

How Magellan Optimally Uses GLONASS in the ProMark 500 GNSS Receiver

1. Background

GLONASS brings to the GNSS world not only extra satellites; it also brings problems that the GPS+GLONASS receiver manufacturer must resolve. Many manufacturers speak of the benefits that GLONASS can bring to precision GNSS instruments, but few are willing to talk about the possible performance degradations that can be caused by GLONASS.

It is a major challenge to get a performance benefit from GLONASS, especially for professional products/algorithms. GPS+GLONASS RTK receivers are at the top of the professional equipment price range; but taking advantage of GLONASS to justify this price differential with GPS only is a very difficult task.

Magellan patented the use of GLONASS measurements to augment GPS measurements in 1999 (US Patent 5,914,685). Rather than trying to combine the results of two systems that use separate ellipsoidal models and clock for their reference, Magellan first solves for a GPS solution then treats the GLONASS signals like GPS measurements. This eliminates many of the problems faced by other manufacturers, namely how to combine separate solutions from two systems, or how to take benefit from adding a single GLONASS satellite. In the ProMark3 RTK product Magellan uses a similar strategy combining GPS+SBAS.

Besides the strategy on using the GLONASS signals in combination with GPS, manufacturers face additional problems including the effect of hardware biases resulting from the Frequency Division Multiple Access (FDMA) nature of the GLONASS.

In general, when adding GLONASS or any other GNSS signal to GPS, the primary directive must be:

Take advantage of complementary GNSS signals when and where possible, but never spoil performance.

It is known that many 3rd party receivers and Networks sometimes show worse performance when working in GPS+GLONASS mode compared to GPS only. Moreover, some dealers recommend their users to disable using GLONASS in their applications. These examples prove that the second part of the slogan above is not met for these receivers/Networks.

At the same time, GLONASS data can objectively (as provided by GLONASS space and control segment) as well as subjectively (as processed by a receiver) have a lot of unknowns in appearance and behavior (e.g., problems with orbits and Satellite clock appear from time to time for some Satellites). That is why GNSS receivers must be maximally robust with respect to ANY possible problems with GLONASS signals.

Magellan did its best to follow this slogan in PM500. Magellan claims that in some important cases (e.g. blocked sky) adding GLONASS to GPS does improve RTK performance (time to cm, reliability, availability of signals, etc.). Magellan cannot guarantee absolute performance improvement in all the user cases for GLONASS. At the same time, with a high degree of reliability Magellan can guarantee for the ProMark 500 that in all the cases when GLONASS

behaves badly or when assumptions regarding GLONASS data are not met, adding GLONASS to RTK will not degrade performance compared to GPS only performance in the same conditions.

The problems described in this paper are well known and have been successfully solved by Magellan as described below. Magellan implemented a number of valuable robust solutions related with GLONASS usage/processing in our BLADE RTK engine. These solutions mean we do not recommend that Magellan users disable GLONASS manually in cases when GLONASS is not performing properly. The receiver itself makes all the needed checks/preparations to mitigate the possible negative effects of GLONASS whenever or wherever they appear.

2. Hardware bias problem

Hardware GLONASS biases exist because GLONASS uses FDMA technique. Different signals pass through different parts of front-end RF which inserts frequency-dependent delays to code and carrier.

Main factors causing these biases are:

1. Nominal Group Delay (GD) variations caused by non-ideal front-end RF design
2. Particular GD variations for each unit caused by components variations
3. Particular GD variations for each unit caused by environmental conditions (temperature mainly)
4. Special features of correlation/tracking algorithms which can cause changes in observed bias provided the very same GD

Below we are speaking about differential h/w biases between base and rover receivers (RTK mode). That is why any change in biases (say due to temperature) can be caused not only by rover but by base as well.

If base and rover are of the same design and use the very same correlation/tracking algorithms, then factors 1 and 4 cannot provide biases. The only sources of biases are factors 2 and 3. It is experienced that factors 2 and 3 can cause only code biases, while the appearance of carrier biases was not observed.

