# Substantiation of Information Technology on Improving the Accuracy of the Signal Synchronization Received by the Radio Technical System

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**Abstract**
The report considers the issues of selection and substantiation of information technology for the construction and application of the scheme of synchronization of the input signal by the phase-coherent communication system in the angular demodulation of the signal transmitted by the satellite communication system. The aim of the work is the choice of information technology and substantiation of its application in synchronization systems to increase the accuracy of signal synchronization by a phase-coherent communication system adopted by a satellite communication system at angular signal demodulation. The problem to be solved is to investigate the expediency of its application on the basis of the chosen information technology on the basis of assessing the possibility of closed and combined phase synchronization systems to increase the accuracy of signal synchronization received by satellite communication system at angular signal demodulation. The following results were obtained: the choice of information technologies was made and on its basis the analysis of synchronization systems of closed and combined type was carried out; their inconsistencies and advantages in increasing the accuracy of signal synchronization during carrier frequency tracking in angular signal demodulation are determined; the features of signal processing and minimization of phase error in the transient mode of operation of the synchronization system are determined. Conclusions: as an information technology for building synchronization systems in the article offers an invariant approach, which determines the possibility of the schemes presented in the article for building a synchronization system to increase the dynamics and order of astatism, reduce constants and transient errors; it is shown that taking into account the additive Gaussian noise and instability of generators, the desire to minimize the variance of the phase error in the class of closed synchronization systems causes a deterioration of the system dynamics and does not increase the order of astatism; the combined synchronization system with open communication is a synthesized invariant system, has the ability to increase the order of astatism, and is able to minimize the phase error in the angular demodulation of the signal; The selection of open communication parameters in combined synchronization systems can affect the transmission function and thus ensure the minimization of constant and transient errors of the system without affecting the dynamics of the system.

**Keywords** [1]
Signal synchronization accuracy, carrier frequency synchronization, closed type phase synchronization system, combined type phase synchronization system, astatism order, constant error variance, transient error variance.

## 1. Introduction

Improving the efficiency of communication systems largely depends on the quality of operation of systems and devices that are part of them, as well as on the processes and methods of transmission, reception and processing of useful signal, which are directly related to signal modulation - changing carrier parameters in depending on the level of the transmitted signal.

*Information Technology and Implementation (IT&I-2021), December 01–03, 2021, Kyiv, Ukraine*
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Satellite communication systems mainly use angular modulation, which is free from the disadvantages associated with the technical complexity of systems that use amplitude modulation. When angular modulation, the transmission of information is carried out by changing the phase and frequency of the carrier. However, a serious disadvantage of angular modulation should be considered that the transmission of a unit of information requires a wider range of frequencies than amplitude modulation. Angular modulation can be in the form of frequency or phase modulation. Regardless of the type of angular modulation, its implementation requires synchronization of the input signal, which is carried out by the corresponding synchronization systems. For example, in phase-coherent telecommunications and control systems, they are used to restore carrier and clock frequencies and for coherent demodulation of analog and digital signals with angular modulation [1].

The operation of synchronization systems is characterized by the influence of a number of disturbances and noise on their operation. Namely, additive fluctuation noise, perturbation of useful angular modulation (in the case of carrier frequency filtering), phase and frequency jumps and others. In some cases, it is necessary to ensure high accuracy of the system in steady and transient modes. Thus, in satellite communication systems, the main perturbations are additive Gaussian noise and Doppler frequency shifts. Therefore, synchronization systems operating in such conditions should be characterized by low phase error variance and high speed [2].

Noise immunity, accuracy and speed of synchronization systems affect the main performance of phase-coherent communication systems. In turn, these system parameters depend on information technology and the scheme of construction of this system. Thus, improving the accuracy of signal synchronization received by the satellite communication system requires the choice of information technology, and on its basis the selection and justification of the optimal signal synchronization scheme, which can provide low phase error variance and high speed is an urgent and timely scientific task.

A number of works are devoted to the question of the choice of information technology of construction and substantiation of the scheme of synchronization of the input signal of phase-coherent communication systems.In scientific works, for example [3, 4, 5], studies are described, aimed mainly at optimizing the parameters of the filter and the system as a whole for the class of closed synchronization systems (ClSS). However, due to their inherent contradictions, the ClSS does not allow in some cases to ensure the required quality of work. This is especially noticeable when you want to improve the quality of the system on two or more conflicting indicators.

