

## Investigation of a L1-optimized Choke Ring Ground Plane for a Low-Cost GPS Receiver-System

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**Key words:** Low Cost Technology, GPS/GNSS, Monitoring, Multipath Effect, Choke Ring

### SUMMARY

Besides the geodetic dual-frequency GNSS receivers-systems (receiver and antenna), there are also low-cost single-frequency GPS receiver-systems.

The multipath effect is a limiting factor of accuracy for both geodetic dual-frequency and low-cost single-frequency GPS receivers. And the multipath effect is for the short baselines dominating error (typical for the monitoring in Engineering Geodesy). So accuracy and reliability of GPS measurement for monitoring can be improved by reducing the multipath signal.

In this paper, the self-constructed L1-optimized choke ring ground plane (CR-GP) is applied to reduce the multipath signal. Its design will be described and its performance will be investigated.

The results show that the introduced low-cost single-frequency GPS receiver-system, which contains the Ublox LEA-6T single-frequency GPS receiver and Trimble Bullet III antenna with a self-constructed L1-optizmed CR-GP, can reach standard deviations of 3 mm in east, 5 mm in north and 9 mm in height in the test field which has many reflectors. This accuracy is comparable with the geodetic dual-frequency GNSS receiver-system. The improvement of the standard deviation of the measurement using the CR-GP is about 50 % and 35 % compared to the used antenna without shielding and with flat ground plane respectively.

# **Investigation of a L1-optimized Choke Ring Ground Plane for a Low-Cost GPS Receiver-System**

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## **1. INTRODUCTION AND MOTIVATION**

Besides the geodetic dual-frequency GNSS receivers-systems (receiver and antenna) which may cost more than 20 000 €, there are also the so-called low-cost single-frequency GPS receiver-system, which are primarily developed for the mass market and obviously cost effective (cost about 200 €). The investigations at the Institute of Engineering Geodesy (IIGS) and at other research institutions (Schwieger und Gläser 2005, Schwieger 2007, Schwieger 2008, Schwieger 2009, Limpach 2009, Glabsch et al. 2010) show that accuracies of sub-cm can be achieved even with a low-cost single-frequency GPS receiver-system, if the carrier phase measurements of the GNSS receivers are evaluated in relative mode and the length of the baseline is up to several kilometres. Influences of baseline-length-dependent errors, such as ionospheric and tropospheric errors, can be mitigated for short baselines. The monitored objects like landslides or dams have normally an extension up to a couple of kilometres and so the low-cost single-frequency GPS receiver-systems are suitable for these kinds of applications. So the low-cost single-frequency receiver-system provides a cost effective alternative to the geodetic dual-frequency GNSS receiver-system for the monitoring applications.

However, the influence of site-dependent errors particularly the multipath effects cannot be reduced in relative mode, so it is still a general problem for the precise GNSS positioning, particularly in shadowing environment. Multipath effects affect not only the accuracies of relative but also of absolute positioning and it is a limiting factor of accuracies for both geodetic dual-frequency and low-cost single-frequency GNSS receiver-systems.

Since the beginning of the GPS development, there has been a lot of research on the multipath effect, and different methods have been developed to reduce the multipath effects, such as improving the receiver technology (Van Dierendonck et al. 1992), using the Signal-To-Noise Ratio (Axelrad et al. 1994), applying sidereal filtering (Choi et al. 2004) and station calibration (Wanninger and May 2000), or improving the antenna design (Filippov et al. 1998, Krantz et al. 2001, Kunysz 2003, Tatarnikov et al. 2011). Up to now, there is no method which can completely eliminate the influence of the multipath effects. In Zhang (2016) the multipath effects can be reduced, on one hand, by applying the self-constructed L1-optimized choke rings, in another words, by improving the antenna design; on the other hand by considering the temporal and spatial correlations between closely-space antennas (one of the methods is published in English in Zhang and Schwieger 2016).

In this paper the design and the performance of the L1-optimized choke ring will be introduced. In order to show the performance of the L1-optimized choke rings, the same antenna without shielding and with flat ground plane as shielding, as well as geodetic GNSS receiver-system have measured at the same points. The results will be shown and discussed in this paper.

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## 2. OPTIMIZATION OF ANTENNA SHIELDINGS

A very common and simple method to reduce the multipath effect is the optimization of the antenna shieldings, e.g. by apply a flat ground plane (short GP). The flat GP can reduce part of the multipath signals from the ground (compare Figure 1).

