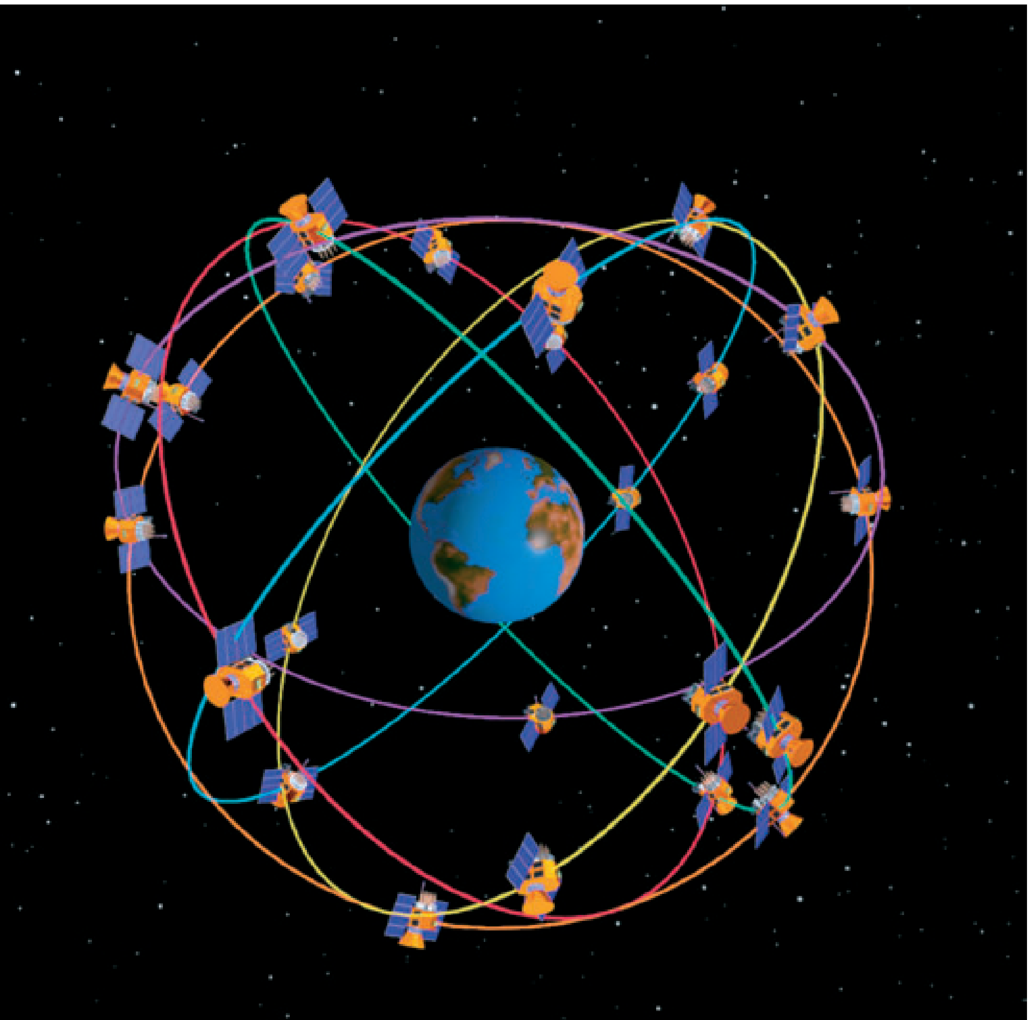
Part 1: Configuration and Techn

Practical Satellite Navigation

Nowadays almost everyone, both inside and outside the GIS and survey sector, is familiar with satellite navigation, and GPS in particular. Even so thorough knowledge of satellite navigation seems to be private to specialists like geodesists and manufacturers. The group of daily users of GPS systems and data however is becoming larger by the day. This article is the first in a series scrutinizing the daily use of GPS and will expand on the GNSS article as published in GeoInformatics 5 - 2005.

By Huibert-Jan Lekkerkerk



GPS Constellation (source: tpegps.port5.com).

The authors' first encounter with satellite navigation dates back to the early nineties of the last century. During my study 'Hydrographic Surveying' in Amsterdam there was a single Sercel NR103 GPS receiver available for training. It was locked away most of the time, since it cost roughly twenty thousand US dollars, a staggering amount of money at that time. The use of GPS was by no means common in those days with most land surveyors still using theodolites, total stations or level instruments. At sea systems like Hyperfix, Syledis and Decca, which are archaic by current standards, were used. What almost no one could have imagined in those days was the enormous flight the developments in satellite navigation would take. At the moment GPS is synonymous for easy, precise and fast positioning in almost every sector. The number of receivers that are offered is large and prices are low. However the knowledge of these systems is usually lagging behind. Who isn't familiar with the example of politicians wanting to use GPS for say road taxing? In theory this sounds good, but everyone who has been using GPS in an urban environment, in tunnels, or under trees knows that the system will not work (properly).

Future developments like Galileo and Glonass will probably improve this, but are still in a development phase. This series of articles will primarily focus on practical problems as mentioned above, their origin and how to prevent them if possible. Starting point will always be practical application of the theory.

