Calculation methods of noise immunity of the receivers under the mutual effect of tracking systems and complex tracking systems

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Abstract. The article discusses the methods for improving the reliability and validity of the GLOSNASS signal. These methods reveal the principles of improving the signal reliability and validity by reducing the noise level from the received signal. The main attention is paid to the calculation of the noise immunity of the receivers under the mutual effect of tracking systems and complex tracking systems. The article deals with the noise immunity of coherent and non-coherent receivers, the noise immunity of the complex tracking systems.

1. Introduction

Currently, the issues related to the use of GLONASS and GPS navigation systems are widely studied [1-5]. The issues related to hardware and software are widely considered [6-12]. It should be noted that most researchers often emphasize two main systems GLONASS and GPS[13-17]. This article analyses the reductionof the noise influence on the navigation signal. In the receivers of satellite radionavigation signals (SRNS) the tracking systems are interconnected. This, in particular, determines the dependence of noise dispersions of equivalent observations on one of the parametersbeingmonitored, on error estimation of another parameter being monitored by another tracking system.Such an interconnection of the tracking systems affects their noise immunity,therefore, the noise immunity of SRNS receivers is analyzed taking into account the mutual effect of various subsystems. In particular, the article analyzes the noise immunity of incoherent and coherent receivers. The method of calculation of noise immunity for the complex tracking systems is also shown.

2. Non-Coherent Receiver Immunity

The non-coherent receiver has two tracking systems: the delay and the frequency of the signal.

The noise variance of the equivalent observations, reduced to the signal delay, depends on the equivalent value of signal-to-noise $\widetilde{q}_{c/n_0} = q_{c/n_0 \sin c^2}\left(\varepsilon_\omega T/2\right)$, but the noise variance of the equivalent observations, reduced to the Doppler frequency,depends onthe tracking errors for delay and Doppler frequency. $\widetilde{q}^2_{c/n_0} = q_{c/n_0}\rho^2\left(\varepsilon_\tau\right)$, where ε_τ and ε_ω are the errors resp. From the above expressions it can be seen that the accounting of tracking errors leads to reduction in the equivalent signal-to-noise ratio, and, consequently, to a reduction in the noise immunity of the signal frequency tracking scheme and signal delay trackingscheme.

When calculating the receiver noise immunity, taking into account the mutual influence of the tracking systems, we will assume $\varepsilon_{\tau(\omega)} = \sqrt{D_{\tau(\omega)}}$, where $D_{\tau(\omega)}$ is the variance of the filtering error of the corresponding parameter determined from the dispersion equations of the corresponding tracking system.

Figure 1 shows the dependence of the signal frequency tracking suppression index taking into account the influence of the signal delay tracking error on its characteristics.

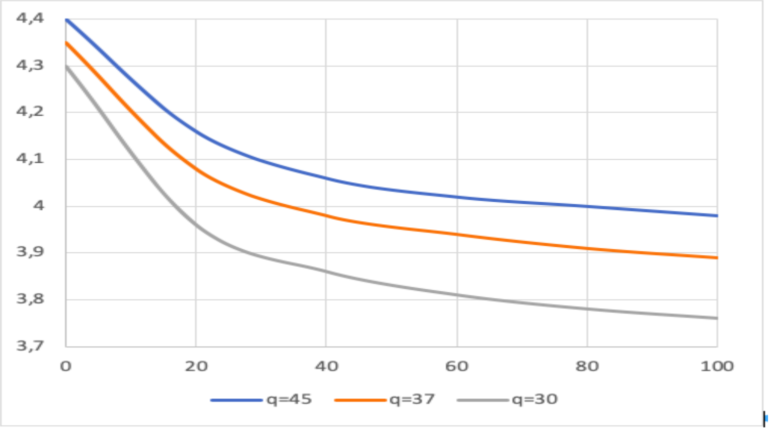

Figure 1. Suppression index of signal frequency tracking.

Figure 2 shows the dependences of the noise immunity index of the signal delay tracking on the effect of signal frequency tracking.

