Chapter 45
Analysis of Signal Characteristic and Positioning Performance Affected by Pseudorange Multipath for COMPASS

Feng Zhang, Haibo He, Bin Tang, Fei Shen and Rong Chen

Abstract With the GNSS modernization, the satellite orbit error, the ionospheric delay and the tropospheric delay has been effectively eliminated or reduced, but the multipath error for different users is non-correlation, which can not be removed through differential technique, and then it will be the major error source for GNSS navigation and positioning. Considering COMPASS constellation contains GEO and IGSO satellites, which are high-orbiting satellites, so the multipath effect of COMPASS is different from that of GPS. In order to analyze the multipath effect of high-orbiting satellites, three schemes are adopted in this paper. (1) Model of code tracking multipath error is deduced based on coherent early minus-late delay lock loop, multipath error envelopes are achieved for different bandwidth and different correlation space. (2) The multipath effects on pseudo-range is quantitative analyzed based on the satellite signals and multipath signals simulated by the signal source. The performance of anti-multipath is analyzed for the first time with different receivers. (3) The pseudorange multipath effect on the navigation and positioning is analyzed with the observations of Compass receiver through differential algorithm of short line. The calculation and analysis shows that: Pseudorange Multipath of B1 is larger than B3, and Pseudorange Multipath of GEO is larger than IGSO and MEO. In static positioning, RMS of Multipath of B1 can reach up to 2.53 m, and RMS of Multipath of B3 can reach up to 0.73 m.

Keywords Multipath error · Code tracking · Simulation analysis · Narrow correlator · Pseudorange difference

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45.1 Introduction

COMPASS has been basically completed for regional navigation and positioning, which includes 5 GEO, 5 IGSO and 4 MEO satellites, so application research has attracted attention of many scholars based on hybrid constellation.

On the analysis and assessment of Beidou position performance, it is found pseudorange multipath error is the main error sources causing dual positioning bad. The Beidou pseudorange multipath not only correlate to satellite constellation and environment of application, but also correlate to signal bandwidth, receiver bandwidth and internal resources. Because of the small spatial correlation, it can not be corrected by differential technique [1]. Despite many methods of anti-multipath have been used, it is still difficult to eliminate multipath error.

At present, code tracking multipath error envelope based on coherent early minus-late delay lock loop is recognized as the evaluation standard [2, 3]. There have been many domestic and foreign papers researching on multipath of GPS signal, but multipath characteristics of Beidou II signal have not been studied in depth, the performance of anti-multipath have not been demonstrated, the multipath effect on positioning performance has not been comprehensively analyzed.

Concerning these problems and needs, in this paper, characteristics and related factors of Beidou civil signals are researched theoretically, performance of anti-multipath is analyzed through simulation for different receivers, and the pseudorange multipath analysis on the navigation and positioning is done with the observations of Compass receiver. It is helpful to study multipath characteristics and improve performance of anti-multipath of receivers.

45.2 Model of Multipath Error Envelope

The composite signal of Direct and multipath signal can be expressed as [4]:

$$r(t) = a_0 e^{j\varphi_0} g(t - \tau_0) + \sum_{i=1}^{N} a_i e^{j\varphi_i} g(t - \tau_i) \tag{45.1}$$

where, $g(t)$ is the complex envelope of emitted signal; a_0, φ_0, τ_0 are amplitude, phase and delay of direct signal; a_i, φ_i, τ_i are amplitude, phase and delay of the ith multipath signal; N is number of multipath signals. To simplify the discussion, considering $N = 1$.

Multipath effects are mainly reflected in the correlation characteristics of synthetical signal with multipath and direct signal [5]. On condition that amplitude of direct signal is 1, amplitude of multipath signal is 0.5, multipath delay are 0.4 chips, correlation properties of synthesized signal as shown in Fig. 45.1.

