ROBAST VARIANT OF CHAOTIC COMMUNICATION SYSTEM

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1. Introduction

The theory and practice of development of communication systems applying dynamic chaos are one decade years old [1], however, possibilities of such systems, principles of their construction and ways of realisation have not been completely discovered. Unique properties of chaotic signals serves a basis of application of new radical methods of coding and decoding an information component of chaotic carrying. This in turn allows in greater or lesser degree to solve a task of efficient masking analogous and digital information. Many examples of information transmission using dynamic chaos can be found in the literature, however experimental studies occupy a little place in it.

Recently, a number of devices for the transmission of information by means of chaotic signals was suggested [2]. The information signal is injected into the sending system including a chaotic oscillations generator. Herewith it can directly participate in forming a chaotic signal of the generator (inverse system approach), be added to it at the output of the chaotic generator (chaotic masking), or modulate one of the chaotic generator parameters (chaotic switching). Therefore, the transmitting chaotic signal contains the information, but it is invisible to the observer who has no knowledge about the transmitter system. Thereby, one or another way of injection of information upon a carrying chaotic oscillation is being chosen. The receiver, who possesses this knowledge, then reproduces the input signal. The techniques for extracting the information components from the chaotic carrying signal can be related either to application of chaotic dynamics of identical chaotic oscillations generator (chaotic synchronisation) or to statistical processing the signals (correlation receiving).

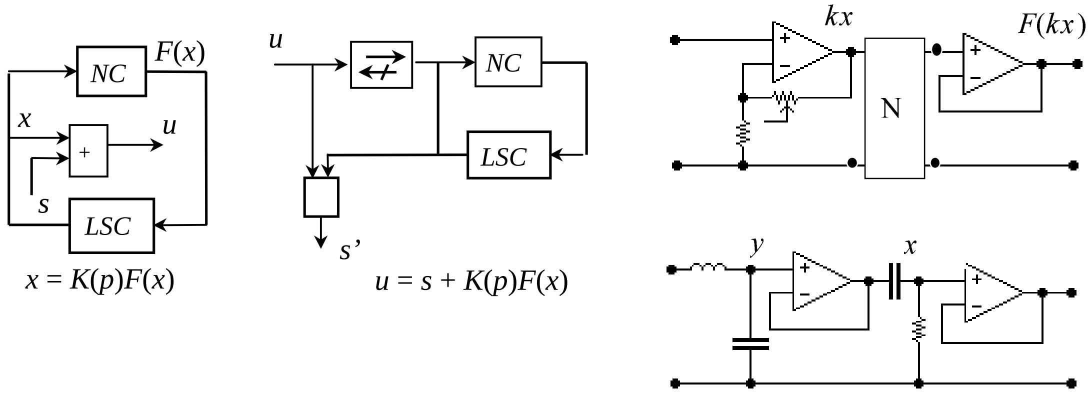
The application of known at the present time ways of injection and extraction of information in chaotic communication systems requires the presence on the receiving side of exact copy of the carrying chaotic signal used as supporting one. In the point of receiving it can be received from the generator of chaotic oscillations which is identical to the generator of the sending side being in the synchronous mode with it. For this purpose the phenomenon of a chaotic synchronization is traditionally used. In such a case the chaotic signal performs three functions simultaneously: it carries an information message from the source to the receiver, it hides the message from alien observer, and plays a role of a synchronizing signal for the receiving system.

However, such an approach causes a number of essential difficulties. First of all, they relate to the requirement of high degrees of identity of chaotic generators (difference of parameters has to be not more than 1 to 2 per cent) and high sensitivity of the synchronic mode to external disturbing factors which exist in real communication channels. The information signal itself appears to be such a disturbing factor emerges which in a number of cases obstructs synchronizing between the transmitter and receiver, as well as greatly influences the sending system generator dynamics. It is an obstacle for wide application of the considered synchronous chaotic communication system in practice.

In connection with noted above, it appears to be correct to separate synchronization of the chaotic generators of the sending and receiving sides from imposition of information on the chaotic carrying oscillation. Such an approach, first, will allow to exclude an influence of the information component on the quality of synchronization, which will be defined now only by the level of fluctuations in the communication channel. Secondly, it will allow to the certain extend nonidentity of the synchronizing generators. The question is now how chaotic transmitters and receivers can be designed and what kind of synchronization (compelled or mutual synchronization) to apply in order to get robast chaotic communication system.

2. General design of the communication system

In order to realize the approach in question, the known system of chaotic masking [3] has been applied (Fig.1).

