Positioning Leadership

Positioning Modes of Operation

NovAtel's dual frequency GNSS receivers have several important performance advantages depending on your positioning requirements. Dual frequency allows direct measurement of the signal delay through the ionosphere and is critical to fast and reliable integer ambiguity resolution when positioning using carrier measurements.

Dual frequency can improve the performance of DGPS, SBAS, and RTK positioning. Using RTCM type 15 messages allows the DGPS user to apply a local ionospheric correction to their dual frequency receiver to improve code positioning performance on larger baselines (hundreds of km). SBAS positioning is improved by applying a local correction instead of using the SBAS ionospheric grid, and RTK solutions are improved on long baselines by using an ionosphere free solution.

By default the OEMV-1, OEMV-1G, OEMV-3, DL-V3 and ProPak-V3 models with L-band software support the standard Canada-Wide Differential Global Positioning System (CDGPS) sub-meter L1/L2 service and the OmniSTAR Virtual Base Station (VBS) sub-meter L1 service. On the OEMV-3, DL-V3 and ProPak-V3, the OmniSTAR VBS service can be upgraded to the Extra Performance (XP) L1/L2 service, which has a specification of 0.15m RMS, or to the High Performance (HP) service, which has a specification of 0.10 m RMS. Refer also to the AUTH command in the *OEMV Firmware Reference Manual.*

The OEMV family of receivers operate in the most accurate positioning mode possible with the signals available, and immediately drop to the next positioning mode if the current signal times out.

The following single and dual frequency modes of operation are described further in this chapter:

- Single Point
- Satellite-Based Augmentation System (SBAS)
- Pseudorange Differential
- L-band
- Carrier-Phase Differential

Refer to the *GPS Overview* section of the *GPS+ Reference Manual* for an overview of GPS positioning.

Note: For information regarding NovAtel's new firmware features – GL1DE™, ALIGN™ and RT-2™ L1TE – download white papers and application notes from the Support page on our web site, http://www.novatel.com/support/index.htm.

1 Single-Point

The NovAtel OEMV family receivers are capable of absolute 2-D single-point positioning accuracies of 1.8 meters Root Mean Square (RMS[1]) (HDOP < 2; no multipath).

[1] RMS: Root Mean Square (a probability level of 68%)

The general level of accuracy available from single-point operation may be suitable for many types of positioning such as ocean going vessels, general aviation, and recreational vessels that do not require position accuracies of better than 1.8 meters RMS. However, increasingly more and more applications desire and require a much higher degree of accuracy and position confidence than is possible with single-point pseudorange positioning. This is where differential GPS (DGPS) plays a dominant role in higher accuracy real-time positioning systems (see the following sections of this chapter).

By averaging many GPS measurement epochs over several hours, it is possible to achieve a more accurate absolute position. This section attempts to explain how the position averaging function operates and to provide an indication of the level of accuracy that can be expected versus total averaging time.

The POSAVE command implements position averaging for base stations. Position averaging continues for a specified number of hours or until the averaged position is within specified accuracy limits. Averaging stops when the time limit or the horizontal standard deviation limit or the vertical standard deviation limit is achieved. When averaging is complete, the FIX POSITION command is automatically invoked.

If the maximum time is set to 1 hour or greater, positions are averaged every 10 minutes and the standard deviations reported in the AVEPOS log should be correct. If the maximum time is set to less than 1 hour, positions are averaged once per minute and the standard deviations reported in the log are not likely to be accurate, as illustrated in Figure 1. As well, in this case, the optional horizontal and vertical standard deviation limits cannot be used.

If the maximum time that positions are to be measured is set to 24 hours, for example, you can then log AVEPOS with the trigger ‘onchanged’ to see the averaging status:

```
posave 24
log com1 avepos onchanged
```

If desired, you could initiate differential logging, then issue the POSAVE command followed by the SAVECONFIG command. This would cause the receiver to average positions after every power-on or reset, then invoke the FIX POSITION command to enable it to send differential corrections.

The position accuracy that may be achieved by these methods depends on many factors: average satellite geometry, sky visibility at antenna location, satellite health, time of day, and so on. The following graph summarizes the results of several examples of position averaging over different time periods. The intent is to provide an idea of the relationship between averaging time and position accuracy. All experiments were performed using a dual frequency receiver with an ideal antenna location, see Figure 1. Figure 2 on page 3 shows the results from the same dual frequency receiver but with WAAS corrections available.

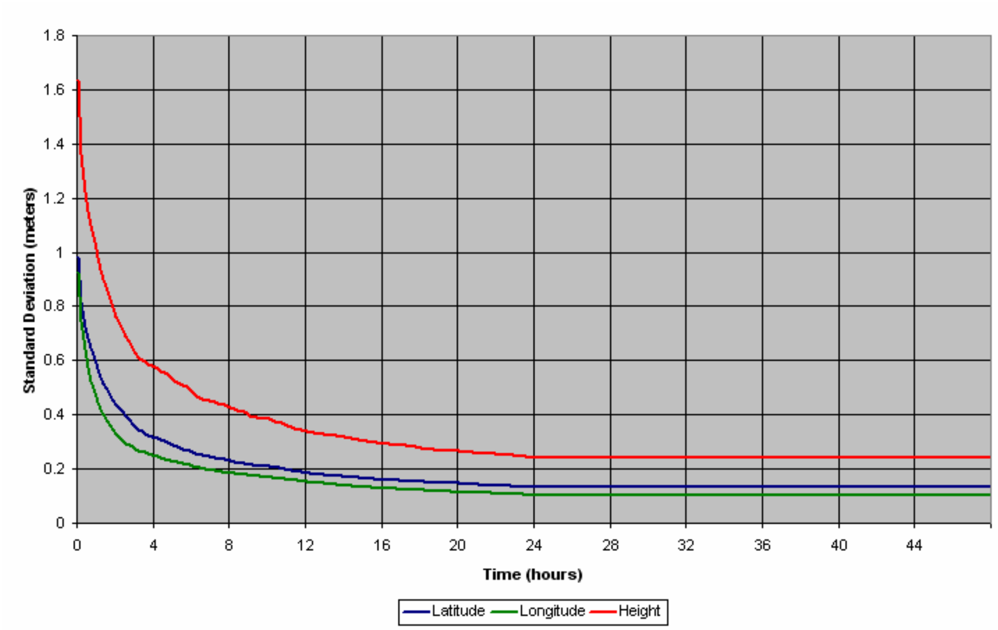

Figure 1: Single-Point Averaging (Typical Results)

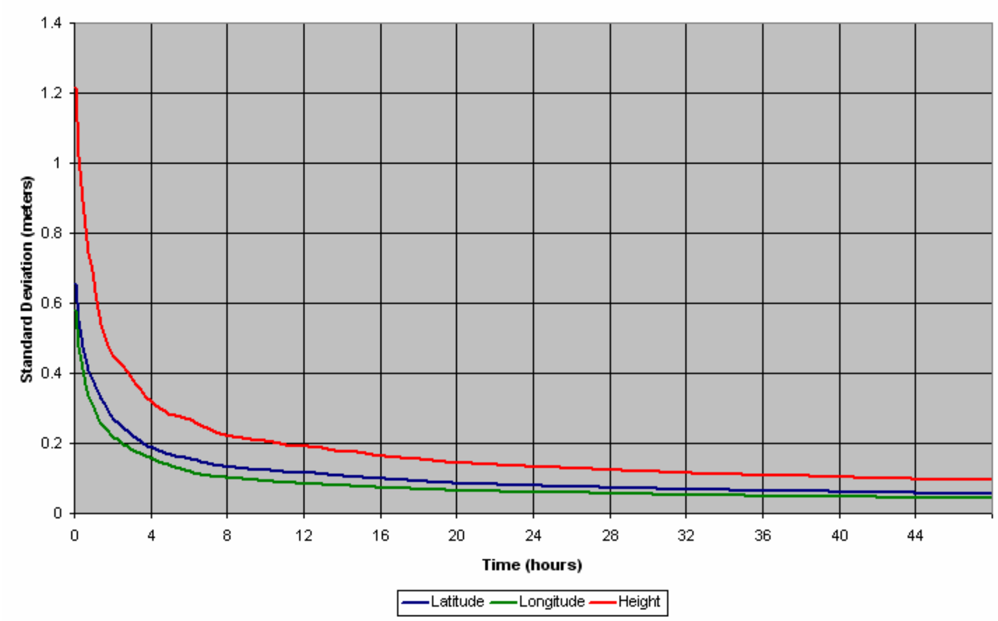

Figure 2: Single-Point Averaging (Typical Results with WAAS)

The position averaging function is useful for obtaining the WGS84 position of a point to a reasonable accuracy without having to implement differential GPS. It is interesting to note that even a six hour occupation can improve single-point GPS accuracy from over 1.5 meters to better than a meter. This improved accuracy is primarily due to the reductions of the multipath errors in the GPS signal.

