New anechoic chamber results and comparison with field and robot techniques

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Abstract
A critical assessment of the accuracy of antenna calibration is most effectively made by comparison between different calibration methods. We present new chamber calibrations of five different GPS receiver antenna types in an anechoic chamber and a comparison with measurements using the absolute field calibration technique with robot mount of IfE/GEO++. The accuracy is described using standard error parameters which allow the characterization of the quality of different antennas. The results validate the absolute calibration methods at the 1 mm level and confirm the presence of significant variations in quality between antennas of different design.

In the presentation we include the results of an earlier test made with a set of antennas calibrated successively at five different institutions, two using the absolute field technique with robot mount and three others applying the standard field calibration with reference antenna. Here, the comparisons show good agreement between two different calibrations with robot at the 1 mm level whereas the standard field calibrations display larger variations of 2 mm at L1 and 4mm at L2 against a mean, probably mostly due to multipath.

1 Introduction

In August 2002 several GPS receiver antenna were calibrated in the in the large anechoic chamber of the Bundeswehr in Greding/Germany. The motivation for the new set of chamber measurements and the new comparisons lies in the context of getting a better insight into the performance of the different calibration methods. On the one hand one of the problems with earlier comparisons should be left behind: that was the fact that the comparisons referred to antenna types but not to identical antennas. Therefore the reason for discrepancies between results could not be correctly interpreted, e.g. there always remains a difference between antennas of the same type in addition to the difference caused by the calibration procedures. Today the absolute results of one and the same antenna can be validated by the independent technique of the robot.

2 The German bench mark test 2002

In early 2002 several institutions in Germany carried out the so-called "German bench-mark test" (Fig.1) initiated by the LGN Niedersachsen (State Survey and Geospatial Basic Information Lower Saxony) in order to study the performance of the different calibration methods. A selected set of five antennas (five different antenna types by three different companies, among them 3 reference station antennas and two rover antennas) was calibrated successively at five different institutions (see Fig. 1).

Institution	Calibration Method	used Software
University of Hannover	robot – absolute	GNPCV
Geo++ Garbsen	robot – absolute	GNPCV
State Survey... Lower Saxony	relative field calibration	WaSoft/Kalib
University of Dresden	relative field calibration	WaSoft/Kalib
University of Bonn	relative field calibration	Bernese GPS Software
University of Bonn	chamber test	not available in spring ´02

Fig. 1: Calibrations done in the first German bench-mark test 2002

Two institutions used the absolute field technique with a robot mount (Fig. 2). They carry out field measurements on a short baseline using a robot capable of tilting and rotating one of the antennas (Wübbena et al. 1997). Three other institutions employ standard field calibration in relative mode with reference antenna. (LGN Hannover, TU Dresden, and our group University of Bonn). Unfortunately at that time it was not possible to have chamber calibrations involved in the test, the only alternative method to obtain absolute results.

Fig. 2: Robot

The official comparisons of the bench-mark-test were done by Ralf Schmid (TU München) and were presented at the 4th GPS Antenna Workshop in Hannover in May 2002. (Schmid et al. 2002). As an example we show the five individual calibration results for the elevation-dependent PCVs for one and the same Leica AT303 (Fig. 3), for the L1 and the L2 carrier in the upper plots of Fig. 4. All results have been converted to the absolute level. The plots below show the variations against the mean.

