

Absolute GNSS Antenna Calibration with a Robot: Repeatability of Phase Variations, Calibration of GLONASS and Determination of Carrier-to-Noise Pattern

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The absolute GNSS antenna calibration with a robot is operationally executed by Geo++ since 2000. In the last years, the conducted antenna calibrations produced an extensive database of individual antennas, different antenna types and setups. The robot calibrations can provide absolute phase center and variations (PCV) of GNSS antennas for the GPS and GLONASS observables L1 and L2 as well as antenna/receiver dependent carrier-to-noise decrease pattern.

Investigations on repeatability of individual GNSS antennas and models are possible using the Geo++ GNPCVDB database. The number of individual calibrations of one antenna type gives insight into the quality of antennas series. Also long-term analysis of individual antennas have been carried out. The analysis will focus on Dorne Margoline type antennas.

The GLONASS constellation was for a long time not sufficient to perform a GLONASS PCV calibration within a reasonable time period. However, with the current constellation several calibrations for different GNSS antenna types have been executed. The GLONASS PCV calibration differs compared to GPS, because of the different frequencies of individual GLONASS satellites. Investigations on a frequency independent modeling of GLONASS PCV are presented.

Operationally, carrier-to-noise (CN0) pattern are estimated simultaneously with the PCV during a robot calibration. The CN0 pattern depend on antenna, wiring and receiver. Comparable antenna/receiver CN0 pattern are obtained using the decrease of CN0 instead of absolute values. CN0 pattern can be effectively used for weighting of GNSS observations. The general aspects of CN0 calibration and some examples are presented.

Investigations on GNSS antenna PCV, GLONASS PCV calibration and CN0 pattern using the absolute GNSS antenna calibration with a robot are discussed.

Introduction

The robot calibration determines GNSS phase center and variations (PCV) on a routinely basis since the beginning of 2000. However, the calibration system is also an excellent tool to determine additional parameters of an antenna, antenna/receiver combination and even site dependent multipath.

Essential part of the GNSS antenna calibration system is a robot, which enables observations in several thousand of different orientations. The average total of different orientations in one calibration is between 6000 and 8000, depending on starting time and satellite constellation. Azimuth-dependent PCV in particular can be reliably and accurately determined. One calibration takes a few hours. In addition the measuring program is automated.

The calibration procedure is a real-time Kalman filter based on undifferenced observable and a feedback process. The currently tracked satellites and their position in the topocentric antenna coordinate system are used to decide on the



Fig. 1: absolute robot calibration of a LEIAT504 LEIS

best suited inclination and rotation of the antenna. The orientation requests are submitted to the robot. The tracking and constellation dependent guidance of the robot ensures independent observation procedures for every calibration. It also optimizes the current observation, antenna coverage, observation time and the PCV accuracy.

A dynamically changing elevations mask uses only satellites above 18 deg or even higher cut-offs for tilted positions. Comprehensive and homogeneous coverage of the antenna hemisphere is finally achieved with observations on the horizon and even 5 deg below (tilted antenna). The observation programs are variable and therefore reduce the possibility of systematic errors. The calibration is complete when complete coverage of the antenna hemisphere is achieved.

The major error source in antenna PCV estimation is multipath, which is accounted for by the observation procedure (elevation marks), high correlation of multipath between two fast executed orientation changes and stochastic modeling. The multipath is generally removed or greatly reduced. Further error components such as ionospheric, tropospheric and orbit biases cancel out using a very close-by reference station.

Spherical harmonics of degree and order (8, 5) are generally used to model the actual PCV.

Recently, GLONASS PCV determination have been analyzed in detail. The robot calibration system is a feedback system using the actual visible satellites to optimize the calibration procedure. The GLONASS constellation was up to now not sufficient to optimize the calibration for GLONASS coverage of the antenna hemisphere, which led to calibration times of more than three days. The current GLONASS constellation allows GLONASS PCV calibration within a reasonable time.

As an additional parameter the carrier-to-noise (CN0) pattern of the antenna/receiver combination is regularly determined during the PCV calibration. Investigations have shown, that the CN0 pattern can be used for the standardization of CN0 values between different receivers and consequently for observation weighting.

In summary, a robot calibration gives absolute 3D offsets, absolute elevation and azimuth dependent PCV in a simultaneous adjustment of L1, L2 as well as S1, S2 pattern for GPS and GLONASS signals. The internal standard deviation estimated is verified by the analysis of repeated calibration of antenna. The standard deviation (1 sigma) is in the order of 0.2 to 0.4 mm (latter for the antenna horizon) for the individual observables L1 and L2.

For completeness, it is referred to the methods using the robot to determine near-field multipath effects of GNSS antenna with the option to separate multipath in a near-field and far-field component (Wübbena et al. 2006) and to estimate absolute multipath within an absolute station calibration (Böder et al. 2001).

Repeatability of Phase Variations

The accuracy of the antenna calibration is an often asked question, especially concerning the azimuthal phase variations. There are two different aspects, which have to be distinguished. There is the accuracy of the robot calibration itself, and also the general repeatability of the type of GNSS antenna. A classification of geodetic antenna with a solid groundplane greater than approximately 25 cm and rover antennas is adequate. The shielding and sensibility of rover antennas against multipath is different compared to geodetic antennas and is considered as the origin of the poorer repeatability.

The accuracy of the robot calibration has been extensively investigated. The complete calibration system has been developed by Geo++ together with the Institut für Erdmessung, Universität Hannover, with special emphasis on the empirical validation of all parameters and the performance (Menge 2004).