Again, it is necessary to keep in mind that the resulting standard deviations of the position averaging can vary quite a bit, but improve over longer averaging times. To illustrate, the position averaging function was run for a period of 40 hours. The resulting standard deviation in latitude varied from 0.152 to 1.5589 meters. Similarly, the variation in longitude and height were 0.117 to 0.819 meters and 0.275 to 2.71

meters respectively. This degree of variation becomes larger for averaging periods of less than 12 hours due to changes in the satellite constellation. The graph provides some indication of the accuracy one may expect from single-point position averaging.

The next section deals with the type of GPS system errors that can affect accuracy in single-point operation.

1.1 GPS System Errors

In general, GPS SPS (Standard Positioning Service) C/A code single-point pseudorange positioning systems are capable of absolute position accuracies of about 1.8 meters or less. This level of accuracy is really only an estimation, and may vary widely depending on numerous GPS system biases, environmental conditions, as well as the GPS receiver design and engineering quality.

There are numerous factors which influence the single-point position accuracies of any GPS C/A code receiving system. As the following list shows, a receiver's performance can vary widely when under the influences of these combined system and environmental biases.

- **Ionospheric Group Delays:** The earth's ionospheric layers cause varying degrees of GPS signal propagation delay. Ionization levels tend to be highest during daylight hours causing propagation delay errors of up to 30 meters, whereas night time levels are much lower and may be as low as 6 meters.
- **Tropospheric Refraction Delays:** The earth's tropospheric layer causes GPS signal propagation delays. The amount of delay is at the minimum (about three metres) for satellite signals arriving from 90 degrees above the horizon (overhead), and progressively increases as the angle above the horizon is reduced to zero where delay errors may be as much as 50 metres at the horizon.
- **Ephemeris Errors:** Some degree of error always exists between the broadcast ephemeris' predicted satellite position and the actual orbit position of the satellites. These errors directly affect the accuracy of the range measurement.
- **Satellite Clock Errors:** Some degree of error also exists between the actual satellite clock time and the clock time predicted by the broadcast data. This broadcast time error causes some bias to the pseudorange measurements.
- **Receiver Clock Errors:** Receiver clock error is the time difference between GPS receiver time and true GPS time. All GPS receivers have differing clock offsets from GPS time that vary from receiver to receiver by an unknown amount depending on the oscillator type and quality (TCXO versus OCXO, and so on). However, because a receiver makes all of its single-point pseudorange measurements using the same common clock oscillator, all measurements are equally offset, and this offset can generally be modeled or quite accurately estimated to effectively cancel the receiver clock offset bias. Thus, in single-point positioning, receiver clock offset is not a significant problem.
- **Multipath Signal Reception:** Multipath signal reception can potentially cause large pseudorange and carrier phase measurement biases. Multipath conditions are very much a function of specific antenna site location versus local geography and man-made structural influences. Severe multipath conditions could skew range measurements by as much as 100 meters or more. Refer to the *Multipath* section of the *GPS+ Reference Manual* for more information.

2 Satellite-Based Augmentation System (SBAS)

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). The Chinese SNAS and Indian GAGAN systems are also planned. At the time of publication, there are three WAAS satellites over the Pacific Ocean (PRN 122, PRN 134 and PRN 135), an EGNOS satellite over the eastern Atlantic Ocean (PRN 120) and another EGNOS GEO satellite over the African mid-continent (PRN 124). SBAS data is available from any of these satellites and more satellites will be available in the future.

Note: Since July, 2003, WAAS has been certified for Class 1/ Class 2 civilian aircraft navigation.

Figure 3 shows the regions applicable to each SBAS system mentioned in the paragraph above and how NovAtel is involved in each of them.

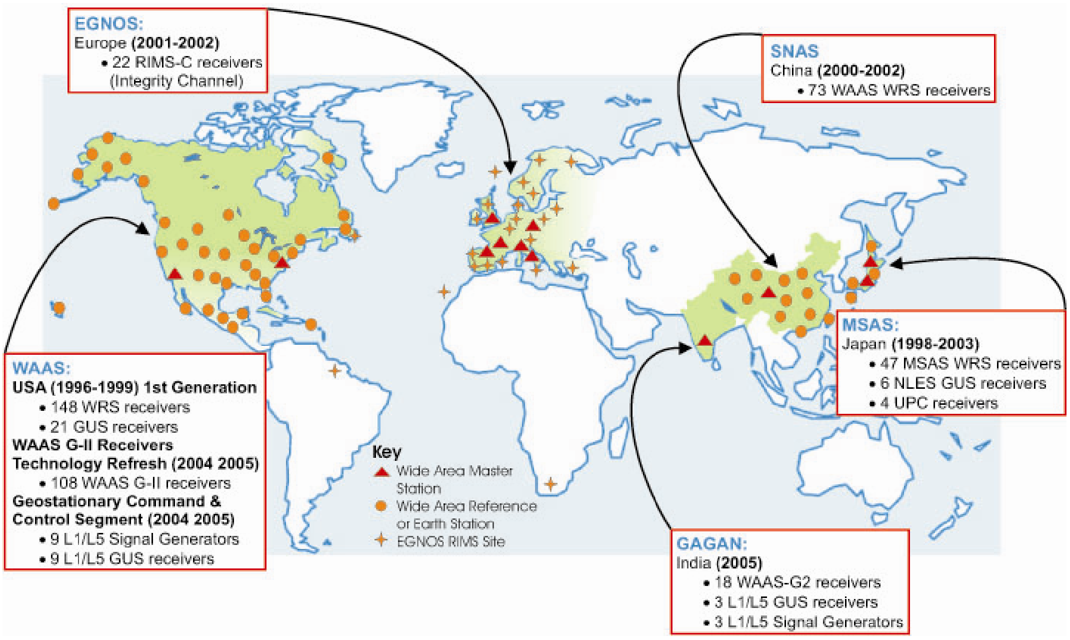

Figure 3: SBAS and NovAtel 2006

SBAS is made up of a series of Reference Stations, Master Stations, Ground Uplink Stations and Geostationary Satellites (GEOs), see Figure 4 on page 6. 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 OEMV family GPS 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 and residual errors information for each monitored satellite. You can set which ionospheric corrections model the receiver should use, refer to the SETIONTYPE command.

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.

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 and maintenance

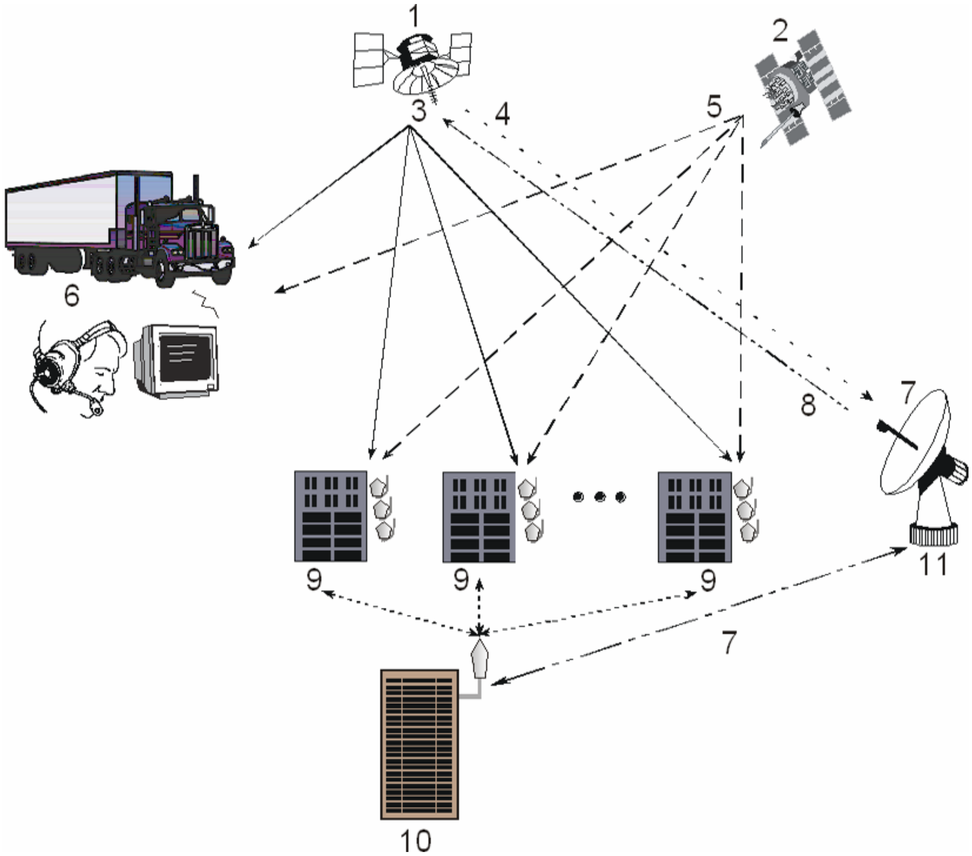

Figure 4: The SBAS Concept

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		

2.1 SBAS Receiver

All models of NovAtel OEMV receivers are equipped with SBAS capability. The ability to incorporate the SBAS corrections into the position is available in these models.