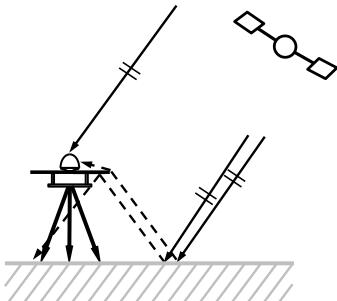


Figure 1: Antenna with flat ground plane

The GP or generally the shieldings can change the antenna gain. The antenna gains combined with flat GP with various diameters were analysed in Sciré-Scappuzzo and Makarov (2009). The results showed that the optimal diameter of the GP is about 1.5-factor of the wave length of the signal. That means the optimal diameter of GP is about 28.5 cm and 36 cm for GPS L1- and L2-frequency. It may explain the fact that commercial choke ring antennas have normally a diameter of 36 to 38 cm. The flat GP can only partly reduce the multipath signal from the ground. One reason is that the signal can be diffracted by the sharp border of the GP, so that the diffracted signal can still be received by the antenna (compare Figure 1, Dilßner 2007). The other reason is that the so-called surface wave be conducted due to the electrical conductivity of the GP, when the reflected wave arrive the metal choke ring (compare Figure 2), this wave can also arrive the antenna.

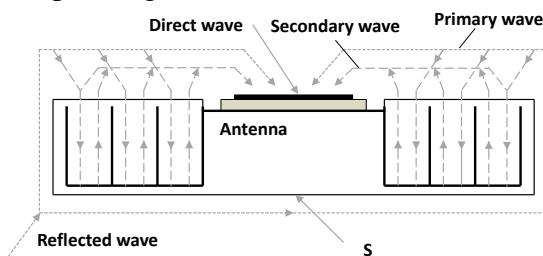


Figure 2: Principle of choke ring (after Filippov et al. 1998)

This surface wave, as illustrated in Figure 2, propagates in the so-called choke ring ground plane (short CR-GP) to the top of the grooves and continues to the backside of the CR-GP and can be called as “primary” wave; the other so-called “secondary” wave is reflected by the grooves (Filippov et al. 1998). So the primary wave propagates from top to bottom of the grooves and the secondary wave propagates from bottom to top of the grooves. If the groove depth of the choke ring is about  $\frac{1}{4}$  of wave length, the phase shift between the primary wave and secondary wave is about  $180^\circ$ . In this way the two waves will substantially cancelled each other so that the surface wave can be destroyed (Filippov et al. 1998). Thus the antenna gain for the low elevation angle (the most multipath signals come from low elevation angles) will be significantly reduced.

The standard type of choke ring antenna (with Dorne & Margolin antenna and choke ring ground plane) was developed by Jet Propulsion Laboratory (JPL) at first and the first geodetic application of the choke ring antenna was published in Tranquilla and Colpitts (1989) and Tranquilla et al. (1994). Nowadays many manufacturers offer their choke ring antennas in adopted form.

## 2.1 Design of L1-optimized Choke Ring Ground Plane

As explained above, the most important parameter of the choke ring is the groove depth.  $\frac{1}{4}$  of the GPS L1- and L2-frequency is about 47 mm and 60 mm. The groove depth of commercial choke ring varies from about 50 mm to 64 mm (see Unavco 2016), which is a compromise solution between GPS L1- and L2-frequency, in this case the multipath effect cannot be mitigated for both frequencies at the same time. In Filippov et al. (1998) introduced a dual depth dual-frequency CR-GP having a special electrical magnetic filter, so that the signal of L1-frequency can be reflected in the depth of 47 mm while the signal of L2 is reflected in the depth of 60 mm.

In our case, the single-frequency GPS receiver-system can only receive GPS L1-frequency, so there is no compromise or filter necessary, the groove depth can be optimized directly for GPS L1-freueny.

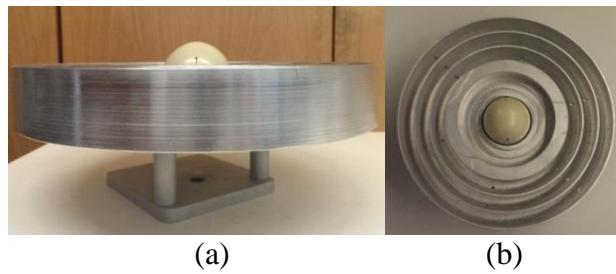


Figure 3: self-constructed CR-GP with antenna (side view and top view)

The L1-optizmed choke ring ground plane, which is self-constructed in the workshop of IIGS, is shown in Figure 3. The CR-GP is milled from one aluminium piece. The material cost is about 400€. The cheaper variate is to bend several pieces of aluminium to the ring and weld them on the ground plane. This variety can be deformed easily and there will be some signal disruption at the joint points. So the authors have decided for this stable variant.