Currently, there are three different robots in use, which are operated by Geo++, the Institut für Erdmessung and since May 2006 by the state survey authorities of Berlin (Senatverwaltung für Stadtentwicklung Berlin). The three robots have been used to investigate the absolute PCV repeatability of a geodetic antenna with different robots at different locations.

robot	operated	antenna	date of PCV calibration
		ASH700936D_M NONE	
Geo++	in Garbsen	CR14348	2005-08-08
ife	in Hannover	CR14348	2006-02-15
Berlin	tested in Garbsen	CR14348	2006-01-14

Tab. 1: calibration information for three different robots

The mean offsets are included in the comparison, while the PCV were converted to the antenna reference point beforehand. The condition PCV equals zero for the zenith is maintained and no adjustment (shift) of the individual PCV performed. The repeatability of the PCV for an individual ASH700936D_M NONE antenna between the three robots has a magnitude of L1 PCV differences smaller than 0.5 mm and smaller than 1 mm for L2 PCV differences (Fig. 2 and Fig. 3). Even for the ionospheric free L0 signal, which corresponds in the worst case to an amplification of the differences by a factor of about three, the values are smaller than 1 mm above 10 deg.

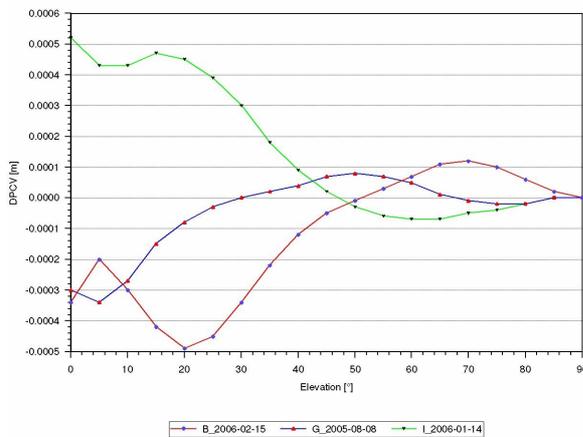


Fig. 2: L1 dPCV of individual antenna from calibrations with different robots

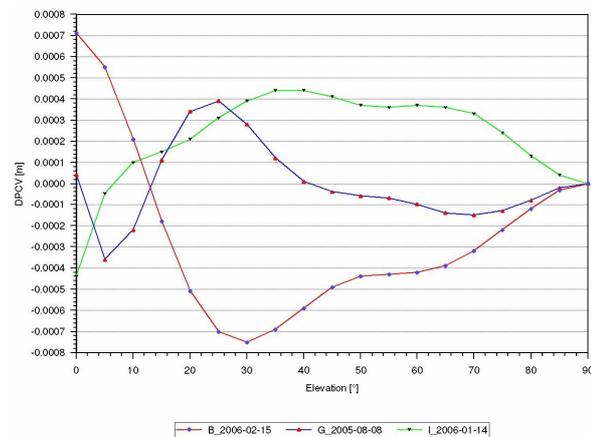


Fig. 3: L2 dPCV of individual antenna from calibrations with different robots

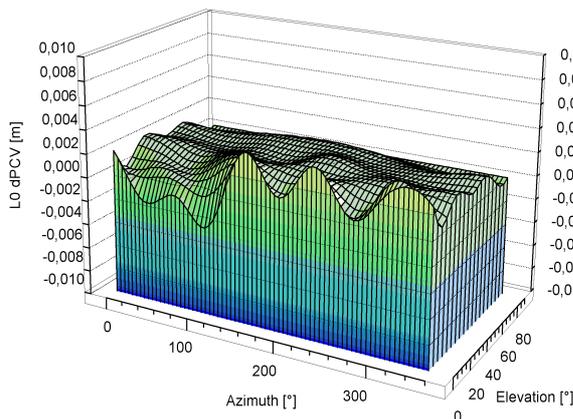


Fig. 4: repeatability of L0 PCV after two months, ASH700936D_M SNOW

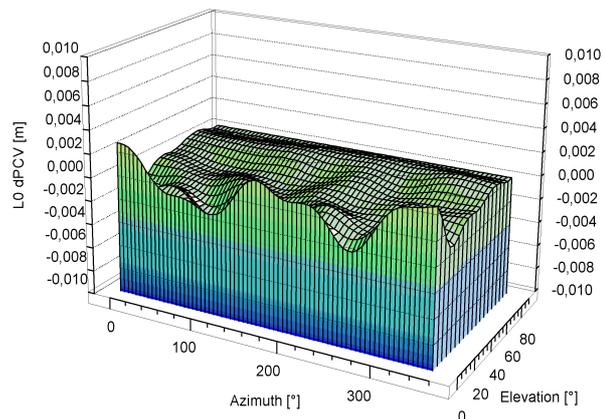


Fig. 5: repeatability of L0 after 26 months, ASH700936D_M SNOW

In a long term analysis, an individual geodetic antenna ASH700936D_M SNOW has been calibrated several times. One calibration was two months apart (Fig. 4) and a second one was conducted after more than two years (Fig. 6). The repeatability considering the PCV differences for L0 PCV are in average in the order of 1-2 mm. The maximum difference value at the horizon is about 4 mm. Different long term investigations showed up to now no significant time dependency or aging of antenna or PCV, respectively (Wübbena et al. 2003).

The repeatability corresponds to the standard deviation (1 sigma, not shown here) and documents the stability in the determination of azimuthal PCV. Nevertheless, an additional example for the significance of azimuthal PCV will be given using the geodetic antenna TPSCR3_GGD CONE.

