Combined System of Phase Synchronization with Increased Astatism order in Frequency Monitoring Mode

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Abstract. The improvement problems for phase synchronization system of phase coherent telecommunication systems and control in radio engineering devices are considered in this work. Namely, the results of the synthesis of open communication in the combined system of phase synchronization are presented under the condition of increasing the astatism order, while monitoring the carrier frequency (pilot signal), the phase of which is modulated by a deterministic Doppler signal. As a result, it is established that keeping in the open channel of the combined system of synchronization for physically realized units, allows to increase the astatism order of the system and to synthesize invariant systems. The frequency discriminator use as an open link allows to increase the astatism order of the combined system of synchronization for the system to the second order. The open channel is made in the form of parallel (sequential) inclusion of two links of the frequency discriminator with the proposed transfer function allows to increase the astatism order to the third and higher order and does not affect the system stability. The effect on the phase error variance of the synchronization system can be achieved by changing the parameters of the disconnected circuit link of the system synchronization.

Keywords: Carrier Frequency Synchronization, Closed-loop Synchronization System, Combined Synchronization System, Disconnect Synthesis, Astatism Order.

1 Introduction

Scientific research about data transmission issues, finding ways and methods to improve the use of communications are extremely important for the challenges facing modern telecommunications and communications systems (Fig. 1).

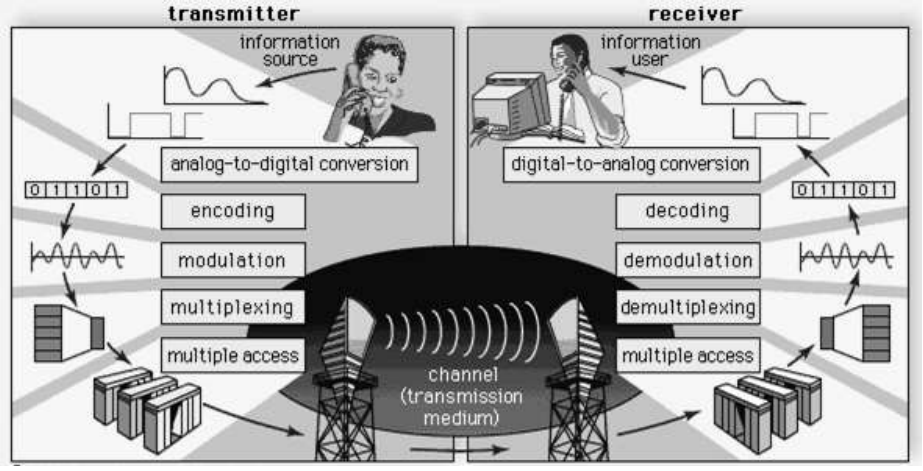

Fig. 1. Modern telecommunication system scheme

Successful solution to the problem of further efficiency improving of communication systems largely depends on the quality of the systems and devices (that are part of them) functioning. Phase synchronization systems are widely implemented in various radio engineering devices of communication technology, radar and control, as well as in the device of exact magnetic recording. In particular, in phase-coherent telecommunication and control systems, they are used for carrier and clock frequency recovery 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 filtration), phase and frequency jumps, and others [2, 3]. In some cases, it is necessary to ensure the high accuracy of the system in a stable and transient modes. For example, in space lines, the main perturbations are additive Gaussian noise and Doppler frequency shifts.

In telecommunication networks using ATM 1/0, Fast Ethemet l / 0, Fast Ethernet 4/0 data transfer technologies, performance depends on a number of characteristics. Namely: loading of the channel on input and output (byte); the number of input and output packets; the number of errors in their registration; CPU usage (%); the amount of free memory of the processor and the I / O system for the router (byte) [4]. The most informative parameter of such a network is channel loading. Which, in turn, depends on the dynamics of the synchronization system (Fig. 2).

Therefore, synchronization systems operating under such conditions should be characterized by low phase error variance and high speed.

