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An analysis the mutual influence of channels in radiotechnical information-measuring system

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Abstract

The development of new radiotechnical information-measuring systems (IMSs) of the ground control complex of flying objects should be aimed at increasing their capabilities for accurate and reliable control of signals navigation parameters. This is especially important in a time-limited communication session, as well as for ensuring the operational control of the trajectories of ballistic objects during their flight along unequipped routes.

In recent years, wideband noise-like signals (WNLSs) are often used in radio systems – complex discrete signals, modulated by a harmonious signal in frequency, phase and amplitude by a pseudo-random sequence code. The use of the WNLSs is explained by a number of their properties: better noise immunity and concealment, greater accuracy in measuring the speed and range of moving objects, the prospect of more efficient use of such signals in the allowed frequency ranges, and the possibility of their multipath propagation.

IMSs with WNLSs have several advantages: increased noise immunity, secrecy, the ability to measure the motion parameters of an aircraft object with one signal and transmit information, sufficient accuracy and high reliability of information transfer. In the future, this may lead to the construction of unified, mobile information-measuring systems, the tactical and technical characteristics of which will meet modern requirements. However, the main reasons preventing the wider implementation of complex pseudo-random signals in the practice of radio engineering IMSs are the difficulties associated with their optimal processing.

In this paper, the analysis of information-measuring systems with wideband noise-like signals was performed to determine the degree of mutual influence of the channels, when filtering interrelated parameters of signal. It is established, that the errors caused by the mutual influence of the channels are minimal if the parameter estimate coincides with its true value, and there are no divergences on the filtered parameter. Thus, the filtering accuracy of each of the parameters depends on the degree of their correlation, on the signal-to-noise ratio, and on the steepness of autocorrelation function the input signal complex envelope.

Keywords: information-measuring system, navigation parameters of signals, reliability of information.

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Introduction

Terrestrial radio engineering complexes and systems, which are classified as information-measuring, are used to ensure the measurement and prediction of trajectories of flying objects (FOs), including space, as well as the control of their movement.

The development of new radio information-measuring systems terrestrial control complexes, of course, should be aimed to increase their ability to accurately and reliably monitor the navigational parameters of signals. This issue is especially important in case of the limited communication session time, as well as the provision of operational control of the trajectories of ballistic objects during their flight over unequipped routes [1].

However, nowadays, none of the existing systems assesses the reliability of the information received while determining the parameters of motion, especially in real time.

Formulation of the problem

Above mentioned purposes of the IMS functioning result in following major requirements:

- high accuracy of navigation measurements in real time by different consumers;

- resistance to natural and organized obstacles;
- global operation and access to the system at any time;
- providing control of the flying objects solely by stations of the subsystem of control;
- authorized use of the signal for high-precision navigation measurements.

In this case, the parameters of the measuring systems in general largely determined by the parameters of the signal used.

Information-measuring systems with WNLSs have a number of advantages compared to others: higher noise immunity, secrecy, the ability to measure one-dimensional FO motion parameters and transmit information, sufficient accuracy and high reliability of transmission of information by one signal.

The results of the analysis and modeling of the IPCs with wideband noise-like signals show that the receiver filtering of interrelated signal parameters must additionally include a cross-linking device. In this case, the accuracy of the filtration of each parameter depends on the degree of its correlation with the other.

Purposes and objectives of the study

Therefore, the purpose of the article is to analyze the mutual influence of channels in the radio information-measuring system.

Analysis of recent research and publications

The task to design an IMS intended to measure distance and radial velocity, is solved for different representation of the input process.

