ANALOG DEVICES

AN-540
APPLICATION NOTE

One Technology Way • P.O. Box 9106 • Norwood, MA 02062-9106 • 781/329-4700 • World Wide Web Site: http://www.analog.com

Understanding Global Positioning System Receiver Specifications

Dilution of Precision

Dilution Of Precision (DOP) is a measure of the contribution of the relative geometry of the user and the satellites to the error in the location/navigation data generated, making use of the satellites. GPS receivers choose the combination of satellites to be used for position computation based on their geometric location with respect to the user. The lesser the DOP resulting from a particular combination of satellites, the better the accuracy that can be achieved. When the receiver is tracking more than four satellites, it computes the DOP associated with each possible combination of four satellites and chooses the combination with the least DOP for use in computation of the user's position.

The DOP is inversely proportional to the volume of the tetrahedron formed with the user and the four satellites at the five corners. Generally a combination of satellites where, in each of the satellites there is a different azimuth angle with respect to the user and as much spread apart as possible from each other, results in a very good DOP.

The effect of DOP can be resolved into HDOP, VDOP, PDOP and TDOP.

HDOP (Horizontal Dilution Of Precision) is the contribution of the relative geometry of the satellite constellation and the user's position to the computed horizontal position coordinates, that is, the 2D position.

VDOP (Vertical Dilution Of Precision) is the contribution of the relative geometry of the satellite constellation and the user's position to the computed height above sea level, that is, the altitude.

TDOP (Time Dilution Of Precision) is the contribution of the relative geometry of the satellite constellation and the user's position to the computed time.

PDOP (Position Dilution Of Precision) is the contribution of the relative geometry of the satellite constellation and the user's position to the computed in 3D position coordinates, that is, the 2D position as well as the altitude.

$$PDOP^2 = HDOP^2 + VDOP^2$$

GDOP (Geometric Dilution Of Precision) is the contribution of the relative geometry of the satellite constellation and the user's position to the computed position coordinates and time.

$$GDOP^2 = PDOP^2 + TDOP^2$$

Number of Channels

To compute the user's position, speed, heading and time, the GPS Receiver needs a minimum of four parallel correlation channels. GPS receivers have evolved to incorporate six, eight or twelve channels in their architectures.

The following factors influence the necessity/effectiveness of the number of channels in a receiver:

Satellite Visibility

Studies show that most of the time, at most places, eight to ten satellites will be visible above the horizon (above zero degrees of elevation angle). Above 10 degrees of elevation, not more than eight satellites are visible. Above 20 degrees, six or fewer satellites are usually visible.

When installed on a ship, a GPS receiver is likely to acquire/track signals from satellites at very low elevation angles (nearing zero degrees), because in marine applications, the sky is very open with little to obstruct the antenna's view.

In contrast, a GPS installed in an automobile does not usually enjoy such a view of the sky. Signals from satellites below elevation angles of 10 degrees are very hard to track, and even more difficult to acquire, due to buildings, trees, etc. In city areas and in thickly wooded terrain, this problem becomes worse and the visibility mask is more than 20 degrees.

Geometrical Dilution of Precision

The relative geometry of the satellites, and the user, greatly influence the accuracy obtainable in the user's position computed from GPS satellites. The accuracy obtainable is directly proportional to the volume of the tetrahedron formed by the user and the four satellites chosen for position computation. This is called Geometric Dilution of Precision. The receivers achieve better accuracy in computed position by choosing the right combination of satellites from among the visible satellites.

With more channels, and when visibility is good, the receiver has a better choice of satellite combinations. In this respect, a higher number of channels is desirable. But again, more channels than the number of visible satellites do not help.

Dynamic Loss of Satellite Signals

In terrain where the antenna's view of the sky is dynamically obstructed and cleared frequently, more channels improves the percentage of time for which GPS-computed position data is generated by the receiver. Here again, an increase in the number of channels helps to a point when the number of channels becomes equal to the number of visible satellites above visibility mask angle.

Time-to-First-Fix

When the receiver is powered ON/initialized, it relies on the initial estimates of position and time as well as the age of the almanac data to compute the satellite visibility data. With more channels, the receiver's time to first fix will improve. This is even more true when the receiver is switched ON and left to itself to find the position, without an estimate data. In the case of GPS receivers incorporating hardware correlators, increasing the number of channels considerably improves the time-to-first-fix. However, in the case of Accord/ADI solution, where a soft correlator approach is employed and FFT techniques are used for acquisition of satellite signals, initial estimates of data are of less importance than in the case of receivers using hardware correlators. Since the time taken by our correlator to scan the entire visible sky for a satellite signal is much less than the time taken by other receivers, eight parallel channels are sufficient to give time-to-first-fix in a time of better than two minutes in Autonomous Cold Start.