GPS History in Short

Satellite navigation comprises all the systems developed, or under development, for navigation or positioning purposes based upon satellites. Satellite navigation dates back to the last century. In 1964 the American Transit system was declared operational and offered a precision in the order of 400 meters. Even though receiver prices were high, the system was in use until 1992 by, amongst others, the US Navy.

The greatest disadvantage of the Transit system was the relative low precision and low update rate. For this reason the American government started the development of a successor to Transit or, as it was known by then, the Navy Navigational Satellite System (NNSS). This successor was christened Navigation by Satellite Timing and Ranging (NAVSTAR) but was later given the name Global Positioning System (GPS). On the 8th of December 1993 the system was officially declared operational, but by then had already been in use for almost 10 years by the army and survey industry.

Glonass and Galileo

Parallel to the development of GPS, Russia has been developing a similar system called Glonass. Glonass was declared operational in 1997 but the number of satellites deteriorated

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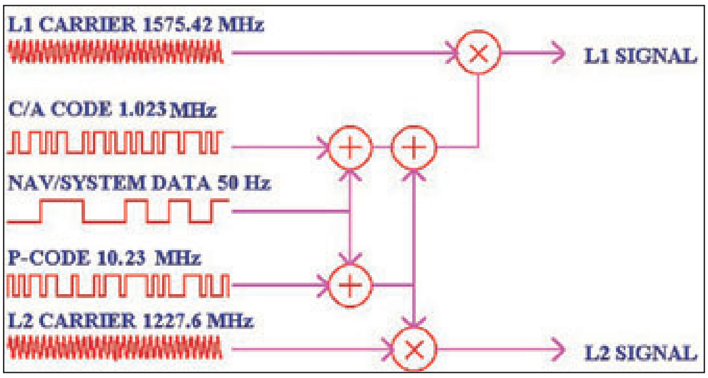


GPS Signals for the current constellation. The L5 frequency and the L2C code are not shown (source: P.H. Dana 1996).

shortly thereafter by lack of funding. In 2001 the launching program was reinstated and expectations are that the system will be operational again in 2010.

At the moment Europe is working hard on its own satellite navigation system, Galileo. The expectation of the European Union is that the system will be operational in 2008.

This series describes the practical application of satellite navigation in general, but will use GPS as a basis for demonstrating practical matters. The table on page 45 shortly describes the differences between GPS, Glonass and Galileo.

Satellite Navigation System Components

Every satellite navigation systems consists of three components:

- Space Segment: is made up of the satellites, which are called Space Vehicles (SV) in GPS. A full GPS constellation consists of 24 SVs (21 plus 3 active spares);
- Control Segment: a network of tracking stations around the world. From these stations the satellites are tracked, checked and corrected if necessary;
- User Segment: consists of all the users and receivers.

Currently 30 GPS satellites are active, revolving around the earth at a height of 20,240 kilometres. There are six GPS orbits, with at least four satellites per orbit. Each orbit makes an angle with the equator, called inclination, of roughly 55 degrees. The actual inclination depends on the satellite and orbit. A complete revolution of a single satellite around the earth takes 11 hours and 58 minutes. This results in a GPS constellation change of four minutes per day.

As a result of the 55-degree inclination, the orbit of the individual GPS satellite will not reach above 55 degrees latitude North or South. As a result, the number of available satellites above the horizon will become less above these latitudes. Furthermore this inclination has an influence on the actual precision of our position determination. More about this phenomenon in the upcoming article on errors and quality indicators.

Signals

Basically a navigation satellite is nothing more than a radio transmitter sending certain messages at a specific time interval. The transmitted messages consist of two elements; a code used for the actual positioning and two navigation messages called ephemeris and almanac indicating amongst others orbit information.

Depending on the navigation system this information is transmitted at two or more frequencies. These frequencies are usually indicated using the frequency band in which they are transmitted. GPS for example transmits at the L1 (1575 MHz) and L2 (1227 MHz) frequency bands. To compare: a European GSM telephone transmits at 900 MHz and 1800 MHz. In the near future GPS will also transmit at a third frequency band, L5 (1176 MHz).