The antenna used here is Trimble Bullet III (short TBIII) antenna (Trimble Bullet III 2016) which costs about 100€, so it is low-cost antenna. The Ublox ANN-MS antenna which is included in the EVK-6T is not used. Because the performance of the antenna is even more important than that of receiver (Takasu and Yasuda 2008), in Zhang and Schwieger (2013) different low-cost antennas were tested combined with Ublox LEA-6T GPS receiver. The results showed that the TBIII antenna has a better performance than the ANN-MS antenna.

The developed CR-GP is simplified version of the dual depth dual frequency CR-GP of Filippov et al. (1998). In the Filippov et al. (1998) is given that the optimal groove depth for L1-freueny is  $48\pm3$  mm. The antenna element of the Trimble Bullet III is 45 mm above the bottom of the antenna. So for this reason, the groove depth of this L1-optimized choke ring is 45 mm. The antenna gain

with different number of rings of the CR-GP was tested in Test in Sciré-Scappuzzo and Makarov (2009) showed that the optimal number of rings of the choke ring is about 3 or 4. The authors have decided for 3 rings. The diameter is about 32 cm which is about 1.5 factor of the L1-wave length.

## 2.2 Antenna Calibration

Since the shieldings can change the antenna near field and antenna gain significantly, the antenna calibration with the shielding is necessary (Dilßner 2007, Zeimetz 2012). For this reason the TBIII antennas were calibrated absolutely in an anechoic chamber at University of Bonn (see Figure 4).

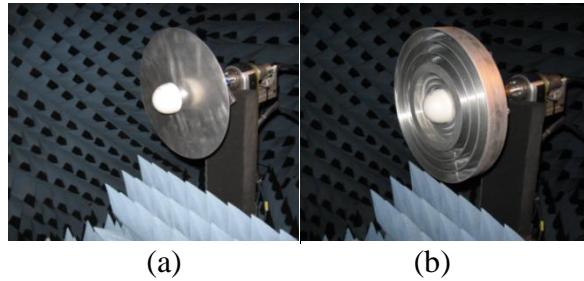


Figure 4: Calibration of TBIII antenna with flat GP (a) and CR-GP (b) (University Bonn 2013a and University Bonn 2013b)

The same TBIII antenna was calibrated with flat GP and CR-GP. The horizontal antenna Phase Centre Offsets (PCO) are sub-mm to maximum 1.3 mm in both cases. The antenna Phase Centre Variations (PCV) are shown in Figure 5. It can be found out that the PCV of TBIII antenna with CR-GP is obviously smaller and more homogeneous than that with flat GP. This results show how the shieldings change the antenna characteristics.

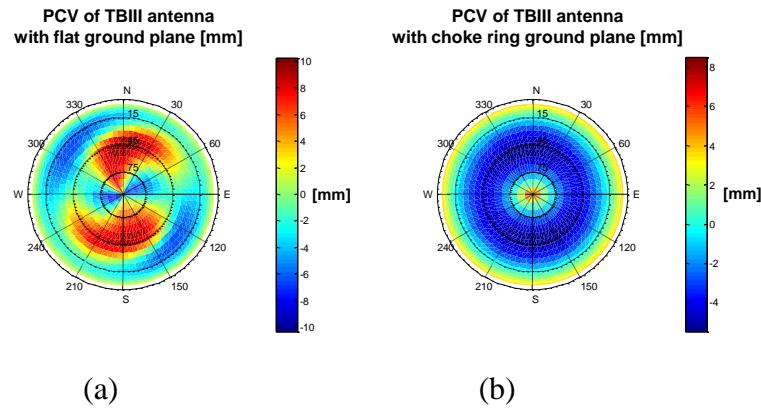


Figure 5: PVZ of TBIII antenna with flat GP (a) and CR-GP (b)

Since the low-cost GPS antennas are developed and produced for the mass market, it is possible, that they have a larger manufacturing tolerance and the PCV and PCO varies from antenna to antenna significantly. The antenna calibration is expensive. In our case, it is even more expensive than the antenna. If individual calibration is necessary for the low-cost GPS antenna, then the low-cost antenna is not really a cost effective solution anymore.

To see the difference of antenna, two TBIII antennas were calibrated with the same shielding. The differences of the PCO of two antennas are in the range of sub-mm.

