# Magellan BLADE™ Technology

White Paper

## Magellan's BLADE™ Technology, What It Means to GNSS Users

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# Introduction

BLADE™ is Magellan's proprietary, state-of-the-art Global Navigation Satellite System (GNSS) Real-Time Kinematic (RTK) and Differential GNSS (DGNSS) engine that is the core GNSS data processing technology in Magellan's Professional products.

BLADE contains patented techniques[1] for the optimal combination of different GNSS signals.

Most existing RTK engines were created as GPS (L1 only or L1&L2) engines. They were not initially designed to properly support other GNSS signals for each RTK-specific application. Adding other GNSS signals and specific functions to existing GPS-only source code may lead to non-optimal performance.

BLADE was initially designed as a complete GNSS multi-band engine (GPS+GLONASS+SBAS or other GNSS signals, L1&L2 or other bands) to support a very wide range of RTK applications from classic RTK/DGNSS rover against static Base/Network up to exotic applications like RTK against a moving base or attitude determination.

The universal and flexible implementation of BLADE allows Magellan to use the same engine without any changes in different RTK products from L1 GPS+SBAS™ RTK (ProMark3 RTK™) up to L1&L2 GPS+GLONASS™ RTK (ProMark 500™) and beyond. Thanks to the initial flexible design, BLADE can easily absorb all future incoming signals, such as GPS L2C and L5, GLONASS CDMA and L5 and Galileo[2].

State-of-the-art coding allows the easy porting of BLADE to different platforms/OS. It can be used as the core of an OEM GNSS solution or as a separate RTK application running on 3rd party processors.

The BLADE engine is also the core of Magellan's GNSS Solutions™ office software for data post-processing. When used in post-processing applications, BLADE can be run forward and backward many times to achieve post-processing performance that is better than real-time performance.

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1. US Patent 5914685.
2. Magellan's strategy is to make products that utilize GNSS signals when they bring real value to the user. Magellan invented GPS+GLONASS and patented the technique for optimally combining these GNSS signals in 1999.

The key distinguishing features of the BLADE engine include:

- Instant RTK
- Long Range RTK
- Effective RTK in shaded areas
- Float/Fixed and Flying™ RTK
- OTF ambiguity initialization as well as initialization with different geometric constraints
- GPS+GLONASS, GPS+SBAS and GPS+GLONASS+SBAS RTK
- L1 and L1+L2 RTK
- RTK against moving base
- Attitude determination functions, including self-calibration
- Effective support of high update rate for both Time-Tagged and Fast RTK modes
- Robust performance with brief data link outages
- Built-in effective Network data (VRS, FKP, MAC) processing
- Supporting the entire range of RTCM-2, RTCM-3, CMR/CMR+ messages as well as Magellan's proprietary ATOM™ format.

High-end BLADE performance is achieved not only by optimal processing of GNSS raw data (Magellan and third party), but also with the proper usage of other available information (e.g. atmospheric parameters at base and rover).

## Benefits of BLADE

Magellan's BLADE technology provides the following user benefits:

- Use of SBAS and GLONASS ranging signals to strengthen the GPS solution allowing reliable RTK with GPS+SBAS or GPS+GLONASS+SBAS receivers.
- Faster time to a decimeter-accurate solution when not resolving ambiguities.
- Use of third party reference stations for GLONASS correction data resulting in reliable rover operation in any RTK Network.
- Reliable fixed RTK solutions with constant checking for correct ambiguity resolution.
- Routine operation over baselines up to 70km.

