Absolute Receiver Antenna Calibrations with a Robot

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- Developments for Absolute PCV Field Calibration
- Details on Calibration and Analysis
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- Characteristics of Absolute PCV Field Calibration
- Verification of Absolute PCV
- Some Examples on Radome Constructions
- Individual/Type Correction
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- Acknowledgment
Motivation and Goal

- problems with existing field calibration procedure
- problems with absolute chamber calibration results
- PCV urgently needed for mixed antenna type applications
  (e.g. RTK networks, engineering tasks)
- separation of multipath (MP) and phase variations (PCV)
- absolute PCV independent from reference antenna
- high resolution and precision for PCV
- site and location independent
- field procedure
Development of Absolute PCV Field Calibration

- close cooperation with IfE (since 1995)
- spherical harmonics PCV model, post-processing with GEONAP (1995)
- automated absolute PCV field calibration in real-time using robot (2000)
- operational absolute PCV field calibration (since 2000)
  - publication of absolute PCV for AOAD/M_T (2000)
  - proposal of GPP_NULLANTENNA (2000)
  - absolute PCV supplied for analysis/verification/use (2000–2001)
  - Geo++ GNPCVDB antenna database (2001)
Development of Multipath Elimination Techniques and PCV Separation

- siderial differences in post-processing
  - first approach
  - observation on two days
  - same geometry/environment eliminates MP

- short-term differences in real-time
  - operational procedure
  - same MP for subsequent epochs eliminates MP

- PCV reintroduced by orientation changes (rotations and tilts)
Development of Automated Antenna Mount

- orientation changes of antenna required
- mount for rotating and tilting antenna
  - precise, fixed and stable rotation point
  - automation
  - operational procedure
- finally use of a robot
  - fast changes
  - automated robot guidance
  - real-time

Development of Robot Calibration Procedure

- corrections for robot required
- accuracy for antenna positions: 0.2 – 0.3 mm
Details on Absolute PCV Field Calibration

- homogeneous coverage of antenna
  - 6000 – 8000 different positions
- dynamic robot guidance
  - depends on satellite constellation
  - optimizes observation time
- dynamic elevations mask
  - satellites with high elevation (>18°)
  - actual negative elevation (−5°) used
Analysis of Operational Absolute PCV Field Calibrations

- different locations (Geo++, IfE)
- different times (days, seasons, ...)
- different weather (temperature, rain, snow, wind, ...)
- different robots (hardware, robot calibrations, performance, ...)
- different reference antennas (all major manufacturers)
- different GPS receivers (all major manufacturers)
- different north orientations
- different mounting on robot
- ...
Repeatability and Accuracy of Absolute PCV Field Calibration

example LEIAT303

- absolute L0 PCV: -10 to 15 mm range
- std. dev. of L2 PCV: 0.2 to 0.4 mm range
- difference L0 PCV 5 month apart: 1 mm mean, except horizon
Characteristics of Absolute PCV Field Calibration

- absolute 3D offset
- absolute PCV
- PCV from (<) 0° to 90° elevation
- 0° to 360° azimuthal PCV
- simultaneous L1, L2 GPS and GLONASS PCV
- high resolution and precision
- free of multipath influence
- site and location independent
- at least two independent calibrations
- duration of several hours
- standard deviation 0.2–0.3 mm (1 sigma) for complete PCV (offset plus PCV)
- verification of accuracy through repeatability
Verification of Absolute PCV

- concern “15 ppb scale” for global networks
- experiment simulating “large network”
  - inclined and rotated AOAD/M_T simulates geographical separation
  - no effects from atmosphere, orbits, satellite antenna using short baseline, true reference
- coordinates from 24 h data, L0 + tropospheric scale parameter
- proof by comparing absolute and relative PCV performance
Effect of Radome Construction

- difference absolute L0 PCV LEIAT504 / LEIAT504 LEIS: −4 to 2 mm range

- difference absolute L0 PCV LEIAT504 / LEIAT504 SCIS: −14 mm range
Effect of Radome Construction

- difference absolute L0 PCV
  ASH700936M_E/ASH700936M_E SNOW: −2 to 4 mm range

- difference absolute L0 PCV
  TRM29659.00/TRM29659.00 TCWD: −8 to 8 mm range
Individual or Type Mean PCV Correction

- Individual calibration best choice
  - Most antennas not accessible
  - Option for new installations
- Type mean suitable for other applications
  - Simple procedure
  - Uncertainty remains

- Significant differences between antenna types observed
  - Manufacturing series
  - Assembling errors
  - Outliers even for “Dorne Margolin Type” choke ring antenna
Example of Individual PCV Difference

- “Dorne Margolin Type” choke ring antenna
- best geodetic antenna type
- example of outlier
  - primarily L1 east offset
  - effect for L0 absolute PCV: −6 to 8 mm range
- different manufacturers
  - 1 outlier out of 10 antennas
  - 1 outlier out of 26 antennas

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Benefits of Absolute PCV Field Calibration and Correction