In actual uses, the relative phase and amplitude changes ceaselessly for the multipath signal relative to the direct signal, which cause the code loop

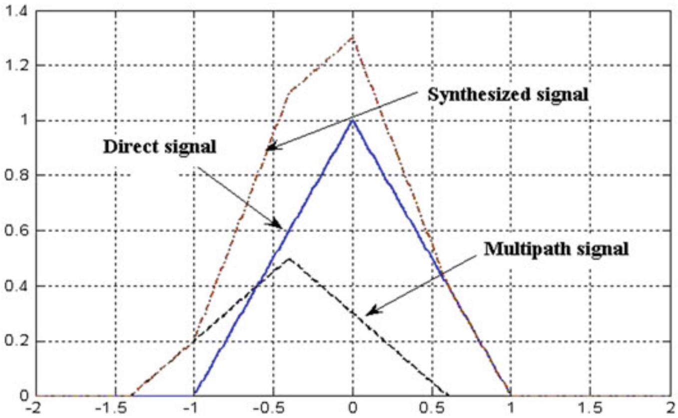

Fig. 45.1 Correlation properties of synthesized

discriminator deviates from the equilibrium tracking point, so tracking error is introduced in PRN code [6]. Code loop is usually designed to be coherent early minus-late delay lock loop, and multipath error envelope of code loop discriminator output as:

$$D(\varepsilon_\tau) = a_0[R(\varepsilon_\tau - d/2) - R(\varepsilon_\tau + d/2)] \pm a_1[R(\varepsilon_\tau - \tau - d/2) - R(\varepsilon_\tau - \tau + d/2)] \tag{45.2}$$

where, $R(\tau)$ is the code correlation function, ε_τ is time delay estimation of direct signal, d is space of coherent early minus-late delay correlator, multipath error is ε_τ when Discriminator output is zero, equal to resolving the following equation:

$$D(\varepsilon_\tau) = 0 \tag{45.3}$$

The first order Taylor series expansion of $D(\varepsilon_\tau)$ in the vicinity of 0 is:

$$D(\varepsilon_\tau) = D(0) + D^{'}(0) \times \varepsilon \tag{45.4}$$

Considering signal bandwidth, the relationship between code correlation function and power spectrum density is:

$$R(\tau) = \int_{-\beta_r/2}^{\beta_r/2} S(f) e^{j2\pi f \tau} df \tag{45.5}$$

where, β_r is signal bandwidth, $S(f)$ is power spectrum density. From Eqs. (45.2) to (45.5) we can attain multipath error:

$$\bar{\varepsilon}_\tau = \frac{\pm a \int_{-\beta_r/2}^{\beta_r/2} S(f) \sin(2\pi f \tau) \sin(\pi f d) df}{2\pi \int_{-\beta_r/2}^{\beta_r/2} f S(f) \sin(\pi f d)[1 \pm a \cos(2\pi f \tau)] df} \tag{46.6}$$

where, $a = a_1/a_0$ is amplitude ratio of multipath and direct signal, when the $\pm$ are the + and − according to the phase difference, Eq. (45.6) is multipath error envelope, and all actual multipath errors should be located within the envelope.

Based on formula (45.6), multipath error envelopes are achieved for different bandwidth and different correlation space. Results are as shown in Fig. 45.2.

As can be seen from Fig. 45.2, multipath error is related to signal bandwidth and correlation space. Performance of anti-multipath is limited only by reducing correlation space on condition that signal bandwidth is narrow. Anti-multipath effect of narrow correlator technology is obvious for signal of wide bandwidth [7]. The code rate of B1 is 2.046, and B3 is 10.023 MHz, which is 5 times larger than B1. From the simulation results we can see that B3 is better than B1 on performance of anti-multipath.

45.3 Analysis on Simulation Data

Signals of two satellites are simulated with signal source. One channel signal is pseudorange of 1 satellite, which do not contain multipath, as the reference signal. Second channel is 2 satellite which is placed in the same position to 1 satellite. At the same time, one multipath signal is simulated for 2 satellite using the third channel, its amplitude is half of direct signal, signal delay increase gradually from 0 to 1.5 chips by step of 0.01 m/s.

Beidou receivers track and achieve pseudorange observation of 1 and 2 satellite, and pseudorange of 2 satellite will be affected by multipath.

