GPS+
Reference
Manual

GPS+ Reference Manual

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Chapter 1 GPS Overview

The Global Positioning System (GPS) is a satellite navigation system capable of providing a highly accurate, continuous global navigation service independent of other positioning aids. GPS provides 24-hour, all-weather, worldwide coverage with position, velocity and timing information.

The system uses the NAVSTAR (NAVigation Satellite Timing And Ranging) satellites which consists of 24 operational satellites to provide a GPS receiver with at least six satellites in view at all times. A minimum of four satellites in view are needed to allow the receiver to compute its current latitude, longitude, altitude with reference to mean sea level and the GPS system time.

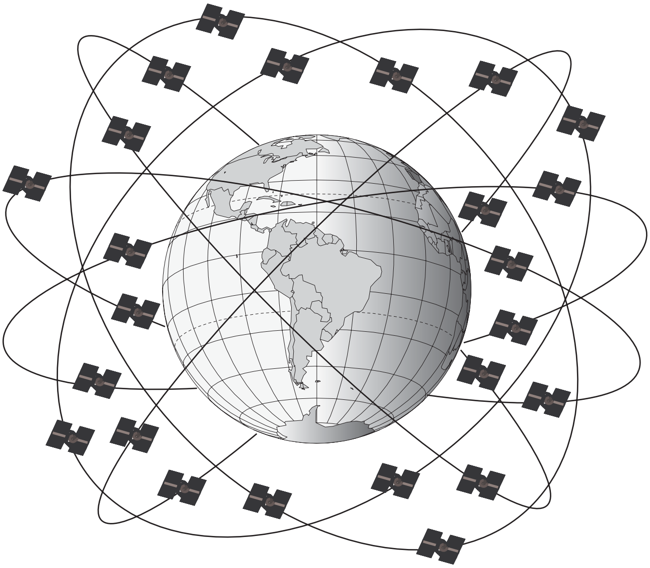


Figure 1: NAVSTAR Satellite Orbit Arrangement

1.1 GPS System Design

The GPS system design consists of three parts:

- The Space segment
- The Control segment
- The User segment

All these parts operate together to provide accurate three dimensional positioning, timing and velocity data to users worldwide.

1.1.1 The Space Segment

The space segment is composed of the NAVSTAR GPS satellites. The constellation of the system consists of 24 satellites in six 55° orbital planes, with four satellites in each plane (plus room for spares). The orbit period of each satellite is approximately 12 hours at an altitude of 20 183 kilometers. This provides a GPS receiver with at least six satellites in view from any point on earth, at any particular time.

The GPS satellite signal identifies the satellite and provides the positioning, timing, ranging data, satellite status and the corrected ephemerides (orbit parameters) of the satellite to the users. The satellites can be identified either by the Space Vehicle Number (SVN) or the Pseudorandom Code Number (PRN). The PRN is used by the NovAtel receiver.

The GPS satellites transmit on two L-band frequencies; one centered at 1575.42 MHz (L1) and the other at 1227.60 MHz (L2). The L1 carrier is modulated by the C/A code (Coarse/Acquisition) and the P code (Precision) which is encrypted for military and other authorized users. The L2 carrier is modulated only with the P code.

1.1.2 The Control Segment

The control segment consists of a master control station, five base stations and three data up-loading stations in locations all around the globe.

The base stations track and monitor the satellites via their broadcast signals. The broadcast signals contain the ephemeris data of the satellites, the ranging signals, the clock data and the almanac data. These signals are passed to the master control station where the ephemerides are re-computed. The resulting ephemerides corrections and timing corrections are transmitted back to the satellites via the data up-loading stations.

1.1.3 The User Segment

The user segment, such as the NovAtel receiver, consists of equipment which tracks and receives the satellite signals. The user equipment must be capable of simultaneously processing the signals from a minimum of four satellites to obtain accurate position, velocity and timing measurements.

1.2 Height Relationships

What is a geoid?

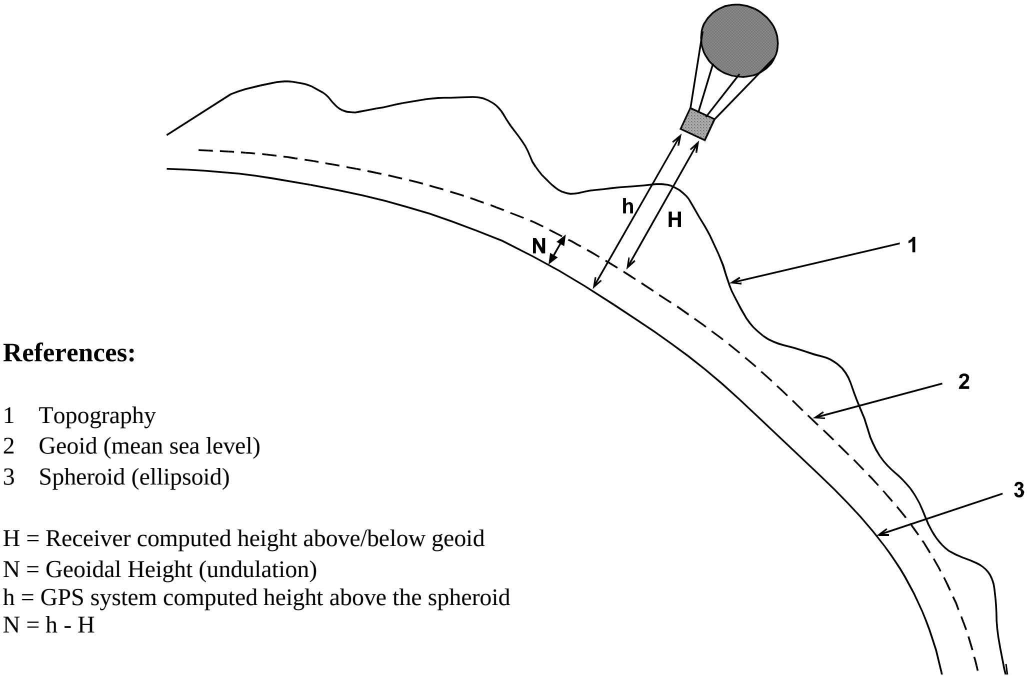
An equipotential surface is any surface where gravity is constant. This surface best represents mean sea-level and not only covers the water but is projected throughout the continents. In North America this surface is most commonly used at its zero value, that is, all heights are referenced to this surface.

What is an ellipsoid?

An ellipsoid, also known as a spheroid, is a mathematical surface which is sometimes used to represent the earth. Whenever you see latitudes and longitudes describing the location, this coordinate is being referenced to a specific ellipsoid. GPS positions are referred to an ellipsoid known as WGS84 (World Geodetic System of 1984).

What is the relationship between a geoid and an ellipsoid?

The relationship between a geoid and an ellipsoid is shown in *Figure 2, Illustration of Receiver Height Measurements on Page 7*.



References:

1 Topography
2 Geoid (mean sea level)
3 Spheroid (ellipsoid)

H = Receiver computed height above/below geoid
N = Geoidal Height (undulation)
h = GPS system computed height above the spheroid
N = h - H

Figure 2: Illustration of Receiver Height Measurements

From the above diagram, and the formula **h = H + N,** to convert heights between the ellipsoid and geoid we require the geoid-ellipsoid separation value. This value is not easy to determine. A world-wide model is generally used to provide these values. NovAtel GPS receivers store this value internally. This model can also be augmented with local height and gravity information. A more precise geoid model is available from government survey agencies for example, U.S. National Geodetic Survey or Geodetic Survey of Canada (see *Chapter 8, Standards/References* starting on *Page 31*).

Why is this important for GPS users?

The above formula is critical for GPS users as they typically obtain ellipsoid heights and need to convert these into mean sea-level heights. Once this conversion is complete, users can relate their GPS derived heights to more “usable” mean sea-level heights.

1.3 GPS Positioning

GPS positioning can be categorized as follows:

1. single-point or relative
2. static or kinematic
3. real-time or post-mission data processing

A distinction should be made between *accuracy* and *precision*. *Accuracy* refers to how close an estimate or measurement is to the true but unknown value; *precision* refers to how close an estimate is to the mean (average) estimate. *Figure 3* illustrates various relationships between these two parameters: the true value is "located" at the intersection of the cross-hairs, the centre of the shaded area is the "location" of the mean estimate, and the radius of the shaded area is a measure of the uncertainty contained in the estimate.

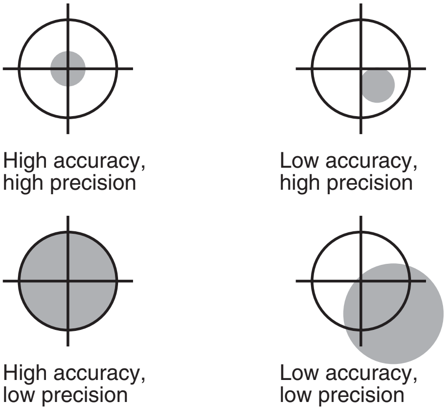


Figure 3: Accuracy versus Precision[1]

1.3.1 Single-Point vs. Relative Positioning

In *single-point* positioning, coordinates of a GPS receiver at an unknown location are sought with respect to the earth's reference frame by using the known positions of GPS satellites being tracked. The position solution generated by the receiver is initially developed in earth-centered coordinates which can subsequently be converted to any other coordinate system. With as few as four GPS satellites in view, the absolute position of the receiver in three-dimensional space can be determined. Only one receiver is needed.

In *relative* positioning, also known as *differential* positioning, the coordinates of a GPS receiver at an unknown point (the “rover” station) are sought with respect to a GPS receiver at a known point (the “base” station). The concept is illustrated in *Figure 4, Example of Differential Positioning on Page 9.* The relative-position accuracy of two receivers locked on the same satellites and not far removed from each other - up to tens of kilometers - is extremely high. The largest error contributors in single-point positioning are those associated with atmospheric-induced effects. These errors, however, are highly correlated for adjacent receivers and hence cancel out in relative measurements. Since the position of the base station can be determined to a high degree of accuracy using conventional surveying techniques, any differences between its known position and the position computed using GPS techniques can be attributed to various components of error as well as the receiver’s clock bias. Once the estimated clock bias is removed, the remaining error on each pseudorange can be determined. The base station sends information about each satellite to the rover station, which in turn can determine its

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[1] Environment Canada, 1993, Guideline for the Application of GPS Positioning, p. 22.

© Minister of Supply and Services Canada position much more exactly than would be possible otherwise.

The advantage of relative positioning is that much greater precision (presently as low as 2 mm, depending on the method and environment) can be achieved than by single-point positioning. In order for the observations of the base station to be integrated with those of the rover station, relative positioning requires either a data link between the two stations (if the positioning is to be achieved in real-time) or else post-processing of the data collected by the rover station. At least four GPS satellites in view are still required. The absolute accuracy of the rover station's computed position will depend on the accuracy of the base station's position.

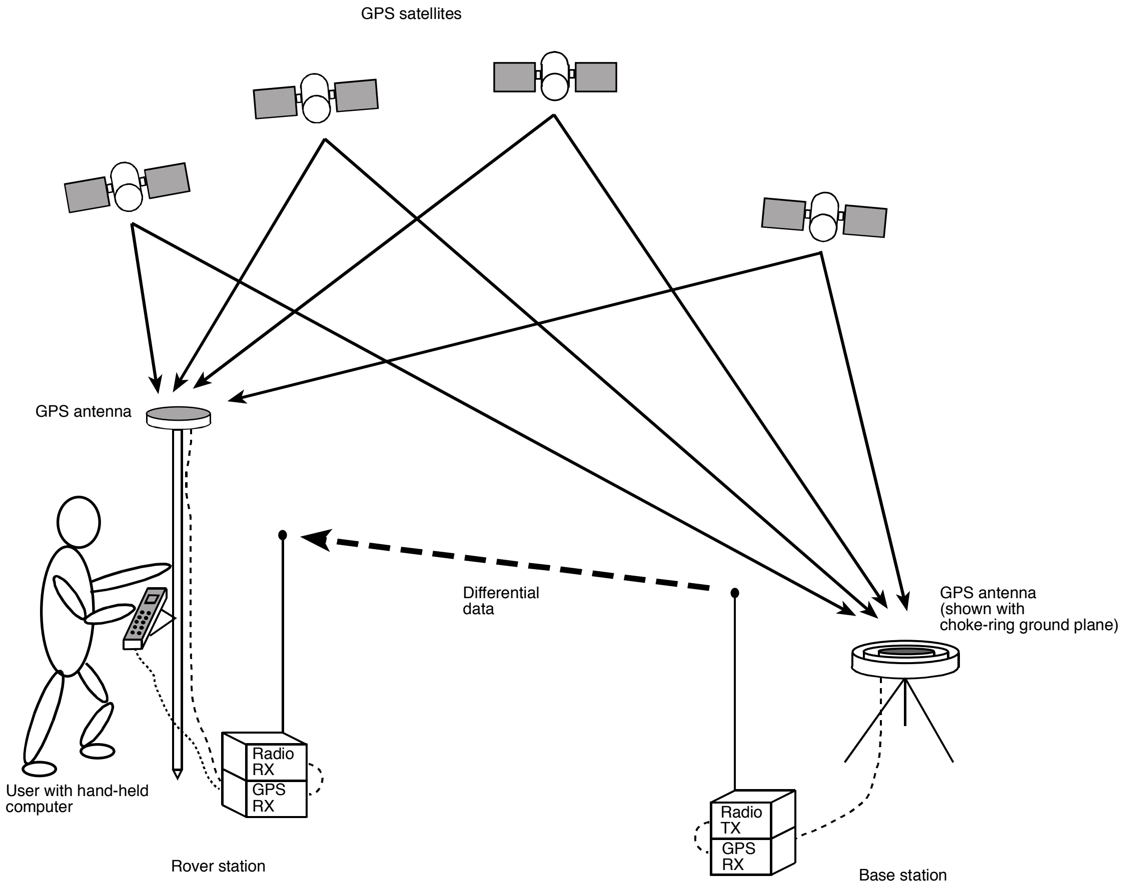

Figure 4: Example of Differential Positioning

1.3.2 Static vs. Kinematic Positioning

Static and *kinematic positioning* refer to whether a GPS receiver is stationary or in motion while collecting GPS data. Refer to *Chapter 6, Volume 1* of the *OEM4 Manual* set for more details on static and real time kinematic positioning. SUPERSTAR-II based product manuals also contain a chapter on positioning modes of operation.