In scientific works, for example [3, 5, 6], studies are described, mainly aimed at optimizing the parameters of the filter and the system as a whole for the class of closed synchronization systems (CSS). However, due to the contradictions inherent in the CSS, in some cases they do not allow to provide the required quality of work. This is especially noticeable when you want to improve the quality of the system by two or more conflicting indicators.

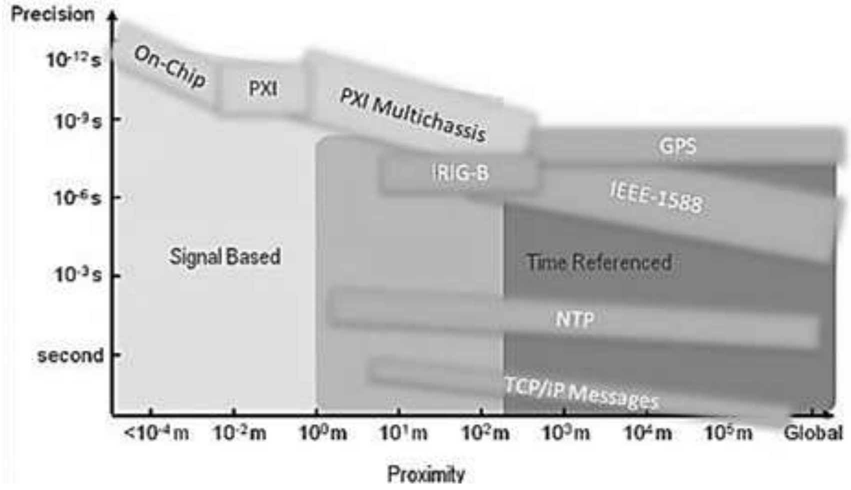

Fig. 2. Synchronization technologies

The analysis of the CSS showed that when accounting for the additive Gaussian noise and the instability of the generators, the desire to minimize the variance of the phase error in the class of the CCS causes a deterioration of the system dynamics and does not allow to increase the order of astatism.

There are great opportunities for improving the quality of synchronization systems in the class of combined synchronization systems (CbSS), which can combine the principles of regulation on deviation and perturbation, which were defined as promising methods in [1, 7]. However, the capabilities of the CbSS of different types have been little explored to date.

2 Synthesis of open communication under the condition of increasing the astatism order and minimizing the dispersion of the phase error during tracking carrier frequency

In this paper, the features of the synthesis of open communication are considered, with the condition of increasing the astatism order and minimizing the dispersion of the phase error during carrier frequency monitoring.

The block diagram of the linear model of the CbSS synchronization system considered in the work is shown in Fig. 1. The aforementioned CbSS model includes an additional link with a transfer function by means of which the open communication is made and the open control channel is formed [7].

Using the above model CbSS, we will solve the problem of synthesis of open communication with the condition of increasing the order astatism, in tracking the carrier frequency (pilot - signal), the phase of which is modulated by a deterministic Doppler signal, and the influence of noise can be neglected. This is the case, for example, in multi-station equipment, when the satellite support station transmits a synchronization signal (code word) and all other stations transmit signals with non-modulated carriers at this interval. Open-loop CbSS was reviewed and synthesized on the condition that astatism was increased.

Consider open-ended CbSS with an increase in the order of astatism. The block diagram of the combined system of synchronization of CbSS is shown in Fig. 3. Where is the $W_4(S)$ transfer function of the synthesized link.

