Leica GPS1200+
The only future proof GNSS

January 2009

Werner Lienhart, PhD

Technical Literature
White Paper

- when it has to be **right**

Leica Geosystems

1. Introduction

In the coming years two new global navigation satellite systems (GNSS) will reach their operational stage. Furthermore, the two currently existing GNSS will be modernized and transmit new signals. In this article we present the new Leica GPS1200+ GNSS receivers which are capable of tracking signals of all four satellites systems. The use of four independent satellite systems and signals of three frequency bands will bring significant benefits to the user. Due to Leica Geosystems' future proof concept existing Leica GPS1200 receivers can easily be updated to the new technology.

2. Evolution of Global Navigation satellite systems

Currently, two Global Navigation Satellite Systems (GNSS) are operational. These are the American Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS). Both systems use satellites orbiting the earth at an altitude of about 20 000km. These so called Medium Earth Orbiters (MEO) transmit signals in two frequency bands L1 and L2.

During the last 25 years the space infrastructure of GPS and GLONASS was constantly updated by introducing new satellite generations. Already five generations of GPS satellites have been launched (Block I, Block II, Block IIA, Block IIR, Block IIR-M). Two new generations (Block IIF, Block III) will come within the coming years. As will be explained later the Block IIF and Block III satellites are of special interest for high precision applications since these satellites will transmit signals on an additional L5 frequency.

The GLONASS system currently has two satellite types in orbit (GLONASS, GLONASS-M) and plans to launch a new type (GLONASS-K) from 2010 onwards (GPS World News, 2008) that will also transmit signals on a new frequency L3. The exact frequency of GLONASS L3 is not defined yet, but it is likely to be identical or close to GPS L5.

GPS and GLONASS will soon be complimented by the European Galileo and the Chinese Compass system. Both systems already have test satellites in orbit. Several operational satellites are planned to be launched within the next two years. Figure 1 shows the centre frequencies of the currently transmitted and future planned signals. For GPS, GLONASS and Galileo the values were taken from the latest versions of the interface control documents (ICD-GPS-200 rev C, 1993; GLONASS ICD, version 5.0, 2002; Galileo OS SIS ICD, Draft 1, 2008). For Compass the frequencies which China filed at the International Telecommunication Union (ITU) are plotted (Chen et al., 2007).

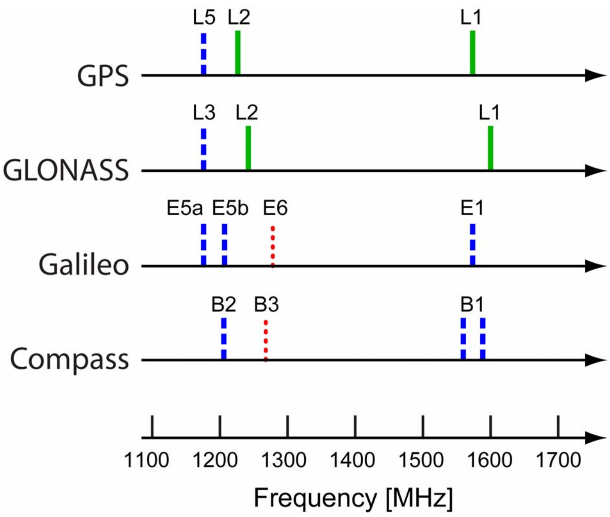

Figure 1: Centre frequencies of currently transmitted and future satellite signals (frequencies which are not operational yet are shown as dashed lines, signals which will not be free of charge or are encrypted are shown as dotted lines)

3. Leica Geosystems' Future Proof Concept

For most GNSS equipment there is only one option to upgrade to new technology, and that is to invest into a new receiver. Leica Geosystems is the only manufacturer which offers a Future Proof concept that does not require the purchase of a new receiver in order to benefit from new satellite signals.

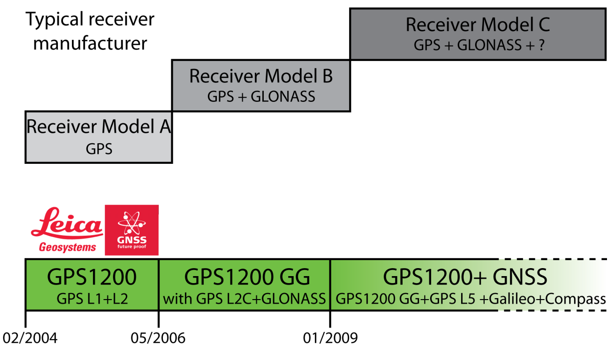

Figure 2: Leica Geosystems' Future Proof Concept compared to other manufacturers' approaches

The GPS1200 system introduced in 2004, see figure 2, was designed to be easily upgradeable to support new signals by exchanging only the antenna elements and the measurement engine. By keeping the same housing and the same electronics a GPS only receiver purchased back in 2004 can easily be upgraded to support all four GNSS and the new signals with minimal investment.