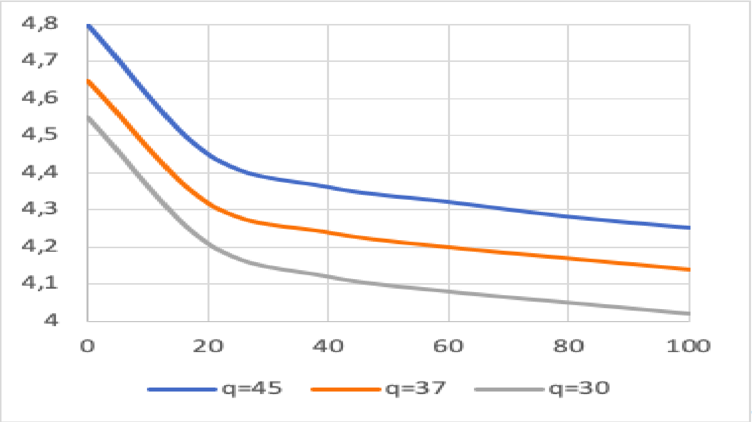

Figure 2. Suppression index of signal delay tracking.

From the comparison of the dependencies shown in Figures 1 and 2, it follows that the noise immunity of the non-coherent receiver is determined by the noise immunity of the signal frequency tracking and is 33...41 dB for dynamic consumers ($\sigma_a \geq 4g$) and 41...45 dB for poorly dynamic consumers ($\sigma_a \leq 0{,}5g$).

3. Coherent Receiver Immunity

The coherent receiver monitors the delay and phase of the signal. Similar to the previous section, it can be shown that the signal phase tracking system has little effect on the noise immunity of the signal delay tracking system. Therefore, we consider only the effect of signal delay tracking on the noise immunity of the signal phase tracking scheme.

The effect of tracking error on the delay ε_τ leads to a change in the equivalent signal-to-noise ratio in accordance with the formula $\tilde{q}^2_{c/n_0} = q_{c/n_0}\rho^2(\varepsilon_\tau)$. Figure 3 shows the dependences of the suppression index of signal frequency tracking under the effect of signal delay tracking. The noise immunity of the coherent receiver is determined by the noise immunity of the signal phase tracking and is 34...36 dB for dynamic consumers ($\sigma_a \geq 4g$) and 33 dB...40 dB for poorly dynamic consumers ($\sigma_a \leq 0{,}5g$).

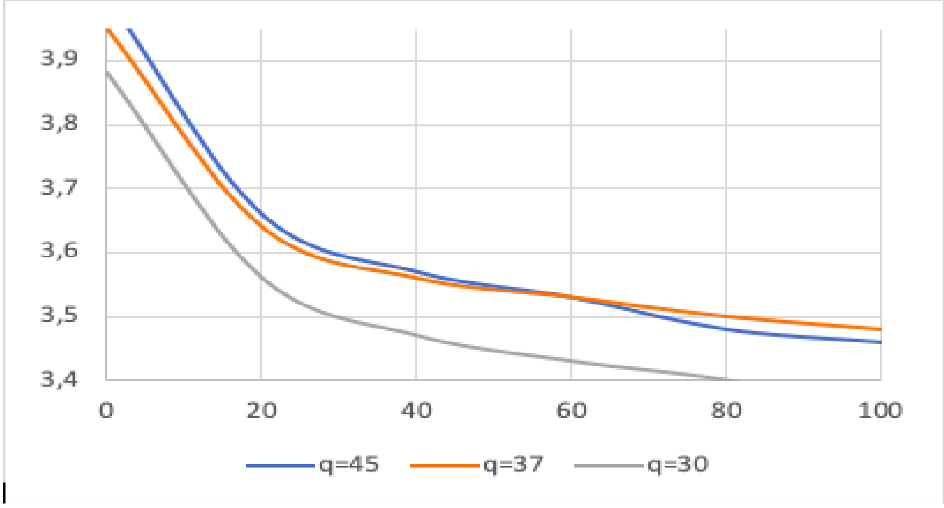

Figure 3. Suppression index of independent signal phase tracking (on Y-axis is index K_n, on X-axis is index σa).

The noise immunity of the coherent receiver is 4...5 dB lower than the noise immunity of the non-coherent receiver.

4. Receiver Immunity of the complex tracking system

In the complex tracking systems the smoothing filter processes signals from the outputs of two or more discriminators. The above method of noise immunity calculation can be used in this case. We illustrate this by the example of a complex tracking system for delay and Doppler frequency shift of an non-coherent receiver.

