UNAVCO Inc.
Mr. Dittmann
6350 Nautilus Drice
Boulder, CO 80301
United States of America

GeoService®
Satellitengestützte Vermessungen GmbH

Steinriede 8
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Your Order, dated

☎ **+49 5131 4689-0**
-15, Mrs. Schmidt

Please quote this reference

Our Reference	Date
Bü160502-0801-UNA1129	August 30th, 2016

Dear Mr. Dittmann,

Please find enclosed the original certificate of Type Mean for your TRM41249.00 NONE antenna.

Sincerely yours

GeoService GmbH

i.A. Patricia Schmidt

Patricia Schmidt

Geo++® GmbH
Steinriede 8, 30827 Garbsen, Germany
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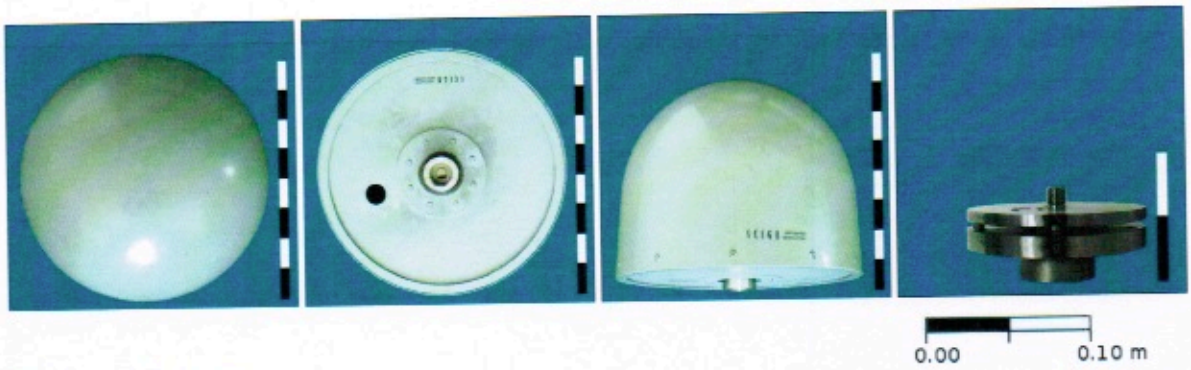
Calibration of GPS Antenna Trimble 41249.00 SCIT
Deriving a GNPCV Type Mean from Absolute Calibrations with a Robot

(IGS Name*: TRM41249.00_____SCIT)



Calibration Method

The applied Geo++® calibration method of GNSS antennas with a robot determines the absolute antenna offset in horizontal and vertical position as well as the absolute elevation and azimuth dependent phase center variations (PCV) for both frequencies. The resulting PCV are completely independent from the used reference antenna (absolute calibration) and allow the complete modeling of the receiving characteristic of the antenna.

Scope of the applied absolute GPS antenna calibration is:

- absolute offsets and absolute PCV
- special approach with inclined and rotated antenna (robot)
- elimination of multipath
- coverage of the complete elevation range from 0° to 90°
- coverage of complete antenna hemisphere
- precise determination of PCV using a large number of different antenna orientations
- simultaneous estimation of L1 and L2 PCV for GNSS
- weather independent measurements
- at least two redundant calibrations per individual antenna

Basic concept of the calibration method is the separation between multipath and phase center variation. A special observation procedure with different antenna orientations is used for the determination of absolute PCV and for multipath elimination.

The processing is done in real-time. Primary result is a spherical harmonic expansion of the PCV as function of zenith distance and azimuth with complete variance-covariance data directly after the calibration. Finally absolute horizontal and vertical mean offsets as well as absolute elevation and azimuth dependent phase observation corrections for the calibrated antenna can be derived.

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* It is not officially included in the IGS naming convention at writing of this protocol. Check rcvr_ant.tab or gpp_rcvr_ant.tab.