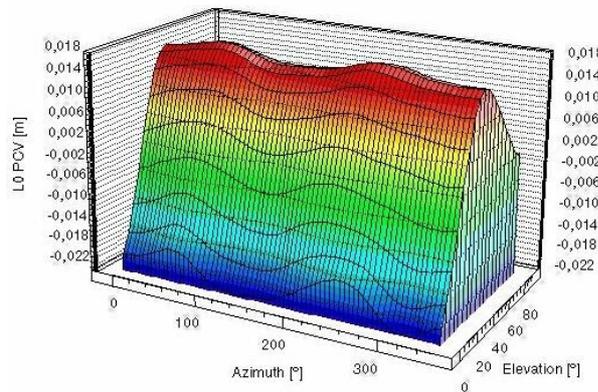


Fig. 6: antenna type mean PCV L0: 132 Ants, 318 Cals, TPSCR3_GGD CONE

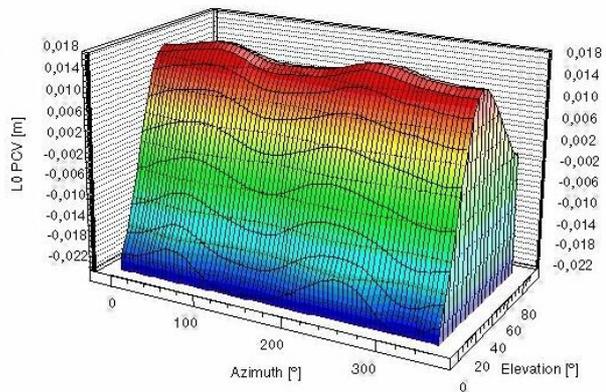


Fig. 7: individual PCV L0: 1 Ant, 2 Cals, TPSCR3_GGD CONE

The Topcon CR3 antenna is a choke ring antenna, but not with a Dorne Margoline reception element. The general PCV pattern is similar to the DM-type choke ring antennas. In the Geo++ GNPCVDB database, the type mean for this antenna is based on 132 individual antennas and 318 antenna calibrations. The absolute PCV pattern of the ionospheric free L0 signal is depicted in Fig. 6. A randomly selected individual antenna (Fig. 7) shows high correlation even for the small azimuthal variation of 2 mm when compared to the type mean. This high correlation again verifies the significance of the azimuthal PCV, because otherwise the large sample of the type mean would have averaged uncertainties of one individual antenna.

However, it is important to remark, that also individual PCV differences of the selected antenna might be present. A perfect agreement of the individual and the type mean PCV pattern cannot be expected.

The accuracy of the robot calibration has also been verified by several chamber calibrations of different individual antennas and antenna types (the latest ones are e.g. Becker et al. 2006, Görres et al. 2006).

Geo++ GNPCVDB Database

The GNPCVDB database contains absolute PCV type means, which are computed from the antenna calibrations performed with the robot. A rigorous adjustment of the spherical harmonics is executed using the complete variance-covariance matrix of the individual calibrations. It is therefore the best estimate for the type means.

In April 2006, the number of different antenna types is about 125 based on 957 individual calibrated antennas and 3748 individual calibrations. The actual number of antenna calibration is much larger, but a comparable weight of individual antennas is attempted. In addition, very special antennas or setup are not incorporated into the database. The database provides public information on the PCV calibrations (PCV graphics, antenna pictures, antenna reference point (ARP), north definition, etc.). A license is required for actual use of the numeric absolute PCV numbers.

For scientific benefit PCV type means of selected geodetic GNSS antennas are provided to IGS.

The numerous antenna calibrations of the database allow investigations, which could not be performed with a small sample size. There have been analysis concerning model series, stability of antenna types, modifications of antenna types, time dependence, aging, classification of PCV characteristics and more (Wübbena et al. 2003).

Choke ring antennas with a Dorne Margoline (DM) element for the actual reception of the GNSS signals are considered as the most precise and stable geodetic antennas. Therefore DM-type antennas are often used on IGS sites. All major manufacturer provide DM-type antennas, which basically have comparable dimensions and differ only in electronic parts (e.g. antenna low-noise amplifier (LNA)).

The comparison of a large number of individual antennas makes it necessary to use one representative number. Mean offsets derived from absolute antenna calibrations are not suited to describe an antenna's PCV completely. In addition, horizontal offsets are representing azimuthal PCV, which therefore are affected by the individual characteristic of the antenna. Despite these facts, offsets are used in the following for the convenience to provide some analysis of a large sample of antennas within one graph.

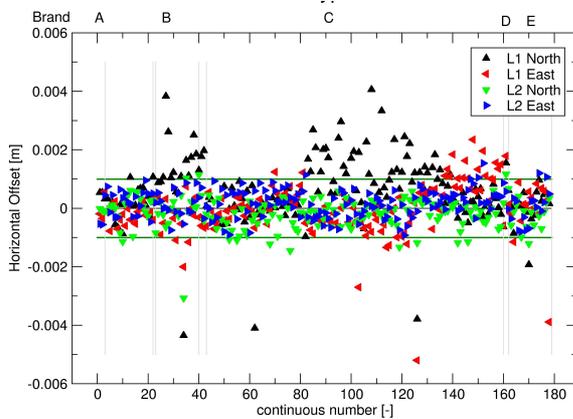


Fig. 8: horizontal offset DM-type choke ring antennas

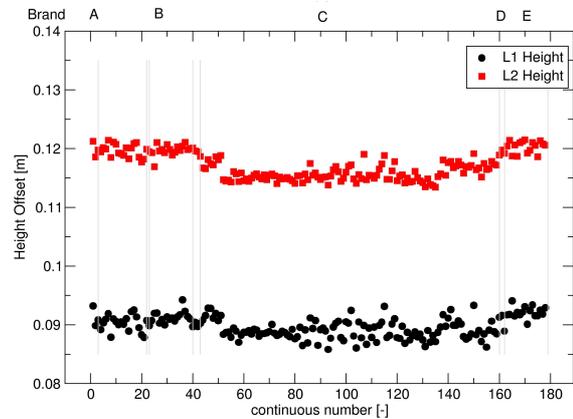


Fig. 9: height offset DM-type choke ring antennas

The horizontal offsets determined in a robot calibration are very stable and are in general repeatable at the sub-millimeter level. The height offset is different and can only be reproduced at the one millimeter level. An offset analysis of eight different DM-type choke ring antennas from five different manufacturers has been repeated (first analysis see Wübbena et al. 2003). As long as the radome has only known minor impact on the PCV, the comparison did not distinguish between radome and without (NONE).