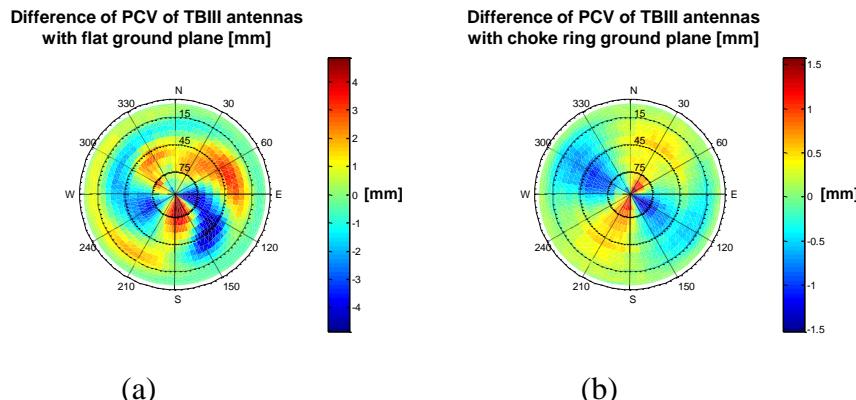


Figure 6: Differences of PVZ of TBIII antenna with flat GP (a) and CR-GP (b)

Figure 6 shows the differences of the PCV of two TBIII antennas with flat GP and CR-GP respectively. In Figure 6 is presented that the difference of PCV of TBIII antennas with CR-GP is smaller than with flat GP, and it varies between  $-1.5$  mm and  $+1.5$  mm and its mean value is nearby zero.

The difference of PCO between the antennas is not that important for monitoring, since it doesn't change with the time. For a short baseline, if the same type of antenna with the identical orientation is applied, only the difference of the PCVs between the two antennas cannot be eliminated by calculating double difference. Figure 6 shows that the difference of the PCV of TBIII antenna with CR-GP is so small that the type antenna calibration is sufficient in this case and an individual calibration is not necessary.

### 3. Comparison of different Shieldings

Compared with flat GP, the cost of the CR-GP is much higher. Although the antenna calibration shows that the PCV of TBIII antenna with CR-GP is much better than with flat GP. However, the most important fact is that quality (accuracy and reliability) of the measurement with the CR-GP is significantly better than that with flat GP.

#### 3.1 Test Scenario

For this purpose, the TBIII antennas with the flat GP and CR-GP have measured with Ublox LEA-6T GPS receiver at the same point, and to see the effect of shieldings, the TBIII without any shielding has also measured. Besides, the geodetic dual-frequency receiver-system (Leica GX1230 GNSS receiver with AX1203 GNSS antenna) was taken for comparison, simply because it is best geodetic receiver-system at IIGS as the measurements were carried out, and it should give reliable and accurate "reference values" for the measurement points.



Figure 7: Four combinations of antenna-shieldings

So that means there are totally four combinations of receiver-antenna-shielding (see Figure 7):

- 1) TBIII antenna without shielding + Ublox LEA-6T single-frequency GPS receiver,
  - 2) TBIII antenna with flat GP + Ublox LEA-6T single-frequency GPS receiver,
  - 3) TBIII antenna with CR-GP + Ublox LEA-6T single-frequency GPS receiver,
  - 4) Leica AX1203 GNSS antenna without additional shielding + Leica GX1230 GNSS receiver.
- According to Leica (2016) there is already a GP integrated in AX1203 GNSS antenna.

In Figure 8 and Figure 9 the photo and the draft of test field are shown. Two points P1 and P2 were set up next to the metal wall on the roof of the IIGS-building, with a distance between two points of 0.5 m. A SAPOS station (Satellitenpositionierungsdienst der Deutschen Landesvermessung), which is one of the reference stations of the German Satellite Positioning Service, is only about 500 m away from the test field (compare Figure 9). This station is taken as reference station and the two stations in the test field are taken as rover stations for processing the baselines, so that two baselines can be obtained.