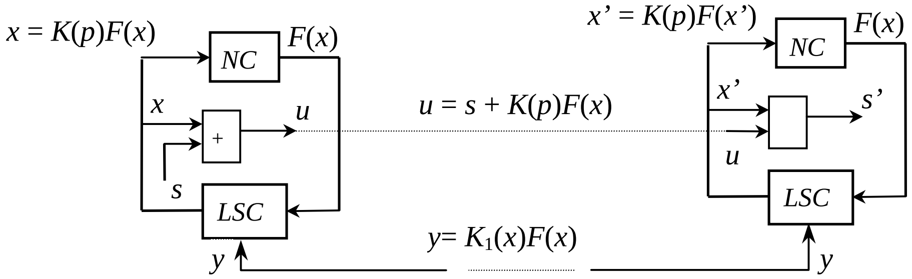


(*a*) (*b*) (*c*) (*d*)

Fig.1. Realization of the chaotic masking communication system. The sending side is marked (*a*) and receiving side (*b*). *NC* is the nonlinear converter (*c*), *LSC* – the linear selective circuit (*d*), *F*(*x*) - the nonlinear transmission characteristic of *NC*, $K(p = d/dt) = K_1(p)K_2(p)$ is the linear differential operator reflecting frequency characteristics of *LSC*.

Information signal *s*(*t*) enters the input of the summator and mixes additively with the chaotic generator signal *x*(*t*) entering other input of the summator. A mixture of the chaotic and information signals *u*(*t*) goes from the summator to the communication channel (Fig. 1,*a*). At the receiving side (Fig. 1,*b*), the signal from the communication channel enters the subtract device and through the unidirectional element to the self-initiating generator of chaotic oscillations. If parameters of both generators coincide, then the synchronization of chaotic signals of the transmitter and receiver appears to be possible. In this case a signal at the output of the subtractor is absent. Appearance of a small information component causes some disturbance of a coherent mode, however, the signal *s'*(*t*) emerges from the output of the subtractor. This signal allows to restore the sent information with the error proportional to the value *s*(*t*).

For communication system with a separate channel of synchronization a similar principle of imposition of information on the chaotic carrying signal is used (Fig. 2). However, the synchronizing chaotic signal *y*(*t*) uncorrelated, in general, to the signal *x*(*t*) is being sent to the receiving side simultaneously with the signal *u*(*t*) from the generator of chaotic oscillations. At the receiving side the signal *u*(*t*) enters one input of the subtracting device, the other input of which the chaotic signal *x'*(*t*) synchronized with the signal *x*(*t*) enters. It is important to select the signals *x*(*t*) and *y*(*t*) so as their mutual correlation would be minimum. This would not allow an undesirable side to apply a similar procedure for the extraction of information when intercepting the signals *u*(*t*) and *y*(*t*). Otherwise, the signal *y*(*t*) becomes a key allowing an opponent to have an access to the information sent.

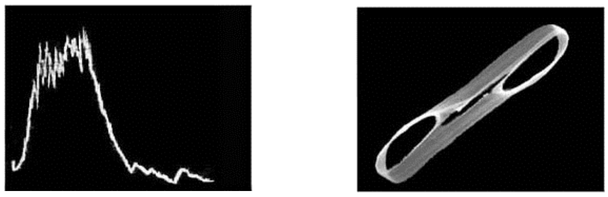


(*a*) (*b*)

Fig. 2. Chaotic communication system with a separate channel of synchronization. The sending side (*a*), receiving side (*b*).

3. Results and discussion

Generators of chaotic oscillations of the transmitter and receiver are ring oscillating systems. They consist of the nonlinear amplifier, low-pass filter of the second order and high-pass filter of the first order consecutively connected and closed to circle of a feedback (Fig. 1 *c*,*d*). To ensure uncoupling the elements and unidirectedness of the signal, the buffers of voltage are enclosed in the system. When parameters are being selected appropriately, given auto-generators produce continuous spectrum of chaotic oscillations within the range of frequencies 0,1...3,5 kHz with the maximum oscillations amplitude of 3,2 V (Fig. 3).



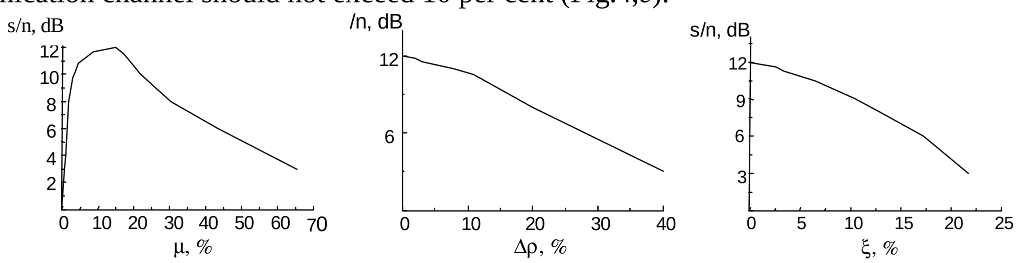
(*a*) (*b*)

Fig. 3. The energy spectrum (*a*) and phase portrait (*b*) of a chaotic signal, used as carrying when information is being transmitted.