Inaccuracies in the filtering of the carrier oscillation phase in the ClSS reduce the signal-to-noise ratio at the output of the coherent receiver. Therefore, when filtering the phase, it is necessary to ensure minimal error. The desire to increase the ability to filter the synchronization system in the class ClSS leads to the inevitable narrowing of the retention band, and the desire to increase the order of astatism impairs the dynamics of the system.

Improving the dynamics can be done, for example, by recording the signal at the current time and reading at the next clock interval M times, as defined in [6]. However, the processing of information in such systems is not in real time, and in addition, the recording and reproducing devices introduce additional distortions. Certain researches in the direction of improvement of qualities of ClSS due to change of the scheme of realization in the direction of its combination and reduction by various methods of the minimum errors at a phase filtration stage were carried out and their results are stated in the following works. In [7], the peculiarities of the implementation of the carrier frequency recovery system with coherent demodulation of the signal with a continuous phase are shown. The question of practical realization of the system of phase autotuning of frequency on a modern element base is investigated. The article does not consider the synthesis of open communication in the scheme considered as the optimal scheme. Also, this article does not address the issue of increasing the order of astatism.

Substantiation of prospects for research in the direction of synthesis of open communication is well presented in [8]. But the synthesis of open communication in the combined synchronization system was not considered. In the article [9] the possibility of constructing a clock synchronization system for signal receivers with minimal frequency manipulation based on an autocorrelation demodulator is considered. The operation of an autocorrelation demodulator with a complex signal envelope with minimal frequency manipulation has been studied. On the basis of machine modeling dependences of parameters of a clock signal on inaccuracies of execution of elements of the scheme are received. This article does not address the issue of synthesis of open communication in the given scheme of clock synchronization and there is no consideration of the issue of increasing the order of astatism.

The author of [10] proposed a method of synchronization of the sequence of signals, which expands in conditions of significant excess of the noise level over the level of the information signal. For synchronization the service channel which works on one frequency with information is used. Channel distribution is performed during the formation of signals of quadrature channels: in-phase channel is used to generate a phase-locked signal with spread spectrum, quadrature channel is used to transmit a clock signal.

## 2. Statement of the research problem

The choice of information technologies of optimization and substantiation of the rational scheme of synchronization which would provide to reduce a dispersion of constant and transient errors in the course of tracking of carrier frequency in the presence of noise in the communication channel at angular demodulation of a signal. the problem to which this work is devoted.

## 3. Choice and substantiation of information technology

As the main information technology, on the basis of which we will evaluate the possibilities of different synchronization schemes to minimize the variance of the phase error, we choose the concept of invariant system. And to the considered schemes we will apply the requirement, as to the selective invariant system which basic indicator of quality will be an opportunity on increase of the order of astatism.

In the General case, the phase modulation of the signal contains four components [11]:

$$\varphi_{inp}(t) = d(t) + M(t) + \Delta\Psi(t) + N(t) \tag{1}$$

Where:

$d(t)$ – Doppler shift at the input;

$M(t)$ – useful angular modulation;

$\Delta\psi(t)$ – generator instability.

Depending on the application of the synchronization system, some components in the above expression are useful, others – obstacles.

When using a synchronization system for angular demodulation, the value to be tracked will be $M(t)$. And the values $\Delta\psi(t)$ and $N(t)$ included in vortex 1 are an obstacle.

In this case, for phase modulation (FM) $M(t)=K_m m(t)$. And for frequency modulation (FM) $M(t)=K_m \int m(t)dt$. Where is the $K_m$ – modulation index, and $m(t)$ is the modulating function [11].

In what follows, we consider a modulating signal $m(t)$ of two types: with the "maximally flat (butterworth) shape of the spectrum" and asymptotic Gaussian processes.

Their energy spectra can be described according to the following expressions [11]:

$$G_1(\omega,n)=K_1(n)\Big/\left[1+\left(\omega/\omega_c\right)^{2n}\right] \tag{2}$$

$$G_2(\omega,n)=K_2(n)\Big/\left[1+\left(\omega/\sqrt{n}\omega_c\right)^{2n}\right]^n \qquad n = 1,2,3... \tag{3}$$

Where:

$$K_1(n)=\pi\, sinc\left(\pi/2n\right)/\omega_c \quad K_2(n)=(4\pi)/\left[\sqrt{n}\omega_c\right]$$

$$sin\,c = sin\,x\,/x$$

$\omega_c$ – frequency corresponding to half the power.