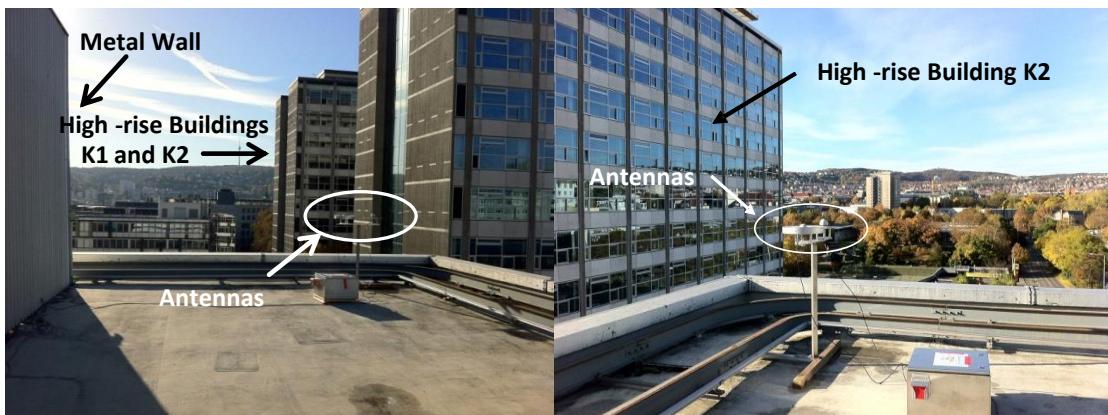


Figure 8: Photos of Test Field

As it can be seen from Figure 9, there are many obstructions in the antenna surroundings, but the multipath effect and diffraction are most likely caused by the metal wall (about 4.6 m away), the two high buildings (about 50 m and 100 m away) and the ground (antennas are about 1.2 m above the ground), since the area of the reflector should be bigger than the so-called Fresnel zone to cause multipath effects (Van Nee 1995). The CR-GP can reduce the influence of the reflected signal coming from the ground, but they cannot prevent these reflected signals arriving higher than is the antenna horizon (Weill 1997).

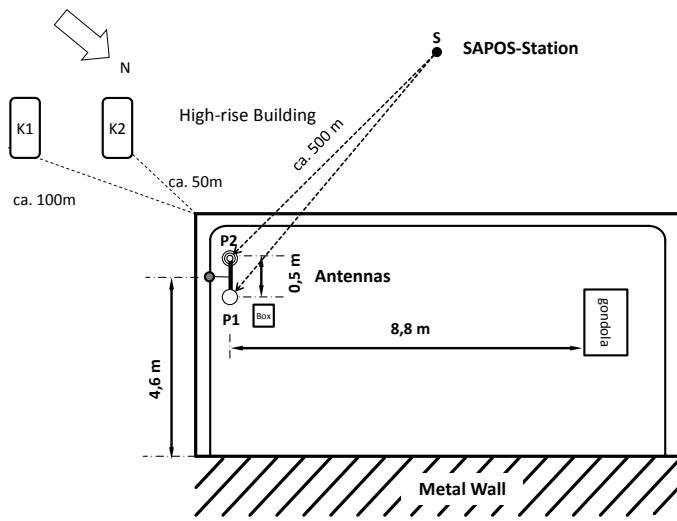


Figure 9: Test field of antenna-shieldings (not to scale)

Two combinations of antenna-shielding are measured at two points at the same time for about one day, so there is four sessions. Table 1 shows the date and the combinations of the antenna-shieldings of these four sessions.

Table 1: Sessions of antenna-shieldings test

Session Nr.	Date	Antenna and shieldings	
		P1	P2
1	24.-25. 10.13	TBIII+ CR-GP	TBIII+ flat GP
2	27.-28. 10.13	TBIII+ flat GP	TBIII+ CR-GP
3	26.-27. 04.14	Leica AX1203	TBIII without shielding
4	27.-28. 04.14	TBIII without shielding	Leica AX1203

### 3.2 Data Processing

Since the measurements are carried out at different days and the time span between the first two sessions and the session 3 and 4 is quite large, the sessions are adjusted to get the approximately the same satellite configuration. The satellite orbits repeat actually not in 23 hours 56 minutes 4 seconds, the so-called sidereal day (Seeber et al. 1997, Choi et al. 2004). The satellite period varies even from satellite to satellite and from time to time. The average satellite period is according to the investigating in Zhang (2016) about 246 seconds shorter than 24 hours (23 hours 55 minutes 54 seconds). This value matches very well to the investigating in Seeber et al. (1997). So 20 hours are cut from the original observation time for the data processing (compare Table 2).

Table 2: Observation Time for Data Processing

Session Nr.	Observation time (GPS-Zeit)
1	24.10.13 10:30:30 - 25.10.13 06:30:29
2	27.10.13 10:17:18 - 28.10.13 06:17:18
3	26.04.14 21:51:06 - 27.04.14 17:51:05
4	27.04.14 21:47:00 - 28.04.14 17:46:59

The GPS raw data are recorded from the two receivers at 1 Hz, stored on a PC, evaluated and post-processed. The raw data are in UBX binary format and are converted into RINEX format using the TEQC (TEQC 2014) provided by Unavco (Unavco 2016), and the baseline is processed by software Wa1 provided by Wasoft (Wasoft 2015).

