation Availability

The fraction of time that varying numbers of slots in the baseline 24-slot constellation are occupied by satellites that are healthy and transmitting a usable PPS SIS can be computed using a simple binomial probability model with the two probabilities of 0.957 and 0.043. The results of that computation are given in Table A.7-2 compared to the standard model for selected numbers of occupied slots.

Table A.7-2. Constellation Availability

Number of Baseline Constellation Slots	Binomial Model: Fraction of Time	Standard Model: Fraction of Time
All 24 Slots	0.348	0.720
23 or More Slots	0.724	0.890
22 or More Slots	0.918	0.954
21 or More Slots	0.981	0.980

Notes:

1. *The bottom line result of the simple binomial model and the standard model are both compatible with the specified PPS SIS availability performance standard given in Section 3.7.*

2. *Additional terms in the binomial model are:*

20 or more slots	*0.99685*
19 or more slots	*0.99957*
18 or more slots	*0.99995*

   Operational constraints (see Section 3.7) preclude allowing the number of occupied slots to fall below 20.

3. *For additional information on the standard model, see "*RAIM Detection and Isolation Integrity Availability With and Without CAG*", by M. Ananda, J. Leung, P. Munjal, and B. Siegel, in Proceedings of ION GPS-94, the 7th International Technical Meeting of the Satellite Division of the Institute of Navigation, Salt Lake City, September 1994.*

A.7.4 Availability of Accuracy

Availability of accuracy is a derived quantity which can be computed based on a particular set of user receiving equipment assumptions combined with the performance standards specified in this document for: (1) the baseline constellation definition, (2) the PPS SIS accuracy, and (3) the PPS SIS availability. Availability of accuracy computations are discussed in Appendix B of this document.

A.7.4.1 PDOP≤6.0 Threshold for "Availability of Adequate Accuracy"

It can be shown that the baseline 24-slot constellation defined by Tables 3.2-1 and 3.2-3 provides a position dilution of precision (PDOP) value of less than or equal to 6.0 continuously at all points in the terrestrial service volume, under certain user receiving equipment assumptions, when all orbital slots in the baseline 24-slot constellation are filled with healthy Navstar satellites broadcasting a usable PPS SIS. A PDOP value of 6.0 has long been used as a rule-of-thumb threshold for defining whether the satellite-to-user geometry is adequate to enable a good GPS position solution. Using this PDOP≤6.0 threshold as a metric for defining "adequate accuracy", the baseline 24-slot constellation is said to provide 100% global availability of adequate accuracy when all orbital slots in the baseline 24-slot constellation are occupied by healthy Navstar satellites broadcasting a usable PPS SIS.

Note:

1. *The fraction of the terrestrial volume over time which satisfies the PDOP≤6.0 threshold is known as the "constellation value" (CV). When all orbital slots in the baseline 24-slot constellation are occupied by healthy Navstar satellites broadcasting a usable PPS SIS, and certain user receiving equipment assumptions are satisfied, the CV is equal to 1.000.*

A.7.4.2 Availability of Accuracy Impacts Due to Expanded Slots

It can also be shown that all 7 variations of the expanded 24-slot constellation defined by Tables 3.2-1, 3.2-2, and 3.2-3 provide global availability of accuracy that is at least as good as the fully-occupied baseline 24-slot constellation when all orbital locations in the expanded 24-slot constellation variation (baseline slots and expanded slots) are occupied by healthy Navstar satellites broadcasting a usable PPS SIS. Expandable slots occupied by a pair of healthy satellites enhance the overall PPS SIS performance; but no credit can be taken for them relative to the baseline 24-slot constellation performance standards. The *PPS PS* provides no standards for the probabilities of any of the expandable slots being in their expanded configurations and occupied by pairs of healthy satellites.

A.7.4.3 Availability of Accuracy Impacts Due to Surplus Satellites

The presence or absence of surplus satellites (i.e., operational Navstar satellites which are not occupying a defined orbital slot in the baseline 24-slot constellation) does not affect the availability of accuracy from the baseline 24-slot constellation. If present and healthy, surplus satellites can be shown to enhance the provided availability of accuracy; but no credit is taken for them relative to the baseline 24-slot constellation performance standards. Similarly, the absence of healthy surplus satellites has no adverse impact on the availability of accuracy relative to the baseline 24-slot constellation performance standards. There are no standards given for the probabilities of any number of surplus satellites being present.

GLOBAL POSITIONING SYSTEM PRECISE POSITIONING SERVICE PERFORMANCE STANDARD

APPENDIX B

PRECISE POSITIONING SERVICE POSITION, VELOCITY, TIME (PVT) PERFORMANCE EXPECTATIONS

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

February 2007

Integrity - Service - Excellence

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SECTION B.1 Introduction

B.1.1 Historical Perspective

GPS has often been described as having three main segments:

1. Control Segment,
2. Space Segment,
3. User Segment.

This is still true from the system architectural perspective. It really is no longer true from the program organizational perspective. The new organizational perspective is shown in Figure B.1-1.

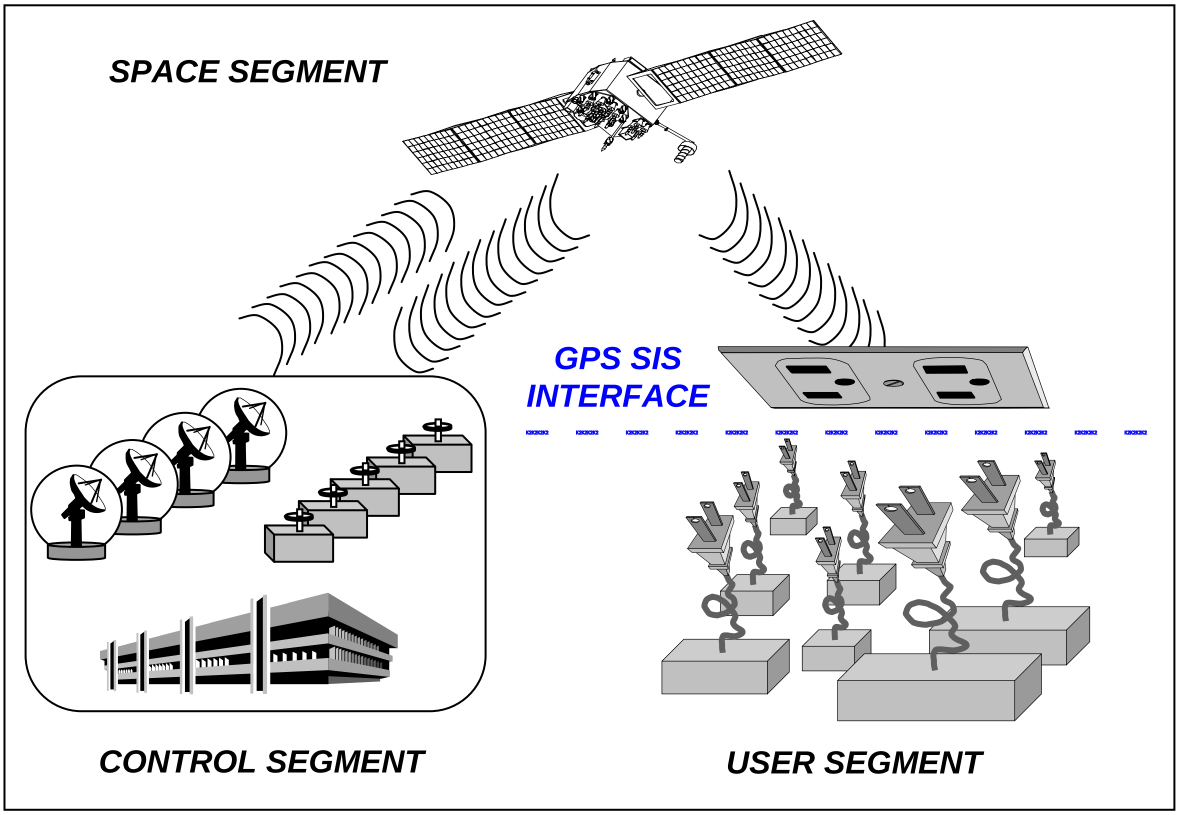


Figure B.1-1. New GPS Organizational Perspective

The U.S. Government owns the GPS Control Segment and the GPS Space Segment. The USAF operates and maintains both of these GPS segments. The Space and Control Segments are part of the GPS program organization. The U.S. Government cannot be said to own, operate, or maintain the User Segment portion of GPS. The User Segment encompasses millions of GPS receivers. While the DoD does develop and procure military PPS receivers for U.S. and allied users, these make up a very small fraction of the world's total GPS receiver population.

Long ago, the GPS Joint Program Office (JPO), predecessor organization of today's GPS Wing (GPSW), began developing all three segments of GPS. Although the USAF was the executive service responsible for the JPO, the GPS JPO was truly a "joint" program office in that it included members from all branches of the U.S. military and later grew to include personnel from allied nations (with particularly strong participation from the North Atlantic Treaty Organization [NATO] countries) and from other Departments of the U.S. Government. The GPS JPO not only developed the initial Control, Space, and User Segments of GPS; the GPS JPO also operated and maintained them as well. Around the end of the 1970s, the GPS JPO either owned or directly controlled virtually every GPS receiver in the entire world. Back then it made sense to specify GPS requirements in terms of the PVT performance seen by the end user since all three segments were under GPS JPO control. The GPS receiver's displayed PVT was the final interface at the end of the GPS process.

During the 1980s, the GPS JPO developed and deployed the Operational Control System (OCS) which it initially ran before turning it over to Air Force Space Command (AFSPC). The GPS JPO developed and began deploying the operational Block II series of Navstar satellites which were then handed over to AFSPC for on-orbit operations and maintenance. The GPS JPO also developed and procured many different types of PPS receivers which were delivered to the Army, Navy, and Air Force, as well as other Federal Agencies and Allied Governments. Not all PPS receivers were developed or produced by the GPS JPO however. Programs with specialized applications that required unique capabilities began developing and producing their own PPS receivers. Some NATO governments also initiated their own PPS receiver development efforts. A few civil electronics manufacturers even started producing and selling commercial SPS receivers. Since the bulk of the world's GPS receivers were still configuration managed by the GPS JPO, specifying GPS requirements in terms of the PVT performance delivered to the end user still made sense. But as evidenced by the PPS user equivalent range error (UERE) budgets which appeared both in the *GPS SORD* and in NATO STANAG 4294 at the end of the 1980s, it had become necessary to specify the PPS SIS performance to accommodate those PPS receivers not developed by the GPS JPO.

By the late 1990s, most PPS receivers were being bought by military system integrators directly from the manufacturer for use as a sensor embedded in other products. The GPS JPO was still developing and procuring a few types of stand-alone PPS receivers for domestic use and foreign military sales, but those were only a very small fraction of the world's production of PPS receivers. More and more, PPS receivers have become just another component in integrated systems. End users often do not see PPS-based PVT, they instead see navigation signals based on integrated PPS-inertial, PPS-Doppler, or PPS-terrain matching. The PPS receivers embedded in these systems are purchased, operated, and maintained by organizations other than the GPSW. Neither the GPSW nor the Joint Service System Management Office (JSSMO) nor AFSPC's 50 SW (GPSW's partners for maintaining GPSW-procured PPS receivers and for operating and maintaining the Control/Space Segments respectively) are responsible for the performance of these PPS receivers. The GPSW, JSSMO, and 50 SW responsibility ends at the PPS SIS interface as shown in Figure B.1-1. The same principle applies to the huge number of SPS receivers produced in the 1990s -- those SPS receivers are not purchased, operated, or maintained by the GPS program organization; and the GPS program organization's responsibility towards those SPS receivers ends at the SPS SIS interface.

The GPS program organizational line of demarcation is at the PPS SIS interface (and SPS SIS interface) as shown in Figure B.1-1. Operating and maintaining the Control/Space Segments to produce the PPS SIS is the responsibility of the GPS program organization. The PPS (and SPS) User Segment is not the responsibility of the GPS program organization. This line of demarcation was recognized by the *GPS ORD* published in 2000. Paragraph 4 of the *GPS ORD* starts with: "*The requirements identified during this ORD's development define the accuracy, integrity, availability, continuity…capabilities of the GPS SIS that the Space and Control Segments must meet. This ORD…states no UE [User Equipment] requirements…*"

B.1.2 Global Utility Metaphor

GPS has been metaphorically described as a "global utility". This metaphor is seen in Figure B.1-1 with the "electrical socket in the sky" representing the PPS SIS interface and the PPS receivers shown "plugging in" to that interface. The PPS SIS ISs/ICDs (particularly IS-GPS-200) are where the technical details like "AC, 60 Hz, 120 volts" are defined. Appendix B of this document is where the GPS utility's performance parameters are specified like:

a. The number of amperes each wall socket can deliver (accuracy)
b. The maximum probability of dangerous voltage spikes (integrity)
c. The mean time between unexpected blackouts (continuity)
d. The fraction of time unaffected by blackouts (availability)
e. The area served by the power company (coverage)

The metaphor is particularly appropriate when the GPS program organizations are described as being "service providers". The metaphor does break down, however, when one tries to apply it to cost: utilities charge consumers for the services rendered, GPS is free of direct consumer charges.

B.1.3 Direct Use of the Information in Section 3

The standards given in Section 3, along with the referenced ISs/ICDs, comprise a full and complete description of the PPS SIS interface provided to the User Segment's PPS receivers. Those standards and the ISs/ICDs provide the signal information needed by a manufacturer to design a PPS receiver that will successfully interface with the PPS SIS. Some of the information in Section 3 is needed by developers of augmentations systems (e.g., DGPS) to design the parameters in the augmentation signal; for example, see NATO STANAG 4392. The information in Section 3 is also directly applicable to designing a system to integrate GPS with an inertial sensor; see Appendix R of RTCA/DO-229C or NATO STANAG 4572.

The information in Section 3 is essential to determining whether the PPS SIS can support a worldwide air navigation capability, up to and including precision approach. This capability is one of the four mission performance requirements specifically called out in the *Mission Need Statement for Improved Worldwide Navigational Positioning System* (MNS 003-92). One of the other four mission performance requirements specifically identified for GPS in MNS 003-92 is capability to provide integrity commensurate to that required by the *Federal Radionavigation Plan* (DoD-4650.5). Section 3 is the only place where the detailed PPS SIS integrity information needed for PPS RAIM algorithms is specified. The information in Section 3 was specifically required to address integrity as well as the other Required Navigation Performance (RNP) parameters -- accuracy, continuity, and availability -- to support a worldwide air navigation capability.

B.1.4 Indirect Use of the Information in Section 3 (PVT Performance)

The standards in Section 3 describe the PPS SIS interface without constraining how the PPS SIS is used. The PPS SIS standards are independent of the application of the PPS SIS information. Although this independence is technically correct, there is a long-standing tradition in the GPS System Specification of addressing the implications of the SIS specifications to end users in the form of PVT accuracies. The *GPS ORD* continued this tradition by assuming hypothetical "benchmark" User Equipment (UE) and using it to translate the SIS specifications into user PVT performance terms. This appendix of the *PPS PS* perpetuates the tradition by showing how the *GPS ORD* used its SIS specifications and benchmark UE assumptions to derive representative user PVT performance values and applying that same process to the PPS SIS standards given in Section 3.

SECTION B.2 Computing PVT Accuracy

This section introduces the notion of using a computer model to translate GPS SIS performance standards into user PVT performance expectations. It also describes some computer models that have been found to be acceptable for translating the PPS SIS performance standards into PPS PVT performance expectations.

B.2.1 Basic Equations for PVT Accuracy

The basic equation for PVT accuracy in GPS is:

$$\text{Accuracy} = \text{UERE} \times \text{DOP} \qquad \text{(B-1)}$$

Equation B-1 is a simple approximation that has been found adequate for many applications. It is appropriate when all pseudorange errors are zero mean, normally distributed, characterized by the same UERE such that a single dilution of precision (DOP) number can be used. It is the same equation used by the *GPS ORD* to derive representative end user PVT performance values from its SIS specifications and benchmark UE assumptions. See TOR S3-G-89-01 for additional information regarding the use of this equation. See Section B.2.3 for more information on UERE and Section B.2.4 for more information on DOP.

There are different variations of equation B-1 used for different accuracy values (horizontal position accuracy, vertical velocity accuracy, etcetera). The variations of equation B-1 of relevance to this appendix are:

$$\text{UHNE} = \text{UERE} \times \text{HDOP} \qquad \text{(B-2)}$$
$$\text{UVNE} = \text{UERE} \times \text{VDOP} \qquad \text{(B-3)}$$

$$\text{UHVE} = \text{UERRE} \times \text{HDOP} \qquad \text{(B-4)}$$
$$\text{UVVE} = \text{UERRE} \times \text{VDOP} \qquad \text{(B-5)}$$

$$\text{UTE} = \text{UERE} \times \text{TDOP} \div c \qquad \text{(B-6)}$$

where:

UHNE = User Horizontal Navigation Error (rms)
UVNE = User Vertical Navigation Error (rms)

UHVE = User Horizontal Velocity Error (rms)
UVVE = User Vertical Velocity Error (rms)

UTE = User Time Error (rms)
c = speed of light, m/sec

Notes:

1. *The UHNE and UVNE are called "navigation" errors instead of "position" errors for historical reasons.*
2. *The UHNE and UVNE are also known as the "distance root-mean-square" (drms) statistics for historical reasons.*

B.2.2 Basic Equation for Time Transfer Accuracy

The basic equation for time transfer accuracy relative to UTC(USNO) in GPS is:

$$\text{UUTCE} = ((\text{UERE} \times \text{TTDOP} \div c)^2 + (\text{UTCOE})^2)^{1/2} \qquad \text{(B-7)}$$

where:

UUTCE = User UTC(USNO) Error (rms)

TTDOP = Time Transfer Dilution of Precision

UTCOE = UTC(USNO) Offset Error (rms)

Note:

1. *The form of equation B-7 is the root-sum-square (rss) of two root-mean-square (rms) values. The result is still an rms value.*

B.2.3 UERE Values

B.2.3.1 Specified UERE Values

When computing expected PVT accuracy for specification-compliance purposes, the UERE values to use in equations B-2, B-3, B-6, and B-7, and the UERRE values to use in equations B-4 and B-5, are the ones given in the appropriate GPS signal specification, system/segment specification, or equivalent document for the particular circumstances being considered. The *GPS ORD*, for example, specifies two different UERE values for two different circumstances; a 1.5 m 1-sigma value for terrestrial users, and a 1.7 m 1-sigma value for space users. Appendix A of this *PPS PS* gives 12 different UERE values in Tables A.4-1 through A.4-4 for 12 different circumstances. (Remember that the UERE values in Tables A.4-1 through A.4-4 are only illustrations; the only standards given in this document are for the PPS SIS.)

