C/A code biases in high-end receivers

Andrew Simsky and Jean-Marie Sleewaegen

a.simsky@septentrio.com; jm.sleewaegen@septentrio.com

Septentrio, Belgium

Abstract

Some high-end receivers produce anomalous meter-level PRN-dependent biases when multipath-mitigating code tracking is used. Anomalous biases up to 1.65m occur for PRNs **7,8,15,17,21 and 24**. The analysis reported in this paper reveals the reason for this anomaly:

The autocorrelation peaks for the PRNs 7,8,15,17,21 and 24 exhibit slight deviations from the ideal triangle. When multipath mitigation is enabled, this distortion may be mistaken for multipath and induces the bias.

This anomaly can not only affect IGS processing, but all bias-sensitive applications, such as code-based DGPS or WAAS. Once these anomalous biases are known and understood, they are easily compensated either in the receiver or in post-processing.

Normal code biases

(Background information)

P1-P2 bias, τ_{gd} (time group delay)

- Average difference between P1 and P2 code ranges
- Broadcast by GPS satellites in the navigation message
- Also tabulated by IGS data processing centers

C/A – P1 bias (group delay of C/A code)

- Average difference between C/A and P1 code ranges
- Not broadcast by GPS satellites (not available in real time)
- Tabulated by IGS processing centers (CODE at the UniBe)
- Include constant receiver-side component
- May be affected by multipath-mitigation tracking methods

Well-known τ_{gd} (time group delay), defined in the GPS ICD, refer to the P1 code and do not directly apply to the C/A code. The C/A code has an additional group delay, which is neither defined nor transmitted by the GPS itself. This delay may affect positioning for those users, who use either C/A code or iono-free C/A+P2 combination for positioning (many receivers do not track P1 code).

Normal C/A – P1 code biases

(tabulated and disseminated by CODE)

http://www.aiub.unibe.ch/download/CODE/P1C1.DCB

```
CODE'S 30-DAY GPS P1-C1 DCB SOLUTION, ENDING D032, 2004          05-
FEB-04 11:57
----------------------------------------------------------------------
---------

DIFFERENTIAL (P1-C1) CODE BIASES FOR SATELLITES AND RECEIVERS:

PRN / STATION NAME        VALUE (NS)  RMS (NS)       VALUE (METERS)
***   ****************    *****.***   *****.***      *****.***
G01                          -0.052       0.010          -0.016
G02                          -1.092       0.016          -0.327
G03                           0.008       0.012           0.002
G04                           1.391       0.014           0.417
G05                          -0.816       0.013          -0.245
G06                           0.614       0.010           0.184
G07                          -0.961       0.024          -0.288
G08                          -0.599       0.007          -0.180
G09                           0.384       0.015           0.115
G10                          -1.402       0.013          -0.420
G11                           0.489       0.019           0.147
G13                           1.432       0.011           0.429
G14                           0.185       0.017           0.055
G15                          -0.937       0.017          -0.281
G16                          -0.514       0.013          -0.154
G17                          -0.810       0.012          -0.243
G18                          -0.065       0.012          -0.020
G20                          -1.108       0.009          -0.332
G21                          -0.432       0.018          -0.130
G22                           0.377       0.017           0.101
G23                          -0.428       0.033          -0.128
G24                           0.342       0.013           0.103
G25                           0.564       0.016           0.169
G26                           1.294       0.009           0.388
G27                          -0.067       0.010          -0.020
G28                          -0.274       0.014          -0.082
G29                           0.788       0.012           0.236
G30                           2.023       0.015           0.605
G31                          -0.335       0.011          -0.100
```

These biases are caused by hardware delays in GPS satellites and are obtained as a by-product of IGS processing. They have a zero average and do not contain the receiver-dependent component (which is normally a PRN-independent constant).

C/A – P1 biases measured by receivers

Table 1. Deviations of measured C/A-P1 biases from normal (IGS-CODE recommended) values, meters.

