Performance Analysis of Acquisition Methods for DGPS Reference Receiver under Noisy Environment

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Abstract

The previous acquisition method of GPS receiver for reference station adopts not only the coherent integration method but also the non-coherent integration method in order to enhance sensitivity under noisy environment. However, under noisy environment, the previous GPS signal acquisition method causes the non-coherent integration loss which is a major factor among losses that can be caused during GPS signal acquisition. The non-coherent integration loss also increases with the strength of the received noise. This paper has intention of analyzing the performance of the GPS signal acquisition method proposed to effectively enhance sensitivity of DGPS reference receiver under noisy environment. This paper presents that the proposed GPS signal acquisition method suppresses the non-coherent integration loss through post-processing simulation. Furthermore, with regard to the mean acquisition time, it is shown that the number of search cells of the proposed GPS signal acquisition method is much fewer than that of the previous GPS signal acquisition method.

Keywords: Differential GPS, GPG Signal Acquisition, Non-coherent Integration Loss

1. Introduction

The DGPS reference receiver noise has an effect on the DGPS positioning performance of remote GPS receivers. The reason is that the correction data generated by DGPS reference receiver include DGPS reference receiver noise as well as common errors with remote GPS receivers, which are atmospheric error, clock error, and ephemeris error and that most of common errors are eliminated on differential systems with the exception of receiver noise. Particularly the DGPS positioning accuracy is degraded by increased DGPS reference receiver noise due to noise provoked by machines and communication equipments. A good example of that is near-band microwave link transmitter overcoming front-end filter of DGPS reference receiver [2]. For the above reasons, the low receiver noise should be required of DGPS reference receivers under any radio noise environment.

It is generally known that the GPS receiver noise is affected by signal-to-noise ratio or sensitivity [4]. For sensitivity enhancement, the previous acquisition method of DGPS reference receivers adopt not only the coherent integration method but also the non-coherent integration method since the long coherent integration time increases the number of search cells. However under noisy environment the previous GPS signal acquisition method causes the non-coherent integration loss, which is a major factor among losses that can be caused during GPS signal acquisition. The non-coherent integration loss also increases with the strength of the received noise.

In order to reduce the receiver noise under noisy environment, this paper proposes a novel acquisition method for DGPS reference receivers, which is superior the previous GPS signal acquisition method regarding sensitivity. It is shown that the performance difference between the proposed and previous GPS signal acquisition method is caused by the non-coherent acquisition loss. And this paper presents that the proposed GPS signal acquisition method suppresses the non-coherent integration loss under noisy environment. Furthermore, with regard to the mean acquisition time, it is presented that the number of the search cells of the proposed GPS signal acquisition method is much smaller than that of the previous GPS signal acquisition method. From post-processing simulation, it is shown that the GPS signal of high signal-to-noise ratio is achieved under increased noise floor and the number of search cells of the proposed GPS signal acquisition method is reduced to 25% of the previous GPS signal acquisition method.

This paper is organized as follows. Section 2 introduces the structure of the previous acquisition method for DGPS reference receiver and shows the previous GPS signal acquisition method causes the non-coherent integration loss under noisy environment. In Section 3, this paper proposes a novel acquisition method for DGPS reference receiver in order to enhance sensitivity under noisy environment. Section 4 describes a simulation scheme for performance analysis of GPS signal acquisition methods and shows the analysis results. Finally concluding remarks are given in Section 5.

2. Acquisition Loss of DGPS Reference Receiver

In this paper, the input signal samples of acquisition for DGPS reference receiver are assumed to be baseband signal samples, which L1 signal and C/A-codes are converted into, and the input signal samples of acquisition are represented as follows:

$$x(t_k) = \sqrt{2P_s}\, D(t_k) C(t_k - T_0) \cos(2\pi f_r t_k + \phi_o) + n(t_k) \qquad (1)$$

, where the samples would be taken at

$$t_k = \frac{k}{2f_c}; \;\; k = 0, 1, 2, \ldots \qquad (2)$$

, P_s is signal power, $D(t_k)$ is 50bps navigation data, $C(t_k)$ is C/A-code, T_o is C/A-code delay, f_r is baseband frequency