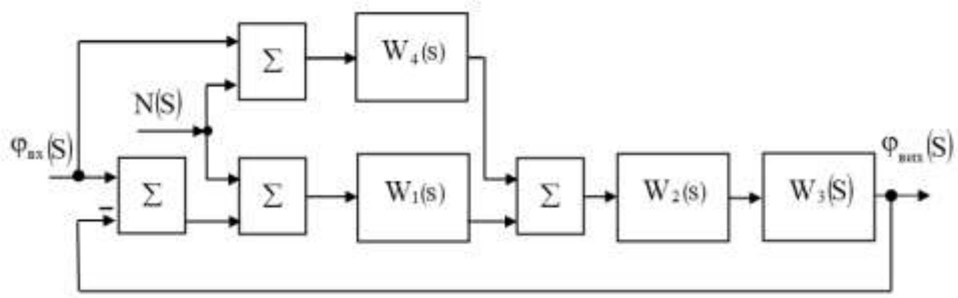

Fig. 3. Block diagram of a linear model of a combined synchronization system with an additional link

In accordance with the scheme of Fig. 1 the equation of CbSS dynamics [6] can be written as:

$$\varphi(S) = \varphi_{вх}(S) - \varphi_{вих}(S),\ \varphi_{вих}(S) = W_3(S)\Sigma(S),\ \Sigma(S) = W_4(S)\varphi_{вх}(S) + W_1(S)W_2(S)\varphi(S).$$

If we exclude the intermediate variables, we obtain the equation of the KCC dynamics for the error:

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

whence the condition of absolute invariance [9]:

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

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

$$\begin{gathered}[F_1(S)F_2(S)F_3(S) + D_1(S)D_2(S)D_3(S)]F_4(S)\varphi(S) = \\ = [F_3(S)F_4(S) - D_3(S)D_4(S)]F_1(S)F_2(S)\varphi_{вх}(S)\end{gathered} \tag{2}$$

It can be seen from expression (2) that the denominator of the transfer function of the open channel $F_4(S)$ is included in the characteristic equation of CbSS (2) in the form of a factor

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

where $F_3(S)=F_1(S)F_2(S)F_3(S)+D_1(S)D_2(S)D_3(S)$ is the characteristic polynomial of CbSS.

Therefore, open communication does not affect the stability of the system [8]. The presence of the difference in the right-hand side of the CbSS dynamics equation (2) 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 [7, 8].

It can be seen from expression (2) that in order to achieve absolute invariance in the system, the transfer function of the open channel must have the following form:

$$W_4(S)=1/W_3(S)=F_3(S)/D_3(S)=D_4(S)/F_4(S) \tag{3}$$

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 under the conditions of physical realization [7, 8].

Thus, it is impossible to achieve absolute invariance in continuous systems with the help of links or continuous computing devices. However, the introduction of a system of physically implemented units $W_4(S)$ into the open channel allows to increase the order of astatism of the system and to synthesize ε – invariant systems [9].

As follows from the examples above, to reduce the persistent error it is necessary to increase the astatism order of the system. Moreover, the value that we strive for in the synthesis of the system is determined by the nature of the change of input influence and the requirements for the accuracy of the system in a stable mode [9].

Write in general terms the transfer function of physically implemented open communication:

$$W_4(S)=\left(\sum_{i=0}^{n}K_{4i}S^{i}\right)\Big/\left(\sum_{j=0}^{m}T_{4j}S^{j}\right)=D_4(S)/F_4(S), \ m\geq n. \tag{4}$$

The astatism order of the system is determined by the degree of the operator, which is a common factor of the numerator of the transfer function by mistake [9].

The transfer function by error of CbSS according to equation (2):

$$W_{\underset{\varphi}{K}}(S)=\frac{\left[F_3(S)F_4(S)-D_3(S)D_4(S)\right]F_1(S)F_2(S)}{\left[F_1(S)F_2(S)F_3(S)+D_1(S)D_2(S)D_3(S)\right]F_4(S)}=\frac{D_{\varphi K0}(S)S^{\nu_K}}{F_K(S)}\,. \tag{5}$$

Substituting expression (5) into expression (4) and laying down the requirement that the system has an astatism of the order νк=l, we obtain an expression for the numerator of the transfer function, which is determined by the expression:

$$D_{\varphi K}(S)=\left[F_3(S)\sum_{j=0}^{m}T_{4j}S^{j}-D_3(S)\sum_{i=0}^{n}K_{4i}S^{i}\right]F_1(S)=D_{\varphi K0}(S)S^{1}\ \cdot \tag{6}$$

The task is to select the coefficients K_{4_i} and T_{4_j} the transfer function of the open channel in such a way that the polynomial $D_{\varphi}k(S)$ contains as S^1 a common factor.