## Technical Description

**Features**

1. **General**: Extended Kalman filter of variable size to process data sequentially epoch-by-epoch forward [and backward for post-processing usage] used to estimate the baseline between a single static or moving base and a single static of moving rover.
2. **Positioning modes**: Code differential, Float RTK, Flying RTK, Fixed RTK.
3. **Measurements currently used**: Code [+carrier] from L1 GPS only up to GPS+GLONASS+SBAS L1&L2. (BLADE is open to processing future signals including GPS and GLONASS L5, Galileo, and Compass data).
4. **Acceptable measurement quality**: From high-quality measurements down to non-coherent signal tracking. BLADE performance is driven by base and rover measurement data quality.
5. **Base data formats accepted**: RTCM 2.3, RTCM 3.1, CMR/CMR+, Magellan Proprietary ATOM.
6. **Network data formats accepted**: FKP, MAC, VRS.
7. **Carrier ambiguity**: From Float/Flying, through partially fixed and up to fixed solution with different levels of reliability.
8. **Initialization**: On-The-Fly [+ different geometric constraints].
9. **Dynamics**: From pure static to unpredictable kinematics, adaptive filter is default.
10. **Baseline length**: Limited only by common satellites in view.
11. **Solution protection**: Built-in guard against incorrect ambiguity determination [+ the use of tracking channel warnings].
12. **Reporting accuracy**: rms estimate of position fix.

**Modules and Functions**

1. Extended Kalman Filter of variable size
2. Built-in guard & warning processing
3. Ambiguity transformation/search/fixing routines
4. Service procedures.

### Kalman Filter

Kalman filter (KF) models up to the following states:

- 3D position & clock (4 states)
- [3D velocity & clock drift (4 states)]
- [Single Difference L1 ambiguity (one for each Sat)]
- [Single Difference L2 ambiguity (one for each Sat)]
- [Single Difference ionosphere (one for each Sat)]
- [L1-L2 GPS code bias (1 state)]
- [Troposphere parameter (1 state)]
- [L1-L2 vertical antenna offset (1 state)]

All optional states are initialized when needed and deleted when values are not observable.

KF works with Single Difference (SD) measurements between rover and base.

KF may absorb up to 4 blocks of original SD measurements per epoch:

- L1 (C/A or P1) code (GPS+SBAS+GLONASS)
- L1 (C/A or P1) carrier (GPS+SBAS+GLONASS)
- L2 (P2 or CS) code (GPS+GLONASS)
- L2 (P2 or CS) carrier (GPS+GLONASS).

KF may take advantage of the following supplementary information:

- *A priori* position information (Known Point Initialization option)
- *A priori* baseline length and maximum elevation difference information (heading option).

KF may support up to 9 kinematic modes:

- Pure static
- Quasi static
- Walking
- Ship
- Automobile
- Aircraft
- Unlimited
- Adaptive - default
- User defined.

### Built-in Guard

The built-in guard includes:

- Raw base and rover data checks
- Rover receiver channel warning processing
- Distance-free SD measurement combinations processing
- SD failure guard for each epoch
- Reset management.

SD failure epoch guard is intended to:

- Detect small and medium code outliers for all kinematic modes
- Detect small (up to 0.5 cycle) carrier cycle slips for all kinematic modes.

The efficiency of SD failure guard depends on the number of measurements at an epoch and the kinematic model used.

The SD failure guard is built into the KF routine, and performs sequentially:

- Anomaly detection
- Anomaly isolation

Reset management includes:

- Detection of suspected but not-repaired data anomalies or KF divergence (wrong ambiguity fix, missed cycle slips, etc.)
- Flexible mapping of different types of detected anomalies into one of 4 types of RTK resets (from the 'hardest' up to the 'softest')

### Ambiguity Routines

KF estimates SD ambiguity, while only Double Difference (DD, between satellites) ambiguities are subject to search and fix.

Ambiguity responsible routines include:

- Selection of DD ambiguity and combinations to be searched
- Integer search of up to 100 of the most probable solutions
- Different search/fixing strategies
- Support of decision rules
- KF state vector and covariance transformation in case of ambiguity fixing
- Adaptive partial-fixing routines
- Thin algorithms related with GLONASS carrier biases
- Special aids to support heading option.

Adaptive partial fixing allows for a fixed ambiguity solution in cases where a few (*a priori* unknown) carriers are biased.