At the first stage, investigation of an initial system of chaotic masking was conducted. To ensure high quality of chaotic synchronizing in the couple of 'master – slave' system, passive elements included in generators were selected with the error up to 1 per cent. In the absence of the information signal $s(t)$ at the input of transmitter, a mode of compelled (external) chaotic synchronization between generators of the sending and receiving systems is observed. As a result, the chaotic signal of the receiver becomes shape-coinciding with the chaotic signal of the transmitter ($x(t) = x'(t)$). In this case a certain noise signal level (-31.5 dB from the input signal level) characterizing degree of mistiming between auto-oscillating systems exists at the output of the receiving system subtractor.

It was supposed that for the method of information transmission in question a hard restriction on a proportion of the information component in its mixture with the chaotic carrying exists. It is connected with a synchronization failure and is an obstacle for wide application of the considered synchronous chaotic communication system in practice.

However, the experiment has shown that increasing the information component in a mixture with the chaotic carrying signal up to 15 per cent (in this case $s(t) = A\sin(2\pi f)$) and 26 per cent (speech signal) causes sharp increase in the 'signal/noise' ratio which reaches maximum values of 12 dB and 14 dB, accordingly (Fig.4,*a*). In a case when the receiving side has a deviation of one of its parameters from the same parameter of the sending system, quality of restored information falls proportionally to the value of this deviation (Fig.4,*b*). It has been revealed that in order to ensure satisfactory quality of the restored information signal, the value of additive noise in the communication channel should not exceed 10 per cent (Fig.4,*c*).



(*a*) (*b*) (*c*)

Fig. 4. Dependence of the 'signal/noise' ratio on the proportion of the information component in a mixture with the chaotic carrying signal (*a*), on the value of deviation of the receiving system parameter (*b*), and on the proportion of additive noise in the channel (*c*); $s(t) = A\sin(2\pi f)$.

At the next stage a communication system with a separate channel of synchronization has been realized and experimentally explored. Compelled and mutual synchronization between the sending and receiving systems was developed. In both variants of chaotic synchronization chaotic signals of auto- oscillating systems of the receiver and transmitter coincide in their shape ($x(t) = x'(t)$), herewith at the output of the receiving system subtractor a certain noise signal level (-60 dB from the input signal level) exists, pointing at practically ideal coincidence of the signals. The experiment confirmed that quality of chaotic synchronization (degree of the signals coincidence) is not so strictly defined by the degree of identity of parameters of the interacting system, as in the case of the chaotic masking communication system.

High quality and stability of chaotic synchronization between the receiver and transmitter has allowed to reach the greater values of the 'signal/noise' ratio at the output of the receiver, which do not depend on the proportion of the information component in a mixture with the chaotic carrying signal. As far as in the case of the system of chaotic masking this proportion was limited by disturbing the masking characteristics of the carrying chaotic signal and could reach 15 per cent ($s(t) = A\sin(2\pi f)$) and 26 per cent (speech signal). The 'signal/noise' ratio in both cases was more than 40 dB.

It has been revealed that change in a wide range of any parameter of the sending or receiving systems does not cause disturbance of synchronous mode and deterioration of the information signal restored in the receiver. It has been shown that the presence of additive noise in the communication channel up to 18 per cent of the signal sent causes reduction of the 'signal/noise' ratio at the output of the receiver to 12 dB and 18 dB for the sinusoidal and speech signals, accordingly.

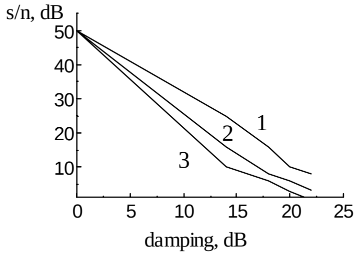


Fig.5. Dependence of the 'signal/noise' ratio on the damping value in the mutual synchronization channel, with a different values of the information signal; $s(t) = A\sin(2\pi f)$; 1,2,3 – the proportion of the information signal in the chaotic carrying, accordingly: 15%, 10%, 6%.

When transmitting information, damping was entered the synchronization channel. It has been revealed that in a case of compelled synchronization already when the value of damping was small (0.5 dB), synchronization between the sending and receiving systems disappeared and the 'signal/noise' ratio sharply dropped to zero. However, in the case of mutual synchronization when the value of damping was 20 dB, the 'signal/noise' ratio at the output of the receiver was 10 dB (Fig. 5). It is necessary to note that for some values of relationship between the sending and receiving systems modes of regular synchronization appear; in the experiment such values correspond to damping of 12 and 14 dB. This significantly distorts a spectrum of the chaotic carrying that causes demasking of the information sent.

4. Conclusion

The results of experiments obtained have shown a possibility and prospects of development of the chaotic communication systems with a separate synchronization channel. Such systems are capable to function in real conditions and serve for the confidential transmission of information.

References

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