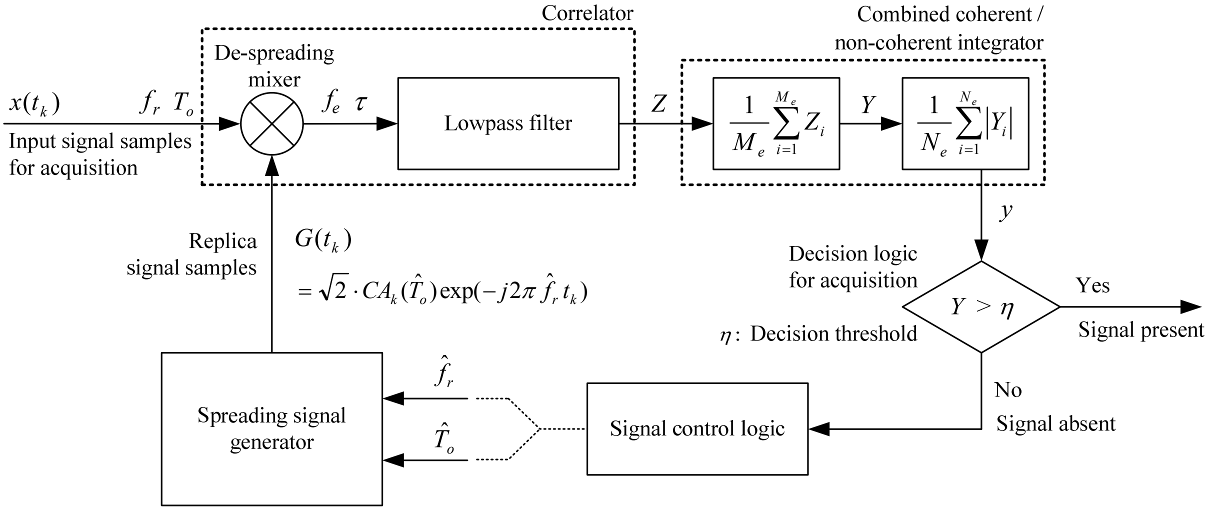


Figure 1. The previous GPS signal acquisition method.

including frequency offset (Doppler, receiver clock error, etc.), ϕ_o is carrier phase, f_c is chip rate of C/A-code, and $n(t_k)$ is additive white Gaussian noise with the properties defined as follows:

$$\begin{aligned} &E[n(t_k)] = 0 \\ &\mathrm{var}[n(t_k)] = E\left[n^2(t_k)\right] = \sigma_n^{\ 2} . \end{aligned} \tag{3}$$

GPS signal acquisition is a search process, which requires replication of both the code and the carrier of the satellite to acquire the satellite signal [4]. GPS signal acquisition has intention of finding the correct cell including T_o, f_r in two-dimensional search pattern, after determining the range of Doppler and C/A-code phase uncertainty. The aim of GPS signal acquisition for DGPS reference station is exactly the same as that of GPS signal acquisition for general GPS receiver except that the high sensitivity is required of DGPS reference receivers under any radio noise environment. In order to acquire the high sensitivity, DGPS reference receiver as well as high sensitivity GPS receiver for indoor positioning has utilized the combined coherent/non-coherent integrator as shown in Figure 1. The input signal samples of acquisition, $x(t_k)$, are divided into in-phase and quadrature-phase components by receiver-generated replica signal samples, $G(t_k)$. The output of correlator for a C/A-code period (T_p) can be written as

$$Z_k = \pm\sqrt{P_s}\, R(\tau)\frac{\sin\left(\omega_e T_p / 2\right)}{\omega_e T_p / 2}\left(\cos\phi_o + j\sin\phi_o\right) + n^c + j\,n^s \tag{4}$$

$$f_e = f_r - \hat{f}_r,\quad \tau = T_0 - \hat{T}_0,\quad R(\tau) = \begin{cases} 1-|\tau|\,; & |\tau| \le 1 \\ 0\,; & |\tau| > 1 \end{cases} \tag{5}$$

, where $R(\tau)$ is the autocorrelation function defined as Eq. (5), τ is the phase shift of replica C/A-code signal, and n^c, n^s are the in-phase and quadrature-phase component of $n(t_k)$ and the corresponding noise statistics are as follows:

$$E\left(n^c\right) = E\left(n^s\right) = 0\,,\quad \mathrm{var}\left(n^c\right) = \mathrm{var}\left(n^s\right) = \frac{\sigma_n^{\ 2}}{2 f_c T_p} . \tag{6}$$