PRN	Raw C/A code (no multipath mitigation)		Multipath mitigation used Anomalous biases shown in **red**	
	PolaRx	receiver B	PolaRx (**anomaly suppession disabled**)	receiver B
01	0.034	0.114	-0.066	0.064
02	-0.087	-0.077	0.133	0.113
03	-0.008	-0.008	0.162	0.032
04	-0.063	-0.013	-0.053	0.057
05	-0.045	0.115	-0.055	0.175
06	-0.024	0.066	-0.040	-0.104
07	0.082	-0.028	**-0.358**	**-1.708**
08	-0.040	0.03	**0.430**	**1.410**
09	0.045	-0.055	0.035	0.045
10	0.030	0.060	0.030	0.150
11	0.067	-0.070	-0.203	-0.103
13	-0.081	-0.131	-0.231	-0.051
14	0.015	0.065	-0.165	-0.165
15	0.039	0.059	**-0.401**	**-1.671**
16	-0.144	-0.114	-0.094	-0.094
17	0.097	-0.023	**-0.283**	**-1.63**
18	-0.010	-0.050	-0.19	-0.07
20	-0072	-0.052	-0.052	0.018
21	-0.080	-0.030	**-0.670**	**-1.82**
23	0.082	0.14	0.162	0.092
24	0.043	0.013	**-0.357**	**-1.59**
25	-0.041	-0.091	-0.089	-0.031
26	-0.002	-0.022	-0.042	0.058
27	0.000	-0.02	0.15	0.04
28	-0.052	-0.082	-0.102	-0.002
29	0.026	-0.006	0.076	-0.036
30	0.125	0.055	0.005	-0.095
31	-0.010	0.000	-0.030	0.07
STD	**0.06**	**0.06**	**0.24**	**0.79**

When no multipath mitigation is used, the measured C/A code biases are normal within tolerance. When multipath mitigation is used, abnormal biases occur for PRNs 7,8,15,17,21,24.

Note: In PolaRx (Septentrio's receiver, see p. 13), anomalies of the C/A code are compensated by default. For this test the compensation has been disabled.

C/A – P1 biases measured by receivers.