Fig. 8 shows the horizontal offsets, while Fig. 9 height offsets. Some outliers and some significant changes in model series are obvious for the horizontal offsets. The individual antennas are sorted for each brand by increasing antenna serial numbers. There is a single sided increase in the band width of L1 North offsets, which switches to notable L1 East offsets. The height offset does not reveal such detailed information due to its weaker properties compared to the horizontal offsets. However, the standard deviation over all antennas is still about 2 mm. There are different height offset levels for different model types, which must be attributed to slightly different values of the height dimension or to the LNA.

There is always the potential of individual PCV differences, which may show up e.g. in the mean PCV offsets. An individual calibration of the antenna only reveals such problems, which causes RTK network providers to conduct individual antenna calibration.

Calibration of GLONASS PCV

It is common to use GPS PCV for the correction of GLO(NASS) PCV in lack of better information. The current status of GLO PCV calibrations is due to some major differences to GPS.

Individual GLONASS satellites do have different frequencies. Hence, a GNSS antenna calibration will determine GLO PCV from a mixture of frequencies observed during the field calibration. For a long time the satellite constellation was not sufficient to perform calibrations for the GLONASS signals with adequate accuracy and within a reasonable time frame. In the beginning of the absolute field calibration, the robot optimized for GLONASS was stopped after three complete days without sufficient coverage of the antenna hemisphere.

Chamber calibration were conducted by Schupler, Clark (2001) analyzing besides GPS and the civil GPS frequency L5 also the GLONASS frequencies. The tests, however, focused on influences of radomes, amplifiers and materials in the vicinity of the antenna (near-field effects). The antenna calibration were not applied to field-collected data or used for direct comparison of GPS and GLO PCV.

Several issues related to GLONASS are therefore still pressing and important to investigate. First the assumption of identity between GPS and GLO PCV is of concern. In case that the GPS PCV are not representative for GLONASS, the magnitude of the differences must be determined. Ideally, the GLONASS calibration should consider the different carrier frequencies, which requires to investigate the feasibility of a frequency dependent calibration. The significance and the need for separate GLONASS calibration must finally be discussed.

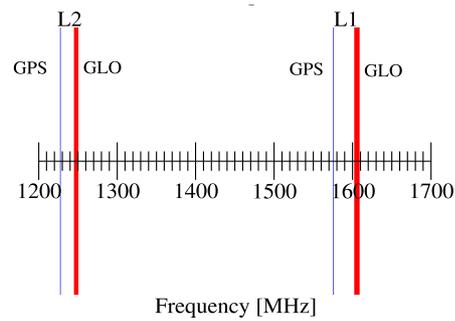


Fig. 10: GNSS frequencies

The robot calibration supports GLONASS, but estimated up to now only absolute PCV for L1 and L2 from the mixture of observed GLONASS frequencies. Therefore the calibration are satellite constellation dependent and are expected to be not as accurate as for GPS.

An alternate PCV modeling has been developed, which allows frequency dependent GLONASS PCV in terms of the individual frequency of the satellites. Fundamental assumption of the model is linearity of PCV changes for GPS/GLO, GLO/GLO frequencies (see Fig. 10). This assumption is justified from the frequency ranges and is compliant with results from chamber calibrations (Schupler, Clark 2001).

Based on the reference signal L1 and L2 from GPS, a so-called Delta PCV with the unit meter per 25.0 MHz is estimated for the GLONASS signals. The scaling has been chosen, because it is an easy to handle scaling based on the approximate mean difference between GPS and GLONASS frequencies. The mean for both frequencies L1 and L2 is ~ 24 MHz for the frequency number range $k = (-7 \dots +12)$ and ~ 22 MHz for the range $k = (-7 \dots +6)$.

Up to 2005 GLONASS satellites used frequency channels $k = (0 \dots +12)$ without any restrictions. The channel numbers $k = 0$ and $k = 13$ are used for technical purposes. After 2005 launched GLONASS satellites will use frequency channels $k = (-7 \dots +6)$.

The robot calibration simultaneously estimates PCV for GPS and GLO. The robot guidance can be optional optimized either for GPS or GLONASS observations. The modular concept of the real-time GNSMART software allows also simultaneous adjustments with different models using the same data. For the analysis of the GLONASS PCV calibration a conventional model with mixed frequencies and the new model estimating Delta PCV was set up optimized for GLONASS L2 observations.