Thin algorithms related with GLONASS biases include background estimation of fractional part of GPS-GLONASS carrier bias in order to use it to speed up ambiguity fixing after full loss of lock.

With heading option, *a priori* information about baseline length and maximum expected elevation is used for deselecting the wrong integers.

### Service Procedures

1. RTK resets/initialization management
2. Particular states health monitoring
3. Estimators of achieved accuracy
4. Estimators of GLONASS inter-channel hardware biases.

BLADE supports different kinds of RTK resets:

- Whole RTK reset (reset all possible, imitates receiver start up)
- Whole KF reset (some information from service procedures is not reset)
- Partial KF reset (biases and ionosphere are not reset, imitates receiver reacquisition after short-term full blockage)
- Soft KF reset (position and ambiguity states are slightly released).

BLADE can estimate actually achieved accuracy, based on post-fit residual analysis. It takes into account not only the magnitude of residuals, but also their time correlation.

In the background of KF processing, BLADE can effectively estimate GLONASS hardware biases, which are usually specific for a given pair of receivers. This information may be saved in Battery Backed-Up receiver memory in order to be used and updated during next sessions with the same receivers. This feature allows considering GLONASS measurements to be of equal quality to their GPS counterparts.

# BLADE Performance in Detail

## Preamble

All performance figures presented in this White Paper were obtained with default BLADE settings. Specifically, no static assumption was made when processing static data. All the tests related to ambiguity fixing were performed with a preset 99% reliability level. In all the cases, the reliability requirement was met (in most of the tests, 100% reliability was achieved).

All performance figures were derived on a computer with pre-collected data using a PC-based version of the BLADE engine, which worked in the exact real-time manner as if it were running in a receiver.

All performance figures are statistical. Sufficient data was used to evaluate these figures with a high level of confidence.

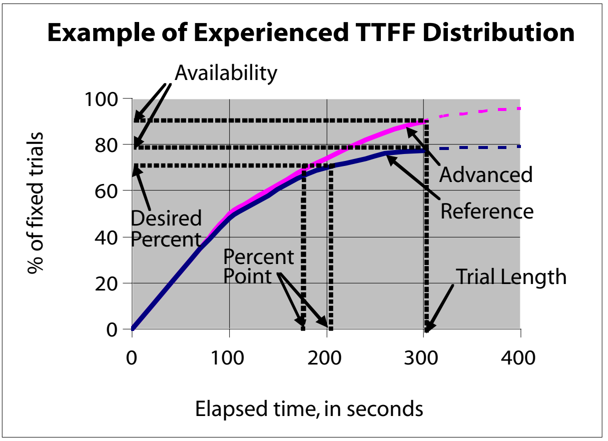
The performance evaluation procedure in each case consisted of running the BLADE engine with automatic reset every 300 or 600 seconds to get a sufficient number of independent, fixed-length RTK trials. The result of each trial was subject to further statistical evaluation.

Unlike some other vendors, Magellan always uses the fixed-length trial methodology (compared to float-length trials) because only this approach is statistically adequate, and is generally more pessimistic than the float-length trials.

The diagram below shows the meaning of Time To First Fix (TTFF) performance figures we provide when speaking about fixed ambiguity solutions in BLADE. First of all, the results of all the fixed-length trials are used to build a cumulative distribution function vs. time (t) elapsed from BLADE reset. Since not all the trials can be fixed (trial length is T=300 sec in this example), this distribution function is valid only for t<T. The values for t>T usually cannot be well extrapolated and are not used in any BLADE performance evaluation.

Below, instead of plotting the complete distribution function, we provide some typical values (marked red) corresponding to the desired parameter (marked yellow). These are:

- Availability = the percentage of ambiguity fixed trials over all the trials of length T.
- TTFF percent point = the minimum time needed to fix ambiguity in given percent of trials.