The following spectra are characteristic of a wide class of signals used in communication [11]:

$$G_1(\omega,1) = G_2(\omega,1) = G \quad (\omega,1)$$

When $n = 1$ they are the same. This spectrum is characteristic of a stationary telegraph signal, where the factors contain the parameters of the amplitude of the "rectangular wave" and the intensity of the sign change. The spectrum (2) is $n = \infty$ uniform in the band $\omega_c$ [60]:

$$G_1(\omega,1)= \begin{matrix} \pi P/\omega_C, |\omega| \le \omega_C \\ 0, |\omega| \le \omega_C \end{matrix}$$

This spectrum has a modulating multi-channel process with channel amplitude-modulated signals with the transmission of one sideband signals (AM TSИ signals) [11]. If this process modulates the phase of the signal then $G_\phi(\omega) = K_m^2 G_1(\omega, \propto)$, and if the frequency, the phase spectrum will be $G_\phi(\omega) = K_m^2 G_1(\omega, \propto)/\omega^2$. The spectrum of the form (3), on the other hand $n = \infty$, approaches Gaussian.

$$G_2(\omega) = \frac{2\pi}{\omega_c} e^{-(\omega/\omega_c)^2}$$

This spectrum has a phase of the signal modulated by a random process that has passed through a linear device with a bell-shaped frequency response [11]:

$$G_\phi(\omega) = (q/\Pi) exp(-\omega^2/\Pi)$$

where is $q$ the coefficient depending on the signal-to-noise ratio, $\prod$ is the integrated band of the linear device preceding the limiter in the synchronization system.

Let us assume for simplification $d(t) = \Delta\psi(t) = 0$. That is, consider the case when the main interfering factor is additive Gaussian noise, and the effect of Doppler shift and generator instability is small. If necessary, their impact can be easily taken into account.

Then the phase modulation spectrum will be determined only$m(t)$ and equal to:

$$G_M(\omega) = K_m^2 G_i(\omega) \tag{4}$$

In order to substantiate as an information technology the proposed invariant approach to the evaluation of synchronization systems, we turn to the evaluation of some schemes of its construction.

## 4. Analysis of a closed synchronization system

Let's evaluate the possibility of increasing the accuracy of signal synchronization by the criterion of minimizing the phase error when using closed synchronization systems (ClSS).

Preliminary analysis of such schemes has shown that their application has advantages in simplicity of design [2, 3]. As an information technology for the construction of synchronization systems, we consider an invariant approach, in which we determine the possibility of a closed synchronization system to increase the order of astatism [14,15]. Usually ClSS includes several units that perform their tasks and have certain transfer functions. The following transfer functions include [12,13]:

– $W_1(S)$ – the transfer function of the phase discriminator (PD);
– $W_2(S)$ – filter (F);
– $W_3(S)$ – adjustable generator (AGn).

These transfer functions are as follows:

$$W_4(S) = K_1 + \left( D_1(S) \big/ F_1(S) \right) \qquad W_3(S) = K_3 \big/ S = D_3(S) / F_3(S)), \tag{5}$$

When $K_1 = A_1 K_{PD}$ ; $K_3$ – AGn gain; $S$ - Laplace operator.

To assess the possibility of such a system to minimize the phase error, we consider ClSS synchronization with a proportional-integrating filter (PIF) in a closed loop with a transfer function of the form [12, 13]:

$$W_2(S) = (T_1 S + 1) \big/ (T_2 S + 1) \tag{6}$$

If the condition is met $T_1/T_2 \leq\leq 1$, then such a filter is close to an ideal integrator (IF) with a transfer function [12]:

$$W_2(S) = \left( (T_1 S + 1) \big/ (T_2 S) \right) \tag{7}$$

The transfer function for the error of such ClSS will be [13, 14]:

$$W(S)=\frac{1}{1+W_1(S)W_2(S)W_3(S)}=\frac{T_2(S+1)S}{a_0S^2+a_1S+a_2}=\frac{D_{\varphi з0}(S)S^{\nu_з}}{F_з(S)}, \qquad (8)$$

When $a_0=T_2$, $a_1=A_0KT_1+1$, $a_2=A_0K$, $K=K_1/K_3$, $D_{\varphi з0}(S)=T_2(S+1)$

From the vortex. (8) it is seen that the achievement of invariance in the ClSS is impossible, because equality must be observed $D_{\varphi 30}(S)=0$. The schedule of the transfer function in the Taylor series showed that when used in CCC PIF it is inoperable, and to restore its efficiency it is necessary to increase the order of astatism [14].