It is proven that there are NO carrier biases between PM500 base and PM500 rover.

If base and rover are of different types and/or use different correlation/tracking algorithms, then factors 1 and 4 can dominate as the main source of code and (especially) carrier biases.

Good introduction into GLONASS biases analysis is Magellan ION 2000 article *Statistical Characterization of Hardware Biases in GPS+GLONASS receivers*.

3. Half-cycle ambiguity problem

Old GLONASS Satellites (currently they are #1,4,8 occupying Frequency numbers 6 and 7) transmit only P-code signal on L2. New GLONASS-M Satellites (the 13 Satellites currently occupying Frequency numbers -2...5) transmit simultaneously L2 CA and L2 P.

The summary of these signals is as follows (confirmed by RTCM):

- Signal L2 CA is modulated by the data of known content (same as L1 CA). That is why one can easily restore its polarity and provide carrier phase observation with **integer** cycle ambiguity.
- Signal L2 P for new GLONASS-M Sats is modulated by the data of unknown content. That is why one generally cannot restore its polarity correctly. So this signal can provide carrier phase observation only with **half-an-integer** cycle ambiguity.
- Signal L2 P for old GLONASS Sats is not modulated by any data. That is why one can restore its polarity correctly. So this signal can provide carrier phase observation with **integer** cycle ambiguity.

The official RTCM recommendation for GLONASS L2-enabled receivers is (refer to '*GLONASS interoperability issues, February 2008*', 027-2008-sc104-493.pdf):

- Track L2 CA signal for new GLONASS-M Sats
- Track L2 P signal for old GLONASS Sats

Magellan PM500 receiver follows this recommendation exactly.

It has been proven that there is always an integer cycle ambiguity between PM500 base and PM500 rover.

However, there is no guarantee that all others (3rd party) GLONASS L2-enabled receivers follow this recommendation.

Magellan monitored a few receivers of different manufactures by analysis of CA/P code indicator they set for their GLONASS L2 data generated in standardized RTCM-3 messages. Unfortunately, many of them set CA/P code flag differently and often incorrectly (i.e., some vendors set CA flag for old GLONASS Sats which is logically incorrect). This means that generally when getting reference data from 3rd party receivers it is not certain which GLONASS L2 tracking strategy they use and if their carrier phase observations contain full integer or half integer ambiguity.

4. GLONASS RTK technology from Magellan

The hardware code and carrier biases and possible half cycle ambiguity are the main problems related with GPS+GLONASS RTK performance. These problems are well known worldwide and Magellan created its own strategy to overcome these negative GLONASS features in the ProMark500 RTK receiver.

The solutions from Magellan include:

- OTF calibration of code biases

- Providing and processing receiver name
- Possibility to work with full and half cycle ambiguity
- Supporting receiver name database
- OTF calibration of carrier biases

3.1. OTF calibration of code biases

PM500 RTK engine estimates GLONASS code hardware biases for L1 and L2 along with other RTK related states (position, velocity, carrier ambiguity, residuals ionosphere etc). A priori it is known that code hardware biases are of meters to tens of meters magnitude and stable with time; so an appropriate stochastic model is used for modeling them.

This bias estimation is actually the On-The-Fly calibration described in Magellan's ION 2000 article *Statistical Characterization of Hardware Biases in GPS+GLONASS receivers*.

GLONASS code bias calibration does not mean that the receiver must specially be put into a calibration mode. On the contrary, Magellan uses OTF calibration, and the receiver can provide high quality float and fixed ambiguity solutions even if calibration is in progress.

The code bias calibration procedure is reset each time the base station ID or base receiver name is changed. The calibration procedure contains different protections to prevent incorrect selection of the pre-calibrated bias values. Calibrated values are not saved in receiver BBU, i.e., the calibration process re-starts with each receiver start up.

The code calibration algorithm works equally well with Magellan or 3rd party base. In practice it is seen that code hardware biases can exist between receivers of the same design (sample to sample variations, temperature variations, etc.).