The linearized tracking system is described by the equations

$$\hat{\tau}_k = \tilde{\tau}_k + K_{1,k}\left(\tilde{y}_{\tau,k} - \hat{\tau}_k\right) + K_{2,k}\left(\tilde{y}_{v,k} - \hat{v}_{k-1}\right), \tilde{\tau}_k = \hat{\tau}_{k-1} + T\hat{v}_{\tau,k-1,},$$

$$\hat{v}_{\tau,k} = \hat{v}_{\tau,k-1} + K_{3,k}\left(\tilde{y}_{\tau,k} - \hat{\tau}_k\right) + K_{4,k}\left(\tilde{y}_{v,k} - \hat{v}_{k-1}\right),$$

the gains of this system are described by the ratios

$$K_{1,k} = D_{11,k} / D_{\tilde{\eta}_\tau}, K_{2,k} = D_{12,k} / D_{\tilde{\eta}_v}, K_{3,k} = D_{12,k} / D_{\tilde{\eta}_\tau}, \tilde{K}_{4,k} = D_{22,k} / D_{\tilde{\eta}_v},$$

where $D_{\tilde{\eta}_v} = D_{\tilde{\eta}_\omega} / (2\pi f_0)^2$, the variance of filtering errors in the steady state are described by the formulas

$$D_{11ycm} = \sqrt{S_{\tilde{\eta}_\tau} S_{\tilde{\eta}_v} (1 + 2\sqrt{\rho})} / (1 + \sqrt{\rho}), D_{12ycm} = S_{\tilde{\eta}_v} (1 + \sqrt{\rho}),$$

$$D_{22ycm} = \sqrt{S_{\varepsilon_\tau} S_{\tilde{\eta}_v} (1 + 2\sqrt{\rho})} / (1 + \sqrt{\rho}),$$

where $S_{\tilde{\eta}_v} = S_{\tilde{\eta}_\omega} / (2\pi f_0)^2, \rho = S^2_{\tilde{\eta}_v} / (S_{\varepsilon_\tau} S_{\tilde{\eta}_\tau})$ means dimensionless parameter.

For real signal levels and dynamics of consumer movement, the parameter $\rho << 1$ and variance of filtering errors can be presented in a simplified form $D_{11ycm} \approx \sqrt{S_{\tilde{\eta}_\tau} S_{\tilde{\eta}_v}}, D_{12ycm} = S_{\tilde{\eta}_v}, D_{22ycm} = \sqrt{S_{\varepsilon_\tau} S_{\tilde{\eta}_v}}$ In this case, the optimal filtering equations $\hat{v}_{\tau,k} = \hat{v}_{\tau,k-1} + \tilde{K}_{4,k} \tilde{y}_{v,k} - \hat{v}_{k-1}$ are also simplified, and the estimate of signal delay rate (Doppler frequency shift) is generated only by the signals from output of the frequency discriminator.

Therefore, the noise immunity of the tracking ring at the signal frequency does not depend on the characteristics of the delay tracking ring. The dependences of the suppression index for the signal frequency tracking in the considered case are shown in Figure 4.

Comparison of these dependencies with similar data shown in Figure 1 demonstrates that noise immunity has decreased slightly. This is explained by the fact that in this case the description of the Doppler frequency shift by the first order equation is accepted, and accordingly in the complex tracking system the frequency tracking ring also has the first order (smoothing filter of the first order). In this regard, it should be noted that the increase of the noise immunity of the tracking system with an increase in the order of the smoothing filter is also observed in other types of tracking systems (phase and signal delay).

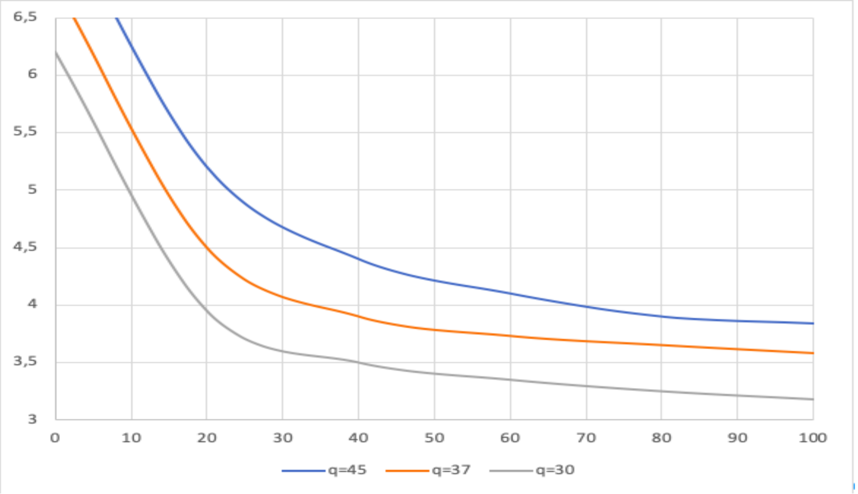

Figure 4. Suppression index of frequency tracking ring

(on Y-axis is index K_n, on Y-axis is index σa).