The coherent and non-coherent integration of the previous GPS signal acquisition method are respectively

$$Y = \frac{1}{M_e}\sum_{i=1}^{M_e} Z_i \tag{7}$$

$$y = \frac{1}{N_e}\sum_{i=1}^{N_e} |Y_i| \tag{8}$$

, where M_e is coherent integration time and N_e is the number of non-coherent integration. The combined coherent/non-coherent integration, Eqs. (7) and (8), results in Eq. (4) becoming the following:

$$Y = \sqrt{P_s}\, R(\tau)\frac{\sin\left(\omega_e M_e T_p / 2\right)}{\omega_e M_e T_p / 2}\left(\cos\phi_o + j\sin\phi_o\right) + \tilde{n}^c + j\tilde{n}^s \tag{9}$$

, where the noise samples ($\tilde{n}^c$ and $\tilde{n}^s$) have the following expectations and variances:

$$\begin{aligned} &E\left(\tilde{n}^c\right) = E\left(\tilde{n}^s\right) = 0 \\ &\mathrm{var}\left(\tilde{n}^c\right) = \mathrm{var}\left(\tilde{n}^s\right) = \frac{\sigma_n^{\ 2}}{2 f_c T_p M_e} . \end{aligned} \tag{10}$$

The previous GPS signal acquisition using the combined coherent/non-coherent integration obtains an additional gain, G_p, besides processing gain through correlation for a C/A-code period. G_p is the function of M_e, N_e, and acquisition losses (L_{acq}). The relation between G_p and L_{acq} can be represented as follows:

$$G_p = \sqrt{M_e N_e} / L_{acq} \tag{11}$$

, where L_{acq} is the product of acquisition losses as follows:

$$L_{acq} = L_f \cdot L_\tau \cdot L_{nc}\,, \qquad (12)$$

L_f is the loss due to the Doppler bin (S_f) of search cell, L_τ is the loss due to the code bin (S_τ) of search cell, and L_{nc} is the non-coherent integration loss under noisy environment. The upper bound of L_f and L_τ becomes the following:

$$\overline{\sigma}\left(L_f\right) = \left[\frac{\sin\left(S_f\, M_e\, T_p\, \pi/2\right)}{S_f\, M_e\, T_p\, \pi/2}\right]^{-1} \qquad (13)$$

$$\overline{\sigma}\left(L_\tau\right) = \left(1 - \frac{S_\tau}{2}\right)^{-1}. \qquad (14)$$

Equation (13) shows the longer the coherent integration time, the smaller the Doppler bin. Therefore the previous DGPS reference receivers for sensitivity enhancement adopt not only the coherent integration method but also the non-coherent integration method since the long coherent integration time increases the number of search cells. However the non-coherent integration is affected by SNR (signal-to-noise ratio) before non-coherent integration. Under noisy environment, the process of non-coherent integration results in the following non-coherent integration loss:

$$L_{nc} = \frac{\alpha_c\,\sqrt{4-\pi}}{2\left[\Gamma\left(\frac{1}{2}+1\right)\,{}_1\mathrm{F}_1\left(-\frac{1}{2}\,;1\,;-\frac{\alpha_c^{\;2}}{2}\right) - \sqrt{\pi}\right]} \qquad (15)$$

, where $\Gamma(\cdot)$ is a gamma function, ${}_1\mathrm{F}_1(\cdot)$ is a confluent hypergeometric function, and α_c is SNR before non-coherent integration given as follows:

$$\alpha_c = \sqrt{2\, f_c\, T_p\, M_e}\;\frac{\sqrt{2\, P_s}}{\sigma_n}\,. \qquad (16)$$

The non-coherent integration loss is plotted in Figure 2. As can be seen from Figure 2 and Eq. (15), it is known that SNR of less than 10dB before non-coherent integration causes the non-coherent integration loss and the non-coherent integration loss also increases with the strength of noise.

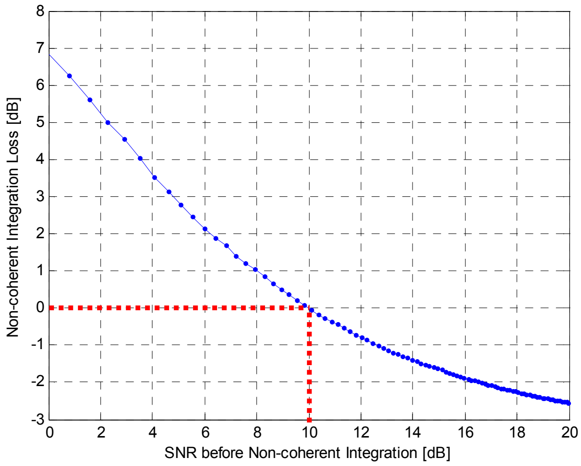


Figure 2. The non-coherent integration loss.