Fig. 3: LEIAT303 LEIC

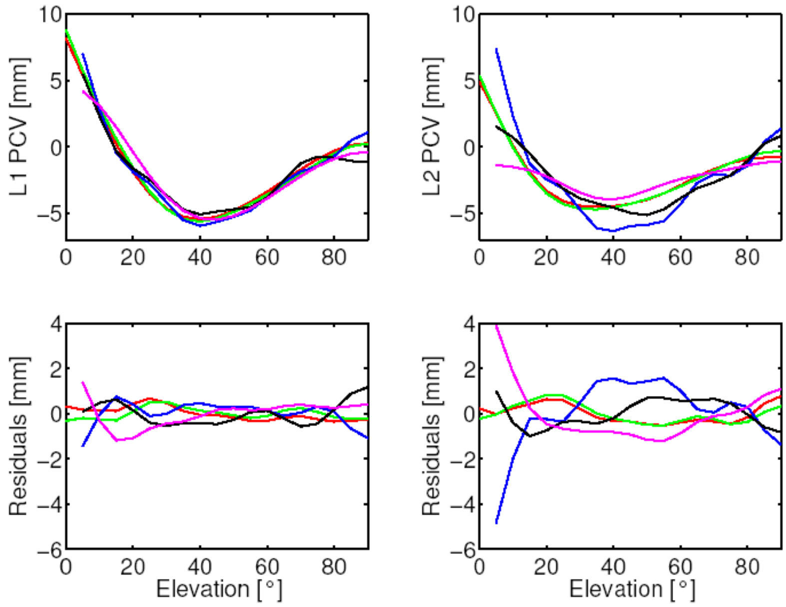

Fig. 4: Results of the German bench-mark test for the Leica AT303 with radom.

Here, the comparisons of the different calibration methods for one and the same antenna show an excellent good agreement between the two different calibrations with robot at the 1 mm level for all elevations with a quite smooth course, whereas the standard field calibrations display larger variations of 2 mm at L1 resp. 4mm at L2 to the mean at most. The well known problems for low elevations appear, which are few observations near the zenith as well as systematic effects near the horizon (multipath, troposphere etc.), and of course the effect of the reference antenna. If we express the results in RMS differences over all elevations (Fig. 5), it can clearly be seen that absolute PCVs derived from relative field calibrations are a factor of two worse than those from robot calibrations.

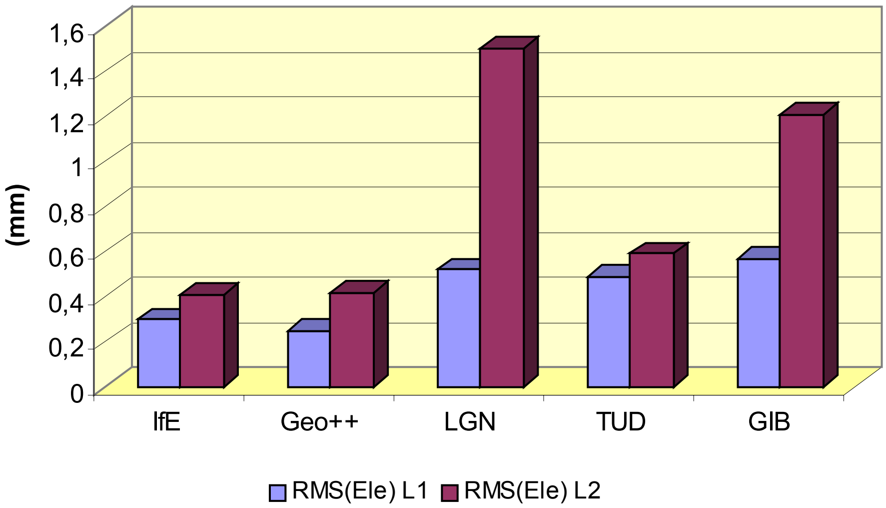

Fig. 5: RMS differences over all elevations of the German bench-mark test for the Leica AT303 with radom.

The most important question still remaining was the confirmation of the absolute results by an independent technique using the same antenna.

3 Antenna Calibration in the anechoic chamber in Greding

The anechoic test chamber of the "Technical Center for Information Technology and Electronics" in Greding/Germany the largest anechoic chambers in Europe with a size of 41m in length and 16m in width and 14m height (Fig. 6). The absorbing material is designed for frequencies from 0.5 GHz upwards. So it is well suited for the GPS frequencies L1 and L2. We used a transmitting antenna from the Max-Planck-Institute for Radioastronomie in Bonn which is able to produce the proper right hand circular polarized radiation.