Additionally, keeping the same housings (same connectors, same electronics), allows our customers to use all of their existing accessories (radio modules, cables, batteries, etc.)

The Future Proof concept was proven the first time in May 2006 when older GPS1200 receivers could be upgraded to support the GPS L2C and GLONSS signals, see figure 2. Now Leica Geosystems proves the Future Proof design for the second time by introducing an upgrade to GPS L5, Galileo and Compass. This upgrade is available for GPS1200 GG receivers and also for GPS only receivers from the market introduction of GPS1200 in 2004.

4. GPS1200+ GNSS

GPS1200+ GNSS covers a whole family of receivers and antennas, ranging from light weight rovers (ATX1230+ GNSS) to receivers for continuously operating reference stations (GRX1200+ GNSS). A selection of receivers and antennas is shown in figure 3. A detailed product overview can be found on the Leica Geosystems homepage (www.leica-geosystems.com).

Figure 3: Selection of GPS1200+ GNSS products: AX1203+ GNSS (left), GX1230+ GNSS (centre), ATX1230+ GNSS (right)

The main characteristics of the GPS1200+ GNSS products are given in Table 1. Detailed technical specifications are available on the Leica Geosystems homepage. The number of supported channels has been increased from 72 to 120. 72 channels became the industry standard within the last few years. However, a simple calculation reveals that 72 channels will not be enough to track all possible signals.

Simply add GPS L5 and the Galileo signals to today's constellation and assume an average of 10 satellites per GNSS.

This adds up to
3 x 10 GPS sat. (L1/L2/L5) = 30 channels
2 x 10 GLONASS sat. (L1/L2) = 20 channels
4 x 10 Galileo sat. (E1/E5a/E5b/Alt-BOC) = 40 channels
90 channels

For this calculation only signals with officially defined signal structure have been taken into account. Taking into account the remaining signals from table 1 will increase the number of required channels beyond 100.

Table 1: Signals supported by GPS1200+ GNSS

General	Number of channels	120
Supported Satellite signals	GPS	L1, L2, L5
	GLONASS	L1, L2, L3*
	Galileo	E1, E5a, E5b, Alt-BOC
	Compass	B1*, B2*

*GPS1200+ GNSS receivers will be able to track these signals according to currently publicly available information

GPS1200+ GNSS receivers were developed to bring maximum benefit to high precision applications. Therefore the receivers also support the Galileo Alt-BOC signal, which will be the most accurate signal in space. The special properties of Alt-BOC will be discussed in a later section of this paper.

GPS1200+ GNSS receivers support all Open Service (OS) signals which are signals that can be received free of charge by the user. The Galileo E6 frequency is not supported because the Galileo Commercial Service (CS) will operate on this frequency. Since users might have to pay the satellite system provider for the use of this signal, it is not of interest for the intended market. Furthermore, a fifth Galileo signal would only bring minimal benefit for high precision applications. The Compass frequency B3 is also not supported because it only covers the authorized service (Inside GNSS, 2008b).

5. When should new technology be offered?

For a surveyor the timing of GNSS hardware investment is important. It is equally important for a manufacturer to decide when to develop new technology and bring it to the market. Part of Leica Geosystems' Future Proof philosophy is to make new developments only when they are technically justified bring user benefit.