3. A Novel Acquisition Method for DGPS Reference Receivers

This paper proposes a novel acquisition method for DGPS reference receivers. The proposed GPS signal acquisition method adopts differential non-coherent integrator instead of non-coherent integrator. Figure 3 illustrates the structure of differential non-coherent integrator proposed in this paper. In Figure 3, the output of differential non-coherent integrator is

$$y = \frac{1}{M_p\, N_p} \sum_{i=1}^{N_p} Sqr\left[\mathrm{Re}\left(\sum_{j=1}^{M_p} Z_{j+M_p(i-1)} \sum_{j=1}^{Mp} Z^{*}_{i+M_p(i-2)}\right)\right] \qquad (17)$$

, where M_p is coherent integration time, N_p is the number of differential non-coherent integration, $*$ denotes complex conjugate, and $Sqr(\cdot)$ is defined as follows:

$$Sqr(\cdot) = \begin{cases} \sqrt{\lambda} & ;\ \lambda \ge 0 \\ -\sqrt{-\lambda} & ;\ \lambda < 0 \end{cases} \qquad (18)$$

Using the output of coherent integration given in Eq. (9), the output of differential mixer, $\tilde{Y}$, becomes Eq. (19), where $\tilde{\tilde{n}}^c$ and $\tilde{\tilde{n}}^s$ are noise terms with the properties defined as Eq. (20).

$$\tilde{Y} = P_s R^2(\tau)\frac{\sin^2\left(\pi f_e M_p T_p\right)}{\left(\pi f_e M_p T_p\right)^2} + \tilde{\tilde{n}}^c + j\tilde{\tilde{n}}^s \qquad (19)$$

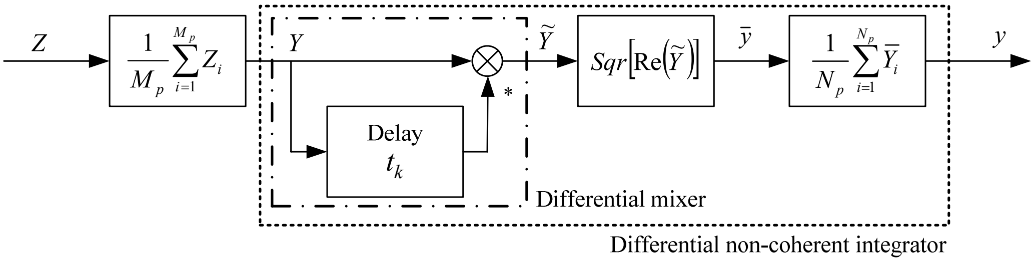


Figure 3. The structure of the proposed differential non-coherent integrator.

$$
\begin{aligned}
&E\left(\tilde{\tilde{n}}^{c}\right)=E\left(\tilde{\tilde{n}}^{s}\right)=0\\
&var\left(\tilde{\tilde{n}}^{c}\right)=var\left(\tilde{\tilde{n}}^{s}\right)=\frac{\sigma_n^{\ 4}}{2(f_c T_p M_p)^2}
\end{aligned}
\tag{20}
$$

By then assuming $|\omega_e| \le 2\pi / t_k$ and applying Eq. (18) to Eq. (19), the output of $Sqr(\cdot)$ operator, $\bar{y}$, becomes as follows:

$$
\bar{y}=\sqrt{P_s}R(\tau)\frac{\sin(\pi f_e M_p T_p)}{\pi f_e M_p T_p}+\bar{n} \tag{21}
$$

, where the properties of the noise ($\bar{n}$) are

$$
E(\bar{n})=0\,,\ \ var(\bar{n})=\frac{\sigma_n^{\ 2}}{2 f_c T_p M_p}\,. \tag{22}
$$

Theorem 1: The proposed GPS signal acquisition method using differential non-coherent integration obtains the following additional gain

$$
G_p=\sqrt{M_p N_p}\Big/\left(L_f L_\tau\right). \tag{23}
$$

Theorem 1 illustrates that non-coherent integration loss does not occur in the proposed GPS signal acquisition method and that the M_p in the proposed GPS signal acquisition method can reduce by less than M_e in the previous GPS signal acquisition method. The number of search cells for the proposed method has the properties defined as Theorem 2.

Theorem 2: Assuming that $M_e = k \cdot M_p$ and k is a positive real number, the number of search cells of the proposed GPS signal acquisition method is reduces to $1\big/k$ th of the number of search cells of the previous GPS signal acquisition method.