Computational Assets

Every extra correlation channel imposes additional computational load on the Navigation Processor in the receiver, therefore, more channels than the number of visible satellites are a disadvantage.

Ephemeris Collection

Availability of Ephemeris Data from a visible satellite qualifies the satellite to be considered by the receiver for use in its position computation. The receiver is likely to provide GPS-computed position data for a better percentage of time when it has collected ephemeris data from most/all visible satellites. This is especially true when the user's vehicle is moving in obstructed terrain. More channels help in this regard too, but again only to a point where they are not more than the number of visible satellites above the mask angle of elevation. From all of the above considerations, eight parallel channels is the optimum number.

FFT Techniques

FFT—Fast Fourier Transform—converts the time domain samples of a signal to frequency domain. This technique is used in GPS signal processing to improve satellite signal acquisition time and hence Time-to-First-Fix (TTFF).

The background for using FFT technique in GPS receiver is explained below:

GPS satellites continually transmit unique pseudorandom (PN) codes, phase modulated on an L-band carrier at 1575.42 MHz, to users all over the world. These PN codes available for civilian users are known as C/A (Coarse Acquisition) codes. The C/A codes provide single peak correlation properties and low cross correlation properties.

As the GPS satellite signal travels in space from the satellite to the user equipment, there is a time delay due to transit. This transit time is a measure of the range between satellite and user equipment. Four such range measurements to four satellites are required in the computation of user's position.

The transit time is manifested as phase change in the received PN code, which is measured using correlation technique. These measurements are performed on the signals received from all visible satellites.

To make range measurements more complicated, continuous motion of GPS satellites and the user equipment bring about a shift in the frequency of received signal due to Doppler effect. Thus, the signal processing section of GPS receiver will have to perform a search for received C/A code in both time domain (phase) and frequency domain (Doppler).

One method is to perform a "Cell-by-Cell" search. This approach involves generating local C/A codes to perform correlation in time domain with received C/A codes from all visible satellites. The process is repeated by changing frequency of local code in small steps.

If the search domains—both in time and frequency—are unknown, the acquisition process will take a very long time. To reduce this acquisition time, receiver aid is provided in terms of the user's estimated position and time.

To reduce the acquisition time, frequency domain correlation, using FFT techniques, is more effective compared to time domain correlation. The technique converts the incoming GPS signal to baseband, transforms it to frequency samples and correlates the frequency samples of incoming and local codes. The correlation peak will give the frequency of incoming signal. With the knowledge of frequency of incoming signal, a search can be made only in time domain. Thus, satellite signal acquisition using FFT technique is more efficient and does not require any receiver aid.

All-In-View vs. High Four

While it is possible to compute the user's three dimensional position from a minimum of four satellites, all the visible satellites can be simultaneously used to compute the position. This is known as the All-In-View solution. The All-In-View solution is more advantageous in situations where the receiver is able to track many more satellites than four. The advantage comes from the fact that the DOP that results from a combination of six or seven satellites is often better than that from a combination of four satellites.

S/A Effects

The US Department of Defense (DOD) introduces a controlled degradation of accuracy achievable by all civilian GPS receivers. This is known as Selective Availability. The DOD may switch ON/OFF this degradation and can control the level of degradation. When the Selective Availability is ON, the accuracy obtainable is worse (about 100 meters 2D rms at certain levels of S/A) than when it is not ON. The effects of S/A can be overcome by using Differential GPS corrections. Most often, receivers specify the accuracy of their position when S/A is not ON because S/A is an extrinsic phenomenon and accuracy specifications when S/A is not ON truly represent the receiver performance. The Block I GPS satellites did not have S/A capabilities, but all the current Block II GPS satellites do have S/A capabilities and so the S/A is almost always likely to be ON.

Raw Data Access

GPS Receivers usually output computed position, speed, heading and time on the RS-232 link for use in the host. In situations where the measurements made by the GPS receiver on the satellite signals are required by the host rather than the computed position etc., raw measurement data output can also be provided. One example of such a situation is an Integrated Navigation System incorporating GPS and an Inertial Navigation System.

For more information please contact:
Tel: +1 781 461 3732
Fax: +1 781 461 4360
E-Mail: systems.solutions@analog.com

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