SBAS data can be output in log format (RAWWAASFRAMEA/B, WAAS0A/B-WAAS27A/B), and can incorporate these corrections to generate differential-quality position solutions. Standard SBAS data messages are analyzed based on RTCA standards for GPS/WAAS airborne equipment.

An SBAS-capable receiver permits anyone within the area of coverage to take advantage of its benefits with no subscription fee.

2.2 SBAS Commands and Logs

The command SBASCONTROL enables the use of the SBAS corrections in the position filter. All NovAtel receivers are SBAS capable and capable of receiving SBAS corrections.

Several SBAS specific logs also exist and are all prefixed by the word WAAS except for the RAWWAASFRAME log.

The PSRDIFFSOURCE command sets the station ID value which identifies the base station from which to accept pseudorange corrections. All DGPS types may revert to SBAS, if enabled using the SBASCONTROL command.

Refer to the *OEMV Family Firmware Reference Manual* for more details on the SBAS commands and logs mentioned above.

3 Pseudorange Differential

There are two types of differential positioning algorithms: *pseudorange* and *carrier phase*. In both of these approaches, the “quality” of the positioning solution generally increases with the number of satellites which can be simultaneously viewed by both the base and rover station receivers. As well, the quality of the positioning solution increases if the distribution of satellites in the sky is favorable; this distribution is quantified by a figure of merit, the Position Dilution of Precision (PDOP), which is defined in such a way that the lower the PDOP, the better the solution. Pseudorange differential is the focus of this section. Carrier-phase algorithms are discussed in Carrier-Phase Differential on page 16.

3.1 Pseudorange Algorithms

Pseudorange algorithms correlate the pseudorandom code on the GPS signal received from a particular satellite, with a version generated within the base station receiver itself. The time delay between the two versions, multiplied by the speed of light, yields the *pseudorange* (so called because it contains several errors) between the base station and that particular satellite. The availability of four pseudoranges allows the base station receiver to compute its position (in three dimensions) and the offset required to synchronize its clock with GPS system time. The discrepancy between the base station receiver’s computed position and its known position is due to errors and biases on each pseudorange. The base station receiver calculates these errors and biases for each pseudorange, and then broadcasts these corrections to the rover station. The rover receiver applies the corrections to its own measurements; its corrected pseudoranges are then processed in a least-squares algorithm to obtain a position solution.

The “wide correlator” receiver design that predominates in the GPS industry yields accuracies of 3-5 m Spherical Error Probable (SEP[2]). NovAtel’s patented PAC technology reduces noise and multipath interference errors, yielding accuracies of 1 m SEP.

[2] 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.

3.2 Position Solutions

Due to the many different applications for differential positioning systems, two types of position solutions are possible. NovAtel's carrier-phase algorithms can generate both *matched* and *low-latency* position solutions, while NovAtel's pseudorange algorithms generate only low-latency solutions. These are described below:

1. The *matched* position solution is computed at the rover station when the observation information for a given epoch has arrived from the base station via the data link. Matched observation set pairs are observations by both the base and rover stations which are matched by time epoch, and contain the same satellites. The matched position solution is the most accurate one available to the operator of the rover station, but it has an inherent *latency* – the sum of time delays between the moment that the base station makes an observation and the moment that the differential information is processed at the rover station. This latency depends on the computing speed of the base station receiver, the rates at which data is transmitted through the various links, and the computing speed of the rover station; the overall delay is on the order of one second. Furthermore, this position cannot be computed any more often than the observations are sent from the base station. Typically, the update rate is one solution every two seconds.
2. The *low latency* position solution is based on a prediction from the base station. Instead of waiting for the observations to arrive from the base station, 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 the position solution. Because only the base station observations are predicted, the rover station's dynamics are accurately reflected. The *latency* in this case (the time delay between the moment that a measurement is made by the rover station and the moment that a position is made available) is determined only by the rover processor's computational capacity; the overall delay is in the order of a hundred milliseconds. Low-latency position solutions can be computed more often than matched position solutions; the update rate can reach 20 solutions per second. The low-latency positions are provided for data gaps between matched positions of up to 60 seconds (for a carrier-phase solution) or 300 seconds (for a pseudorange solution, unless adjusted using the DGPSTIMEOUT command). A general guideline for the additional error incurred due to the extrapolation process is shown in Table 1.

Table 1: Latency-Induced Extrapolation Error

Time since last base station observation	Typical extrapolation error (RMS) rate
0 - 2 seconds	1 cm/s
2 - 7 seconds	2 cm/s
7 - 30 seconds	5 cm/s

3.3 Dual Station Differential Positioning

It is the objective of operating in differential mode to either eliminate or greatly reduce most of the errors introduced by the system biases discussed in GPS System Errors. Pseudorange differential positioning is quite effective in removing most of the biases caused by satellite clock error, ionospheric and tropospheric delays (for baselines less than 50 km), and ephemeris prediction errors. However, the biases caused by multipath reception and receiver clock offset are uncorrelated between receivers and thus cannot be cancelled by "between receiver single differencing" operation.

Differential operation requires that stations operate in pairs. Each pair consists of a base station and a rover station. A differential network could also be established when there is more than one rover station linked to a single base station.

In order for the differential pair to be effective, see Figure 5, differential positioning requires that both base and rover station receivers track and collect satellite data simultaneously from common satellites. When the two stations are in relatively close proximity (< 50 km), the pseudorange bias errors are considered to be nearly the same and can be effectively cancelled by the differential corrections. However, if the baseline becomes excessively long, the bias errors begin to decorrelate, thus reducing the accuracy or effectiveness of the differential corrections.

The Base Station

The nucleus of the differential network is the base station. To function as a base station, the GPS receiver antenna must be positioned at a control point whose position is precisely known in the GPS reference frame. Typically, the fixed position is that of a geodetic marker or a pre-surveyed point of known accuracy.

The base receiver must then be initialized to fix its position to agree with the latitude, longitude, and height of the phase centre of the base station GPS receiver antenna. Of course, the antenna offset position from the marker must be accurately accounted for.

Because the base station's position is fixed at a known location, it can now *compute* the range of its known position to the satellite. The base station now has two range measurements with which to work: *computed pseudoranges* based on its known position relative to the satellite, and *measured pseudoranges* which assumes the receiver position is unknown. Now, the base station's measured pseudorange (unknown position) is differenced against the computed range (based on known position) to derive the differential correction which represents the difference between known and unknown solutions for the same antenna. This difference between the two ranges represents the combined pseudorange measurement errors resulting from receiver clock errors, atmospheric delays, satellite clock error, and orbital errors.

The base station derives pseudorange corrections for each satellite being tracked. These corrections can now be transmitted over a data link to one or more rover stations. It is important to ensure that the base station's FIX POSITION setting be as accurate as possible, as any errors here directly bias the pseudorange corrections computed, and can cause unpredictable results depending on the application and the size of the base station position errors. As well, the base station's pseudorange measurements may be biased by multipath reception.

