WHITE PAPER

DEFINING THE FUTURE OF SATELLITE SURVEYING WITH TRIMBLE R-TRACK TECHNOLOGY

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ABSTRACT

In September 2003 Trimble® R-Track technology in three new receivers: the Trimble R8, Trimble R7 and NetRS®. Trimble R-Track technology enables tracking of the new L2-band civilian signal, L2C, and provides surveyors with the benefits of the first stage in GPS Modernization. Trimble's in-house research and development team has continued to develop R-Track technology in response to the changes in worldwide GNSS (Global Navigation Satellite Systems). Trimble's latest receivers, the Trimble R8 GNSS system and the Trimble NetR5 reference station, both contain enhanced R-Track technology. As a result, the surveying industry can now take advantage of the first surveying receiver to track the new L2C signal and the coming L5 band of GPS Modernization, plus GLONASS, the Russian satellite constellation. In this white paper, we outline the new capabilities of the Trimble R8 GNSS, and demonstrate how the latest R-Track technology will improve productivity on today's jobsite.

INTRODUCTION

During the last decade we have seen tremendous advances in the surveying industry. Most changes have been related to user equipment: surveying tools are now smaller, lighter, more productive, and easier to use. In the next decade we will continue to see user equipment enhancements, but there will also be developments in the worldwide space segment, or GNSS (global navigation satellite systems).

GNSS refers collectively to the worldwide civil positioning, navigation, and timing determination capabilities available from one or more satellite constellations. The world's GNSS include, but are not limited to, the United States' GPS, Russian Federation's GLONASS and European Union's Galileo, along with complementary regional systems such as the U.S. WAAS and European EGNOS. Both the US and Russian GNSS are in the process of Modernization, while the European Union's Galileo is moving quickly towards operational capability.

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With so many changes literally on the horizon, to protect the surveying professional's investment in equipment and technology, Trimble has developed the Trimble R8 GNSS system. Powered by a new RTK engine and containing enhanced Trimble R-Track technology, the receiver offers comprehensive support for all currently available and imminent satellite navigation signals, including GPS and GLONASS.

Figure 1. Trimble R8 GNSS System

THE CHANGING GNSS WORLD

This is an exciting time for surveyors utilizing satellite positioning technology. As details of GPS and GLONASS Modernization, and the birth of the European Galileo system, are released, new custom integrated circuits and algorithms that blend the different systems need to be developed. This is an expensive and time-consuming process that requires close collaboration of hardware and software teams.

GPS MODERNIZATION

After the launch of the first GPS satellite in 1978, the status of GPS signals remained consistent until 1998 when, in that year, the U.S. DoD announced a plan for GPS Modernization.

GPS Modernization involves the launch of new satellites that will transmit not only new military signals, but also two new signals for civilian users. Two years later, in 2000, Selective Availability (SA)[1] o f GPS was turned off. Both actions demonstrated recognition of the strength and importance of the civilian user community, of which surveyors form a significant part.

GPS Today

Today's GPS satellites transmit two carrier frequencies—L1 and L2—both of which contain pseudo-random codes that provide positioning, timing, and navigation information. These pseudo-random codes enable GPS receivers to track several satellite signals at the same time, so that precise positioning can be calculated anywhere on earth. The difference between the two carriers is shown in Table 1.

Table 1. GPS Carriers Today

Carrier	Frequency	Code
L1	1575.42 MHz	C/A and P/Y
L2	1227.6 MHz	P/Y2

[1] Prior to 2000, the U.S. DoD applied signal degradation to limit user accuracy.

[2] The first Block IIR-M satellite was launched on 25 September 2005 providing L2C signals.

As shown in Table 1, the L1 carrier contains the C/A (Coarse/Acquisition) code, which is commercially available. The L2 carrier contains only the P/Y code, an encrypted code reserved for military use.

Initially, commercial GPS receivers could only receive the civilian L1 carrier, and to achieve survey-accuracy positioning, surveyors had to postprocess their GPS data. However, within a decade the scientific and surveying communities had developed innovative ways to use the L1 carrier to also acquire use of the L2 carrier. These communities developed dual-frequency GPS receivers that measured the arrival time of the L1 and L2 carriers, and corrected for the errors that accumulate over distance.

Dual-frequency receivers were originally only used for long-distance postprocessed measurements, but now they are used for real-time measurements also. It is therefore no surprise that of all civilian users, surveyors use the L2 carrier more than any other group to achieve centimeter-level accuracy for RTK work.

Although today's indirect method of acquiring the use of the L2 carrier works satisfactorily, L2 measurements are not received with the same strength as L1 measurements.

THE FIRST NEW CIVILIAN SIGNAL: L2C

As part of GPS Modernization, the U.S. DoD is adding a commercial code, called the "civil signal" or "CS", to today's L2 carrier. The resulting civilian L2C signal enables receivers to access two clean signals for the error correction required for advanced RTK surveying.