1.3.3 Real-time vs. Post-mission Data Processing

Real-time or *post-mission* data processing refer to whether the GPS data collected by the receiver is processed as it is received or after the entire data-collection session is complete. Refer to *Chapter 6, Volume 1* of the *OEM4 Manual* set for more details on static and real time kinematic positioning.

Chapter 2 INS Overview

GPS positioning observes range measurements from orbiting Global Positioning System Satellites. From these observations, the receiver can compute position and velocity with high accuracy. NovAtel GPS positioning systems have been established as highly accurate positioning tools, however GPS in general has some significant restrictions, which limit its usefulness in some situations. Accurate GPS positioning requires line of site view to at least four satellites simultaneously. If these criteria are met, differential GPS positioning can be accurate to within a few centimetres. If however, some or all of the satellite signals are blocked, the accuracy of the position reported by GPS degrades substantially, or may not be available at all.

In general, an Inertial Navigation System (INS) uses forces and rotations measured by an IMU to calculate acceleration, velocity and attitude. This capability is embedded in the firmware of our *plus* series of receivers. Forces are measured by accelerometers in three perpendicular axes within the IMU and the gyros measure rotations around those axes. Over short periods of time, inertial navigation gives very accurate acceleration, velocity and attitude output. The IMU must have prior knowledge of its initial position, initial velocity, initial attitude, Earth rotation rate and gravity field. Since the IMU sensor measures changes in orientation and acceleration, the INS determines changes in position and attitude, but initial values for these parameters must be provided from an external source. Once these parameters are known, an INS is capable of providing an autonomous solution with no external inputs. However, because of errors in the IMU sensor measurements that accumulate over time, an inertial-only solution will degrade with time unless external updates such as position, velocity or attitude are supplied.

NovAtel’s SPAN system’s combined GPS/INS solution integrates the raw inertial measurements with all available GPS solution and raw measurement information to provide the optimum solution possible in any situation. By using the high accuracy of the GPS solution, the INS measurement errors can be modeled and mitigated. Conversely, the continuity and relative accuracy of the INS solution enables faster GPS signal reacquisition and RTK solution convergence.

The advantages of using SPAN technology are its ability to:

- Provide a full attitude solution (roll, pitch and azimuth)
- Provide continuous solution output (in situations when a GPS-only solution is impossible)
- Provide faster signal reacquisition and RTK solution resolution (over stand-alone GPS because of the tightly integrated GPS and IMU observations)
- Output high-rate (up to 100 Hz) position, velocity and attitude solutions for high-dynamic applications
- Use raw phase observation data (to constrain INS solution drift even when too few satellites are available for a full GPS solution)

Chapter 3 Satellite-Based Augmentation System

A Satellite-Based Augmentation System (SBAS) is a type of geo-stationary satellite system that improves the accuracy, integrity, and availability of the basic GPS signals. Accuracy is enhanced through the use of wide area corrections for GPS satellite orbits and ionospheric errors. Integrity is enhanced by the SBAS network quickly detecting satellite signal errors and sending alerts to receivers to not use the failed satellite. Availability is improved by providing an additional ranging signal to each SBAS geostationary satellite.

SBAS includes the Wide-Area Augmentation System (WAAS), the European Geo-Stationary Navigation System (EGNOS), and the MTSAT Satellite-Based Augmentation System (MSAS). At the time of publication, there are two WAAS satellites over the western Atlantic Ocean and the Pacific (PRN 122 and PRN 134 respectively) and one EGNOS satellite over the eastern Atlantic Ocean (PRN 120). SBAS data is available from any of these satellites and more satellites will be available in the future.

The primary functions of SBAS include:

- data collection
- determining ionospheric corrections
- determining satellite orbits
- determining satellite clock corrections
- determining satellite integrity
- independent data verification
- SBAS message broadcast and ranging
- system operations & maintenance

As shown in *Figure 5, The SBAS Concept* on *Page 13*, the SBAS is made up of a series of Reference Stations, Master Stations, Ground Uplink Stations and Geostationary Satellites (GEOs). The Reference Stations, which are geographically distributed, pick up GPS satellite data and route it to the Master Stations where wide area corrections are generated. These corrections are sent to the Ground Uplink Stations which up-link them to the GEOs for re-transmission on the GPS L1 frequency. These GEOs transmit signals which carry accuracy and integrity messages, and which also provide additional ranging signals for added availability, continuity and accuracy. These GEO signals are available over a wide area and can be received and processed by NovAtel receivers with appropriate firmware. GPS user receivers are thus able to receive SBAS data in-band and use not only differential corrections, but also integrity, residual errors and ionospheric information for each monitored satellite.

The signal broadcast via the SBAS GEOs to the SBAS users is designed to minimize modifications to standard GPS receivers. As such, the GPS L1 frequency (1575.42 MHz) is used, together with GPS-type modulation, for example, a Coarse/Acquisition (C/A) pseudorandom (PRN) code. In addition, the code phase timing is maintained close to GPS time to provide a ranging capability.

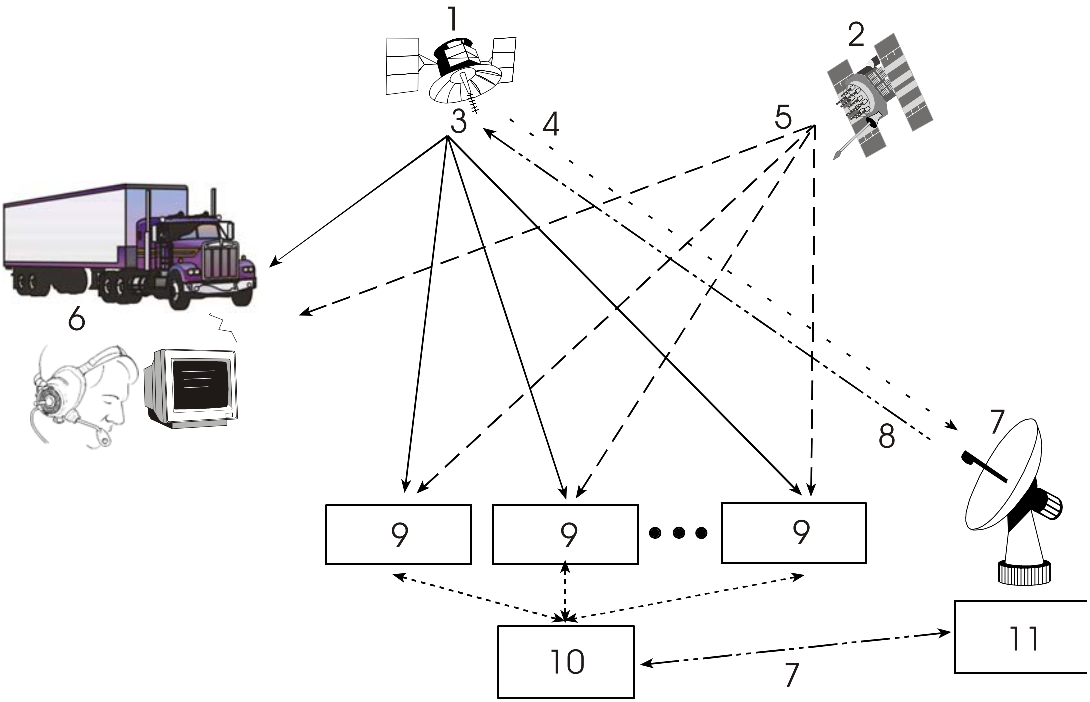

Figure 5: The SBAS Concept

Reference	Description	Reference	Description
1	Geostationary Satellite (GEO)	8	C-Band
2	GPS Satellite Constellation	9	SBAS Reference Station
3	L1	10	SBAS Master Station
4	L1 and C-Band	11	Ground Uplink Station
5	L1 and L2		
6	GPS User		
7	Integrity data, differential corrections and ranging control		

3.1 SBAS Receiver

Many models of the NovAtel receivers are equipped with an SBAS option. The ability to simultaneously track two SBAS satellites, and incorporate the SBAS corrections into the position, is available in some models.

These models can output the SBAS data in log format, and can incorporate these corrections to generate differential-quality position solutions. Standard SBAS data messages are analyzed based on RTCA standard DO-229B Change 1 Minimum Operational Performance Standards for GPS/WAAS airborne equipment. Please refer to your *SUPERSTAR II Firmware Reference Manual* or *Volume 2* of the *OEM4 Manual* set for details on SBAS commands and logs.

An SBAS-capable receiver permits anyone within the area of coverage to take advantage of its benefits.

Chapter 4 L-Band Positioning

The transmission of OmniSTAR or CDGPS corrections are from geostationary satellites. The L-Band frequency of geostationary satellites is sufficiently close to that of GPS that a common, single antenna, like the NovAtel GPS-600-LB, may be used.

Both systems are portable and capable of sub-meter accuracy over their coverage areas.

The OmniSTAR system is designed for worldwide coverage. A subscription charge by geographic area is required. The CDGPS system is a free Canada-wide DGPS service that is accessible coast-to-coast, beyond the U.S. border, and into the Arctic.

4.1 Coverage

The two systems provide different coverage areas:

- Worldwide OmniSTAR
- Canada/America-Wide CDGPS

4.1.1 Worldwide OmniSTAR

In most world areas, a single satellite is used by OmniSTAR to provide coverage over an entire continent - or at least very large geographic areas. In North America, a single satellite is used, but it needs three separate beams to cover the continent. The three beams are arranged to cover the East, Central, and Western portions of North America. The same data is broadcast over all three beams, but the user system must select the proper beam frequency. The beams have overlaps of several hundred miles, so the point where the frequency must be changed is not critical.

The North American OmniSTAR Network currently consists of ten permanent base stations in the Continental U.S., plus one in Mexico. These eleven stations track all GPS satellites above 5 degrees elevation and compute corrections every 600 milliseconds. The corrections are sent to the OmniSTAR Network Control Center (NCC) in Houston via wire networks. At the NCC these messages are checked, compressed, and formed into packets for transmission up to the OmniSTAR satellite transponder. This occurs approximately every few seconds. A packet will contain the latest corrections from each of the North American base stations.

All of the eastern Canadian Provinces, the Caribbean Islands, Central America (south of Mexico), and South America is covered by a single satellite (AM-Sat). A single subscription is available for all the areas covered by this satellite.

OmniSTAR currently has several high-powered satellites in use around the World. They provide coverage for most of the World's land areas. Subscriptions are sold by geographic area. Any Regional OmniSTAR service center can sell and activate subscriptions for any area. They may be arranged prior to traveling to a new area, or after arrival. Contact OmniSTAR at www.omnistar.com for further details.

4.1.2 Canada/America-Wide CDGPS

The CDGPS service utilizes the MSAT-1 and MSAT-2 communications satellites.

In order to enable CDGPS positioning, you must enable L-band tracking to the CDGPS signal. The CDGPS signal is broadcast on 4 different spot beams on the MSAT-1 satellite. Depending on your geographic location, there will be a different frequency for the CDGPS signal as shown in *Figure 6*.

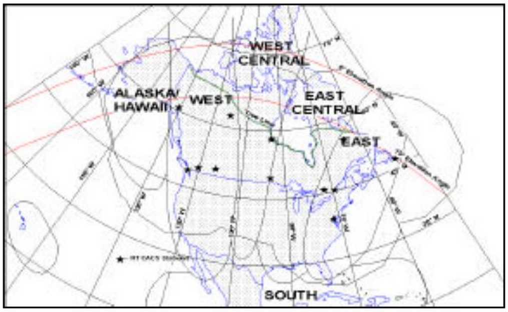

Figure 6: CDGPS Frequency Beams

The following are the spot beam names and their frequencies:

East	1,547,646 Hz
East-Central	1,557,897 Hz
West-Central	1,557,571 Hz
West	1,547,547 Hz

The data signal is structured to perform well in difficult, or foliated conditions, so the service is available more consistently and has a high degree of service reliability.

CDGPS features wide area technology, possible spatial integrity with all Government of Canada maps and surveys [1], 24-hour/7 days-a-week built-in network redundancies and an openly published broadcast protocol.

Figure 7, CDGPS Percentage Coverage Map on *Page 16* is a conservative map of the coverage areas that CDGPS guarantee. The coverage may be better in your area.

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[1] If the coordinates are output using the CSRS datum. Refer to the DATUM command in *Volume 2* of the *OEM4 Manual* set.