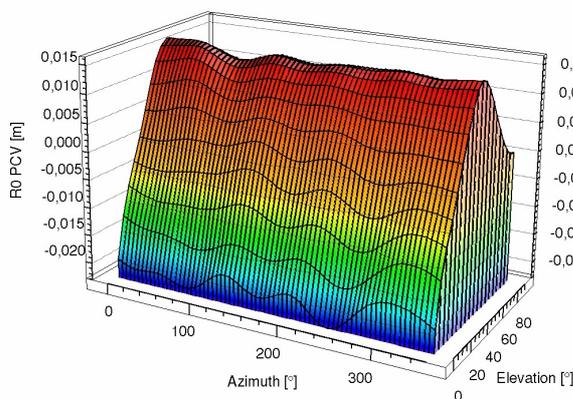


Fig. 11: GLO L0 PCV: Mixed GLO Calibration, ASH700936D_M SNOW

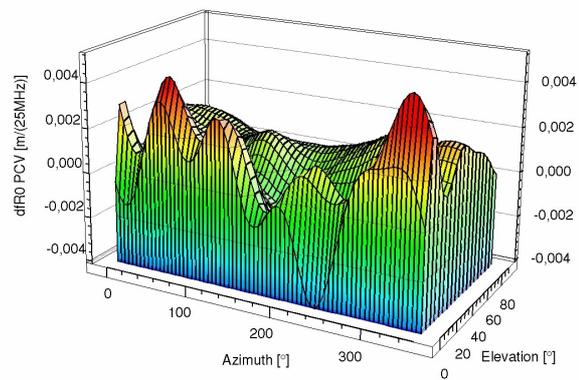


Fig. 12: GLO L0 Delta PCV in [m/25 MHz], ASH700936D_M SNOW

The absolute GLO PCV pattern of a DM-type choke ring ASH700936D_M NONE antenna with elevation and azimuthal variations is depicted in Fig. 11 and the GLO Delta PCV in Fig. 12. This demonstrated the general characteristics of the absolute PCV and the relative PCV information. In

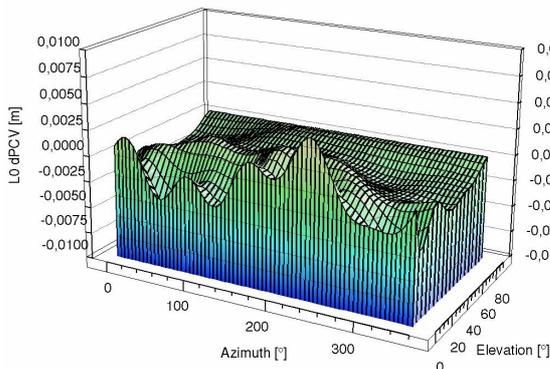


Fig. 13: L0 difference GPS vs. GLO ($k = +4$),
ASH700936D_M NONE

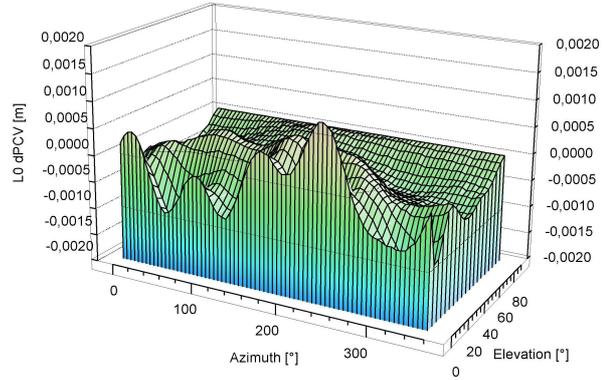


Fig. 14: L0 difference GLO ($k = -7$) vs. GLO ($k = +6$),
ASH700936D_M NONE

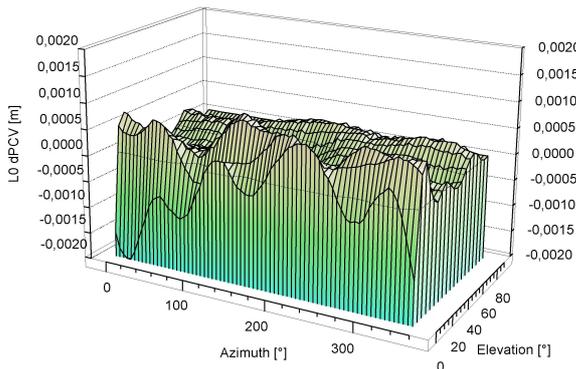


Fig. 16: L0 difference GLO mix vs. GLO ($k = +4$),
ASH700936D_M NONE

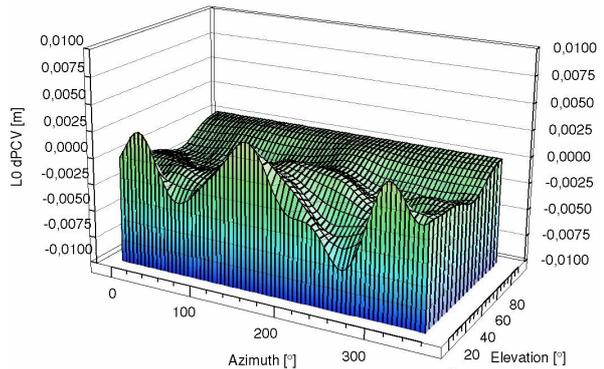


Fig. 15: L0 difference GPS vs. GLO ($k = +4$),
TPSCR3_GGD CONE

Fig. 13 the PCV difference between GPS and GLO is given. The GLO PCV are computed from the Delta PCV model using $k = +4$, which is the mean frequency channel for the current GLONASS constellation. The mean L0 PCV difference between GPS and GLO is 2 mm with a maximum of over 5 mm at low elevations.

The GLONASS frequencies beyond 2005 have the largest frequency difference for the frequency channels $k = -7$ and $k = +6$. Fig. 14 shows the difference between these two individual GLONASS frequencies for the L0 signal. The mean L0 GLO PCV differences are slightly larger than 1 mm with a maximum value of about 1.5 mm.

The difference between a mixed frequencies and a frequency dependent GLONASS calibration is computed for frequency channel $k = +4$ and has a magnitude of L0 PCV differences smaller than 1 mm and a maximum of 2 mm (Fig. 16).