Replacing the UIF with an ideal integrating IF filter or two series-connected IFs can increase the order of asthma ClSS [14,15]. To switch from the link with the transfer function (6) to (7), the parameter $T_1$ must be reduced and $T_2$ increased. Since both of these parameters are included in the characteristic equation of the ClSS $F_3(S)=0$, their change will affect the quality of the transition process.

Let's evaluate this influence. The characteristic equation of ClSS has two roots $S_{1,2}=\left(-a_1\pm\sqrt{a_1^2-4a_0a_2}\right)/2a_0$, where the coefficient $a0$ depends on the parameter $T_2$, and $a_1$from $T_1$.

Therefore $a_1$, it decreases and $a0$ increases, which causes a decrease in the absolute value of the roots (or their real parts), the imaginary parts of the roots increase, the transition process becomes oscillating and weakly attenuating. In this case, as shown in [15], the choice of system parameters must be made under the condition of compromise adjustment. A similar situation arises in the ClSS of a higher order, the approach of the filter in a closed loop to the integrating second order also worsens the transition process, ie the transient error increases and the dynamics of the system decreases [15,23].

In addition, as follows from the relations and conclusions given in [14], for ClSS, by switching from UIF to IF it is possible to reduce the permanent error, but it is not possible to eliminate it completely, and at r = 2 in (1.4) the system remains inoperable. Thus, minimizing the phase error variance in the class of closed synchronization systems can be done by optimizing the parameters of the filter and the system as a whole, but this leads to a deterioration of the system dynamics.

## 5. Combined synchronization system (CbSS) analysis.

As a precondition for the analysis of Combined synchronization system (CbSS), it should be noted that the error transfer function and the phase error dispersion in the optimal system in the spectrum of the input signal of type (2) can be described by expressions [11].

$$W_{OPT}(S)=1-\left[\frac{\omega^{2n}+\omega_c^{2n}}{\omega^{2n}+в_c^{2n}}\right]_+=\frac{D_0(S)}{F_0(S)}, \qquad \sigma_{OPT}^2=\frac{2nK_m^2}{C(n)}\{[1+C(n)]^{1/2n}-1\},$$

when $C(n)=2\pi qK_m^2\sin c(\pi/2n)$, $q=(2A_0^2)/\omega_cN_0$, $в_1^{2n}=\omega_c^{2n}[1+C(n)]$

For example, the $n=2$ characteristic equation of the optimal Wiener system $F_0(S)=S^2+\sqrt{2}в_1S+в_1^2=0$ has two complex roots $S_{1,2}=(\sqrt{2}в_1)(-1\pm j)/2$. That is, the transient in the system will be oscillating with a weakly decaying amplitude.

You can reduce the transition component of the error only by increasing the parameter $в_1$. However, this is impossible, as for the specified values of the signal and interference $в_1 = const$ and it is impossible to change [11,15]. As a CbSS, consider a system that has one or two links of open communication. Preliminary analysis shows that, in general, CbSS is free from contradictions between established and transient errors. And by synthesizing an open connection in them, it is possible to achieve an additional reduction of the transient component of the error with the optimal steady-state error and vice versa [14,16]. It will be relevant to evaluate the possibility of CbSS on the influence of open-loop synthesis under the condition of minimizing the phase error variance and the identical task of optimizing the closed-loop parameters with a proportionally integrating open-circuit filter synthesized to ensure optimal phase error dispersion. The equation of CbSS dynamics can be given in the form [11,15]:

$$\varphi(S)=\varphi_{inp}(S)-\varphi_{out}(S), \quad \varphi_{out}(S)=W_3(S)\sum(S),$$

$$\sum(S) = W_4(S)\varphi_{inp}(S) + W_1(S)W_2(S)\varphi(S)$$

If we exclude intermediate variables, we obtain the equation of CbSS dynamics with respect to the error:

$$[1+W_1(S)W_2(S)W_3(S)]\varphi(S)=[1-W_3(S)W_4(S)]\varphi(S)\ , \tag{9}$$

hence the condition of absolute invariance [15]:

$$1-W_3(S)W_4(S)=0.$$

Given that $W_i(S)=D_i(S)/F_i(S)$, we rewrite equation (1) as follows:

$$\begin{aligned}&[F_1(S)F_2(S)F_3(S)+D_1(S)D_2(S)D_3(S)]F_4(S)\varphi\ (S)=\\&=[F_3(S)F_4(S)-D_3(S)D_4(S)]F_1(S)F_2(S)\varphi_{вх}(S)\end{aligned} \tag{10}$$