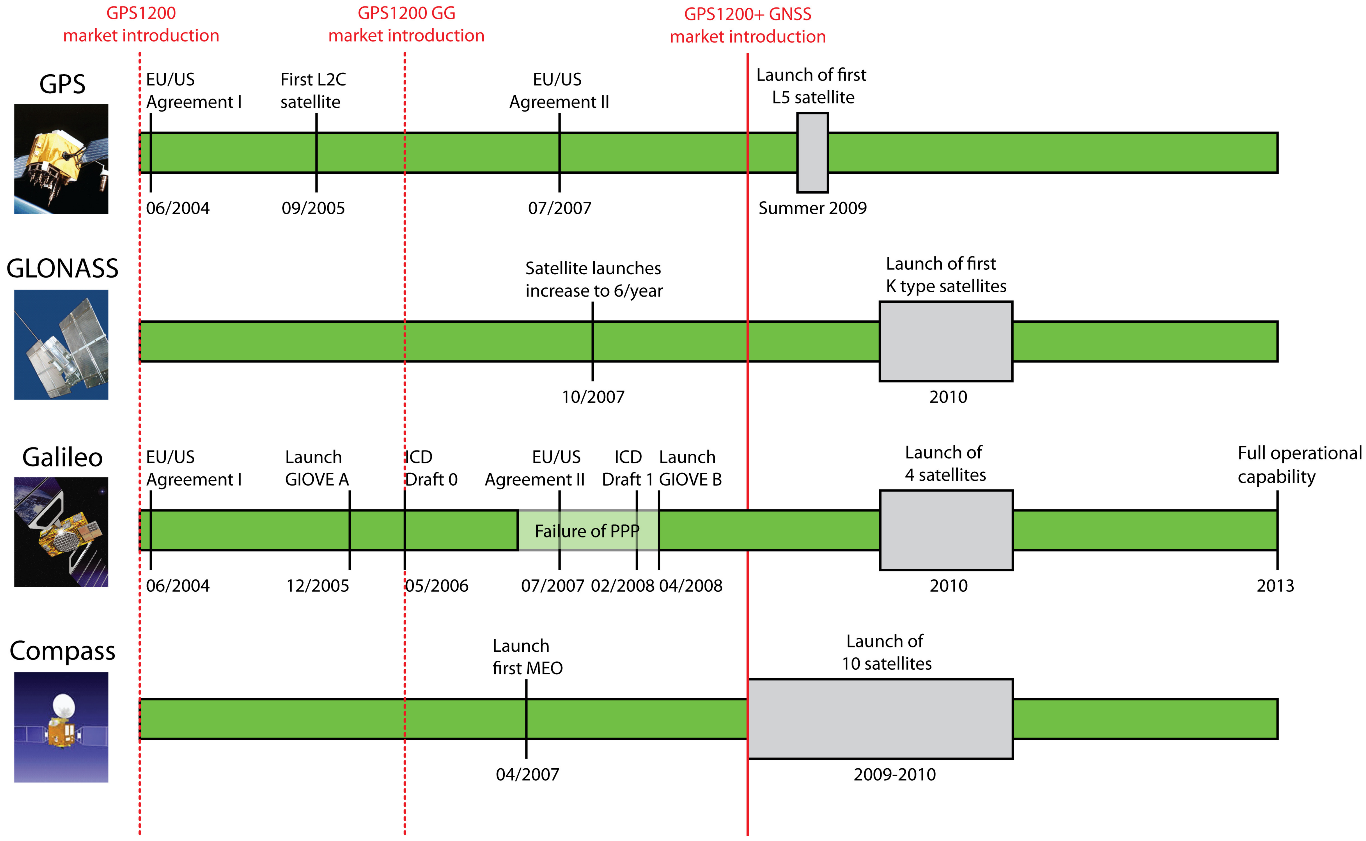

Figure 4: The market introduction of GPS1200+ in the context of GNSS evolution

Therefore, due to the developments of the various GNSS within the last two years Leica is convinced that now is the right time to offer a receiver capable of GPS L5, Galileo and Compass.

Figure 4 highlights past and future events which are important for product development and market introduction. Key elements which give the reason for the market introduction of GPS1200+ GNSS in January 2009 are described in more detail in the following sections.

5.1 Modernization of GPS

The next step in the GPS modernization will be the launch of the first GPS Block IIF satellite. According to the current launch schedule this will be in summer 2009 (www.boeing.com). GPS Block IIF satellites will transmit signals on the new L5 frequency. GPS1200+ GNSS receivers will be able to track signals on three individual frequencies (L1/L2/L5) as soon as the first GPS Block IIF satellite becomes operational. New linear combinations can be made with these three frequencies. Their benefit will be discussed in section 6.

5.2 Galileo funding and signal structure

The Galileo project had project delays from the start that later turned into a severe crisis. In spring 2007 the concession negotiations between the Galileo Joint Undertaking (GJU) and the industrial consortium responsible for completing the Galileo system failed. At that time different alternative plans where investigated which even included the stop of the Galileo program (Inside GNSS, 2007).

This crisis increased within the following months and lead eventually to a failure of the Public Private Partnership (PPP). The Galileo program was then turned into a traditional publicly funded project. With the agreement on the budget in April 2008 by the European Commission's transport ministers the Galileo program came back on track (Inside GNSS, 2008a).