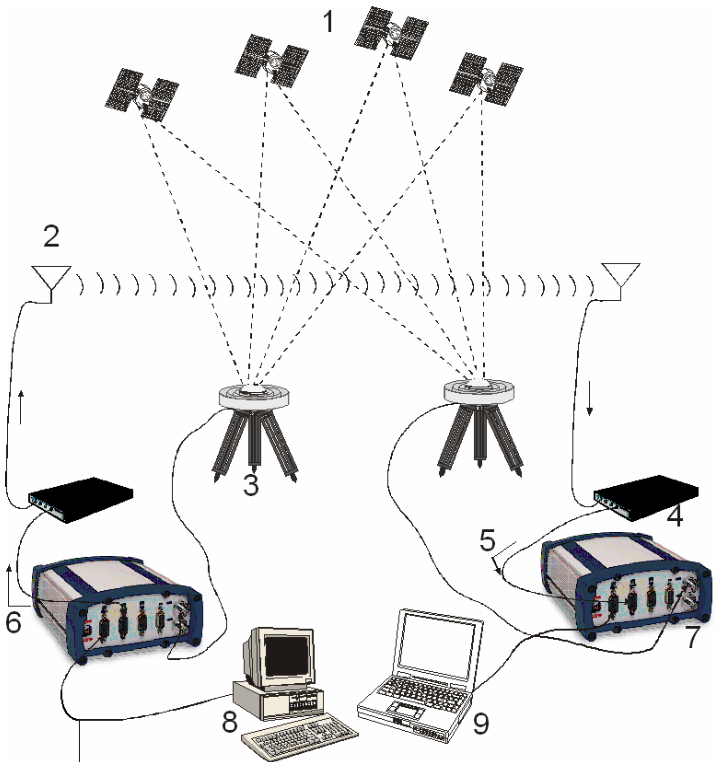

Figure 5: Typical Differential Configuration

Reference	Description	Reference	Description
1	Constellation	7	GPS Receiver
2	Radio Data Link	8	Base Station
3	GPS Antenna with Choke Ring	9	Rover Station
4	Modem		
5	Differential Corrections Input		
6	Differential Corrections Output		

The Rover Station

A rover station is generally any receiver whose position is of unknown accuracy, but has ties to a base station through an established data link. If the rover station is not receiving differential corrections from the base station, it is essentially utilizing single-point positioning measurements for its position solutions, thus is subject to the various GPS system biases. However, when the rover GPS receiver is receiving a pseudorange correction from the base station, this correction is applied to the local receiver's measured pseudorange, effectively cancelling the effects of orbital and atmospheric errors (assuming baselines < 50 km), as well as eliminating satellite clock error.

The rover station must be tracking the same satellites as the base station in order for the corrections to take effect. Thus, only common satellite pseudoranges utilize the differential corrections. When the rover is able to compute its positions based on pseudorange corrections from the base station, its position accuracies approach that of the base station. Remember, the computed position solutions from the receiver are always that of its antenna's phase centre.

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, such as the NovAtel GPS-702L, may be used.

Both systems are portable and capable of sub-meter accuracy over their coverage areas. See also Figure 8 on page *15*.

The OmniSTAR system is designed for coverage of most of the world's land areas. A subscription charge by geographic area is required. The CDGPS system is a free Canada-wide DGPS service that is accessible coast-to-coast, throughout most of the continental United States, and into the Arctic.

4.1 Coverage

The two systems provide different coverage:

- OmniSTAR - Most of the World's Land Areas
- CDGPS - Canada/America-Wide

OmniSTAR Geographic Areas

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 every few seconds. A packet contains 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 travelling to a new area, or after arrival. Contact OmniSTAR at www.omnistar.com for details.

Canada/America-Wide CDGPS

In order to enable CDGPS positioning, you must set the L-band frequency for the geographically appropriate CDGPS signal using the ASSIGNLBAND command. See also *L-band Commands and Logs* on page 15 for information on this command.

The CDGPS signal is broadcast on 4 different spot beams on the MSAT-1 satellite. Depending on your geographic location, there is a different frequency for the CDGPS signal as shown in Figure 6.

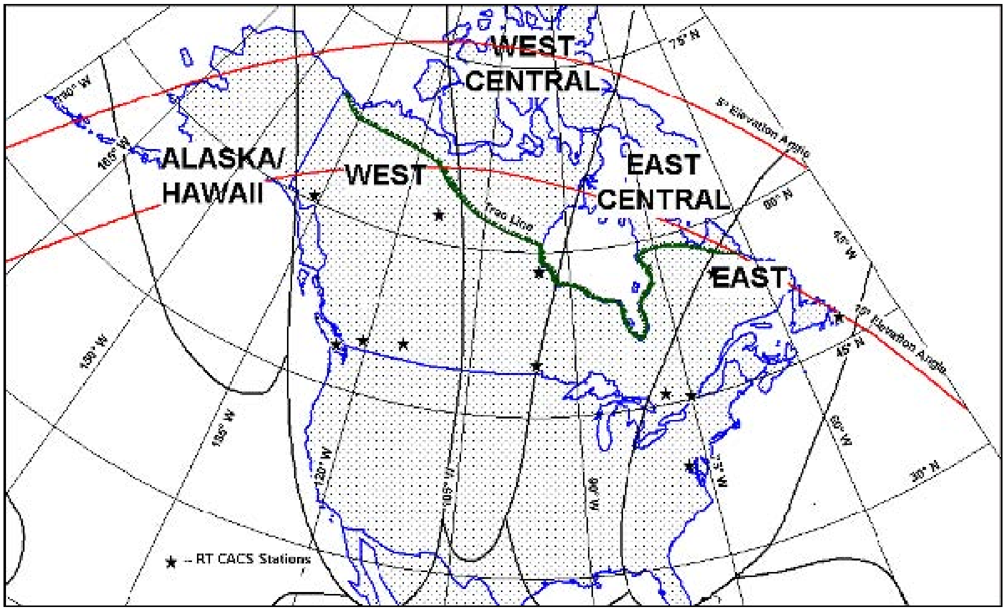

Figure 6: CDGPS Frequency Beams

The following are the spot beam names and their frequencies (in kHz or Hz):

East	1547646 or 1547646000
East-Central	1557897 or 1557897000
West-Central	1557571 or 1557571000
West	1547547 or 1547547000

Note: The CDGPS service does not include the MSAT Alaska/Hawaii beam shown in Figure 6 on page 12.

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

CDGPS features wide area technology, possible spatial integrity with all Government of Canada maps and surveys [3] [4], 24-hour/7 days-a-week built-in network redundancies and an openly published broadcast protocol.

Figure 7 is a conservative map of the coverage areas that CDGPS guarantee. The coverage may be better in your area.

[3] If the coordinates are output using the CSRS datum, refer to the DATUM command.

[4] The Geological Survey of Canada website is at http://gsc.nrcan.gc.ca/index_e.php.

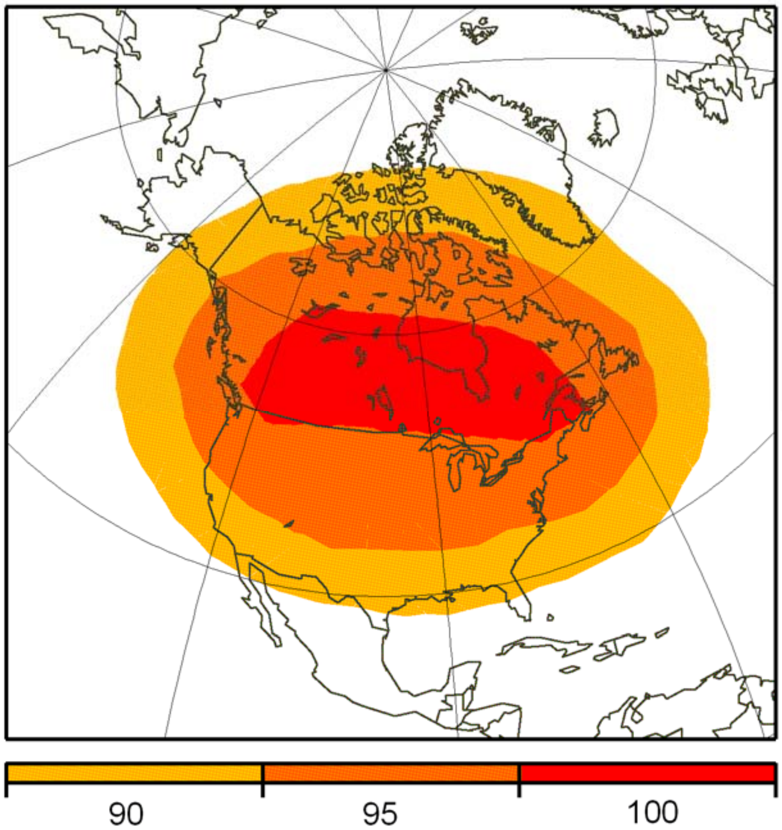

Figure 7: CDGPS Percentage (%) Coverage Map

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 PRN 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 (subscription required) and CDGPS
Extra Performance	OmniSTAR XP service accuracy is 0.15 m RMS. A subscription is required.
High Performance	OmniSTAR HP service accuracy is 0.10 m RMS. A subscription is required.