Notes:

1. *The GPS ORD describes its specified UERE values as being "URE values" due to its strong SIS-centric focus.*
2. *Equations B-1 through B-7 are all formulated using rms statistics. Care must be taken to ensure that the UERE values (or URE values) and UTC(USNO) offset accuracy values used in these equations are rms statistics. UERE values, URE values, and UTC(USNO) offset accuracy values expressed as 1-sigma statistics are equivalent to rms statistics and can be used directly in Equations B-1 through B-7. UERE values, URE values, and UTC(USNO) offset accuracy values expressed as 95% statistics can be converted to rms statistics for use in Equations B-1 through B-7 by dividing them by a factor of 1.96 assuming that the errors are zero mean and normally distributed.*

B.2.3.2 Derived UERE Values

To compute expected PVT accuracy for long-term planning purposes for a particular type of GPS receiver, the UERE values to use in equations B-2, B-3, B-6, and B-7 can be derived as the rss of the appropriate GPS SIS URE and the UEE for that particular GPS receiver under consideration. Recognize that not all PPS receivers are required to satisfy the same UEE specification. Dating as far back as the late 1970s, the "traditional" UEE specification for a medium quality PPS receiver is 7.1 m 95% (3.6 m 1-sigma). The *GPS ORD* assumes a "benign conditions" UEE specification for a high quality PPS receiver is 1.6 m 95% (0.8 m 1-sigma). These two different UEE values result in two different derived UERE values. For example, consider the 11.8 m 95% value for the PPS SIS URE specified in Table 3.4-1 for dual-frequency use at any AOD during normal operations without WAGE (or equivalently, the 11.8 m 95% value obtained by root-sum-squaring (rss-ing) the Space Segment and Control Segment contributions to the PPS URE budget in Table A.4-1 in Appendix A of this *PPS PS*). This is a "base" URE value to which the appropriate PPS receiver UEE value is root-sum-squared (rss-ed). If the UEE specification for the PPS receiver being considered is the traditional 7.1 m 95% value obtained by rss-ing each of the User Segment contributions to the PPS UERE budget in Table A.4-1 in Appendix A of this *PPS PS*, then the derived UERE value to use in equations B-2, B-3, B-6, and B-7 would be computed as follows:

$$\text{UERE} = ((\text{URE})^2 + (\text{UEE})^2)^{1/2} \qquad \text{(B-8)}$$

$$\text{UERE} = ((11.8 \text{ m } 95\%)^2 + (7.1 \text{ m } 95\%)^2)^{1/2}$$

$$\text{UERE} = 13.8 \text{ m } 95\%$$

$$\text{UERE} = (13.8 \text{ m } 95\%) \div 1.96$$
$$= 7.0 \text{ m 1-sigma}$$

Which is exactly the number shown in Table A.4-1.

On the other hand, if the UEE value is the modernized 1.6 m 95% value assumed by the *GPS ORD* for "benchmark UE", then the derived UERE value for equations B-2, B-3, B-6, and B-7 for dual-frequency use without WAGE at any AOD during normal operations would be computed as follows:

$$\text{UERE} = ((\text{URE})^2 + (\text{UEE})^2)^{1/2}$$

$$\text{UERE} = ((11.8 \text{ m } 95\%)^2 + (1.6 \text{ m } 95\%)^2)^{1/2}$$

$$\text{UERE} = 11.9 \text{ m } 95\%$$

$$\text{UERE} = (11.9 \text{ m } 95\%) \div 1.96$$
$$= 6.1 \text{ m 1-sigma}$$

For reference, the error budgets comprising some typical UEE values applicable to airborne, dual-frequency, P(Y)-code PPS receivers in normal operations are given in Table B.2-1.

Table B.2-1. Typical UEE Error Budgets (95%)

Error Source	Traditional Specification	Improved Specification	Modern Receiver	GPS ORD Assumption
Ionospheric Delay Compensation	4.5	2.0	1.8	0.8
Tropospheric Delay Compensation	3.9	4.0	3.9	1.0
Receiver Noise and Resolution	2.9	2.0	2.0	0.4
Multipath	2.4	0.5	0.2	0.2
Other User Segment Errors	1.0	1.0	1.0	0.8
UEE (m), 95%	7.1	5.0	4.8	1.6

B.2.3.3 Hypothetical UERE Values

In addition to specified and derived UERE values, it is also possible to compute hypothetical UERE values and UERRE values to use in equations B-2 through B-7. Hypothetical UERE values are often used in analytical "what if" studies. A common hypothetical UERE value used in many studies is the UERE for a "perfect GPS receiver" with zero UEE. This UERE is obtained by setting the UEE to zero in equation B-8. This is the same as using the SIS URE in lieu of the UERE. The PVT accuracy using this "perfect GPS receiver" UERE is known as the "SIS-only PVT accuracy".

B.2.3.4 Specified URE Values

An important example of using the SIS-only URE in lieu of the UERE for computing expected PVT accuracy is contained in the *Standard Positioning Service Performance Standard* (*SPS PS*). The *SPS PS* restricts itself to just the SIS, specifically excluding the UERE contribution of ionospheric delay compensation errors, tropospheric delay compensation errors, receiver tracking channel noise and resolution errors, multipath errors, and other user segment errors. All of the expected positioning and timing accuracy standards given in the SPS are SIS-only PVT accuracy values based on a 6 m rms URE over all AODs during normal operations and a perfect GPS receiver.

B.2.3.5 Higher-Fidelity UERE Values

Higher-fidelity UERE values can be computed by observing the URA numbers contained within the transmitted GPS SIS, averaging them over time, and using the results to compute higher-fidelity "transmitted on-orbit average" URE values to use in equation B-8. Even higher-fidelity URE values can be computed based on historical trends revealed by instantaneous URE measurements produced by independent monitors such as differential GPS systems. Such higher-fidelity URE values commonly reveal long-term variations between the Navstar satellites with the SIS from some satellites consistently being more accurate than others. Caution must be exercised in making use of any higher-fidelity UERE values computed these ways: (1) equations B-2, B-3, B-6, and B-7 are only valid if the same UERE value applies to each and every SIS, and (2) previous URE performance does not provide any guarantee of future URE performance.

B.2.3.6 Dissimilar UERE Values

Equations B-2, B-3, B-6, and B-7 are only valid when all pseudorange measurements are characterized by the same UERE value. If the UERE values are different, then different equations must be used for computing the expected PVT accuracy.

When the UERE values are different and there are pseudorange measurements available from more than four visible satellites, most GPS receivers will compute a "weighted position solution". In a weighted position solution, more or less trust (weight) will be placed on each pseudorange measurement according to the expected UERE value for that pseudorange measurement. More weight will be placed on pseudorange measurements with smaller expected UEREs, while less weight will be placed on pseudorange measurements with larger expected UEREs.

There are still DOP values which apply to weighted position solutions, but these DOP values depend on the specific set of weighting factors used to compute the weighted position solution as well as the satellite-to-user geometry. To distinguish them from the simple DOP values of an unweighted position solution, these DOP values are known as "weighted DOPs". Weighted DOPs are not discussed in this appendix due to their complexity.

B.2.4 DOP Values

B.2.4.1 DOP Values at a Time-Space (T-S) Point

Each particular satellite-to-user geometry has its own set of DOP values. Using the baseline 24-slot constellation defined in Tables 3.2-1 and 3.2-3, the nominal satellite-to-user geometry can be computed for any time at any point in the GPS coverage volume. Knowing the satellite-to-user geometry at a specific time-space (T-S) point, and knowing which subset of the visible satellite's SISs will be used in the PVT solution or time transfer solution at that specific T-S point, allows the particular subset of DOP values to be computed for that specific T-S point.

B.2.4.2 Computing DOP Values

Although it is possible to compute the DOP values by hand for a specific T-S point, this is a very tedious and time-consuming task. Computer models are therefore universally used for computing the DOP values. Every GPS receiver that provides an output of the current DOP values has such a computer model inside. RAIM availability prediction programs which are used in aviation applications also use such a computer model. Stand-alone software for computing DOP values are available from many sources; these programs all embody a computer model.

Typical computer models for computing the DOP values use the following inputs at a minimum:

a. An almanac data file, with data similar to that shown in Table A.2-1 in Appendix A which defines the satellite constellation to be used in the computation. The almanac data file customarily includes all parameters transmitted by the on-orbit Navstar satellites as part of their broadcast almanac data set in the NAV messages, including the health bits. Some almanac data files also include average URA values based on recent observations.

b. Operator-commanded overrides of the health settings built into the almanac data.

c. The operator-specified T-S point (or set of T-S points) for which the DOP values are to be computed.

d. Parameters which describe the exact type of GPS receiver to be emulated, especially the GPS receiver algorithm for selecting the subset of visible satellite SISs to be used in the PVT solution or time transfer solution (described in the following section).

The output of the typical computer models, at a minimum, are the computed DOP values.

Note:

1. *Example stand-alone software programs for computing DOP values and expected PVT accuracy can be downloaded at no cost from the web at http://www.arinc.com./gps. These software programs are part of the GPS System Effectiveness Model (SEM). A different software program for computing predicted RAIM availability can be accessed at no cost from the web at http://augur.ecacnav.com. This software program is known as AUGUR. There are many other software programs available for computing DOP values and related information.*

B.2.4.3 Receiver Algorithms for Selecting SISs/Measurements to be Used

B.2.4.3.1 Satellite (SIS) Selection Algorithm

Most typical computer models allow the operator to control the "satellite selection" algorithm the emulated GPS receiver will use to select the SISs used in the PVT solution or time transfer solution. Most older PPS receivers which can only track and use a maximum of four PPS SISs at a time will select the subset of four healthy PPS SISs which gives the best (lowest) Geometric Dilution of Precision (GDOP) value from among all visible combinations of four PPS SISs. Certain older PPS receivers originally designed for maritime use which can only track and use a maximum of four PPS SISs at a time will select the subset of four healthy PPS SISs which gives the best (lowest) Horizontal Dilution of Precision (HDOP) value. Many modern PPS receivers which can track and use up to a maximum of twelve PPS SISs will select the SISs from highest twelve satellites in the sky.

B.2.4.3.2 Other Sensor Measurements

Some computer models allow the operator to control whether the emulated GPS receiver will mimic the ability of a real GPS receiver to use information input by an aiding sensor. For aviation use, most GPS receivers can take advantage of vertical position supplied by a barometric altimeter. Computer models which predict RAIM availability, emulate this capability by treating the barometric altimeter measurements as a form of pseudorange measurements. For maritime use, most GPS receivers can take advantage of the fact that their vertical position is at mean sea level; some computer models also emulate this capability. Some GPS receivers can accept acceleration information from an inertial measurement unit (IMU). The use of inputs from aiding sensors, and the related computer modeling, is beyond the scope of this appendix. See TSO-C129/C129a and Appendix G of RTCA/DO-229C for further information on modeling the use of barometric altimeter inputs for aviation.

B.2.4.3.3 Mask Angle

Most typical computer models allow the operator to control the minimum mask angle above the local horizon which the emulated GPS receiver will use for determining whether a satellite is visible (and therefore available). Many older PPS receivers have a variable mask angle which ranges from 10 degrees to 0 degrees as a function of the number of satellites in view. Some SPS receivers have a mask angle of 7.5 degrees, while others have a mask angle of 5 degrees. Modern aviation receivers often use a mask angle of 2 degrees. Time transfer receivers and some surveying receivers commonly use a mask angle of 15 degrees. Some "all-in-view" GPS receivers do not have a mask angle per se; their only limitation on satellite availability is the radio horizon. GPS receivers designed for space applications usually have negative mask angles.

B.2.4.3.4 Maximum Number of SISs to be Used

Many computer models allow the operator to control the maximum number of SISs the emulated GPS receiver will use in the PVT solution or time transfer solution. Most older PPS receivers are hardware limited to tracking and using a maximum of four PPS SISs at one time. Many modern PPS receivers can track and use up to a maximum of twelve PPS SISs at a time. If there are, say, exactly five PPS SISs available at a given T-S point, the difference between the 4-SIS ("4-satellite") DOP value and the 5-SIS ("5-satellite") DOP value is usually, but not always, substantial. Using five or more SISs for the PVT solution or time transfer solution always results in DOP values that are at least as good as the 4-SIS DOP values.

Note:

1. *Although not always technically true, a GPS receiver that can track and use 12 SISs at a time is commonly referred to as being an "all-in-view" (AIV) GPS receiver.*

B.2.5 Combining UERE/UERRE and DOP Values

With a uniform UERE value and UERRE value, the DOPs produced by a suitably configured computer model can be simply scaled by those UERE and UERRE values according to equations B-2 through B-6 to determine the expected PVT accuracy for the circumstances being considered. Alternatively, the computer model may have the capability to use the UERE or UERRE values and can automatically perform the scaling and output the expected PVT accuracy directly. The same is also true for time transfer solutions; the operator can manually process equation B-7 or the computer model can process equation B-7 using the UERE and UTCOE values.

When the UERE values and UERRE values are different across pseudorange measurements, a computer model which automatically performs the scaling is essential for reliably determining the expected PVT accuracy. Manually using equations B-2 through B-6, or equation B-7, is not practical. This is doubly true if there are more than four pseudorange measurements available and if the subject GPS receiver computes weighted position solutions.

SECTION B.3 Example PVT Performance Expectations

This section describes some example PVT performance expectations for GPS users. It begins by describing some of the statistics used in the *GPS ORD* for translating the PPS SIS performance specifications into PPS PVT performance expectations. It then describes how those same statistics are used in the *SPS PS*. It concludes with a discussion of the "classic" positioning service accuracy specifications and gives some results from a computer model using the baseline 24-slot constellation almanac given in Table A.2-1 in Appendix A along with a selected variety of different UERE/URE/UEE specifications, standards, and assumptions. The UERE/URE/UEE specifications, standards, and assumptions have been specially selected to illustrate the traceability of the PVT performance expectations to other documents.

B.3.1 Position Accuracy Statistics in the *GPS ORD*

The *GPS ORD* defines a pair of accuracy values known as "service availability thresholds" (SATs), and it then uses those SAT values to describe the requirements for "service availability". The first SAT is a horizontal position accuracy of 6.3 m 95%, the second SAT is a vertical position accuracy of 13.6 m 95%. These two SAT values are essential parts of the *GPS ORD*. In the *GPS ORD*, they appear in paragraph 4.1.3.1 which gives the service availability requirements, they are in Table 4.1.3-1 which introduces the relationship between accuracy and availability; and they are in paragraph 4.1.4.1 which specifies the position accuracy requirements. These two SAT values thus play a very key role in the *GPS ORD* positioning availability and accuracy requirements.

B.3.1.1 Sources of the SAT Values

The *GPS ORD*'s horizontal SAT (HSAT) of 6.3 m 95% and vertical SAT (VSAT) of 13.6 m 95% do not come from any operational requirement. They are <u>not</u> user requirements. Instead, the HSAT and VSAT values are simply the result of DOP values picked off a pair of DOP distribution curves multiplied by the 2.9 m 95% (1.5 m 1-sigma) UERE value specified in the *GPS ORD*. The SAT values are therefore really just the results of equations B-2 and B-3 where the UERE value is the one specified in the *GPS ORD.* The HSAT value corresponds to a particular HDOP value and the VSAT value corresponds to a particular VDOP value. The process for picking the particular HDOP and VDOP values is described below.

B.3.1.2 HDOP Distributions and VDOP Distributions

The *GPS ORD* process for picking the particular HDOP and VDOP values to use in equations B-2 and B-3 to compute the HSAT and the VSAT is based on an HDOP distribution and a VDOP distribution like the ones illustrated in Figures B.3-1 and B.3-2.

Figure B.3-1 shows an HDOP distribution for the baseline 24-slot constellation (non-expanded) in the form of two histogram curves, one direct and one cumulative. The range of HDOP values is most easily seen from the direct distribution curve (the dotted one which looks vaguely like a bell-shaped curve offset away from zero). The smallest HDOP value is 0.68, the biggest HDOP value is 2.49. The most likely HDOP value (i.e., value with the maximum area under the direct distribution curve) occurs at 0.91. The cumulative distribution curve (the solid one which starts at 0% at an HDOP of 0.00 and rises to 100% at an HDOP of 2.49) is the one that gives the "no worse

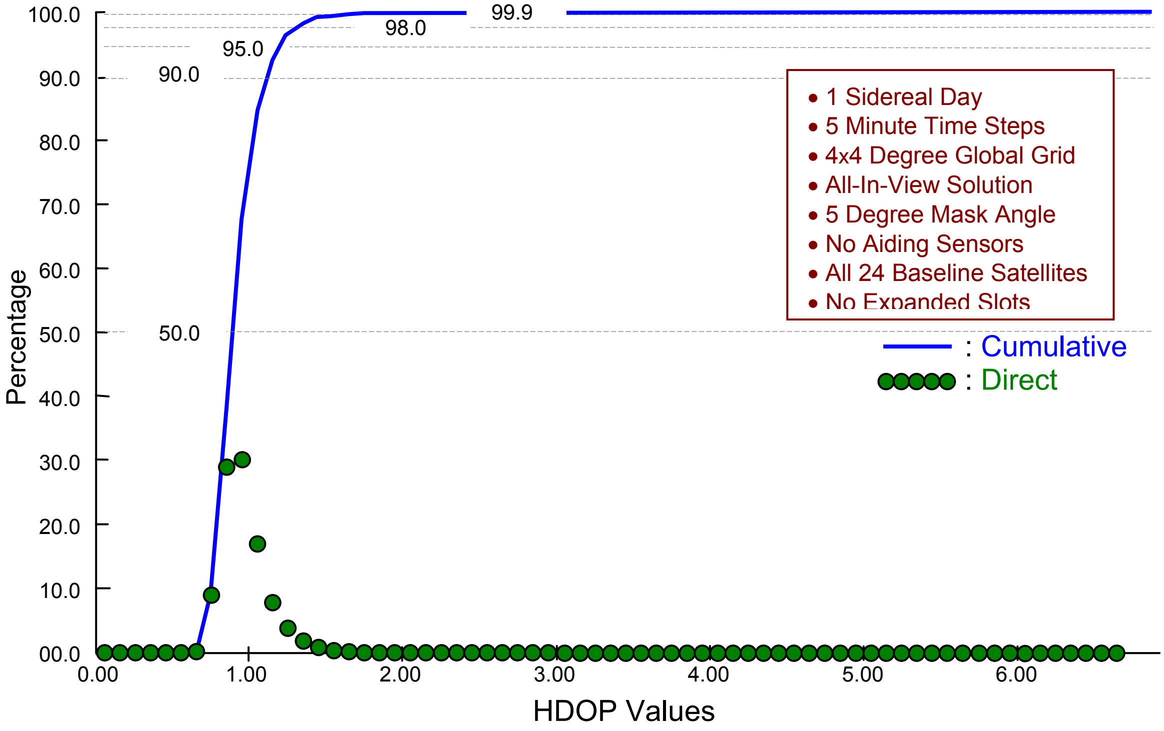


Figure B.3-1. HDOP Distribution Curves

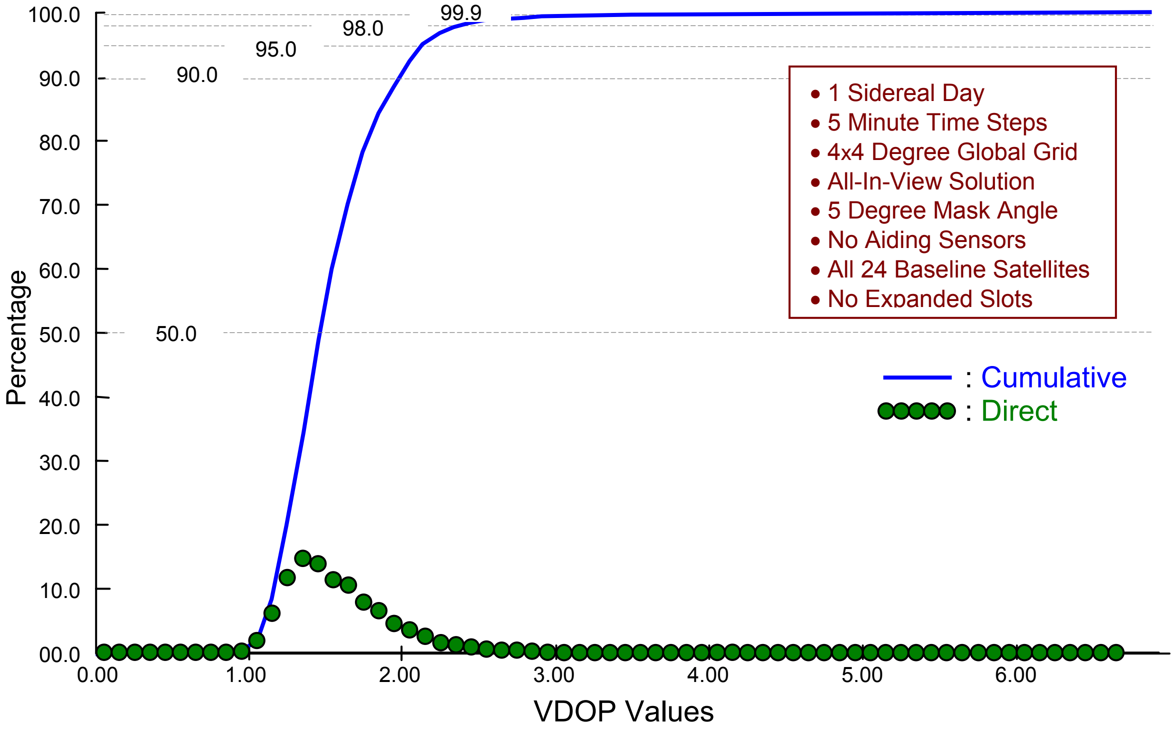


Figure B.3-2. VDOP Distribution Curves

than" (NWT) percentages. This cumulative distribution curve shows 50.0% of the HDOP values are NWT 0.94, 90.0% of the HDOP values are NWT 1.16, 95.0% of the HDOP values are NWT 1.25, 98.0% of the HDOP values are NWT 1.37, and 99.9% of the HDOP values are NWT 1.80.