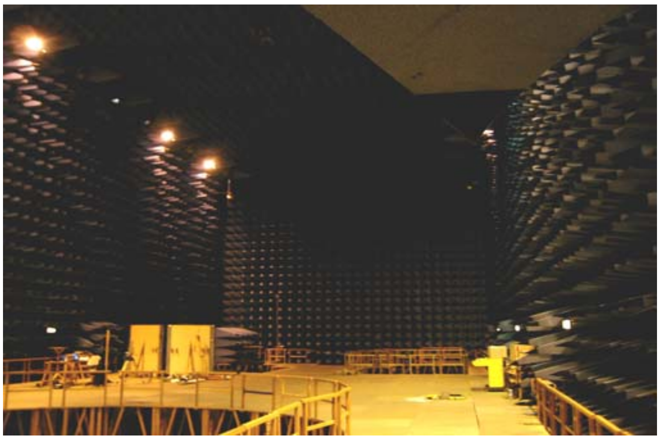

Fig. 6: Anechoic test chamber in Greding/Germany

In the measurement setup during the test run (see Fig. 7) the transmitting antenna is kept fixed and the receiving antenna, which is to be tested, is mounted on a positioner that rotates the antenna around two independent axes and can be shifted in three directions. The distance between both antennas was about 18m. The transmitted and received GPS signal are compared in the network analyser. Recordings are performed for both carriers. In addition to the phase recordings the location of the center of rotation of the test antenna has to be determined with high accuracy with respect to a physical point on the test antenna, e.g. the antenna reference point.

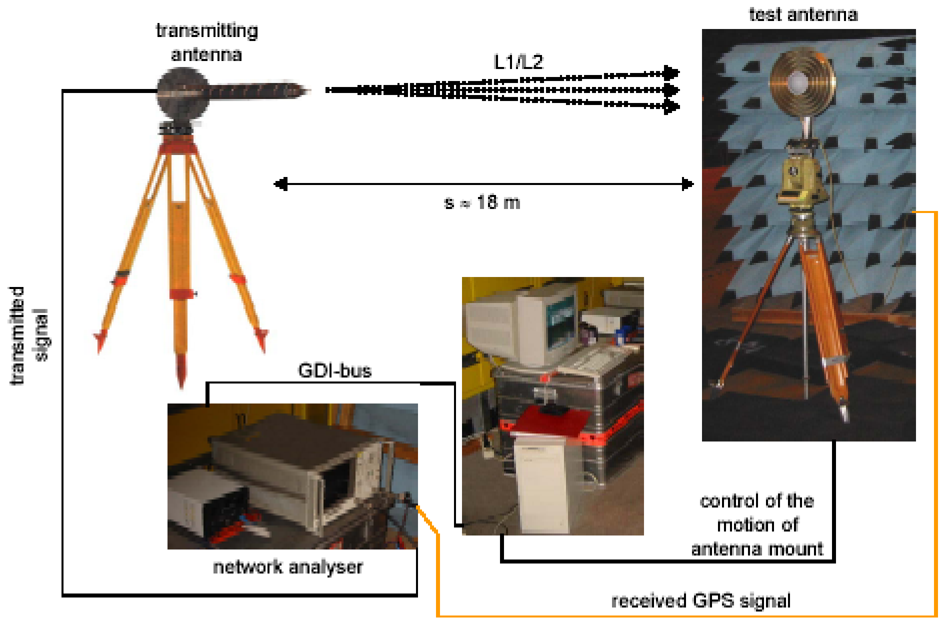

Fig. 7: Measurement setup in the anechoic test chamber

In August 2002 we tested five different antennas from two manufacturers (see Fig. 8). Three antennas are made by Trimble, two 10years old (geodetic and compact) and one new Zephyr geodetic antenna with ground plane, as well as two antennas with choke ring manufactored by Leica. We calibrated the Leica AT 504 which is designed after the Dorne Margolin T and the Leica AT 303 also with choke rings and a radome.