Thus, in [2] the synthesis method is based on the filtration of Gaussian processes. In this case, the input mixture of useful signal and interference appears in the form:

$$y(t)=S[t,\vec{\lambda}(t)]+n(t), \tag{1}$$

where $\mathrm{S}[t,\vec{\lambda}(t)]=\mathrm{A}_\mathrm{c}\sum_{l=1}^{R}\sum_{k=1}^{L}a_\mathrm{k}\,\mathrm{rect}\big[t-(k-1)\tau_\mathrm{i}-T_\mathrm{i\text{-}1}-$ $-\tau_0(t)\big]\cos[\omega_0 t+\varphi_0]$;

$\vec{\lambda}(t)$ – signal parameters vector; $\mathrm{A}_\mathrm{c}=\mathrm{const}$ – amplitude of the video signal; R – an integer number (for a continuous infinite signal $R\to\infty$); $L=2^\mathrm{k}-1$ – the number of partial pulses with length τ_i in the M-sequence period (elements of a numerical sequence), each element of the M-sequence is exclusive disjunction of k previous elements; a_k is equal to 1 or (–1) in accordance with the law of alternation of the M-sequence elements; $\mathrm{rect}[\cdot]$ – rectangular pulse of unit height; $T_\mathrm{i\text{-}1}=L\tau_\mathrm{i}(i-1)$; $\tau_0(t)$ – stochastic sequence delay; $n(t)$ – white Gaussian noise with zero mean and δ – correlation function.

Equations that describe the algorithm of construction of measuring channels of the system are obtained:

$$\begin{gathered}\hat{\dot{\varphi}}+\hat{K}_{\varphi\varphi}\frac{2}{N_0}y(t)\mathrm{A}_\mathrm{c}\,g(t-\hat{\tau})\sin(\omega_0 t+\hat{\varphi})=\hat{\dot{\varphi}}_0;\\ \hat{\dot{\tau}}+\hat{K}_{\tau\tau}\frac{2}{N_0}y(t)\mathrm{A}_\mathrm{c}\frac{\partial g(t-\hat{\tau})}{\partial\tau}\cos(\omega_0 t+\hat{\varphi})=\hat{\dot{\tau}}_0,\end{gathered} \tag{2}$$

where $\hat{K}_{\varphi\varphi}$, $\hat{K}_{\tau\tau}$ – the second central moments of the multidimensional Gaussian distribution, which approximates the aposteriori distribution of probabilities. The coefficients are equal to the dispersion of filtering parameter and determined by relations:

$$\hat{K}_{\varphi\varphi}=\left(\frac{2N_{\dot{\tau}_0}}{\mathrm{A}_1^2}\right)^{\frac{1}{4}};\qquad \hat{K}_{\tau\tau}=\left(\frac{2N_{\dot{\varphi}_0}}{\mathrm{A}_2^2}\right)^{\frac{1}{4}}, \tag{3}$$

where $\dot{\tau}_0$, $\dot{\varphi}_0$ – the delay change rate and phase of the received signal, respectively.

In [3] construction of the receiver of phase-manipulated (FM) WNLS is considered at the filtration of the Markov processes. In this case, the filtration equations are written as:

$$\begin{gathered}\frac{d\hat{\tau}(t)}{dt}=A_\tau(\hat{\tau})+\sigma_\tau^2\frac{\partial F(\hat{\tau},\hat{\varphi},t)}{\partial\hat{\tau}}+R_{\tau\varphi}\frac{\partial F(\hat{\tau},\hat{\varphi},t)}{\partial\hat{\varphi}};\\ \frac{d\hat{\varphi}(t)}{dt}=A_\varphi(\hat{\tau})+\sigma_\varphi^2\frac{\partial F(\hat{\tau},\hat{\varphi},t)}{\partial\hat{\varphi}}+R_{\tau\varphi}\frac{\partial F(\hat{\tau},\hat{\varphi},t)}{\partial\hat{\tau}},\end{gathered} \tag{4}$$

where $A_\alpha(\hat{\alpha})$ – coefficient of wear in differential apriori equations for $\alpha(t)$; σ_α^2 – dispersion of filtration; $R_{\alpha\beta}$ – mutual moments of the second order; $F(\cdot)$ – function of plausibility.

Finally, in [4] the multidimensional filtration of Gaussian and Markov processes is considered. Herewith multidimensional discriminators and smoothing circles, built on the basis of vector filtration equations, are introduced into consideration.

Under certain assumptions and limiting the number of filtered parameters as well as in the condition that the system transmits information by inverse manipulation of information parcels all methods of synthesizing follow-up filters result in the filtration scheme represented in the Fig.