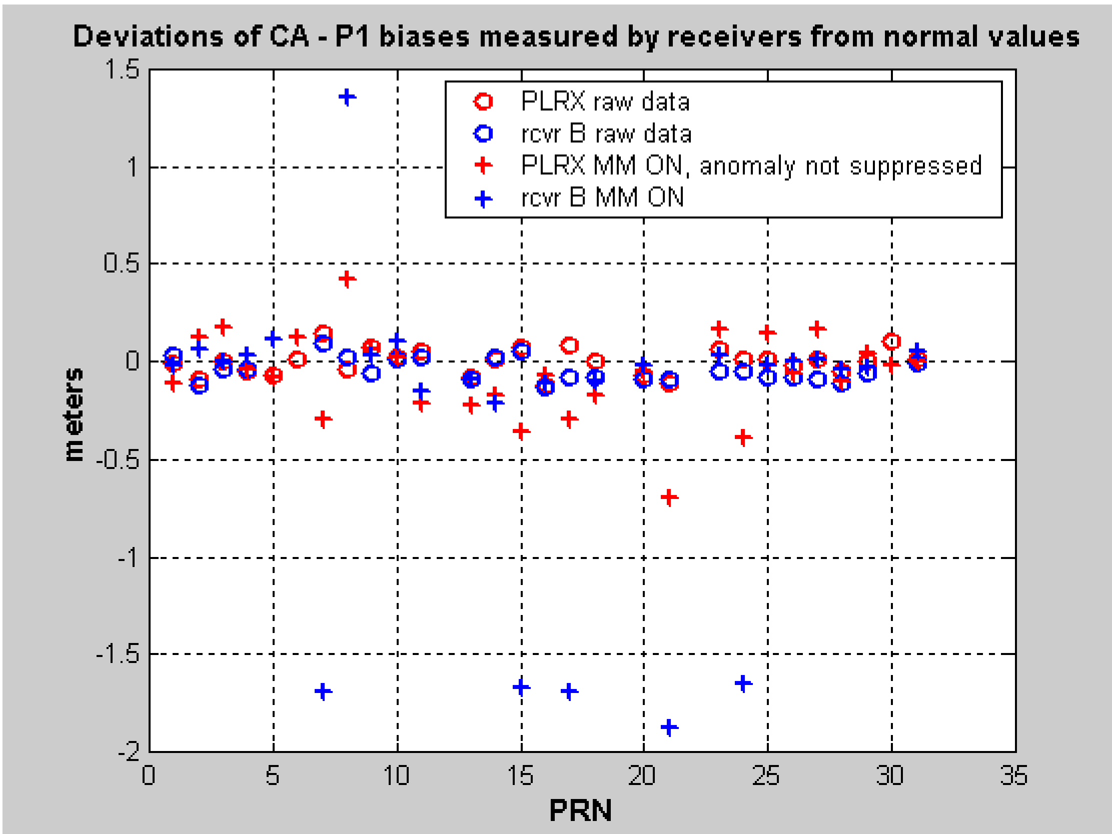

Figure 1. Deviations of C/A – P1 code biases (meters) directly computed with actual GPS data sets from CODE-recommended values for PolaRx2 and receiver B. Receiver hardware delay is taken out, so that all the biases have zero average. MM stands for "Multipath mitigation".

This plot corresponds to the data in Table 1. Without multipath mitigation there is a good agreement between observed and recommended values of C/A – P1 code biases. When multipath mitigation is used, anomalous biases can be clearly seen for six PRNs: 7, 8, 15, 17, 21, 24. The sign of the anomalous bias is positive for PRN 8 and negative for all the other PRNs. The absolute value is about 1.6 meters for receiver B and about 0.5 m for PolaRx.

Note: In PolaRx (Septentrio's receiver, see p. 13), anomalies of the C/A code are compensated by default. For this test the compensation has been disabled.

Principle of multipath mitigation (APME)

When no multipath is present, the GPS receiver only receives the line-of-sight signal from the satellite. It computes the correlation function of this signal with the local replica of the PRN code, and tracks the main peak of this correlation function. In ideal conditions (no multipath), the correlation function is a triangle.

When multipath is present, the incoming signal is a superposition of several copies of the same signal with different delays, amplitudes and phases. All these copies contribute to the correlation in such a way, that the composite correlation peak deviates from its ideal triangular shape. Such distortion is illustrated in Figure 2.

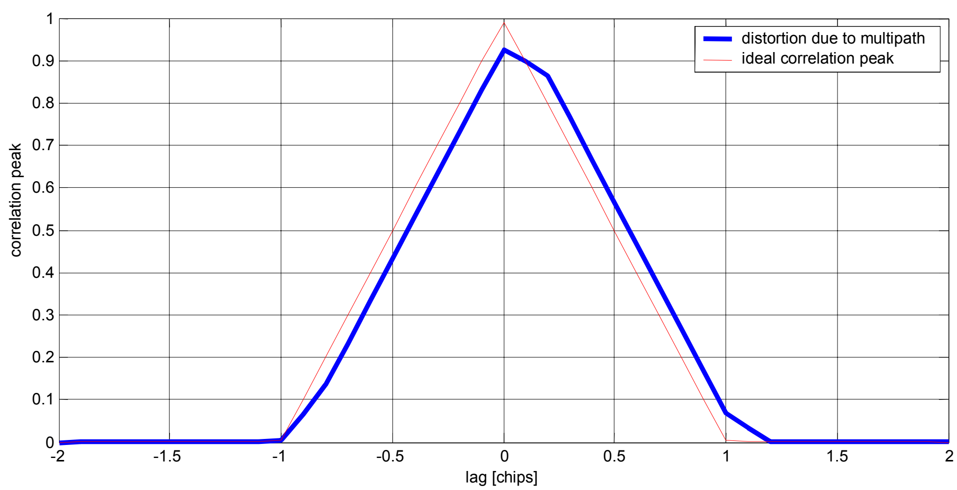

Figure 2. Distortion of the main code correlation peak due to multipath.

Many multipath mitigation methods used in high-end receivers attempt to compensate multipath errors by sensing the deviations of the shape of the correlation peak from an ideal triangle. The method used in PolaRx is based on the same principle. It is called APME, which stands for A-Priori Multipath Estimation, and has been proposed in [1].

Why some PRNs are anomalous?

The autocorrelation functions of the C/A-code exhibit spurious correlation peaks for all the PRNs. For most satellites, these side peaks are located at least 2 chips away from the main correlation peak. Therefore the shape of the main auto-correlation peak is not affected. This is illustrated in Figure 3.