On the technical side, the European Union and the United States had several discussions to make the Galileo signals compatible to GPS signals. In an agreement made in June 2004 the signal modulation of Galileo E1 and GPS L1 was fixed to a Binary Offset Carrier (BOC) modulation (Avila-Rodriguez et al., 2007). According to this agreement the BOC(1,1) modulation was also defined for Galileo E1 in the first draft of the ICD (GAL OS SIS ICD, Draft 0, 2006). The power spectral density of this signal is shown in figure 5.

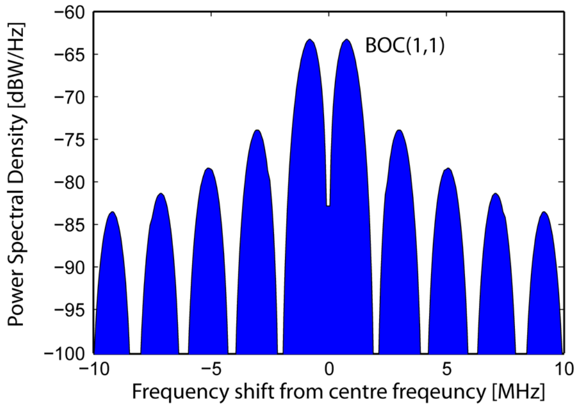

Figure 5: Power spectral density of a BOC(1,1) signal

Further discussions between the European Union and the United States and scientific investigations lead to a revision of the initial decision. In a second agreement made in July 2007 the baseline was changed to a Multiplexed BOC (MBOC) signal with the following normalized power spectral density:

$$G_{MBOC(6,1,1/11)}(f) = \frac{10}{11} G_{BOC(1,1)}(f) + \frac{1}{11} G_{BOC(6,1)}(f) \quad (1)$$

As can be seen from eq. (1) the spectral power of a MBOC signal consists of the sum of the spectral power of two BOC signals.

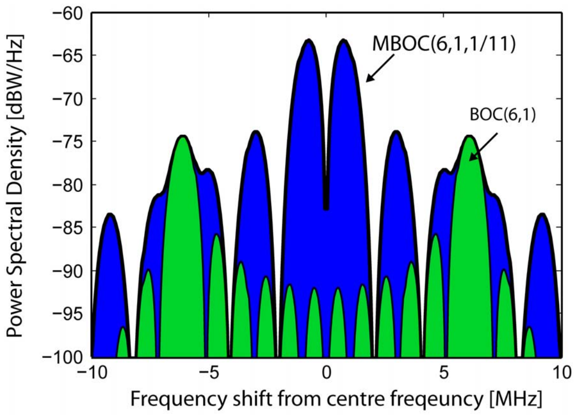

Figure 6: Power Spectral Density of the Galileo E1 MBOC signal

The Galileo version of the MBOC signal is specified in an updated version of the Galileo ICD which was published in February 2008. The second Galileo test satellite GIOVE-B is already transmitting the MBOC signal, whereas the older first Galileo test satellite GIOVE-A is transmitting the BOC signal. Figure 6 shows the power spectral density of the MBOC signal. The portion of the BOC(6,1) power on the MBOC signal is shown in green. A receiver designed to track only a BOC signal may still be able to track the Galileo E1 signals but will lose 1/11 of the signal power.

One other important fact of Galileo is that so called Memory Codes are used instead of Gold Codes as used by GPS. This was defined in the first draft of the Galileo ICD and has been retained.

Summarizing the above, Galileo funding is now secured and the signal structures are finalized since spring 2008. Only with these two items solved serious hardware development can be made.

Developing hardware without solid knowledge can result in products which do not achieve their specifications, see for instance interview with Javad Ashjaee published in GPS World March 2008 (GPS World, 2008).

Manufacturers which developed hardware without knowledge of Memory Codes (before first ICD was available in spring 2006) will most likely not be able to track the final Galileo navigation satellites. The Galileo test satellites may be tracked because these do not transmit Memory Codes as defined in the ICD but Gold Codes like GPS.

Unlike Galileo E1 which uses MBOC modulation, the signals of E5a and E5b are modulated using Binary Phase Shift Keying (BSPK) similar to today's GPS signals. Galileo satellites can multiplex these two signals and inject it through a very wide band channel. The result is the so called Alternative-BOC (Alt-BOC) signal, see figure 7. The benefits of this wide band signal will be discussed in section 6.