Since the TTFF can be very dependent on time and local environmental conditions, the absolute performance often tells nothing valuable. That is why for each test we provide comparative figures, which demonstrate the benefits of the "advanced" BLADE over another standard "reference" post processing engine, providing thereby a direct comparison. This “reference” case can be another engine running with the same data, or the same BLADE engine not using an 'advanced' option.

It must be noted that in many cases the difference between "reference" and "advanced" cases is not so obvious at the 50% level of TTFF. However, the difference can be dramatic at the 90% and 99% levels. These points refer to so-called worst case scenario where the BLADE technology shows its full power.

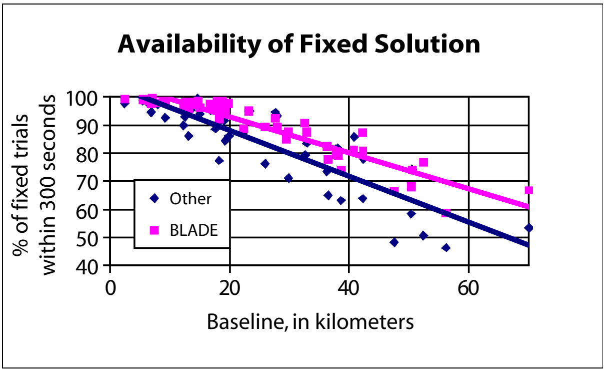
## Long Range RTK Performance (GPS L1&L2)

The diagram below shows the performance of the long-range GPS L1&L2 RTK algorithm with the BLADE engine compared to another RTK engine previously used by Magellan.

For each of the 50 baselines that were collected, more than 400 independent 300-second trials were conducted.

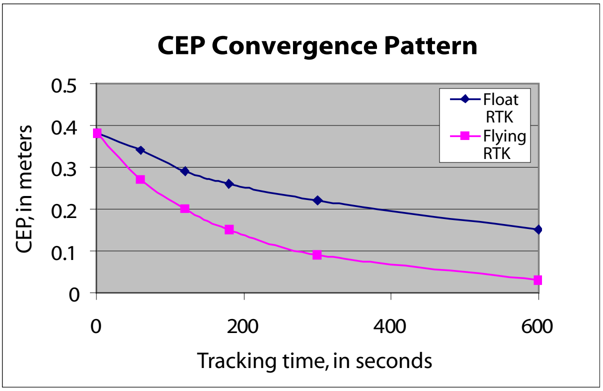
The diagram shows that the BLADE engine insures:

- Very high fixed-solution availability for short baselines (<20 km)
- Good fixed-solution availability for up to 70-km baselines.




## Flying RTK Performance (GPS L1)

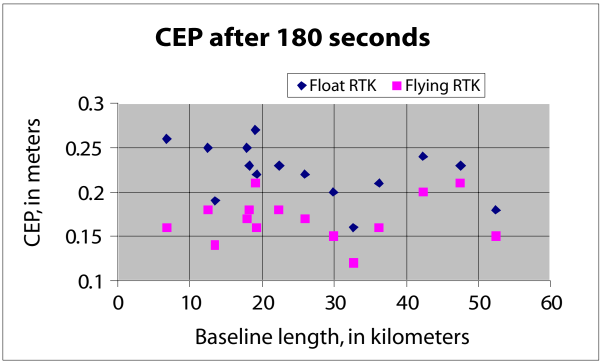
The diagram below demonstrates the benefit of BLADE by applying the Flying RTK algorithm rather than the conventional Float RTK algorithm. The results are shown for L1 GPS only, over a short baseline.




The CEP error (50% horizontal) is plotted vs. the time elapsed after BLADE was reset. The collected data include more than 150 reset operations for each of the different 22 baseline lengths used, which ranged from several meters up to ten kilometers.

This plot shows that with BLADE's Flying RTK, Magellan can insure much better position convergence compared to conventional Float RTK algorithms.

The diagram below shows how the CEP figure can be improved for long baselines using the Flying RTK algorithm. The CEP was measured three minutes after BLADE reset.