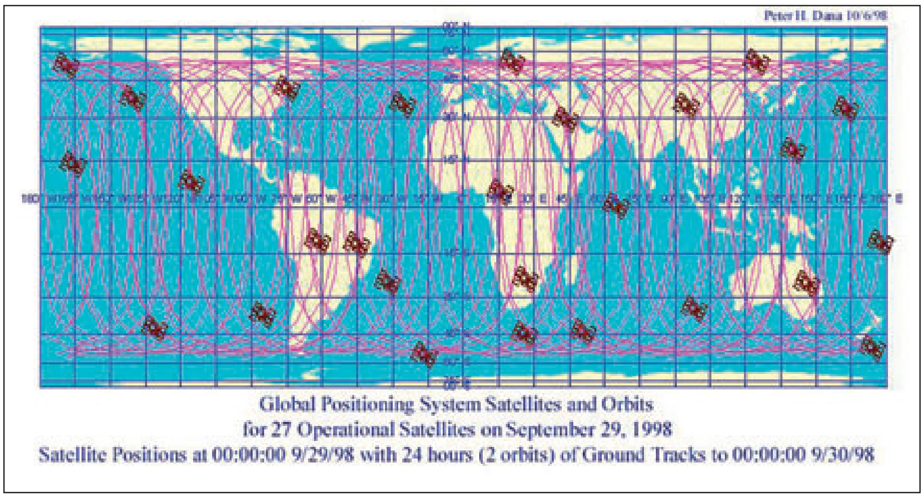
Within GPS every satellite is designated with its own unique identification code called Pseudo Random Noise (PRN). Currently the GPS system uses two PRN codes per satellite for navigation. The first is for general (civilian) use called the Coarse Access or C/A code and is transmitted on the L1 frequency. The second is the Precision or P code that can only be used by military users and is transmitted on both the L1 and L2 frequency bands. New GPS satellites will furthermore have a so-called L2C code which is basically a C/A code in the L2 band.

Satellite Reception

The effective power at which signals are transmitted from the satellite amounts to 500 Watt. This may seem like much, but one should realise that the signal has to cover more than 20,000 kilometres.

Upon reaching the receiver antenna the signal is much weaker than the background noise. A GPS receiver employs a special technique called auto correlation to distinguish the GPS signal from the background noise, the PRN code playing a key role in this process. The PRN code for the satellite is generated in the GPS receiver and then compared with the received signal for that satellite. This results in a highly accurate detection of the signal.

Since the signal is very weak when reaching



Tracking of 27 GPS satellites for two orbits. As can be seen there are no GPS satellites reaching a latitude of more than 60 degrees North or South (source: P.H. Dana 1998).

	GPS	Galileo	Glonass
(Probably) operational in the year	1993	2008	2010
Number of satellites when operational (active + spares)	21 + 3	27 + 3	21 + 3
Current number of satellites	30	1	13
Number of orbits	6	3	3
Number of satellites per orbit	4	10	8
Inclination of satellites	55°	56°	64.8°
Orbit height (kilometres)	20,240	23,222	19,100
Frequency bands used	L1, L2, (L5)	L1, E1, E2, E5, E6	L1, L2

Specific parameters of global navigation satellite systems.

a receiver, a good antenna is needed. Usually antennas incorporating amplifiers are used. But even when using a state-of-the-art antenna, a small obstruction between the satellite and the receiver will block the signal completely. Glass is usually no problem, but under trees or inside and under cranes GPS performance is greatly reduced because the signals are blocked.

Satellite Detection

In order to use auto correlation the receiver needs to know in advance which satellites to expect above the horizon. This is necessary since most receivers don't have as many reception channels (usually 12) as there are available satellites (around 30 at the moment). If we now have a GPS receiver having been used in America and accordingly switched off and back on in Europe, it would try to find the satellites that are visible above the horizon in America. Eventually these satellites will come into view, but this can take as long as eight hours. If we tell the receiver our approximate location, it will use the information from the almanac or ephemeris to determine which satellites are visible above the horizon. This initial position does not have to be very accurate; a couple hundreds of kilometres is in general good enough.
If we have a "clean" receiver without an almanac, or if the almanac is faulty, the initialisation will take longer as well. In this case the complete almanac must be received from the satellites. This can take several hours, depending on the number of visible satellites. An alternative is to download an almanac into the receiver from the Internet or another GPS receiver. GPS almanacs and ephemeredes are, amongst others, available from the US Coast Guard Navigation Center.

The next article in this series will deal with the positioning method and timing within satellite navigation systems.

Huibert-Jan Lekkerkerk (info@hydrografie.info) is a freelance writer and trainer in the field of positioning and hydrography. For more information about the topics discussed go to www.navcen.uscg.gov (GPS), www.esa.int (Galileo) and www.glonass-center.ru (Glonass).

Artist Impression of a GPS Satellite (source: www.gulfsurveyors.com).

Starting this issue, Huibert-Jan Lekkerkerk, will reinforce the writing staff of GeoInformatics on the topic of surveying. Huibert-Jan studied both Hydrography (1995) and Maritime Electronics (1997) at the Higher Nautical College Amsterdam, the Netherlands. From 1995 until 1998 he worked as a hydrographic surveyor and software engineer at Hydrographic and Marine Consultants where, amongst others, he was involved in the development of a maritime GIS and an autonomous survey vessel. From 1998 until 2005 he worked in various functions at the D.O.O.R. group, first as hydrographic surveyor, later on as consultant / project manager and trainer. As a trainer for Skilltrade, a trainings institute for hydrographic and geological survey, he trained various branches of the Dutch government as well as personnel of various survey companies. In 2005 he left D.O.O.R. Nederland to take up the function of project manager information standards at the InformationDesk standards Water. Besides his function at IDsW, Huibert-Jan is also active as a freelance writer and trainer in the field of positioning and surveying. His fields of expertise are inshore surveying and dredging with an emphasis on GPS, Multibeam echo sounding and Attitude sensors.