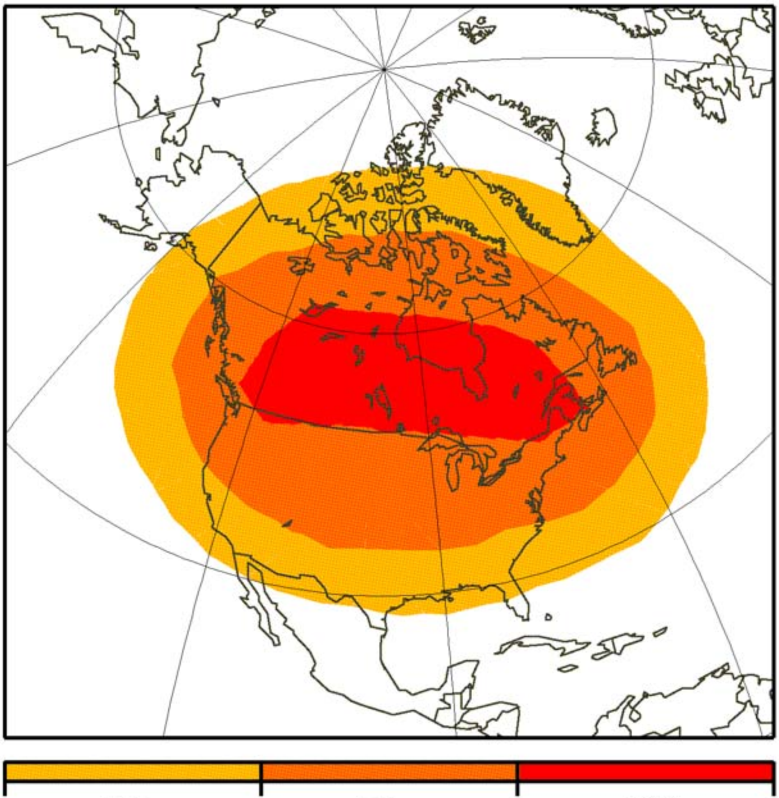

Figure 7: CDGPS Percentage Coverage Map

In *Figure 7*, 100% coverage means that a correction is received for every visible satellite (at or above 10 degrees). 90% coverage means that a correction is received for 90% of visible satellites. For example, if a user views 10 satellites but has 90% coverage then there are no corrections available for one of the satellites. In that case, our firmware shows that a correction is missing for that SV and excludes it from the position calculation.

4.2 L-Band Service Levels

Two levels of service are available:

Standard	- Sub-meter accuracy from OmniSTAR VBS and CDGPS
High Performance	- Sub-decimeter accuracy from OmniSTAR HP

4.2.1 Standard Service

The OmniSTAR VBS service uses multiple GPS base stations in a solution and reduces errors due to the GPS signals traveling through the atmosphere. It uses a wide area DGPS solution (WADGPS) and data from a relatively small number of base stations to provide consistent accuracy over large areas. A unique method of solving for atmospheric delays and weighting of distant base stations achieves sub-meter capability over the entire coverage area - regardless of your location relative to any base station. This achieves a truly wide-area system with consistent characteristics.

CDGPS is able to simultaneously track two satellites, and incorporate the corrections into the position. The output is SBAS-like (see WAAS32-WAAS45 in *Volume 2* of the *OEM4 Manual* set), and can incorporate these corrections to generate differential-quality position solutions. CDGPS allows anyone within the area of coverage to take advantage of its benefits.

NovAtel's ProPak-LBplus provides GPS with L-Band corrections in one unit, using a common antenna. This means that, with CDGPS or a subscription to the OmniSTAR VBS service, the ProPak-LB*plus* is a high quality receiver with sub-meter capabilities.

The position from the GPSCard in the receiver is used as the L-Band system's first approximation.

After the L-Band processor has taken care of the atmospheric corrections, it then uses its location versus the base station locations, in an inverse distance-weighted least-squares solution. L-Band technology generates corrections optimized for the location. It is this technique that enables the L-Band receiver to operate independently and consistently over the entire coverage area without regard to where it is in relation to the base stations.

4.2.2 High Performance Service

The OmniSTAR High Performance (HP) service gives you more accuracy than the OmniSTAR VBS or CDGPS services. OmniSTAR HP computes corrections in dual-frequency RTK float mode (within about 10 cm accuracy). To obtain OmniSTAR HP corrections, your receiver must have an HP subscription from OmniSTAR.

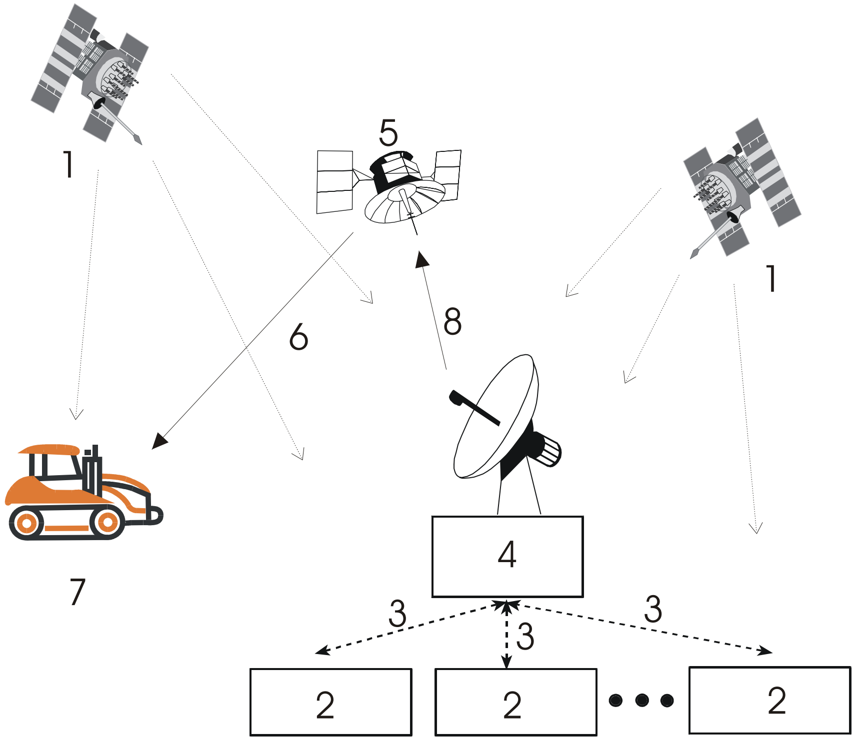

Figure 8: OmniSTAR Concept

Reference	Description
1	GPS satellites
2	Multiple L-Band ground stations
3	Send GPS corrections to 4
4	Network Control Center where data corrections are checked and repackaged for uplink to 5
5	L-Band Geostationary Satellite
6	L-Band DGPS signal
7	Correction data are received and applied real-time
8	DGPS uplink

4.3 L-Band Commands and Logs

The ASSIGNLBAND command allows you to set OmniSTAR or CDGPS base station communication parameters. It should include relevant frequencies, for example:

```
assignlband omnistar 1551489 1200
```

or,

```
assignlband cdgps 1547547 4800
```

The PSRDIFFSOURCE command lets you identify from which base station to accept RTCA1, RTCM1, CDGPS or OmniSTAR VBS differential corrections. For example, in the PSRDIFFSOURCE command, OMNISTAR enables OmniSTAR VBS and disables other DGPS types. OmniSTAR VBS produces RTCM-type corrections. CDGPS produces WAAS-type corrections. AUTO means the first received RTCM or RTCA message has preference over an OmniSTAR VBS or CDGPS message.

The RTKSOURCE command lets you identify from which base station to accept RTK (RTCM, RTCA, CMR and OmniSTAR HP) differential corrections. For example, in the RTKSOURCE command, OMNISTAR enables OmniSTAR HP, if allowed, and disables other RTK types. OmniSTAR HP computes corrections in RTK float mode or within about 10 cm accuracy. For RTK models, AUTO means the NovAtel RTK filter is enabled and the first received RTCM, RTCA or CMR message is selected. For non-RTK models, AUTO means the OmniSTAR HP message, if allowed, is enabled.

The PSRDIFFSOURCE and RTKSOURCE commands are useful when the receiver is receiving corrections from multiple base stations.

Several L-Band specific logs also exist and are prefixed by the letters RAWLBAND, LBAND or OMNI. CDGPS corrections are output similarly to SBAS corrections. There are four SBAS fast corrections logs (WAAS32-WAAS35) and one slow corrections log (WAAS45) for CDGPS. The CDGPS PRN is 209.

✉ In addition to a NovAtel receiver with L-Band capability, a subscription to the OmniSTAR, or use of the free CDGPS, service is required.

Consult *Volume 2* of the *OEM4 Manual* set for more details on individual L-Band commands and logs.

Chapter 5 L5 Overview

The United States plans to implement a third civil GPS frequency (L5[1]) at 1176.45 MHz beginning with GPS satellites to be launched in 2005. This frequency is located within the 960-1215 MHz frequency band already used worldwide for Aeronautical Radio Navigation Services (ARNS) as well as by the Department of Defense (DoD). Certain measures have been taken within the United States to ensure that L5 can coexist with government systems operating at the same or nearby frequencies.

The carriers of the L5 signal are modulated by two bit trains in phase quadrature. The L5 signal is contained within a 24 MHz band centered about L5. L5 power is increased by 6 dBW compared to the L1 signal (-154 dBW versus -160 dBW). This is equally split between an in-phase (I) data channel and a quadrature (Q) data-free channel, which improves resistance to interference, especially from pulse emitting systems in the same band as L5. Both I and Q channels are encoded with the Neuman-Hoffman Codes. The L5 signal is also Forward Error Correction (FEC) encoded. Code-Division-Multiple-Access (CDMA) techniques allow differentiating between the SVs since all SVs transmit the same L5 frequency.

The benefits of the L5 signal include:

- Signal redundancy, where the L5 signal is completely redundant to the L1 signal, creates frequency diversity and includes a direct acquisition capability so that you do not have to rely on the L1 and L2 signals for initial acquisition
- User capability to perform ionospheric delay corrections
- Higher integrity level and continuity of service
- Enhanced interference rejection capabilities
- Coherent data-free component allows the receiver to track the carrier at lower signal-to-noise ratios
- Neuman-Hoffman encoding reduces the effect of narrowband interference and improves the cross-correlation properties between SV signals
- FEC encoding permits a receiver to correct errors introduced in the transmission process due to noise or interference and makes it easier to extract the navigation message from weak signals
- 6 dB stronger signal and more robust signal structure than L1
- Greater reliability for safety-of-life applications, interference mitigation worldwide, and position accuracies are provided

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[1] For further information on the L5 signal, you may wish to refer to:

NAVSAT GPS L5 Signal Specification, Document No. RTCA/DO-261

Chapter 6 Multipath

Multipath signal reception is one of the most plaguing problems that detracts from the accuracy potential of GPS pseudorange differential positioning systems. This section provides a brief look at the problems of multipath reception and some solutions.

Multipath occurs when an RF signal arrives at the receiving antenna from more than one propagation route (multiple propagation paths), see *Figure 9*.

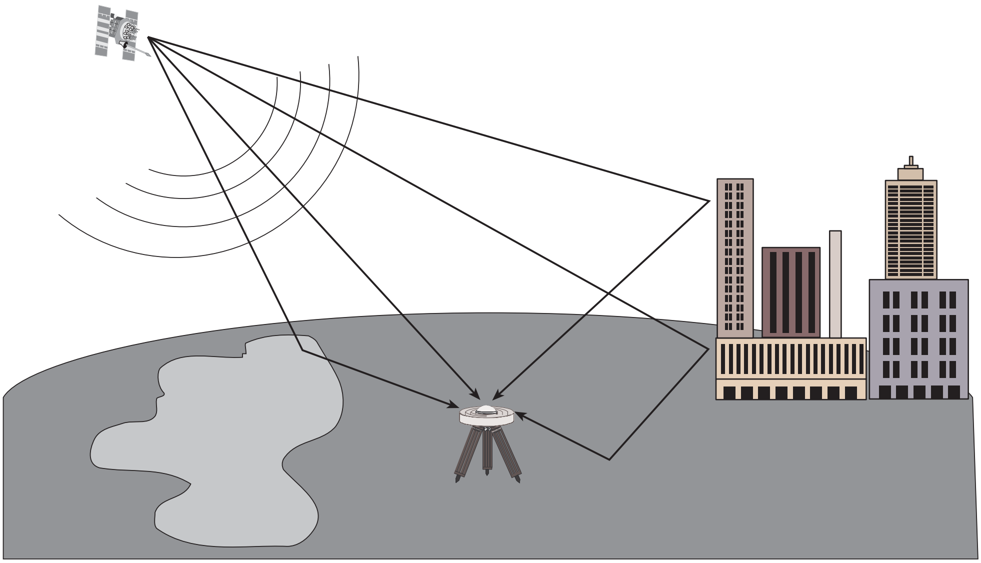

Figure 9: Illustration of GPS Signal Multipath

6.1 Why Does Multipath Occur?

When the GPS signal is emitted from the satellite antenna, the RF signal propagates away from the antenna in many directions. Because the RF signal is emitted in many directions simultaneously and is traveling different paths, these signals encounter various and differing natural and man-made objects along the various propagation routes. Whenever a change in medium is encountered, the signal is either absorbed, attenuated, refracted, or reflected.

Refraction and reflection cause the signals to change direction of propagation. This change in path directions often results in a convergence of the direct path signal with one or more of the reflected signals. When the receiving antenna is the point of convergence for these multipath signals, the consequences are generally not favorable.

Whenever the signal is refracted, some signal polarity shifting takes place. When full reflection occurs, full polarity reversal results in the propagating wave. The consequences of signal polarity shifting and reversal at the receiving antenna vary from minor to significant. As well, refracted and reflected signals generally sustain some degree of signal amplitude attenuation.