Antenna Type	IGS-Code	
Trimble compact	TRM22020.00+GP	with groundplane
Trimble Zephyr geodetic	TRM41249.00	stealth groundplane (anti-reflex)
Trimble geodetic	TRM14532.00	
Leica AT 504	LEIAT504	Dorne Margolin Antenna with chokerings (designed after D/M T)
Leica AT303	LEIAT303_LEIC	micropuls antenna with chokerings (identical to AT503)

Fig. 8: Antennas tested in the anechoic chamber in 2002

4 Antenna Calibration Model

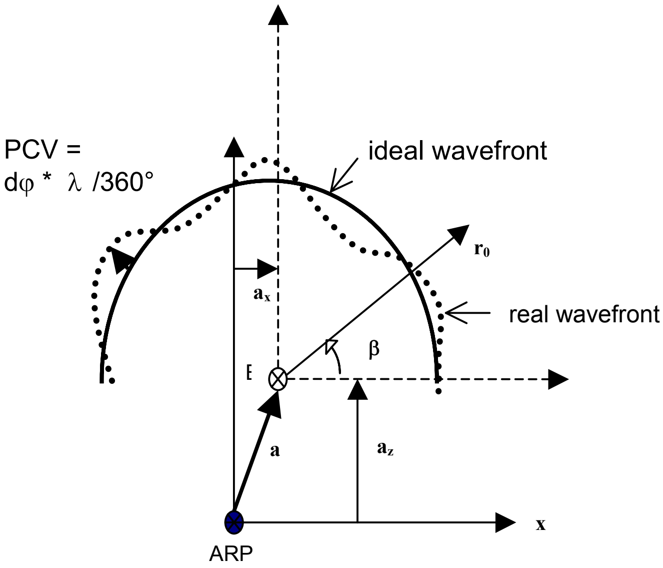

Fig. 9: Antenna Calibration Model

The adopted antenna calibration model is the well-known antenna phase center variation correction scheme, where the total phase center correction in the direction of the satellite consists of the absolute mean antenna phase center offset with respect to the antenna reference point plus the elevation and azimuth dependent phase center variations (Fig. 9).

$$dr(\alpha,\beta) = \mathbf{a} \cdot \mathbf{r_o} + \lambda \cdot d\varphi(\alpha,\beta)$$
$$\text{with PCO: } \mathbf{a}(\varphi) = (a_x, a_y, a_z)$$

The estimation procedure according to this model is done in two steps due to practical aspects. The first step contains the estimation of the mean phase center offset with respect to the ARP:

$$\Sigma\, d\varphi(\alpha,\beta)^2 = \text{Min!}$$

In the second step we record the PCVs directly without fitting a function.

In the chamber setup during the test runs the receiving antenna is rotated through zenith angles from -90 to +90 degrees for various azimuth values as well as being rotated round the vertical axis through all azimuth angles. It has to be noted that during these tests which were limited to three days we could not achieve a complete coverage of the hemisphere of the antenna, but only measured one selected meridian and one parallel circle through all azimuths at at fixed elevation.

To be able to determine the accuracy of the results we estimated a model function (e.g. harmonic function) for the phase center variations:

$$dr(\beta) = \Sigma\, (a_k \cos\beta + b_k \sin\beta)\ ,\ k = 0,\ldots 3, \text{ or } 5$$

The time we will come up to a routine equipment we will of course use spheric harmonic functions in a full three-dimensional performance. From the differences between modelled and measured data the normalized RMS is obtained to give a measure of the scatter of the phase pattern.

5 Results of the chamber measurements

The measurements of the elevation-dependent PCVs results in very smooth patterns for all five tested antenna (Fig. 10). The measured values were directly. The resolution of the device was about 0.1 mm.

Two types of typical patterns may be distinguished: the patterns of the group with two or three maximas for the old Trimble antennas. For the L2 plot all antennas behave in a similar mode. Conspicuous are non-symmetric patterns for the older Trimbles, which we have already noticed in our earlier chamber tests in the small chamber in Bonn (Max-Planck-Institute for Radioastronomie). It is