The main material

It should be noted that the synthesis results obtained with different initial assumptions, which lead to practically the same algorithm of information-measuring system construction, are not accidental. They can be explained by the fact that, firstly, as an observation model, one use: an additive mixture of a useful signal with a white Gaussian noise. As a matter of fact,

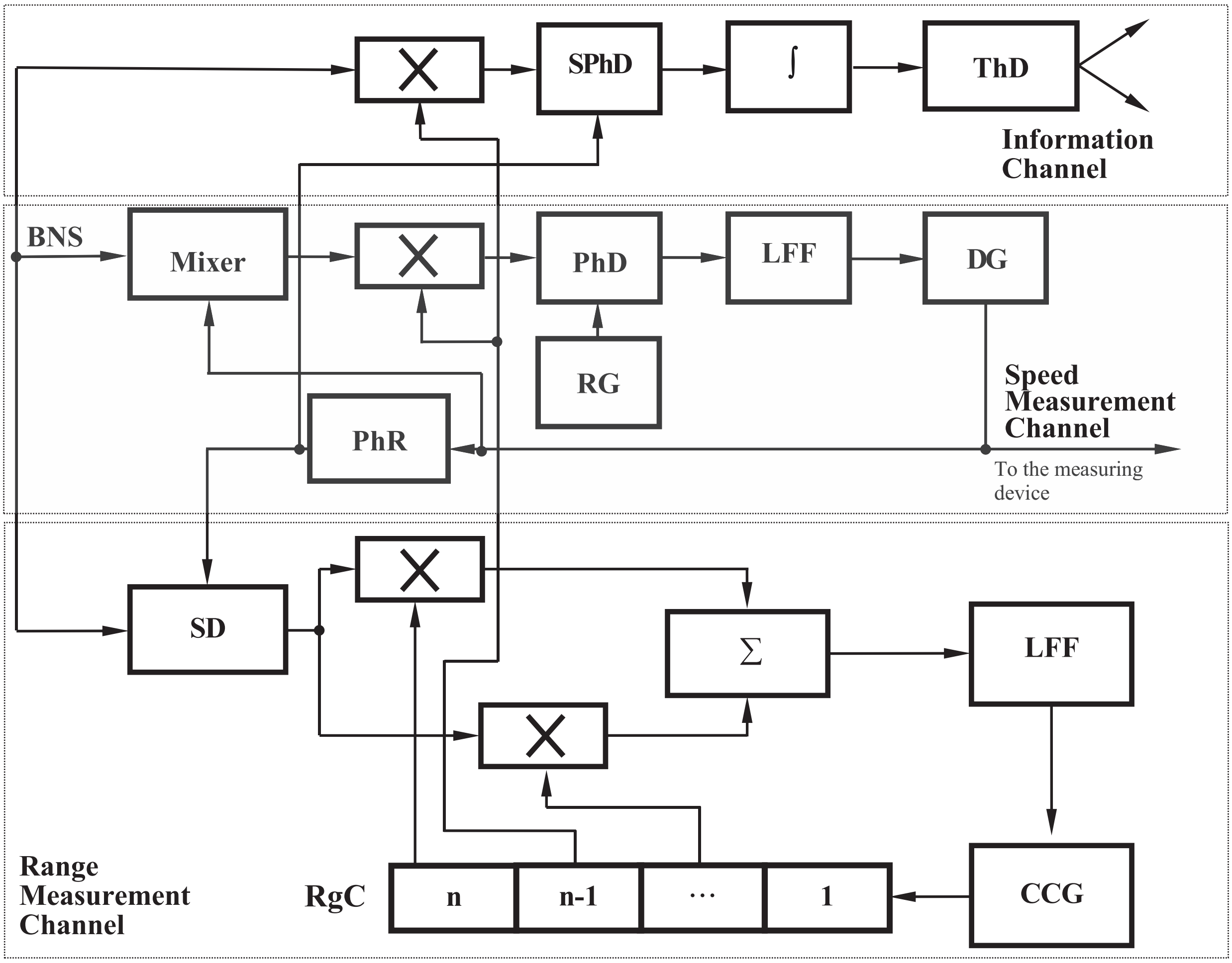

Fig. The scheme of channels interconnection in information-measuring system: ∫ – integrator; Σ – adder; X – multiplier; SPhD – synchronous phase detector; ThD – threshold device; PhD – phase detector; LFF – low frequency filter; DG – driven generator; RG – reference generator; PhR – phase rotator; SD – synchronous detector; CCG – controlled clock generator; BNS – broadband noisy signal; RgC – register cells.

the function of plausibility in all the definite cases has the same form. Secondly, the synthesis is carried out (under certain assumptions on the a priori distribution) by one criterion of the maximum of function of likelihood.