It is generally understood that, in multipath conditions, both the direct and reflected signals are present at the antenna and the multipath signals are lower in amplitude than the direct signal. However, in some situations, the direct signal may be obstructed or greatly attenuated to a level well below that of the received multipath signal. Obstruction of direct path signals is very common in city environments where many tall buildings block the line of sight to the satellites. As buildings generally contain an abundance of metallic materials, GPS signal reflections are abundant (if not overwhelming) in these settings. Obstructions of direct path signals can occur in wilderness settings as well. If the GPS receiver is in a valley with nearby hills, mountains and heavy vegetation, signal obstruction and attenuation are also very common.

6.2 Consequences of Multipath Reception

Because GPS is a radio ranging and positioning system, it is imperative that ground station signal reception from each satellite be of direct line of sight. This is critical to the accuracy of the ranging measurements. Obviously, anything other than direct line of sight reception will skew and bias the range measurements and thus the positioning triangulation (or more correctly, trilateration). Unfortunately, multipath is almost always present to some degree, due to real world conditions.

When a GPS multipath signal converges at the GPS antenna, there are two primary problems that occur:

1. a multiple signal with amplitude and phase shifting, and
2. a multiple signal with differing ranges.

When a direct signal and multipath signal are intercepted by the GPS antenna, the two signals will sum according to the phase and amplitude of each. This summation of signals causes the composite to vary greatly in amplitude, depending on the degree of phase shift between the direct signal versus the multipath signal. If the multipath signal lags the direct path signal by less than 90° the composite signal will increase in amplitude (relative to the direct signal, depending on the degree of phase shift between 0° and 90°). As well, if the multipath signal lags the direct path signal by greater than 90° but less than 270° the composite signal will decrease in amplitude. Depending on the relative amplitude of the multipath signal (or signals), the composite signal being processed by the receiver correlator may experience substantial amplitude variations. A worst case scenario is when the multipath signal experiences a lag of 180° and is near the same strength as the direct path signal – this will cause the multipath signal to almost completely cancel out the direct path signal, resulting in loss of satellite phase lock or even code lock.

Because a multipath signal travels a greater distance to arrive at the GPS antenna, the two C/A code correlations are, by varying degrees, displaced in time, which in turn causes distortion in the correlation peak and thus ambiguity errors in the pseudorange (and carrier phase, if applicable) measurements.

As mentioned in previous paragraphs, it is possible that the received multipath signal has greater amplitude than the direct path signal. In such a situation the multipath signal becomes the dominant signal and receiver pseudorange errors become significant due to dominant multipath biases and may exceed 150 meters. For single point pseudorange positioning, these occasional levels of error may be tolerable, as the accuracy expectations are at the 1 to 5 meter CEP level (depending on the GPS card model and using a standard correlator). However, for pseudorange single differencing DGPS users, the accuracy expectations are at the one to 0.45 to 1 meter CEP level (depending on the GPS card model and with no multipath). Obviously, multipath biases now become a major consideration in trying to achieve the best possible pseudorange measurements and position accuracy.

If a differential base station is subject to significant multipath conditions, this in turn will bias the range corrections transmitted to the differential rover receiver. And in turn, if the rover receiver also experiences a high level of multipath, the rover receiver position solutions will be significantly biased by multipath from both stations. Thus, when the best possible position solutions are required, multipath is certainly a phenomenon that requires serious consideration.

6.3 Hardware Solutions For Multipath Reduction

A few options exist by which GPS users may reduce the level of multipath reception. Among these include: antenna site selection, special antenna design, and ground plane options.

6.3.1 Antenna Site Selection

Multipath reception is basically a condition caused by environmental circumstances. Some of these conditions you may have a choice about and some you may not.

Many GPS reception problems can be reduced, to some degree, by careful antenna site selection. Of primary importance is to place the antenna so that unobstructed line-of-sight reception is possible from horizon to horizon and at all bearings and elevation angles from the antenna. This is, of course, the ideal situation, which may not be possible under actual operating conditions.

Try to place the antenna as far as possible from obvious reflective objects, especially reflective objects that are above the antenna's radiation pattern horizon. Close-in reflections will be stronger, and typically have a shorter propagation delay allowing for auto correlation of signals with a propagation delay of less than one C/A code chip (300 meters).

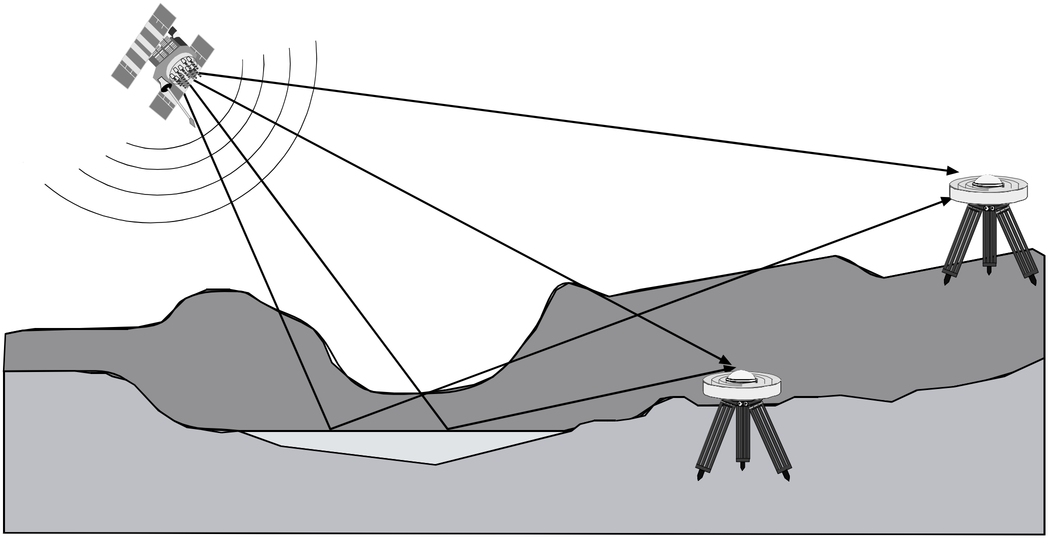

Figure 10: GPS Signal Multipath vs. Increased Antenna Height

When the antenna is in an environment with obstructions and reflective surfaces in the vicinity, it is advantageous to mount the antenna as high as possible to reduce the obstructions, as well as reception from reflective surfaces, as much as possible. See *Figure 10, GPS Signal Multipath vs. Increased Antenna Height* on *Page 23* for an example.

Water bodies are extremely good reflectors of GPS signals. Because of the short wavelengths at GPS frequencies, even small ponds and water puddles can be a strong source of multipath reception, especially for low angle satellites. Thus, it can be concluded that water bodies such as lakes and oceans are among the most troublesome multipath environments for low angle signal reception. Obviously, water body reflections are a constant problem for ocean going vessels.

6.4 Antenna Designs

Low angle reflections, such as from water bodies, can be reduced by careful selection of the antenna design. For example, flat plate microstrip patch antennas have relatively poor reception properties at low elevation angles near their radiation pattern horizon.

Quadrifilar helix antennas and other similar vertically high profile antennas tend to have high radiation gain patterns at the horizon. These antennas, in general, are more susceptible to the problems resulting from low angle multipath reception. So, for marine vessels, this type of antenna encourages multipath reception. However, the advantages of good low angle reception also means that satellites can be acquired more easily while rising in the horizon. As well, vessels subject to pitch and roll conditions will experience fewer occurrences of satellite loss of lock.

Examples of the above antennas may be seen in *Figure 11, Illustration of Quadrifilar vs. Microstrip Patch Antennas* on *Page 25*.

A good antenna design will also incorporate some form of left hand circular polarization (LHCP) rejection. Multipath signals change polarization during the refraction and reflection process. This means that generally, multipath signals may be LHCP oriented. This property can be used to advantage by GPS antenna designers. If a GPS antenna is well designed for RHCP polarization, then LHCP multipath signals will automatically be attenuated somewhat during the induction into the antenna. To further enhance performance, antennas can be designed to increase the rejection of LHCP signals.

The Model 700 series of GPSAntennas are active antennas designed to operate at the GPS L1 and L2 frequencies, 1575.42 and 1227.60 MHz. The microstrip receiving elements are coupled to filters and a low-noise amplifier (LNA). The units are optimized to receive right-hand-circularly-polarized signals, and their radiation pattern is shaped to reduce signals arriving at low elevation angles. These features decrease the errors associated with electromagnetic interference and multipath. Also, the model 700 gain roll-off compares well to a patch antenna roll-off mounted on a large choke ring ground plane. This antenna provides comparable performance to the choke ring ground plane antenna while being much lighter and smaller.

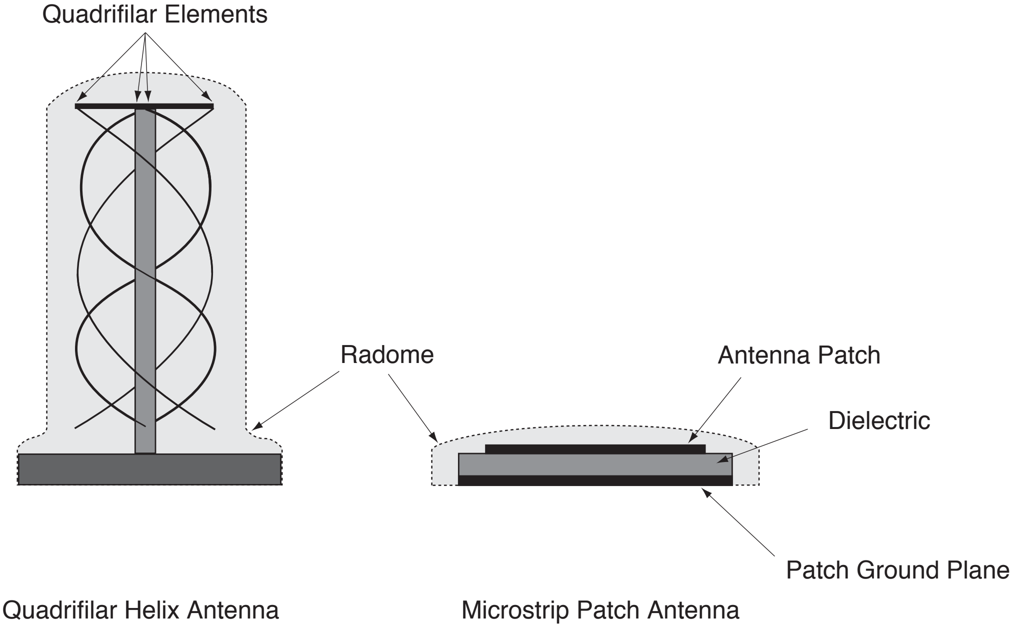

Figure 11: Illustration of Quadrifilar vs. Microstrip Patch Antennas

6.5 Antenna Ground Planes

Nearby objects can influence the radiation pattern of an antenna. Thus, one of the roles of the antenna ground plane is to create a stabilizing artificial environment on which the antenna rests and which becomes a part of the antenna structure and its resultant radiation pattern.

A small ground plane (relative to one wavelength at the operating frequency) may have minimal stabilizing effect, whereas a large ground plane (multiple wavelengths in size) will have a highly stabilizing effect.

Large ground planes also exhibit a shielding effect against RF signal reflections originating below the antenna's radiation pattern horizon. This can be a very effective low angle shield when the antenna is elevated on a hill or other structure above other reflecting surfaces such as vehicles, railway tracks, soil with high moisture content, water bodies, etc.

One of the drawbacks of a "flat plate" ground plane is that it gives a “hard boundary condition”. This means it allows electromagnetic waves to propagate along the ground plane and diffract strongly from its edge. The “soft boundary” condition, on the other hand, will prevent the wave from propagating along the surface of the ground plane and thereby reducing the edge diffraction effects. As a result the antenna will exhibit a completely different radiation pattern. The “soft boundary” condition is typically achieved by a quarter wavelength deep, transversely corrugated ground plane surface (denoted as “choke ring ground plane”). When the depth of the corrugation (choke rings) is equal to a quarter wavelength, the surface wave vanishes, and the surface impedance becomes infinite and hence provides the “soft boundary” condition for the electromagnetic field. This results in modifications to the antenna radiation pattern that is characterized by low back lobe levels, no ripples in the main lobe, sharper amplitude, roll-off near the horizon and better phase center stability (there are smaller variations in 2 axes). This is what makes NovAtel's GPS antennas so successful when used with the NovAtel GPSAntenna choke ring ground plane.

6.6 NovAtel’s Receiver Solutions for Multipath Reduction

The multipath antenna hardware solutions described in the previous paragraphs are capable of achieving varying degrees of multipath reception reduction. These options, however, require specific conscious efforts on the part of the GPS user. In many situations, especially kinematic, few (if any) of the above solutions may be effective or even possible to incorporate. By far, the best solutions are those which require little or no special efforts in the field on the part of the GPS user. This is what makes NovAtel’s internal receiver solutions so desirable and practical.

NovAtel has placed long term concerted effort into the development of internal receiver solutions and techniques that achieve multipath reduction, all of which are transparent to the receiver user. These achievements have led first to Narrow Correlator tracking technology and now PAC technology.

It utilizes innovative patented correlator delay lock loop (DLL) techniques. As it is beyond the scope of this manual to describe in detail how the correlator techniques achieve the various levels of performance, the following paragraphs will provide highlights of the advantages of PAC technology.