### 3.3 Quality Analysis

In Wa1 it is possible to deliver the baseline in UTM-system for every measurement epoch, which means one can get the baseline in east, north and height for every second in this case.

The outliers in the coordinates' time series, which are probably caused by unfixed ambiguities, are detected according to the  $3\sigma$ -rule and linearly interpolated, and the standard deviation is calculated. The percentage of outliers  $o$  and the standard deviation  $s$  are regarded as parameter for describing the reliability and accuracy of the measurements, respectively. Reliability and accuracy are two parameters to describe to quality of GPS measurement (Zhang 2016).

Since Leica geodetic GNSS receiver-system cannot only receive all the frequencies of GPS signal (L1, L2 and L5) but also the signals of GLONASS. Its data were processed firstly only using the GPS L1-frequency, and then with all the available signals.

The results of quality analysis of the antenna-shielding on point P1 and P2 are shown in Table 3 and Table 4. Since P2 is more far away from the metal wall than P1, the quality of the measurement on P2 is better than that on P1, with the exception of Leica receiver-system. The possible reason is that the antenna and receiver of Leica receiver-system have detected some of the multipath signal and eliminated them.

Table 3: Results of Quality Analysis of antenna-shielding test on P1

Quality	Receiver		Ubox LEA-6T GPS-L1-Receiver		Leica GX1230 GNSS-Receiver	
	Antenna		Trimble Bullet III		Leica AX1203	
Shielding		-	GP	CR-GP	-	-
Frequency		GPS-L1	GPS-L1	GPS-L1	GPS-L1	GNSS
Reliability (Percentage of Outliers)	$o_E$ [%]	4.5	3.2	2.8	1.5	1.0
	$o_N$ [%]	4.3	3.8	3.2	2.4	1.1
	$o_h$ [%]	4.0	3.7	2.8	1.7	0.9
	$o_m$ [%]	4.3	3.6	2.9	1.9	1.0
	Accuracy	$s_E$ [mm]	7.0	6.0	3.5	4.0
						3.5

	(Standard Deviation- $1\sigma$ )	$s_N$ [mm]	10.8	8.3	5.0	6.1	4.4
		$s_h$ [mm]	16.5	14.3	9.0	11.2	9.8
		$s_p$ [mm]	20.9	17.6	10.9	13.4	11.3

Table 4: Results of Quality Analysis of antenna-shielding test on P2

	Receiver		Ubox LEA-6T GPS-L1-Receiver			Leica GX1230 GNSS-Receiver	
	Antenna		Trimble Bullet III			Leica AX1203	
	Shielding		-	GP	CR-GP	-	-
	Frequency		GPS-L1	GPS-L1	GPS-L1	GPS-L1	GNSS
Quality	Reliability (Percentage of Outliers)	$o_E$ [%]	3.9	1.6	1.4	1.9	1.8
		$o_N$ [%]	4.8	2.1	1.9	3.0	1.6
		$o_h$ [%]	3.9	1.8	1.4	2.8	1.8
		$o_m$ [%]	4.2	1.8	1.6	2.6	1.7
	Accuracy (Standard Deviation- $1\sigma$ )	$s_E$ [mm]	6.6	5.2	3.2	3.5	3.5
		$s_N$ [mm]	9.3	7.4	4.8	4.9	5.2
		$s_h$ [mm]	16.9	12.3	8.4	8.4	10.4
		$s_p$ [mm]	20.4	15.3	10.2	10.3	12.1

To have a better overview of the results of quality analysis, the mean value of results on point 1 and 2 is calculated and shown in Table 5. Besides, the mean value of percentage of outliers  $o_m$  and Standard Deviation in Position  $s_p$  of Table 5 are visualized in Figure 10.

As shown in Figure 10, the TBIII antenna with CR-GP is more reliable and accurate than without shielding and with flat GP. The improvement of the standard deviation of the measurement using the CR-GP is about 50 % and 35 % compared with that using antenna without shielding and with flat GP respectively.