Standard Service

The OmniSTAR VBS service uses multiple GPS base stations in a solution and reduces errors due to the GPS signals travelling 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.

CDGPS is able to simultaneously track two satellites, and incorporate the corrections into the position. The output is SBAS-like (see WAAS32-WAAS45 in the *OEMV Firmware Reference Manual*), 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.

CDGPS\OmniSTAR VBS services are available on OEMV-1 and OEMV-3-based products.

NovAtel's DL-V3 and ProPak-V3 provide GNSS positions with L-band corrections in one unit, using a common antenna. This means that, with CDGPS or a subscription to the OmniSTAR service, the DL-V3 or ProPak-V3 are high quality receivers with sub-meter positioning capabilities. To obtain OmniSTAR corrections, your receiver must have a subscription from OmniSTAR.

The position from the OEMV 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.

High Performance Service

The OEMV-3, DL-V3 or ProPak-V3 with the software model for OmniSTAR High Performance (HP) service gives you more accuracy than with the OmniSTAR VBS or CDGPS services. OmniSTAR HP computes corrections in dual-frequency RTK float mode (within about 10 cm accuracy). The XP service is similar to HP but less accurate (15 cm) and more accurate than VBS (1 m). HP uses reference stations while XP uses clock model data from NASA's Jet Propulsion Laboratory (JPL). To obtain HP or XP corrections, your receiver must have an HP or XP subscription from OmniSTAR.

Notes:

1. For optimal performance, allow the OmniSTAR HP or XP solution to converge prior to starting any dynamic operation.
2. OmniSTAR XP is now available over a wider coverage area than previously.

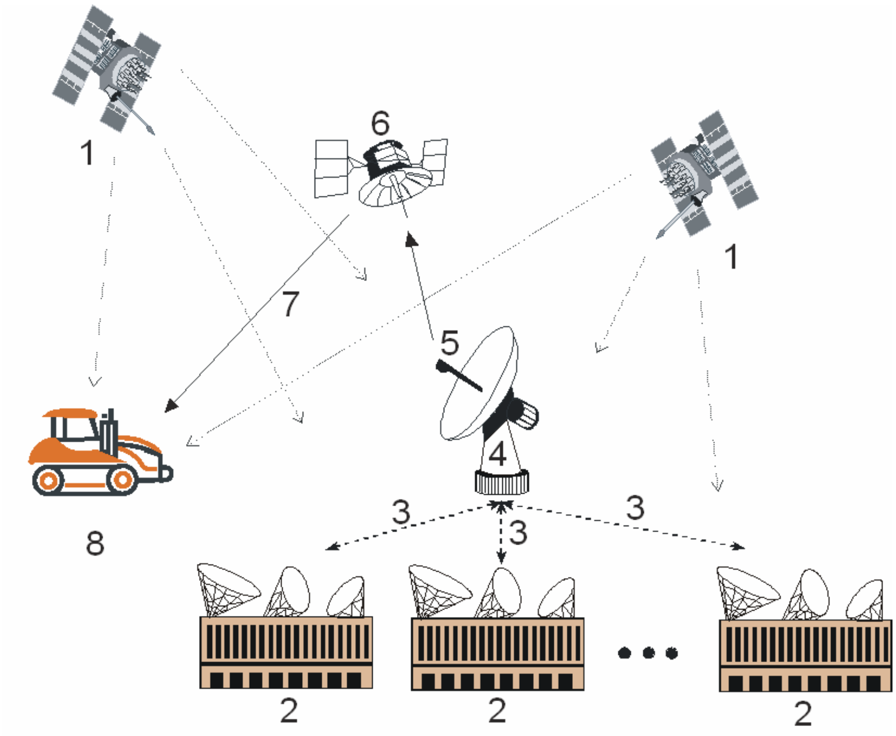

Figure 8: L-band Concept

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 6
5	DGPS uplink
6	L-band geostationary satellite
7	L-band DGPS signal
8	Correction data are received and applied real-time

4.3 L-band Commands and Logs

The ASSIGNLBAND command allows you to set OmniSTAR or CDGPS base station communication parameters. It should include a relevant frequency and data rate, for example:

```
assignlband omnistar 1536782 1200
```

or,

```
assignlband cdgps 1547547 4800
```

Note: Use the `ASSIGNLBAND OMNISTARAUTO` command for automatic beam selection if your receiver has previously stored the OmniSTAR satellite list.

The PSRDIFFSOURCE command lets you identify from which source to accept RTCM, RTCA, OMNISTAR VBS, or CDGPS differential corrections. For example, in the PSRDIFFSOURCE command, OMNISTAR enables OmniSTAR VBS and disables other DGPS types. 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 source to accept RTK (RTCM, RTCMV3, RTCA, CMR, CMRPLUS and OmniSTAR XP and HP) differential corrections. For example, in the RTKSOURCE command, OMNISTAR enables OmniSTAR HP or XP, if allowed, and disables other RTK types. AUTO means the NovAtel RTK filter is enabled and the first received RTCM, RTCA or CMR message is selected and the OmniSTAR HP or XP message, if allowed, is enabled. The position with the best standard deviation is used in the BESTPOS log.

The HPSEED command allows you to specify the initial position for OmniSTAR HP.

The HPSTATICINIT command allows you to speed up the convergence time of the HP or XP process when you are not moving.

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

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.

Notes:

1. In addition to a NovAtel receiver with L-band capability, a subscription to the OmniSTAR, or use of the free CDGPS, service is required. Contact NovAtel for details, see *Customer Service* on *Page 18*.
2. All PSRDIFFSOURCE entries fall back to SBAS (even NONE) for backwards compatibility.

Refer to the *OEMV Firmware Reference Manual* for more details on individual L-band commands and logs.

5 Carrier-Phase Differential

Carrier-phase algorithms monitor the actual carrier wave itself. These algorithms are the ones used in real-time kinematic (RTK) positioning solutions - differential systems in which the rover station, possibly in motion, requires base-station observation data in real-time. Compared to pseudorange algorithms, much more accurate position solutions can be achieved: carrier-based algorithms can achieve accuracies of 1-2 cm (RMS).

Kinematic GPS using carrier-phase observations is usually applied to areas where the relation between physical elements and data collected in a moving vehicle is desired. For example, carrier-phase kinematic GPS missions have been performed in aircraft to provide coordinates for aerial photography, and in road vehicles to tag and have coordinates for highway features. This method can achieve similar accuracy to that of static carrier-phase, if the ambiguities can be fixed. However, satellite tracking is much more difficult, and loss of lock makes reliable ambiguity solutions difficult to maintain.

A carrier-phase measurement is also referred to as an *accumulated doppler range* (ADR). At the L1 frequency, the wavelength is 19 cm; at L2, it is 24 cm. The instantaneous distance between a GPS satellite and a receiver can be thought of in terms of a number of wavelengths through which the signal has propagated. In general, this number has a fractional component and an integer component (such as 124 567 967.330 cycles), and can be viewed as a pseudorange measurement (in cycles) with an initially unknown constant integer offset. Tracking loops can compute the fractional component and the change in the integer component with relative ease; however, the determination of the initial integer portion is less straight-forward and, in fact, is termed the *ambiguity*.

In contrast to pseudorange algorithms where only corrections are broadcast by the base station, carrier-phase algorithms typically “double difference” the actual observations of the base and rover station receivers. Double-differenced observations are those formed by subtracting measurements between identical satellite pairs on two receivers:

$$ADR_{double\ difference} = (ADR_{rx\ A,sat\ i} - ADR_{rx\ A,sat\ j}) - (ADR_{rx\ B,sat\ i} - ADR_{rx\ B,sat\ j})$$

An ambiguity value is estimated for each double-difference observation. One satellite is common to every satellite pair; it is called the *reference* satellite, and it is generally the one with the highest elevation. In this way, if there are *n* satellites in view by both receivers, then there are *n-1* satellite pairs. The difference between receivers A and B removes the correlated noise effects, and the difference between the different satellites removes each receiver's clock bias from the solution.