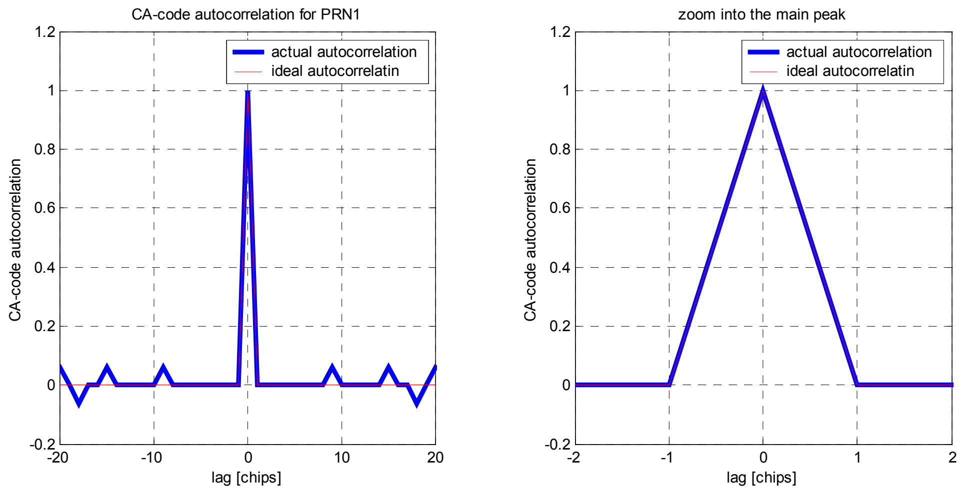

Figure 3. C/A-code autocorrelation for PRN1 (main peak is shown in the right plot).

For PRNs 7, 15, 17, 21 and 24, a positive side peak is located only one chip away from the main peak. The result is a slight positive distortion of the main peak. This is illustrated in Figure 4.

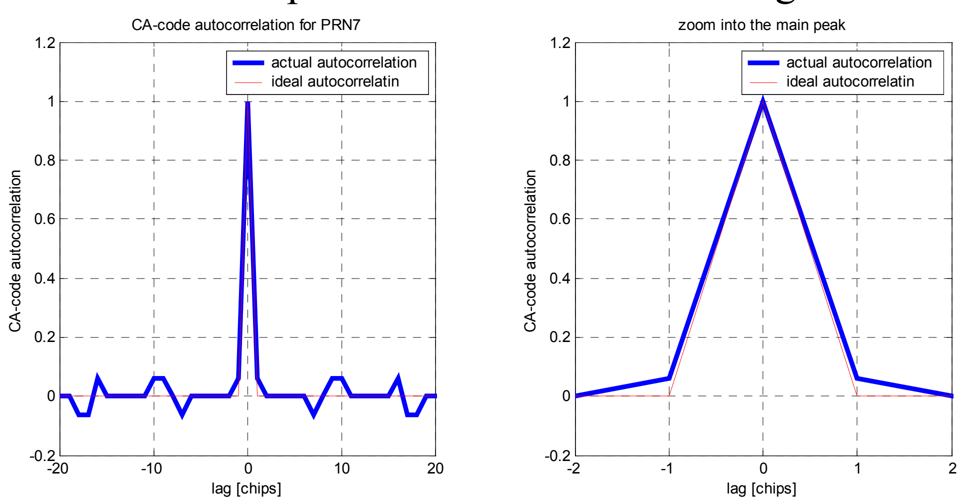

Figure 4. C/A-code autocorrelation for PRN7.

For PRNs 8 and 22, a negative side peak is located one chip away from the main peak. The result is a slight negative distortion of the main peak. This is illustrated in Figure 5.