6.6.1 Pulse Aperture Correlator Technology (PAC)

NovAtel's OEM4 family of receivers achieve a higher level of pseudorange positioning performance versus standard (wide) or narrow correlator receivers, by virtue of its celebrated PAC technology. By utilizing PAC tracking techniques, the receiver is capable of pseudorange measurement improvements better than 4:1 when compared to standard (wide) correlation techniques and 2:1 when compared to narrow correlation techniques. The PAC technology dramatically reduces multipath reception (approaching a factor of 16 compared to standard correlators and 8 compared to narrow correlators) by virtue of its very narrow correlation function.

Figure 12, Comparison of Multipath Envelopes on *Page 27* illustrates relative multipath-induced tracking errors encountered by the different correlation technologies. As can be seen, standard correlators are susceptible to substantial multipath biases for C/A code chip delays of up to 1.5 chips, with the most significant C/A code multipath bias errors occurring at about 0.25 to 0.75 chips (approaching 80 m error). The Narrow Correlator tracking technology multipath susceptibility peaks at about 0.2 chips (about 10 m error) and remains relatively constant out to 0.95 chips where it rapidly declines to negligible error after 1.1 chips. On the other hand the PAC technology multipath susceptibility peaks at about 0.1 chips (about 5 m error) then reduces to a negligible amount at about the 0.2 chip mark.

While positioning in single point mode, the multipath and ranging improvement benefits of a PAC technology receiver versus narrow or standard correlators, are overridden by a multitude of GPS system biases and errors. In either case positioning accuracy will be in the order of 1.8 m (CEP). However the benefits of PAC technology becomes most significant during pseudorange DGPS operation, where the GPS system biases are largely removed.

Receivers operating DGPS with standard correlators typically achieve positioning accuracies in the two to five meter CEP range (low multipath environment and using a choke ring ground plane or

GPS-702 antenna). NovAtel's Narrow Correlator tracking technology receivers are able to achieve accuracies in the order of 0.75m CEP while NovAtel's PAC technology receivers are able to achieve accuracies in the 0.35 to 0.5 m CEP. PAC technology achieves this higher accuracy through a combination of low noise ranging measurements combined with a very narrow correlation window that dramatically reduces the effects of multipath interference and distortion.

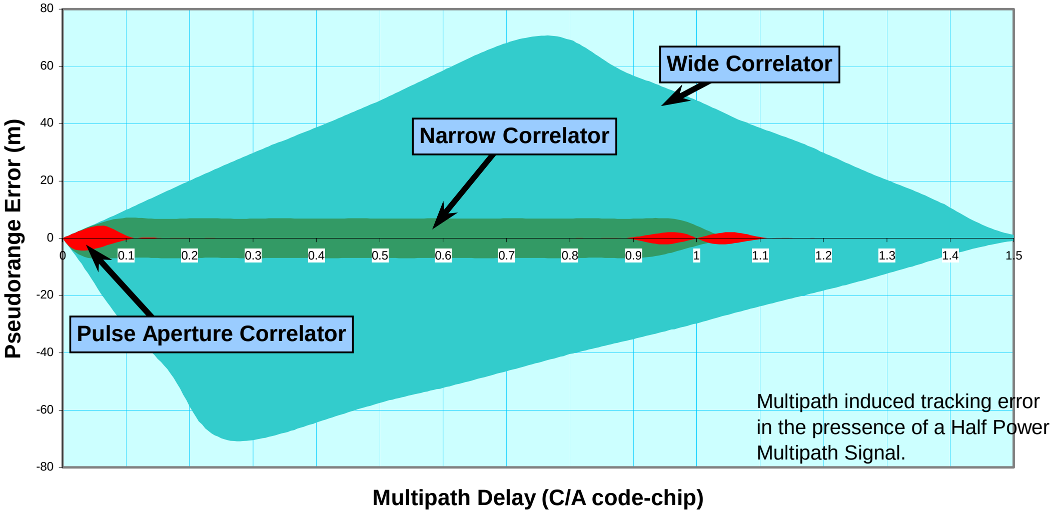

Figure 12: Comparison of Multipath Envelopes

6.6.2 Summary

Any localized propagation delays or multipath signal reception cause biases to the GPS ranging measurements that cannot be differenced by traditional DGPS single or double differencing techniques. Multipath is recognized as the greatest source of errors encountered by a system operating in single-point or differential mode. It has been discussed that careful site selection and the GPSAntenna Model 700, or good antenna design combined with a choke ring ground plane, are fairly effective means of reducing multipath reception.

Internal receiver solutions for multipath elimination are achieved through various types of correlation techniques, where the "standard correlator" is the reference by which all other techniques can be compared.

PAC technology has a four fold advantage over standard correlators: improved ranging measurements due to a sharper, less noisy correlation peak, and reduced susceptibility to multipath due to rejection of C/A code delays of greater than 1.0 chip. When used with a choke ring ground plane, PAC technology provides substantial performance gains over standard or narrow correlator receivers operating in differential mode.

Chapter 7 TTFF and Satellite Acquisition

Time to First Fix, or TTFF, is the time it takes the receiver to calculate a position after a reset or upon power-up. The TTFF varies and depends on what is stored in non-volatile memory (NVM) at the time of power-up, and on what other information is available.

The speed at which the receiver locates and locks onto new satellites is improved if the receiver has approximate time and position, as well as an almanac. This allows the receiver to compute the elevation of each satellite so it can tell which satellites are visible and their Doppler offsets, improving TTFF.

Without this information, the receiver must blindly search through all possible satellite PRN codes and Doppler offsets (as in a cold start).

Re-acquisition is the resumption of tracking and measurement processing.

7.1 OEM4-based Products

Once satellites are acquired, the receiver will normally waits another 18-36 seconds before receiving broadcast ephemeris data to calculate a position. To avoid this delay, the receiver saves ephemeris data in its NVM and will use that data if it is less than 2 hours old.

Table 1: Typical Receiver TTFF for OEM4-Based Products

Mode	Information Available to the Receiver				Typical TTFF
	Approx. Position	Approx. Time	Almanac	Recent Ephemeris	
Cold Start	no	no	no	no	50 s
Warm Start	yes	yes	yes	no	40 s
Hot Start	yes	yes	yes	yes	30 s

⌧ The TTFF numbers quoted assume an open environment. Poor satellite visibility or frequent signal blockage increases TTFF.

Upon power-up, the receiver does not know its position or time, and therefore, cannot use almanac information to aid satellite acquisition. You can set an approximate GPS time using the SETAPPROXTIME command or RTCAEPHEM message. The RTCAEPHEM message contains GPS week and seconds and the receiver will use that GPS time if the time is not yet known. Several logs provide base station coordinates and the receiver will use them as an approximate position allowing it to compute satellite visibility. Alternately, you can set an approximate position by using the SETAPPROXPOS command.

Approximate time and position must be used in conjunction with a current almanac to aid satellite acquisition. For a summary of the OEM4 family command and logs used to inject an approximated time or position into the receiver, see *Table 2*.

Table 2: Approximate Time and Position Methods

Approximate	Command	Log
Time	SETAPPROXTIME	RTCAEPHEM
Position	SETAPPROXPOS	RTCAREF *or* CMRREF *or* RTCM3

Base station aiding can help in these environments. A set of ephemerides can be injected into a rover station by broadcasting the RTCAEPHEM message from a base station. This is also useful in environments where there is frequent loss of lock (GPS ephemeris is three frames long within a sequence of five frames. Each frame requires 6 seconds of continuous lock to collect the ephemeris data. This gives a minimum of 18 s and a maximum of 36 s continuous lock time.) or, when no recent ephemerides (new or stored) are available.

7.2 SUPERSTAR II-based Products

The receiver enters Navigation mode, refer to the *Operational States* section of the *SUPERSTAR II User Manual*, and provides valid outputs in less than 45 seconds after completion of the self-test and the following initialization criteria have been met:

1. Valid time (±10 minutes) and position data (±100 km) from actual position
2. Valid almanac data (less than a year old)
3. At least 4 satellites greater than 5° elevation above the horizon
4. HDOP < 6

The time allowed for self-test and device initialization is less than 5 seconds.

In the case where the following additional conditions are met, the TTFF is reduced to 15 seconds:

- Unit has not been off for more than a week before nominal power is re-applied
- Last navigation fix occurred within the last 2 hours
- Valid ephemeris data (less than 4 hours old) for at least 5 satellites

With no initialization, the time from power application to valid navigation output is typically 2 minutes.

There is no disruption of navigation data output when a satellite signal is lost unless there is a power interruption for a period of less than or equal to 200 ms. Also, the receiver re-acquires the satellite signal within 0.3 seconds after satellite visibility has been restored.

When a satellite signal is lost due to signal masking, the signal is typically re-acquired within 2-3 seconds after the satellite signal meets the minimum input levels. The vehicle dynamics during the masking period are assumed to be less than or equal to 0.5 g acceleration and 100 m/s velocity.

When total signal masking occurs, navigation resumes within 3-5 seconds of a Navigation mode criteria being met.

The receiver is capable of acquiring satellite signals with a minimum input carrier-to-noise density ratio (C/N0) to the correlator of 34 dB-Hz. Once a signal has been acquired, the receiver is capable of tracking satellite signals with a minimum input carrier-to-noise density ratio (C/N0) to the correlator of 31 dB-Hz.

Chapter 8 Standards/References

✉ Website addresses are subject to change however they are accurate at the time of posting.

NOVATEL INC.

Contact your local NovAtel dealer first for more information. To locate a dealer in your area or if the problem is not resolved, contact NovAtel Inc. directly.

Customer Service Dept.
1120 - 68 Avenue NE
Calgary, AB., Canada, T2E 8S5

Phone :1-800-NOVATEL (U.S. & Canada), or 403-295-4900Fax: 403-295-4901

E-mail: support@novatel.ca Website: http://www.novatel.com

RTCM STANDARDS REFERENCE

For detailed specifications of RTCM, refer to RTCM SC104 Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service, Version 2.3

Radio Technical Commission For Maritime Services
1800 North Kent St., Suite 1600
Arlington, VA 22209, USA

Phone: +1-703-527-2000 Fax: +1-703-351-9932

E-Mail: information@rtcm.org Website: http://www.rtcm.org/

RTCA STANDARDS REFERENCE

For copies of the Minimum Aviation System Performance Standards DGNSS Instrument Approach System: Special Category-1 (SCAT-1), contact:

RTCA, Inc.
1828 L Street, NW
Suite 805
Washington, DC 20036

Phone: 202-833-9339 Fax: 202-833-9434

E-Mail: info@rtca.org Website: http://www.rtca.org

GPS SPS SIGNAL SPECIFICATION REFERENCE

For copies of the Interface Control Document (ICD)-GPS-200, contact:

ARINC Research Corporation
2551 Riva Road
Annapolis, MD 21401-7465

Phone: 800-633-6882 Fax: 410-573-3300

Website: http://www.arinc.com

NMEA REFERENCE

National Marine Electronics Association, 0183 Standard for Interfacing Marine Electronic Devices

NMEA Executive Director
Seven Riggs Avenue
Severna Park, MD 21146

Phone: 410-975-9425 Fax: 410-975-9450

E-Mail: info@nmea.org Website: http://www.nmea.org

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Geodetic Survey Division
Geomatics Canada
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Phone: (613) 995-4410 Fax: (613)995-3215

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U.S. NATIONAL GEODETIC SURVEY

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
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Silver Spring, MD 20910-3282

Phone: (301)713-3242 Fax: (301)713-4172

E-Mail: ngs.infocenter@noaa.gov Website: http://www.ngs.noaa.gov

NAVSTAR GPS

NAVSTAR GPS
United States Naval Observatory (USNO)
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Phone: (202) 762-1467

Website: http://tycho.usno.navy.mil/gps.html

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Chapter 9 Unit Conversion

Sections 9.1 to *9.4* list commonly used equivalents between the SI (Système Internationale) units of weights and measures used in the metric system, and those used in the imperial system. A complete list of hexadecimal values with their binary equivalents is given in *Section 9.5* while an example of the conversion from GPS time of week to calendar day is shown in *Section 9.6*.

9.1 Distance

1 meter (m) = 100 centimeters (cm) = 1000 millimeters (mm)

1 kilometer (km) = 1000 meters (m)

1 nautical mile = 1852 m

1 international foot = 0.3048 m

1 statute mile = 1609.344 m

1 US survey foot = 0.3048006096 m

1 inch = 25.4 mm

9.2 Volume

1 liter (l) = 1000 cubic centimeters (cc)

1 gallon (Imperial) = 4.546 liters

1 gallon (US) = 3.785 liters

9.3 Temperature

degrees Celsius = (5/9) x [(degrees Fahrenheit) - 32]

degrees Fahrenheit = [(9/5) x (degrees Celsius)] + 32

9.4 Weight

1 kilogram (kg) = 1000 grams

1 pound = 0.4536 kilogram (kg)

9.5 Hexadecimal, Binary and Decimal Equivalents

Hex	Binary	Decimal	Hex	Binary	Decimal	Hex	Binary	Decimal	Hex	Binary	Decimal
0	0000	0	4	0100	4	8	1000	8	C	1100	12
1	0001	1	5	0101	5	9	1001	9	D	1101	13
2	0010	2	6	0110	6	A	1010	10	E	1110	14
3	0011	3	7	0111	7	B	1011	11	F	1111	15

Binary	**Decimal**	**Binary**	**Decimal**	**Binary**	**Decimal**	**Binary**	**Decimal**
10000	16	100101	37	111010	58	1001111	79
10001	17	100110	38	111011	59	1010000	80
10010	18	100111	39	111100	60	1010001	81
10011	19	101000	40	111101	61	1010010	82
10100	20	101001	41	111110	62	1010011	83
10101	21	101010	42	111111	63	1010100	84
10110	22	101011	43	1000000	64	1010101	85
10111	23	101100	44	1000001	65	1010110	86
11000	24	101101	45	1000010	66	1010111	87
11001	25	101110	46	1000011	67	1011000	88
11010	26	101111	47	1000100	68	1011001	89
11011	27	110000	48	1000101	69	1011010	90
11100	28	110001	49	1000110	70	1011011	91
11101	29	110010	50	1000111	71	1011100	92
11110	30	110011	51	1001000	72	1011101	93
11111	31	110100	52	1001001	73	1011110	94
100000	32	110101	53	1001010	74	1011111	95
100001	33	110110	54	1001011	75	1100000	96
100010	34	110111	55	1001100	76	1100001	97
100011	35	111000	56	1001101	77	1100010	98
100100	36	111001	57	1001110	78	1100011	99
						1100100	100[a]

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[a] These binary to decimal equivalents only go up to decimal 100 for the purpose of example. Please use a calculator for other conversions.

