

GPS+GLONASS Technology and the GG24™ Receiver



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GPS

When the Global Positioning System (GPS) became operational in 1993, it promised to provide a new utility as pervasive and as useful as the telephone. For many GPS users, this potential has already become a reality. Pilots now use GPS to locate airports, mariners can find harbors, hikers can find their way, and surveyors can measure positions to centimeter accuracy. New applications allow farmers, miners and construction workers to guide their machines using GPS. However, just as the telephone system had limitations, the GPS system has limitations that become apparent in certain applications. Many of these impediments to full utilization of GPS are dramatically reduced by the augmentation of GPS with GLONASS satellites.

AVAILABILITY

A navigation system is “available” when it produces valid position fixes. The availability of a valid and accurate GPS position fix depends most strongly on the visibility of enough satellites. A GPS receiver needs to “see” at least four satellites to calculate latitude, longitude and altitude. For real-time centimeter accuracy, five or more satellites are required. This is easy in a perfect environment. With 24 GPS satellites orbiting the earth, there are usually seven satellites visible 10 degrees or more above the horizon. But if there is a mountain, building or other obstruction nearby, the number of visible satellites may fall to four, three, or fewer, with the possibility that the GPS receiver has too few satellites to compute a position.

INTEGRITY

A navigation system has “integrity” when it can warn the user that the position fix is in error. It’s even better if the system can remove the error and provide a correct solution. A GPS receiver must have five satellites to be able to detect an integrity problem. To remove the problem, a sixth satellite must be visible. The U.S. Department of Transportation suggests that the capability to exclude an anomalous satellite be possible 99.999% of the time for a primary-means air navigation system. Even if all 24 GPS satellites are operational, GPS-only navigation

cannot meet this very stringent requirement. So, for the moment, airlines still include a more expensive, less accurate means of navigation with their GPS.

ACCURACY

Stand-alone GPS has a demonstrated accuracy of better than 20 meters, horizontal, 95% of the time. The imperfect predictions of satellite orbits, satellite clock behavior and atmospheric effects on the signals are the primary causes of error in the basic GPS. GPS accuracy has been so good that the U.S. decided to deny the full capability of GPS to users who are not specifically authorized this level of accuracy. The denial of accuracy is called Selective Availability (SA) and is part of the GPS Standard Positioning Service (SPS). SPS promises a position within 100 meters of truth, horizontal, 95% of the time. Authorized users have access to the GPS Precise Positioning Service (PPS), which is not corrupted by SA, and achieve 20 meter accuracy¹.

For marine safety, accuracy of 10m or better is often required. Navigation aids, such as buoys, are usually positioned to 10m accuracy. A GPS receiver alone cannot provide this level of accuracy because of Selective Availability.

Users and governments in many countries have set up differential reference stations to minimize the effect of SA errors and the errors in the less than perfect predictions of orbit, clock and atmospheric behavior. The reference stations compute and transmit corrections to users in the service area depending on the reference station provider. Unfortunately, the radios needed to receive these corrections often cost more than the GPS receiver itself.

The White House has pledged to review the policy of Selective Availability yearly, *starting in the year 2000*. Until then, some SPS GPS users have a choice of less accuracy or more

¹ Unless specifically identified otherwise, the term “accuracy” used in this paper will mean that the horizontal distance from the true location to the estimated location is within the accuracy value 95% of the time. This value is often referred to as 2dRMS.

expensive differential GPS. In parts of the world where no differential reference stations are available, SPS GPS users will typically be stuck with an accuracy of 100 meters.

The impact of SA is magnified in the vertical component. Hikers may spend all day climbing a mountain, for example, Colorado's Pikes Peak. Upon reaching the top at 14,110 feet, their GPS receiver tells them they are at only 13,800 feet. Ten minutes later, the same receiver may indicate that they are at 14,400 feet. This is a result of Selective Availability, which not only produces errors, but constantly changes them. Not very reassuring for hikers hoping to use GPS in areas where an extra few hundred feet may mean the difference between being on the cliff or over the edge.

Surveyors, miners, farmers and others have generally solved the accuracy problem by installing their own differential reference stations. They can and do achieve position accuracy of centimeters. However, even here, the constantly changing errors from Selective Availability make an impact; the radio corrections must arrive rapidly and constantly. A few seconds of lost radio reception results in rapidly growing errors, even though the GPS receiver may be tracking several satellites.

Summary:

- For many users, GPS is a utility like a telephone, but the system has limitations.
- In areas of signal blockage, there may not be enough visible satellites to compute a position.
- GPS alone cannot guarantee the six or more satellites needed for integrity determination.
- GPS accuracy is degraded by the policy of Selective Availability.

GPS + GLONASS

Ask yourself this question: *"What if we could add another 24 satellites to the GPS system, but this time without any deliberate degradation of accuracy. Would this remove the limitations on the system?"*

The answer is: *Yes!*

All of the limitations discussed earlier would be dramatically reduced simply by adding an

additional 24 satellites to the current GPS constellation with no deliberate degradation of accuracy and no encryption of the most accurate signals.