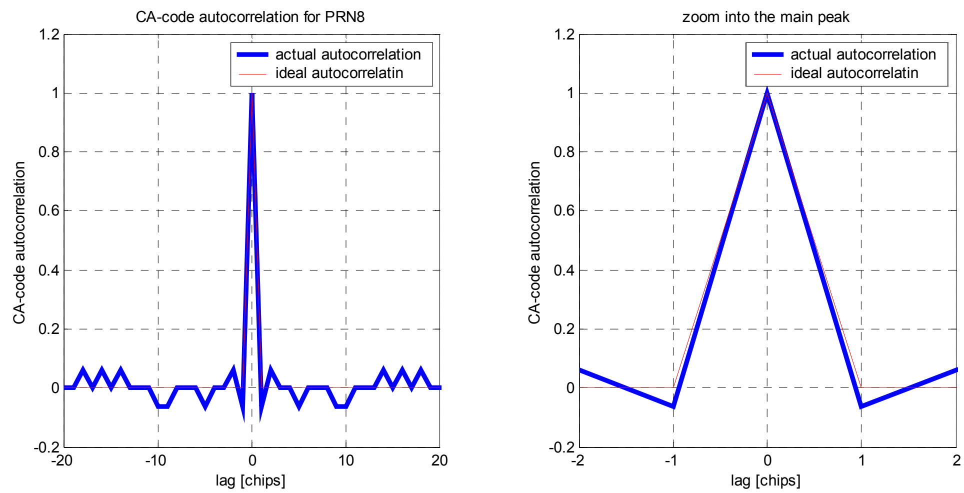

Figure 5. C/A-code autocorrelation for PRN8.

The deviations of the main peak from its ideal triangular shape for PRNs 7, 8, 15, 17, 21, 22 and 24 are interpreted as multipath by those multipath mitigation algorithms, which assume that the main autocorrelation peak has the same shape for all the satellites, and cause anomalous biases of the C/A code for these PRNs.

According to the proposed theory, these anomalous biases are expected to be positive from PRNs 8 and 22 and negative for PRNs 7, 15, 17, 21, 24. The absolute values of all the biases are expected to be equal. This perfectly agrees with our experimental material presented in Table 1 and Figure 1. However, we do not present data on PRN 22, because this PRN was not transmitting at the time when the data was collected (at the time of this presentation PRN22 has resumed transmitting).

Handling of anomalous biases

In the case of PolaRx, the absolute value of code biases caused by non-ideal shape of autocorrelation peaks can be computed from the formulas of APME and amounts to 0.55 m. In PolaRx receiver, compensation of these biases is now done internally (based on the results of this research). For receiver B no compensation was possible within the receiver, but it could be done in post-processing: the empirical estimate of the C/A code bias for the receiver B is 1.65 m (see Figure 1).

Once anomalies are removed, the deviations of C/A code biases from normal values fall within 30 cm envelope (see Figure 6). The STD is reduced to 14 cm for PolaRx2 and 10 cm for receiver B.

