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Temporary statistical characteristics of fast fluctuations of GPS radio signals in reception conditions on surface routes

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Abstract. This article presents experimental data on temporal changes in the level and phase of GPS signals as well as the results of their statistical processing. For the first time, correlations between the time correlation interval of the received radio signal level, flicker index and the time of its observation are reflected. For the first time, it has been shown experimentally that there is an inverse relationship between the correlation interval and the scintillation index. In addition, the frequency of changes in the signal level with oscillation frequencies on the order of hertz fractions is indicated. This information complements the results of the static processing of recommendations ITU-R P.531-13 and can be used to improve the efficiency of quasi-coherent processing of satellite signals.

1. Introduction

The effectiveness of satellite global radio navigation systems is determined by the ratio of useful radio signal energy to the noise power and the degree of its distortion due to the scattering and reflection of radio waves by the external medium. The ionosphere, troposphere, terrain topography and underlying surface shall be understood as the outer environment of the "satellite-earth" radio path.

The effect of radio signals distortion by the propagation medium on the efficiency of the satellite radio systems operation can be reduced by optimal processing of the received signals. Optimal location algorithms are based on an a priori knowledge of the statistical properties of the medium or interference that distort signals. Thus, distortions of the received radio signals of GPS satellites appear in amplitude and phase scintillations and the amplitude flicker is described by the Nakagami law as well as the phase scintillations are described by the normal distribution law [1]. At low intensities, the phase and amplitude scintillations turn out to be strictly correlated [1]. However, the data on the intensity of the amplitude and phase scintillations of the radio signals given in the recommendation [1] are insufficient. This paper reflects the results of the processing of experimental data on the signals of the satellite global GPS navigation system complementing the results of recommendation [1] regarding statistical characteristics of temporal fluctuations in level and phase.

The objective of the article is to reflect the statistical characteristics of the amplitude and phase fluctuations of radio signals for the global satellite radio navigation system GPS which are obtained from literature data.

The initial data for estimating the statistical characteristics of the amplitude and phase fluctuations of the radio signals were the time dependences of the signal and phase level with a description of the conditions for obtaining them reflected in the literature data.

The statistical characteristics of fast fluctuations in the level and phase of the radio signal in this paper are understood to mean: standard deviation, span and correlation interval. As is known, the spread of the radio signal level is directly related to the scintillation index S_4 [1].

2. Results of experimental data processing.

Statistical data such as the amplitude and phase fluctuation dispersion, the time correlation interval of GPS signals are determined from the experimental data [2-16] using the formulas [17]. Examples of temporal realizations of the power level and the phase of the received GPS signal are shown in Figures 1-3 [2]. Unfortunately, no detailed description of the measurement conditions for signals as well as the equipment used contained in many literature sources.

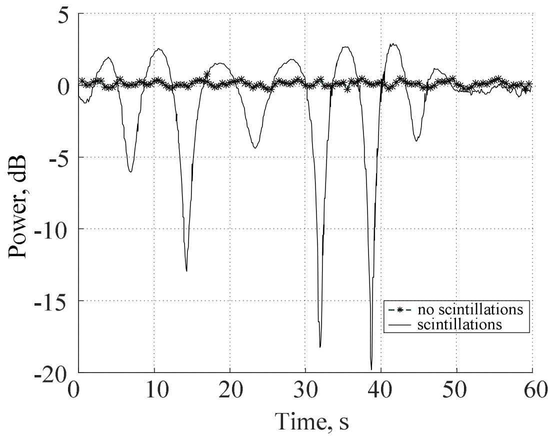

Figure 1. Chart of dependence of the power level of the received GPS signals as a function of time [2] (red line (solid) - flicker signal, blue line (dot-dash) - signal without flicker) [2]

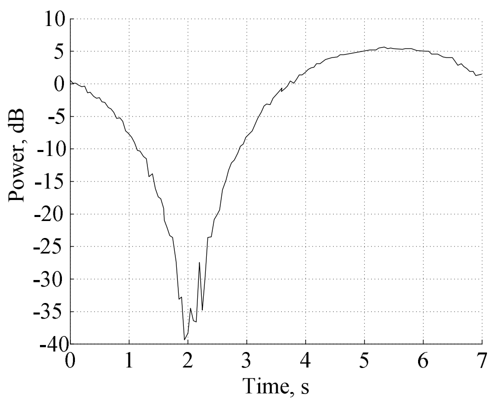

Figure 2. Chart of the dependence of received GPS signal power level on time [2]