Figure B.3-2 shows the corresponding VDOP distribution, also in the form of two histogram curves. Recognize that there is really only one HDOP distribution shown in Figure B.3-1 and one VDOP distribution shown in Figure B.3-2. The direct distribution curve and the cumulative distribution curve in each figure are just two different ways of looking at the same DOP distribution.

The HDOP distribution in Figure B.3-1 is only one out of a great many possible HDOP distributions for the baseline 24-slot constellation (equivalently for the VDOP distribution in Figure B.3-2). That is why it is said to be an HDOP distribution, not the HDOP distribution. The HDOP distribution in Figure B.3-1 is specific to the particular conditions identified on the figure, namely:

1. 1 Sidereal Day
2. 5 Minute Time Steps
3. 4x4 Degree Global Grid
4. All-In-View Solution
5. 5 Degree Mask Angle
6. No Aiding Sensors
7. All 24 Slots Occupied by Healthy Satellites
8. No Expanded Slots

Of these eight conditions, only the first one, "1 sidereal day", is standard because the baseline 24-slot constellation imposes it (the constellation geometry repeats every sidereal day, roughly 23 hours 56 minutes). The DOP distributions computed over any sidereal day are identical to the DOP distributions computed over any other sidereal day for the baseline 24-slot constellation provided the other conditions remain the same. This is not true for DOP distributions computed over periods which are not an integer multiple of a sidereal day. The DOP distributions computed over a solar day (exactly 24 hours) do not repeat from solar day to solar day.

The next two conditions, "5 minute time steps" and "4x4 degree global grid", define the set of T-S points at which the DOP values are computed to go into the DOP distributions. 5 minute time steps results in 287 independent time steps over a sidereal day. The 4x4 degree global grid refers to the angular distance between the spatial points uniformly distributed around the equator. The latitude spacing is uniform from pole to pole, but the longitude spacing varies with the cosine of the latitude to ensure that each spatial point represents an equal area of the Earth's surface. These two circumstances vary between different computer programs. For instance, the standard T-S points used for civil aviation analyses (see paragraph 2.5.9.2 of RTCA/DO-229C) are based on 5 minute time steps and a 3x3 degree grid which only covers the Northern Hemisphere. Due to symmetry, the Northern and Southern Hemispheres see the same DOP distributions every half sidereal day.

The fourth, fifth, and sixth conditions, "AIV solution", "5 degree mask angle", and "no aiding sensors", define the assumptions about receiver algorithms for selecting SISs and measurements (see paragraph B.2.4.3). These three conditions vary among different computer programs as much as they do among different types of GPS receivers. These three conditions are the same ones used by the *GPS ORD* in picking the HDOP and VDOP values to use in generating the horizontal and vertical SAT values.

The seventh condition is that "all 24 slots in the baseline constellation are occupied by satellites which are operational and healthy”. This is the circumstance that the *GPS ORD* intentionally varies in picking the HDOP and VDOP values used to compute the horizontal and vertical SAT values.

The final condition, that there are “no expanded slots”, is a conservative assumption.

B.3.1.3 "Global Average" HDOP Distributions and VDOP Distributions

The DOP distributions in the preceding paragraph are "global averages" in the sense that if one randomly selects a time during the day and a place on the Earth's surface, then the probability that one will find a DOP value that is NWT any particular value is given by the cumulative DOP distribution. From Figure B.3-1 for example; at an "average" point in time and space, there is 50.0% probability of the HDOP being NWT 0.94, 90.0% of the HDOP being NWT 1.16, 95.0% of the HDOP being NWT 1.25, and so on.

Given the DOP distributions shown in Figures B.3-1 and B.3-2, it is possible to compute the actual mathematical average HDOP and VDOP values. From Figure B.3-1, the mathematical average HDOP value is 0.96. This average HDOP value differs slightly from the 50.0% probability HDOP value of 0.94 because the 50.0% probability HDOP value is actually the median value of the distribution. The average value of a probability distribution and the median value of that distribution are generally not equal. The average and the median are equal only for certain special types of distributions; but those distributions are exceptions rather than the rule.

B.3.1.4 "Worst-Case" HDOP Distributions and VDOP Distributions

Instead of averaging over a full sidereal day over the entire globe as described above, one can instead focus on the "worst-case" T-S point. From Figure B.3-1 for example; the worst-case T-S point has an HDOP that is 2.49. From Figure B.3-2; the worst-case T-S point has a VDOP that is 5.43.

Note:

1. *The worst-case T-S point for HDOP is generally not the same T-S point as the worst-case T-S point for VDOP.*

B.3.1.5 Intermediate Population HDOP Distributions and VDOP Distributions

Between the "global-average" (global population) with all T-S points and the "worst-case" extreme with only one T-S point, it is possible to define intermediate populations of T-S points for computing DOP distributions. One intermediate population of interest is a full sidereal day over the Continental U.S. (CONUS). Another intermediate population is the "worst-case point in time over a sidereal day" over the CONUS. There are many intermediate populations. With a suitable computer model, the number of intermediate populations for which one could compute the DOP distributions is virtually boundless.

For the HSAT and VSAT values, the *GPS ORD* uses the "worst-case point in space" over a day for its intermediate populations. These populations are subsets of the global population. Before lumping all the DOP values for all the space points together into the global population, the DOP distributions are computed for each space point individually. These individual space point DOP cumulative distributions are then sorted to find the "worst" DOP distributions where "worst" is defined to be the DOP cumulative distribution with the highest NWT value at a given probability.

B.3.1.6 *GPS ORD* "Global-Average" and "Worst-Case" DOP Distributions

The analysis that went into the *GPS ORD* computed the "global-average" (global population) and "worst-case" (single space point population) DOP distributions. These computations covered the condition where all 24 slots are occupied by satellites which are operational and healthy, as well as the degraded conditions where each baseline satellite in the constellation is assumed to have either suffered a hard failure or been set unhealthy (24 cases) and where each pair of baseline satellites in the constellation is assumed to have suffered a hard failure or been set unhealthy (276 cases). The results of these computations are given in Table B.3-1. Note the similarity between the "worst-case" (single point population) columns of Table B.3-1 and the HDOP/VDOP portions of Table 1 in Part II of the Requirements Correlation Matrix (RCM) in Annex A of the *GPS ORD*.

Notes:

1. *The DOP distribution results shown in Table B.3-1 and in Table 1 in Part II of Annex A of the* GPS ORD *are the direct result of the baseline 24-slot constellation defined in Section 3.2. No other information is needed to produce the results in Table B.3-1 except an understanding of the particular receiver algorithm assumptions used to set up the computer model (i.e., "AIV solution", "5 degree mask angle", and "no aiding sensors"). In other words, going from the baseline 24-slot constellation definition to the results shown in Table B.3-1 requires nothing more than a computer-aided translation.*

2. *The probability levels in Table B.3-1 and in Table 1 in Part II of Annex A of the* GPS ORD *have the same meaning as in Figures B.3-1 and B.3-2.*

3. *Because the satellite-to-user geometry repeats every sidereal day at each space point, the "Worst Case" (Single Point) probability levels in Table B.3-1 are averaged over a sidereal day. Because the Navstar satellite orbit period is exactly one-half sidereal day and because the orbits are north-south symmetric about the equator (i.e., near-circular orbits), the satellite-to-Earth geometry effectively repeats four times every sidereal day and so the "Global Average" (Globe. Pop.) probability levels in Table B.3-1 can be considered as averages over one-quarter sidereal day.*

Table B.3-1. DOP Distribution Tabular Results

Constellation Circumstance	**"Worst Case" (Single Point) HDOP†**	**"Worst Case" (Single Point) VDOP†**	**"Global Avg." (Globe. Pop.) HDOP††**	**"Global Avg." (Globe. Pop.) VDOP††**
99.9% Probability				
All 24 Baseline Satellites	~2.3	~4.4	~1.8	~3.5
1 Failed Satellite	>100	>100	~2.4	~4.9
2 Failed Satellites	*	*	~4.0	~7.9
98.0% Probability				
All 24 Baseline Satellites	~2.0	~3.4	~1.4	~2.4
1 Failed Satellite	~3.0	~6.0	~1.6	~2.8
2 Failed Satellites	~6.7	~14.1	~1.8	~3.3
90.0% Probability				
All 24 Baseline Satellites	~1.4	~2.5	~1.2	~2.0
1 Failed Satellite	~1.8	~3.0	~1.3	~2.2
2 Failed Satellites	~2.1	~4.4	~1.4	~2.3

* No Solution – with 2 satellites down the cumulative distribution never reaches 99.9% availability.
† Worst (highest value) satellite down or worst (highest value) pair of satellites down.
†† Average satellite down or average pair of satellites down.

B.3.1.7 Picking DOP Values for Computing SAT Values

Theoretically, any pair of HDOP and VDOP values from Table B.3-1 could have been picked to serve as the basis for the HSAT and VSAT values since the HDOP and VDOP values are all derived from the same definition of the baseline 24-slot constellation. Because the *GPS ORD* establishes a new requirement for the simultaneous loss of the SIS from no more than two satellites out of the baseline 24-slot constellation, picking any of the six pairs of HDOP and VDOP values in the rows labeled as "2 Failed Satellites" is consistent with this requirement. Furthermore, because the *GPS ORD* shifted the future performance focus for GPS from being a global system to being an anywhere system ("any latitude and longitude"), picking any of the nine pairs of HDOP and VDOP values in the columns labeled as "Worst Case (Single Point)" is more consistent with this focus shift than picking any of the pairs of HDOP and VDOP values in the columns labeled as "Global Avg. (Globe. Pop.)". There are thus only three pairs of HDOP and VDOP values that are consistent with both "2 failed satellites" and "worst-case location", and one of those pairs can be automatically ruled out because it represents the "No Solution" result.

There are only two candidate pairs of HDOP and VDOP values in the intersections of the rows labeled as "2 Failed Satellites" and the columns labeled as "Worst Case (Single Point)": the 98.0% probability values of 6.7 & 14.1 and the 90.0% probability values of 2.1 & 4.4. Picking either pair would have been just as consistent with the *GPS ORD* and each would have been just as relevant to the baseline 24-slot constellation definition. Because they "look better" in some sense for the user, the HDOP and VDOP values of 2.1 & 4.4 from the 90.0% probability level on the DOP distributions were picked as the basis for the SAT values in the *GPS ORD*. The HDOP value of 2.1 for the HSAT is about half of the traditional rule-of-thumb limit of 4.0 on the HDOP value for good horizontal accuracy. The VDOP value of 4.4 for the VSAT is almost exactly the same as the traditional rule-of-thumb limit of 4.5 on the VDOP for good vertical accuracy. Together, the HDOP and VDOP values rss to a value of 4.9 which is significantly less than the traditional rule-of-thumb limit of 6.0 on PDOP for good overall positioning accuracy.

B.3.1.8 Computing the SAT Values

The HDOP value of 2.1 can be substituted into equation B-2 along with the 1.5 m 1-sigma UERE value to find the HSAT value in terms of the UHNE as follows below. (Note that the UERE must be expressed as a 1-sigma value to find the UHNE as a drms value.)

$$\begin{aligned} \text{UHNE} &= \text{UERE} \times \text{HDOP} \\ &= 1.5\text{ m} \times 2.1 \\ &= 3.15\text{ m drms} \end{aligned} \tag{B-9}$$

The UHNE value computed above is a two-dimensional (2-D) accuracy statistic. It therefore represents a 63% probability assuming two approximately equal components (east/north, alongtrack/crosstrack, X/Y, etcetera). From TOR S3-G-89-01, the correct conversion factor to translate this UHNE value to a radial 95% probability value (R95) is 1.73. Thus,

$$\begin{aligned} \text{R95} &= \text{UHNE} \times 1.73 \\ &= 5.45\text{ m }95\% \end{aligned} \tag{B-10}$$

The *GPS ORD* did not, however, use the precise conversion factor of 1.73 to translate from the 63% probability UHNE to the HSAT value at 95%. The *GPS ORD* used an approximate conversion factor of 2.0.

$$\begin{aligned} \text{HSAT} &= \text{UHNE} \times 2.0 \\ &= 6.3\text{ m }95\% \end{aligned} \tag{B-11}$$

This HSAT value is the value that appears in Table 4.1.3-1, paragraph 4.1.3.1, and paragraph 4.1.4.1 of the *GPS ORD*.

The computation of the VSAT value is analogous to the HSAT computation. The VDOP value of 4.4 is substituted into equation B-3 along with the 1.5 m 1-sigma UERE value:

$$\begin{aligned} \text{UVNE} &= \text{UERE} \times \text{VDOP} \\ &= 1.5\text{ m} \times 4.4 \\ &= 6.60\text{ m drms} \end{aligned} \tag{B-12}$$

The UVNE value computed above is a one-dimensional accuracy statistic and represents a 68% probability. TOR S3-G-89-01 gives a conversion factor of 2.0 (i.e., 1.96 rounded to 2 significant digits) to translate this UVNE value to a linear 95% probability value (L95). The *GPS ORD* used this conversion factor. Thus,

$$\begin{aligned} \text{L95} &= \text{UVNE} \times 2.0 \\ &= 13.2 \text{ m } 95\% \end{aligned} \tag{B-13}$$

Equating the above L95 statistic with VSAT, the VSAT is:

$$\begin{aligned} \text{VSAT} &= \text{L95} \\ &= 13.2 \text{ m } 95\% \end{aligned} \tag{B-14}$$

This VSAT value is exactly the value that appears in Table 4.1.3-1 of the *GPS ORD*. When this value was carried over into paragraph 4.1.3.1 and paragraph 4.1.4.1, it was inflated slightly to a value of 13.6 m 95%.

The relationship between the HSAT value of 6.3 m 95% and the HDOP value of 2.1 is illustrated in Figure B.3-3. This figure shows the HDOP values at each time point over a sidereal day under the circumstances of a "worst-case" constellation (2 worst failed satellites) at one of the four "worst-case" space point locations. This figure uses the *GPS ORD*'s approximate conversion factor of 2 to translate from the 63% probability UHNE to the HSAT value at 95% as described above.