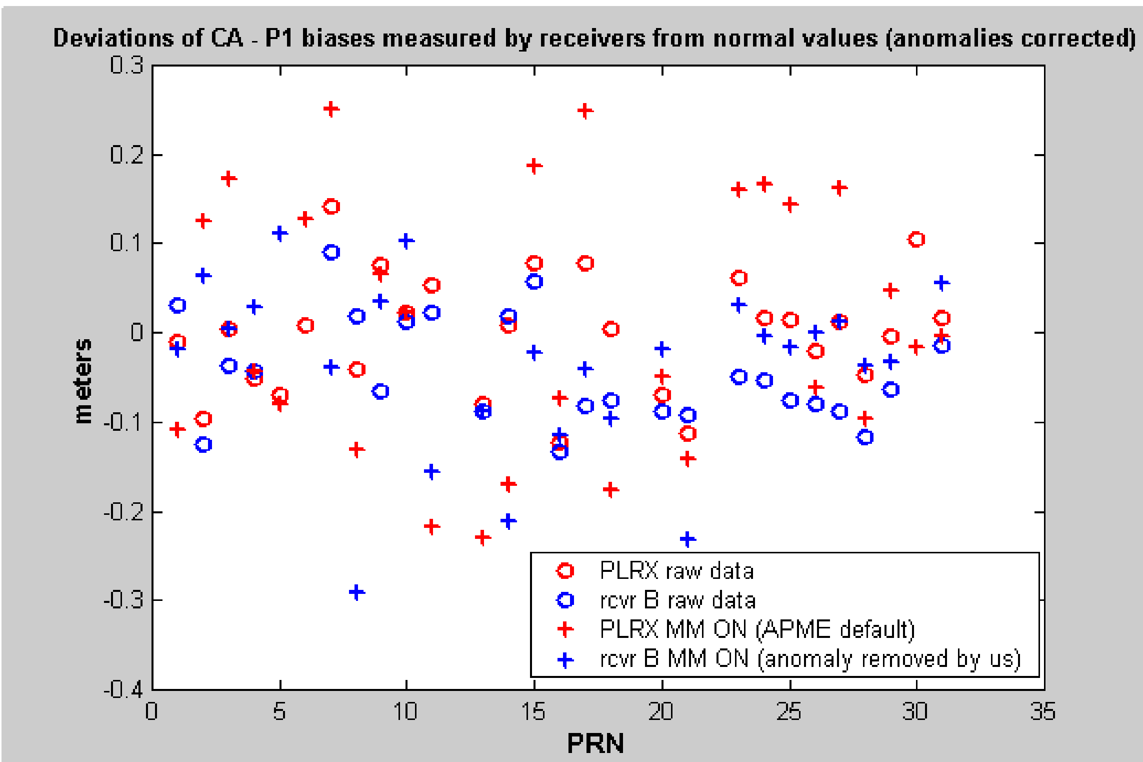

Figure 6. Compare to Figure 1; in this plot anomalous biases are compensated. MM stands for "Multipath mitigation".

C/A – P1 biases and receiver positioning

Currently the default action of GPS receivers is to correct only for the broadcast τ_{gd} (P1-P2 biases). This is the requirement of the GPS ICD, which implies that P1 and P2 codes are used for positioning.

However, many existing civilian receivers do not generate P1 code. These receivers use only C/A code and will benefit from additionally correcting it for biases specific only for this code. Quite obviously, corrections for normal C/A code biases may be applied unconditionally, while anomalous biases must be compensated only if they actually appear as a side effect of some multipath mitigation techniques.

Below we summarize the possible effect of C/A code biases (both normal and anomalous) on positional accuracy.

Standalone positioning

When normal C/A code biases are taken into account, the improvement of accuracy is less significant than with the τ_{gd} correction due to relatively smaller values (< 1 m). For dual-frequency positioning, based on the iono-free combination of C/A and P2 code, the positional accuracy is improved by about 10% when IGS-recommended C/A code biases are added on top of τ_{gd}.

Anomalous code biases, if they occur, may have quite significant adverse effect on standalone positioning. In case of receiver B with C/A code biases as large as 1.5 m, the accuracy of standalone positioning is at least 30% worse as compared to the positional solution with fully compensated biases.

DGPS positioning

In the case of DGPS positioning, C/A code biases have no effect on the positional solution as long as the biases on the base and rover receivers are equal and cancel out together with other satellite-side effects. Therefore, normal C/A code biases have no effect on DGPS/SBAS positioning as long as all the involved receivers handle them consistently (for example, do not correct for them).

Anomalous C/A code biases may have significant adverse effect on DGPS accuracy if they are different in base and rover receivers. Table 2 shows the example where receiver B with multipath mitigation ON was used for zero-baseline processing with the PolaRx (for the PolaRx, multipath mitigation was not used). Receiver B shows significant anomalous C/A code biases, and therefore positional errors are abnormally high. Receiver A does not show anomalous C/A code biases and, therefore, the zero-baseline accuracy is normal.

Pairs of receivers for zero-baseline DGPS	**Height, meters**			**Longitude, meters**			**Latitude, meters**		
	rms	**bias**	**Std**	**rms**	**bias**	**Std**	**rms**	**bias**	**std**
PolaRx + rcvr A (no anomalies)	0.18	-0.02	0.18	0.14	-0.03	0.13	0.19	0.00	0.19
PolaRx + rcvr B with MM on	0.98	0.54	0.81	0.47	0.05	0.46	0.68	-0.45	0.51

Table 2. Normal positional accuracy of zero-baseline DGPS (top raw) and affected by anomalous biases (bottom raw).

This means that DGPS users must be careful when they use multipath mitigation on rover or base receivers. Anomalous code biases may appear as a side effect of multipath suppression and the result may be deterioration of accuracy instead of improvement.