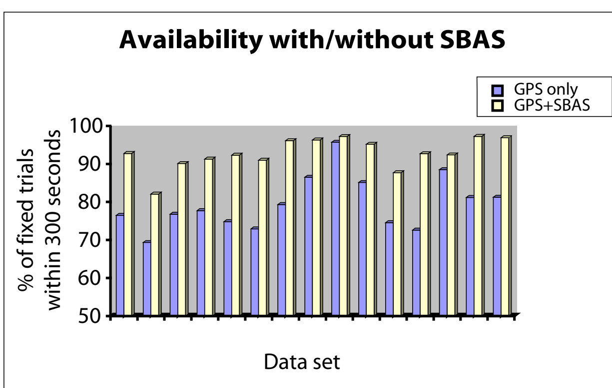

Again, L1 GPS-only data were used for evaluation. The plot shows that, even for long baselines, with only L1 GPS data, Flying RTK can deliver decimeter-level performance.

## GPS+SBAS RTK performance (L1)

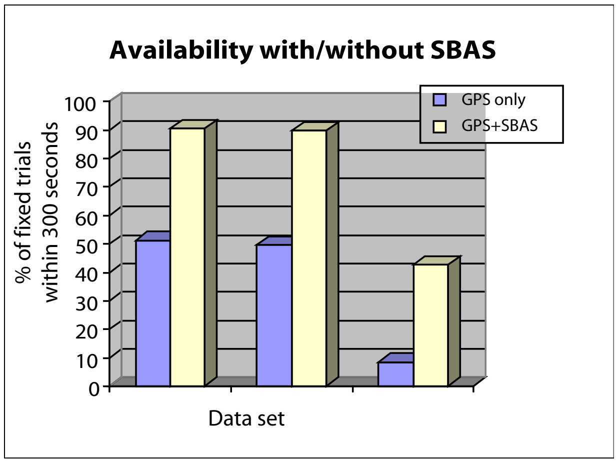
The diagram below demonstrates the improvement in fixed position availability using SBAS ranging data (pseudorange and carrier phase) in the BLADE RTK process.

Fifteen data sets (each at least 24 hours long) were used from open-sky baselines that varied in length from a few tens of meters to 7 km.

One or two common SBAS satellites were available to both base and rover. Most of the data sets were collected in Europe (EGNOS) and US (WAAS), the last data set corresponds to China (MSAS). Thanks to SBAS ranging, the improvement in fixed position availability is obvious.



Using SBAS ranging in BLADE, the improvement is even more dramatic when processing baselines under medium/heavy shading. SBAS satellites noticeably improve geometry and result in dramatic improvement in performance over the GPS-only case. The first two data sets correspond to medium sky shading, while the third one corresponds to heavy shading where a GPS-only solution is typically useless.

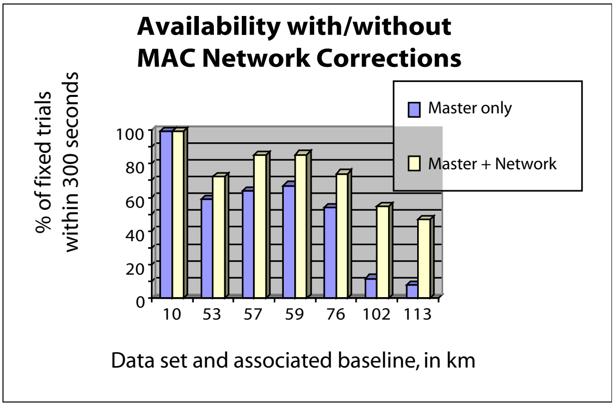


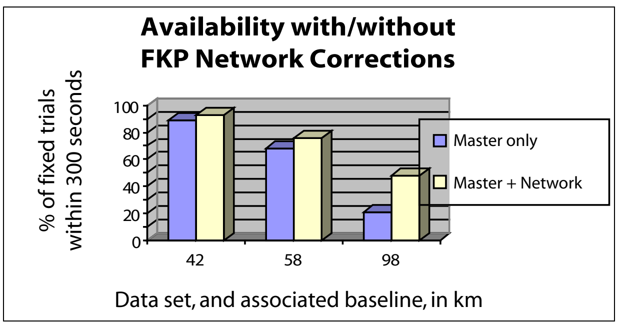

## Network Performance (GPS L1&L2)

The two diagrams below show BLADE performance in GPS networks transmitting single-base (master) data and standardized network corrections:

- MAC as RTCM-3 messages 1014-1016 (Orpheon Spider Network, France)
- FKP as RTCM-2 message 59 (Teria FKP Network, France)

Making proper use of different types of network corrections in the BLADE engine shows that the range of fixed ambiguity RTK can be extended effectively to over one hundred kilometers.

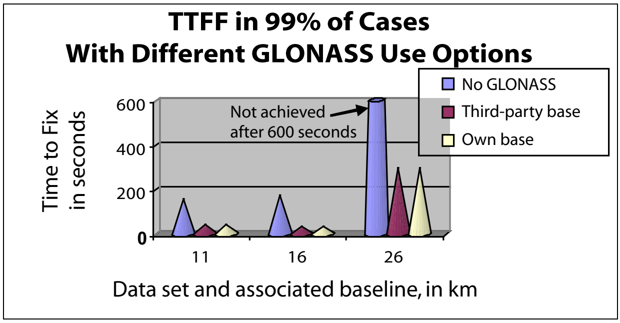



## GLONASS Performance (L1&L2)

The diagram below shows 99% point to fix ambiguity for three different short baselines. The trial duration was 600 seconds. All data sets were collected with Magellan ProMark 500 GPS+GLONASS L1&L2 receivers and processed with three different assumptions:

- GPS only, i.e. no GLONASS data was used.
- GPS+GLONASS with “third-party base” assumption. In this case, GLONASS differential carrier phase biases were assumed to be not known *a priori* and the receiver ran an OTF bias calibration.
- GPS+GLONASS with “own base” assumption. In this case GLONASS differential carrier phase biases were known to be zero.

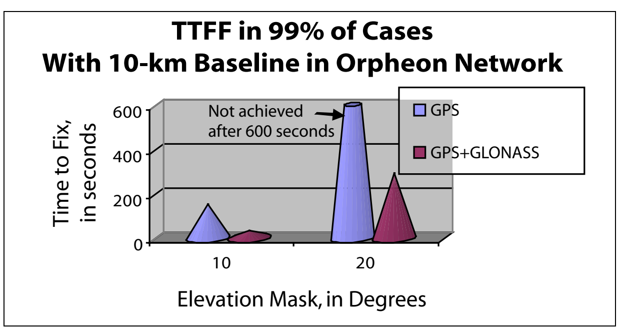



The diagram shows that:

- Using GLONASS brings good improvement compared to GPS only.
- OTF GLONASS carrier bias calibration (i.e. third-party base assumption) demonstrates a performance level similar to the "own base" assumption.

The diagram below shows BLADE performance when actually working against a third-party base from an unknown manufacturer (i.e. carrier bias calibration needs to be run), for which using GLONASS data in the BLADE algorithm can dramatically improve TTFF performance.

This appears more clearly in the test with specially applied 20-degree elevation mask, for which 99% point of TTFF was not even achieved after 600-second intervals.

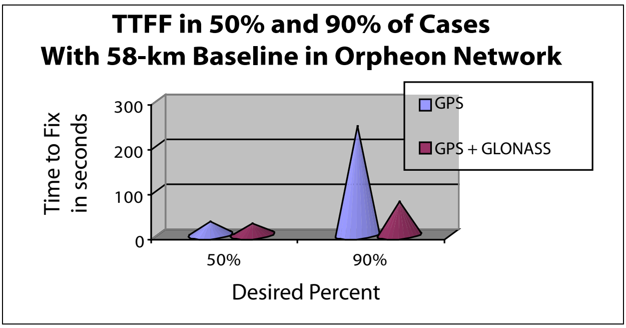



When working in a network, 10-km baselines are not really the typical case of use. Usually, rovers work on baselines from 30 to 70 kilometers, and may be either within or out of range of the network.