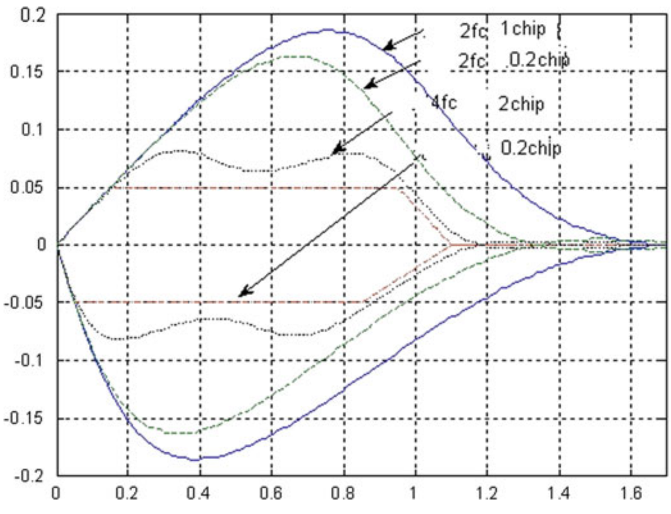

Fig. 45.2 Multipath error envelopes for different bandwidth and different correlation space

Through pseudorange of satellite 1 minus pseudorange of satellite 2, we can attain pseudorange error of different time and multipath value, and then generate picture of multipath error envelope. It can be used to analyze effect on pseudorange accuracy for known multipath value.

The results of B1 and B3 frequencies are as shown in Figs. 45.3, 45.4, 45.5, 45.6, 45.7, 45.8.

1. Results of multipath simulation for B1
2. Results of multipath simulation for B3

In Figs. 45.3, 45.4, 45.5, 45. 6, 45.7, and 45.8, abscissa represents simulated multipath errors, longitudinal coordinates are pseudorange measuring errors. As can be seen from the result:

1. The multipath error of pseudorange is related to signal Bandwidth. Bandwidth of B1 is narrow, so the effect of multipath is serious; B3 frequency bandwidth is wide, so the multipath effect is relatively small.
2. Effect of multipath is different for different receivers, which may be related to baseband algorithm and correlation space in receiver. The correlation space of corporation C is smaller, which can remarkably reduce multipath effect of B3.
3. Comparing with simulated multipath, real received pseudorange multipath is reduced in different degree, which indicates that Beidou receivers have certain ability of anti-multipath.

45.4 Analysis on Practical Test Data

Based on the real measuring data of Beidou receivers for civil navigation, differential method of short baseline is designed in this paper. First of all, double difference observation equation is achieved using two stations and their known