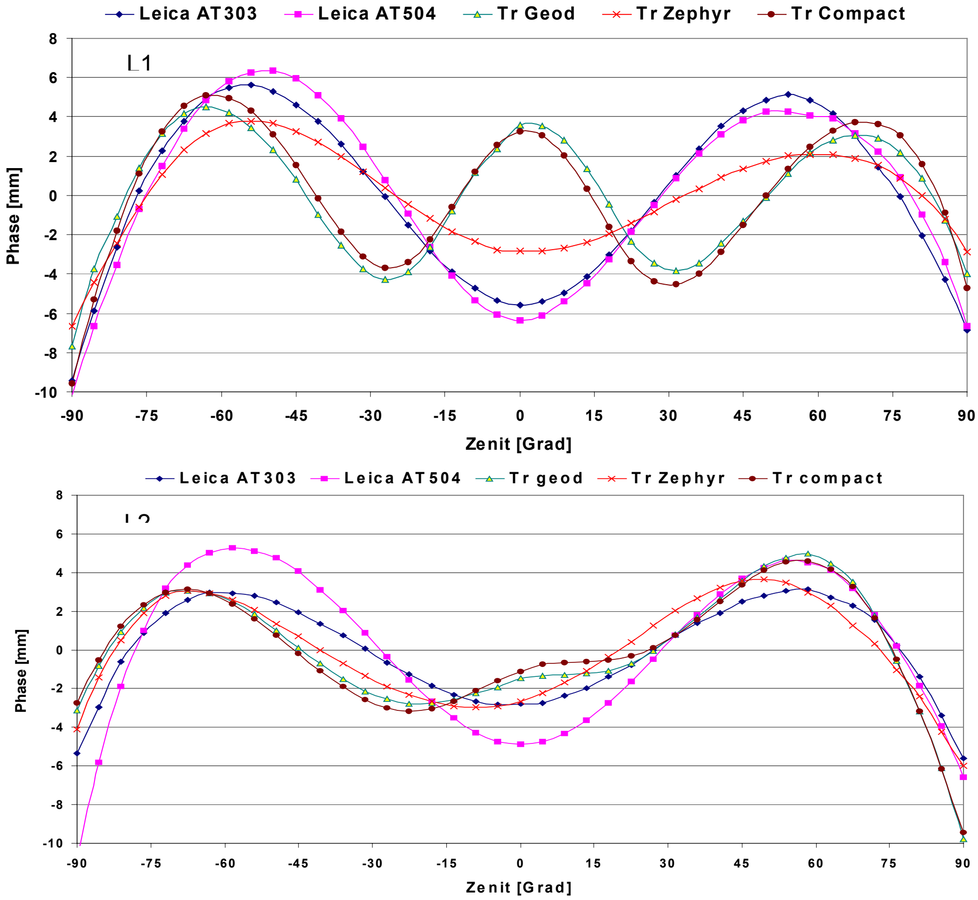

Fig. 10: Elevation-dependent phase pattern from chamber tests

clearly to be seen, that the large chamber enables the possibility to study in detail the characteristics of the patterns on a high-level of precision, in particular because no assumptions of the shape of the curves have to be made.

Azimuth-dependence has so far only been recorded for the elevation of 12.5 degrees (Fig.11). The observed oscillation is considerably smaller than for the elevation-dependence. Conspicious again is the shape and the larger scatter of the pattern of the Trimble geodetic antenna in contrast to the modern ones.

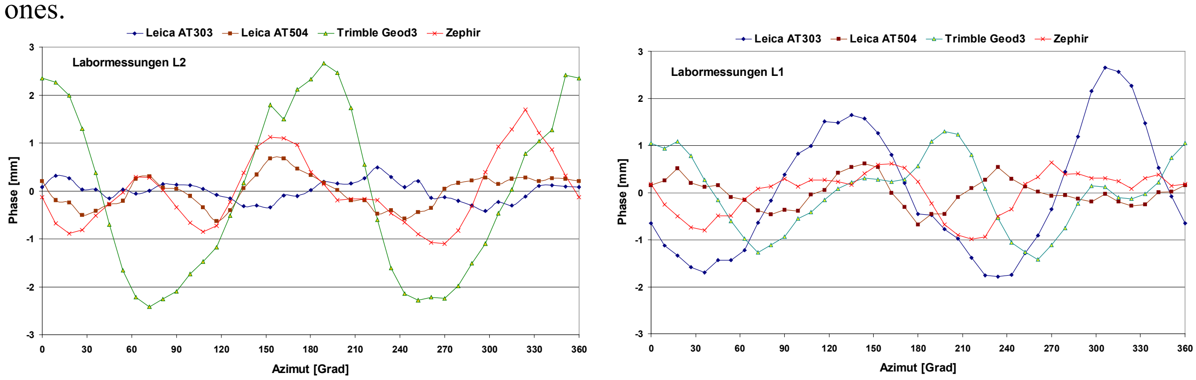

Fig. 11: Azimuth-dependent phase pattern from chamber tests (Elevation 12.5°)