From expression (10) it is seen that the denominator of the transfer function of the open channel $F_4(S)$ is included in the characteristic equation CbSS (9) in the form of a coefficient

$$F_k(S)=[F_1(S)F_2(S)F_3(S)+D_1(S)D_2(S)D_3(S)]F_4(S)=F_3(S)F_4(S)$$

when $F_3(S)=F_1(S)F_2(S)F_3(S)+D_1(S)D_2(S)D_3(S)$ – characteristic polynomial CbSS. Therefore, open communication does not affect the stability of the system [16,17].

The presence of a difference in the right-hand side of the equation of dynamics of CbSS (9) allows due to the appropriate choice of polynomials $D_4(S)F_4(S)$ to influence both the constant and the transient components of the error. From expression (2) it is seen that to achieve absolute invariance in the system, the transfer function of the open channel must have the following form:

$$W_4(S)=1/W_3(S)=F_3(S)/D_3(S)=D_4(S)/F_4(S) \tag{11}$$

It follows that the order of the polynomial $D_4(S)$ must be higher than the order of the polynomial $F_4(S)$, which is impossible from the conditions of physical realization [16,17]. Thus, the achievement of absolute invariance in continuous systems by means of units or computing devices of continuous type is impossible. However, the introduction of physically realized links $W_4(S)$ into the open channel of the system allows to increase the order of astatism of the system and to synthesize $\varepsilon$ – invariant systems [15, 16].

The variance of the phase error of KSS for the case under consideration can be expressed by the following quadratic polynomial: $\sigma^2_{\varphi K} = \sigma_1 K_4^2 + \sigma_2 K_4 + \sigma_3$. By comparing $\sigma^2_{\varphi K} = \sigma^2_{OPT}$ and solving the obtained equation, we determine the value of the parameter $K_4$ of the additional connection, which provides a minimum variance of the phase error at the required quality of the transient process. That is, it seems appropriate to use the KSS with open communication in the synchronization schemes for angular demodulation of the signal transmitted by the satellite synchronization system.

Direct synthesis of open communication in CbSS under the condition of increasing accuracy during angular demodulation is a separate scientific problem and needs further solution.

It is advisable to separately investigate and take into account the effectiveness of the introduction of open communication in the presence of restrictions on the original coordinate and its derivatives and assess the sensitivity of the system to the deviation of the parameters of open and closed channels.

Issues of improving the quality of the phase synchronization system are constant important scientific tasks and in a number of studies are solved by creating appropriate optimal schemes for its construction in the direction of minimizing the variance of the phase error and at the same time ensuring high speed. It is obvious that these schemes solve the problem of minimizing the phase error through the development of scientifically sound optimal construction schemes that operate on the basis of developed mathematical models. These mathematical models must take into account both the parameters of the components of the scheme of construction of the synchronization system and the factors of external perturbations, which is quite fully defined in [18, 19, 20].

The results of evaluation of the limitations formed by the influence of the random input signal on the process of minimizing the phase error during the monitoring of the carrier frequency of the combined synchronization system of the radio communication device presented [20] showed that: in the presence of restrictions on any coordinate of the input signal the introduction of an additional link of open communication in the implementation of CbSS is reduced and at some threshold values becomes "0" and the introduction of an additional link does not give the desired effect and becomes impractical. It should be noted that in general, when receiving the input signal by the synchronization system, the actual problem is to reduce the effect of noise interference in order to increase the signal-to-noise ratio (SNR). This problem is also relevant for other technical systems operating under various influencing factors. One of the methods to reduce the impact of noise at the input of the synchronization system is quite illustratively presented in [19,20]. The scientific article [20] is devoted to orthogonal Lager filtering of noise processes, which are described by linear random processes. The proposed filtration method makes it possible to reduce the influence of noise interference, which is described by stationary linear random processes, during the operation of correlation systems. The idea of this method is to use orthogonal Lagerr filters as input links of the correlation system. This method can be used in further studies to increase the efficiency of the process of minimizing the variance of the phase error in the process of monitoring the carrier frequency.