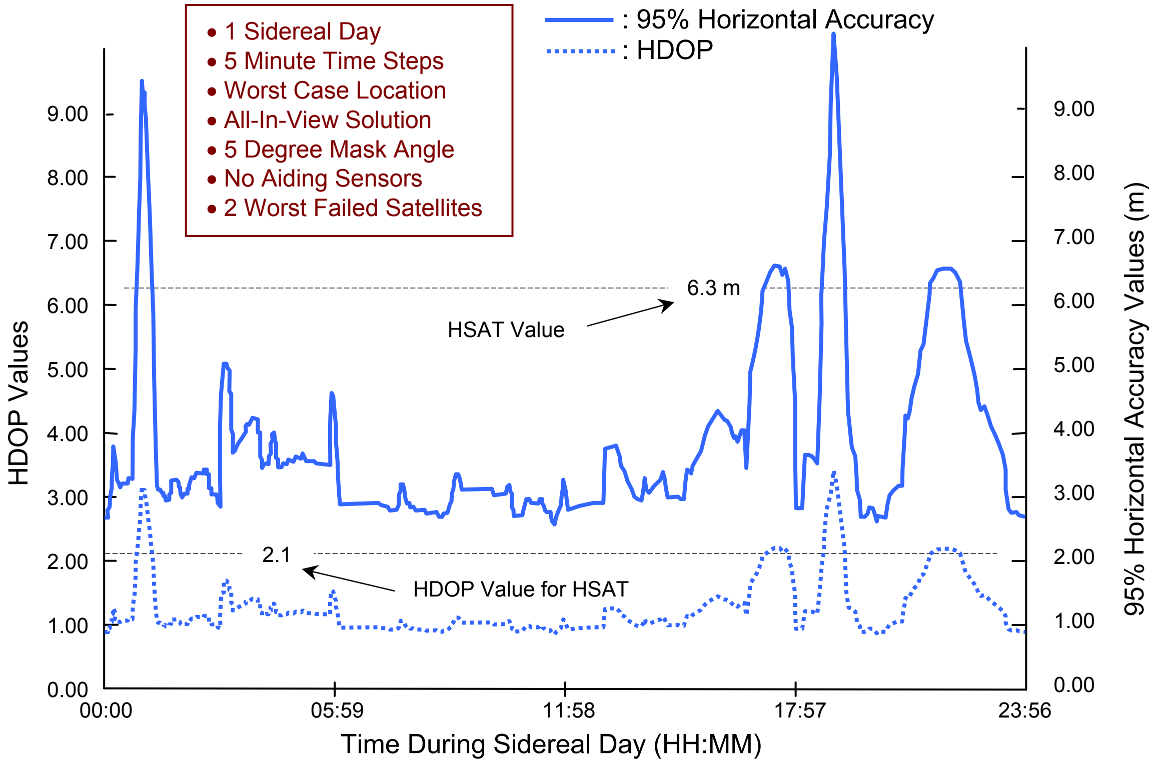


Figure B.3-3. HSAT and HDOP Relationship

Notes:

1. *The 63%-to-95% conversion factor of 2 coupled with the assumed UERE of 1.5 m 1-sigma in the GPS ORD results in an exact 3-to-1 ratio between the HSAT and HDOP values in Figure B.3-3.*

2. *There are always four "worst-case" locations when considering a full sidereal day. Because the Navstar satellite orbit period is exactly one-half sidereal day, the same geometry repeats twice each day in the Northern Hemisphere separated by 180 degrees of longitude and by one-half sidereal day. Due to north-south symmetry, that same geometry also repeats twice each day in the Southern Hemisphere separated by 180 degrees of longitude and by one-half sidereal day. The southern "worst-case" locations are offset from the northern "worst-case" locations by 90 degrees of longitude and one-quarter sidereal day.*

B.3.1.9 Implications of HSAT and VSAT Values

As far as the *GPS ORD* goes, the HSAT and VSAT values define whether the GPS service is available or not. Note that the HSAT and VSAT values are not tied to the actual horizontal or vertical position accuracy, they are "projected error" values (reference paragraph 4.1.3.1 of the *GPS ORD*). As described above, the HSAT and VSAT values are based on an assumed 1.5 m 1-sigma UERE. Since this assumption is known, the UERE value can be factored out of the HSAT and VSAT values to simplify them to become the HDOP availability threshold (HDOP-AT) and VDOP availability threshold (VDOP-AT) values respectively. These HDOP-AT and VDOP-AT values can then be used for determining whether the GPS service is or is not available based on the projected DOPs. Because the projected DOPs can be computed in advance, GPS service availability can be computed in advance. The "recipe" is as follows:

If HDOP $\leq$ HDOP-AT (= 2.1)

and

If VDOP $\leq$ VDOP-AT (= 4.4)

Then GPS Service is available as defined in the *GPS ORD*
Otherwise, GPS Service is unavailable as defined in the *GPS ORD*

Recognize that this *GPS ORD*-defined discrimination between the GPS service being available or not available has little or no implications for most PPS users. It would only be relevant to a PPS user whose mission depended on having an HDOP value less than or equal to 2.1 and a VDOP value less than or equal to 4.4 (or equivalently, a horizontal position accuracy of 6.3 m 95% and a vertical position accuracy of 13.2 m 95%).

B.3.1.10 Different UERE Value Assumptions

Instead of the 1.5 m 1-sigma UERE assumption in the *GPS ORD*, a SIS URE of 6.0 m 1-sigma (11.8 m 95%) over all AODs during normal operations as specified in the *SPS PS* could be used in lieu of the UERE for a "perfect GPS receiver study". Or the UERE could be assumed to be the 7.0 m 1-sigma (13.8 m 95%) UERE value in Table A.4-1 in Appendix A of this *PPS PS* for dual-frequency PPS without WAGE at any AOD during normal operations. Or the UERE could be assumed to be 4.7 m 1-sigma (9.2 m 95%) for dual-frequency PPS without WAGE over all AODs during normal operations based on Table 3.4-1 and on "traditional" UEE assumptions, Or the UERE could be assumed to be the 4.0 m 1-sigma (7.9 m 95%) UERE value in Table A.4-3 in Appendix A of this *PPS PS* for dual-frequency with WAGE at a WAGE AOD of 2 hours. Any of these could be a reasonable assumption depending on one’s objective.

No matter what UERE is assumed, it has no effect on any of the DOP-related discussions in the preceding paragraphs. Figures B.3-1 and B.3-2, and Table B.3-1 are independent of the assumed UERE. The impacts of a changed UERE are limited to the discussions in paragraphs B.3.1.8 and B.3.1.9 where a change in UERE will cause a simple proportionate change in the HSAT and VSAT values (keeping the same conservatism as currently in the *GPS ORD*). Increasing the assumed UERE by a factor of 4.67 (7.0 m divided by 1.5 m) will change the HSAT value by a factor of 4.67 from 6.3 m 95% to 29 m 95% and the VSAT value by a factor of 4.67 from 13.6 m 95% to 63 m 95%. This proportionality as a function of the assumed UERE is illustrated in Table B.3-2 for each of the example UERE assumptions. Changing the assumed UERE does not change the underlying HDOP-AT or VDOP-AT values however.

Table B.3-2. HSAT & VSAT as a Function of Assumed UERE

Assumed UERE	HSAT	VSAT
1.5 m 1-sigma (3.0 m 95%)	6.3 m 95%	13.6 m 95%
6.0 m 1-sigma (11.8 m 95%)	25 m 95%	54 m 95%
7.0 m 1-sigma (13.8 m 95%)	29 m 95%	63 m 95%
4.7 m 1-sigma (9.2 m 95%)	20 m 95%	43 m 95%
4.0 m 1-sigma (7.9 m 95%)	17 m 95%	36 m 95%

Notes:

1. *Once the DOP distributions and the PVT-related results are computed for a given UERE value, switching to a different UERE value is a simple matter of scaling the previous results.*
2. *Table B.3-2 uses the 13.6 m 95% VSAT value given in paragraphs 4.1.3.1 and 4.1.4.1 of the GPS ORD rather than the 13.2 m 95% value given in Table 4.1.3-1 of the GPS ORD.*

B.3.2 Position Accuracy Statistics in the *SPS PS*

The *SPS PS* continues with the HSAT and VSAT concept initially developed in the *GPS ORD*. The SPS PS defines service availability using exactly the same HDOP-AT and VDOP-AT values used the *GPS ORD*. This should be expected since the *SPS PS* and the *GPS ORD* are both based on the same worst 2-satellite failure case for the baseline 24-slot constellation and both have the same focus on the worst-case location anywhere on the face of the Earth.

B.3.2.1 Relationship of *SPS PS* SATs with the *GPS ORD* SATs

The *SPS PS* uses the same HDOP-AT and VDOP-AT values as the *GPS ORD*. These HDOP-AT and VDOP-AT values are:

$$\text{HDOP-AT} = 2.10$$

$$\text{VDOP-AT} = 4.53$$

The availabilities of HDOPs less than this HDOP-AT value and VDOPs less than this VDOP-AT value are given as 90% or better in both the *SPS PS* and the *GPS ORD* for the same conditions.

As described in the preceding section, the *GPS ORD* converts these HDOP-AT and VDOP-AT values into HSAT and VSAT values assuming a 1.5 m 1-sigma UERE and a value of 2.0 for both the UHNE-to-R95 conversion factor and the UVNE-to-L95 conversion factor. Specifically:

<u>GPS ORD:</u>

$$\begin{aligned} \text{HSAT} &= \text{HDOP-AT} \times 1.5\text{ m} \times 2.0 \\ &= 2.10 \times 1.5\text{ m} \times 2.0 \\ &= 6.3\text{ m } 95\% \end{aligned}$$

$$\begin{aligned} \text{VSAT} &= \text{HDOP-AT} \times 1.5\text{ m} \times 2.0 \\ &= 4.53 \times 1.5\text{ m} \times 2.0 \\ &= 13.6\text{ m } 95\% \end{aligned}$$

The *SPS PS* computes its HSAT and VSAT values the same basic way as the *GPS ORD* with the same UHNE-to-R95 conversion factor and UVNE-to-L95 conversion factor, but the *SPS PS* uses a 6.0 m 1-sigma UERE instead of a 1.5 m 1-sigma UERE and it also applies an additional margin factor equal to the square root of 2. This makes the HSAT and VSAT values in the *SPS PS* exactly 5.66 bigger than the HSAT and VSAT values in the *GPS ORD*. This can be seen by:

<u>SPS PS:</u>

$$\begin{aligned} \text{HSAT} &= \text{HDOP-AT} \times 6.0\text{ m} \times 2.0 \times \sqrt{2} \\ &= 2.1 \times 6.0\text{ m} \times 2.0 \times 1.41 \\ &= 36\text{ m } 95\% \end{aligned}$$

$$\begin{aligned} \text{VSAT} &= \text{VDOP-AT} \times 6.0\text{ m} \times 2.00 \times \sqrt{2} \\ &= 4.53 \times 6.0\text{ m} \times 2.0 \times 1.41 \\ &= 77\text{ m } 95\% \end{aligned}$$

Note:

1. *The worst 2-satellite failure and worst-case location assumptions already combine to make the SAT values very conservative even without the additional square-root-of-2 factor. From the conservative binomial model described in Table A.7-2, there is only a 0.082 probability of being in a 2-satellite failure situation (or worse). There are 276 possible combinations of 2-satellite failures, so the probability of the worst 2-satellite failure occurring is 0.0036 (i.e., 1 in 276). From the 2x2 degree grid spacing used in the SPS PS, there are roughly 10,000 possible space points on the surface of the Earth where 4 of those points will be identical worst-case locations due to symmetry. The probability of being at one of those 4 location points is approximately 0.0004 (1 in 2,500). Together, these three factors give a probability of 0.00000011 (about 1 in 10 million) for actually encountering DOP values as large as the SAT values.*

B.3.2.2 *SPS PS* SATs and Service Availability Standards/Position Accuracy Standards

B.3.2.2.1 SATs for the Worst-Case Location

The HSAT value of 36 m 95% and the VSAT value of 77 m 95% appear in two tables in the *SPS PS* applied to the worst-case location with the worst 2-satellite failure. They are in the second half of Table 3-3 in the *SPS PS* for the "SPS Service Availability Standard", and they are in the middle portion of Table 3-6 in the *SPS PS* for the "Positioning and Timing Accuracy Standard". Although these two appearances of the HSAT and VSAT values for the worst-case location may seem redundant, they are not.

Assuming that the SPS SIS-only UERE is always less than or equal to 6.0 m 1-sigma (actually the assumption is that the SPS SIS-only UERE is always less than or equal to 8.5 m 1-sigma based on the additional margin factor of the square root of 2), Table 3-3 for the "SPS Service Availability Standard" in the *SPS PS* can be satisfied with an HDOP distribution which has 90% of its population of HDOPs less than or equal to the HDOP-AT value and a VDOP distribution that has 90% of its population of VDOPs less than or equal to the VDOP-AT value. A worst-case location with a major DOP hole where no position solution is possible 9.9% of the time could still satisfy the "SPS Service Availability Standard" if the HDOP and VDOP values were less than the HDOP-AT and VDOP-AT values whenever a position solution was possible.

Table 3-6 for the "Positioning and Timing Accuracy Standard" precludes such a worst-case location with a major DOP hole where no position solution is possible 9.9% of the time. Such a worst-case location would have infinitely large horizontal and vertical positioning accuracies 90.1% of the time. This would not satisfy the Table 3-6 specifications for a horizontal positioning accuracy of 36 m 95% of the time and a vertical positioning accuracy of 77 m 95% of the time.

Note:

1. *A worst-case location with a major DOP hole where no position solution is possible 4.9% of the time could still satisfy the Table 3-6 specifications in the SPS PS for a horizontal positioning accuracy of 36 m 95% of the time and a vertical positioning accuracy of 77 m 95% of the time.*

B.3.2.2.2 SATs for the Global Average

The HSAT value of 36 m 95% and the VSAT value of 77 m 95% also appear in one table in the *SPS PS* applied to the global average. This appearance is in the first half of Table 3-3 in the *SPS PS* for the "SPS Service Availability Standard". It is reasonable that the HSAT and VSAT values should be applied to the global-average availability standard, since the SAT values are defined as *service availability thresholds* and there is nothing that necessarily restricts their application to only worst-case locations.

Note:

1. *Table 3-3 in the SPS PS applies the same HSAT and VSAT values to the global average availability and the worst-case location availability. As expected, the availability standard for the global average is much higher than for the worst-case location (99% versus 90%).*

B.3.2.3 *SPS PS* Global-Average Position Accuracy Standards

The *SPS PS* provides global-average position accuracy standards in the first portion of Table 3-6. These global-average position accuracy standards are:

- 13 m 95% All-in-View Horizontal Error (SIS Only)
- 22 m 95% All-in-View Vertical Error (SIS Only)

These global-average position accuracy standards can be converted to global-average DOP values by dividing by the 6.0 m 1-sigma SIS-only URE value in the *SPS PS*, and dividing by the 2.0 conversion factor used in the *SPS PS* for converting to 95% position accuracy statistics. Thus:

$$\begin{aligned}\text{Global-average HDOP} &= 13\text{ m }95\% \div 6.0\text{ m } \div 2.0\\ &= 1.1\end{aligned}$$

$$\begin{aligned}\text{Global-average VDOP} &= 22\text{ m }95\% \div 6.0\text{ m } \div 2.0\\ &= 1.8\end{aligned}$$

In keeping with the other accuracy-related standards in the *SPS PS*, this global-average HDOP value and global-average VDOP value are for the worst 2-satellite failure.

B.3.3 "Classic" Position Accuracy Statistics

For its first quarter century -- from inception until publication of the *GPS ORD* -- GPS position accuracies were always described in terms of a total overall statistic. For example, the 16 m spherical error probable (SEP) specification given in the *GPS SORD* for PPS users was such a total overall statistic. As a total overall statistic, this 16 m SEP specification meant that over all T-S points, 50% of the PPS user position fixes would have a three-dimensional (3-D) accuracy equal to or better than 16 m. Equivalently stated, the 16 m SEP specification meant that if a PPS user went out at a random point in time at random location on the surface of the Earth, that user would have a 50% probability of getting a position fix with 3-D accuracy equal to or better than 16 m.

The *GPS ORD* introduced a radical paradigm shift in describing GPS position accuracy. The focus went from "how good is GPS on average" to "how bad can GPS possibly be". The *GPS ORD* describes GPS position accuracy assuming the "worst-case" constellation (2 worst failed satellites) and the "worst-case" location (any single point on the Earth). The *GPS ORD* position accuracy specifications are thus both extremely conservative ("worst-case" constellation and "worst-case" location) and extremely liberal (excluding the worst 10% of the sidereal day as being "unavailable"). The *SPS PS* carries on with this paradigm shift, but partially omits the liberal caveat on excluding the worst 10% of a sidereal day.

The *SPS PS* does take a step towards the classic way of describing GPS position accuracy with the global-average position accuracy standards given in the first portion of Table 3-6. It maintains the extreme conservatism of the worst 2-satellite failure condition, but at least it considers the full population of all T-S points rather than just focusing on the worst-case space point over a sidereal day.

This section of the *PPS PS* addresses the classic way of describing GPS position accuracy. It is also known as the “global ensemble” description of GPS position accuracy.

B.3.3.1 Reasons for Needing the DOP Distributions

A global-average DOP value by itself is really not adequate from computing a global-average position accuracy value. The actual DOP distribution must be taken into account in order to compute an accurate accuracy value. The following simple example illustrates why this is so.

Note:

1. *Because the probability conversion factors for the Gaussian (normal) distribution can be found in any good statistics textbook, the following example uses GPS vertical position accuracy since the vertical position accuracy follows a Gaussian distribution.*

B.3.3.1.1 Global Average Accuracy Without DOP Distribution Information

Say one knows the global-average VDOP for some constellation condition (e.g., worst 2-satellite failure) is exactly 1.80, but one does not know the distribution of the population of VDOP values. One might just assume that all VDOP values are exactly 1.80. Under this assumption, for a 4.00 m 1-sigma UERE and the more precise 95% conversion factor of 1.96 (instead of 2.0), one would deduce that the 95% global-average vertical accuracy is:

$$\begin{aligned}\text{Vertical L95} &= \text{UERE} \times \text{VDOP} \times 1.96\\ &= 4.0\text{ m} \times 1.80 \times 1.96\\ &= 14.11\text{ m } 95\%\end{aligned}$$

This deduction is shown graphically in Figure B.3-4. Observe this figure shows only one Gaussian distribution (Normal distribution with a zero mean) and that this Gaussian distribution has been rotated 90 degrees from its usual orientation to better correspond to the position fix errors in the vertical dimension.

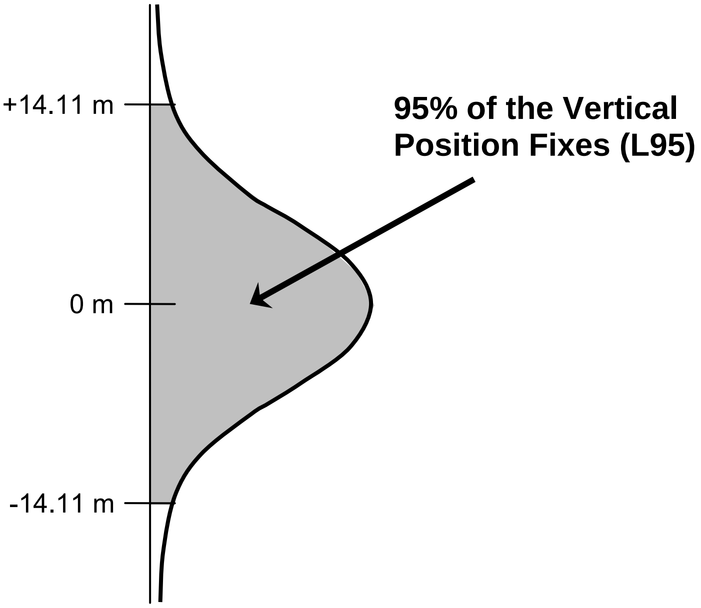


Figure B.3-4. Vertical L95 for UERE=4.0 m 1-sigma and VDOP=1.80

B.3.3.1.2 Global Average Accuracy With DOP Distribution Information

Say that one later finds better information which says that the distribution of the population of VDOP values is such that half of the VDOP values are exactly 1.40 and the other half of the VDOP values are exactly 2.20. The global-average VDOP is still exactly 1.80. In this case, with the same UERE assumption, one would deduce that the L95% global-average vertical accuracy for each of the two sub-populations are:

50% Sub-Population with VDOP = 1.40

Vertical L95 = UERE x VDOP x 1.96
= 4.0 m x 1.40 x 1.96
= 10.98 m 95%

50 % Sub-Population with VDOP = 2.20

Vertical L95 = UERE x VDOP x 1.96
= 4.0 m x 2.20 x 1.96
= 17.25 m 95%

These two sub-populations are illustrated in Figure B.3-5. Observe that each sub-population is shown only half as large as in the previous Figure B.3-4, which corresponds to each sub-population having 50% of the total population.