The normalized RMS of the elevation- as well as azimuth-dependent PCVs are given in Fig. 12. The two groups of antennas are clearly to be distinguished again, as are the older ones with a high scatter and the modern ones with substantially smoother patterns.

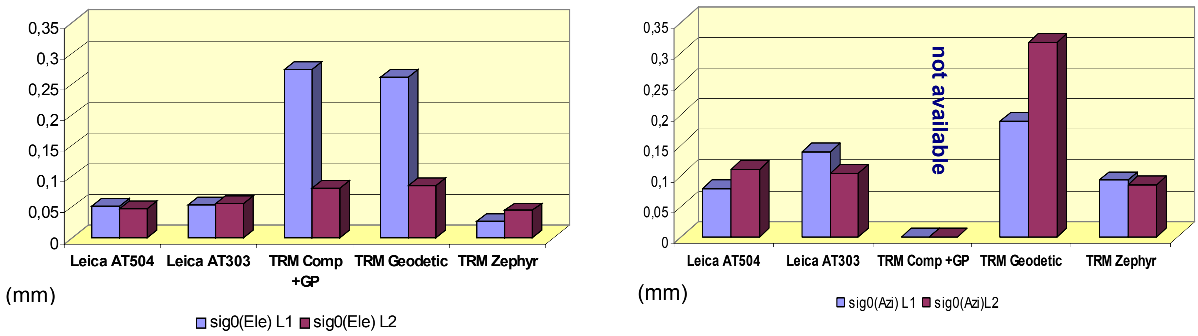

Fig. 12: Normalized RMS for elevation- and azimuth-dependent PCV

6 Comparison of chamber measurements with robot technique

Because a critical assessment of the obtained accuracy of antenna calibration is most effectively made by comparison between different calibration methods the particular Leica AT303 antenna was calibrated using the absolute field calibration technique with robot mount as well. Absolute corrections for the receiver antennas can be obtained from only this two independent methods. The receiver antenna corrections stemming from robot measurements were kindly made available by the company Geo++.

After correct conversion of the offsets, the elevation-dependent calibration results for this identical antenna agree on the level of 1mm (Fig. 13), although we are comparing the raw sample for the chamber results and a harmonic function of the robot results.

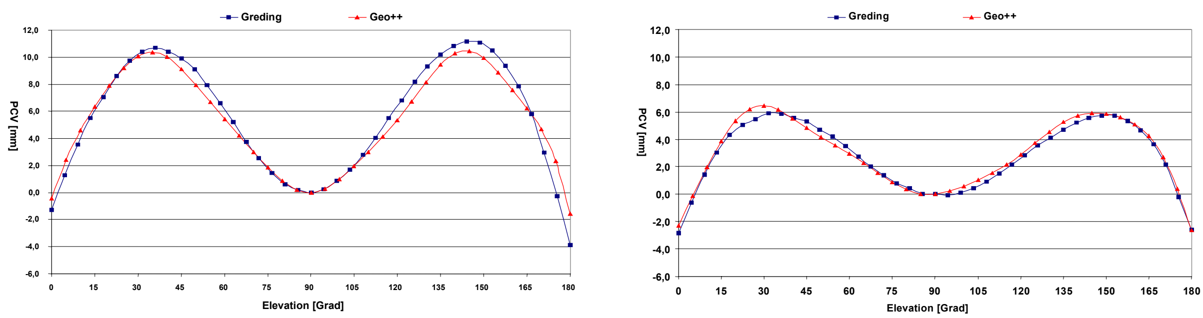

Fig. 13: Comparison of elevation-dependent phase pattern from chamber and robot calibration for the Leica AT 303 (identical antenna)

In the comparison for the azimuth-dependence (Fig. 14) a small phase shift can be seen, probably due to an uncertainty of the antenna orientation in the chamber setup.