Now ask yourself another question: *"When might we expect such a system to be in place and ready to use?"*

The answer is: *Now!*

Believe it or not, the extra 24 satellites needed to expand GPS to a true utility are already in orbit and operational. In January 1996, the Russians completed their full constellation of 24 operating satellites in the GLObal Navigation Satellite System (GLONASS), a system almost exactly the same as GPS. However, GLONASS has two significant differences from GPS: no deliberate degradation of accuracy and no encryption of the most accurate signals. The addition of GLONASS to GPS enhances the three important factors: availability, integrity and accuracy.

Summary:

- The extra satellites needed to remove the GPS limitations are already operational.
- The addition of GLONASS to GPS dramatically improves availability, integrity and accuracy.

AVAILABILITY

Figure 1
Availability: GPS-only Limited in the Urban Canyon



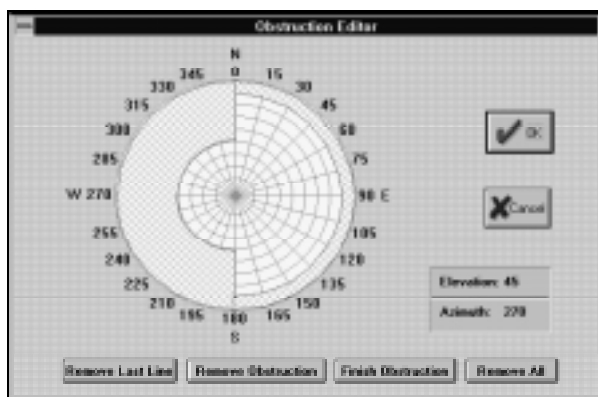
Compare the number of visible satellites shown in Figure 1 with the number of satellites visible in Figure 2. The boat on the water sees enough satellites to compute a position even with GPS-only. But the car in the city doesn't have enough GPS satellites to determine position.

Figure 2
More Availability:
GPS+GLONASS Approaches 100%



Figure 1 clearly shows that environments with obstructions, such as a cityscape, reduce satellite visibility often to the point where the receiver can no longer compute a position. By adding the 24 GLONASS satellites to the 24 GPS satellites, there is twice the likelihood that there is a satellite in the part of the sky that is visible. The availability of a GPS+GLONASS™ position fix is significantly improved over GPS-only in such situations. Figures 3 and 4 demonstrate this point.

Figure 3
Obstruction Editor



We use tools called Mission Planners to analyze how many satellites will be visible from any given location, with any known obstructions blocking part of the sky. Satellite visibility changes depending on time and location. For the purposes of this paper, we chose an arbitrary point at 37 degrees North, 122 degrees West (this is Sunnyvale, California, where Ashtech GPS+GLONASS receivers are built and tested). We constructed an obstruction 45 degrees above the horizon, covering the whole western sky, as well as a 10 degree obstruction for the eastern sky. Examples of this kind of obstruction include urban canyons, especially when the user is close to tall buildings, open pit mines and mountainous terrain. Figure 3 shows this blockage scenario.

Figure 4 shows the satellite availability for only the 24 GPS satellites. The straight lines and right-side axis show the number of satellites visible at each time through 24 hours. The broken line and left-side axis shows a value called PDOP. PDOP is a statistical measure of the accuracy of the computed three-dimensional position and is influenced by how the satellites are spread around the sky. If PDOP doubles, then the expected position errors also double. A good range of values for PDOP is 6 or less. When fewer than 4 satellites are visible, latitude, longitude and altitude cannot be calculated. When fewer than 5 satellites are available, real-time centimeter accuracy is not possible.

Figure 4
Satellite Availability with GPS-only and 45° Obstruction

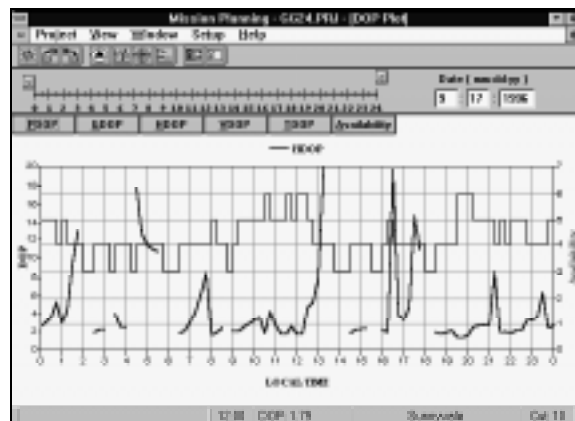
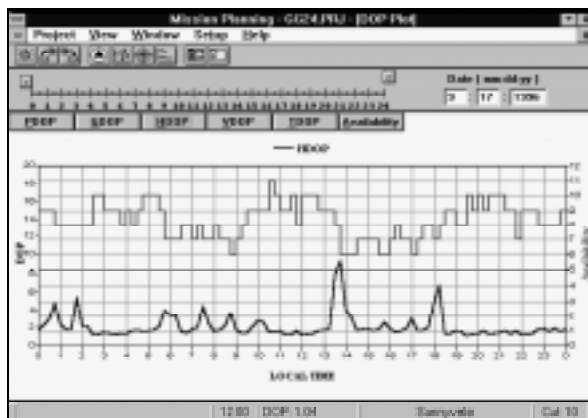


Table 1
Satellite Visibility with GPS-only and 45° Obstruction

Criterion	Availability
5 or more satellites visible, real-time centimeter-decimeter accuracy ²	33%
4 or more satellites visible, PDOP less than 6, 3D position possible	86%

When GPS and GLONASS are used together, the receiver needs 1 extra satellite in the solution to account for the different reference times used by the two systems. However, these reference times change very slowly with respect to each other, so once the receiver has seen 5 satellites and computed a full solution, it can then continue to compute latitude, longitude and altitude with just 4 satellites from both systems combined (e.g., 2 GPS satellites and 2 GLONASS satellites).