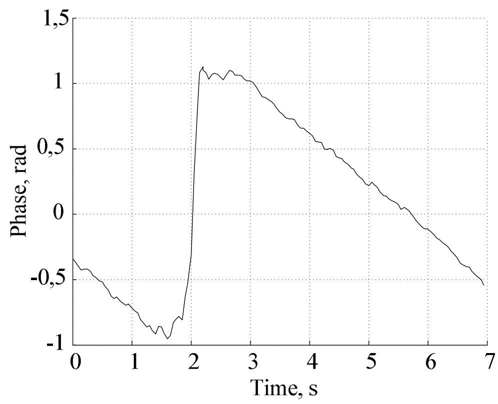

Figure 3. Chart of the dependence of received GPS signal phase on time [2]

Qualitative nature of the time dependences of signal and phase levels presented in the literature [2-14] are significantly different. This is due to the different reception conditions of the navigation signal. In particular, the presence of local objects in the navigation receiver leads to a quasideterministic time dependence of the level and phase of the signal.

In this case, deep dips in the signal level and differences characteristic for interference fading are observed (Figures 1-3) due to interference fading of the signal [3].

In case of insignificant influence of the reflected signals by the underlying surface and local objects, deep dips shown in Figure 1 (the signal is separated by a dash-dot line) are absent as well as the level and phase of the signal chaotically vary with time.

In the Figure 3 and 4 shows charts of the fluctuation spectrum amplitude and normalized autocorrelation function of the received GPS signal, respectively.

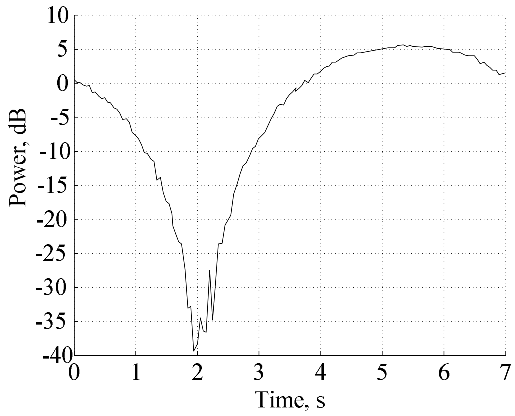

Figure 4. Amplitude fluctuation spectrum of the received GPS signal

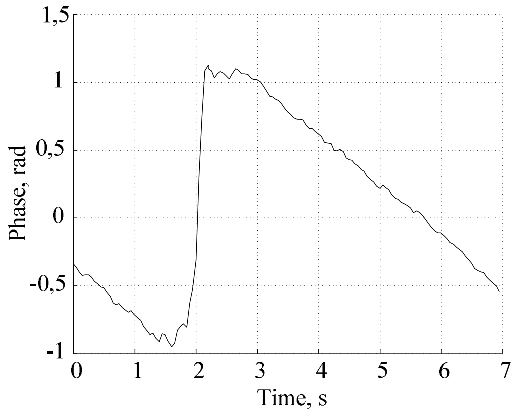

Figure 5. Normalized autocorrelation function of received GPS signal

According to Figures 3 and 4, the level and spectral composition of the signal level time dependence contains harmonic components. The fundamental harmonic is observed at a frequency of about 0.13 Hz. This effect should be used for optimal digital signal processing.

For convenience, the experimental data and estimates of statistical characteristics of the level and phase fluctuations of the navigation radio signal are presented in Tables 1, 2 and 3, respectively. These tables show: σ_E – standard deviation of level fluctuations, Δ_E – amplitude range, T – GPS signal observation time, τ_{kE} and $\tau_{k\varphi}$ – intervals of time correlation of the radio signal level and phase, respectively.