To verify the presented result a different antenna type TPSCR3_GGD CONE was also calibrated. The Topcon CR3 antenna has a similar absolute PCV pattern as the ASH700936D_M NONE choke ring antenna. The dimensions, electronic parts and the actual receiving element are completely different. In addition, different satellite constellations have been used during the calibrations due to the feedback mechanism of the robot calibration system. In Fig. 15 a high correlation in the L0 PCV difference GPS/GLO ($k = +4$) of Fig. 13 is present, which supports independently the significance and magnitude of the estimated PCV differences between GPS and GLO using the proposed Delta PCV model.

At a first glance, the differences from the direct comparison of the GPS/GLO and GLO/GLO PCV are numerically small. But from investigations on the accuracy requirements of PCV determinations and analysis of near-field multipath effects it is known, that the impact on the position domain is much larger. Especially an amplification while estimating tropospheric scaling factors will increase the effects significantly.

The estimation of GPS PCV and Delta PCV for GLO is an useful approach to determine for every

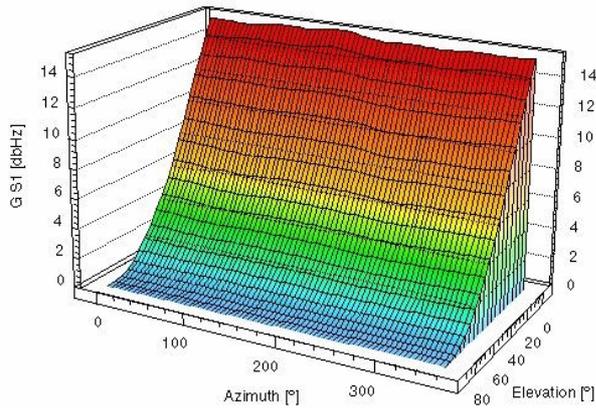


Fig. 17: GPS C/N0 decrease with JPS LEGACY receiver and ASH700936D_M SNOW antenna

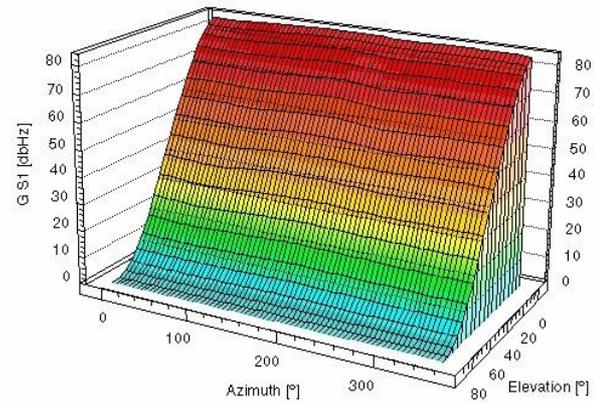


Fig. 18: GPS C/N0 decrease with ASHTECH Z-XII3 receiver and ASH700936D_M SNOW antenna

GLONASS frequency a phase variation pattern. For the future Delta PCV might also be an option to determine Galileo PCV with hybrid GNSS receivers until a sufficient constellation allows the absolute estimation of Galileo PCV.

Determination of Carrier-to-Noise Pattern

There exists several differing definitions on signal-to-noise and carrier-to-noise numbers, which are considered of minor importance in the following. Therefore, the term C/N0 is preferable used.

The carrier-to-noise (C/N0) information obtained from GNSS receivers are entire observables, which reflect especially multipath acting on the measurements. There are several investigations on this topic with focus on different aspects (see for instance Comp, Axelrad 1996, Ray et al. 1999, Schumann 2004, Bilich et al. 2004). One major problem for C/N0 observables is that they depend on the antenna and receiver combinations, which complicate the operational use in GNSS applications especially with mixed equipments.

Within the robot calibration routinely C/N0 pattern are determined, which are modeled with spherical harmonics (currently set to degree and order as used for PCV). The pattern mainly describes the influence of the antenna on the signal strength, hence, the antenna's reception characteristic (gain). The C/N0 for the zenith is set to zero, which therefore gives a C/N0 decrease function. The absolute information is also stored and accessible, but the absolute values depend on several external factors, which generally destroy their usefulness.

An identical antenna operated with two different receiver types may see different signal-to-noise S1 and S2 figures and consequently different decrease functions. In Fig. 17 and Fig. 18 examples of the L1 C/N0 decrease functions are given for an individual antenna obtained with a JPS LEGACY receiver and a ASHTECH Z-XII3 receiver. The range of the first one is up to 14 dBHz, while it is 80 units for the second one. The 14 dBHz range is a typical L1 C/N0 value for the latest receiver technology, which tends to adjust the signal-to-noise numbers among different models. Older models significantly differ, which is obvious from the figures.

An effective use of C/N0 observable requires its standardization, which must account for the different constituents influencing the C/N0 readings. The satellite uses different nadir dependent signal strengths to guarantee comparable signal levels everywhere on earth. The signal is furthermore attenuated due to the distance between satellite and receiver (space loss) and affected by the atmosphere. The antenna effects on C/N0 are dominated by the antenna gain pattern and the LNA. Additional attenuation can be contributed to the cable and wiring between antenna and receiver. The receiver technology and firmware version (parameter settings) will finally define the actual C/N0 readings.

Summarizing, these effects are

- satellites dependent

- signal strength
- radiation pattern
- atmospheric dependent
 - space loss
 - attenuation (troposphere, ionosphere)
- equipment dependent
 - antenna „gain pattern“
 - cable and wiring attenuation
 - receiver hardware and firmware

A CN0 standardization procedure has been developed, which requires several conversions and corrections to be applied to the initial CN0 observable. The standardization can be written in a simplified equation (see also Tab. 2):

$$CN0_{\text{standardized}} = CN0 - ((\text{Sat} + \text{Atm}) + \text{Cab} + \text{Ant} + \text{Rec}) = \text{MP} + \text{Diff} + \epsilon$$

The satellite contribution can be corrected using the ICD GPS “received power function”, which also considers the space loss differences and atmospheric effects. Additional calibrations using global observations are feasible, but not yet investigated in detail. The robot calibration provides the antenna and LNA characteristics with the CN0 pattern, while the cable/wiring effects are eliminated sufficiently using a decrease function. The relative CN0 values are not affected by the influence of e.g. the cable length. A mapping function is required to convert CN0 observables to dBHz and to get comparable CN0 observables between receivers. Multipath and diffraction are maintained in this procedure. Therefore it is applicable for e.g. CN0 based observation weighting.