Figure 5
Satellite Availability with GPS+GLONASS and 45° Obstruction



² To achieve real-time centimeter accuracy, a process known as carrier-phase ambiguity resolution is necessary. This requires 5 or more GPS satellites. If 5 or more satellites are available, and PDOP is large, then carrier-phase ambiguity resolution is still possible, but the expected accuracy will be worse.

Table 2
Satellite Visibility with GPS+GLONASS and 45° Obstruction

Criterion	Availability
Real-time centimeter-decimeter accuracy possible ³	100%
3D position possible	100%

These tests were repeated at different sites, from the equator to the North Pole. The results were very similar between 0 degrees and 60 degrees latitude (within 10% of the above results for GPS-only; within 5% of the above results for GPS+GLONASS). North of the Arctic Circle, the GPS+GLONASS results were similar; however, GPS-only results deteriorated dramatically to less than 50% availability of 4 or more satellites. The results for the Southern Hemisphere are symmetrical to the Northern Hemisphere.

Another consequence of satellite availability is that, when centimeter accuracy is possible, the time required to achieve centimeter accuracy decreases as the number of satellites increases. The improvement of GPS+GLONASS over GPS-only is shown in Table 3.

Table 3

Receiver	Time from satellite lock to cm accuracy
GPS L1	30-40 min.
GG24GPS+GLONASS L1	5-15 min.

³ To achieve real-time centimeter accuracy, a process known as carrier-phase ambiguity resolution is necessary. This requires 6 or more GPS+GLONASS satellites. If 6 or more satellites are available, and PDOP is large, then carrier-phase ambiguity resolution is still possible, but the expected accuracy will be worse.

Summary:

- Visibility of GPS satellites is severely restricted by large obstructions that block part of the sky, for example, skyscrapers.
- When large obstructions block part of the sky, the availability of real-time high-precision (centimeter and decimeter) is more than doubled by the addition of GLONASS to GPS.
- The time taken to achieve 1cm accuracy is reduced by 3 to 6 times with GPS+GLONASS.

INTEGRITY

The DoT's Volpe National Transportation System Center, Cambridge, MA, recently analyzed the ability of GPS and combined GPS+GLONASS to satisfy the requirements of a primary-means air navigation system⁴. The conclusion was that GPS does not satisfy the demands but GPS+GLONASS most likely will provide an acceptable solution.

To be acceptable as a primary-means of navigation, the navigation equipment must satisfy the necessary levels of availability, integrity and accuracy for a particular area, route, procedure of operation. Essentially, the requirements demand a 99.999% visibility of at least six satellites above a five degree mask angle including the possibility of satellite outages for planned or unplanned maintenance. Six satellites are required to identify an anomaly and to exclude the satellite that contains the anomaly. With no satellite outages, six or more satellites are visible for 97.2% of the time. It's no surprise that the study concludes that "GPS alone does not provide sufficient availability to serve as a primary means of navigation."

The DoT study analyzed the coverage provided by a full GPS constellation augmented by a full GLONASS constellation. The DoT also analyzed coverage from a partial GPS constellation augmented by a partial GLONASS constellation. In both the fully operational and the partial constellation cases, the combined constellations had a large and dramatic improvement over the GPS-only

constellation. The conclusion was that "Fully operational GPS and GLONASS systems provide 100% availability for all phases of flight." Even partial constellations provided complete availability in many situations. For example, with only 21 GPS satellites and 21 GLONASS satellites, availability was 100% for oceanic and en-route phases of flight, 99.99% for the terminal phase and 99.64% for the non-precision approach phase.

The following tables are taken from the study and summarize the results for GPS-only and for GPS+GLONASS.

Table 4
FDE Availability for Oceanic, En Route, Terminal, and NPA Modes of Flight

	GPS	GPS+GLONASS
Oceanic	99%	100%
En Route	97.77%	100%
Terminal	4.97%	100%
NPA	60.12%	100%

⁴ *Fault Detection and Exclusion Performance Using GPS and GLONASS*, Karen L. Van Dyke, Navigation: Journal of the Institute of Navigation, Vol. 42, No. 4, Winter 1995, pp. 581-594.

Table 5
Maximum FDE Outage Duration for
Oceanic, En Route, Terminal, and NPA
Modes of Flight

	GPS	GPS+GLONASS
Oceanic	35 min.	0 min.
En Route	65 min.	0 min.
Terminal	80 min.	0 min.
NPA	295 min.	0 min.

Summary:

- Integrity: GPS+GLONASS has enough satellites to meet the integrity requirements for primary-means navigation for aircraft; GPS-only does not.