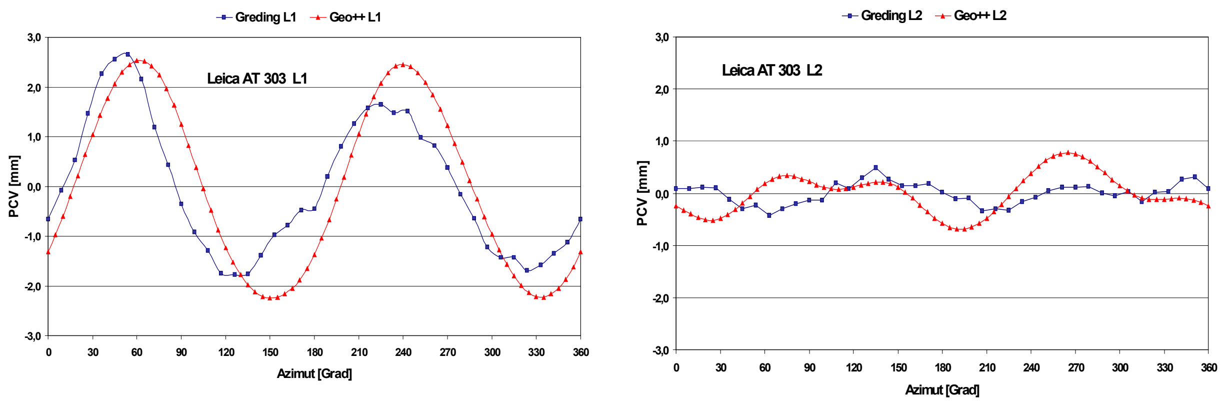

Fig. 14: Comparison of azimuth-dependent Phase pattern (elevation 12.5°) of chamber and robot calibration for the Leica AT 303 (identical antenna)

For the other antenna types, where not exactly the same antenna could be calibrated but one of the same type, the agreement is less good. Residual offset differences between both patterns were estimated (see Fig. 15). In the case of the Leica AT504 and the Trimble antennas with the asymmetric shape of the pattern the offsets rose to 4 and 5 mm respectively, but where nearly 0 for the Leica AT303 and the Trimble Zephyr geodetic.

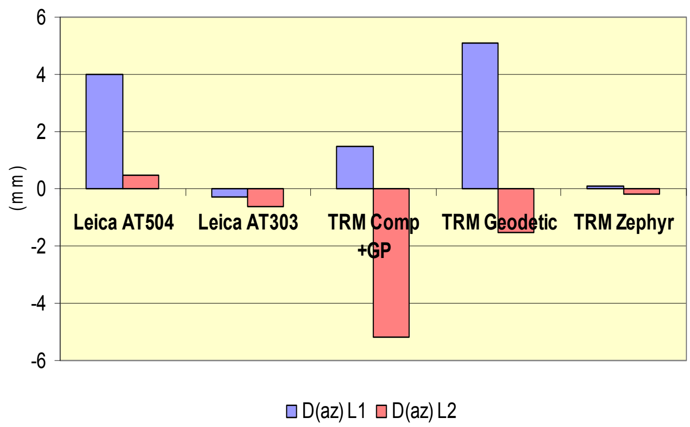

Fig. 15: Residual-Offsets from best-fit between Chamber (Greding) and robot (GEO++)

The reason for these differences with a systematic characteristic may be due to uncertainties in the measurement of the mechanical center of rotation relative to the ARP, or secondly due to the fact that we only measured one meridian and one parallel circle and not a sample of the entire pattern. Third there is a higher scatter between individual antennas of the same type even for choke ring antennas (Wübbena et al. 2003). The total precision of the calibration consists of the error of the accuracy of the PCO and the PCV from the adjustment and the error of the mechanical measurement of the point of rotation for all calibration methods.

$$\sigma_{antcal}^2 = \sigma_{PCO/PCV}^2 + \sigma_D^2$$

After the additional fit the pure quality in the agreement in terms of RMS difference of the PCV patterns can be seen (Fig. 16). The plots show that both methods agree on the 1mm-level or even better, if if an identical antenna is calibrated.