Table 5: Results of Quality Analysis of antenna-shielding test (mean of P1 and P2)

	Receiver		Ubox LEA-6T GPS-L1-Receiver			Leica GX1230 GNSS-Receiver	
	Antenna		Trimble Bullet III			Leica AX1203	
	Shielding		-	GP	CR-GP	-	-
	Frequency		GPS-L1	GPS-L1	GPS-L1	GPS-L1	GNSS
Quality	Reliability (Percentage of Outliers)	$o_E$ [%]	4.2	2.4	2.1	1.7	1.4
		$o_N$ [%]	4.6	3.0	2.6	2.7	1.4
		$o_h$ [%]	4.0	2.8	2.1	2.3	1.4
		$o_m$ [%]	4.2	2.7	2.3	2.2	1.4
	Accuracy (Standard Deviation- $1\sigma$ )	$s_E$ [mm]	6.8	5.6	3.4	3.8	3.5
		$s_N$ [mm]	10.1	7.9	4.9	5.5	4.8
		$s_h$ [mm]	16.7	13.3	8.7	9.8	10.1
		$s_p$ [mm]	20.7	16.4	10.5	11.9	11.7

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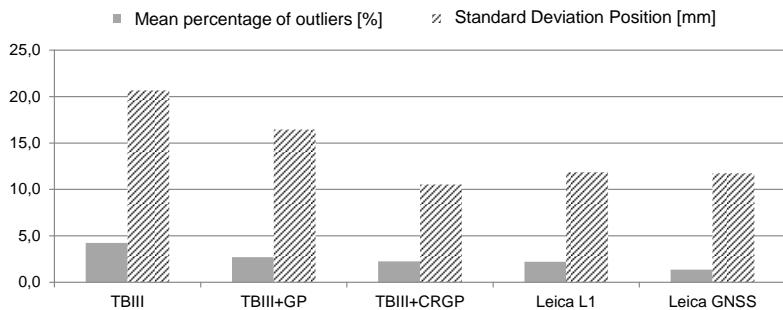


Figure 10: Quality of combination of antenna-shielding (mean of P1 and P2)

The TBIII antenna with CR-GP can achieve a standard deviation of ca. 3 mm in east, 5 mm in north and 9 mm in height in this reflexion intensive environment. The accuracy of the TBIII antenna with CR-GP is even better than the Leica AX1203 antenna, if only GPS L1-frequency is processed. That is mainly because the integrated ground plane in Leica AX1203 antenna cannot reduce the multipath signal as good as the CR-GP.

If all the available data of Leica AX 1203 antenna with GX1230 receiver are processed, it has the best reliability but not the best accuracy. The TBIII antenna with CR-GP has a better accuracy than the Leica AX 1203 antenna with GX1230 receiver. However, one should not forget that the standard deviation is calculated without outliers. Here the TBIII antenna with CR-GP has more outliers detected than the Leica receiver-system. So, generally the TBIII antenna with CR-GP has shown in this test a result, which is comparable with Leica AX 1203 antenna with GX1230 receiver. Besides, the CR-GP is the best shielding.

### 3.4 Frequency Analysis

Many obstructions in the antenna surroundings, it can be seen in Figure 8 and Figure 9. The reflected signal can cause periodic multipath effects (Georgiadou and Kleusberg 1988) on the carrier phase measurement and the periodic effects or many harmonic oscillations can be also found in the coordinates (Heister et al. 1997). In Irsigler (2008), the frequency of multipath on the carrier phase can be estimated for horizontal and vertical reflectors using the equation (1):

$$\delta\varphi(t) = \frac{2}{\lambda} \cdot \begin{cases} h \cdot \cos E^s(t) \cdot \dot{E}^s(t) & \text{horizontal} \\ -d \cdot \sin E^s(t) \cdot \dot{E}^s(t) & \text{vertical} \end{cases} \quad (1)$$

$\lambda$  is the wavelength (19 cm approximately for the L1-frequency);  $h$  and  $d$  are the vertical and horizontal distances between the antenna and the reflector. The closer the reflector is located, the longer is the period.  $E^s$  and  $\dot{E}^s$  are the elevation of the satellite and its change over time (velocity). A satellite with high elevation can cause long and short periodic multipath effects respectively for horizontal and vertical reflectors. The faster the satellite is moving, the shorter generated period of the multipath effect. The wavelength is constant, for one antenna, the distance  $h$  and  $d$  does not change so much. However, the elevation of the satellite changes all the time and the velocity of elevation is not constant, either. For this reason, the frequency of multipath effects varies all the time. Using the mean value of the velocity of the elevation 0.07 mrad/s and equation (1), the period

caused by the multipath effects can be calculated. The period caused by the ground should be more than 20 minutes (that means the frequency should be smaller than 0.83 mHz), and that from the metal wall varies from about five minutes to half an hour (that means the frequency should be between 0.55 and 3.3 mHz). The antennas should be affected by the multipath effects by both ground and metal wall. Generally, one can say that the frequency which is less than 0.55 mHz is mainly caused by multipath signals from the ground. It should be known that these calculated periods or frequencies are only the roughly estimated values, since the satellite velocity is not constant.