This scheme is a classical IMS scheme using WNLS. There are three interconnected channels in it: the distance measurement channel, speed measurement channel and information channel.

Since both measuring channels are interconnected, the receiver can generally be considered as a multidimensional follow-up meter, the feature of which is the zero-shift of the α discriminator in the presence of discrepancy in the β parameter.

It is interesting to consider the mutual influence of channels. Since the phase automatic frequency control is actually monitoring the phase of the signal (by frequency to the phase-to-phase), the time delay and the phase $\varphi(t)$ of the received signal are considered as interrelated parameters.

Let's consider the case of small disagreements with $\tau(t)$ and $\varphi(t)$. The input signal FM WNLS $U_{\text{inp}}(t)$ is described by the expression:

$$U_{\text{inp}}(t) = S_0 \sum_{n=0}^{N\text{-}1} v_{\text{n}} \left\{ l\left[t - n\tau_0 - \tau_0(t)\right] - \right.$$
$$\left. -\left[t - (n+1)\tau_0 - \tau_0(t)\right] \right\} \cos\left[\omega_0 t + \varphi(t)\right] + n(t), \quad (5)$$

where S_0 – the known amplitude of the signal; N – the number of elementary characters in the pseudorandom sequence; $\tau_0(t)$ – signal delay, which is a normal random process with mean value $D(t)/c$ and correlation function:

$$R_\tau(t_1, t_2) = \sum_{i,k=1}^{6} \langle \Delta q_{\text{i}} \Delta q_{\text{k}} \rangle f(t_1) f(t_2); \quad (6)$$

c – speed of light; $D(t)$ – function of the measured range; Δq_{i}, Δq_{k} – normally distributed deviations relative to the apriori known average values of the Kepler parameters of the orbit of the object; $f(t_{\text{i}}) = \partial D(q_0, t) / \partial(q_{0\text{i}} c)$ – elements of vector-column;

$\varphi(t) = \int_{t_0}^{t} (\omega - \omega_0)\, dt$ – a phase run signal, which is a normal random process with a mean value $2\pi D(t)/\lambda_0$ and correlation function:

$$R_\varphi(t_1,t_2)=\sum_{i,k=1}^{6}\rangle\Delta q_\mathrm{i}\Delta q_\mathrm{k}\langle f'(t_1)f'(t_2); \qquad (7)$$

λ_0 – wavelength at the carrier frequency of oscillation; $f'(t_\mathrm{i})=\partial D(q_0,t)/\partial(q_{0\mathrm{i}}\lambda_0)$ – elements of the column-vector.

The matrix $\underline{\mathbf{\Sigma}}_{\mathrm{equ}}$ of measurement errors τ(*t*) and φ(*t*) will be determined by the following expression:

$$\underline{\mathbf{\Sigma}}_{\mathrm{equ}}=\underline{\mathbf{K}}_{\mathrm{D}}^{-1}\underline{\mathbf{\Sigma}}\underline{\mathbf{K}}_{\mathrm{D}}^{-1\mathrm{T}}, \qquad (8)$$

where $\underline{\mathbf{K}}_{\mathrm{D}}$ – the matrix of steepness of discriminators; $\underline{\mathbf{\Sigma}}$ – matrix of the average squares of the fluctuation components at the outputs.