It should be noted that the polynomial $F_4(S)$ is included in the characteristic equation of the combined synchronization system. Therefore, the scope of parameter changes T_{4_j} is limited by the quality requirements of the transition process.

If the order of the higher derivative of the input signal r and you want to eliminate the fixed error, then the inequality l> r must be satisfied.

The general view of the transfer function $W_4(S)$ of the open communication satisfying the condition of expression (4) and providing ν_{K} = l is determined by the expression [9]:

$$W_4(S)=\left(\sum_{i=\nu_з}^{n}K_{4i}S^{i}\right)\Big/\left(\sum_{j=0}^{m}T_{4j}S^{j}\right)=D_4(S)/F_4(S) \tag{7}$$

where ν_3 is the astatism order of the original system without connection.

Usually take m = n. Higher degree of polynomials $D_4(S)$ and $F_4(S)$ will be ν $\nu_3+\Delta\nu-1=m\ \cdot$

Where $\Delta\nu=1-\nu_3$ is the value by which the astatism order is to be increased.

Therefore, m = l-1.

Since the order of astatism of the original system ν_3 = 1, expression (7) will be:

$$W_4(S)=\left(\sum_{i=1}^{l-1}K_{4i}S^{i}\right)\Big/\left(\sum_{j=0}^{l-1}T_{4j}S^{j}\right)=D_4(S)/F_4(S)\ \cdot \tag{8}$$

Substituting polynomials from $D_4(S)$, $F_4(S)$ (8) in (6) we obtain

$$\begin{aligned}D_{\varphi}k(S)&=(T_{40}-K_3K_{41})S+(T_{41}-K_3K_{42})S^2+\ldots\\&+\left(T_{4(1-2)}-K_3K_{4(1-1)}\right)S^{(1-1)}+\left(T_{4(1-1)}\right)S^{1}\end{aligned} \tag{9}$$

From expression (9), taking into account expression (6) we obtain:

$$\left\{\begin{array}{l} T_{40}-K_3K_{41}, \\ T_{41}-K_3K_{42}, \\ \ldots\ldots\ldots\ldots\ldots\ldots, \\ T_{4(l-2)}-K_3K_{4(l-1)}=0 \end{array}\right\}$$

Determine the type of transfer function of the open communication for the above cases [11-14].

The order of the higher derivative of the input signal r = 1. The order of astatism l = 2 is required.

$$W_4(S)=\left(K_{41}S\right)\Big/\left(T_{41}S+T_{40}\right) \tag{10}$$

The polynomial (9) thus has the form:

$$D_\varphi k(S)=(T_{40}-K_3K_{41})S+T_{42}S^2$$

When the condition is met $K_{41}=T_{40}/K_3$ we will get $D_\varphi k(S)=T_{41}S^2$. That is, the use of a frequency discriminator as an open link allows to increase the order of the system's astatism to the second order

At r = 2; l = 3, the type of transfer function $W_4(S)$ will be:

$$W_4(S)=\left(K_{42}S^2+K_{41}S\right)/\left(K_{42}S^2+T_{41}S+T_{40}\right).$$

From expression (9) we obtain $T_{40}-K_3K_{41}=0$, $T_{41}-K_3K_{42}$ then $T_{41}-K_3K_{42}$, that is, we obtain a system of synchronization with third-order astatism.

Open channel with such a transfer function can be made in the form of parallel (sequential) inclusion of two units with the transfer function of the form (10) [15-17].

The block diagram of the combined system of synchronization of the CbSS with the broken channel with the inclusion of two units, as an implementation option, is shown in Fig. 4.