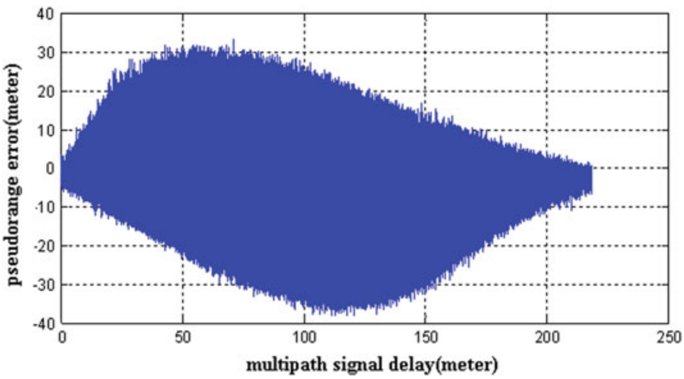

Fig. 45.3 Results of multipath simulation of B1 for corporation A

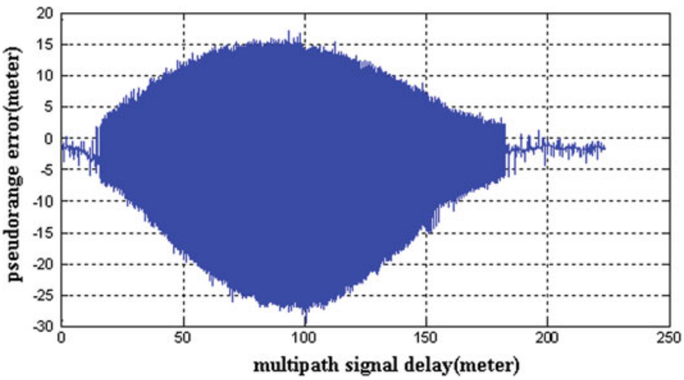

Fig. 45.4 Results of multipath simulation of B1 for corporation B

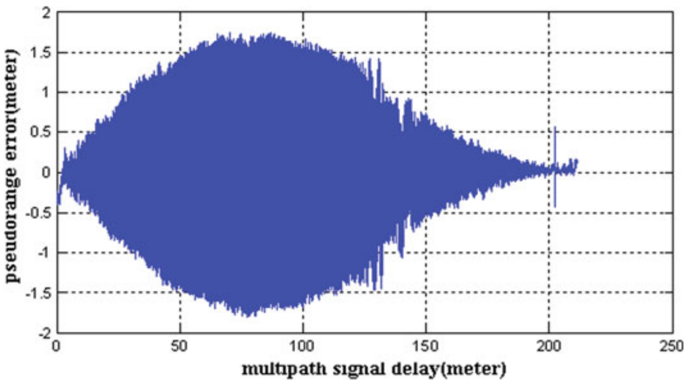

Fig. 45.5 Results of multipath simulation of B1 for corporation C

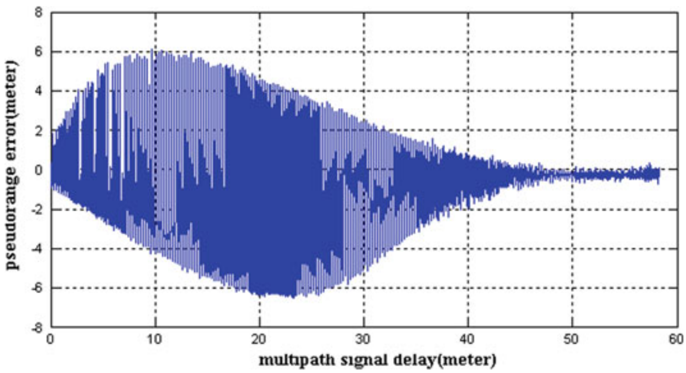

Fig. 45.6 Results of multipath simulation of B3 for corporation A

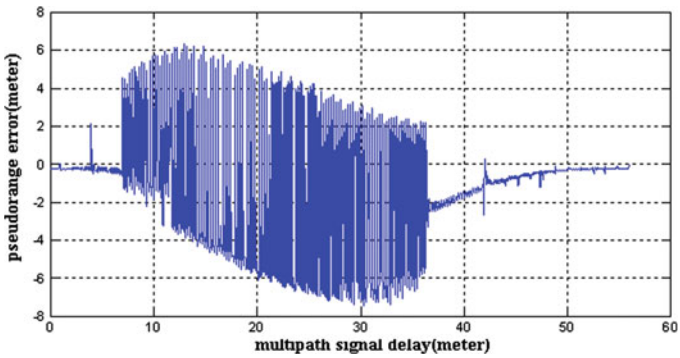

Fig. 45.7 Results of multipath simulation of B3 for corporation B

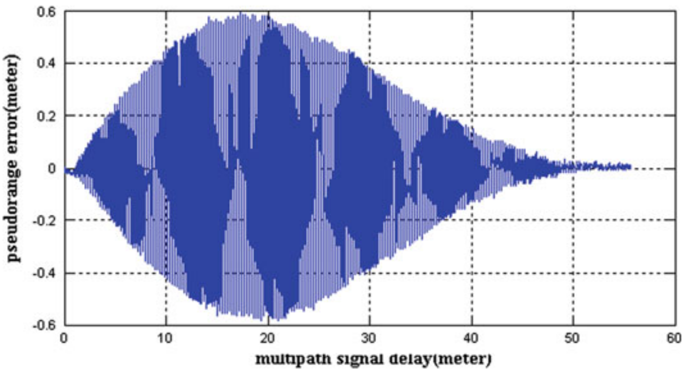

Fig. 45.8 Results of multipath simulation of B3 for corporation C

coordinates [8], which can eliminate errors such as satellite clock error, receiver clock error, ionospheric delay, tropospheric delay and hardware delay. Secondly, based on the double difference observation equation and error propagation law, the single difference equation is separated, whose residuals only contain multipath and noise of pseudorange. According to the propagation law of random errors, non differential multipath and noise of pseudorange can be attained by dividing $\sqrt{2}$. This method can completely eliminate hardware delay and other errors [9], and can reflect the multipath and noise value of pseudorange more intuitively.