- high precision absolute PCV
- reliable azimuthal PCV
- separation of error components possible (e.g. station MP calibration, atmospheric parameter)
- unbiased absolute positioning
- mixed antenna type application possible (e.g. RTK networks)
- engineering application with inclined antennas (negative elevation)
- ...
Geo++ GNPCVDB Antenna Database

- type means from calibrated antennas
- rigorous adjustment using complete variance–covariance matrix of individual calibrations
- about 64 different antenna types (Dec. 2001)
  - 344 individual calibrated antennas
  - 1939 individual calibrations
- public information on e.g. PCV pattern shape, etc.
- license for access and use of absolute PCV
- http://gnpcvdb.geopp.de/
Acknowledgments

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References

• selected publications:


• additional publications can be found under http://www.geopp.com/publikationen/lst_gpcv.htm
Global Ionosphere Maps Produced by CODE
Estimation of Elevation-Dependent Satellite Antenna Phase Center Variations

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IGS Network, Data and Analysis Center Workshop 2002
Courtyard Marriott, Ottawa, Canada
10 April 2002
Contents

• Introduction
• Estimation strategy
• Results
  - Repeatability between satellites of the same block
  - Daily repeatability
  - Differences between satellite blocks (Blocks II/IIA/IIR)
  - Dependence on global scale
  - Influence on global parameters (troposphere, earth rotation, orbits)
• Conclusions
Introduction

• Relative receiver antenna PCVs (elevation-dependent) are in use.

• Absolute receiver antenna PCVs are available from
  - anechoic chamber measurements and
  - absolute field calibrations (robot).

• **Problem:** Absolute PCVs cause a large terrestrial scale change of about 15 ppb in global GPS solutions.

• **Conclusion:** Satellite antenna PCVs have to be taken into account, because of the relationship between PCVs of the satellite antenna and the receiver antenna.
Estimation Strategy

- IGS network (more than 100 stations)
- Daily solutions with estimation of satellite antenna phase patterns and all relevant global parameters
- Global scale fixed (by constraining station coordinates)
- Absolute receiver antenna PCVs from Hannover (IfE/Geo++)
- Polygon approach, 1°-resolution (0°-14°)
- Sum of all pattern values constrained to be zero (a mean variation is absorbed by the satellite clock)
Total: 223213
Maximum: 13.941°
Sampling Rate: 600 sec
Elevation Cut–Off Angle: 10°
No. of Stations: 120
Repeatability Between Satellites (Block IIR)

Satellite Antenna Phase Center Variation [mm]

Nadir Angle [°]

Block IIR
PRN 11
PRN 13
PRN 20
PRN 28
Nadir Angle [°] vs. Satellite Antenna Phase Center Variation [mm] for Block II/IIA, Block IIR, and Standard Deviation from Day 240–247.
Effect of Scaling of the Global Network on Phase Pattern (Block IIR)

Nadir Angle [°] vs. Satellite Antenna Phase Center Variation [mm]

-15 ppb
-10 ppb
-5 ppb
without scaling
+5 ppb
+10 ppb
+15 ppb
Effect of SAPCV Estimation on Troposphere Parameters (Day 245)

- Station PERT
- Station ALBH

Without SAPCV
With SAPCV
Effect of SAPCV Estimation on Earth Rotation Parameters

Day of Year 2000

X-Pole [''] (0.001'' correspond to approx. 3 cm)

without SAPCV

rms

with SAPCV

0.05

0.049

0.048

0.047

0.046

0.045

245

246

247

248

249

Day of Year 2000
Helmert Transformation between Orbits (With resp. Without SAPCV) for Different Satellite Blocks

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Block II/IIA (24 Sat.)

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Block IIR (7 Sat.)
Conclusions

• Satellite antenna PCVs estimable
• Repeatability (daily, between satellites): \( \sim 1-3 \) mm
• Different patterns for Block II/IIA and Block IIR
• Systematic effect on Block II/IIA orbits:
  \[ \text{rms} \sim 5 \text{ cm}, \ Y\text{-component of the geocenter} \sim 2 \text{ cm} \]
• Systematic effect on tropospheric delay: \( \sim 3 \) mm
• Consistent absolute PCVs now available for receivers and satellites
Multipath characteristics of GPS signals as determined from the Antenna and Multipath Calibration System (AMCS): Preliminary results

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Harvard-Smithsonian Center for Astrophysics

P. Jarlemark
SP Swedish National Testing and Research Institute

B. Corey, A. Niell
MIT/Haystack Observatory

C. Meertens, V. Andreatta
UNAVCO/UCAR Facility
Overview

• Description of the AMCS
• Some Preliminary Results
• Conclusions and Future Work

Park et al., (in preparation)
AMCS Accuracy Goal and Method

- **Goal:** Develop an *in situ* method for absolute calibration of site-dependent GPS phase-measurement errors such as scattering, multipath and unmodeled antenna phase variations (“SMA effects”) with an accuracy of 1 mm (each frequency).