ACCURACY

The Ashtech GG24™ GPS+GLONASS receiver improves accuracy over a GPS-only receiver and over a GLONASS-only receiver.

In autonomous operation, the GG24 receives and uses the signals from the GPS satellites and the GLONASS satellites. The GPS signals are deliberately degraded to provide 100m position accuracy (with 95% probability). The GLONASS signals are not deliberately degraded, but are still subject to the errors in the prediction of the orbit, clock and atmosphere. The result of combining the signals from the two systems is position accuracy of 16m.

In differential operation, the GG24 receives corrections from a differential reference station (such as another GG24) placed at a known point. These corrections remove the deliberate errors on GPS and the unintentional errors on both GPS and GLONASS. This results in accuracy of 90cm, which is similar to

a state-of-the-art GPS-only system (such as the Ashtech G12). When satellite visibility is restricted, Differential GPS+GLONASS accuracy can become significantly better than Differential GPS-only because enough GPS+GLONASS satellites remain visible to keep Position Dilution of Precision (PDOP) low.

The following plots show data collected with a GG24 receiver, using both GPS+GLONASS as well as data collected with a GPS-only receiver. Seven hours of data were collected simultaneously, at the same place and using both receivers. The plots show the computed position. The position has been overlaid on a (U.S.) football field to show scale. The scatter shows the positions computed by the receivers. The center of the football field is the true position of the receiver. The circles in each plot show the radius containing 95% of the scattered positions.

Figure 6 illustrates large errors that are directly attributable to the degradation caused by Selective Availability. Comparing this plot with the following GPS+GLONASS plot shows that the difference in errors is the difference between the whole football field and ten yard markers.

Figure 6
GPS-only, 95% Circle = 42 Yards

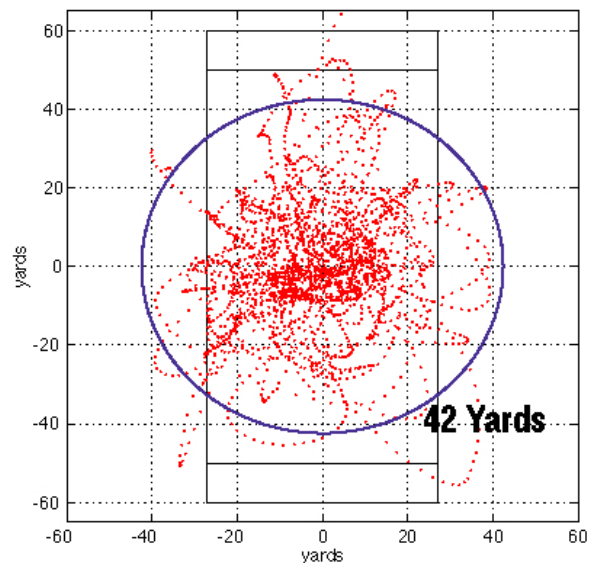


Figure 7

**GPS+GLONASS, 95% Circle =
13 Yards**

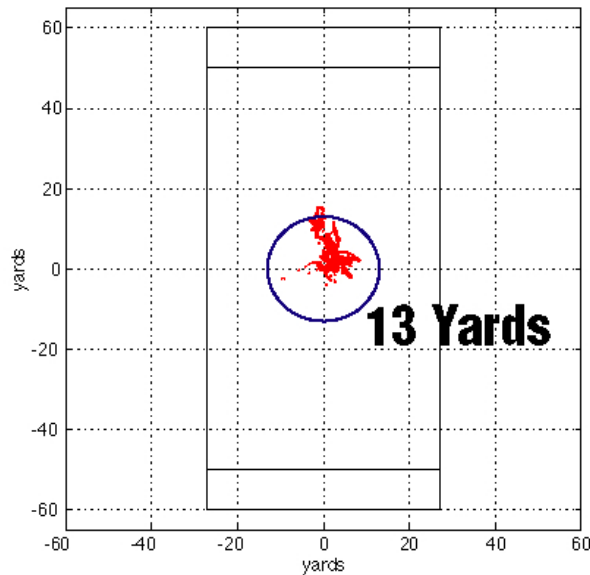
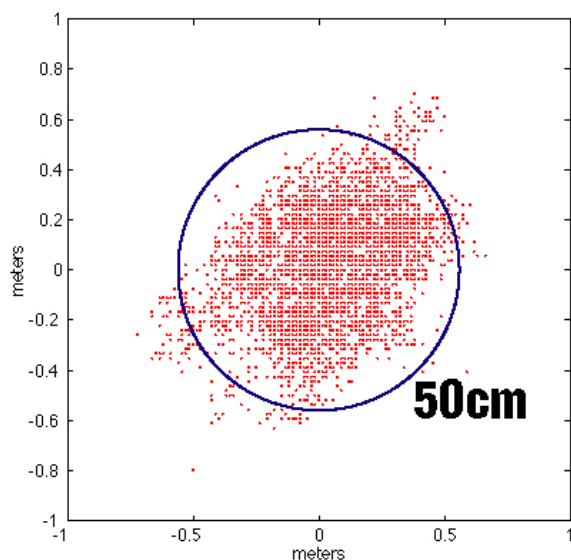


Figure 8 shows data collected in Differential GPS mode. This shows how accuracy improves to approximately half a meter with differential corrections. Differential GPS+GLONASS accuracy is similar. Continuing the football analogy, differential accuracy is about the size of $1\frac{1}{2}$ footballs.