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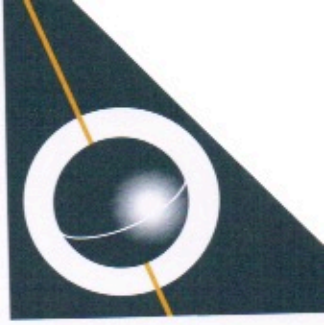

Calibration Procedure

A sample of individual TRM41249.00 SCIT calibrations conducted with the Geo++® calibration method with a robot is the basis for the calculation of the type mean. The individual calibrations are rigorously adjusted considering the full variance-covariance information.

Scope of the GNPCV type calibration:

- individual calibrations at least of five antennas of same manufacturing series
- adjustment of a type mean using entire variance–covariance data

The type mean of the TRM41249.00 SCIT antenna is derived from four individual antennas with serial numbers 60233533, 12611683, 60187535 and 12470985. Each antenna was calibrated at least twice, which gives 14 individual GPS calibrations.

Calibration Result

The GNPCV Type Mean is the adjusted mean of the five individual TRM41249.00 SCIT GNSS antennas. The Antenna Reference Point (ARP) is the reference point used in the calibration. The reference direction to north is defined by the receiver connector (RXC). The antenna height has to be measured to the ARP, which is vertically defined to the bottom of antenna mount (BAM) and horizontally to the rotation axis defined by the center of 5/8“ thread.

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Calibration Result GPS

The absolute GPS PCV excluding the mean phase center offsets for the L1 and L2 frequency are depicted below:

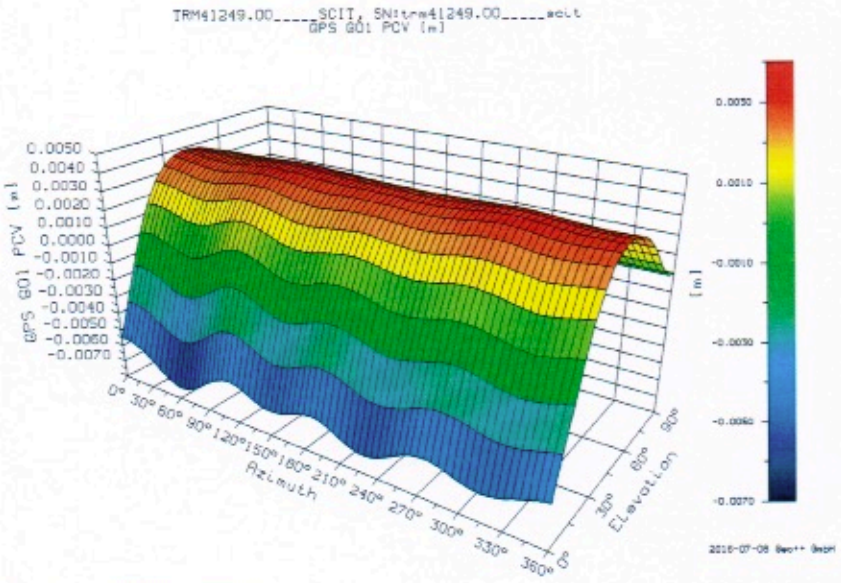

Figure 1: GPS L1 PCV

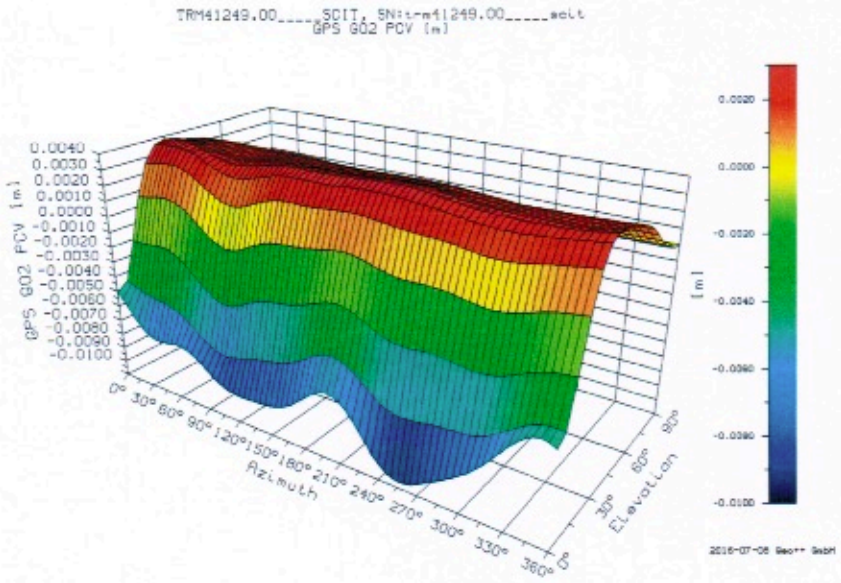

Figure 2: GPS L2 PCV

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As a numerical reference, the pure elevation dependent PCV are listed below in the international ANTEX format (see ANTEX format description for details). However, the complete model of the antenna consists of elevation and azimuth dependent PCV value

```
     1.4            M                                    ANTEX VERSION / SYST
A                                                        PCV TYPE / REFANT
                                                         END OF HEADER
                                                         START OF ANTENNA
TRM41249.00     SCIT                                     TYPE / SERIAL NO
ROBOT                Geo++ GmbH          5    2016-02-09METH / BY / # / DATE
     5.0                                                 DAZI
     0.0  90.0   5.0                                     ZEN1 / ZEN2 / DZEN
     4                                                   # OF FREQUENCIES
   G01                                                   START OF FREQUENCY
     +0.83      +0.05     +66.21                         NORTH / EAST / UP
   NOAZI   +0.00   -0.02   -0.10   -0.24   -0.45   -0.74  -1.10   -1.50   -1.90   -2.21   -2.38   -2.35   -2.13   -1.73   -1.13
-0.27   +0.98   +2.76   +5.14
   G01                                                   END OF FREQUENCY
   G02                                                   START OF FREQUENCY
     +0.76      +0.26     +57.68                         NORTH / EAST / UP
   NOAZI   +0.00   -0.09   -0.35   -0.73   -1.19   -1.70  -2.25   -2.82   -3.34   -3.70   -3.78   -3.48   -2.81   -1.86   -0.78
+0.39   +1.78   +3.72   +6.55
   G02                                                   END OF FREQUENCY
   R01                                                   START OF FREQUENCY
     +0.83      +0.05     +66.21                         NORTH / EAST / UP
   NOAZI   +0.00   -0.04   -0.16   -0.38   -0.66   -1.02  -1.44   -1.88   -2.34   -2.71   -2.94   -2.98   -2.81   -2.46   -1.91
-1.07   +0.15   +1.90   +4.24
   R01                                                   END OF FREQUENCY
   R02                                                   START OF FREQUENCY
     +0.76      +0.26     +57.68                         NORTH / EAST / UP
   NOAZI   +0.00   -0.10   -0.38   -0.77   -1.23   -1.71  -2.24   -2.81   -3.39   -3.82   -4.00   -3.77   -3.13   -2.18   -1.10
+0.00   +1.25   +3.04   +5.85
   R02                                                   END OF FREQUENCY
   G01                                                   START OF FREQ RMS
   NOAZI    0.00    0.01    0.03    0.06    0.07    0.08  0.08    0.08    0.08    0.09    0.09    0.09    0.10    0.10
0.10    0.10    0.11    0.12
   G01                                                   END OF FREQ RMS
   G02                                                   START OF FREQ RMS
   NOAZI    0.00    0.01    0.03    0.06    0.08    0.09  0.09    0.09    0.09    0.09    0.09    0.10    0.10    0.11    0.11
0.11    0.11    0.13    0.14
   G02                                                   END OF FREQ RMS

                                                         END
```

Garbsen, August 17, 2016

Dr.-Ing. G. Wübbena

Literature

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, Vol. 44, No. 2, 247-256.

Menge, F., G. Seeber, C. Völksen, G. Wübbena, M. Schmitz (1998). Results of Absolute Field Calibration of GPS Antenna PCV. Proceedings of International Technical Meeting, *ION GPS-98*, Nashville, Tennessee.

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Schmitz, M., G. Wübbena, G. Boettcher (2002). Tests of phase center variations of various GPS antennas, and some results. *GPS Solutions*, Volume 6, Number 1-2, Springer, 18-27.