3.2. Providing and processing receiver name

To make GLONASS data processing more effective, it is desirable for an RTK rover to know the base receiver name.

The PM500 receiver being used as a base provides such a possibility for 3rd party rovers. The Official PM500 name ('ProMark500') by default is generated in the following messages:

- RTCM-3 MT 1033
- RTCM-2 MT 16
- CMR MT 2
- CMR+ MT 0
- Proprietary ATOM message

It should be noted that only RTCM-3 MT 1033 is standardized as the message containing receiver name and firmware version, and it can automatically be processed by a rover. On the other hand, all the other ways are not standardized and can be used only for visualization purpose to allow 3rd party RTK rover to make its own decision regarding the actual base receiver name.

A PM500 receiver being used as a rover can take advantage of processing the base name if it is available. This is automatically done for RTCM-3 MT 1033, which any 3rd party base can generate. Since receiver name support has not matured yet, processing MT 1033 is used in PM

500 mainly for the single purpose of distinguishing between a ProMark500 base and a 3rd party base.

Once the GNSS community matures to provide carrier bias data for all receivers, processing RTCM-3 MT 1033 in PM500 will allow working with receiver name database (see section 3.4).

3.3. Possibility to work with full cycle and half cycle carrier ambiguities

ProMark 500 insures full cycle carrier ambiguity for L1 and L2. By default, PM500 RTK rover considers that any 3rd party base also provides full cycle ambiguity for L1 and L2. That is why PM500 RTK rover works with full cycle ambiguity assumption regardless of whether the base is a PM 500 or a 3rd party base.

At the same time, it is a priori known that a 3rd party base may provide only half cycle ambiguity for L2, in which case PM500 rover can be commanded to work with a half cycle assumption for L2, i.e., still having a possibility to fix L2 ambiguity to half-an-integer.

3.4. Supporting receiver name database

Here is an extraction from official RTCM meeting minutes, Berlin, February 5-6 2008.

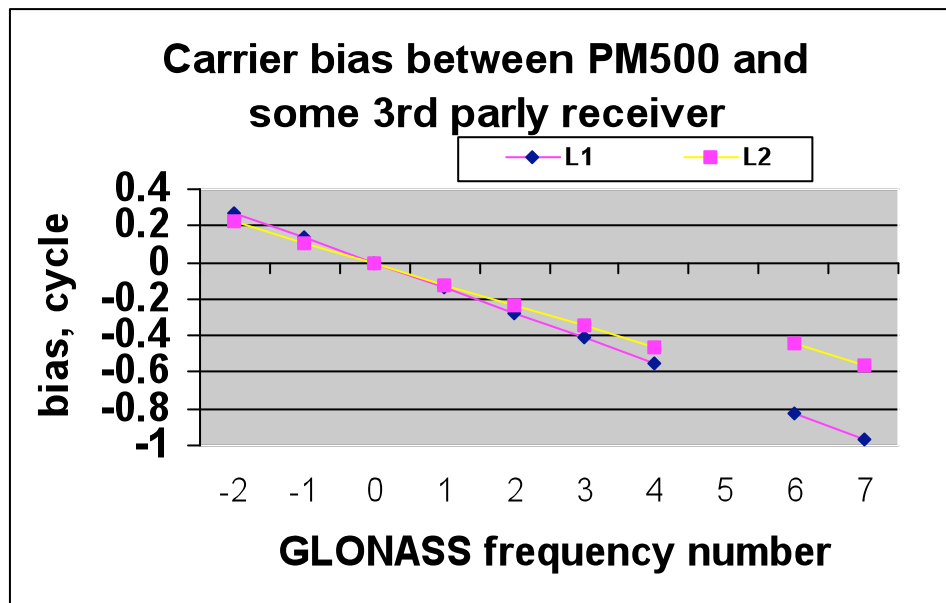
To address the interchannel bias problem, Mr. Zinoviev [GLONASS WG Chair] will e-mail working group members requesting calibration data against GPS wherein code and carrier biases are measured simultaneously. Then other members can try using those corrections against their own data to see if results improve. Meanwhile, some members will develop a calibrated bias message (time-code-carrier) with data field ranges based on the results.