**Figure 8
Real-Time RTCM Code Differential GPS,
95% Circle = 50cm**



Summary:

- In autonomous mode, GPS-only accuracy is guaranteed to be 100m (95%) by the policy of Selective Availability. Comparable GPS+GLONASS accuracy is 16m.
- Differential GPS has similar accuracy to Differential GPS+GLONASS – when visibility is restricted, Differential GPS+GLONASS can be much better.

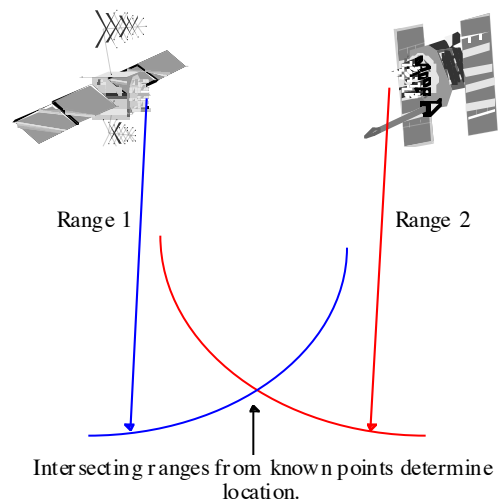
HOW GPS AND GLONASS WORKS

THE BASIC IDEA – SATELLITE RANGING

Both GPS and GLONASS work on the principle of trilateration: if we know our distance from several known points, then we can compute where we are. The known points for GPS and GLONASS are the satellites.

The signals from the satellites travel at the speed of light. The distance to a satellite is measured by timing how long the satellite signal takes to reach us. Multiply the time of travel by the speed of light to calculate the distance.

**Figure 9
Time Delay of Signal x Speed of Light =
Distance to Satellite**



The basic technical problem is that this requires very accurate clocks in the satellites and in the receiver since light travels rather

fast (in fact, it takes approximately 0.06 seconds for the satellite signals to travel to the earth). The timing issue is solved for the satellites by using very precise atomic clocks, which are all synchronized with each other to nanosecond accuracy (one-billionth of a second). The cesium clocks used on GPS satellites cost in the order of \$1M each.

Inside a GPS receiver is a low-cost quartz clock. This clock introduces an error when the measurements are made, *but* the error can be calculated and removed because the satellite clocks are precisely synchronized. To calculate latitude, longitude, altitude and the receiver clock error, at least four satellites are needed. This is the old mathematical exercise of *solving four unknowns (latitude, longitude, altitude and time) with four equations (four satellite measurements)*.

What about GPS+GLONASS? As discussed earlier, the GPS satellite clocks are all synchronized. Similarly, the GLONASS satellites are all synchronized with each other. However, GPS time is not synchronized with GLONASS time. So now the receiver clock has two time-related unknowns: the difference with GPS time, and the difference with GLONASS time. These two clock terms, plus latitude, longitude and altitude, give 5 unknowns, which are solved by having 5 satellites (or more) in view.

Summary:

- We determine our position by knowing our distance from other known positions.
- We measure the distance to the satellites by timing the delay of the transmitted signals and then multiplying it by the speed of light.
- The satellites have extremely expensive and accurate clocks.
- Receivers do not need expensive clocks, but they do need:
 - At least 4 satellites in view for a GPS-only or GLONASS-only receiver
 - At least 5 satellites in view for a solution using both GPS and GLONASS satellites

SIGNAL STRUCTURE – HOW THE TIME DELAY IS MEASURED

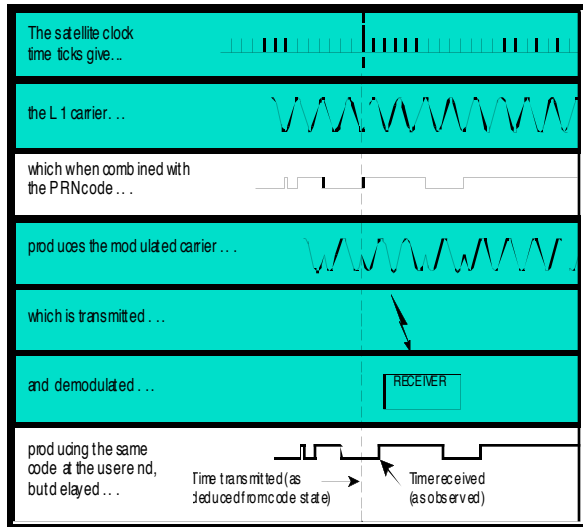
In the previous section, we showed how positions are determined by measuring the time of travel of the transmitted signals, but how do receivers actually measure this delay?

Both the GPS and GLONASS satellites transmit a signal known as a PRN (Pseudo Random Noise) code. This code is chosen for its robustness to interfering signals. The code is a sequence of “1’s” and “0’s.” The code is actually transmitted through space by modulating it onto a carrier wave. The carrier wave is a sinusoidal signal. If we could hear it, it would sound like a high pitched single tone. Every time the PRN code changes from a “1” to a “0” (or back), the carrier wave is flipped through 180 degrees. This is known as modulation and is shown in the following figure. The modulated carrier travels through space and, after approximately 0.06 seconds, reaches the earth.