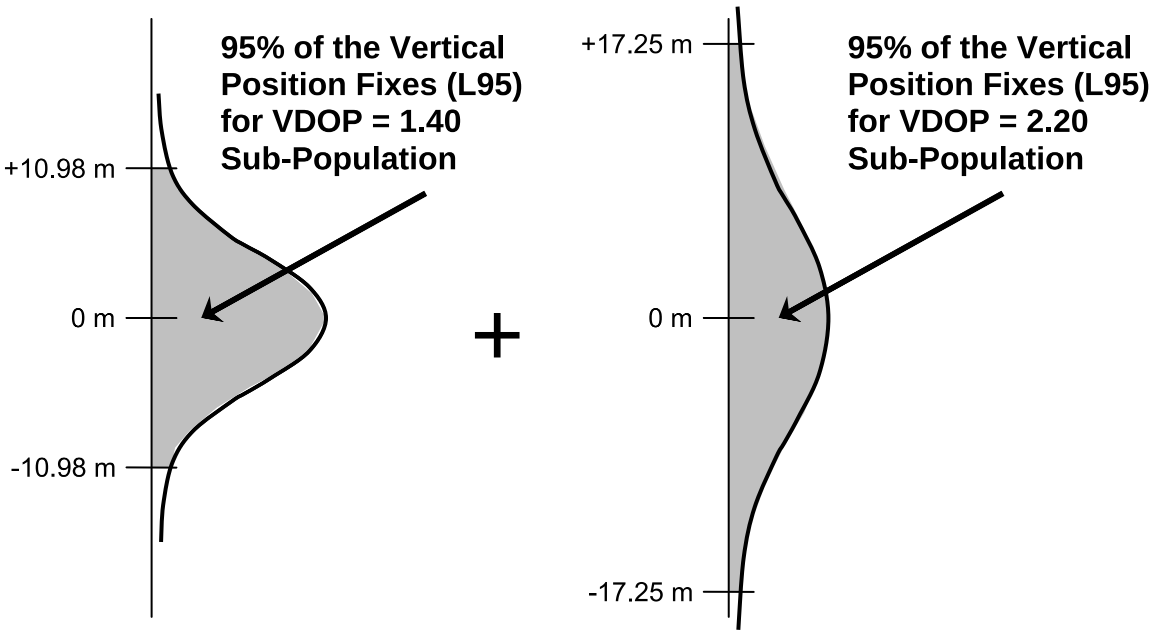


Figure B.3-5. Vertical L95 for VDOP=1.40 Sub-Population and VDOP=2.20 Sub-Population

Taking the simple average of the 95% global-average vertical accuracies for each of these two sub-populations will give the same result as before, namely 14.11 m 95%. However, this is not correct because there is no mathematical basis for simply averaging two sub-populations. To illustrate the error, compare the sum of the two weighted fractions of each sub-population beyond the 14.11 m 95% value against the 5% of the total population beyond the 14.11 m 95% value which results from the simple average. For reference, note that the 1-sigma equivalents of each sub-population distribution are:

10.98 m 95% = 5.60 m 1-sigma for VDOP=1.40 Sub-Population
17.25 m 95% = 8.80 m 1-sigma for VDOP=2.20 Sub-Population

50% Sub-Population with VDOP = 1.40

14.11 m 95% = 2.520-sigma relative to a 5.60 m 1-sigma distribution

0.0118 = Fraction of sub-population beyond 2.520-sigma (i.e., beyond ±14.11 m) for a Gaussian distribution

0.0059 = Weighted fraction of total population beyond ±14.11 m given that this sub-population is ½ of the total population

50% Sub-Population with VDOP = 2.20

14.11 m 95% = 1.604-sigma relative to a 8.80 m 1-sigma distribution

0.1088 = Fraction of sub-population beyond 1.604-sigma (i.e., beyond ±14.11 m) for a Gaussian distribution

0.0544 = Weighted fraction of total population beyond ±14.11 m given that this sub-population is ½ of the total population

Weighted Sum of the Two Sub-Populations with 50% of VDOP = 1.40 and 50% of VDOP = 2.20

Fraction of total population beyond ±14.11 m = 0.0059 + 0.0544
= 0.0603

Equivalent accuracy statistic for total population = 14.11 m 93.97%

Using the simple fact that the global average VDOP = 1.80 will lead one to deduce that 5% of the total population of vertical position fixes will be beyond ±14.11 m. But using better information which defines the underlying VDOP distribution as being two equal sub-populations with VDOP = 1.40 and VDOP = 2.20 will reveal that actually 6.03% of the total population of vertical position fixes will be beyond ±14.11 m. In this example, the statistical error introduced by using the global-average VDOP value by itself instead of using the underlying VDOP distribution is thus slightly greater than 1% in overall probability terms.

The error introduced by not using information about the underlying VDOP distribution is more dramatic in scalar accuracy terms. For the same overall probability of 95%, using the better VDOP information results in a scalar accuracy of 14.82 m which is 5% larger than the 14.11 m value which results from using the simple global average VDOP. The numerology which produced this result is as follows.

50% Sub-Population with VDOP = 1.40

0.0080 = Unweighted fraction of VDOP=1.40 sub-population greater than or equal to 14.82 m not accounting for the fact that this sub-population is ½ of the total population

0.0040 = Weighted fraction of total population beyond ±14.82 m given that this sub-population is ½ of the total population

50% Sub-Population with VDOP = 2.20

0.0920 = Unweighted fraction of VDOP=2.20 sub-population greater than or equal to 14.82 m not accounting for the fact that this sub-population is ½ of the total population

0.0460 = Weighted fraction of total population beyond ±14.82 m given that this sub-population is ½ of the total population

Weighted Sum of the Two Sub-Populations with 50% of VDOP = 1.40 and 50% of VDOP = 2.20

Fraction of total population beyond ±14.82 m = 0.0040 + 0.0460
= 0.0500

Equivalent accuracy statistic for total population = 14.82 m 95%

B.3.3.1.3 Procedure for Using DOP Distribution Information

Observe that the VDOP distribution is accounted for in this simple example by first computing the position accuracy distribution for each sub-population VDOP value, generating the weighted sum of the position accuracy distributions for each sub-population VDOP value using the probability of that sub-population VDOP value occurring, and then finally determining the statistics for the total position accuracy distribution for the full ensemble population.

The same procedure can be generalized for use with sub-population HDOP distribution information, sub-population PDOP distribution information, sub-population TDOP distribution information, sub-population TTDOP distribution information, and so on.

Note:

1. *The total position accuracy distribution is often called the "global ensemble" position accuracy distribution because it is the weighted-sum of many position accuracy sub-distributions.*

B.3.3.2 Basic Procedure for Computing Classic Position Accuracy Statistics

The classic GPS position accuracy procedure is similar to the example in the preceding paragraph, but the sub-populations are each individual T-S point by itself. Letting each T-S point be its own sub-population simplifies the weighting since each sub-population is therefore simply weighted by 1 over the total number of T-S points. It also accommodates different types of position accuracy computations, particularly those where the basic "UERE x DOP" equation does not apply (e.g., with aiding sensors, or with weighted solutions). The classic GPS position accuracy procedure is:

1. The geometry at each T-S point over a sidereal day and across the Earth is computed for the particular circumstances being considered.
2. The solution matrix is computed for the geometry at each T-S point. (This solution matrix is the same one a GPS receiver would compute based on that geometry given the same circumstances.)
3. A Monte Carlo simulation is run for each T-S point geometry where simulated pseudorange error samples drawn from a Gaussian distribution with a 1-sigma value equal to the specified UERE are deterministically converted via the solution matrix to produce simulated position error samples (horizontal, vertical, spherical, etcetera). The position error samples at each T-S point represent the position accuracy at that T-S point.
4. The position error samples produced by the Monte Carlo simulation for each T-S point geometry are combined together to produce a very large ensemble of position error samples from all T-S points.
5. The ensemble of position error samples from all T-S points is then sorted to find the 95th percentile (or 50th percentile, 90th percentile, 98th percentile, 99.9th percentile, etcetera) statistics. These statistics are the classic total overall GPS position accuracy values.

This is exactly the procedure used to develop the classic 16 m SEP (50th percentile) specification given in the *GPS SORD* for PPS users.

B.3.3.3 Expanded Procedure for Computing Classic Position Accuracy Statistics

The basic procedure in paragraph B.3.3.2 applies to the circumstances being considered, such as assuming a particular set of 2 satellites are failed out of the baseline 24-slot constellation. The basic procedure can be expanded to cover multiple circumstances by appropriately weighting and summing the ensembles of position error samples from all T-S points for each circumstance being considered into a super ensemble (an "ensemble of ensembles").

One of the main applications for this expanded procedure is addressing the probabilities of being in different constellation conditions. For example, consider the standard model for constellation availability described in Table A.7-2. The standard model has the baseline 24-slot constellation fully populated with 24 healthy satellites transmitting a usable PPS SIS 72.0% of the time, 23 healthy satellites transmitting a usable PPS SIS 17.0% of the time, 22 healthy satellites transmitting a usable PPS SIS 6.4% of the time, 21 healthy satellites transmitting a usable PPS SIS 2.6% of the time, and 20 or fewer healthy satellites transmitting a usable PPS SIS 2.0% of the time. The appropriate weightings for each ensemble of position error samples is the constellation condition probability divided by the number of possible combinations making up each constellation condition. Specifically:

1 ensemble for the full 24-satellite constellation weighted by 0.720, plus
24 ensembles for all possible 23-satellite constellations, each weighted by 0.170/24, plus
276 ensembles for all possible 22-satellite constellations, each weighted by 0.064/276, plus
2,024 ensembles for all possible 21-satellite constellations, each weighted by 0.026/2,024, plus
10,626 ensembles for all possible 20-satellite constellations, each weighted by 0.020/10,676.

B.3.3.4 Expanded Classic Position Accuracy Statistics

Following the expanded procedure with 5 minute time steps, with a 4x4 degree grid, with an AIV solution, with a 5 degree mask angle, with no aiding sensors, with all 12,951 ensembles weighted as described in the preceding paragraph, and with the 1.5 m 1-sigma (2.9 m 95%) UERE given in *the GPS ORD*, the resulting classic GPS position accuracy statistics would be:

2.7 m = 95% Horizontal Position Accuracy
4.9 m = 95% Vertical Position Accuracy

The corresponding classic GPS position accuracy statistics for the 6.0 m 1-sigma (11.8 m 95%) SPS SIS-only URE value in the *SPS PS*, would be:

10.7 m = 95% Horizontal Position Accuracy
19.8 m = 95% Vertical Position Accuracy

The corresponding classic GPS position accuracy statistics for the 7.0 m 1-sigma (13.8 m 95%) UERE value in Table A.4-1 in Appendix A of this *PPS PS* based on dual-frequency use without WAGE at any AOD during normal operations (includes the "traditional" UEE assumption of 7.1 m 95% in Table B.2-1), would be:

12.5 m = 95% Horizontal Position Accuracy
23.1 m = 95% Vertical Position Accuracy

The equivalent classic GPS position accuracy statistics, assuming a 4.7 m 1-sigma (9.2 m 95%) UERE based on the 5.9 m 95% URE value in Table 3.4-1 for dual-frequency use without WAGE over all AODs during normal operations combined with the "traditional specification" UEE assumption of 7.1 m 95% in Table B.2-1, would be:

8.4 m = 95% Horizontal Position Accuracy
15.5 m = 95% Vertical Position Accuracy

More optimistic GPS position accuracy statistics, assuming a 4.0 m 1-sigma (7.7 m 95%) UERE based on the same 5.9 m 95% URE value in Table 3.4-1 for dual-frequency use without WAGE over all AODs during normal operations but now assuming the "improved specification" UEE assumption of 5.0 m 95% in Table B.2-1, would be:

7.0 m = 95% Horizontal Position Accuracy
12.8 m = 95% Vertical Position Accuracy

And, finally, the most optimistic GPS position accuracy statistics assume a 3.0 m 1-sigma (5.9 m 95%) UERE based on the 4.4 m 95% URE value in Table 3.4-1 for dual-frequency with WAGE and the "modern" UEE of 4.8 m 95% as in Table B.2-1 to result in:

6.0 m = 95% Horizontal Position Accuracy
10.8 m = 95% Vertical Position Accuracy

Notes:

1. *The above position accuracies all scale linearly with the UERE or SIS-only URE.*
2. *The above position accuracies are total overall statistics. Because the 9.2 m 95% (4.7 m 1-sigma) UERE value conservatively applies to today's PPS user -- it means that if a PPS user with representative receiver (AIV solution, 5 degree mask, no aiding sensor, traditional UEE) goes out at a random point in time at random location on the surface of the Earth, that PPS user will have a 95% probability of getting a position fix with horizontal accuracy equal to or better than 8.4 m and a vertical accuracy equal to or better than 15.5 m.*

B.3.4 "Current" Position Accuracy Statistics

B.3.4.1 Background for GPS System Specification

The current GPS System Specification, SS-GPS-300F, uses a hybrid approach for specifying position accuracy statistics. In part, it is like the *GPS ORD*. It uses the same HSAT and VSAT concept described in Section B.3.1, but it expresses the specification results in terms of the “required accuracy for a given availability” as opposed to the *GPS ORD* specifying the “required availability for a given accuracy”. For the current GPS System Specification, the given availability value is 99%.

The current GPS System Specification also uses some of the concepts from the classic expanded position accuracy statistics discussed in the previous section. It uses a global ensemble (“global average”) and it uses the same constellation condition probability weighting for all possible 24- through 20-satellite constellations. Unlike the classic expanded position accuracy statistics, the current GPS System Specification ensembles the DOP distributions from each T-S point rather than ensembling the position fix error distributions. The DOP results for the weighted mix of all possible 24- through 20-satellite constellations is shown in Table B.3-3.

Table B.3-3. Global Ensemble DOPs for Weighted Mix of Constellation States

Percentile	HDOP	VDOP	PDOP
50%	0.945	1.535	1.815
60%	0.985	1.625	1.905
67%	1.015	1.695	1.975
75%	1.055	1.795	2.075
80%	1.095	1.865	2.155
90%	1.205	2.085	2.325
95%	1.315	2.305	2.605
97%	1.405	2.475	2.795
98%	1.485	2.625	2.945
99%	1.655	2.925	3.305
99.9%	2.655	5.055	5.595

Notes:

1. *Weighted based on 24 satellites 72.0% of the time, 23 satellites 17.0% of the time, 22 satellites 6.4% of the time, 21 satellites 2.6% of the time, and 20 or fewer satellites 2.0% of the time.*
2. *5 degree mask angle assumed.*

B.3.4.2 GPS System Specification Position Accuracy Statistics

Since the current GPS System Specification uses a given availability of 99% for its position accuracy statistics, the corresponding HDOP value from Table B.3-3 is 1.655 and the VDOP value is 2.925. These HDOP and VDOP values are then used basically as shown in equations (B-9) through (B-14) given earlier in this section to develop position accuracy statistics. With UERE values expressed as 1-sigma quantities, the summary equations are:

$$\begin{aligned}\text{Horizontal R95} &= \text{UERE} \times \text{HDOP} \times 1.73 \\ &= \text{UERE} \times 1.655 \times 1.73 \qquad \text{(B-15)}\end{aligned}$$

$$\begin{aligned}\text{Vertical L95} &= \text{UERE} \times \text{VDOP} \times 1.96 \\ &= \text{UERE} \times 2.925 \times 1.96 \qquad \text{(B-16)}\end{aligned}$$

For equations (B-15) and (B-16), the GPS System Specification uses two different UERE values. The two UERE values are:

a. 4.0 m 1-sigma UERE for dual-frequency PPS use without WAGE over all AODs during normal operations and assuming the "improved specification" UEE assumption of 5.0 m 95% in Table B.2-1 (for a UEE of 2.6 m 1-sigma).

b. 4.8 m 1-sigma UERE for single-frequency PPS use without WAGE over all AODs during normal operations, assuming the "improved specification" UEE assumption of 5.0 m 95% in Table B.2-1 (UEE of 2.6 m 1-sigma), and intentionally ignoring the contribution of the single-frequency ionospheric delay model errors.

Substituting each of these UERE values into equations (B-15) and (B-16), and rounding as appropriate, produces the position accuracy statistics given in the current GPS System Specification as follows.

a. For the 4.0 m 1-sigma UERE:

Horizontal R95 = 11.5 m 95%
Vertical L95 = 23.0 m 95%

a. For the 4.8 m 1-sigma UERE:

Horizontal R95 = 13.7 m 95%
Vertical L95 = 27.5 m 95%

SECTION B.4 Customized PVT Performance Expectations

This section describes some of the methods which can be employed to obtain PVT performance expectations customized to the particular circumstances of an actual "real world" mission. These methods are general suggestions for typical PPS users and applications. They are meant to be informative in the sense of being recipes that can optionally be followed to obtain the desired information. They are not prescriptive in the sense of being procedures that should or must be complied with.

B.4.1 Three Timeframes

There are three time frames over which customized PVT performance expectations are typically desired. They are: (1) in advance of the mission, (2) during the mission, and (3) after the mission. The three time frames, along with the primary reasons customized PVT performance expectations are desired, are illustrated in Figure B.4-1.

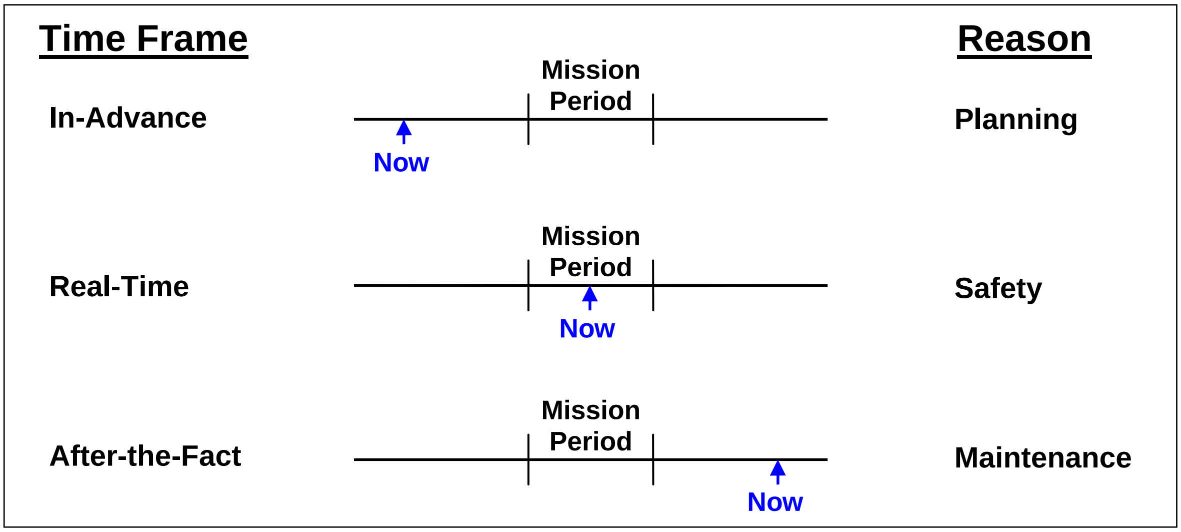


Figure B.4-1. Three Time Frames

Of the three time frames for PVT performance expectations, the most important one is almost always the real-time one. In-advance PVT performance expectations can be important for mission planning (or for interpreting specifications like the *GPS ORD* and the *SPS PS*). After-the-fact PVT performance expectations can be important for determining whether maintenance actions are necessary (e.g., if your PPS receiver suddenly lost accuracy during a mission, was it because the PPS receiver failed or was it because you encountered an unexpected DOP hole?). But real-time PVT performance expectations are almost always the most important because they will alert you when unexpected conditions occur -- particularly conditions which can make the output PVT data unreliable -- and thereby help you safely accomplish your mission using your PPS receiver.