9.6 GPS Time Conversions

The following sections provided examples for converting to and from GPS time.

9.6.1 GPS Time of Week To Day of Week with Time of Day

The value given for GPS Time of Week represents the number of seconds into the week. Therefore, to determine the day and time from that value, calculations are performed to break down the number of seconds into day, hour, minute, and second values.

For example, starting with a GPS Time of Week of *511200 seconds*, the calculations are done as follows:

511200 seconds	Day of Week	511200 / 86400 seconds per day	**5**.916666667 **days**
	Hour	0.916666667 × 86400 / 3600 seconds per hour	**22**.0000 **hours**
	Minute	0.000 × 3600 / 60 seconds per minute	**0**.000 **minutes**
	Second	0.000 × 60 seconds per minute	**0**.000 **seconds**

Therefore, 511200 seconds represents *day 5 (Thursday) + 22 hours, 0 minutes, 0 seconds into Friday.*

9.6.2 Calendar Date to GPS Time

Converting a calendar date to GPS Time is calculated as shown in the example below, using the calendar date *13:30 hours, January 28, 2005*.

Years from January 6, 1980 to January, 28, 2005		25 years
Number of days in 25 years (25 years × 365 days/year)		9,125 days
Add one day for each leap year (a year which is divisible by 4 but not by 100, unless it is divisible by 400 as every 100 years a leap year is skipped)	+	7 days
Add days from January 6 to January 27 (January 28th is not finished)	+	22 days
Total days	=	9,154 days
Total number of seconds (9154 days × 86400 seconds/day)	=	790,905,600 seconds
Total number of weeks (790,905,600 seconds / 604,800 seconds/week)	=	**1307**.714285 **weeks**
Days into week (0.714285 × 7 days/week)		5 days
Number of seconds in 5 days (5 days × 86400 seconds/day)		432,000 seconds
Add number of seconds into the 6th day, January 28th (13.5 hours × 3600 seconds/hour)	+	48,600 seconds
Total seconds into week	=	**480,600 seconds**

The resulting value for GPS Time is *Week 1307, 480,600 seconds*.

Chapter 10 Electrostatic Discharge Control (ESD) Practices

10.1 Overview

Static electricity is electrical charge stored in an electromagnetic field or on an insulating body. This charge can flow as soon as a low-impedance path to ground is established. Static-sensitive units can be permanently damaged by static discharge potentials of as little as 40 volts. Charges carried by the human body, which can be thousands of times higher than this 40 V threshold, can accumulate through as simple a mechanism as walking across non-conducting floor coverings such as carpet or tile. These charges may be stored on clothing, especially when the ambient air is dry, through friction between the body and/or various clothing layers. Synthetic materials accumulate higher charges than natural fibers. Electrostatic voltage levels on insulators may be very high, in the order of thousands of volts.

Various electrical and electronic components are vulnerable to electrostatic discharge (ESD). These include discrete components, hybrid devices, integrated circuits (ICs), and printed circuit boards (PCBs) assembled with these devices.

10.2 Handling ESD-Sensitive Devices

ESD-sensitive devices must only be handled in static-controlled locations. Some recommendations for such handling practices follow:

- Handling areas must be equipped with a grounded table, floor mats, and wrist strap.
- A relative humidity level must be maintained between 20% and 80% non-condensing.
- No ESD-sensitive board or component should be removed from its protective package, except in a static-controlled location.
- A static-controlled environment and correct static-control procedures are required at both repair stations and maintenance areas.
- ESD-sensitive devices must be handled only after personnel have grounded themselves via wrist straps and mats.
- Boards or components should never come in contact with clothing, because normal grounding cannot dissipate static charges on fabrics.
- A circuit board must be placed into an anti-static plastic clamshell before being removed from the work location and must remain in the clamshell until it arrives at a static-controlled repair/test center.
- Circuit boards must not be changed or moved needlessly. Handles may be provided on circuit boards for use in their removal and replacement; care should be taken to avoid contact with the connectors and components.
- On-site repair of ESD-sensitive equipment should not be undertaken except to restore service in an emergency where spare boards are not available. Under these circumstances repair station techniques must be observed. Under normal circumstances a faulty or suspect circuit board must be sent to a repair center having complete facilities, or to the manufacturer for exchange or repair.

- Where protective measures have not been installed, a suitable alternative would be the use of a Portable Field Service Grounding Kit (for example, 3M Kit #8501 or #8507). This consists of a portable mat and wrist strap which must be attached to a suitable ground.
- A circuit board in a static-shielding bag or clamshell may be shipped or stored in a cardboard carton, but the carton must not enter a static-controlled area such as a grounded or dissipative bench top or repair zone. Do not place anything else inside the bag (for example, repair tags).
- Treat all PCBs and components as ESD sensitive. Assume that you will damage the PCB or component if you are not ESD conscious.
- Do not use torn or punctured static-shielding bags. A wire tag protruding through the bag could act as a "lightning rod", funneling the entire charge into the components inside the bag.
- Do not allow chargeable plastics, such as binders, within 0.6 m of unshielded PCBs.
- Do not allow a PCB to come within 0.3 m of a computer monitor.

10.3 Prime Static Accumulators

Table 3 provides some background information on static-accumulating materials.

Table 3: Static-Accumulating Materials

Work Surfaces	• formica (waxed or highly resistive) • finished wood • synthetic mats • writing materials, note pads, etc.
Floors	• wax-finished • vinyl
Clothes	• common cleanroom smocks • personal garments (all textiles) • non-conductive shoes
Chairs	• finished wood • vinyl • fiberglass
Packing and handling	• common polyethylene bags, wraps, envelopes, and bubble pack • pack foam • common plastic trays and tote boxes
Assembly, cleaning, and repair areas	• spray cleaners • common solder sucker • common soldering irons • common solvent brushes (synthetic bristles) • cleaning, drying and temperature chambers

10.4 Handling Printed Circuit Boards

ESD damage to unprotected sensitive devices may occur at any time. ESD events can occur far below the threshold of human sensitivity. Follow this sequence when it becomes necessary to install or remove a circuit board:

1. After you are connected to the grounded wrist strap, remove the circuit board from the frame and place it on a static-controlled surface (grounded floor or table mat).
2. Remove the replacement circuit board from the static-shielding bag or clamshell and insert it into the equipment.
3. Place the original board into the shielding bag or clamshell and seal it with a label.
4. Do not put repair tags inside the shielding bag or clamshell.
5. Disconnect the wrist strap.

Chapter 11 Acronyms

1PPS	One Pulse Per Second
2-D or 2D	Two Dimensional
3-D or 3D	Three Dimensional
AC	Alternating Current
A/D	Analog-to-Digital
ADR	Accumulated Doppler Range
ADR	Accumulated Delta Range
AGC	Automatic Gain Control
AL	Alarm Limit
AMSAT	American Satellite
APC	Aircraft Power Conditioner
ARNS	Aeronautical Radio Navigation Services
ARP	Antennna Reference Point
AS	Anti-Spoofing
ASCII	American Standard Code for Information Interchange
ASIC	Application Specific Integrated Circuits
AVL	Automated Vehicle Locations
BCD	Binary Coded Decimal
BDE	Borland Database Engine
BDS	Black Diamond System
BIH	Bureau l'International de l'Heure
BIST	Built-In Self-Test
BIT	Built-In Test
BNR	Binary Numerical Representation
BPS	Bits per Second
BPSK	Bi-Phase Shift Key
BSG	Baseband Signal Generator
BTS	Conventional Terrestrial System (BIH defined)
BW	Bandwidth
C/A Code	Coarse/Acquisition Code
CAN	Controller Area Network
CASM	Coherent Adaptive Subcarrier Modulation
CBIT	Continuous Built In Test
cc	Cubic Centimeters
CCITT	Command, Control, and Intelligence Technical Test
CD	Clock Drift
CD	Compact Disc
cd	Change Directory
CDGPS	Canada-Wide Differential Global Positioning System
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CE	Conformité Européenne
CEP	Circular Error Probable
CISPR	International Special Committee On Radio Interference
CKSC	Clock/Status Card
CLK	System Clock
CMG	Course Made Good

CMP	Comparator Message Processor
CMR	Compact Measurement Record
C/No	Post Correlation Carrier to Noise Ratio in dB-Hz
CoCom	Coordinating Committee on Multilateral Export Controls
COG	Course Over Ground
CPLD	Complex Programmable Logic Device
CPU	Central Processing Unit
CR	Carriage Return
CRC	Cyclic Redundancy Check
CRR	Common Reference Receiver
CSA	Canada Shipping Act
CTP	Conventional Terrestrial Pole
CTS	Clear To Send
CTS	Conventional Terrestrial System
CW	Continuous Wave
dB	Decibel
dBm	Decibel Relative to 1 milliWatt
DC	Direct Current
DCD	Data Carrier Detected
DCE	Data Communications Equipment (Modem)
DCO	Digitally Controlled Oscillator
DDS	Direct Digital Sampling
DGNSS	Differential Global Navigation Satellite System
DGPS	Differential Global Positioning System
DHCP	Dynamic Host Configuration Protocol
DLL	Delay Lock Loop
DoD	Department of Defence (U.S.)
DOP	Dilution Of Precision
DPB	Digital Pulse Blanking
DR	Dead Reckoning
DRAM	Dynamic Random Access Memory
DRMS	Distance Root Mean Square
DSP	Digital Signal Processor
DSR	Data Set Ready
DTE	Data Terminal Equipment
DTR	Data Terminal Ready
D/U	Desired/Undesired
e	Eccentricity
ECEF	Earth-Centred-Earth-Fixed
EEPROM	Electrically Erasable Programmable Read Only Memory
EGNOS	European Geo-Stationary Navigation Overlay System
EMC	Electromagnetic Compatibility
ESD	Electrostatic Discharge
ESN	Electronic Serial Number
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
FDA	Frequency Distribution Amplifier
FEC	Forward Error Correction
FEPROM	Flash Erasable Programmable Read Only Memory
FIFO	First In, First Out
FMEA	Failure Mode Effects Analysis

FOG	Fibre Optic Gyro
FOM	Figure of Merit
FPGA	Field-Programmable Gate Array
FR	Factory Reset
FTP	File Transfer Protocol
FTS	Frequency and Time Standard
FW	Firmware
GDOP	Geometric Dilution Of Precision
GEO	Geostationary Satellite
GIC	GPS Integrity Channel
GLONASS	Global Navigation Satellite System
GMT	Greenwich Mean Time
GND	Ground
GNSS	Global Navigation Satellite System
GPAI	General Purpose Analog Input
GPS	Global Positioning System
GUS	Ground Uplink Station
GUST	WAAS GUS-Type 1
GUSTR	WAAS GUST Type-1 Receiver
HDOP	Horizontal Dilution Of Precision
hex	Hexadecimal
HFOM	Horizontal Figure of Merit
HP	High Performance *(standard OmniSTAR service)*
HTDOP	Horizontal Position and Time Dilution Of Precision
Hz	Hertz
I and Q	In-Phase and Quadrature (Channels)
I Channel	In-phase Data Channel
IBIT	Initiated Built In Test
IC	Integrated Circuit
ICD	Interface Control Document
ICP	Integrated Carrier Phase
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical & Electronics Engineers
IF	Intermediate Frequency
IGRF	International Geometric Reference Field
IM	Intermodulation
IMLA	Integrated Multipath Limiting Antenna
IMU	Inertial Measuring Unit
INH	Inhibit
INS	Inertial Navigation System
I/O	Input/Output
IODE	Issue of Data (Ephemeris)
IP	Internet Protocol
IRQ	Interrupt Request
ISG	IF Signal Generator
ISO	International Standards Organization
KPA	Klystron Power Amplifier
L1	The 1575.42 MHz GPS carrier frequency including C/A and P Code
L2	The 1227.60 MHz 2nd GPS carrier frequency (P Code only)
L5	The 1176.45 MHz 3rd civil GPS frequency that tracks carrier at low signal-to-noise ratios