The GPS+GLONASS receiver has the PRN codes programmed into its memory. The receiver reproduces the PRN codes of the satellites in view, and moves them until they match the received signal. By knowing how much the code had to be moved, the receiver computes what is called a *pseudo-range*.

If the receiver’s clock were accurate and synchronized to the satellite time reference, the shift of the code is a measure of range to the satellite. Because the receiver’s clock is not synchronized, the code had to be shifted to account both for the range to the satellite and for the offset of the receiver’s clock. Thus, the actual measurement is called *pseudo-range* instead of simply range.

Figure 10
Modulation



Summary:

- The satellites generate known codes which are transmitted on a carrier wave.
- The receiver duplicates the code and, by matching it with the (delayed) code from the satellite, determines the time of travel.
- The actual receiver measurement, called pseudo-range, is the range plus the receiver clock offset.

SIGNAL STRUCTURE – TECHNICAL

DETAILS

GPS and GLONASS have a very similar signal structure.

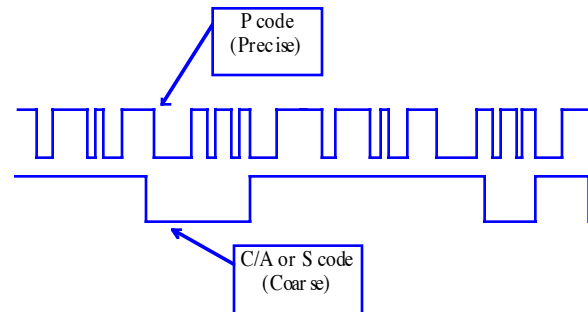
- Both transmit on two frequency bands, called L1 and L2.
- Both have PRN codes in the L1 frequency band, known as Coarse/Acquisition (C/A) code for GPS and Standard (S) code for GLONASS.
- Both have more accurate PRN codes, known as Precise (P) code, on both L1 and L2 frequencies.
- Both transmit almanacs and ephemerides at a data rate of 50bps.

PRN CODES

The P code is more precise because the rate at which “1’s” and “0’s” occur is 10 times faster

than the C/A or S code (for both GPS and GLONASS).

Figure 11



If we measure the dimensions of a piece of paper using two rulers, one with ten times greater resolution on the tick-marks than the other ruler, we can see why the P code is more precise. Like the P code, the ruler with more tick-marks offers increased precision.

Both C/A (GPS) and S (GLONASS) PRN codes repeat every 1 millisecond.

The difference between the GPS and GLONASS signal structure is that GPS uses the same frequencies for all satellites but different PRN codes for each satellite. This is called Code Division Multiple Access, or CDMA. Alternatively, GLONASS uses the same PRN codes for all satellites but different frequencies within the L1 and L2 bands for each satellite. This is known as Frequency Division Multiple Access, or FDMA.

GPS satellites are usually identified by their PRN codes, since they are all different. GPS PRN codes are numbered from 1 through 32.

GLONASS satellites are usually identified by their orbital slot-number. There are 24 orbital slots, numbered sequentially 1 through 24; a satellite takes the number of the slot it occupies.

The major differences in implementation between GPS and GLONASS are:

1. GPS has Selective Availability on both C/A and P codes; that is, they are deliberately

degraded by “dithering” the transmit time. GLONASS has no deliberate degradation.

2. GPS encrypts the P code on both L1 and L2 with a secret encrypted code. This is known as “Anti-Spoofing.” GLONASS has no encryption.

ALMANACS

Both GPS and GLONASS satellites transmit navigation information about themselves in almanacs. Each satellite transmits an almanac which tells the receiver which satellites are operating and where they are. This is how the receiver knows which satellites are above the horizon. GPS satellites are identified in their almanac by their PRN numbers. GLONASS satellites are identified by their orbital slot numbers. Each slot number has an associated carrier number that is in the almanac, and it tells the GPS+GLONASS receiver on which frequency to find the satellite.

FREQUENCY

Each GPS satellite transmits at an L1 frequency of 1575.42 MHz, and at an L2 frequency of 1227.60 MHz. Each GLONASS satellite transmits at an L1 frequency of $1602 + K \times 9/16$ MHz, and at an L2 frequency of $1246 + K \times 7/16$ MHz. “K” symbolizes the carrier number given in the almanac for each satellite. Currently, “K” is in the range 1 through 24. Some changes are planned for the GLONASS frequency plan:

Stage 1. Present to 1998

The carrier numbers will be assigned in such a way as to avoid the frequencies in the band 1610.6-1613.8 MHz used in Radio Astronomy. This means that the carrier number assignments K=16,17,18,19,20 will not be used. To compensate for the lost frequencies, identical frequencies will be used for two satellites on opposite sides of the earth.

Stage 2. 1998 to 2005

The next generation of GLONASS-M satellites will use the carrier number assignments 1 through 12.