<i>Affecting CN0</i>	<i>Abbr.</i>	<i>Correction</i>
satellite	Sat	ICD GPS “received power function”
atmosphere	Atm	ICD GPS “received power function”
antenna	Ant	robot calibration
cable/wiring	Cab	relative CN0 (CN0 decrease function)
receiver	Rec	standardization (mapping function related to ASHTECH Z-X)

Tab. 2: standardization of CN0: affecting components and corrections

A remaining step is to provide a mapping function for the receiver/antenna combinations. Several selected receivers are depicted in Fig. 19 and Fig. 20 showing elevation dependent CN0 L1 and L2. The CN0 differences between receivers require at first the conversion of signal-to-noise units to dBHz, which is sometimes provided by the receiver manufacturers or has to be determined empirically. There are significant differences in the shape of the functions. Cable and receiver setups allow parallel shifts of the function, which, however, are not sufficient to coincide all functions.

For the remaining differences an additional mapping function is required. The proposed standardization is using the Ashtech Z-Xtreme as a reference. It represents the latest receiver technology during the analysis (in 2004) and uses the Z-tracking technology for L2. From 24 h data sets observed with different antennas and receivers in all combinations the mapping function is determined. An example is given for a JPS LEGACY with four different antennas (refer to Fig. 21 and Fig. 22). The graphs show the starting points for the determination of the mapping functions. A polynomial of 3rd degree is used as the mathematical model. The dotted line in the graphs represents the line with a gradient of one starting at the origin. The goal is to convert the CN0 values to this line, which then gives the standardized CN0 values relative to the ASHTECH Z-X receiver.