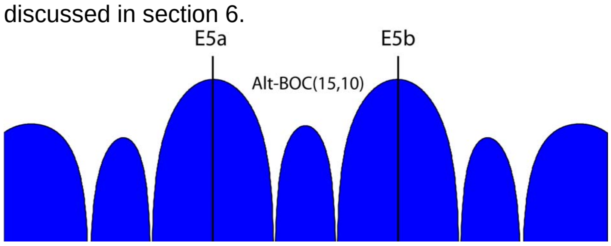

Figure 7: Power Spectral Density of the Galileo E5 Alt-BOC signal

5.3 Compass development

Since 2000, China is also building up their navigation system Compass (also called Beidou). The Compass system consists of two systems, a global navigation system and a local augmentation system. In the final stage Compass will consist of 30 MEO satellites of the global navigation system and of 5 geostationary satellites (GEO) of the augmentation system. The first MEO satellite was launched in April 2007. 10 more satellites are planned to be launched within the next two years (Inside GNSS, 2008c).
Summarizing the arguments of this section Leica believes that beginning of 2009 is the right time to release GPS1200+ GNSS because:

- the first GPS L5 capable satellites will be launched in 2009
- the Galileo signal definition is in a solid status since July 2007, Galileo funding is secured and the first “real” Galileo navigation satellites will be launched in 2010
- several Compass satellites will be launched in 2009 and 2010

6. User benefit

User benefits result from the increased number of tracked satellites, the use of three frequencies and the special Galileo Alt-BOC signal.

6.1 Benefit of additional satellite systems

Adding two more satellite systems to GPS and GLONASS has the potential to double the number of observed satellites which will result in a better geometry for the position calculation. Although, in an open sky environment the additional satellites will not significantly improve the position accuracy, they can be vital in high obstructed environments like urban canyons. Using the satellites of three or four GNSS can result in a phase fixed position at locations where this would not be possible with GPS and GLONASS alone. Additionally, using more signals of several independent GNSS increases the reliability of satellite position.

6.2 Benefit of additional frequencies

The currently operational satellite systems will introduce signals on a new frequency which is lower than the L2 frequency in the near future. Galileo will also offer signals in three frequency bands free of charge. The availability of signals on three frequencies makes new linear combinations possible. Using different linear combination can significantly reduce the initialization time. With new concepts e.g. TCAR (Triple Carrier Phase Ambiguity Resolution, Forssell et al., 1997) it will be possible to fix ambiguities almost instantaneously (Eisfeller and Schüler, 2006).

Another advantage of a third frequency such as L5 is that its frequency difference from L1 is larger than the difference between L2 and L1. Therefore, the L1/L5 ionospheric free linear combination will have lower noise than the currently used L1/L2 ionospheric free linear combination (Urquhart and Santos, 2008).

The low noise of the ionospheric free L1/L5 linear combination and the possibility to form more linear combinations will significantly increase the baseline length and will also allow fixing ambiguities during high ionospheric activities. This will become important in the near future as solar activity increases again. Solar activity is generally quantified by the sunspot number which has an 11-year cycle.

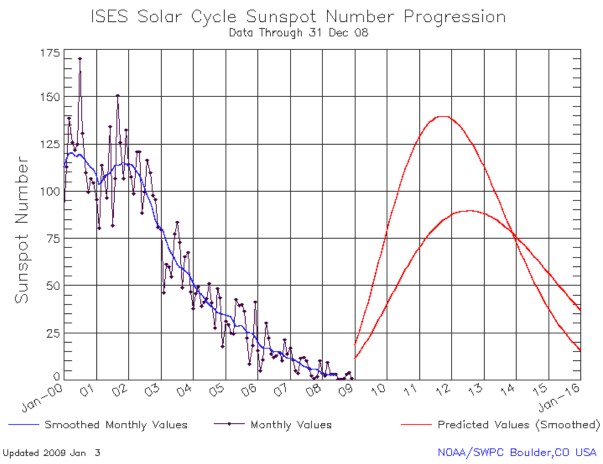

Figure 8: Sunspot numbers of solar cycles 23 and 24 (National Oceanic and Atmospheric Administration, 2009)

Figure 8 shows the downturn of the last solar cycle and two prediction scenarios of the coming solar cycle. According to National Oceanic and Atmospheric Administration (NOAA) the next maximum is expected around 2011 or 2012 (National Oceanic and Atmospheric Administration, 2007).