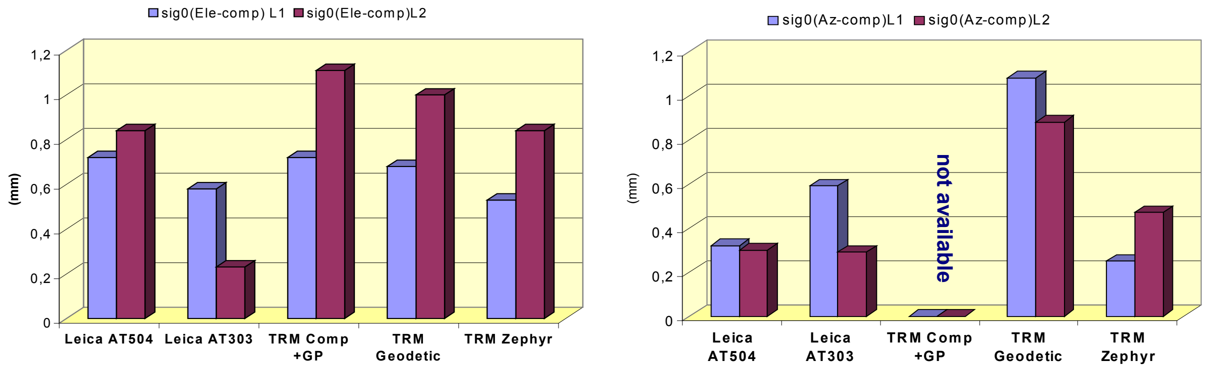

Fig. 16: Comparison of elevation- and azimuth-dependent PCVs between Chamber measurements and robot:

7 Conclusions

Recent calibrations show high potential for receiver antenna calibration in the anechoic chamber. The results validate the absolute calibration methods of chamber measurements and robot by agreement of the estimated parameters on the 1mm-level if this comparison is made for an identical antenna. The results confirm the presence of significant variations in quality between antennas of different design. In contrast to the relative field calibrations the chamber test and the robot permit homogenous distribution of observations with regard to the antenna hemisphere and the estimation of PCV for low elevations with the same high quality. Since we directly use the sampled PCV values (no fitting function!) the chamber provides the possibility to study the characteristics of the patterns of the PCVs in greater detail on a high level of precision.

For the future it is planned to continue the chamber tests with an improved antenna mount in order to be able to measure the whole hemisphere of the antenna under test in an automatic mode.

References

Campbell, J., Görres, B., Siemes, M., Wirsch, J., Becker, M.: Zur Genauigkeit der GPS Antennenkalibrierung auf der Grundlage von Labormessungen und deren Vergleich mit anderen Verfahren, Allgemeine Vermessungs-Nachrichten, 111/2-11, 2004

Feldmann-Westendorff, U., B. Sorge: Vergleichstest von Kalibrierverfahren für GPS-Antennen, 4. GPS-Antennenworkshop, Hannover, Mai 2002

Schmid, R., M. Rothacher: Ergebnisse und Analyse des Vergleichstests von Kalibrierverfahren für GPS-Antennen; 4. GPS-Antennenworkshop, Hannover, Mai 2002

Wübbena, G., M. Schmitz, F. Menge, G. Seeber, C. Völksen (1997): A New Approach for Field Calibration of Absolute Antenna Phase Center Variations, NAVIGATION, Journal of the Institute of Navigation, Summer 1997, Volume 44, Number 2.

Wübbena, G., M. Schmitz, G. Boettcher (2003). Analyse umfangreicher Messreihenvon GPS Antennen PCV aus absoluten Roboter-Feldkalibrierungenseit Januar 2000. in B. Görres, J. Campbell, G. Seeber (eds.), 5. GPS-Antennen-Workshop 2003 Geodätisches Institut der Universität Bonn