B.4.2 Real-Time PVT Performance Expectations Directly from Your Receiver

The best (and simplest) course of action is to use the real-time PVT performance expectations produced by your PPS receiver whenever possible for your "real world" mission.

B.4.2.1 Real-Time Accuracy Estimates Directly from Your Receiver

Virtually all PPS receivers automatically generate real-time PVT accuracy estimates and output them for your use. This is simple thing for a PPS receiver to do since it already has all the information it needs to generate those PVT accuracy estimates whenever the receiver is turned on and producing a PVT solution: it knows exactly where each Navstar satellite is in the sky, which PPS SISs it is tracking, and which SISs/satellites it is using to produce the PVT solution at each instant in time. Using its own estimate of its current antenna position directly from the PVT solution, the PPS receiver precisely computes the current satellite-to-receiver geometry (all PPS receivers must precisely compute the current satellite-to-receiver geometry in order to produce their PVT solutions). Having already precisely computed the satellite-to-receiver geometry, it only takes a few additional equations to compute and output precise DOP values in real time.

To produce as accurate a PVT solution as possible, a PPS receiver will place more weight on its more accurate measurements and less weight on its less accurate measurements. The weighting factors it uses basically amount to real-time estimates of the UERE for each PPS SIS being used in the PVT solution. The PPS receiver begins by using the URA number transmitted by each satellite (see Subframe 1 in Figure 2.2-1 and paragraph A.5.2 in Appendix A) as the best available estimate of the current URE provided by that satellite's PPS SIS. Following equation B-8, these estimates of the current UREs are then rss-ed with receiver-developed estimates of the current UEEs to produce estimates of the current UERE for each PPS SIS.

Notes:

1. *The currently transmitted URA number is the best estimate of the current URE available to a PPS receiver. The currently transmitted URA number automatically takes the time since last upload into account -- see the "graceful degradation effect" and the normal variations in URE as a function of AOD described in Section A.4. Using the current URA number provides a higher fidelity estimate of the PPS SIS URE than any other method (e.g., using the PPS SIS URE performance standard in Section 3.4). DGPS systems are not a source of better PPS SIS URE estimates. DGPS systems do not broadcast URE estimates, they instead broadcast corrections for the instantaneous UREs along with estimates of the accuracy of those differential corrections (i.e., differential URE estimates, commonly known as “User Differential Range Error” [UDRE] estimates). DGPS correction UDRE estimates are analogous to PPS SIS URE estimates, and DGPS receivers use the broadcast UDRE estimates the same way that a PPS receivers use the transmitted URA numbers.*

2. *The PPS receiver computation of the current estimated UEE varies significantly from receiver to receiver, but all PPS receivers address at least the first four components of the UEE shown in Table B.2-1; namely: (1) ionospheric delay compensation errors, (2) tropospheric delay compensation errors, (3) receiver tracking channel noise and resolution errors, and (4) multipath errors. PPS receivers will also automatically take into account the effects of SA (if any) if the receiver is temporarily operating in an "SPS mode" for any reason.*

With the current satellite-to-receiver geometry and current UERE estimates computed, it is a simple matter for the PPS receiver to perform the multiplications indicated by equations B-2 and B-3 to compute the current UHNE and UVNE values. (Note that equations B-2 and B-3 are not actually used by PPS receivers because the real-time UERE estimates are generally not identical across all pseudorange measurements, but the basic principle still applies and the process will be discussed in terms of equations B-2 and B-3 for simplicity.) For historical reasons, PPS receivers do not use UHNE and UVNE; they use the following terminology instead:

$$EHE = UHNE = UERE \times HDOP \quad (B\text{-}17)$$

$$EVE = UVNE = UERE \times VDOP \quad (B\text{-}18)$$

$$EPE = (EHE^2 + EVE^2)^{½} \quad (B\text{-}19)$$

or

$$EPE = UNE = UERE \times PDOP \quad (B\text{-}20)$$

where:

EHE = Estimated Horizontal Error (2-D, rms, meters)
EVE = Estimated Vertical Error (1-D, rms, meters)
EPE = Estimated Position Error (3-D, rms, meters)

and

UNE = User Navigation Error (3-D, rms, meters)

Note:

1. *In addition to the EHE, EVE, and EPE values, many PPS receivers will also output the full set of numbers which result from the multiplication of the satellite-to-receiver geometry and the individual UERE estimates. This full set of numbers, often called a "covariance matrix", is output over a digital interface. Covariance matrix type outputs are typically used for integrating the output PPS PVT solution with the outputs of another sensor system like an IMU. Covariance matrix type outputs are too complicated to be of use to a human operator. They are therefore beyond the scope of this appendix.*

As seen from equations B-17 through B-20, the PPS receiver does all the work for you in real time. The EHE, EVE, and EPE values output by the PPS receiver in real time are your customized PVT performance expectations. Even if you never need to worry about customized PVT performance expectations in advance or after the fact, it is still important to keep an eye on the EHE, EVE, and EPE values output/displayed by your PPS receiver in real time. If something unanticipated should happen -- like a surprise DOP hole caused by multiple satellite failures, PPS SIS obscuration due to an unforeseen obstruction, or loss of PPS SIS tracking due to RFI (e.g., jamming) -- the EHE, EVE, and EPE values will let you know about it in real time.

In fact, since DOP holes are the most likely cause of an unexpectedly bad PVT solution, and since PPS receivers are so good (reliable) at reporting any DOP holes via the EHE, EVE, and EPE values, the output EHE, EVE, and EPE values are actually the first line of defense for integrity warnings. An unexpectedly bad PVT solution is defined to be an integrity failure unless it is accompanied by a timely warning. The real-time EHE, EVE, and EPE values provide a timely warning whenever an unexpectedly bad PVT solution is caused by a surprise DOP hole. The EHE, EVE, and EPE values are thus what keep surprise DOP holes from becoming integrity failures.

One example would be a PLGR (Precision Lightweight GPS Receiver), also known as an "AN/PSN-11". Those experienced with PLGR operations should recognize the EPE value as the "±number" that appears in the upper right-hand corner of your PLGR's display screen. When the "±number" is displayed, what you are seeing is actually the real-time result of equation B-19 or B-20. And when you set up a "2D-E" alert, you are entering a value that the PLGR will use to compare against its real-time EHE, computed according to equation B-17, to determine whether to issue the alert to you or not. If you have your PLGR configured to display the Figure of Merit (FOM) instead of the EPE in the upper right-hand corner of the display screen, then what you see as the FOM is actually a simplified version of the EPE. The correspondence between the PLGR's computed EPE value and the displayed FOM value is shown in Table B.4-1. Many other PPS receivers also display EPE and FOM this same way.

Table B.4-1. EPE-to-FOM Correspondence

EPE Value	Displayed FOM Value
EPE ≤ 25 m	1
25 m < EPE ≤ 50 m	2
50 m < EPE ≤ 75 m	3
75 m < EPE ≤ 100 m	4
100 m < EPE ≤ 200 m	5
200 m < EPE ≤ 500 m	6
500 m < EPE ≤ 1,000 m	7
1,000 m < EPE ≤ 5,000 m	8
5,000 m < EPE	9

Note:

1. *A widely used rule-of-thumb is to only rely on the output PVT solution when the FOM value equals 1. For a single-frequency PPS receivers like the PLGR, the UERE can be assumed to be on the order of 16.3 m 95% (URE over all AODs, average ionosphere, no WAGE). The corresponding 1-sigma UERE value is 8.3 m. For a FOM value of 1 (or equivalently an EPE value less than or equal to 25 m) with this UERE, the PDOP value would have to be less than or equal to 3.0. This gives rise to a related rule-of-thumb which can be used if the FOM/EPE values are unavailable: "Only rely on a single-frequency PPS receiver's output PVT solution if the PDOP is less than or equal to 3.0."*

B.4.2.2 Real-Time Integrity Estimates Directly from Your Receiver

In addition to automatically generating and outputting real-time PVT accuracy estimates, many modern PPS receivers will also automatically generate and output real-time PVT integrity estimates using a RAIM algorithm whenever possible. There are two parts to every RAIM algorithm: (1) the non-measurement part, and (2) the measurement part.

The non-measurement part of a modern PPS receiver's RAIM algorithm is similar to the receiver's PVT accuracy estimate computation. The inputs are the same: the computed satellite-to-receiver geometry and the current estimated UERE for each PPS SIS. The non-measurement part of the RAIM algorithm determines whether the geometry and the UERE will be good enough to allow the receiver to reliably detect a PPS SIS integrity failure if one were to occur. This basically comes down to a determination whether RAIM is available or not. The geometry and the UERE are used to compute and output a quantity commonly known as the horizontal protection level (HPL). The HPL is the radius of a circle in the horizontal plane which the RAIM algorithm will be able to assure contains the true horizontal position with a very high probability.

Notes:

1. *The HPL does not depend on the actual pseudorange measurements. The HPL does depend on the receiver tracking and using the SISs from at least 5 satellites unless additional sources of aiding information are available.*
2. *The assurance level for a typical RAIM algorithm is set to a miss detection probability of 99.99999% ($1 - 10^{-7}$) per hour, with a false alert probability of 0.00001% (10^{-5}) per hour, based on the PPS SIS standards given in Section 3.*
3. *Some receivers will also compute and output the corresponding vertical protection level (VPL) and/or time protection level (TPL).*

The measurement part of a PPS receiver's RAIM algorithm is where the actual pseudorange measurements from the PPS SISs are used to determine whether a PPS SIS integrity failure has occurred or not. The inputs to the measurement part of the RAIM algorithm are the computed satellite-to-receiver geometry, the current estimated UERE, and the current pseudorange measurements. Some receiver's RAIM algorithms will only detect whether a SIS integrity failure is present or not. Other RAIM algorithms go a step further by computing and outputting a quantity known as the horizontal uncertainty level (HUL). The HUL is similar to the HPL except the HUL reflects the actual errors in the pseudorange measurements.

Notes:

1. *The HUL depends on the receiver tracking and using the SISs from at least 5 satellites unless additional sources of aiding information are available.*

2. *Some receivers will also compute and output the corresponding vertical uncertainty level (VUL) and/or time uncertainty level (TUL).*

3. *Rather than simply using a RAIM algorithm for fault detection (FD), many modern receivers will also use their RAIM algorithm for fault detection and exclusion (FDE). FDE processing requires the receiver to track and use the SISs from at least 6 satellites unless additional sources of aiding information are available.*

There are three basic definitions which govern the integrity implications of the HPL and the HUL with respect to a known horizontal alert limit (HAL) for a particular mission phase (e.g., an aircraft conducting a non-precision approach where the HAL is defined based on the presence of nearby obstacles). These three basic definitions are:

1. RAIM is defined to be available to provide integrity for a particular mission phase whenever the HPL is less than or equal to the HAL for that mission phase (i.e., $\text{HPL} \leq \text{HAL}$).

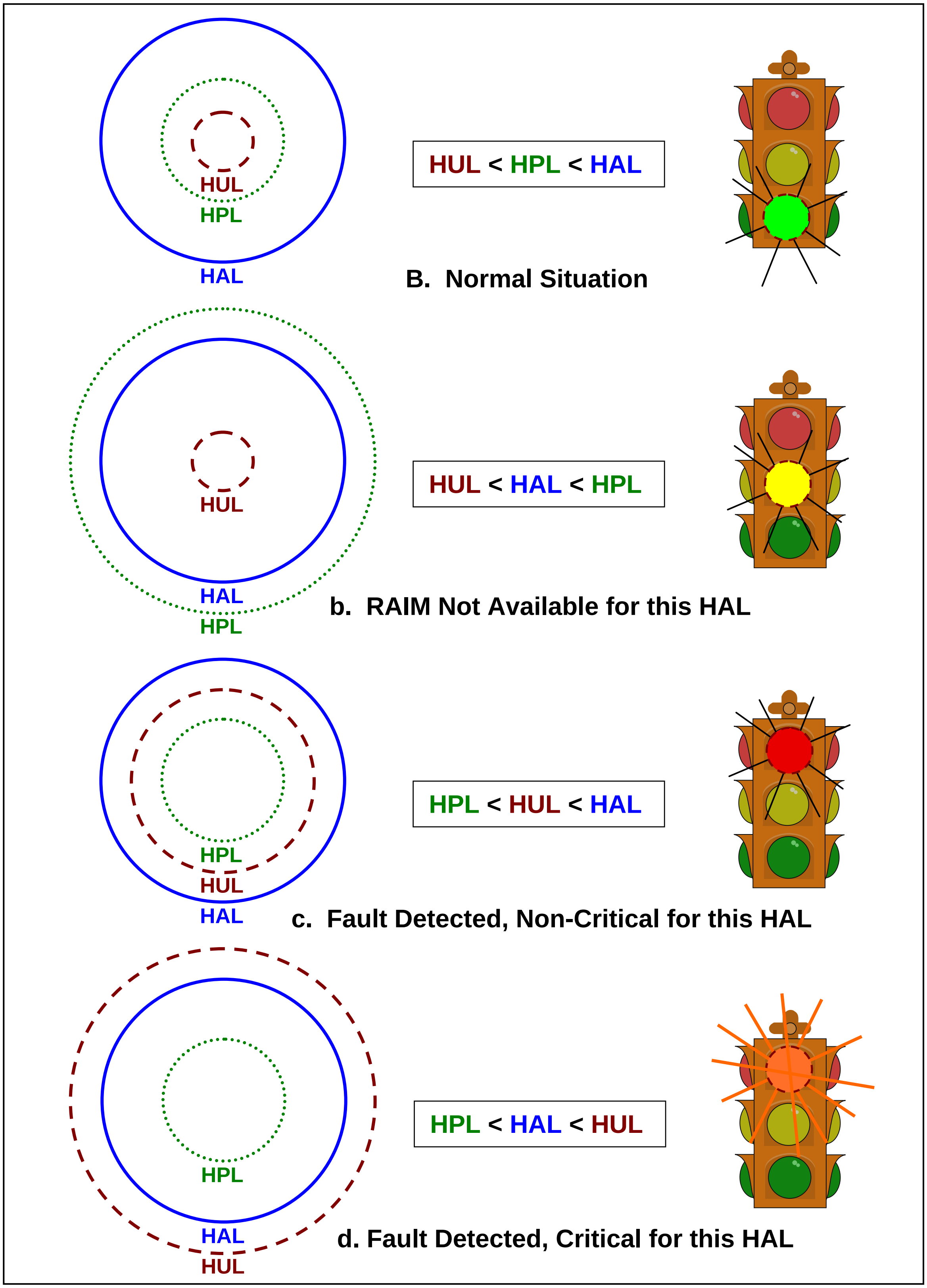
2. A PPS SIS integrity fault is defined to be detected whenever the HUL is greater than or equal to the HPL (i.e., $\text{HUL} \geq \text{HPL}$).

3. A mission-critical PPS SIS integrity fault is defined to be detected for a particular mission phase whenever the HUL is greater than or equal to the HAL for that mission phase (i.e., $\text{HUL} \geq \text{HAL}$).

The three basic definitions governing the integrity implications of the HPL and HUL values output by a PPS receiver with respect to the HAL for a particular mission phase are illustrated in Figure B.4-2 for a variety of situations. The illustrated situations are as follows:

a. The normal situation where $\text{HUL} < \text{HPL} < \text{HAL}$ is illustrated by panel "a" at the top of Figure B.4-2. In this situation, RAIM is available to provide integrity for this mission phase because $\text{HPL} < \text{HAL}$. No PPS SIS integrity fault has been detected because $\text{HUL} < \text{HPL}$. These two integrity implications combine to give an "all systems go" result which is symbolized by the green light on the stoplight icon.

b. Panel "b" shows a situation where RAIM is not strictly available to provide integrity for this mission phase because $\text{HPL} > \text{HAL}$. Even though RAIM is not strictly available, it is still working well enough to determine that no PPS SIS integrity fault is detected because $\text{HUL} < \text{HPL}$. The combination of these two integrity implications gives an "exercise caution" result symbolized by the yellow light on the stoplight icon.



B. Normal Situation

b. RAIM Not Available for this HAL

c. Fault Detected, Non-Critical for this HAL

d. Fault Detected, Critical for this HAL

Figure B.4-2. HPL, HUL, HAL Relationships

c. Panel "c" in Figure B.4-2 shows a situation where RAIM is available because HPL < HAL, and where a PPS SIS integrity fault has been detected because HUL > HPL. The fact that HUL < HAL means that the detected PPS SIS integrity fault is defined as not being mission critical. The combination of these three integrity implications gives a "weak should not use" result symbolized by the dim red light on the stoplight icon.

d. Panel "d" shows a slightly different situation than panel "c". RAIM is still available because HPL < HAL, and a PPS SIS integrity fault has been detected because HUL > HPL. The difference from panel "c" is that HUL > HAL which means the detected PPS SIS integrity fault is mission critical. The combination of these three integrity implications gives a "strong do not use" result symbolized by the bright red light on the stoplight icon.

Different PPS receivers implement their RAIM algorithms in different ways and have different displays for the real-time integrity results. PPS receivers for aviation applications often have HAL values stored in their database for different phases of flight and will provide simple indications (like with the stoplight icon in Figure B.4-2) using flags on the pilot's navigation display. Some handheld PPS receivers let you enter a HAL value and provide simple indications based upon that HAL. Other PPS receivers only output the HPL and HUL values; they leave it up to you to compare those values against whatever HAL you decide is appropriate for your mission phase.

No matter how a PPS receiver implements its RAIM algorithm, if you are using PVT solution from that receiver for any safety critical application -- it is vitally important that you pay heed to the real-time PVT integrity information provided by your receiver. That real-time PVT integrity information will alert you when unexpected conditions occur which make the output PVT solution unreliable and potentially unsafe.

B.4.3 In-Advance PVT Performance Expectations

B.4.3.1 General Rule -- Don't Worry About It

As a general rule, most PPS users do not need customized PVT performance expectations in advance of a mission. There are three main reasons for this general rule.

B.4.3.1.1 <u>Good PPS PVT Performance</u>
The PPS SIS provided by the Navstar satellites is robust enough, and sufficient Navstar satellites are kept healthy in the on-orbit constellation, that good PPS PVT performance can be reasonably be assumed any time of day anywhere in the world. For example, paragraph B.3.3.4 describes the classic position accuracies at a random time, random location, any AOD for a PPS user without WAGE but with traditional UEE as 12.5 m 95% horizontal and 23.1 m 95% vertical averaged over all constellation conditions (from 24 satellites healthy and transmitting a useable PPS SIS to only 20 of 24 satellites healthy and transmitting a useable PPS SIS).