In the RTK system, a floating ambiguity solution is continuously generated from a Kalman filter. When possible, fixed-integer ambiguity solutions are also computed because they are more accurate, and produce more robust standard-deviation estimates. Each possible discrete ambiguity value for an observation defines one *lane*. That is, each lane corresponds to a possible pseudorange value. There are a large number of possible lane combinations, and a receiver has to analyze each one in order to select the correct one. L2 measurements provide additional information making results faster and more reliable. In summary, NovAtel's RTK system permits L1/L2 receivers to choose integer lanes while forcing L1-only receivers to rely exclusively on the floating ambiguity solution.

Once the ambiguities are known, it is possible to solve for the vector from the base station to the rover station. This baseline vector, when added to the position of the base station, yields the position of the rover station.

5.1 Real-Time Kinematic (RTK)

RT-2 (OEMV-2 and OEMV-3) and RT-20 (OEMV-1, OEMV-1G, OEMV-2 and OEMV-3), all with AdVance RTK, are real-time kinematic software products developed by NovAtel. Optimal RTK performance is achieved when both the base and rovers are NovAtel products. However, AdVance RTK will operate with equipment from other manufacturers when using RTCM messaging.

RT-2 and RT-20 are supported by GPS-only and GPS + GLONASS OEMV-based models. Also, RT-20 with GPS + GLONASS provides faster convergence.

NovAtel's RTK software algorithms utilize both carrier and code phase measurements; thus, the solutions are robust, reliable, accurate and rapid. While RT-20 and RT-2 operate along similar principles, RT-2 achieves its extra accuracy and precision due to its being able to utilize dual-frequency measurements. Dual-frequency GPS receivers have two main advantages over their single-frequency counterparts when running RTK software:

1. resolution of cycle ambiguity is possible due to the additional information
2. longer baselines are easier due to the removal of ionospheric errors

Depending on the transmitting/receiving receivers and the message content, various levels of accuracy can be obtained. Please refer to the particular accuracy as shown in the following table:

Table 2: Summary of RTK Messages and Expected Accuracy

<table>
<tr><th>Message Formats</th><th>Transmitting (Base)</th><th>Receiving (Rover)</th><th>Accuracy Expected</th></tr>
<tr><td rowspan="3">L1 and L2 RTK:
GPS-only:
RTCAOBS with RTCAREF
CMROBS with CMRREF
RTCM Types 18 and 19 with 3 and 22
RTCM Types 20 and 21 with 3 and 22
GPS + GLONASS
RTCM Types 31 and 32 with Type 3
RTCM Type 59GLO with Type 3
RTCAOBS2 with RTCAREF</td><td rowspan="2">L1/L2</td><td>L1/L2</td><td>1 cm +1 ppm RMS
(RT-2)</td></tr>
<tr><td>L1</td><td>20 cm RMS
(GPS-only RT-20)
10 cm RMS
(GPS+GLONASS RT-20)</td></tr>
<tr><td>L1 only</td><td>L1/L2 or L1 only</td><td>20 cm RMS
(GPS-only RT-20)
10 cm RMS
(GPS+GLONASS RT-20)</td></tr>
<tr><td>L1 RTK:
GPS-only
RTCM Type 59 with Type 3
GPS + GLONASS
RTCM Type 59GLO with Type 3</td><td>L1 only</td><td>L1/L2 or L1 only</td><td>20 cm RMS
(GPS-only RT-20)
10 cm RMS
(GPS+GLONASS RT-20)</td></tr>
<tr><td>L1 Pseudorange Corrections:
RTCM Type 1
RTCA Type 1</td><td>L1/L2 or
L1 only</td><td>Any differential-enabled OEMV</td><td>45 cm RMS
(DGPS)</td></tr>
</table>

Below are tables that show how many GPS and/or GLONASS satellites you need to obtain a fixed ambiguity solution, Table 3 below, and how many you need to keep a fixed ambiguity solution, see Table 4. Note that fixed ambiguities are only provided in RT-2 mode.

Table 3: To Obtain a Fixed Ambiguity Solution

	#GPS Satellites							
#GLO Satellites	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	No	No	No	Float	**Fix**	**Fix**	**Fix**	**Fix**
2	No	No	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
3	No	Float	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
4	Float	Float	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
5	Float	Float	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
6	Float	Float	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
7	Float	Float	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
8	Float	Float	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**

Table 4: To Maintain a Fixed Ambiguity Solution

	#GPS Satellites							
#GLO Satellites	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	No	No	No	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
2	No	No	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
3	No	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
4	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
5	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
6	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
7	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**
8	Float	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**	**Fix**

The RTK system in the receiver provides two kinds of position solutions. The Matched RTK position is computed with buffered observations, so there is no error due to the extrapolation of base station measurements. This provides the highest accuracy solution possible at the expense of some latency which is affected primarily by the speed of the differential data link. The MATCHEDPOS log contains the matched RTK solution and can be generated for each processed set of base station observations. The RTKDATA log provides additional information about the matched RTK solution. The RTKDATA, RTKPOS and BESTPOS logs also show a verification flag in the "rtk info" field. It is recommended that you check this verification flag, especially in severe environments.

The Low-Latency RTK position and velocity are computed from the latest local observations and extrapolated base station observations. This supplies a valid RTK position with the lowest latency possible at the expense of some accuracy. The degradation in accuracy is reflected in the standard deviation and is summarized in Position Solutions on page 8. The amount of time that the base station observations are extrapolated is provided in the "differential lag" field of the position log. The Low-Latency RTK system extrapolates for 60 seconds. The RTKPOS log contains the Low-Latency RTK position when valid and an "invalid" status when a low-latency RTK solution could not be computed. The BESTPOS log contains the low-latency RTK position when it is valid, and superior to the pseudorange-based position. Otherwise, it contains the pseudorange-based position. Similarly, RTKVEL and BESTVEL contains the low-latency RTK velocity.

RT-20 solutions always use floating L1 ambiguities. When valid L2 measurements are available, RT-2 solutions have other solution types that depend on convergence time, baseline length, number of satellites, satellite geometry and the level of ionospheric activity detected.

RT-2 Performance

RT-2 software, in both static and kinematic GPS-only and GPS + GLONASS modes, provides accuracies of 1 cm +1 ppm RMS for baselines from 0 to 40 km. A plot of convergence versus baseline length is shown in Figure 9 on page *21* for typical multipath, ionospheric, tropospheric, and ephemeris errors, where typical is described as follows:

- A typical multipath environment would provide no carrier-phase double-difference multipath errors greater than 2 cm or pseudorange double-difference multipath errors greater than 2 m on satellites at 11° elevation or greater. For environments where there is greater multipath, please consult NovAtel Customer Service.
- Typical unmodeled ionospheric, tropospheric and ephemeris errors must be within 2σ of their average values, at a given elevation angle and baseline length. It is assumed that the tropospheric correction is computed with standard atmospheric parameters. All performance specifications are

based on a PDOP < 2 and continuous tracking of at least 5 satellites (6 preferred) at elevations of at least 11.5° on both L1 and L2.

Note: Refer to the GPGST usage box, like this one, in the *OEMV Firmware Reference Manual* for a definition of RMS and other statistics.

RTKPOS or BESTPOS logs contain some error due to predictions from base station observations. The expected error of a RTKPOS or BESTPOS log will be that of the corresponding MATCHEDPOS log plus the appropriate error from Table 5.

There are no data delays for a matched log and therefore no need to add an additional error factor.

Table 5: RT-2 Degradation With Respect To Data Delay

Data Delay (s)	Distance (km)	Accuracy (RMS)
0 - 2	1	+1 cm/s
2 - 7	1	+2 cm/s
7 - 30	1	+5 cm/s
>60	1	single point or pseudorange differential positioning [2]

[1] Mode = Static or Kinematic

[2] After 60 seconds reverts to pseudorange positioning (single point or differential depending on messages previously received from the base station).