Experimental data is obtained in Beijing using two navigational receivers away from 34 m, and they record original pseudorange and navigation data in double frequency positioning mode of B1 and B3. The time span of data is 06:00, 27/8/2012 to 06:20, 28/8/2012 in Beidou time, which is about 24 h, and the interval is 1 s, the cut-off angle is 5°.

Residuals of differential pseudorange for B1 and B3 are computed. Results of some visible satellite are as shown in Figs. 45.9, 45.10, 45.11, 45.12, 45.13, 45.14).

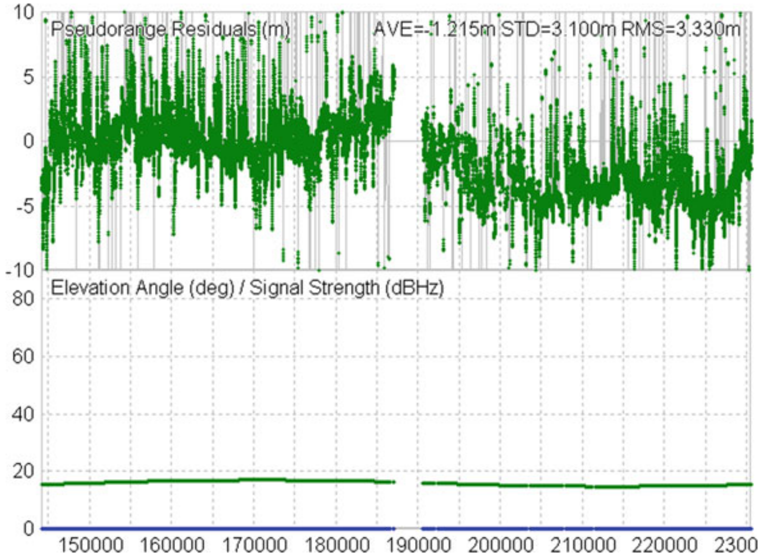

Fig. 45.9 Pseudorange multipath errors of C05 satellite on B1

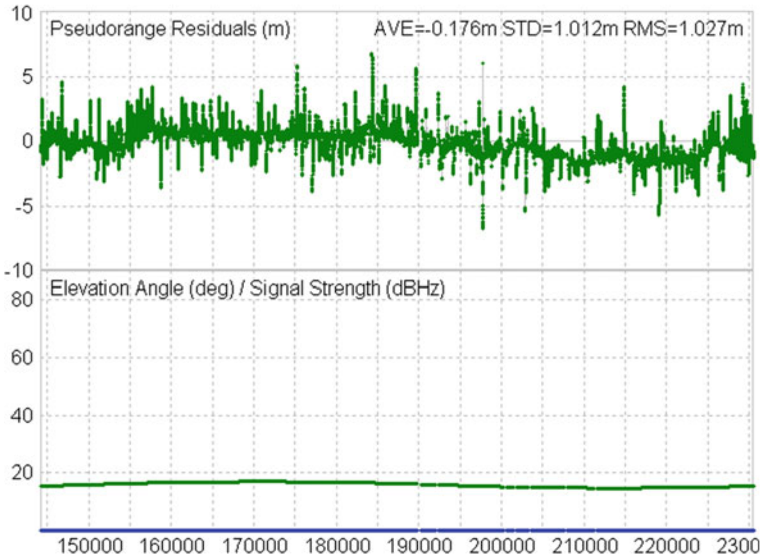

Fig. 45.10 Pseudorange multipath errors of C05 satellite on B3

In the figure, abscissa represents time (seconds in Beidou week), and ordinate respectively represent multipath value of pseudorange (m) and elevation angle of satellite (degrees). As shown in the figure: Multipath value of pseudorange is related to satellite. Multipath of GEO is larger than IGSO and MEO satellite. RMS