4. Performance Analysis

In order to verify the performance of GPS signal acquisition method proposed in the previous Section, this paper performs the analysis of signal-to-noise ratio after acquisition process. Firstly GPS data are collected with the signal strength of less than 26dB-Hz for the performance analysis. And then the collected GPS data are provided to the input signal samples of the previous and proposed GPS signal acquisition method implemented by MATLAB. Finally the post-processing simulation is performed to obtain the output of non-coherent integrator and differential non-coherent integrator at each search cell. Figure 4 shows GPS data collection setup. It is assumed that M_p and N_p of the previous GPS signal acquisition method are respectively 5 and 200, that M_e and N_e of the previous GPS signal acquisition method are respectively 20 and 50, that S_f and S_τ is determined so as to satisfy $\bar{\sigma}(L_f) = 0.9$ dB and $\bar{\sigma}(L_\tau) = 2.5$ dB, and that the search range of Doppler and code phase is provided as ±2000Hz and ±64chip. S_f, S_τ and the total number of search cells (C_N) of the proposed and previous GPS signal acquisition method therefore become the following:

$$
S_f = 100\,\text{Hz},\ S_\tau = 1/2\,\text{chip},\ C_N = 10240
$$

; the proposed method (24)

$$
S_f = 25\,\text{Hz},\ S_\tau = 1/2\,\text{chip},\ C_N = 40960
$$

; the previous method. (25)

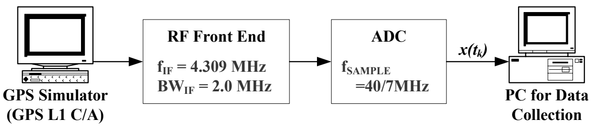
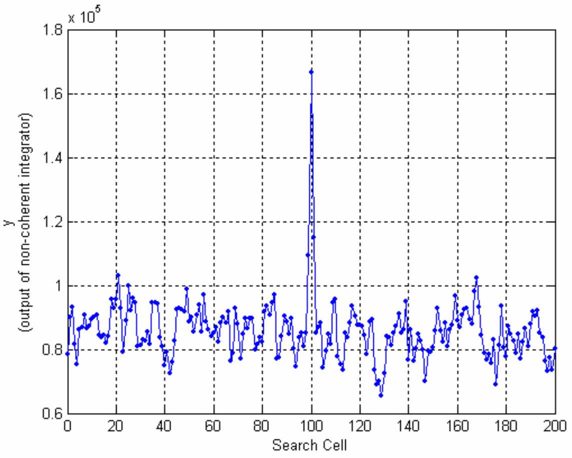
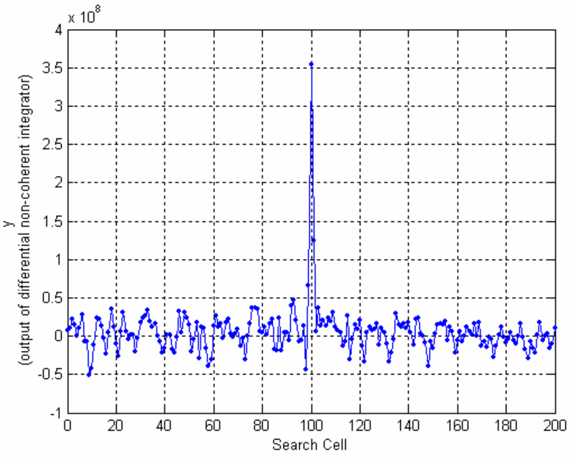


Figure 4. GPS data collection setup for post-processing simulation.

Figure 5 shows the output of non-coherent integrator and differential non-coherent integrator in the vicinity of correct cell, where RF environment is set up with 130dBm GPS signal and noise of 22dB higher than noise floor at normal temperature. From Figure 5, it is seen that the noise distribution of the previous GPS signal acquisition method has the property of nearly zero mean, and the noise distribution of the previous GPS signal acquisition method has the property of non-zero mean. For this reason, it can be expected that the proposed GPS signal acquisition method holds back the non-coherent integration loss.



(a) The output of the previous GPS signal acquisition method. (signal-to-noise ratio: 21.53 dB)



(b) The output of the proposed GPS signal acquisition method. (signal-to-noise ratio: 26.08 dB)

Figure 5. The comparison of acquisition results.