LAAS	Local Area Augmentation System
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
LF	Line Feed
LGF	LAAS Ground Facility
LHCP	Left Hand Circular Polarization
LNA	Low Noise Amplifier
LO	Local Oscillator
LSB	Least significant bit
MAT	Multipath Assessment Tool
MEDLL	Multipath Estimating Delay Lock Loop
MET	Multipath Elimination Technology
MGRS	Military Grid Reference System
MHz	MegaHertz
MINOS	Multiple Independent NOmadic Stargazer
MKI	Mark Input
MMCX	Multimedia Communications Exchange (Lucent)
MOPS	Minimum Operational Performance Standard
MPC	Modulated Precision Clock
MPM	Multipath Meter
ms	Millisecond
MSAS	MTSAT Satellite Based Augmentation System
MSB	Most significant bit
MSL	Mean sea level
MSR	Measure Output
MTBF	Mean Time Between Failures
MTSAT	Multi-Functional Transport Satellite
NAS	National Airspace System (United States)
NAV	RINEX Ephemeris File
NAVSTAR	NAVigation Satellite Timing And Ranging (synonymous with GPS)
N/C	Not Connected
NCC	Network Control Center
NCO	Numerically Controlled Oscillator
NH	Neumann-Hoffman
NMEA	National Marine Electronics Association
NOC	Network Operations Center
ns	Nanosecond
NVM	Non-Volatile Memory
OBS	RINEX Observation File
OCXO	Oven Controlled Crystal Oscillator
OEM	Original Equipment Manufacturer
PAC	Pulsed Aperture Correlator
PC	Personal Computer
P Code	Precise Code
PCB	Printed Circuit Board
PCMCIA	Personal Computer Memory Card International Association
PDF	Power Distribution Function
PDF	Portable Document File
PDOP	Position Dilution Of Precision
PIN	Position Indicator

PLL	Phase Lock Loop
PPM	Parts Per Million
PPP	Point to Point Protocol
PPS	Precise Positioning Service or Pulse Per Second
PRN#	PseudoRandom Noise Number
PSR	Pseudorange
PV	Position Valid
PVT	Position Velocity Time
Q Channel	Quadrature Data-Free Channel
RAM	Random Access Memory
RAS	Remote Access Service
RF	Radio Frequency
RFU	Radio Frequency Uplink
RHCP	Right Hand Circular Polarization
RI	Ring Indicator
RINEX	Receiver Independent Exchange Format
RLG	Ring Laser Gyro
RoHS	Restriction of the use of Hazardous Substances
ROM	Read Only Memory
RMA	Return Material Authorization
RMS	Root Mean Square
RSS	Residual Solution Status
RTC	Real-Time Clock
RTCA	Radio Technical Commission for Aviation Services
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematic
RTS	Request To Send
RXD	Received Data
SA	SMART ANTENNA
SA	Selective Availability
SBAS	Satellite Based Augmentation System
SC	Safety Computer
SCAT-I	Special Category I
SEP	Spherical Error Probable
SG	Signal Generator
SI	Système Internationale
SigGen	WAAS GUS Type-1 Signal Generator
SLIP	Serial Line Internet Protocol
SNR	Signal-to-Noise Ratio
SPS	Standard Positioning Service
SQM	Signal Quality Monitoring
SRAM	Static Random Access Memory
SS II	SUPERSTAR II
SV	Space Vehicle
SVID	Space Vehicle Identifier
SVN	Space Vehicle Number
SW	Software
TCP	Transmission Control Protocol
TCXO	Temperature Compensated Crystal Oscillator
TDOP	Time Dilution Of Precision

TES	Time Estimator Status
TIL	Time Integrity Limit
TNM	Telecommunications Network Management
TOA	Time of Almanac
TOE	Time of Ephemeris
TRAIM	Time Receiver Autonomous Integrity Monitor
TTFF	Time-To-First-Fix
TTL	Transistor-Transistor Logic
TXD	Transmitted Data
UART	Universal Asynchronous Receiver Transmitter
UDP	User Datagram Protocol
UDRE	User Differential Range Error
UHF	Ultra High Frequency
USB	Universal Serial Bus
UTC	Universal Time Coordinated or Coordinated Universal Time
V AC	Volts Alternating Current
V DC	Volts Direct Current
VARF	Variable Frequency
VBS	Virtual Base Station *(standard OmniSTAR service)*
VCTCXO	Voltage Controlled Temperature Compensated Crystal Oscillator
VDOP	Vertical Dilution of Precision
VFD	Vacuum Fluorescent Display
VFOM	Vertical Figure of Merit
VSWR	Voltage Standing Wave Ratio
WAAS	Wide Area Augmentation System
WAAS G-II	WAAS Reference Receiver: G-II
WADGPS	Wide Area DGPS
WGS	World Geodetic System
WHQL	Windows Hardware Quality Lab (Microsoft)
WMP	WAAS Message Processor
WNA	Week number of almanac
WPT	Waypoint
XTE	Crosstrack Error
ZUPT	Zero Velocity Update

Chapter 12 Glossary

Acquisition	The process of locking onto a satellite’s C/A code and P code. A receiver acquires all available satellites when it is first powered up, then acquires additional satellites as they become available and continues tracking them until they become unavailable.
Address Field	For sentences in the NMEA standard, the fixed length field following the beginning sentence delimiter "$" (HEX 24). For NMEA approved sentences, composed of a two character talker identifier and a three character sentence formatter. For proprietary sentences, composed of the character "P" (HEX 50) followed by a three character manufacturer identification code.
Almanac	A set of orbit parameters that allows calculation of approximate GPS satellite positions and velocities. The almanac is used by a GPS receiver to determine satellite visibility and as an aid during acquisition of GPS satellite signals.
Almanac Data	A set of data which is downloaded from each satellite over the course of 12.5 minutes. It contains orbital parameter approximations for all satellites, GPS to universal standard time (UTC) conversion parameters, and single-frequency ionospheric model parameters.
Anti-Spoofing	Denial of the P-code by the Control Segment is called Anti-Spoofing. It is normally replaced by encrypted Y-code, [see “P-Code” and “Y-Code”]
ASCII	A 7-bit wide serial code describing numbers, upper and lower case characters, special and non-printing characters. Typically used for textual data.
Attenuation	Reduction of signal strength
Azimuth	The horizontal direction of a celestial point from a terrestrial point, expressed as the angular distance from 000° (reference) clockwise through 360°. The reference point is generally True North, but may be Magnetic North, or Relative (ship's head).
Base Station	The GPS receiver which is acting as the stationary reference. It has a known position and transmits messages for the rover receiver to use to calculate its position.
Bearing	The horizontal direction of one terrestrial point from another terrestrial point, expressed as the angular distance from a reference direction, usually measured from 000° at the reference direction clockwise through 360°. The reference point may be True North, Magnetic North, or Relative (ship's head).
Carrier	The steady transmitted RF signal whose amplitude, frequency, or phase may be modulated to carry information.
Carrier Phase Ambiguity	The number of integer carrier phase cycles between the user and the satellite at the start of tracking. (Sometimes ambiguity for short).
Carrier Phase Measurements	These are “accumulated doppler range” (ADR) measurements. They contain the instantaneous phase of the signal (modulo 1 cycle) plus some arbitrary number of integer cycles. Once the receiver is tracking the satellite, the integer number of cycles correctly accumulates the change in range seen by the receiver. When a “lock break” occurs, this accumulated value can jump an arbitrary integer number of cycles (this is called a cycle slip).

Checksum	By NMEA standard, a validity check performed on the data contained in the sentences, calculated by the talker, appended to the message, then recalculated by the listener for comparison to determine if the message was received correctly. Required for some sentences, optional for all others.
Circular Error Probable (CEP)	Circular error probable; the radius of a circle such that 50% of a set of events occur inside the boundary.
Coarse Acquisition (C/A) Code	A pseudorandom string of bits that is used primarily by commercial GPS receivers to determine the range to the transmitting GPS satellite. The 1023 chip C/A code repeats every 1 ms giving a code chip length of 300 m which, is very easy to lock onto.
Communication Protocol	A method established for message transfer between a talker and a listener which includes the message format and the sequence in which the messages are to be transferred. Also includes the signalling requirements such as bit rate, stop bits, parity, and bits per character.
Control Segment	The Master Control Station and the globally dispersed Reference Stations used to manage the GPS satellites, determine their precise orbital parameters, and synchronize their clocks.
Coordinated Universal Time (UTC)	[See *“Universal Time Coordinated”*]
Course	The horizontal direction in which a vessel is to be steered or is being steered; the direction of travel through the air or water. Expressed as angular distance from reference North (either true, magnetic, compass, or grid), usually 000° (north), clockwise through 360°. Strictly, the term applies to direction through the air or water, not the direction intended to be made good over the ground [see *“Track Made Good”*]. Differs from heading.
Course Made Good (CMG)	The single resultant direction from a given point of departure to a subsequent position; the direction of the net movement from one point to the other. This often varies from the track caused by inaccuracies in steering, currents, cross-winds, etc. This term is often considered to be synonymous with Track Made Good, however, Course Made Good is the more correct term.
Course Over Ground (COG)	The actual path of a vessel with respect to the Earth (a misnomer in that courses are directions steered or intended to be steered through the water with respect to a reference meridian); this will not be a straight line if the vessel's heading yaws back and forth across the course.
Cross Track Error (XTE)	The distance from the vessel’s present position to the closest point on a great (XTE) Circle line connecting the current waypoint coordinates. If a track offset has been specified in the receiver SETNAV command, the cross track error will be relative to the offset track great circle line.
Cycle Slip	When the carrier phase measurement jumps by an arbitrary number of integer cycles. It is generally caused by a break in the signal tracking due to shading or some similar occurrence.

Dead Reckoning	The process of determining a vessel’s approximate position by applying (DR) from its last known position a vector or a series of consecutive vectors representing the run that has since been made, using only the courses being steered, and the distance run as determined by log, engine rpm, or calculations from speed measurements.
Destination	The immediate geographic point of interest to which a vessel is navigating. It may be the next waypoint along a route of waypoints or the final destination of a voyage.
Differential GPS (DGPS)	A technique to improve GPS accuracy that uses pseudorange errors at a known location to improve the measurements made by other GPS receivers within the same general geographic area.
Dilution of Precision (DOP)	A numerical value expressing the confidence factor of the position solution based on current satellite geometry. The lower the value, the greater the confidence in the solution. DOP can be expressed in the following forms. GDOP: Uncertainty of all parameters (latitude, longitude, height, clock offset) PDOP: Uncertainty of 3-D parameters (latitude, longitude, height) HTDOP: Uncertainty of 2-D and time parameters (latitude, longitude, time) HDOP: Uncertainty of 2-D parameters (latitude, longitude) VDOP: Uncertainty of height parameter TDOP: Uncertainty of clock offset parameter
Doppler	The change in frequency of sound, light, or other wave caused by movement of its source relative to the observer.
Doppler Aiding	A signal processing strategy, which uses a measured Doppler shift to help a receiver smoothly track the GPS signal, to allow more precise velocity and position measurement.
Double-Difference	A mathematical technique comparing observations by differencing between receiver channels and then between the base and rover receivers.
Double-Difference Carrier Phase Ambiguity	Carrier phase ambiguities which are differenced between receiver channels Carrier Phase and between the base and rover receivers. They are estimated when Ambiguitya double-difference mechanism is used for carrier phase positioning. (Sometimes double-difference ambiguity or ambiguity, for short).
Earth-Centred-Earth-Fixed (ECEF)	This is a coordinate-ordinate system which has the X-coordinate in the earth's equatorial plane pointing to the Greenwich prime meridian, the Z-axis pointing to the north pole, and the Y-axis in the equatorial plane 90° from the X-axis with an orientation which forms a right-handed XYZ system.
Eccentricity (e)	A dimensionless measurement defined for a conic section where $e= 0$ is a circle, $e = 1$ is an ellipse, $0 < e < 1$ is a parabola and $e > 1$ is a hyperbola.
Elevation	The angle from the horizon to the observed position of a satellite.
Ellipsoid	A smooth mathematical surface which represents the earth’s shape and very closely approximates the geoid. It is used as a reference surface for geodetic surveys.
Ellipsoidal Height	Height above a defined ellipsoid approximating the surface of the earth.

Ephemeris	A set of satellite orbit parameters that are used by a GPS receiver to calculate precise GPS satellite positions and velocities. The ephemeris is used in the determination of the navigation solution and is updated periodically by the satellite to maintain the accuracy of GPS receivers.
Ephemeris Data	The data downlinked by a GPS satellite describing its own orbital position with respect to time.
Epoch	Strictly a specific point in time. Typically when an observation is made.
Field	A character or string of characters immediately preceded by a field delimiter.
Figure of Merit	NovAtel SUPERSTAR II-based L1 receivers provide an estimated accuracy level. The accuracy level estimate is provided in the horizontal and vertical Figure of Merit (FOM). The FOM reflects a 95% confidence level for the position solution accuracy estimate. The FOM accounts for all major sources of errors in the pseudoranges of the satellites used in the position solution. The error sources which are included are ionospheric and tropospheric errors, satellite position errors based on transmitted user range error, and thermal noise.
Fixed Ambiguity Estimates	Carrier phase ambiguity estimates which are set to a given number and held constant. Usually they are set to integers or values derived from linear combinations of integers.
Fixed Discrete Ambiguity Estimates	Carrier phase ambiguities which are set to values that are members of a predetermined set of discrete possibilities, and then held constant.
Fixed Field	A field in which the number of characters is fixed, including the cyclic-redundancy check (CRC) field.
Fixed Integer Ambiguity Estimates	Carrier phase ambiguities which are set to integer values and then held constant.
Flash ROM	Programmable read-only memory.
Geometric Dilution of Precision (GDOP)	[See *“Dilution of Precision (DOP)”*]
Geoid	The shape of the earth if it were considered as a sea level surface extended continuously through the continents. The geoid is an equipotential surface coincident with mean sea level to which at every point the plumb line (direction in which gravity acts) is perpendicular. The geoid, affected by local gravity disturbances, has an irregular shape.
Geodetic Datum	The reference ellipsoid surface that defines the coordinate system.
Geostationary	A satellite orbit along the equator that results in a constant fixed position over a particular reference point on the earth’s surface. (GPS satellites are not geostationary.)