Elements of the matrix $\underline{\mathbf{K}}_{\mathrm{D}}$ are:

$$\left.\overline{\frac{\partial Z^{(1)}}{\partial\Delta f}}\right|_{\substack{\Delta\tau=0\\ \Delta f=0}}=\frac{A_0^2}{N_0}\bar{\ddot{R}}_\mathrm{g}(\tau-\hat{\tau})\sin\left(f-\hat{f}\right);$$

$$\left.\overline{\frac{\partial Z^{(1)}}{\partial\Delta\tau}}\right|_{\substack{\Delta\tau=0\\ \Delta f=0}}=\frac{A_0^2}{N_0}\bar{\dddot{R}}_\mathrm{g}(\tau-\hat{\tau})\cos\left(f-\hat{f}\right); \qquad (9)$$

$$\left.\overline{\frac{\partial Z^{(2)}}{\partial\Delta f}}\right|_{\substack{\Delta\tau=0\\ \Delta f=0}}=\frac{A_0^2}{N_0}\bar{R}_\mathrm{g}(\tau-\hat{\tau})\sin\left(f-\hat{f}\right);$$

$$\left.\overline{\frac{\partial Z^{(2)}}{\partial\Delta\tau}}\right|_{\substack{\Delta\tau=0\\ \Delta f=0}}=\frac{A_0^2}{N_0}\bar{\dot{R}}_\mathrm{g}(\tau-\hat{\tau})\cos\left(f-\hat{f}\right).$$

Here $\bar{R}_\mathrm{g}(\tau-\hat{\tau})$ is averaged over the interval (t_0-t) value of the normalized autocorrelation function of the complex inbound input signal.

As it can be seen, the slope matrix is not a diagonal, that is, the discrepancy with one filtered parameter causes the appearance of components in the discriminator of another parameter.

The elements of the matrix $\underline{\mathbf{\Sigma}}$ are determined from the expressions:

$$\overline{\left(Z_\tau^{(1)}\right)^2}=\frac{4A_0^2}{N_0T}\int_0^T\left\{U_{\mathrm{inp}}(t)\sum_{n=0}^{N-1}\mathrm{J}\cos\left[\omega_0t+\hat{f}(t)\right]\right\}^2dt;$$

$$\overline{\left(Z_\varphi^{(2)}\right)^2}=\frac{4A_0^2}{N_0T}\int_0^T\left\{U_{\mathrm{inp}}(t)\sum_{n=0}^{N-1}\mathrm{J}\sin\left[\omega_0t+\hat{f}(t)\right]\right\}^2dt; \qquad (10)$$

$$\overline{Z_\tau^{(1)}Z_\varphi^{(2)}}=0,$$

where

$$\mathrm{J}=v_\mathrm{n}\left\{\delta\left[t-n\tau_0-\hat{\tau}(t)\right]-\delta\left[t-(n+1)\tau_0-\hat{\tau}(t)\right]\right\}.$$

The result is the matrix elements $\underline{\mathbf{\Sigma}}_{\mathrm{equ}}$:

$$\frac{\underline{\Sigma}_{\mathrm{equ}}^{(\tau\tau)}}{K_\mathrm{M}^2}=\frac{4A_0^2}{N_0T}\cos^2(\varphi-\hat{\varphi})\left\{\left[\bar{\dot{R}}_\mathrm{g}(\tau-\hat{\tau})\right]^2+\right.$$
$$\left.+\left[\bar{\dddot{R}}_\mathrm{g}(\tau-\hat{\tau})\right]^2\right\}\int_0^T\left[U_{\mathrm{inp}}(t)\sum_{n=0}^{N-1}\mathrm{J}\right]^2dt;$$

$$\frac{\underline{\Sigma}_{\mathrm{equ}}^{(\varphi\varphi)}}{K_\mathrm{M}^2}=\frac{4A_0^2}{N_0T}\sin^2(\varphi-\hat{\varphi})\left\{\left[\bar{R}_\mathrm{g}(\tau-\hat{\tau})\right]^2+\right.$$
$$\left.+\left[\bar{\ddot{R}}_\mathrm{g}(\tau-\hat{\tau})\right]^2\right\}\int_0^T\left[U_{\mathrm{inp}}(t)\sum_{n=0}^{N-1}\mathrm{J}\right]^2dt; \qquad (11)$$