6.3 Benefit of Galileo Alt-BOC

The Alt-BOC(15,10) modulation on E5 is one of the most advanced and promising signals the Galileo satellites will transmit. Investigations by several authors, e.g. Simsky et al. (2008), Eisfeller and Schüler (2006), show that the Alt-BOC signal has the lowest multipath and tracking noise. This will make Galileo Alt-BOC the most accurate navigation signal ever transmitted and will significantly improve differential code solutions.

7. Summary

In this article the Leica GPS1200+ GNSS was presented. It was shown that due to the Future Proof Concept all existing GPS1200 equipment can easily be updated to the new technology.

The presented features of GPS1200+ GNSS like quadruple constellation, triple frequency and Galileo Alt-BOC will bring the user significant benefits:

- Longer baseline range
- Higher reliability
- Instantaneous initialization
- Higher accuracy
- Less multipath impact
- Better satellite geometry

Literature

Avila-Rodriguez J.-A., Hein G. W., Wallner S., Issler J.-L. (2007): The MBOC Modulation. Inside GNSS Volume 2, Number 6, September/October 2007, pp. 43-58

Chen A., de Lorenzo D., Enge P., Gao G. X. & Lo S. (2007): GNSS over China – The Compass MEO Satellite Codes. Inside GNSS Volume 2, Number 5, July/August 2007, pp. 36-43

Eisfeller B. & Schüler T. (2006): Das Europäishe Satellitennavigationssystem Galileo. Proc. 66. DVW Seminar, Schriftenreihe des DVW, issue 49, Augsburg, Germany, pp. 17-39

Forsell B., Martin-Neira M., Harris R. A. (1997): Carrier phase ambiguity in GNSS-2. Proc. ION GPS-97, Kansas. City, September 1997, pp. 1727-1736

Galileo OS SIS ICD (2006): Galileo Open Service, Signal In Space Interface Control Document Draft 0. European Space Agency / Galileo Joint Undertaking, 192 p.

Galileo OS SIS ICD (2008): Galileo Open Service, Signal In Space Interface Control Document Draft 1. European Space Agency / European GNSS Supervisory Authority, 166 p.

GLONASS ICD (2002): GLONASS Interface Control Document Version 5.0. Coordination Scientific Information Centre. Moscow, Russia

ICD-GPS-200 (1993) Navstar GPS Space Segment / Navigation User Interfaces, rev. C

Inside GNSS (2007): More Perils for Galileo. Inside GNSS Volume 2, Number 2, March/April 2007, pp. 16-19

Inside GNSS (2008a): It's a go! Inside GNSS Volume 3, Number 3, Spring 2008, p. 13

Inside GNSS (2008b): China adds details to Compass Signal Plans. Inside GNSS Volume 3, Number 6, September/October 2008, p. 12

Inside GNSS (2008c): China to launch 10 Compass SVs over two years. Inside GNSS Volume 3, Number 8, November/December 2008, p. 10

GPS World (2008) High Precision at a new level. Volume 19, Number 3, March 2008, pp. 34-36

GPS World News (2008): GLONASS-K Birds Go Into Production. GPS World News, 02.09.2008

National Oceanic and Atmospheric Administration (2007): Next solar storm cycle will start late. Press release of NOAA, April 25, 2007

Simsky A., Mertens D., Sleewaegen J.-M. & de Wilde W. (2008): MBOC vs BOC(1,1) multipath comparison based on GIOVE-B data. Inside GNSS, Volume 3, Number 6, September/October 2008, pp. 36- 44.

National Oceanic and Atmospheric Administration (2009): Solar Cycle Progression. http://www.swpc.noaa.gov/SolarCycle/

Urquhart L. & Santos M. (2008). Triple-Frequency Carrier Phase Linear Combinations for GNSS. GPS World Tech Talk, 25th August 2008

Whether you want to survey a parcel of land or a construction site, a facade or indoors to create as-built plans or carry out high-precision measurements of bridge and tunnel constructions – Leica Geosystems' surveying instruments provide the right solution for all measuring tasks.

The System 1200 Series instruments as well as the software are designed to meet the daily challenges of modern surveying. They all have outstanding, easy to read and user-friendly interfaces. Their straightforward menu structures, their clearly outlined scope of functions and high technology perfectly mate GNSS and TPS applications in the field. Whether you use the advantages of both technologies combined or each separately – due to the exceptional flexibility of Leica Geosystems instruments, reliable and productive surveying is assured.

When it has to be right

Leica Geosystems AG
Heerbrugg, Switzerland
www.leica-geosystems.com

- when it has to be **right**

Leica Geosystems