## 6. Directions of minimization of influence of a phase error in a transient mode of operation of the combined synchronization system

It is known that in the list of factors of internal disturbances and interferences of telecommunication systems, which directly affect the dynamics of the whole system, there are transients. They are caused by the reaction of the system to the transition from one steady-state to another steady state. For the phase synchronization system, they can be caused by cases when the input signal is received by the circuit for the first time, when the connection is interrupted, due to Doppler frequency shift, etc. [18,17,19].

Thus, the development and creation of a phase synchronization system of the input signal in the direction of increasing its dynamics, as a prerequisite for increasing the bandwidth of the satellite telecommunications system require taking into account the impact of the transition process on its speed. systems. In previous studies on improving the operation of the synchronization system, it was shown that the optimization of the synchronization system to a minimum of the phase error variance leads to a deterioration of its dynamics [18,19].

It is established that transients can be influenced in two ways [20,21.22]:

- reducing the transient time with a single-phase jump of the input signal without taking into account the effects of noise;
- minimization of the transient component of the error while limiting the variance of the main (base) error.

In the case of a decrease in the transient time during a single-phase jump of the input signal without taking into account the effect of noise, the phase of the input signal will be defined as $\varphi_{inp}(t)$=d(t) [20,22]. Since the phase estimation must be accurate enough to be used in a synchronization system, the case with a high signal-to-noise ratio, when noise can be neglected, is of practical interest, and estimating the time of system synchronization in the absence of noise is important. most systems associated with synchronization [19,20]. In addition, this approach allows to development of a technique for the synthesis of open communication in relation to synchronization systems, taking into account nonlinearity.

In the expression to determine the phase of the input signal:

$$\varphi_{inp}(t) = \varphi_0 + \sum_{r=0}^{N-1}(\Omega_r t^{r+1})(r+1),$$

we will consider $r$ = 0 (phase jump) and $r$ = 1 (frequency jump). In this case, we use the method of synthesis of open communication under the condition of suppression of slow-decaying components described in [19,20,21] with respect to linear automatic control systems.

The transfer function of the phase discriminator, taken as an open link, is defined as

$$W_1(S) = K_1 N(\varphi). \tag{12}$$

Where $N(\phi)$ the nonlinear characteristic of the phase discriminator is normalized. The corresponding transfer functions of the system are obtained from the previously found expressions by including them instead $W_1(S)$ of their value from expression (12).

The expression to display the phase error, in this case, is written as:

$$F(S)\varphi(S) = D\varphi(S)\varphi_{вх}(S) \tag{13}$$

The complete solution (2) can be given as forced $\varphi_в(t)$ and transient $\varphi_n(t)$ components.

$$\varphi(t) = \varphi_n(t) + \varphi_в(t).$$

The forced error component $\varphi_в(t)$ in this case depends on the control effect $\varphi_{вх}(t)$ and is defined as the solution of the inhomogeneous differential equation (13). It characterizes the accuracy of the system in a steady state.

The transient component of the error is the solution of a homogeneous differential equation.

$$F(S)\varphi_n(S) = 0.$$

This error occurs in transient modes and is determined by the roots of the characteristic equation.

If the characteristic equation of the synchronization system $F(S) = 0$ has simple (multiple) roots, then the transient component of the error can be represented as the sum of the exponents:

$$\phi_n(t) = \sum_{i=1}^{m} A_i\, e^{S_i t}, \tag{14}$$

where $S_i$ – $i$ – root of the characteristic equation, $A_i$ – initial value $i$ – component of a transient error.

From expression (14) it is seen that the magnitude of the transition error depends both on the roots of the characteristic equation that determine the intensity of the decline of the exponents, and on the initial values of the exponents that characterize their maximum amplitude. Thus, increasing the real parts of the roots, or decreasing the initial values of the component of the transient component of the error, can affect its value. However, in closed synchronization systems, such possibilities are limited, as the coefficients of the characteristic polynomial are selected from the condition of compromise tuning. To synthesize an open connection under the influence of transients, we write the expression for the phase error in the temporary form. To do this, to move from the expression for the phase error in the form (2) to the temporary form of the record (3), we use Cauchy's theorem on subtraction.