$$\frac{\underline{\Sigma}_{\mathrm{equ}}^{(\varphi\tau)}}{K_\mathrm{M}^2}=\frac{4A_0^2}{N_0T}\mathrm{tg}(\varphi-\hat{\varphi})\left\{\bar{\dot{R}}_\mathrm{g}(\tau-\hat{\tau})\bar{R}_\mathrm{g}(\tau-\right.$$
$$-\hat{\tau})\int_0^T\left[U_{\mathrm{inp}}(t)\sum_{n=0}^{N-1}\mathrm{J}\right]^2dt-\bar{\ddot{R}}_\mathrm{g}(\tau-\hat{\tau})\bar{\dddot{R}}_\mathrm{g}(\tau-$$
$$\left.-\hat{\tau})\int_0^T\left[U_{\mathrm{inp}}(t)\mathrm{tg}^2(\varphi-\hat{\varphi})\sum_{n=0}^{N-1}\mathrm{J}\right]^2dt\right\},$$

where

$$K_\mathrm{M}=\frac{2N_0}{A_0^2\sin2(\varphi-\hat{\varphi})}\cdot$$
$$\cdot\frac{1}{\bar{\dot{R}}_\mathrm{g}(\tau-\hat{\tau})\bar{\dot{R}}_\mathrm{g}(\tau-\hat{\tau})+\bar{R}_\mathrm{g}(\tau-\hat{\tau})\bar{\dddot{R}}_\mathrm{g}(\tau-\hat{\tau})}.$$

Conclusions

It should be noted that the matrix $\underline{\mathbf{\Sigma}}_{\mathrm{equ}}$ is a non-diagonal, which uniquely indicates the interconnection of the parameter coding in the signal.

The matrix elements depend on the "signal / noise" ratio and the steepness of the auto-correlation function of the integrated inbound input signal in each of the measuring channels. Moreover, as should be expected, the measurement error increases with a decrease of the "signal / noise" ratio.

The errors caused by the mutual influence of the channels become minimal when partial errors in the channels are absent, that is, the estimation of the parameter coincides with the true value, and there is no discrepancy in one of the filtered parameters.

It should be noted that the information modulation has a significant influence in the measurement errors of the measuring channels, therefore the requirements for the amount and speed of the transmission of information [5] should be substantiated.

Аналіз взаємного впливу каналів у радіотехнічній інформаційно-вимірювальній системі

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Анотація

Розробка нових радіотехнічних інформаційно-вимірювальних систем (ІВС) наземного комплексу управління літальними об'єктами має бути спрямована на підвищення їхніх можливостей щодо точного та достовірного контролю навігаційних параметрів сигналів. Це є особливо важливим в умовах обмеженого у часі сеансу зв'язку, а також для забезпечення оперативного контролю траєкторій балістичних об'єктів при їх польоті за необладнаними трасами.

В останні роки в радіотехнічних системах часто використовують широкосмугові шумоподібні сигнали (ШШС) – складні дискретні сигнали, модульовані гармонічним сигналом за частотою, фазою та амплітудою кодом псевдовипадкової послідовності. Використання ШШС пояснюється рядом їх властивостей: кращою перешкодозахищеністю і прихованістю, більшою точністю вимірювання швидкості та дальності рухомих об'єктів, перспективою більш ефективного використання таких сигналів у дозволених діапазонах частот, а також можливістю їх багатопроменевого поширення.

ІВС з ШШС мають низку переваг: підвищену завадостійкість, скритність, можливість одним сигналом здійснювати виміри параметрів руху літального об'єкту і передавати інформацію, достатню точність і високу достовірність передачі інформації. В перспективі це може привести до побудови уніфікованої, мобільної ІВС, тактико-технічні характеристики якої будуть задовольняти сучасним вимогам. Проте, основною причиною, яка перешкоджає більш широкому запровадженню складних псевдовипадкових сигналів у практику радіотехнічних ІВС, є труднощі, пов'язані з їх оптимальною обробкою.