L2C includes a sophisticated code that capable receivers can use to recover a more powerful L2 measurement than is available to civilian users with today's satellites. The first L2C satellite was launched on 25 September 2005 and the only surveying receivers ready to receive the new L2C signals[3] were the three Trimble systems containing Trimble R-Track technology: Trimble R8, Trimble R7, and the NetRS reference station.

ALSO PLANNED: THE L5 CARRIER

The second step in GPS Modernization will comprise an entirely new carrier broadcast at 1176.45 MHz. This carrier, to be called L5, will provide a higher power level than other carriers and will use a larger bandwidth, enabling longer codes. As a result, acquiring and tracking weak signals will be much easier.

The L5 carrier will be introduced on a new generation of satellites called Block IIF, which is under development. The introduction of L5 will commence[4] no earlier than 2007, and will be completed later than that of L2C.

A full comparison of the modernized carriers is shown in Table 2.

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[3] On 16th December 2005, the satellite was set to healthy; however, the U.S. Air Force does not guarantee the availability or quality of L2C signals until Initial Operational Capability (IOC).

[4] Dates depend on the U.S. DoD.

Table 2. Modernized GPS Carriers

Carrier	Frequency	Code
L1	1575.42 MHz	C/A and P/Y
L2	1227.6 MHz	L2C and P/Y
L5	1176.45 MHz	L5 Civil

GPS III

Once the GPS Modernization program is complete, GPS III will follow with entirely new system architecture and advanced capabilities. An improved level of accuracy and integrity together with additional civilian signals will be the major benefits. The first Block IIIA satellite is due for launch in 2013.[5]

GLONASS

The Russian Federation's GNSS, GLONASS, is managed by the Russian Space Forces and operated by the Coordination Scientific Information Center (KNIT) of the Ministry of Defense of the Russian Federation.

The constellation currently has 12 healthy satellites, and a program is in place to modernize the system. On 25 December 2005 three new satellites were launched; two of these were the first of the modernized GLONASS-M satellites, which have a longer service life of seven years. Satellites with a service life of 10-12 years known as GLONASS-K's are due to begin launching in 2007 when the plan is to have 18 satellites in operation.

In 2004 the United States and the Russian Federation issued a joint statement on cooperation, with the objective of maintaining and promoting interoperability between the two systems, GPS and GLONASS.

Currently, two Trimble GNSS systems support GLONASS: the Trimble R8 and NetR5 receivers offer support via Trimble R-Track technology.

GALILEO

Galileo will be Europe's own GNSS, providing highly accurate, guaranteed global positioning under civilian control. Galileo is being developed by the European Space Agency and the European Commission, and their target is a final constellation of 30 satellites. On 28 December 2005 the first satellite called GIOVE-A was launched for the purposes of demonstration (it does not provide full functionality). A second satellite, GIOVE-B, will follow soon. Operational satellites will be launched in the deployment phase between 2008 and 2010 with the plan to achieve full operational capability (FOC) in 2010.

Trimble fully supports this GNSS advancement and is committed to having Galileo compatible products available well in advance of FOC.

TRIMBLE R-TRACK TECHNOLOGY

In response to the U.S. DoD's announcement in 1999, Trimble's research and development team immediately began working on receiver technology to support GPS Modernization. The team focused on creating a development plan that would enable users to benefit

[5] Dates depend on the U.S. DoD.

from the new technology without complex and costly hardware changes. In the resulting plan, users could purchase a capable receiver at least one year before the signals were to be transmitted.

The first milestone was achieved in late 2003 with the release of three dual-frequency GPS receivers containing Trimble R-Track technology, which supported the L2C signal. Customers who made the investment are now ready for the first transmissions from the GPS Block IIR-M satellite.

Trimble R-Track is now in its second stage of development. In the Trimble R8 GNSS and NetR5 receivers, the technology also supports L5 and GLONASS.

Figure 2. Trimble NetR5 Reference Station

SUPPORTING GNSS ARCHITECTURE

Upgrading from a dual-frequency receiver to a five-frequency receiver while maintaining the same form factor represented a significant challenge.

On the Trimble Maxwell™ custom survey GNSS chip, the second stage of Trimble R-Track technology delivers 72 channels of all-in-view tracking. This capability, which is significantly greater than even the first stage of Trimble R-Track technology, is powered by a new and more powerful RTK engine, which blends measurements from different GNSS into reliable centimeter-level positions. The new RTK engine achieves this accuracy very quickly—initialization is typically achieved in under ten seconds. Enhanced modeling of ionospheric and multipath errors further improves accuracies, especially on long baselines.