High availability of good accuracy is borne out by the global average DOP values given in Table B.3-1. The usual constellation condition has all 24 baseline satellites healthy and transmitting a useable PPS SIS (or 23 out of 24 baseline satellites healthy and transmitting a useable SIS combined with a few surplus satellites which are also healthy and transmitting a useable SIS). With this constellation condition, Table B.3-1 shows that 99.9% of all the HDOP values will be less than 1.80. Substituting this HDOP value into equation B-2 along with a very conservative 7.0 m 1-sigma UERE value, and translating to an R95 value in accordance with equation B-10 gives:

$$\begin{aligned}\text{UHNE} &= \text{UERE} \times \text{HDOP}\\ &= 7.0\text{ m} \times 1.8\\ &= 12.6\text{ m drms}\end{aligned}$$

$$\begin{aligned} R95 &= \text{UHNE} \times 1.73 \\ &= 12.6 \text{ m drms} \times 1.73 \\ &= 21.8 \text{ m } 95\% \end{aligned}$$

A 99.9% availability of a horizontal accuracy of 21.8 m 95% or better any random time at any random location is pretty good odds. Furthermore, 21.8 m 95% is also quite accurate -- it is more than adequate for many real-world missions. While it is certainly possible to search the entire world to find a location with worse accuracy (e.g., see the "worst case" (single point) HDOP column of Table B.3-1), those locations are the 1-in-2,500 exceptions rather than the rule.

If your mission doesn't require horizontal accuracy better than 12.5 m 95% on average, 21.8 m 95% with high availability, or if you can coast along for a few minutes if you should accidentally encounter one of those rare DOP holes, it isn't worth worrying about customized in-advance PVT performance expectations. The odds are heavily stacked in your favor.

B.4.3.1.2 Repetitive Constellation Geometry

Another good reason for not worrying about customized in-advance PVT performance expectations is prior success using the PPS SIS in your particular area of operations. Remember that the constellation geometry repeats every sidereal day (i.e., 4 minutes earlier each succeeding day because a sidereal day is shorter than a solar or "wall clock" day). Unless something drastic happens -- like a satellite suddenly becoming unhealthy or failing to transmit a useable PPS SIS -- the PVT performance expectations for your operational area will not significantly change from sidereal day to sidereal day. If there is a temporary DOP hole due to a satellite outage, that same DOP hole will repeat every sidereal day until the satellite is restored or the outage is repaired. The PPS performance you got yesterday is a very good predictor of the PPS performance you will get today.

The best, and easiest, way to keep current on satellite health or status changes is by subscribing to the NANUs issued by the Control Segment. The NANUs -- both for satellite health or status changes that are scheduled in advance and for after-the-fact surprises -- are sent directly via e-mail almost the instant they are issued. For military PPS users, you can subscribe to the NANUs at http://www.schriever.af.mil/gps. Civil PPS users can subscribe at http://www.navcen.uscg.gov. Both of these web sites also post the NANUs for subsequent downloading on demand.

B.4.3.1.3 Receiver and Mission Characteristics

Certain types of PPS receivers make worrying about customized in-advance PVT performance expectations unnecessary because the expected PVT performance just doesn't vary all that much. Certain types of missions also make worrying about customized in-advance PVT performance expectations impractical because it takes too much effort to develop reliable expectations. Some representative illustrations include:

a. Time Transfer Receivers. Time transfer receivers, which operate from a known location, are affected by TTDOP rather than TDOP. Fortunately for time transfer performance expectations, the TTDOP variations over time are much smaller than the TDOP variations. So long as the PPS SIS is available from at least two visible satellites (a virtual certainty), the TTDOP will be adequate to give excellent time transfer performance.

b. Waterborne Receivers. PPS receivers used for waterborne missions can normally take advantage of aiding information in the vertical direction when they encounter a DOP hole. For example, the PPS receiver on a ship in the middle of the ocean knows the (calibrated) height of its antenna above sea level. The ability to use this information as an extra measurement effectively "fills in" any DOP holes. As a result, waterborne PPS receivers are not usually subject to significant swings in expected PVT performance.

c. Land Navigation in Obstruction-Rich Environments. Land navigation in an environment, which offers a clear view of the sky in all directions (e.g., flat desert terrain) is one thing, but trying to navigate in an environment with nearby buildings, trees, or other obstructions is another thing altogether. There can be so many obstructions around that they completely block every PPS SIS from reaching your PPS receiver's antenna. Even when there is only one nearby obstruction that only blocks one PPS SIS, the loss of that PPS SIS can radically alter the DOP values. In such obstacle-rich environments, it is difficult to try to predict in advance which satellite's PPS SIS will be blocked and when that blockage will start or end. Obscuration angles are very sensitive to small changes in PPS receiver antenna height and location as shown in Figures B.4-3 and B.4-4 for a nearby obstacle.

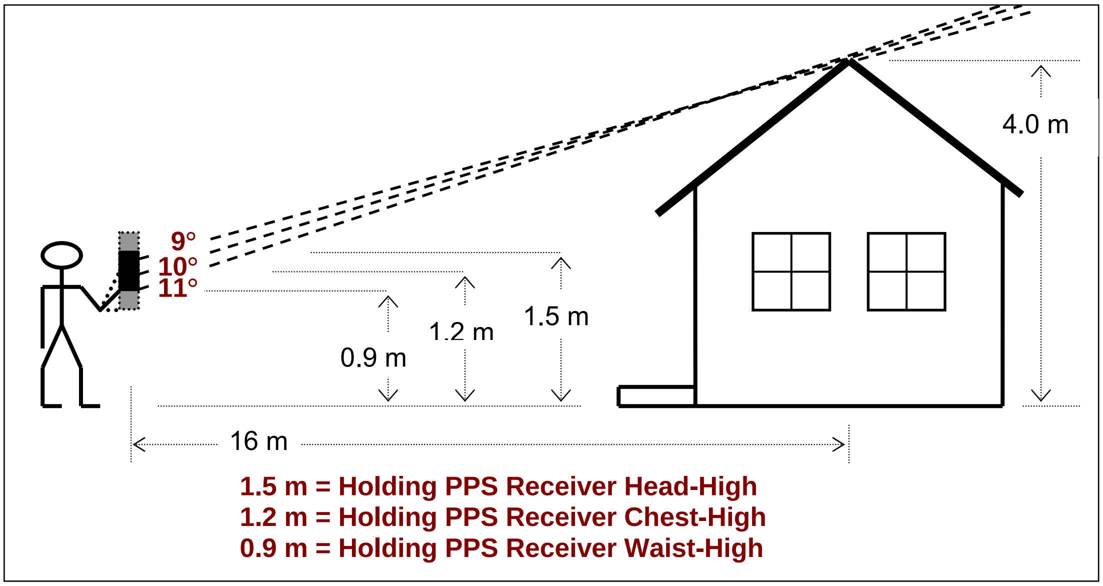


Figure B.4-3. Obscuration Angles versus PPS Receiver Antenna Height

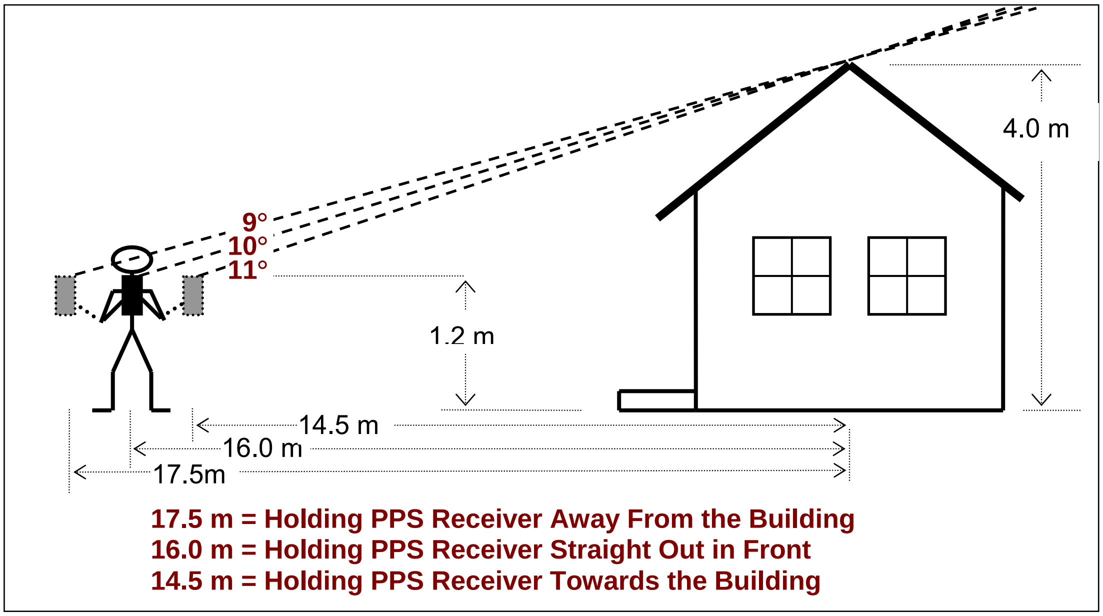


Figure B.4-4. Obscuration Angles versus PPS Receiver Antenna Location

Although it is possible to compute obscuration angles for situations like those in Figures B.4-3 and B.4-4, doing so is generally a wasted effort. Note how accurately you would have to know the height and location of your PPS receiver antenna in order to precisely compute the obscuration angle. If you knew in advance where your PPS receiver antenna was going to be that accurately, then you would already have better height and location information than you are probably going to get from your PPS receiver! Computing obscuration angles and expected DOP values in advance may be a waste of time in these situations, but computing them in real-time is important (as described previously).

B.4.3.2 In-Advance PVT Performance Expectations Directly from Your Receiver

Certain missions which rely on the GPS PPS may be safety-related or critical enough that it is worthwhile to take a simple in-advance look to be sure that the PPS will be available at some future time at some future place to support mission accomplishment. PPS availability is high, but it is not always 100% available everywhere. Accuracy is more available than integrity.

B.4.3.2.1 In-Advance Accuracy Expectations Directly from Your PPS Receiver

Some PPS receivers include provisions to let you define a future time and location and will respond back to you with in-advance accuracy expectations (more properly called in-advance "accuracy predictions"). For example, PLGRs provide a limited accuracy prediction capability via a function called DOP-CALC. The DOP-CALC function uses the almanac data stored in the PLGR's internal memory to compute the time of the best (lowest) predicted PDOP value during the entered time window. So long as the PLGR has collected recent almanac data from one of the satellites (see Subframes 4 and 5 in Figure 2.2-1) and no PPS SISs have failed since that almanac data was generated by the Control Segment, the predicted PDOP values will be very accurate. PLGRs do not, however, store estimated UERE values in their internal memory. This is why the PLGR's accuracy prediction capability is limited to computing and displaying just the predicted PDOP values.

Generally speaking, being limited to predicted PDOP values is not too significant for mission planning purposes in the field. In-advance predictions can never do better than use the "transmitted on-orbit average" URE values (see paragraph B.2.3.4) for each satellite's PPS SIS. Since averaging the satellite-transmitted URA numbers over time is difficult to do under field conditions, the normal approximations are: (1) that all PPS SISs have the same UERE value, and (2) that an appropriate 1-sigma UERE value can be developed from Table 3.4-1 and Table B.2-1 for the particular type of PPS receiver in use. Under these approximations, it is easy enough to simply follow equation B-20 and multiply the predicted PDOP value from the PPS receiver by the appropriate 1-sigma UERE value. For example, since the PLGR is a single-frequency P(Y)-code receiver that usually operates without the benefits of WAGE, an appropriate 1-sigma UERE value could be 8.3 m. Multiplying the PLGR's predicted PDOP by 8.3 m gives a reasonable estimate of the predicted EPE value (e.g., a predicted PDOP of 3.0 times a UERE of 8.3 m 1-sigma gives a predicted EPE of 25 m).

B.4.3.2.2 In-Advance Integrity Expectations Directly from Your PPS Receiver

Some PPS receivers -- particularly avionics PPS receivers -- include provisions to let you define a future time and location and will respond back to you with in-advance integrity predictions. This capability is usually called "predictive RAIM".

For in-advance use, an avionics PPS receiver can use its RAIM algorithm to compute predicted HPL values but it cannot compute predicted HUL values. The HUL computation requires actual pseudorange measurements which are obviously not available in advance. The HPL computation only requires satellite-to-receiver geometry and UERE estimates. Just for accuracy predictions, the satellite-to-receiver geometry can be computed in-advance from the almanac data stored in the receiver's internal memory. The UERE estimates for the particular type of PPS receiver can be developed in a manner comparable to Table B.2-1 and stored in the receiver's internal memory as a uniform number to be applied to all PPS SISs. Most avionics PPS receivers which provide this predictive RAIM capability allow you to select your destination airport and your estimated time of arrival (ETA), and will respond with an automatic "RAIM YES/NO" determination over a window of time surrounding your ETA. The automatic "RAIM YES/NO" determination is made by comparing the predicted HPL value against a HAL value of 0.3 nm for the non-precision approach phase of flight.

Notes:

1. *Using a hard-coded, uniform UERE value is not as realistic as using "transmitted on-orbit average" URE values along with receiver-specific UEE values, but it has been found to be sufficient for in-the-cockpit predictions.*

2. *For additional information on this predictive RAIM capability, see MSO-C129a, TSO-C129, and TSO-C129A.*

B.4.3.3 In-Advance PVT Performance Expectations from a Computer Model

If you must worry about high-fidelity in-advance PVT performance predictions, whether for accuracy or for integrity, then you can use a computer model. There are customized computer models and general purpose computer models.

B.4.3.3.1 Customized PPS Computer Model

If your mission requires you to frequently use high-fidelity PVT performance predictions, then odds are that you will have been provided with a computer model that is set up specifically for your particular PPS receiver. Your computer model may very well be an integral part of the mission planning system you use -- there is a natural synergy between the two because your mission planning system already knows when and where you want to go which is the same as knowing the T-S points for which the PVT performance predictions must be computed. For the highest fidelity PVT performance expectations, your computer model may be integrated with portions of the actual PPS receiver software.

You will need to provide the customized computer model with the appropriate almanac data for the Navstar satellites along with the satellite health settings in effect during the time window of interest. The daily almanac data is available for downloading from either https://www.schriever.af.mil/gps/index.asp or http://www.navcen.uscg.gov . Both of these web sites also have the NANUs which give the dates and times for projected changes in the satellite health settings. For higher fidelity (if possible), you may also want to provide the computer model with the "transmitted on-orbit average" PPS URE values (see paragraph B.2.3.4) for each satellite's PPS SIS. Estimated PPS SIS URE values averaged over a day can be found at http://gps.afspc.af.mil/gpsoc/ ; these URE values can be input to a moving average filter to compute the higher-fidelity "transmitted on-orbit average" PPS URE values. You won't need to know too much about the PPS receiver itself (satellite selection algorithm, UEE values, mask angle, etc.), since that information will have been built directly into your customized computer model.

Notes:

1. *The daily almanac data from the indicated web sites is available in two formats: the SEM format and the Yuma format. Although the information is basically the same as what the satellites broadcast via the PPS SIS, the two formats are not interchangeable. Be sure to download the right format for your customized computer model.*

2. *The SEM format almanac data from both the indicated web sites already has the "transmitted on-orbit average" PPS URA values built into it.*

3. *The highest fidelity will generally be achieved with the almanac data time tagged just prior to the window of interest. Using almanac data from preceding days or following days not recommended due to the potential for satellite repositioning events which will invalidate previous valid almanac data.*

B.4.3.3.2 General-Purpose GPS Computer Model

If you don't have a customized computer model for your PPS receiver, you can use a general-purpose GPS computer model; however, you'll have to know some details about your PPS receiver to set up the computer model right to get good results. In addition to the proper almanac data, health settings, and URE estimates for the satellites, you will also need to know some details about your PPS receiver which were described in general in Section B.2. Those PPS receiver details are:

a. The PPS receiver algorithm for selecting the subset of visible satellite SISs to be used in the PVT solution or time transfer solution.

b. What PPS SISs the receiver can/will use for generating its PVT solution or time transfer solution (e.g., L1/L2 or L1-only, P(Y)-Code or C/A-code, carrier-and-code or code-only). If this information is not available, then a reasonable alternative is the specified UEE value for the particular PPS receiver.

c. Whether the PPS receiver can use aiding data (especially details about using vertical aiding).

d. The PPS receiver's internal mask angle (or its satellite visibility algorithm).

e. The maximum number of PPS SISs that can/will be used in the PVT solution or time transfer solution.

B.4.4 After-the-Fact PVT Performance Expectations

If you need after-the-fact PVT performance expectations customized to a particular circumstance, then you can use a computer model like those described in the preceding section. The process is usually the same. Occasionally, there are a few exceptions.

For high-fidelity after-the-fact PVT performance expectations, you will want to provide the computer model with the actual URA numbers from the PPS SISs during the time window of interest. Most modern PPS receivers use those URA numbers to compute the weighting factors which modify the position solution as well as the effective satellite-to-user geometry. Without the actual URA numbers, the computer model will not be able to replicate what the PPS receiver did in computing its weighted DOPs.

Depending on the reason for needing after-the-fact PVT performance expectations, it may be necessary to simulate actual PPS SIS pseudorange errors (instantaneous UREs) if the problem being investigated is related to a PPS SIS integrity failure. Sometimes, short-duration PPS SIS outages (e.g., short periods of non-standard P(Y)-code or non-standard C/A-code) may need to be simulated. Occasionally, a computer model which handles terrain blockage or unusual receiving antenna orientations may be required. Experience has shown that RFI is often a cause of unexpected PVT performance; specialized computer models which address PPS SIS signal strength can be useful in these cases.

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GLOBAL POSITIONING SYSTEM PRECISE POSITIONING SERVICE PERFORMANCE STANDARD

APPENDIX C

KEY TERMS, DEFINITIONS, ABBREVIATIONS AND ACRONYMS

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

February 2007

Integrity - Service - Excellence

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TABLE OF CONTENTS

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SECTION C.1 Key Terms

Alarm. An indication requiring an immediate response (e.g., to preserve integrity).

Alert. Generic term encompassing both alarm and warning.

Alerted Misleading Signal-in-Space Information (AMSI). The pseudorange or NAV data provided by a PPS SIS provides alerted MSI (AMSI) when the instantaneous URE exceeds the SIS URE NTE tolerance but a timely alert (alarm or warning) is provided.

Authorized User. A user whose GPS receiver both contains current valid PPS keys and has the requisite hardware/software capabilities to be able to properly use those PPS keys. Also known as a PPS user.

Baseline Constellation. Navstar satellites deployed in the defined baseline orbital slots. Each orbital slot is characterized by a near one-half sidereal day period such that the orbit ground trace repeats each sidereal day. The orbital slots are organized by the orbit plane, with each orbit plane having multiple slots and each slot having a unique orbital ground trace. In the baseline 24-slot constellation, there are six orbit planes, each with four slots.

Baseline Satellite. An operational Navstar satellite occupying a defined orbital slot in the baseline constellation. Not all operational satellites occupy slots in the baseline constellation, and not all slots in the baseline constellation are necessarily occupied by an operational satellite. The PPS SIS broadcast by a baseline satellite is required to meet all of the standards in Section 3.