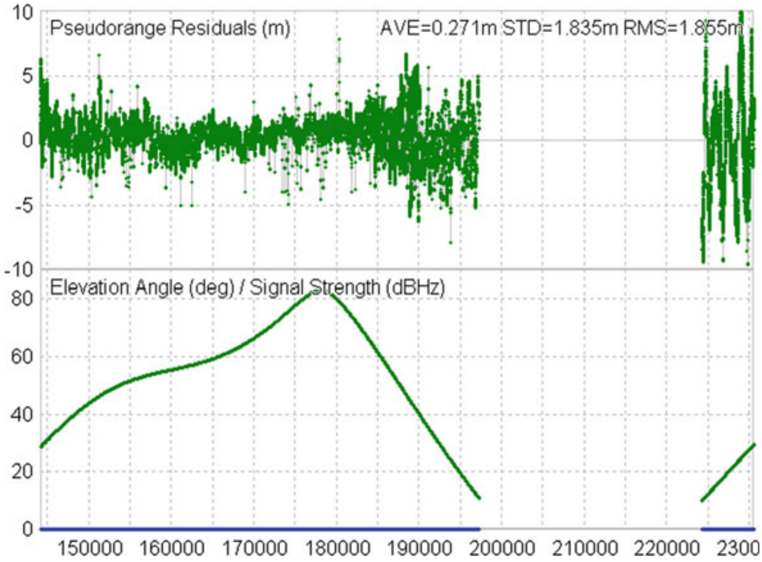

Fig. 45.11 Pseudorange multipath errors of C10 satellite on B1

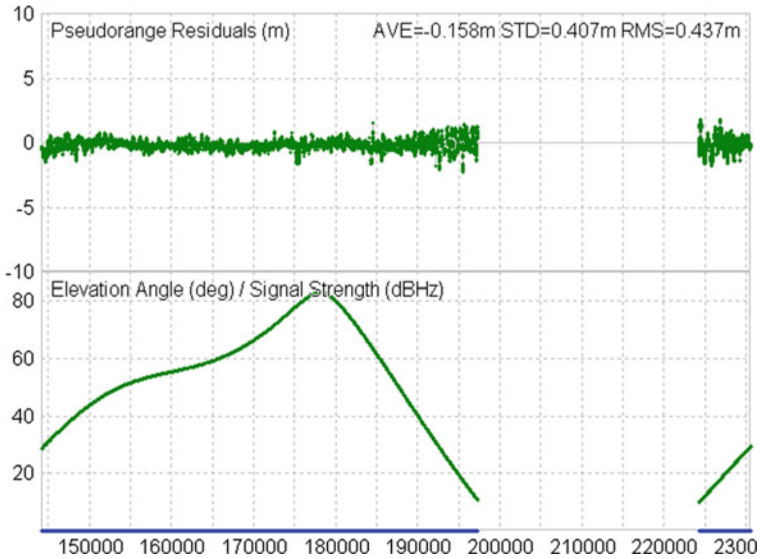

Fig. 45.12 Pseudorange multipath errors of C10 satellite on B3

of Multipath of B1 can reach up to 2.53 m, and RMS of Multipath of B3 can reach up to 0.73 m. Multipath value of pseudorange is also related to frequency, and multipath of B1 is larger than B3 for all satellites, which is caused by narrow bandwidth of B1.