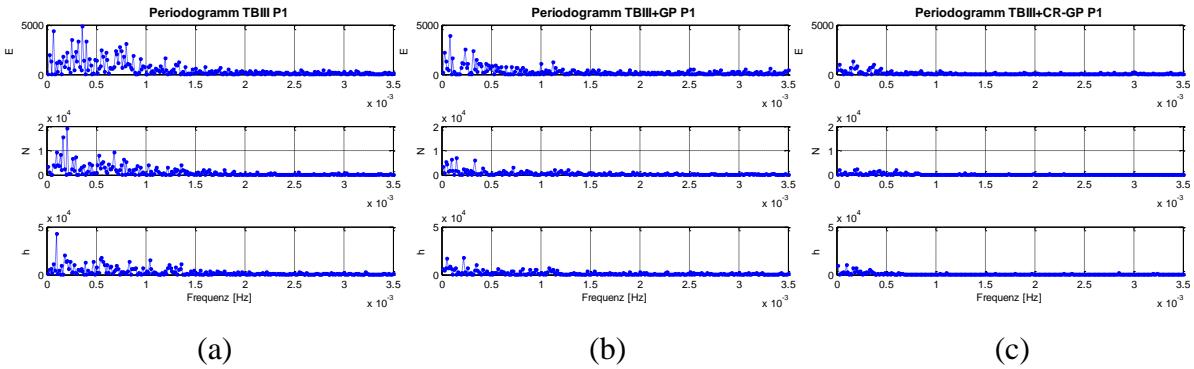


Figure 11: Periodogramm of coordinates' time series of TBIII antenna  
(a) without shielding, (b) with flat GP, (c) with CR-GP on point P1

Figure 11 shows the periodograms (up to 3.5 mHz) of coordinates' time series of the antenna-shielding test on point P1. It can be seen from Figure 11 that the frequencies with high amplitude or energy distribute mainly between 0 and 1.5 mHz. By applying the shielding, the energy between the 0 and 0.55 mHz is reduced considerably, and CR-GP reduced even more energy than the flat GP. That means the shieldings reduced mainly the signal from the ground and the CR-GP is more effective than the flat GP. The periodograms of time series on point P2 show the same effect. These results match very well to the explained theory in section 2 and to the quality analysis in section 3.3.

#### 4. Conclusion

In this paper, the design of a L1-optimized choke ring ground plane (CR-GP) is described. The results of antenna calibration of the TBIII antenna with CR-GP and flat GP are shown. The PCV of the TBIII antenna with CR-GP are smaller and more homogenous than with flat GP. Individual antenna calibration of TBIII antenna with CR-GP is not necessary.

The antenna-shielding test shows CR-GP is the best shielding. The improvement of the standard deviation of the measurement using the CR-GP is about 50 % and 35 % compared with that using antenna without shielding and with flat GP respectively. The standard deviation of TBIII antenna with CR-GP is 3 mm in east, 5 mm in north and 9 mm in height in the test filed which has many reflectors. The TBIII antenna with CR-GP shows in the test reliable and accurate results, which is comparable to the Leica AX 1203 GNSS antenna with GX1230 GNSS receiver.

The frequency analysis shows that the shieldings reduce mainly the multipath signal from the ground and the CR-GP is more effective than the flat GP. These results match very well to theory and also to the quality analysis.

Apart from that, the CR-GP is not for all the application suitable because of its weight. Besides, the single GPS receiver-system has its limitation, if the baseline is long (more than 10 km), and it is also not really suitable for PPP (Precise Point Positioning) up to now, if the accuracy should be in mm or cm level. Because they receive only the L1-frequency, the ionospheric influence cannot be reduced in both cases.

However, the introduced low-cost GPS receiver-system (costs up to 1000 €), which contains the Ublox LEA-6T single-frequency GPS receiver and TBIII antenna with self-constructed L1-optimized CR-GP, can already obtain an accuracy in the range of millimetres which meets the requirements of geodetic precise monitoring for such as landslides, bridges and dams and so on. Based on this reliable and accurate low-cost GPS receiver-system, two algorithms by considering temporal and spatial correlations are developed in Zhang (2016) to improve the accuracy of this system. The accuracy is improved further by 50% in near-real time.

Leading to the conclusion the potential of the low-cost GPS receiver-system for monitoring tasks should not be underestimated.

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Investigation of a L1-optimized Choke Ring Ground Plane for a Low-Cost GPS Receiver-System (8513)  
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