Magellan is in process of following these recommendations.

The figure below shows carrier bias patterns between PM500 rover and a 3rd party base receiver. This pattern was estimated **in Real Time by BLADE RTK engine** on zero baseline for >3 days continuous observation during weekend April 18-21, 2008.

Please note that:

- Since only Double Difference (DD) bias value has meaning, we set bias value for Freq#0 to zero, considering thereby all biases as differential biases against Satellites with Freq#0.
- These biases are of fractional meaning, but we intentionally put them in wider range to show (quasi) linear pattern vs. Freq#.



The pattern is primarily linear with Frequency number. Please note that Frequencies #6, 7 refer to old GLONASS satellites for which ProMark500 tracks L2 P. That is why the L1 bias pattern is linear (all signals are L1 CA), while the L2 pattern has a jump corresponding to transiting to L2 P signals.

The 3rd party receiver used here reported tracking L2CA for old GLONASS satellites. This is logically incorrect, because these Sats do not transmit L2CA.

GLONASS Satellite #7 having Frequency #5 was not available during this weekend test.

Being initially calibrated, this pattern was applied a few days later for another PM500 receiver working with the same 3rd party base. We made sure that using this pattern for compensating for the given 3rd party base carrier biases makes the final Double Differenced (DD) carrier bias free.

Having a good variety of 3rd party receivers, Magellan is able to make similar calibrations against each of them. Having done this, all the calibrated values can be inserted into the receiver name database to allow compensating for carrier phase biases with any base receiver whose name is in the ProMark 500 receiver database.

3.5. OTF calibration of carrier biases

In most cases (at least until all manufactures have calibrated their receivers against each other or against an absolute reference) PM500 RTK rover will have an incomplete receiver name database. This prevents applying the technique described in section 3.4.

In such cases the PM500 RTK receiver automatically applies an On-The-Fly carrier bias calibration technique when the base receiver name is either not known or not available in the PM500 receiver name database.

The idea of OTF calibration is very simple: consider DD carrier hardware biases as a priori unknown parameters following some stochastic model. Even if the idea is simple, the implementation of this solution is not trivial. The Magellan PM500 receiver can successfully make OTF calibrations against 3rd party bases. No assumptions are made regarding bias pattern vs. Freq number (e.g., that it is linear).

It must be noted that this OTF bias calibration is automatic and does not require any special hardware or software setup from user. The calibration process starts as soon as the receiver starts getting corrections from a 3rd party base. During the calibration process, the PM500 RTK receiver is still able to provide float and fixed ambiguity solutions. The calibration process is hidden from the user.

The OTF carrier bias calibration procedure is properly protected to prevent a possible wrong calibration, and it automatically detects the situations when OTF calibration must be reset. If the received base receiver name is changed, the OTF calibration is reset.

5. Concluding remarks

The above demonstrates that Magellan with its new ProMark500 product allows not only tracking of GLONASS L1&L2 signal. Magellan also claims that tracking GLONASS in the ProMark 500 is not only a Marketing feature. On the contrary we confirm that taking benefit from GLONASS in and RTK solution is not a simple task. Because of our patented GLONASS processing techniques, Magellan can take the benefit from using GLONASS observables in RTK process using either Magellan or 3rd party bases or networks.

Unfortunately there is today a lot of ambiguity in the interpretation and standardization of GLONASS data, and this does not allow Magellan to perform ideally in all cases against 3rd party bases and networks. However, Magellan is in line with the worldwide GLONASS standardization process and participates in both the RTCM SC-104 committee and in the creation of new RINEX standards. This guarantees our ability to implement GPS+GLONASS RTK performance enhancements as they are standardized.