Проведено аналіз ІВС з ШШС на предмет визначення ступеня взаємного впливу каналів при фільтрації взаємозалежних параметрів сигналу. Встановлено, що похибки, обумовлені взаємним впливом каналів, мінімальні, якщо оцінка параметру збігається з його істинною величиною, а також відсутні розузгодження за параметром, що фільтрується. Таким чином, точність фільтрації кожного з параметрів залежить від ступеню їхньої кореляції, від співвідношення "сигнал-шум", та від крутизни автокореляційної функції комплексної обвідної вхідного сигналу.

Ключові слова: інформаційно-вимірювальна система, навігаційні параметри сигналів, достовірність інформації.

Анализ взаимного влияния каналов в радиотехнической информационно-измерительной системе

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Аннотация

Разработка новых радиотехнических информационно-измерительных систем (ИИС) наземного комплекса управления летательными объектами должна быть направлена на повышение их возможностей по точному и достоверному контролю навигационных параметров сигналов. Это особенно важно в условиях ограниченного во времени сеанса связи, а также для обеспечения оперативного контроля траекторий баллистических объектов при их полете по необорудованным трассам.

В последние годы в радиотехнических системах часто используют широкополосные шумоподобные сигналы (ШШС) – сложные дискретные сигналы, модулированные гармоничным сигналом по частоте, фазе и амплитуде кодом псевдослучайной последовательности. Использование ШШС объясняется рядом их свойств: лучшей помехозащищенностью и скрытостью, большей точностью измерения скорости и дальности подвижных объектов, перспективой более эффективного использования таких сигналов в разрешенных диапазонах частот, а также возможностью их многолучевого распространения.

ИИС с ШШС имеют ряд преимуществ: повышенную помехоустойчивость, скрытность, возможность одним сигналом осуществлять измерения параметров движения летательного объекта и передавать информацию, достаточную точность и высокую достоверность передачи информации. В перспективе это может привести к построению унифицированной, мобильной ИИС, тактико-технические характеристики которой будут удовлетворять современным требованиям. Однако, основными причинами, препятствующими более широкому внедрению сложных псевдослучайных сигналов в практику радиотехнических ИИС, являются трудности, связанные с их оптимальной обработкой.

Проведен анализ ИИС с ШШС на предмет определения степени взаимного влияния каналов при фильтрации взаимосвязанных параметров сигнала. Установлено, что погрешности, обусловленные взаимным влиянием каналов, минимальны, если оценка параметра совпадает с его истинной величиной, а также отсутствуют рассогласования по фильтруемому параметру. Таким образом, точность фильтрации каждого из параметров зависит от степени их корреляции, от соотношения “сигнал-шум” и от крутизны автокорреляционной функции комплексной огибающей входного сигнала.

Ключевые слова: информационно-измерительная система, навигационные параметры сигналов, достоверность информации.

References

1. Litus Yu.P., Malapheyev E.E., Mikhaylov Yu.V. Vysokotochnaya mnogoparametrycheskaya systema vneshnetrayektornykh izmereniy parametrov dvizheniya letatelnykh apparatov VEGA [High-precision multiparameter system of external trajectory measurements parameters of aircraft movement]. *Prikladnaya radioelektronyka*, 2006, vol. 5, no. 4, pp. 448–453 (in Russian).
2. Tuzov G.I. Statisticheskaya teorya priyoma slozhnykh signalov [Statistical theory of receiving complex signals]. Moscow, Soviet radio, 1977. 400 p. (in Russian).
3. Cherdyntsev V.A. Radiotekhnicheskye sistemy [Radio systems]. Minsk, Vysheyshaya shkola, 1988. 369 p. (in Russian).
4. Bakut P.A., Bolshakov N.A., Gerasimov B.M. Voprosy statisticheskoy teorii radiolokacii [The questions of radar statistical theory]. Moscow, Soviet radio, 1964, vol. 2. 1081 p. (in Russian).
5. Barkudaryan M.V., Kulagin K.K., Mishukov O.M., Chumak B.O. Perspektyvnyi metod obrobky vymiriuval’noi informacii pry polygonnykh vyprobuvanniyakh [A promising method for processing measurement information during testing ground range]. *Systems of Arms and Military Equipment*, 2011, no. 2 (26), pp. 15–18 (in Ukrainian).