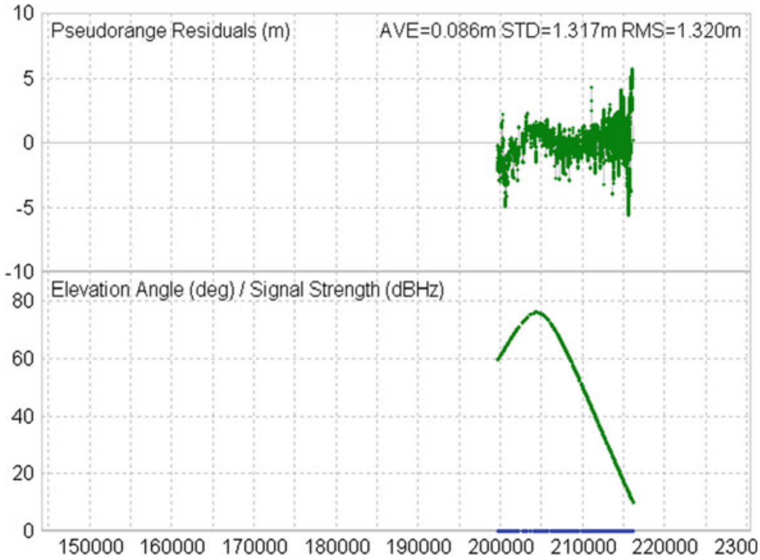

Fig. 45.13 Pseudorange multipath errors of C12 satellite on B1

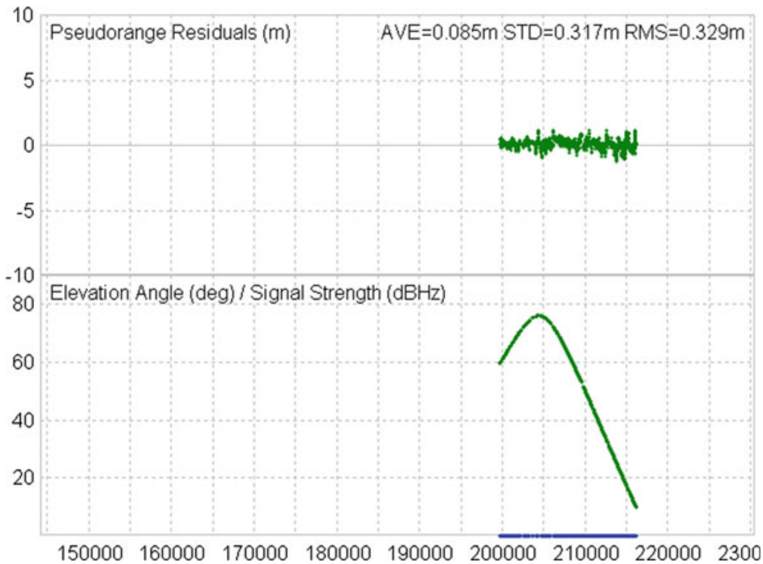

Fig. 45.14 Pseudorange multipath errors of C12 satellite on B3

45.5 Conclusions

Based on the characteristic of Beidou signal system and constellation, pseudorange multipath characteristics and effect on positioning performance are analyzed in detail, and the performance of anti-multipath is analyzed for the first time with different receivers. The conclusions are as follows:

1. Multipath value of B1 is greater than B3 for COMPASS, because bandwidth of B1 is narrow, so it is susceptible to multipath error.
2. Multipath of GEO is larger than IGSO and MEO satellite. RMS of Multipath of B1 can reach up to 2.53 m, and RMS of Multipath of B3 can reach up to 0.73 m.
3. On condition that signal bandwidth is wide, narrow correlator technology can effectively inhibit the effect of multipath error on pseudorange. Simulation results show that multipath of B3 can be significantly reduced through technology of narrow correlator for COMPASS receivers.

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References

1. Qifeng X. GPS satellite navigation and precise positioning. Publ PLA 1994:12–20
2. Huicui Liu, Xiao Cheng (2011) Evaluation of multipath mitigation performances based on error envelope. J Nat Univ Def Technol 33(1):72–75
3. Bao Li, Jiangning Xu (2012) Analysis and simulation on anti-multipath performance of Beidou2 navigation. J Chin Inertial Technol 20(3):339–342
4. Sennott JW, Pietraszewski D (1987) Experimental measurement and characterization of ionospheric and multipath errors in differentical GPS. Navigation 34(2)
5. Mengyang Z, Baoxiong L, Wenshen S (1998) Analysis on multipath in GPS system. J Xidian Univ 26(3):10–14
6. Goldhirsh J, Vogel WJ (1989) Mobile satellite system fade statistics for shadowing and multipath from roadside trace at UHF and L-band. IEEE Trans Antennas Propag 37(4):489–498
7. McGraw GA, Braasch MS. GNSS multipath mitigation using gated and high resolution correlator concepts. Proc Inst Navig NTM 1999: 333–342
8. Ziqing W (1998) The mathematic model of relative positioning for GPS, vol 1998. Publication of Surveying and Mapping, Beijing, pp 33–62
9. Lachapelle G, Falkenberg B, Neufeldt D, Kielland P (1989) Marine DGPS using code and carrier in a multipath environment. In: Proceedings of the second international technical meeting of the satellite division of the ION, GPS-89, Colorado Springs, 26–29 Sept 1989