Stage 3. Beyond 2005

The GLONASS-M satellites will use the carrier number assignments -7 through +4. Carriers 5

and 6 will be used for interaction with the ground control segment.

Any or all of these changes in frequency will have no effect on a well-designed GPS+GLONASS receiver, such as the Ashtech GG24. This is because the capability to handle any of the carrier number assignments is built-in, and the satellite almanac always tells the receiver which assignment to use for each satellite.

EPHEMERIDES

Satellite ephemerides are like a “super-almanac”; that is, they tell the receiver *precisely* where the satellite is. Each satellite (both GPS and GLONASS) transmits its own ephemerides. The GPS satellites provide their positions in terms of the WGS 84 (World Geodetic System, 1984) reference system; the GLONASS satellites provide their positions in terms of the PE-90 (Parameters of the Earth, 1990) reference system. Inside a GG24 receiver, the two systems are translated into a single reference system. Users may choose in which reference system they want positions provided.

SATELLITE ORBITS – TECHNICAL DETAILS

The orbits of GPS and GLONASS are very similar. GPS satellites are distributed in 6 orbital planes, 4 satellites per plane. GLONASS uses 3 planes, 8 satellites per plane. The inclination of the GLONASS planes is slightly higher (64.8 degrees) than GPS (55 degrees). Both systems’ satellite orbits are circular and with similar radii.

Table 6 on the following page summarizes key differences between the GPS and GLONASS systems.

Table 6
Comparison Between GPS and GLONASS Systems

	GPS	GLONASS
Signal Structure		
C/A Code (L1)		
Code Rate	1.023 MHz	0.511 MHz
Chip Length	293m	587m
Selective Availability	Yes	No
P Code (L1 and L2)		
Code Rate	10.23 MHz	5.11 MHz
Chip Length	29.3m	58.7m
Selective Availability	Yes	No
Encryption (Anti-Spoofing)	Yes	No
Signal Separation	CDMA	FDMA
Carrier Frequencies, L1	1575.42 MHz	1602 + K x 9/16 MHz, K $\in$ [-7,24]
Carrier Frequencies, L2	1227.60 MHz	1246 + K x 7/16 MHz, K $\in$ [-7,24]
Satellites		
Number of Satellites	24	24
Number of Orbital Planes	6	3
Satellites Per Plane	4 (unevenly spaced)	8 (evenly spaced)
Orbital Inclination	55°	64.8°
Orbital Radius	26,560 km	25,510 km
Orbital Period	11 ^h 58 ^m	11 ^h 15 ^m
Almanac		
Duration	12.5 minutes	2.5 minutes
Capacity	37,500 bits	7,500 bits
General		
Time Reference	UTC (U.S. Naval Observatory)	UTC (Soviet Union)
Geodetic Datum	WGS 84	PE-90

GPS+GLONASS STANDARDS

There are two standards that are used widely and successfully for GPS applications. These are the Radio Technical Commission for Maritime Services (RTCM) standard for differential corrections, and the National Marine Electronics Association (NMEA) standard for reporting position, velocity and satellite data. Although both of these standards were initially developed for marine use, they have been adopted worldwide for most GPS applications.

RTCM SC-104

The RTCM Special Committee 104 (SC-104) has defined differential correction messages that are used worldwide for GPS. The messages that carry the GPS corrections are Message Type 1 and Message Type 9. In 1995, the committee defined similar messages for GLONASS differential corrections; for example, Message Type 31 is the GLONASS equivalent to Message Type 1, and Message Type 34 is the GLONASS equivalent to Message Type 9.

Other RTCM messages contain information about reference station parameters and satellite health. These have been defined for both GPS and GLONASS.

Additional messages are being developed to further improve the operation of GPS+GLONASS systems in differential mode. For example, a GPS+GLONASS time offset message has been proposed that will allow the reference station to report the time offset between the two systems so that the GPS+GLONASS receiver will not have to calculate it.

Table 7
RTCM SC-104 Messages for GPS and GLONASS

Message Types		
	GPS	GLONASS
Differential Corrections	1	31
Reference Station Parameters	3	32
Constellation Health	5	35
Radiobeacon Almanac	7	33
Partial Satellite Set Differential Corrections	9	34
GPS-GLONASS Time Offset	37	37

NMEA 0183

The National Marine Electronics Association has defined the Standard NMEA 0183 for interfacing marine electronic devices. Six messages have been defined specifically for GPS use:

GGA Global Positioning System Fix Data
GSA GPS DOP and Active Satellites
GSV GPS Satellites in View
GRS GPS Range Residuals for Each Satellite
GST GPS Pseudorange Measurement Noise Statistics in the Position Domain
GBS GPS Satellite Fault Detection with Estimated Bias Statistics

A proposal is currently under review by the committee to determine how best to incorporate GLONASS satellite information.

HOW THE ASHTECH GG24 WORKS

Ashtech's GG24 receiver is the world's first fully integrated GPS+GLONASS receiver. For easy integration with electronic displays, vehicle tracking, flight management, and survey/mapping systems, the GG24 is available on a single OEM board or in a compact packaged sensor format.

NAVIGATION MODES

(AVAILABILITY AND ACCURACY)

The GG24 has 12 parallel channels for tracking GPS satellites, and 12 parallel channels for tracking GLONASS satellites. With this capability, the GG24 will always use the best available constellation to provide the most accurate position.