Global Positioning System (GPS)	Full name is NAVSTAR Global Positioning System. A space-based radio positioning system which provides suitably equipped users with accurate position, velocity and time data. GPS provides this data free of direct user charge worldwide, continuously, and under all weather conditions. The GPS constellation consists of 24 orbiting satellites, four equally spaced around each of six different orbital planes. The system is being developed by the Department of Defence under U.S. Air Force management.
Great Circle	The shortest distance between any two points along the surface of a sphere or ellipsoid, and therefore the shortest navigation distance between any two points on the Earth. Also called Geodesic Line.
Handshaking	Predetermined hardware or software activity designed to establish or maintain two machines or programs in synchronization. Handshaking concerns the exchange of messages or packets of data between two systems with limited buffers. Hardware handshaking uses voltage levels or pulses in wires to carry the handshaking signals. Software handshaking uses data units (for example, binary bits) carried by some underlying communication medium.
Heading	The direction in which a vessel points or heads at any instant, expressed in degrees 000° clockwise through 360° and may be referenced to True North, Magnetic North, or Grid North. The heading of a vessel is also called the ship's head. Heading is a constantly changing value as the vessel oscillates or yaws across the course due to the effects of the air or sea, cross currents, and steering errors.
Horizontal Dilution of Precision (HDOP)	[See *"Dilution of Precision (DOP)"*]
Horizontal and Time Dilution of Precision (HTDOP)	[See *"Dilution of Precision (DOP)"*]
Integer Ambiguity Estimates	Carrier phase ambiguity estimates which are only allowed to take on integer values.
Iono-Free Carrier Phase Observation	A linear combination of L1 and L2 carrier phase measurements which provides an estimate of the carrier phase observation on one frequency with the effects of the ionosphere removed. It provides a different ambiguity value (non-integer) than a simple measurement on that frequency.
Kinematic	The user's GPS antenna is moving. In GPS, this term is typically used with precise carrier phase positioning, and the term dynamic is used with pseudorange positioning.
L-Band	The range of radio frequencies that includes the GPS carrier frequencies L1 and L2 and the OmniSTAR satellite broadcast signal.
L1 Frequency	The 1575.42 MHz GPS carrier frequency, which contains the course acquisition (C/A) code, as well as encrypted P-code, and navigation messages used by commercial GPS receivers.
L2 Frequency	The 1227.60 MHz secondary GPS carrier frequency, containing only encrypted P-code, used primarily to calculate signal delays caused by the ionosphere.

L5 Frequency	The third civil GPS frequency at 1176.45 MHz beginning with GPS satellites to be launched in 2005. This frequency is located within the 960-1215 MHz frequency band. The L5 signal is equally split between an in-phase (I) data channel and a quadrature (Q) data-free channel, which improves resistance to interference, especially from pulse emitting systems in the same band as L5.
Lane	A particular discrete ambiguity value on one carrier phase range measurement or double difference carrier phase observation. The type of measurement is not specified (L1, L2, L1-L2, iono-free).
Local Observation Set	An observation set, as described below, taken by the receiver on which the software is operating.
Local Tangent Plane	A coordinate system based on a plane tangent to the ellipsoid’s surface at the Planeuser’s location. The three coordinates are east, north and up. Latitude, longitude and height positions operate in this coordinate system.
Low-Latency Solution	A position solution which is based on a prediction. A model (based on previous base station observations) is used to estimate what the observations will be at a given time epoch. These estimated base station observations are combined with actual measurements taken at the rover station to provide a position solution.
Magnetic Bearing	Bearing relative to magnetic north; compass bearing corrected for deviation.
Magnetic Heading	Heading relative to magnetic north.
Magnetic Variation	The angle between the magnetic and geographic meridians at any place, expressed in degrees and minutes east or west to indicate the direction of magnetic north from true north.
Mask Angle	The minimum GPS satellite elevation angle permitted by a particular receiver design. Satellites below this angle will not be used in position solution.
Matched Observation Set Pair	Observations from both the base station and the local receiver which have been matched by time epoch, contain the same satellites, and are corrected for any known offsets.
Measurement Error Variance	The square of the standard deviation of a measurement quantity. The standard deviation is representative of the error typically expected in a measured value of that quantity.
Measurement Time Epoch	The point in time at which a receiver takes a measurement.
Multipath Errors	GPS positioning errors caused by the interaction of the GPS satellite signal and its reflections.
Nanosecond	1×10^{-9} second.
Non-Volatile Memory	A type of memory device that retains data in the absence of a power supply.
Null Field	By NMEA standard, indicates that data is not available for the field. Indicated by two ASCII commas, for example, ",," (HEX 2C2C), or, for the last data field in a sentence, one comma followed by either the checksum delimiter "*" (HEX 2A) or the sentence delimiters <CR><LF> (HEX 0D0A). [Note: the ASCII Null character (HEX 00) is not to be used for null fields.]

Obscuration	Term used to describe periods of time when a GPS receiver’s line-of-sight to GPS satellites is blocked by natural or man-made objects.
Observation	Any measurement.
Observation Set	A set of receiver measurements taken at a given time which includes one time for all measurements, and the following for each satellite tracked: PRN number, pseudorange or carrier phase or both, lock time count, signal strength, and tracking status. Only L1 measurements are included in the set. The observation set is assumed to contain information indicating how many satellites it contains and which ones have L1-only and which ones have L1/L1 pairs.
OmniSTAR	A wide-area GPS correction service, using L-band satellite broadcast frequencies (1525 - 1560 MHz). Data from many widely-spaced Reference Stations is used in a proprietary multi-site solution. OmniSTAR Virtual Base Station (VBS) types achieve sub-meter positioning over most land areas worldwide while OmniSTAR High Performance (HP) types achieve 10 cm accuracy. Use of the OmniSTAR service requires a subscription.
Origin Waypoint	The starting point of the present navigation leg, expressed in latitude and longitude.
Parallel Receiver	A receiver that monitors four or more satellites simultaneously with independent channels.
Parity	The even or odd quality of the number of ones or zeroes in a binary code. Parity is often used to determine the integrity of data especially after transmission.
Perigee	The point in a body’s orbit at which it is nearest the earth.
P-Code	Precise code or protected code. A pseudorandom string of bits that is used by GPS receivers to determine the range to the transmitting GPS satellite. P-code is replaced by an encrypted Y-code when Anti-Spoofing is active. Y-code is intended to be available only to authorized (primarily military) users. [See “Anti-Spoofing” , “(C/A) Code” and “Y-Code”]
PDOP	Position Dilution of Precision [See “Dilution of Precision (DOP)”]
Precise Positioning Service (PPS)	The GPS positioning, velocity, and time service which is available on a continuous, worldwide basis to users authorized by the U.S. Department of Defence (typically using P-Code).
PRN Number	A number assigned by the GPS system designers to a given set of pseudorandom codes. Typically, a particular satellite will keep its PRN (and hence its code assignment) indefinitely, or at least for a long period of time. It is commonly used as a way to label a particular satellite.
Pseudolite	An Earth-based transmitter designed to mimic a satellite.
Pseudorange	The calculated range from the GPS receiver to the satellite determined by taking the difference between the measured satellite transmit time and the receiver time of measurement, and multiplying by the speed of light. Contains several sources of error.
Pseudorange Measurements	Measurements made using one of the pseudorandom codes on the GPS signals. They provide an unambiguous measure of the range to the satellite including the effect of the satellite and user clock biases.

Receiver Channels	A GPS receiver specification which indicates the number of independent hardware signal processing channels included in the receiver design.
Reference Satellite	In a double difference implementation, measurements are differenced between different satellites on one receiver in order to cancel the correlated errors. Usually one satellite is chosen as the “reference”, and all others are differenced with it.
Reference Station	See *“Base Station”*
Relative Bearing	Bearing relative to heading or to the vessel.
Remote Station	See *“Rover Station”*
Residual	In the context of measurement, the residual is the misclosure between the calculated measurements, using the position solution and actual measurements.
Root Mean Square (RMS)	A probability level of 68%.
Route	A planned course of travel, usually composed of more than one navigation leg.
Rover Station	The GPS receiver which does not know its position and needs to receive measurements from a base station to calculate differential GPS positions. (The terms remote and rover are interchangeable.)
RT-20	NovAtel’s Double Differencing Technology for real-time kinematic (RTK) carrier phase floating ambiguity resolution.
Radio Technical Commission for Aeronautics (RTCA)	An organization which developed and defined a message format for differential positioning.
Radio Technical Commission for Maritime Services (RTCM)	An organization which developed and defined the SC-104 message format for differential positioning.
Real-Time Kinematic (RTK)	A type of differential positioning based on observations of carrier phase. In NovAtel documents it is also used with reference to RT-2 and RT-20.
SafeTrak	The receiver tracks a satellite by replicating the satellite's PRN code and aligning it with the received PRN code. A cross-correlation check is performed to check alignment and the cross-correlation channel shifts its code phase repeatedly to measure the power. If neccessary, the tracking channel re-acquires the satellite to remove the cross-correlation error.
Satellite-Based Augmentation System (SBAS)	A type of geo-stationary satellite system that improves the accuracy, integrity, and availability of the basic GPS signals. This includes WAAS, EGNOS, and MSAS.
Selective Availability (SA)	The method used by the United States Department of Defence to control access to the full accuracy achievable by civilian GPS equipment (generally by introducing timing and ephemeris errors).
Selected Waypoint	The waypoint currently selected to be the point toward which the vessel is travelling. Also called "to" waypoint, destination or destination waypoint.

Sequential Receiver	A GPS receiver in which the number of satellite signals to be tracked exceeds the number of available hardware channels. Sequential receivers periodically reassign hardware channels to particular satellite signals in a predetermined sequence.
Signal Quality Monitoring (SQM)	Signal Quality Monitoring (SQM) technology is used to monitor GPS and GEO signals in space for anomalous behavior.
Spherical Error Probable (SEP)	The radius of a sphere, centred at the user's true location, that contains 50 percent of the individual three-dimensional position measurements made using a particular navigation system.
Spheroid	Sometimes known as ellipsoid; a perfect mathematical figure which very closely approximates the geoid. Used as a surface of reference for geodetic surveys.
Standard Positioning Service (SPS)	A positioning service made available by the United States Department of Defence which is available to all GPS civilian users on a continuous, worldwide basis (typically using C/A Code).
Space Vehicle ID (SV)	Sometimes used as SVID. A unique number assigned to each satellite for identification purposes. The 'space vehicle' is a GPS satellite.
TDOP	Time Dilution of Precision [See "Dilution of Precision (DOP)"]
Three-Dimensional Coverage (hours)	The number of hours per day when four or more satellites are available with acceptable positioning geometry. Four visible satellites are required to determine location and altitude.
Three-Dimensional (3D) Navigation	Navigation mode in which altitude and horizontal position are determined from satellite range measurements.
Time-To-First-Fix (TTFF)	The actual time required by a GPS receiver to achieve a position solution. This specification will vary with the operating state of the receiver, the length of time since the last position fix, the location of the last fix, and the specific receiver design.
Track Made Good	The single resultant direction from a point of departure to a point of arrival or subsequent position at any given time; may be considered synonymous with *Course Made Good*.
True Bearing	Bearing relative to true north; compass bearing corrected for compass error.
True Heading	Heading relative to true north.
Two-Dimensional (2D) Coverage	The number of hours-per-day with three or more satellites visible. Three visible satellites can be used to determine location if the GPS receiver is designed to accept an external altitude input.
Two-Dimensional Navigation	Navigation mode in which a fixed value of altitude is used for one or more position calculations while horizontal (2D) position can vary freely based on satellite range measurements.
Undulation	The distance of the geoid above (positive) or below (negative) the mathematical reference ellipsoid (spheroid). Also known as geoidal separation, geoidal undulation, geoidal height.

Universal Time Coordinated	This time system uses the second-defined true angular rotation of the Earth measured as if the Earth rotated about its Conventional Terrestrial Pole. However, UTC is adjusted only in increments of one second. The time zone of UTC is that of Greenwich Mean Time (GMT).
Update Rate	The GPS receiver specification which indicates the solution rate provided by the receiver when operating normally.
UTC	[See "Universal Time Coordinated"]
VDOP	Vertical Dilution of Precision [See "Dilution of Precision (DOP)"]
Variable Field	By NMEA standards, a data field which may or may not contain a decimal point and which may vary in precision following the decimal point depending on the requirements and the accuracy of the measuring device.
Waypoint	A reference point on a track.
Wide Lane	A particular integer ambiguity value on one carrier phase range measurement or double difference carrier phase observation when the difference of the L1 and L2 measurements is used. It is a carrier phase observable formed by subtracting L2 from L1 carrier phase data: $\Phi' = \Phi_1 - \Phi_2$. The corresponding wavelength is 86.2 cm.
World Geodetic System 1984 (WGS84)	An ellipsoid designed to fit the shape of the entire Earth as well as possible with a single ellipsoid. It is often used as a reference on a worldwide basis, while other ellipsoids are used locally to provide a better fit to the Earth in a local region. GPS uses the centre of the WGS84 ellipsoid as the centre of the GPS ECEF reference frame.
Y-Code	An encrypted form of P-Code. Satellites transmit Y-Code in replace of P-Code when Anti-Spoofing is in effect. [See "P-Code" and "Anti-Spoofing"]

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