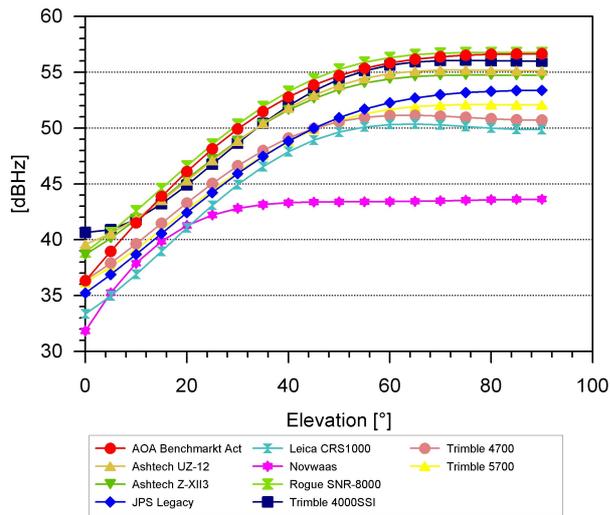


Fig. 19: L1 CN0 mean elevation dependent values of selected receivers

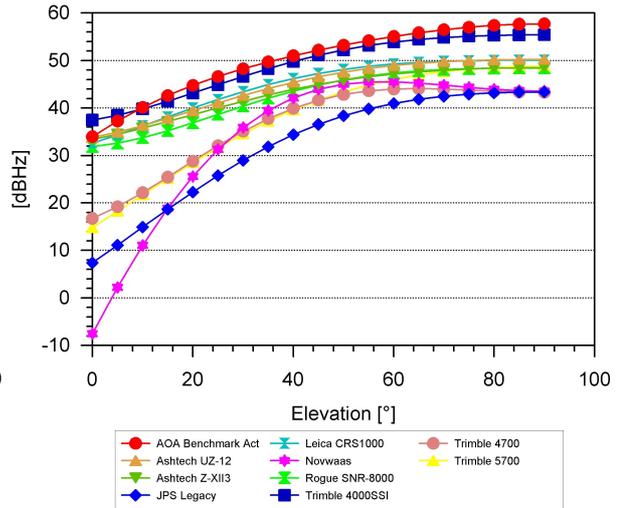


Fig. 20: L2 CN0 mean elevation dependent values of selected receivers

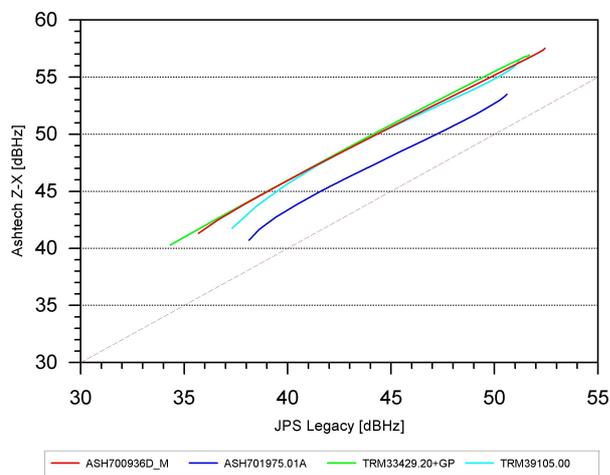


Fig. 21: L1 mapping function JPS LEGACY vs ASHTECH Z-X

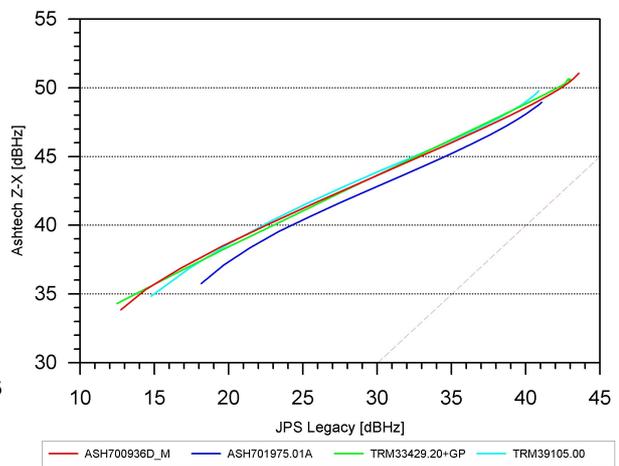


Fig. 22: L2 mapping function JPS LEGACY vs ASHTECH Z-X

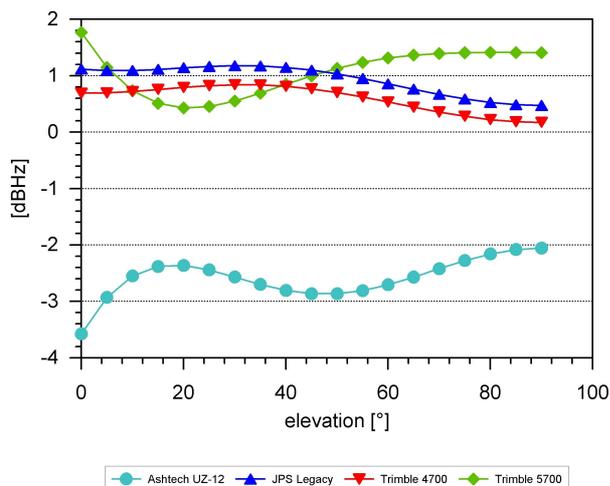


Fig. 23: L1 CN0 deviation from mean before standardization

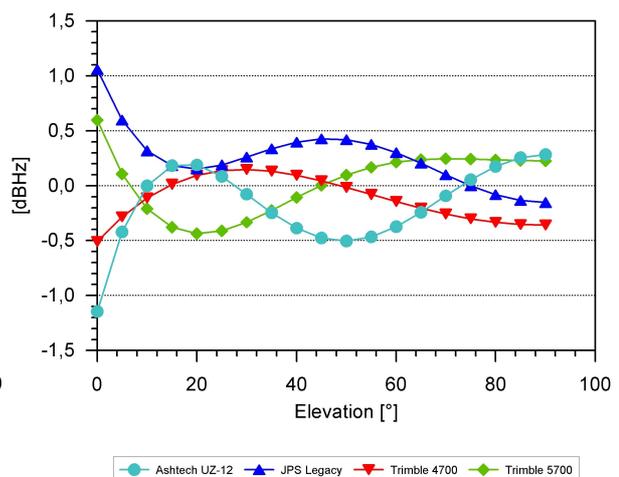


Fig. 24: L1 CN0 deviation from mean after standardization

The benefit of the CN0 standardization is demonstrated using some IGS stations equipped with the same receiver types for which mapping functions were derived. The antenna type was not specially selected, because the standardization procedure should be independent from it. The influence of

antenna, satellite and atmosphere is corrected according to the simplified formula given. The deviation from a mean value for the receivers is shown before and after the standardization in Fig. 23 and Fig. 24. The magnitude of CN0 differences between the receiver's L1 CN0 is about +/- 0.5 dbHz (above 5 deg elevation). This is below the resolution of most signal-to-noise observables. Individual multipath effects and diffraction are maintained.

The proposed standardization procedure demonstrated that comparable CN0 values can be obtained for different receiver/antenna combinations. This is an important step to use CN0 numbers in a mixed receiver/antenna GNSS application. Applying the standardization will finally give improvement at the absolute accuracy level.

Summary and Conclusion

The absolute field calibration with a robot is an operational procedure providing GPS and GLO L1 and L2 PCV as well as the proposed new model called Delta PCV. In addition CN0 pattern are regularly determined.

Since 2000 numerous antenna calibrations have been conducted, which are incorporated in the GNPCVDB database. Some analysis of a large sample of geodetic antennas has been presented. It reveals outliers and individual changes in antenna type series. Only a calibration can finally proof an individual antenna and only a large sample allows detailed investigations on a model type. In the future GNPCVDB will also incorporate GNSS PCV.

Delta PCV can be used to determine frequency dependent GLO PCV. Based on a reference PCV pattern (i.e. GPS), the frequency dependent PCV differences are estimated. Hence, for all GLONASS frequencies an individual correction of the PCV is possible. For the future, Delta PCV may also be used for Galileo until a sufficient constellation for absolute field calibration is achieved.

The field calibration of GLONASS PCV is now possible and reveals some difference to GPS PCV and even differences between the individual GLONASS frequencies. Experiences of the interaction of small PCV differences with tropospheric modeling and the amplification using the ionospheric linear combination suggest to consider the differences in the GLONASS PCV. They represent an improvement of the model, which should not be neglected in the attempt to improve the precision of GNSS applications. Therefore, the GLO PCV should be frequency dependent estimated and applied.

The GPS and GLO S1, S2 observable are used to provide CN0 decrease functions, which mainly contain the antenna characteristics, but also some receiver dependencies. A procedure has been discussed to standardize CN0 decrease functions. It is possible to account for the major influences affecting the CN0 readings of an antenna/receiver system. The standardization allows for the simultaneous use of CN0 observables from different antenna/receiver combination in GNSS applications. A weighting of observations based on standardized CN0 is feasible.

For the use of CN0 decrease functions and Delta PCV an extension of the current IGS ANTEX (Antenna Exchange format) is suggested.

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