Operators of DGPS/RTK networks must also be aware of the possibility that multipath mitigation feature on base station receivers may introduce C/A code biases as a side effect.

PolaRx2 GNSS receiver

The research of C/A code biases presented in this paper was performed with PolaRx2 receiver, designed and manufactured by Septentrio, s/w version 2.3. PolaRx2 is a high-end dual-frequency receiver for geodetic applications [2]. PolaRx2 uses APME multipath mitigation method as a standard feature. Following this research, the compensation of C/A code biases has been included in APME.

Figure 7. The outside view of PolaRx2, a Eurocard-formatted OEM board.

Measurements	**STD of tracking noise at 45dB-Hz, 1 Hz**
C/A code ranges	0.15 m (0.3 m with APME)
P1 and P2 code ranges	0.1 m (no Xcorrelation with C/A code)
L1 phase	0.2 mm (full wavelength)
L2 phase (semicodeless tracking)	0.4 mm (static mode), 1.0 mm(kin. mode)
D1 & D2 (Doppler shifts)	0.5 mm/sec (2.5 mHz)

Table 3. Measurement noise of PolaRx2 [2].

Performance of APME

APME (A-Priori Multipath Estimation) is Septentrio's multipath mitigation technology based on the analysis of the shape of the auto-correlation peak [1]. APME affects only C/A code. Table 4 presents average multipath errors for static data collected on the rooftop of Septentrio with 2 different antennas: geodetic-grade choke-ring AOA antenna and a Sensor Systems antenna used for aircraft navigation.

The reduction of multipath by APME is more significant for the Sensor Systems antenna, which itself performs no suppression of multipath. In this case multipath is reduced by about 30%. For the choke-ring antenna the reduction of multipath is only 20% because the antenna itself already suppresses much of the multipath. The remaining multipath noise (35 cm) comes close to the tracking noise, which means that most of the multipath is suppressed. P1 and P2 codes are not affected by APME, but their multipath is intrinsically lower due to the shorter chip length.

	APME	**C/A code, m**	**P1 code, m**	**P2 code, m**
AOA choke ring	YES	0.35	0.40	0.45
AOA choke ring	NO	0.45	0.40	0.45
Sensor Systems	YES	0.50	0.50	0.55
Sensor Systems	NO	0.75	0.50	0.55

Table 4. STD of the multipath combination with PolaRx2 for all the three code ranges for Septentrio's antenna site in Leuven.

Following the results of this research, APME does not introduce any additional delays to C/A code pseudoranges on top of hardware delays in satellites and receivers.

Conclusions

It has been shown that some high-end receivers produce anomalous meter-level PRN-dependent biases when multipath-mitigating code tracking is used. Anomalous biases up to 1.65 m occur for PRNs **7,8,15,17,21, 22 and 24** due to the deviations of the shape of the autocorrelation peak from ideal triangle for these PRNs. When multipath mitigation is enabled, this distortion is mistaken for multipath and induces the bias.

Anomalous C/A code biases may significantly effect receiver positioning, especially DGPS.

The mechanism of anomalous biases has been investigated with APME, Septentrio's multipath mitigation technique. Once these anomalous biases are known and understood, they can be easily compensated. In PolaRx, Septentrio's receiver, this compensation is applied.

Compensation of anomalous biases of C/A code may be crucial for bias-sensitive applications, such as IGS processing and DGPS/WAAS positioning.

References

1. Sleewaegen, J.- M. and Boon, F. *Mitigating short-delay multipath: a promising new technique*, Proceedings of ION GPS-2001, Sept. 2001.
2. Simsky, A., Sleewaegen J.-M., Bruyninx C. *PolaRx2, a new GPS receiver for geodetic applications. Proceedings of EUREF-2003 symposium*, Toledo, May 2003.
3. Simsky A., Boon F. *Positioning algorithms for the new PolaRx2 receiver*. Proceedings of 11th IAIN World Congress, 21-24 October 2003, Berlin.

Andrew Simsky
a.simsky@septentrio.com

Jean-Marie Sleewaegen
jm.sleewaegen@septentrio.com

Septentrio
satellite navigation