For long baselines, effective OTF calibration of the GLONASS carrier bias is not so easy as on short baselines. This is because systematic errors on long baselines, like residual orbit, troposphere and ionosphere errors, noticeably affect the calibration process.

However, the diagram below shows how the BLADE RTK engine, through an adequate processing of the GLONASS data from a third-party base, can improve the TTFF over the GPS-only case, even for a long 58-km baseline.

On this diagram is a statistical summary gathering the results of two data sets collected in the same conditions (i.e. same receiver, same antenna, same network mount point) but two weeks apart.




One can see that while 50% point of TTFF is almost equivalent for both cases, for 90% point there is a dramatic improvement thanks to using BLADE GPS+GLONASS solution. In other words, GLONASS being not so important in cases when GPS alone is good, is very important in worst cases when the power of GPS alone is not sufficient to get quickly fixed solutions.

# References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- *Centimeter Level Real-Time Kinematic Positioning with GPS+GLONASS C/A Receivers*, D. Kozlov, M. Tkachenko, Navigation: Journal of the Institute of Navigation, vol.45, No.2, Summer 1998, pp. 137-147.
- D. Kozlov, A. Povaliaev, L. Rapoport, S. Sila-Novitsky, V. Yefriemov, *Relative Position Measuring Techniques Using Both GPS and GLONASS Carrier Phase Measurements*, US Patent No. 5,914,685, Jun. 22, 1999.
- *Statistical Characterization of Hardware Biases in GPS+GLONASS Receivers*, D. Kozlov, M. Tkachenko, A. Tochilin, Proceedings of ION-GPS '2000, Salt Lake City, Utah.
- *L1 RTK System with Fixed Ambiguity: What SBAS Ranging Brings*, A. Boriskin, D. Kozlov, G. Zyryanov, Proceedings of ION-GPS '2007, Fort Worth, Texas.
- *Flying™ RTK Solution as Effective Enhancement of Conventional Float RTK*, D. Kozlov, G. Zyryanov, Proceedings of ION-GPS'2007, Fort Worth, Texas.
- *PM3 RTK White Paper*.
- *DG14 RTK White Paper*.
- *Algorithms to Calibrate and Compensate for GLONASS Biases in GNSS RTK Receivers working with 3rd party Networks*, A. Boriskin, G. Zyryanov, Proceedings of ION-GPS '2008, Savannah, Georgia.

Receiver RTK engines:

- Z-Max RTK (L1&L2 GPS) - 2003
- ProMark3 RTK (L1 GPS+SBAS) - 2007
- DG14 RTK (L1 GPS+SBAS) - 2007
- ProMark500 RTK (L1&L2 GPS+GLONASS + L1 SBAS) - 2008
- MB500 - 2008

Office Software:

- GNSS Solution office - 2002
- ADU5 calibration - 2002
- MobileMapper Office - 2005
- MobileMapper 6 Office - 2008

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**Magellan Contact Information:**
**In USA** +1 408 615 3970 ▪ Fax +1 408 615 5200
**Toll Free (Sales in USA/Canada)** 1 800 922 2401
**In South America** +56 2 273 3214 ▪ Fax +56 2 273 3187

**In France** +33 2 28 09 38 00 Fax +33 2 28 09 39 39
**In Russia** +7 495 980 5400 Fax +7 495 981 4840
**In the Netherlands** +31 78 61 57 988 Fax +31 78 61 52 027

**In Singapore** +65 983 842 29 Fax +65 677 798 81
**In China** +86 10 6566 9866 Fax +86 10 6566 0246

**www.pro.magellanGPS.com**