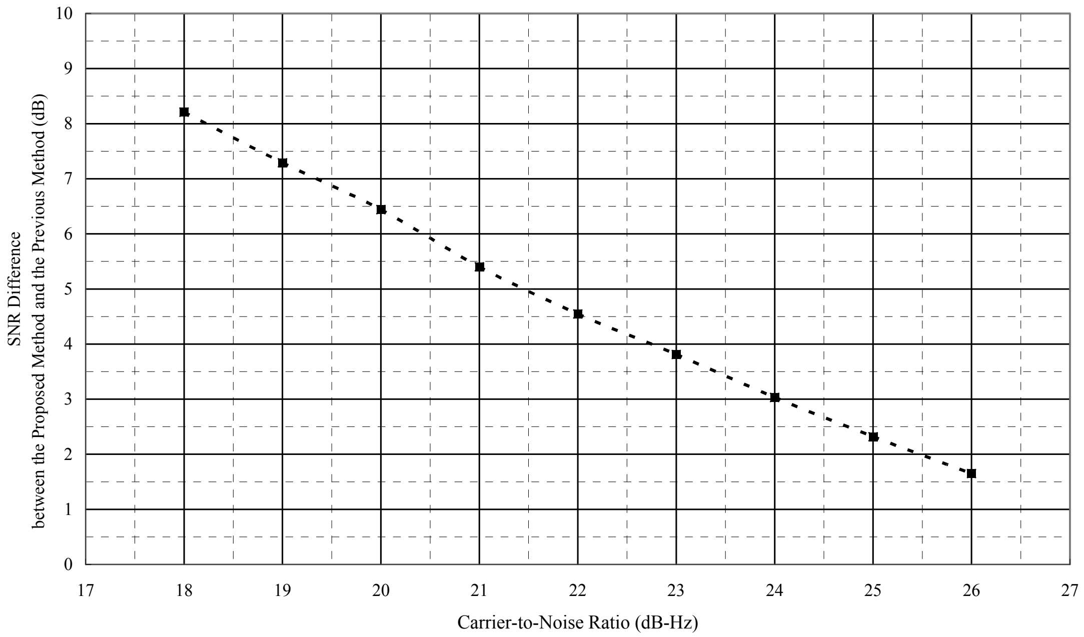


Figure 6. The SNR difference between the proposed and previous GPS signal acquisition method.

In this paper, the SNR difference between the proposed and previous GPS signal acquisition method is analyzed in order to demonstrate the superiority of the proposed method. Figure 6 and Table 1 are the results of performance analysis at intervals of 1dB under RF environment with 130dBm GPS signal and noise of 18~25dB higher than noise floor at normal temperature. In Table 1, the computed SNR difference means the non-coherent integration loss given as Eq. (15) and Figure 2. From Table 1, it can be found that the proposed GPS signal acquisition method acquires a higher gain than the previous GPS signal acquisition method, and that the SNR difference between the proposed & previous GPS signal acquisition method increases with noise floor as much as non-coherent integration loss. Furthermore, with regard to the mean acquisition time, it can be seen that the processing time of the proposed GPS signal acquisition method is reduced to about 25% of the processing time of the previous GPS signal acquisition method by logging the start and end time of simulation.

Table 1. The SNR difference between the proposed and previous GPS signal acquisition method.

Carrier-to-noise ratio (dB-Hz)	Computed SNR difference (dB) {A}	Measured SNR difference (dB) {B}	Difference (dB) {A-B}
18	8.59	8.21	0.38
19	7.63	7.28	0.34
20	6.80	6.44	0.36
21	6.06	5.40	0.66
22	4.83	4.55	0.28
23	4.31	3.81	0.50
24	3.43	3.03	0.40
25	2.70	2.32	0.38
26	2.10	1.65	0.45

5. Conclusion

This paper described the previous acquisition method for DGPS reference receiver and showed that the previous GPS signal acquisition method causes the non-coherent integration loss and that the bigger the noise floor, the bigger the non-coherent integration loss. In this paper, it was proposed the novel GPS signal acquisition method using the differential non-coherent integrator in order to solve the problem of non-coherent integration loss under noisy environment. From Theorem 1 and Theorem 2, the proposed GPS signal acquisition method was found to suppress the non-coherent integration loss and to minimize the number of the search cells by determining a smaller M_e than M_p. From the post-processing simulation, it could be verified that the proposed GPS signal acquisition method holds back the non-coherent integration loss and that the mean acquisition time is reduced as compared with the previous GPS signal acquisition method. For further work, it is necessary to analyze the effect of the Doppler change rate on sensitivity of the proposed GPS signal acquisition method and to make a study of robust correlation scheme under noisy environment.

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