Block II Satellites. The current deployed constellation consists entirely of Block II series Navstar satellites. For the purposes of these performance standards, the Block II satellite and succeeding generations of the Block II (the IIA, IIR, IIR-M, and IIF) provide an identical service.

Dilution of Precision (DOP). The magnifying effect on GPS position error induced by mapping URE into a position solution within the specified coordinate system, through the relative satellite-to-receiver geometry. The DOP may be expressed in any user local coordinate system desired. Examples include HDOP for local horizontal, VDOP for local vertical, PDOP for local horizontal and vertical together, and TDOP for time.

Expanded Constellation. Navstar satellites deployed in a constellation with at least one of the defined-as-expandable baseline orbital slots in its expanded configuration. There are 7 variations of the expanded constellation: 3 variations with 1 expanded slot (25 orbital locations), 3 variations with 2 expanded slots (26 orbital locations), and 1 variation with 3 expanded slots (27 orbital locations).

Expanded Baseline Satellite. An operational Navstar satellite occupying a defined-as-expandable baseline orbital slot in its expanded configuration. There can be up to 6 expanded baseline satellites at any one time.

Full Operational Capability (FOC). Full Operational Capability (FOC) was achieved on 27 April 1995 when the GPS satellite constellation met all of its specified requirements. The DoD formally announced the achievement of FOC to the public on 17 July 1995.

Geometric Range. The difference between the location of a Navstar satellite and the location of a GPS receiver.

Global Average. The rms value of an algebraically signed performance metric or characteristic (e.g., instantaneous URE) over the specified coverage (e.g., Navstar satellite footprint).

GPS Time. A continuous time scale maintained by the GPS Control Segment which began at midnight on the night of 5/6 January 1980 on the Coordinated Universal Time (UTC) scale as established by the U.S. Naval Observatory (USNO).

Hazardously Misleading Information (HMI). The errors in the position solution output by a PPS receiver exceed the user's particular tolerance for error in the current application.

Healthy Satellite. An operational Navstar satellite which is transmitting a healthy PPS SIS. A healthy PPS SIS is a usable PPS SIS which: (a) is not subject to a PPS alert indication, (b) indicates the satellite is healthy in the 6-bit health status word in subframe 1 of the navigation (NAV) message data, (c) does not indicate a URA index "N" value of 15, and (d) does not indicate a User Range Accuracy (URA) alert.

Initial Operational Capability (IOC). Initial Operational Capability (IOC) was declared on 8 December 1993 when the DoD formally made the SPS available to the DOT.

Instantaneous User Range Error (URE). An instantaneous URE is the difference between the expected pseudorange as derived from the NAV message data, and the pseudorange measured at a given location assuming a receiver clock that is perfectly calibrated to GPS time. A SIS URE includes only those error budget components assigned to the GPS Space and Control Segments. A system URE (more commonly known as a User Equivalent Range Error, or UERE) contains all line-of-sight error budget components, to include the spatially dependent SIS URE, ionosphere delay compensation error, troposphere delay compensation error, multipath, and receiver noise. P(Y)-code based PPS SIS UREs differ from SPS SIS UREs in that the SPS SIS URE contains a bias error that exists between the P(Y)-code and the C/A-code on L1.

Major Service Failure. A condition during which the PPS SIS from a healthy Navstar satellite's instantaneous URE exceeds the SIS URE not-to-exceed (NTE) tolerance without a timely alert (alarm or warning) being provided. Also known as a UMSI event.

Misleading Signal-in-Space Information (MSI). The pseudorange or NAV data provided by a PPS SIS provides Misleading Signal-in-Space Information (MSI) when the instantaneous URE exceeds the SIS URE NTE tolerance.

Modernized Block II Satellites. This edition of the *PPS PS* does not address the future PPS signals (e.g., M-code) that will be transmitted by Modernized Block II satellites (the IIR-M and IIF).

Navigation (NAV) Message Data. The data provided to a GPS receiver via each satellite's SIS containing the satellite's predicted clock correction polynomial ("clock"), the satellite's predicted orbital elements ("ephemeris"), a reduced-precision subset of the clock and ephemeris data for all operational satellites in the constellation ("almanac"), pseudorange correction data, parameters relating GPS time to UTC, single-frequency ionospheric correction model parameters, and satellite status information. Detailed definitions of the NAV data are provided in IS-GPS-200. Classified NAV data definitions are provided in ICD-GPS-224 and in ICD-GPS-225.

95th Percentile (95%) URE. A statistical measurement of the instantaneous URE performance sampled over some interval. The 95% URE can apply to an individual satellite or to an ensemble of satellites (e.g., all operational satellites in the constellation).

Operational Satellite. A Navstar satellite which is capable of transmitting, but is not necessarily currently transmitting, a usable ranging signal. For the purposes of these performance standards, any satellite in the transmitted navigation message almanac is considered an operational satellite.

Satellite Outage. A satellite outage occurs when a Navstar satellite either stops transmitting a usable PPS SIS or the PPS SIS becomes unhealthy.

SatZap. A manual technique used by the Control Segment to temporarily remove a Navstar satellite from service by commanding the satellite to substitute transmission of PRN P(Y)-code number 37 for its standard P(Y)-code and substitute transmission of PRN C/A-code number 37 for its standard C/A-code.

Precise Positioning Service (PPS). The GPS broadcast signals based on the L1 P(Y)-codes, L1 C/A-codes, and L2 P(Y)-codes, as defined in IS-GPS-200, ICD-GPS-224 and ICD-GPS-225, providing constellation performance to authorized users, as established in this *PPS Performance Standard (PPS PS)*, in accordance with U.S. Government policy.

PPS Signals. Electromagnetic signals originating from an operational satellite. The PPS signals consist of a Pseudorandom Noise (PRN) C/A-code with NAV data to support the PVT solution generation process on the GPS L1 frequency; a PRN P(Y)-code with identical NAV data to support the PVT solution generation process on the GPS L1 frequency; and a PRN P(Y)-code with identical NAV data to support the PVT solution generation process on the GPS L2 frequency. A brief summary of the GPS PPS signals is provided in Section 2. Formal definitions of the PPS signals are provided in IS-GPS-200, ICD-GPS-224, and ICD-GPS-225.

PPS Signal Ranging Measurement. The difference between the PRN code time of reception (as defined by the PPS receiver's clock) and the PRN code time of transmission (as defined by the satellite's clock) adjusted to GPS system time using the satellite clock correction polynomial and related data contained within the satellite's NAV data multiplied by the speed of light. Also known as the pseudorange.

PVT Solution. The use of pseudorange measurements and NAV data from at least four SISs to solve for three position coordinates and time offset relative to GPS time, plus three velocity coordinates and frequency offset relative to GPS time. In cases where the altitude is known (e.g., maritime GPS receivers), the PVT solution only requires the use of pseudorange measurements and NAV data from at least three SISs to solve for two position coordinates and time offset relative to GPS time, plus two velocity coordinates and frequency offset relative to GPS time.

Root Mean Square (RMS) URE. A statistical measurement of the instantaneous URE performance sampled over some interval. The RMS URE can apply to an individual satellite or to an ensemble of satellites (e.g., all operational satellites in the constellation).

Selective Availability (SA). Protection technique employed by DoD to deny full system accuracy to unauthorized users. On May 1, 2000, President Clinton announced the discontinuance of SA effective midnight 1 May 2000. The effects of SA went to zero at 0400 UTC on 2 May 2000.

Service Disruption. A condition over a time interval during which one or more PPS performance standards are not satisfied.

SIS URE. The SIS URE includes only those pseudorange error budget components assigned to the GPS Space and Control Segments. The SIS URE can be expressed in different ways; e.g., on an instantaneous basis (see the definition of *instantaneous URE*) or on a statistical basis (see the definition of *RMS URE*).

Space Service Volume. One of the two spatial volumes addressed by this *PPS PS.* The space service volume extends from 3,000 km above the surface of the earth up to and including 36,000 km above the earth’s surface.

Standard Positioning Service (SPS). The GPS broadcast signals based on the L1 C/A-codes, as defined in IS-GPS-200, providing constellation performance to peaceful civil, commercial, and scientific users, as established in the *SPS Performance Standard (SPS PS)*, in accordance with U.S. Government policy.

Surplus Satellite. An operational Navstar satellite that is not occupying a defined orbital slot in the baseline constellation or an expanded constellation. Surplus satellites are typically either newly launched satellites waiting to take their place in the baseline/expanded constellation, or are older satellites which are nearing the end of their useful lives and have been shifted out of the baseline/expanded constellation. The PPS SIS broadcast by a surplus satellite is not required to meet all of the standards in Section 3.

Terrestrial Service Volume. One of the two spatial volumes addressed by this *PPS PS*. The terrestrial service volume covers the entire surface of the Earth up to an altitude of 3,000 kilometers. The terrestrial service volume is thus global.

Unalerted Misleading Signal-in-Space Information (UMSI). The pseudorange or NAV data provided by a PPS SIS provides unalerted MSI (UMSI) when the instantaneous URE exceeds the SIS URE NTE tolerance without a timely alert (alarm or warning) being provided.

Unauthorized User. A user whose GPS receiver: (1) does not contain current valid PPS keys, or (2) does not have the requisite hardware/software capabilities to be able to use PPS keys. Also commonly considered to be an SPS user.

Usable PPS Signals. PPS signals which can be received, processed, and used in a PVT solution by a receiver with minimum PPS receiver capabilities.

User Range Accuracy (URA). The URA is a conservative representation of each satellite's expected RMS URE performance based on historical data over the curve fit interval represented by the NAV data from which the URA is read. The URA is a coarse representation of the URE statistic, in that it is quantized to the levels represented by the URA index "N" as defined in ICD-GPS-224, ICD-GPS-225, and IS-GPS-200.

Warning. An indication requiring prompt attention (e.g., to preserve integrity).

SECTION C.2 Definitions

Accuracy. Accuracy is defined to be the statistical difference between the estimate or measurement of a quantity and the true value of that quantity. For the purposes of this *PPS PS*, the PPS SIS quantities are the pseudorange, the pseudorange rate (velocity), and the pseudorange rate rate (acceleration). The statistical differences are expressed either as 95th percentile (95%) differences or as RMS differences.

Availability. Availability is defined as the percentage of time that the PPS SISs are available to a PPS receiver. Availability can be expressed in different ways; e.g., on a per-satellite basis or on per-constellation basis.

Continuity. Continuity is defined to be the probability that an available and healthy PPS SIS will continue to be available and healthy without unscheduled interruption over a specified time interval. PPS SIS continuity is directly related to PPS SIS reliability.

Coverage. The surface area or spatial volume where the PPS SISs are intended to be provided in a manner to meet the specified level of accuracy. The coverage for the PPS SISs is the terrestrial service volume.

Integrity. Integrity is a measure of the trust which can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of the PPS SIS to provide timely alerts (alarms or warnings) to receivers when the PPS SIS should not be used. PPS SIS integrity is directly related to PPS SIS reliability

Reliability. Reliability is the ability of a PPS SIS to perform its required functions over a specified time interval. Reliability includes continuity and integrity.

UTC(USNO) Accuracy. The PPS SIS UTC(USNO) time accuracy is defined to be the statistical difference, at the 95th percentile, between the parameters contained in the PPS SIS which relate GPS time to UTC as maintained by the USNO and the true value of the difference between GPS time and UTC(USNO). Also known as the UTC Offset Error (UTCOE).

SECTION C.3 Abbreviations and Acronyms

- A -

A	Alongtrack
14 AF	14th Air Force (AFSPC)
AFSPC	Air Force Space Command
AII	Accuracy Improvement Initiative
AIV	All-In-View (GPS receiver SIS tracking capability)
AMSI	Alerted Misleading Signal-in-Space Information
AN/PSN-11	Military equipment designator for the PLGR
AOD	Age of Data (with regards to NAV message data or WAGE NMCT data)
AOO	Area of Operations

- B -

BPSK	Bi-Phase Shift Key
BMCS	Backup Master Control Station (part of the OCS)

- C -

C	Crosstrack
c	Speed of light (2.99792458×10^8 m/sec)
C/A-code	Coarse/Acquisition PRN ranging code
CS	Control Segment
CUT	Contingency Upload Threshold
CV	Constellation Value

- D -

1-D	One-Dimensional
2-D	Two-Dimensional
3-D	Three-Dimensional
dBW	Decibels with respect to one Watt
DGPS	Differential GPS
DoD	Department of Defense
DOP	Dilution Of Precision
DOT	Department of Transportation

- E -

EOL	End of Life
ETA	Estimated Time of Arrival
EHE	Estimated Horizontal Error
EPE	Estimated Position Error
EVE	Estimated Vertical Error

- F -

FOC	Full Operational Capability
FOM	Figure of Merit

- G -

GA	Ground Antenna (part of the OCS)
GDOP	Geometric Dilution Of Precision
GEC	Groundtrack Equatorial Crossing (satellite orbital parameter)
GLAN	Geographic Longitude of the Ascending Node (satellite orbital parameter)
GNSS	Global Navigation Satellite System (GPS is one of many different GNSSs)
GPS	Global Positioning System
GPSW	Global Positioning Systems Wing

- H -

HAL	Horizontal Alert Limit (for RAIM)
HDOP	Horizontal Dilution Of Precision
HDOP-AT	Horizontal Dilution Of Precision - Availability Threshold (a DOP limit)
HMI	Hazardously Misleading Information
HOW	Handover Word (part of the NAV message)
HPL	Horizontal Protection Level (from RAIM)
HSAT	Horizontal Service Availability Threshold (an accuracy limit)
HUL	Horizontal Uncertainty Level (from RAIM)

- I -

ICD	Interface Control Document
IMU	Inertial Measurement Unit
IOC	Initial Operational Capability
IODC	Index of Data Clock (part of the NAV message)
IODE	Index of Data Ephemeris (part of the NAV message)
IS	Interface Specification

- J -

JPO	Joint Program Office (predecessor of the GPSW)
JSSMO	Joint Service System Management Office

- K -

- L -

L1	The SIS centered at the 1575.42 MHz frequency
L2	The SIS centered at the 1227.60 MHz frequency
L95	95th percentile of a Linear distribution (e.g., vertical position error)

LOAN	Launch On Anticipated Need (a philosophy for constellation sustainment)
LON	Launch On Need (a philosophy for constellation sustainment)
LSB	Least Significant Bit
LT	Long Term
LTS	Long Term Scheduled (type of outage)
LTS	Launch To Sustain (a philosophy for constellation sustainment)
LTU	Long Term Unscheduled (type of outage)

- M -

MCS	Master Control Station (part of the OCS)
MS	Monitor Station (part of the OCS)
MSB	Most Significant Bit
MSI	Misleading Signal-in-Space Information
MTBF	Mean Time Between Failure
MTBLOC	Mean Time Between Loss of Continuity

- N-

NANU	Notice Advisory to Navstar Users
NATO	North Atlantic Treaty Organization
NAV	Navigation (as in "NAV message")
NGA	National Geospatial-Intelligence Agency
NMCT	NAV Message Correction Table (part of WAGE)
NOTAM	Notice to Airmen
NSC	Non-Standard C/A-code
nsec	Nanosecond
NSY	Non-Standard Y-code
NTE	Not To Exceed (i.e., a tolerance limit)
NWT	No Worse Than

- O -

OCS	Operational Control System
O&M	Operations and Maintenance

- P -

P-code	Unencrypted Precise PRN ranging code
PDOP	Position Dilution of Precision
PLGR	Precision Lightweight GPS Receiver (AN/PSN-11)
PPS	Precise Positioning Service
PRN	Pseudorandom Noise (a characteristic of the SIS ranging codes)
PS	Performance Standard (as in *PPS PS* or *SPS PS*)
PVT	Position, Velocity, and Time
P(Y)-code	Precise PRN ranging code (unencrypted or encrypted)

- Q -

- R -

R	Radial
R95	95th percentile of a Radial distribution (e.g., horizontal position error)
RAAN	Right Ascension of the Ascending Node (satellite orbital parameter)
RAC	Radial-Alongtrack-Crosstrack (orbital coordinate system)
RAIM	Receiver Autonomous Integrity Monitoring
RCM	Requirements Correlation Matrix
RF	Radio Frequency
RFI	Radio-Frequency Interference
rms	Root-Mean-Square
RNP	Required Navigation Performance
rss	Root-Sum-Square

- S -

SA	Selective Availability
SAT	Service Availability Threshold (an accuracy limit)
SEM	System Effectiveness Model
SEP	Spherical Error Probable (3-D accuracy, 50th percentile)
SIS	Signal In Space
2 SOPS	2nd Space Operations Squadron (AFSPC)
SPS	Standard Positioning Service
SS	Space Segment
ST	Short Term
STS	Short Term Scheduled (type of outage)
STU	Short Term Unscheduled (type of outage)
SV	Space Vehicle (e.g., Navstar satellite)
50 SW	50th Space Wing (AFSPC)

- T -

TDOP	Time Dilution Of Precision
T_{GD}	Group Delay Time correction (for single-frequency receivers)
TLM	Telemetry Word (part of the NAV message)
TPL	Time Protection Level (from RAIM)
T-S	Time-Space (description of a point)
TTA	Time to Alert
TT&C	Telemetry, Tracking, and Commanding
TTDOP	Time Transfer Dilution of Precision
TUL	Time Uncertainty Level (from RAIM)

- U -

UE	User Equipment (i.e., GPS receiver, antenna, display system, etc.)
UEE	User Equipment Error (pseudorange inaccuracy due to the receiver)
UERE	User Equivalent Range Error (total pseudorange inaccuracy)
UERRE	User Equivalent Range Rate Error (total pseudorange rate inaccuracy)
UHNE	User Horizontal Navigation Error (user horizontal position error)
UHVE	User Horizontal Velocity Error

UMSI	Unalerted Misleading Signal-in-Space Information
UNE	User Navigation Error (user 3-D position error)
URA	User Range Accuracy (a parameter in the NAV message)
URE	User Range Error (pseudorange inaccuracy due to the SIS)
URRE	User Range Rate Error (pseudorange velocity inaccuracy due to the SIS)
URRRE	User Range Rate Rate Error (pseudorange acceleration inaccuracy due to the SIS)
U.S.	United States (of America)
USAF	U.S. Air Force
USSTRATCOM	U.S. Strategic Command
USNO	U.S. Naval Observatory
UTC	Coordinated Universal Time (the acronym comes from the French)
UTCOE	UTC(USNO) Offset Error (relative to GPS time)
UTE	User Time Error (relative to GPS time)
UUTCE	User UTC(USNO) Error
UVNE	User Vertical Navigation Error (user vertical position error)
UVVE	User Vertical Velocity Error

- V -

VDOP	Vertical Dilution Of Precision
VDOP-AT	Vertical Dilution Of Precision - Availability Threshold (a DOP limit)
VPL	Vertical Protection Level (from RAIM)
VSAT	Vertical Service Availability Threshold (an accuracy limit)
VUL	Vertical Uncertainty Level (from RAIM)

- W -

WAGE	Wide Area GPS Enhancement
WGS-84	World Geodetic System - 1984

- X -

- Y -

Y-code	Encrypted Precise PRN ranging code

- Z -

ZAOD	Zero Age Of Data (a categorization of error or accuracy)