The RT-2 solution can show two pronounced steps in accuracy convergence; these correspond to the single-point solution switching to the floating ambiguity solution which in turn switches to the narrow lane solution. If you were monitoring this using NovAtel’s **CDU** program, the convergence might look something like this:

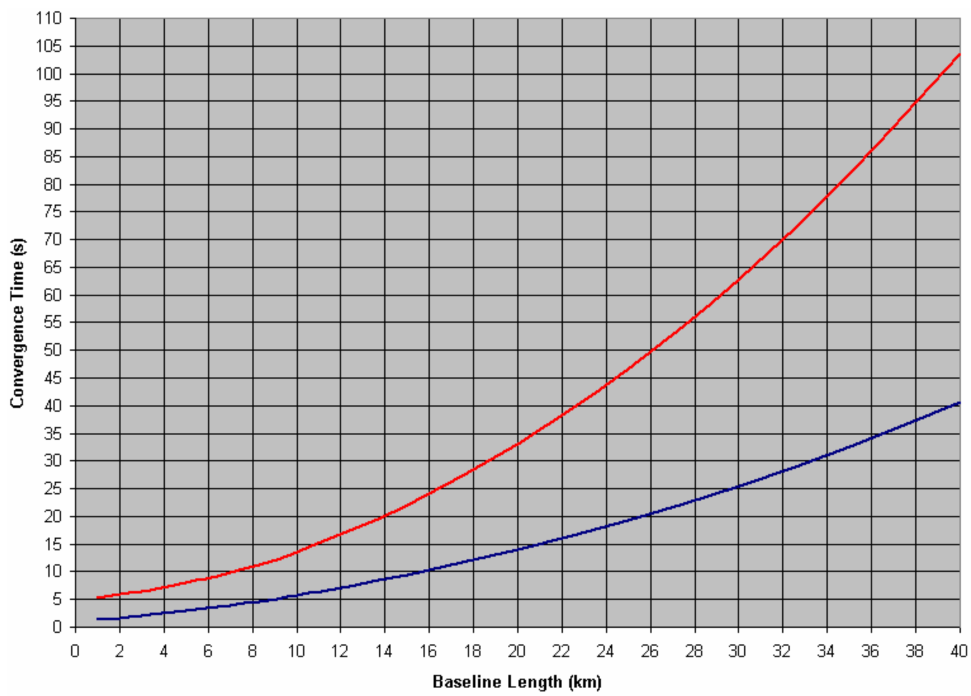

Figure 9: AdVance RTK - Time to Integer Narrow Lane vs. Baseline Length

RT-20 Performance

As shown in Table 6, Figure 10 on page 22 and Figure 11 on page 23, the RT-20 system provides nominal 20 cm accuracy (GPS-ONLY) after 15 minutes of continuous lock in static mode. After an additional period of continuous tracking (from 10 to 20 minutes), the system typically reaches steady state. The time to steady state is about 3 times longer in kinematic mode.

RT-20 double-difference accuracies are based on PDOP < 2 and continuous tracking of at least 5 satellites (6 preferred) at elevations of at least 11.5°.

All accuracy values refer to horizontal RMS error, and are based on low-latency positions. The level of position accuracy at any time will be reflected in the standard deviations output with the position.

Note: RT-20 performance with GPS + GLONASS, converges to 20 cm accuracy faster than GPS-only.

Table 6: RT-20 Performance

Tracking Time (s)	Mode [1]	Data Delay (s)	Distance (km)	Accuracy (RMS)
1 - 180	Static	0	1	45 to 25 cm
180 - 3000	Static	0	1	25 to 5 cm
> 3000	Static	0	1	5 cm or less [2]

Tracking Time (s)	Mode [1]	Data Delay (s)	Distance (km)	Accuracy (RMS)
1 - 600	Kinematic	0	1	45 to 25 cm
600 - 3000	Kinematic	0	1	25 to 5 cm
> 3000	Kinematic	0	1	5 cm or less [2]
	Either	0 - 2	1	+1 cm/s
	Either	2 - 7	1	+2 cm/s
	Either	7 - 30	1	+5 cm/s
	Either	> 30	1	pseudorange or single point [3]
	Either	0	0 - 10	+0.5 cm/km
	Either	0	10 - 20	+0.75 cm/km
	Either	0	20 - 50	+1.0 cm/km

1 Mode = Static or Kinematic (during initial ambiguity resolution)

2 The accuracy specifications refer to the BESTPOSA/B logs which include about 3 cm extrapolation error. MATCHEDPOSA/B logs are more accurate but have increased latency associated with them.

3 After 60 seconds reverts to pseudorange positioning (single point or differential depending on messages previously received from the base station).

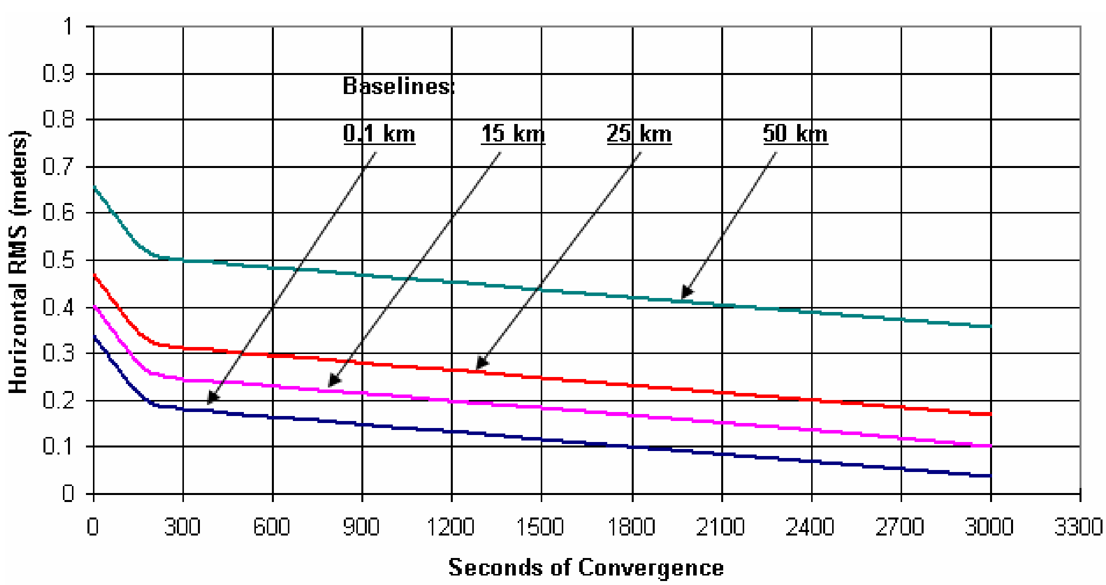

Figure 10: Typical RT-20 Convergence - Static Mode (GPS +GLONASS)

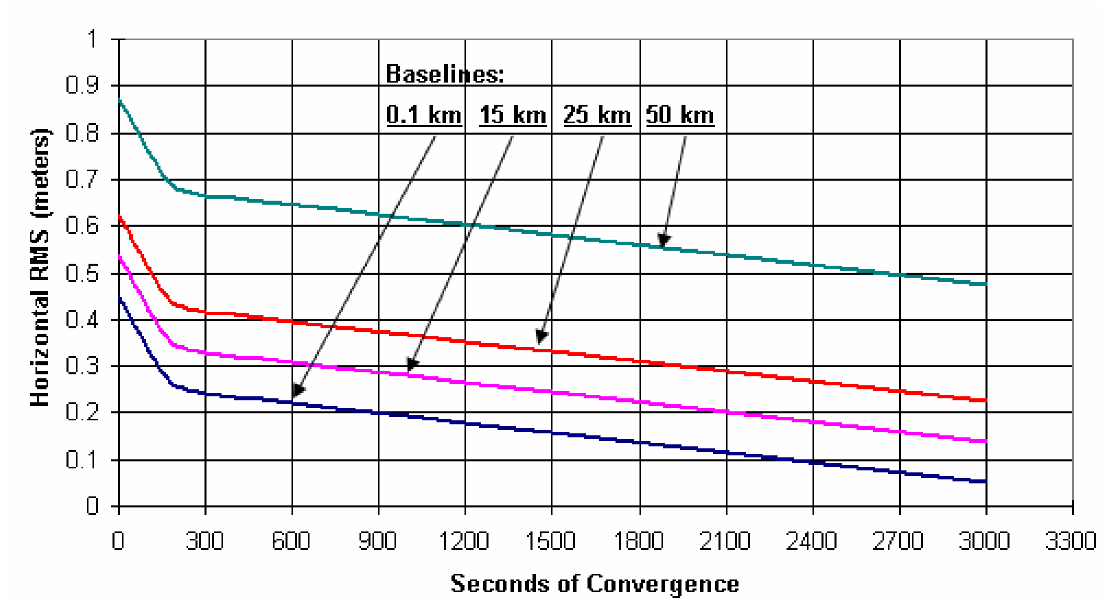

Figure 11: Typical RT-20 Convergence - Static Mode (GPS Only)