A new antenna to track the L5 and GLONASS L1/L2 has also been developed. The antenna expands the already successful Zephyr™ design to include the new signals while maintaining phase center stability and accuracy. This unit is distinguished from earlier models by a slightly higher radome.

TRIMBLE R-TRACK TECHNOLOGY: TRIED AND TESTED

Before the first GPS Modernization satellite was launched, Trimble R-Track technology was used to verify the interoperability of the new Block IIR-M GPS satellite payload with current and modernized survey equipment. Trimble GPS systems were the only L2C-ready survey equipment available to test the new satellite signal.

Tests were run by the Joint Program Office (JPO), which manages the Navstar GPS system. At ITT Industries in New Jersey, JPO used a commercial simulator to imitate

the GPS constellation and generate current signals. The simulated constellation was then coupled with the output from a IIR-M satellite; this process enabled testers to track and use the current signals together with a Block IIR-M satellite, thereby producing a combined solution.

Trimble has also conducted its own testing of the L2C and L5 signals, using a commercial simulator. GLONASS was rigorously tested using live satellite transmissions. In addition, the new RTK engine is continuously tested on a large number of data sets from around the world. By tuning the noise models derived from these datasets, accurate precisions can be determined together with as close to 100% initialization reliability as possible.

TRIMBLE R-TRACK TECHNOLOGY: BENEFITS TO THE SURVEYOR

Even before a complete constellation of L2C-transmitting satellites is available, a surveyor using a Trimble R-Track receiver from 2003 will be able to recover more powerful L2 measurements for enhanced productivity—the first L2C satellite launched is strengthening the solution even while it is the only satellite in the constellation transmitting L2C. This is because the L2C signal is an enhancement of the current dual-frequency solution, and GPS Modernization is backward compatible with legacy user equipment. Customers who bought a Trimble R-Track GPS system in 2003 are now benefiting from the following improvements:

- L2 carrier phase measurements with low noise and less than 1 mm precision
- Increased signal-to-noise ratios for L2C satellites
- Maximum multipath error reduction
- Superior low-elevation tracking

Similarly, when the Block IIF satellites start transmitting L5 in the near future, customers purchasing the Trimble R8 GNSS or NetR5 reference station will have the potential to experience improved performance from their investment. And their investment will be protected. Imagine being able to buy an automobile today that gets better fuel economy as time goes by!

Trimble R-Track technology also provides surveying benefits via GLONASS support. With additional satellites to work with, operation in difficult environments such as wooded areas, near buildings, deep cuttings and urban canyons will be improved. And with the future of the constellation now looking healthier, these benefits are likely to continue.

The key element of R-Track technology is the new RTK engine which maximizes the GNSS signals. With initialization times of just a few seconds, a surveyor's workflow can become more productive. A surveyor can move in and out of canopy without worrying about re-initialization time. While staking a point it is no longer a problem to place the pole on the ground to hammer in a stake. If initialization has been lost, it is regained in seconds. Good survey practice dictates that important points be surveyed multiple times with separate

initializations. This can now be done more quickly than ever before. The enhanced ionospheric modeling also allows operation at longer ranges from the base. Fewer base setups in one day mean more time can be spent surveying, which again leads to increased productivity.

CONCLUSION

The next decade will see many changes in the GNSS world. The L2C and L5 signals that are part of GPS Modernization will present surveyors with opportunities for more robust satellite tracking and all the inherent benefits that this will provide. They also demonstrate a commitment by the U.S. DoD to support the many civilian GPS users worldwide, of whom surveyors represent a significant percentage.

The Russian GLONASS system has a renewed quality and commitment. The additional satellites provide beneficial augmentation to GPS in difficult environments. Technology to embrace the European Galileo will be put in place well in advance of operational capability.

Trimble R-Track technology in the Trimble R8 GNSS and NetR5 reference station has been developed to take advantage of all available signals. The latest version of Trimble R-Track technology in the Trimble R8 GNSS is powered by a new RTK engine, which greatly expedites initialization.

Since most surveyors use their surveying equipment for several years, those purchasing a receiver today—whether for field surveying or infrastructure—should take the changes in GNSS into consideration. And by choosing a Trimble solution, purchasers can rest assured that these GNSS changes have already been taken into consideration by Trimble. A Trimble R8 GNSS receiver that is ready to receive L2C, L5 and GLONASS without hardware upgrades, will protect their investment for many years to come and ensure maximum accuracy and productivity throughout their equipment's lifetime.

In Trimble's Connected Survey Site model, Trimble customers leverage the Trimble tools, techniques, services, and relationships that best serve their needs. Trimble's GNSS developments exemplify this model. Not only is the Trimble R8 GNSS system the most advanced GNSS surveying tool available to surveyors today, it is flexible to support GNSS and integrated surveying techniques. It also supports use of Trimble GNSS infrastructure networks and services.