Table 1. Statistical characteristics of received navigation signals (signal level)

№	T, s	σ_E, dB	Δ_E, dB	τ_{kE}, s	S_4
1	60	3.71	22.70	1.38	0.30
2	7	11.76	43.72	0.80	0.72
3	7	5.66	21.89	0.71	0.44
4	9	13.27	61.26	0.63	1.59
5	9	6.72	30.74	0.72	0.77
6	10	9.35	44.23	0.24	0.78
7	10	5.34	29.47	0.28	0.47
8	20	3.22	20.70	0.45	0.34
9	20	3.12	19.21	0.48	0.34
10	10	5.82	29.03	0.29	0.52

Table 2. Statistical characteristics of received navigation signals (signal level)

№	*T*, s	σ_E, dB	ΔE, dB	τ_{kE}, s	S_4
11	60	4.89	29.89	0.50	0.52
12	60	3.84	22.76	0.58	0.49
13	60	1.57	5.91	2.75	0.18
14	180	1.58	9.04	1.34	0.18
15	180	3.85	15.55	8.15	0.40
16	300	4.33	18.76	9.44	0.48
17	300	3.70	17.08	5.39	0.39
18	120	3.55	16.35	5.43	0.34
19	50	6.15	31.02	1.32	0.53
20	16	0.69	3.09	0.50	0.08
21	7	0.15	0.52	0.30	0.02
22	60	4.30	25.22	0.98	0.93
23	60	3.59	17.99	0.26	0.71
24	25	7.05	38.99	0.42	1.32
25	60	4.44	25.20	1.21	0.93
26	60	4.38	22.06	0.71	0.84
27	60	4.78	21.74	0.54	0.83
28	60	3.83	20.30	0.23	0.79
29	60	5.58	32.15	1.68	1.13
30	60	5.48	22.99	0.99	0.87

Table 3. Statistical characteristics of received navigation signals (phase fluctuations)

№	*T*, s	σ_φ, rad	Δ_φ, rad	$\tau_{k\varphi}$, s
1	7	1.47	1.5	0.58
2	9	0.72	2.70	0.59
3	60	0.71	4.50	1.11
4	60	0.58	3.14	0.99
5	60	1.59	8.05	1.67
6	10	0.28	1.16	0.37
7	10	0.50	1.91	1.25
8	60	0.43	1.71	2.47
9	60	0.33	1.38	2.03
10	60	0.13	0.46	7.61

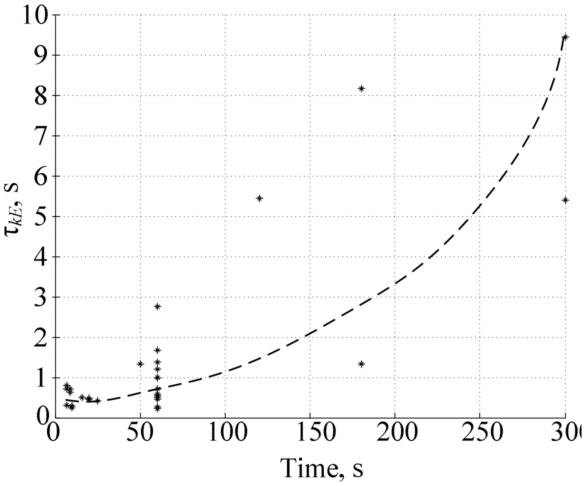

Figure 6. Chart of time interval dependence of (τ_{kE}) on observation time (T)

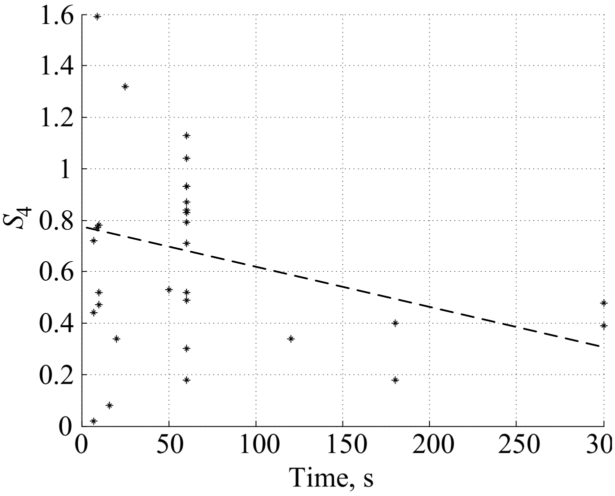

Figure 7. Chart of scintillation index dependence (S_4) on observation time (T)