Figure 5 shows the suppression index graphs for the signal delay tracking ring, which indicate that the noise immunity of the delay tracking ring is virtually independent of the intensity of the consumer's maneuvering. This is quite consistent with the fact that by $\rho << 1$ the dispersion of the signal delay filtering error does not depend on the intensity of the consumer acceleration. The noise immunity also varies slightly when the signal-to-noise ratio changes.

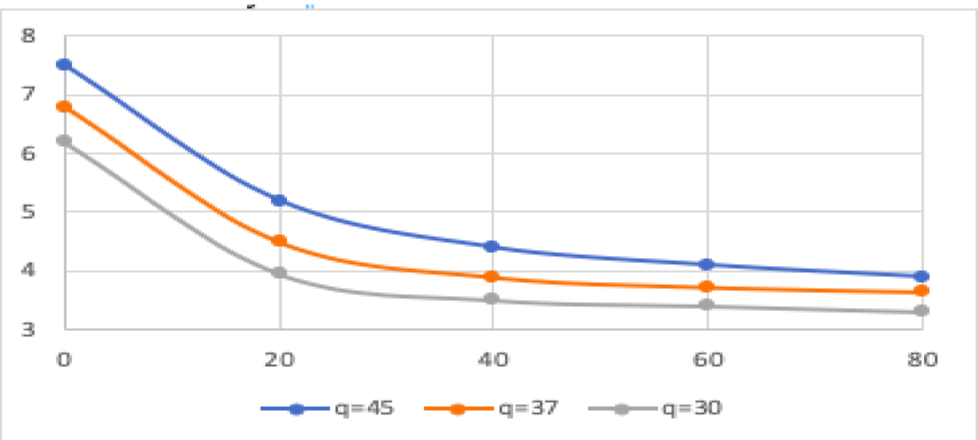

Figure 5. Suppression index of frequency tracking ring

(on Y-axis is index K_n, on Y-axis is index σa).

As above, the noise immunity of the receiver with the complex tracking system is determined by the noise immunity of the signal frequency tracking ring.

The dependences of the suppression index for various types of tracking systems given in this article can be used to calculate the critical signal-to-internal noise ratio $q_{c/n_0 êð}$, at which the receiver still operates with the specified consumer characteristics. For the numerical calculation of this parameter, the ratio should be used

$$q_{c/n_0 êð} = \Delta f_c / K_Ï \quad \text{или} \quad \tilde{q}_{c/n_0 êð} = 101\log(\Delta f_c) - \tilde{\tilde{E}}_Ï \, .$$

So, for the standard accuracy signal and for the value of the suppression coefficient (receiver with integrated tracking system, the input power is dBHz

So, for a signal of standard accuracy $\Delta f_c \approx 1$ МГц and for the value of suppression index $\tilde{K}_Ï$ = 38 дБ (the receiver with the complex tracking system, the input signal power is obtained in $\tilde{P}_c$ = -170 dBHz) we have get $\tilde{q}_{c/n_0 êð} = 22$ dBHz.

5. Conclusion

The article deals with the issues of signal noise reduction.

It should be noted that when analyzing the noise immunity of an non-coherent receiver, we have two systems: the signal delay tracking system and the signal frequency tracking system. In this case, the accounting of tracking errors leads to a decrease in the equivalent signal-to-noise ratio, and, consequently, to a reduction in the noise immunity of the tracking scheme.

The coherent receiver monitors the delay and phase of the signal. In the same way as the non-coherent receiver, after analyzing we can say that the signal phase tracking system has little effect on the noise immunity of the signal delay tracking system.

In complex tracking systems, the smoothing filter processes signals from the outputs of two or more discriminators. In addition, the noise immunity of the receiver with the complex tracking system is determined by the noise immunity of the signal frequency tracking ring.

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