- **Method:** Form single phase differences between a GPS receiver connected to a GPS antenna to be calibrated and a second GPS receiver connected to an antenna free of SMA effects.
Components of the AMCS

- High-gain, multipath-free, 3-m diameter parabolic antenna
- GPS test antenna to be calibrated
- Two GPS receivers
Unique Strengths of the AMCS Method

• Current multipath reduction/calibration methods used include microwave absorber, relative field calibrations, anechoic chamber, mechanical robot, and data filtering.

• The AMCS enables us to accomplish three types of studies that are not possible with any other method:
  
  – In situ, absolute site calibration
  
  – Understand the sources of SMA effects, their dependence on weather and environment, and their time variability
  
  – Development and testing of improved antennas and understanding of site effects
Block diagram of the AMCS

- Test GPS Antenna
- H Maser (5 MHz)
- Az/El Motors
- Az/El Encoders
- Limit Switches
- Antenna Controller
- Antenna Interface Unit
- PC
- RF Amplifier
- 1 GHz Highpass Filter
- Splitter
- DC Block
- GPS Receiver #1
- GPS Receiver #2
- High-gain, Multipath-free, 3-m diameter parabolic antenna
Modes of Operation

• **Zero-Baseline (ZBL) Calibration Mode**
  - Both receivers collect data from the GPS test antenna
  - ZBL-mode data is processed to estimate a clock synchronization error and a phase offset of each satellite, which will be used in AMCS-mode data processing as fixed parameters

• **AMCS Mode**
  - **Static** (Calibration)
    - The parabolic antenna is stationary, pointing toward a certain direction, and the target GPS satellite drifts in and out of the antenna main beam
  - **Tracking**
    - The parabolic antenna tracks the target GPS satellite and its pointing direction is updated at each observation epoch
L₁ Phase Residuals (ZBL/AMCS-static)

![Residuals plot](image)

- Residuals (mm)
- Time since the first epoch of ZBL (seconds)
- ZBL
- AMCS

Legend:
- PRN 02
- PRN 04
- PRN 07
- PRN 09
- PRN 20
- AMCS: PRN 02
Analysis of Residuals (ZBL/AMCS-static)

- **ZBL-mode residuals**: RMS \(\sim 0.5\) mm

- **AMCS-mode (static) residuals**: RMS 1 - 3 mm
  - *Highly systematic variations*
    - Parabolic antenna pointing offset errors
    - Baseline error
    - Parabolic beam pattern errors
    - Low Signal-to-Noise Ratio (SNR) in the AMCS-mode data collection
Correction of Baseline-dependent Error
AMCS-tracking Analysis

• Observing schedule:
  – 10-minute ZBL-mode
  – 10-minute AMCS-mode
  – Steer the parabolic antenna every 10 seconds

• Track the same satellite for several consecutive days

• Track different GPS satellites
  – Elevation angle: high, medium, and low
  – Azimuth angle: extensive coverage
$L_1$ Phase Residuals (AMCS-tracking)
Results of AMCS-tracking Analysis

• Effects are low-amplitude (~5 mm)

• Effects vary extremely rapidly in elevation angle
  – periodicity with variations of ~1° of elevation angle
  – periodicity is not very regular

• Effects are fairly repeatable from day to day
  but they can also vary by amounts large with respect to the AMCS measurement uncertainty of 1mm

• Effects are very sensitive to azimuth and time of day
  perhaps due to moisture on reflecting surfaces, temperature, or both.

• Amplitude variations of multipath effects are typically larger at lower elevation angles
Second GPS Test Antenna

• Objective: are the observed effects due to multipath?

• Installed a second GPS antenna
  – Same antenna type and hardware
  – Reduced multipath environment
  – Microwave absorber

• Observations: 10 days in February 2002

• Compare phase residuals between GPS antennas
• GPS antenna in **higher multipath** environment
  – Residuals are *more repeatable* from day to day
  – Larger amplitude variations
  – Larger signal amplitude at low elevation

• GPS antenna in **lower multipath** environment
  – Residuals are *less repeatable* from day to day
  – Smaller amplitude variations
  – Amplitude rather independent of elevation angle
Summary and Conclusions

• Description of AMCS

• ZBL-mode phase residuals are $\sim 0.5 \text{ mm}$ (RMS)

• AMCS-mode phase residuals
  – Measured absolute SMA effects
  – High spatial resolution (sub-degree)
  – Accuracy is $\sim 1 \text{ mm}$

  – SMA effects are:
    • Low-amplitude ($\sim 5 \text{ mm}$)
    • High-frequency (periodicity with variations of $1^\circ$ elevation angle)
    • Fairly repeatable from day to day
    • Very sensitive to azimuth angle and time of day
Future Research and Calibration

• **Open questions:**
  – How dependent are these effects on environmental conditions?
  – Can an accurate and standard set of calibrations be obtained for a GPS site?
  – What is the ultimate limitations that these effects place on the accuracy of (geodetic and geophysical) estimates obtained from GPS data?

• **Quantitative answers:**
  – Construct a second, field deployable AMCS:
    • Side-by-side tests for accuracy assessment
    • Characterization of SMA effects at various GPS test sites
    • Deliberate introduction of SMA effects for model applicability
    • Time-series analysis of GPS analyses with/without SMA corrections