3. Analysis of experimental data

Figure 6 shows the dependence of the correlation time interval on the time of radio signals observation GPS τ_{kE}=$f(T)$. The dashed line corresponds to the averaged characteristic. Analysis of the correlation coefficient $R_{T,\tau k\varphi}$=-0.836 calculated from the formulas of [17] showed a strong direct link between the time interval of received radio signal correlation and the time of its observation.

Figure 7 shows the dependence of radio signal level scintillation index on its observation time. The correlation coefficient is equal to $R_{T,S4}$ = -0.217, therefore there is a weak feedback between the values of radio signal scintillation index and observation time.

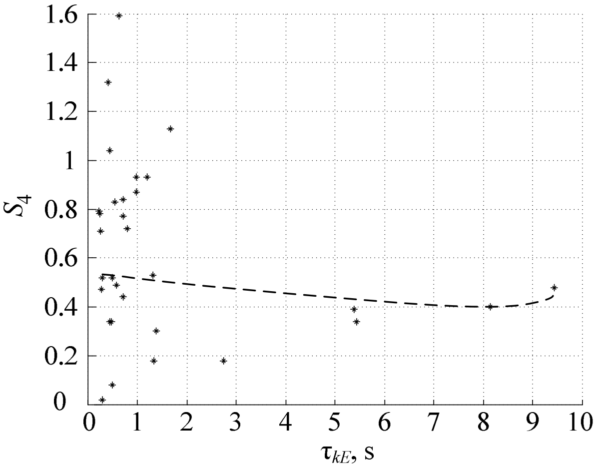

Figure 8. Chart of scintillation index dependence (S) on the time correlation interval (τ_{kE})

Figure 8 shows the dependence of the scintillation index on the time correlation interval. The correlation coefficient is $R_{\tau kE,S4}$ = -0.235. Thus, there is a weak feedback between the values of the index of adio signal scintillation and the time correlation interval.

4. Conclusions

Based on the results of experimental data processing, the following conclusions can be made. For the literature data used, the following time statistical characteristics of fast fluctuations of the GPS navigation signal are typical (Table 4).

Table 4. Statistical characteristics of GPS navigation signal

	σ_E, dB	Δ_E, dB	τ_{kE}, s	S_4	σ_φ, rad	Δ_φ, rad	$\tau_{k\varphi}$, s
Min	0,15	0,52	0,23	0,02	0,13	0,46	0,37
Mean	4,87	24,14	1,6	0,62	0,67	2,56	1,87
Max	13,76	61,26	9,44	1,59	1,59	8,05	7,61

Proposed results allow making the following conclusions.

1. When observing the GPS signal from 7 to 300 seconds, the time correlation interval of the signal level τ_{kE} takes values in the range from 0.23 to 9.44 seconds with an average value of 1.6 seconds. In this case, the root-mean-square fluctuations in the signal level take values in the range from 0.15 to 13.76 dB with an average value of 4.87 dB. The average range of the signal level ranges from 0.52 to 61.26 dB with an average value of 24.14 dB.
2. For the time of GPS signal observation from 7 to 60 seconds, the time correlation interval of phase fluctuations $\tau_{k\varphi}$ takes values in the interval from 0.37 to 7.61 seconds with an average value of 1.87 seconds. In this case, the mean-square fluctuations of the phase fluctuations take values in the range from 0.13 to 1.59 rad with an average value of 0.67 rad. The average range of phase fluctuations takes values in the range from 0.46 to 8.05 rad with an average value of 2.56 rad.
3. Correlation analysis showed that between the time interval of correlation of the received radio signal level τ_{kE} and the time of its observation T there is a strong direct connection as well as weak feedback between the values of the scintillation index S_4 of the radio signal level and the time of its observation T.

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