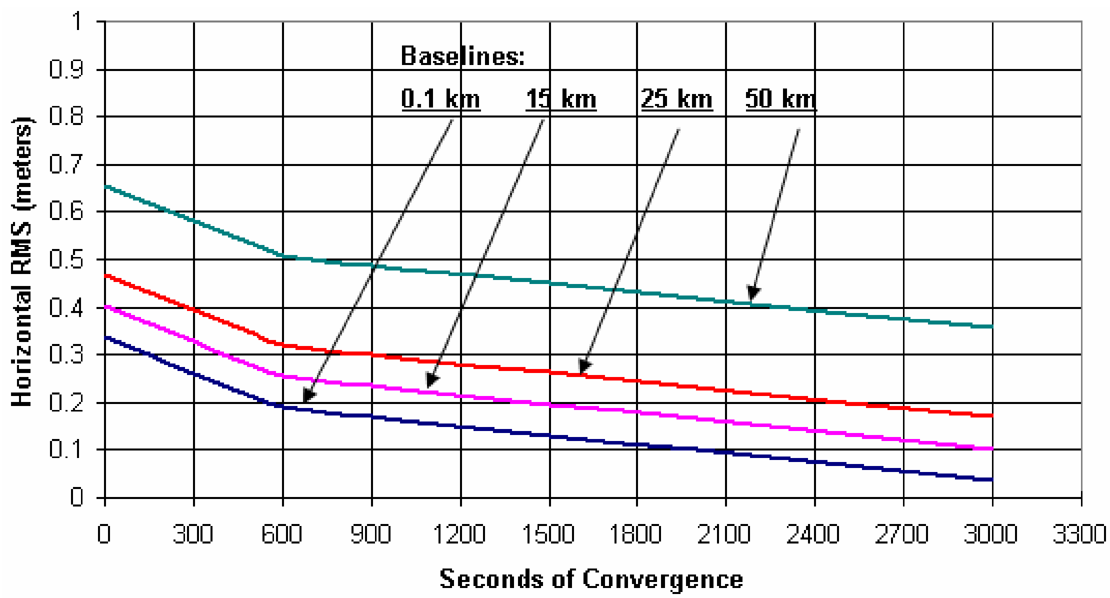

Figure 12: Typical RT-20 Convergence - Kinematic Mode (GPS+GLONASS)

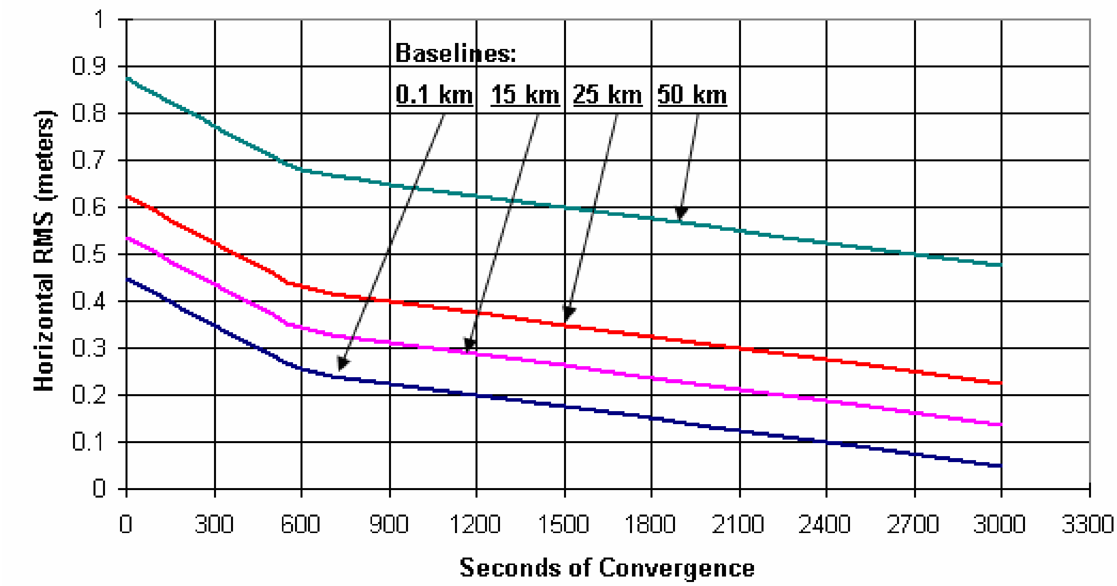

Figure 13: Typical RT-20 Convergence - Kinematic (GPS-only)

Performance Considerations

When referring to the "performance" of RTK software, two factors are introduced:

1. *Baseline length*: the position estimate becomes less precise as the baseline length increases. Note that the baseline length is the distance between the *phase centres* of the two antennas. Identifying the exact position of your antenna's phase centre is essential; this information is typically supplied by the antenna's manufacturer or vendor.

   The RTK software automatically makes the transition between short and longer baselines, but the best results are obtained for baselines less than 10 km. The following are factors which are related to baseline length:

   - ephemeris errors - these produce typical position errors of 0.75 cm per 10 km of baseline length.
   - ionospheric effects - the dominant error for single-frequency GPS receivers on baselines exceeding 20 km. Differential ionospheric effects reach their peak at around 2 pm local time, being at a minimum during hours of darkness.
   - tropospheric effects - these produce typical position errors of approximately 1 cm per 20 km of baseline length. This error increases if there is a significant height difference between the base and rover stations, as well as if there are significantly different weather conditions between the two sites.

   A related issue is that of multipath interference, the dominant error on short differential baselines. Generally, multipath can be reduced by choosing the antenna's location with care, and by the use of the GPS-702 antenna (no need for a choke ring) or a L1/L2 antenna and a choke ring antenna ground plane, refer to the *Multipath* section of the *GPS+ Reference Manual*.

2. *Convergence time*: the position estimate becomes more accurate and more precise with time. However, convergence time is dependent upon baseline length: while good results are available after a minute or so for short baselines, the time required increases with baseline length.

Convergence time is also affected by the number of satellites which can be used in the solution (the more satellites, the faster the convergence) and by the errors listed in *Baseline Length* above.

Performance Degradation

The performance will degrade if satellites are lost at the rover or if breaks occur in the differential correction transmission link. The degradations related to these situations are described in the following paragraphs.

Provided lock is maintained on at least 4 SVs and steady state has been achieved, the only degradation will be the result of a decrease in the geometrical strength of the observed satellite constellation. If steady state has not been achieved, then the length of time to ambiguity resolution under only 4-satellite coverage will be increased significantly.

Rover Tracking Loss

If less than 4 satellites are maintained, then the RTK filter can not produce a position. When this occurs, the BESTPOS and PSRPOS logs will be generated with differential (if pseudorange differential messages are transmitted with RTK messages) or single point pseudorange solutions if possible.

Differential Link Breakdown

1. Provided the system is in steady state, and the loss of observation data is for less than 60 seconds, the Low-Latency RTK positions will degrade according to the divergence of the base observation extrapolation filters. This causes a decrease in accuracy of about an order of magnitude per 10 seconds without a base station observation, and this degradation is reflected in the standard deviations of the low latency logs. Once the data link has been re-established, the accuracy will return to normal after several samples have been received.
2. If the loss of differential corrections lasts longer than 60 seconds, the RTK filter is reset and all ambiguity and base model information is lost. The timeout threshold for RTK differential corrections is 60 seconds, but for Type 1 pseudorange corrections, the default timeout is 300 seconds. Therefore, when the RTK can no longer function because of this timeout, the pseudorange filter can produce differential positions for an additional 240 seconds by default (provided pseudorange differential messages were transmitted along with the RTK messages) before the system reverts to single point positioning. Furthermore, once the link is re-established, the pseudorange filter produces an immediate differential position while the RTK filter takes several additional seconds to generate its positions. The base model must be healthy before solutions are logged to the low latency logs, so there is a delay in the use of real time carrier positioning to the user once the link has been re-established. The RTK logs, such as MATCHEDPOSA/B, use matched observations only (no extrapolated observations). These matched observations will be available after three base observations are received, but will typically have about 1.5 seconds latency associated with them, although longer latencies may occur with some slower data links.
3. The RTK system is based on a time-matched double difference observation filter. This means that observations at the rover site have to be buffered while the base station observation is encoded, transmitted, and decoded. Only 8 seconds of rover observations are saved, so the base station observation transmission process has to take less than 8 seconds if any time matches are to be made. In addition, only rover observations on even second boundaries are retained, so base station observations must also be sent on even seconds if time matches are to be made.