- The greatest accuracy is obtained when differential corrections are available for both GPS and GLONASS satellites. The GG24 can be used as a reference station to generate RTCM corrections for GPS and GLONASS, and a GG24 can use RTCM corrections for both systems.
- If differential corrections are available for only one satellite system (either GPS or GLONASS), the GG24 will automatically use only those measurements for which it has corrections.
- If the GG24 has no differential corrections, it will automatically use all available healthy satellites from both constellations to compute a position.
- If one satellite system is shut down or jammed, or if satellites become unhealthy (generating incorrect data), the GG24 will automatically use the satellites which are operating correctly.

The GG24 uses the information in the almanacs, as well as built-in Receiver Autonomous Integrity Monitoring (RAIM), to determine which satellites are healthy.

Table 8
GG24 Navigation Modes

Available Measurements	GG24 Mode	Typical Horizontal Accuracy Expected ⁵
DGPS and DGLONASS	DGPS & DGLONASS	35cm
GPS and DGLONASS	DGLONASS	50cm
GLONASS and DGPS	DGPS	40cm
GPS and GLONASS	GPS & GLONASS	7m
GLONASS	GLONASS	8m
GPS	GPS	25m

RAIM (INTEGRITY)

The GG24 implements the Receiver Autonomous Integrity Monitoring (RAIM) required for En Route, Terminal and Non-Precision Approach stages of flight. The RAIM alarm limit may also be set by the user to suit other applications. The RAIM algorithm will detect and remove erroneous measurements. The study by the DoT Volpe Center discussed earlier shows that the

⁵ Differential GPS accuracy is affected by the radio data rate. If the data rate is slow, then SA causes errors to grow while the corrections are being transmitted. Both Differential GPS and Differential GLONASS accuracy are affected by the distance between the reference station and the rover. The longer the distance, the worse the accuracy. The accuracy shown was measured in tests of the GG24, with a short baseline between reference and rover, radio data rate 300bps, HDOP<4.

availability of RAIM for these stages of flight is 100% using GPS and GLONASS (availability of RAIM means that there are enough satellites visible to perform Integrity Monitoring). If for any reason RAIM is not available at any time, for example, if too many satellites become blocked, the GG24 will alert a user.

CONCLUSION

GPS is a highly accurate navigation and positioning system. Certain natural and artificial limitations exist that can degrade its availability, integrity and accuracy. Artificial limitations include Selective Availability, which is the deliberate degradation of GPS, and Anti-Spoofing (encryption). Natural causes such as obstructions constrain the number of visible satellites and render less accurate results.

Adding additional satellites to the GPS constellation increases availability, provides robust integrity monitoring, and results in more accurate solutions. Ashtech's GG24 receiver is the first of its kind to seamlessly process data from both GPS and GLONASS satellites. Unquestionably, the exceptional precision offered by the GG24 will usher in a new generation of applications which demand precise positions, all the time, in even the most difficult environments.

GG24 SPECIFICATIONS

The GG24 is available in two different formats:

1. OEM Board, Eurocard Format
2. Sensor, with power supply and internal PCMCIA memory card

The OEM Board

- Standard Eurocard format
 - Size 16.7 × 10.0cm
 - Connector DIN64
- 2 RS-232 Serial ports
- Power: 5 VDC ± 5% input, 2.5W
- Weight: 6 ounces

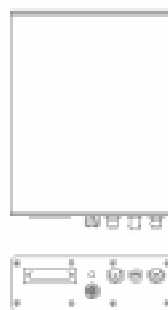
GG24 OEM Board



GG24 Sensor:

- Aluminum housing
- Meets MIL-Spec 810 E standards for wind-driven rain and dust
- 3 RS-232 Serial ports
- Optional internal radio for differential corrections
- Internal PCMCIA memory card up to 40Mbytes
- Power: 6-15 VDC input, <3W
- Weight: 5 pounds

GG24 Sensor



ADDITIONAL INFORMATION

Supplemental information about Ashtech, GPS and GLONASS can be found on the World Wide Web at the following sites:

Ashtech Inc.

www.ashtech.com

U.S. Coast Guard Navigation Center

www.navcen.uscg.mil/gps/gps.htm

Coordination Scientific Information Center
of Russian Space Forces

www.rssi.ru/SFCISIC/glonass.html

MIT Lincoln Laboratory, GLONASS Group

satnav.atc.ll.mit.edu/

CREDITS

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Frank van Diggelen is the Marketing Manager for OEM & Navigation products at Ashtech, Inc., located in Sunnyvale, California. Prior to joining Ashtech, he worked as a Senior Engineer at NAVSYS Corporation in Colorado, and served as a Navigation Officer in the South African Navy.

Dr. van Diggelen holds a Bachelors Degree in Electrical Engineering from the Witwatersrand University in Johannesburg, South Africa, and a Ph.D. in Automatic Control Theory from Cambridge University, England. He has authored and co-authored numerous publications regarding precision GPS, with specific reference to RAIM, GIS, real-time kinematic, multipath mitigation, and other highly specialized GPS navigation and positioning technology.