Then we get [22, 23]:

$$\varphi(t) = \sum_{S_i} \operatorname{Re s}\left[\varphi(S)e^{St}\right] = \sum_{S_i} \operatorname{Re s}\psi(S). \tag{15}$$

Where $\psi(S) = \varphi(S)e^{St}$, the subtraction of the function $f(x)$ at a special point $a$, which is the pole of the multiplicity $m$, and is determined by the expression [15, 16]

$$\operatorname{Re sf}(a) = \frac{1}{(m-1)!}\left\{\frac{d^{m-1}}{dx^{m-1}}\left[(x-a)^m f(x)\right]\right\} \tag{16}$$

We present the transfer function of the synchronization system and the input effect in the form of fine-rational expressions [21, 24, 25]:

$$W_\varphi(S) = \frac{\sum_{i=v}^{m} b_i S^i}{\sum_{i=0}^{m} a_i S^i} = \frac{b_m \prod_{i=v}^{m}(S - S_i)S^v}{a_m \prod_{i=1}^{m}(S - S_i)} = \frac{D_\varphi(S)}{F(S)}$$

$$\varphi_{inp}(S) = \frac{\sum_{i=0}^{h} \beta_i S_i}{\sum_{i=0}^{\mu} \alpha_i S_i} = \frac{\beta_m \prod_{i=1}^{h}(S - q`_i) S^v}{\alpha_m \prod_{i=1}^{\mu}(S - q_i)} = \frac{M(S)}{R(S)} \quad (17)$$

where $S_i^{/}$, $S_i$, $q_i^{/}$, $q_i$ - zeros and pluses of the transfer function and input influence, respectively.

Then the initial value $k$ of the component of the transient component of the error in accordance with the expression (15 and (16) for simple roots of the equation $F(S) = 0$, in general, can be written as follows:

$$A_к = \operatorname*{Res}_{S=S_к} \varphi(S) = \frac{в_m \beta_h \prod_{i=v}^{m}(S_к - S_i) \prod_{i=1}^{h}(S - q_i^{/})}{a_m \alpha_\mu \prod_{i=1, i\neq n}^{m}(S_к - q_i) \prod_{i=1}^{\mu}(S_к - q_i)} = \frac{D_\varphi(S_к) M(S_к)}{F^{/}(S_к) R(S_к)}, \quad (18)$$

where $F^{/}(S_к) = dF(S)/dS$, $S = S_K$ .

From this expression, it is seen that to make equal to zero the initial values $k$ of that component is possible only if the equality is fulfilled $S_к = S_к^{/}$.

## 6. Conclusions

The paper presents the results of selection and substantiation of information technologies for the construction and application of the scheme of synchronization of the input signal by the phase-coherent communication system in the angular demodulation of the signal transmitted by the satellite communication system. As an information technology for the construction of synchronization systems, the article proposes an invariant approach, which determines the possibility of the schemes of construction of the synchronization system presented in the article to increase the order of astatism.

The analysis of closed and combined synchronization systems carried out in the article, on the basis of the offered information technology, showed expediency of application of the specified approach at the decision of a problem on increase of accuracy of synchronization of carrier frequency of a signal at angular demodulation. Analysis of closed synchronization systems showed that when designing such a system with a minimum of phase error in the angular demodulation of the signal, such a system is characterized by a large transient error. It is shown that taking into account the additive Gaussian noise and instability of generators, the desire to minimize the variance of the phase error in the class of closed synchronization systems causes a deterioration of the system dynamics and does not increase the order of astatism. The combined synchronization system with open communication is a synthesized invariant system, has the ability to increase the order of astatism, and is able to minimize the phase error in the angular demodulation of the signal. It is established that in the conditions of instantaneous phase or frequency change it is possible to improve the system dynamics and reduce the transient component of the phase error variance by selecting the parameters of the open link in the direction of suppressing their values of the corresponding roots of the transient characteristic equation.

The selection of open communication parameters in combined synchronization systems can affect the transmission function and thus ensure the minimization of constant and transient errors of the system without affecting the dynamics of the system. The direction of further research initiated in this article may be the synthesis of open communication in combined synchronization systems in the presence of restrictions on input coordinates and the assessment of the sensitivity of such a system to the deviation of open channel parameters during input signal synchronization.

## 7. References


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