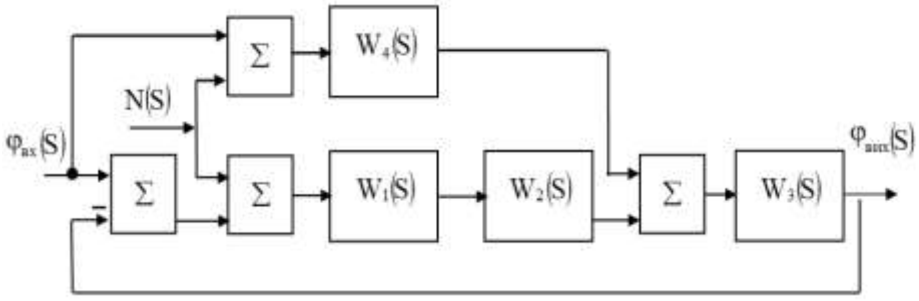

Fig. 4. Block diagram of a linear model of a combined synchronization system with sequential inclusion of additional links

3 Evaluation of the influence of the open link of the combined synchronization system on the phase error variance during carrier frequency monitoring

Certain results of influence of parameters of open communication of CbSS on the relative dispersion of phase error $\eta = \delta^2_{\varphi K} / \delta^2_{\varphi 3} = f(K_4, T_4)$ of the system of phase synchronization are presented in Fig.5 [10, 18].

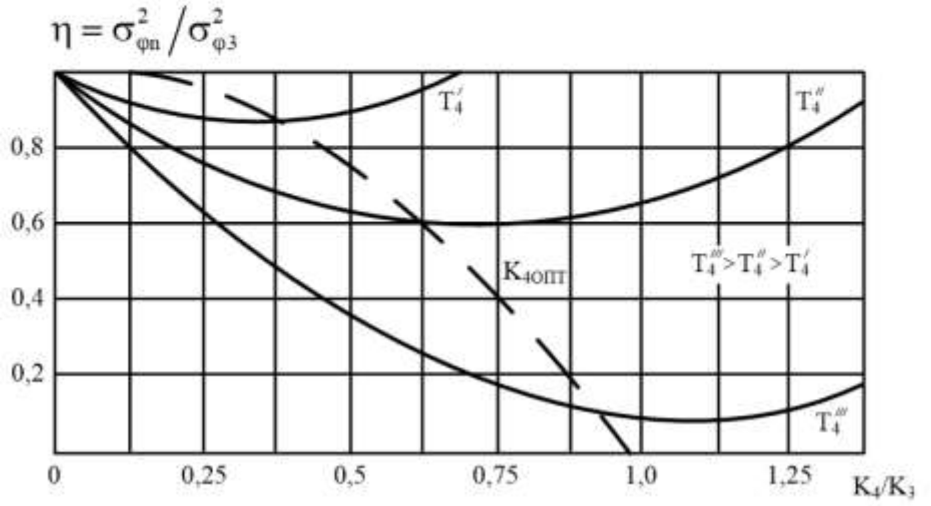

Fig. 5. Dependence of the phase error variance of the CbSS on the parameters of the open channel

Their analysis shows that increasing the time constant parameter T of the transfer function of the link carrier link circuit reduces the phase error variance and causes a change in the optimal parameter of the phase discriminator K [19, 20].

4 Conclusions

Analysis of the simulation results with the help of the proposed expressions showed that keeping in the open channel of the combined system of synchronization of physically realized units, allows to increase the order of astatism of the system and to synthesize invariant systems.

The use of a frequency discriminator as an open link allows to increase the order of astatism of the combined system of synchronization of the system to the second order. The open channel is made in the form of parallel (sequential) inclusion of two units of the frequency discriminator with the proposed transfer function allows to increase the order of astatism to the third and higher order and does not affect the stability of the system.

The effect on the phase error variance of the synchronization system can be achieved by changing the parameters of the link of the disconnected circuit of the system synchronization. Analytical expressions proposed in the paper can become the basis of the method of synthesis of KSS provided the accuracy is improved in a stable mode.

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