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SYNTHESIS OF INVENTORIES TO THE INTERFERENCE OF INFORMATION AND TELECOMMUNICATION SYSTEMS

Abstract. The article deals with the development of analytical algorithms of information and telecommunication systems formation that are invariant to the obstacle (additiveornon-aditiveone). The basic approaches to determine the class of obstacles for which an invariant system can be constructed are discussed and analyzed in detail. It is established that the invariance property of a feedback system guarantees the given probability of receiving information, but it does not guarantee a preset speed of information transmission. Studies have shown that invariance is achieved by reducing the noise immunity of additive noise. In a second-order phase-difference modulation system, the error probability is invariant to the signal frequency, but it is greater than the error rate in the system with phase-difference modulation at a constant signal frequency. As a result of the conducted researches it is established that the maximum of the undetected error does not depend on the characteristics of the interference, but is determined solely by the parameters of the correction code. The ways of improving the qualitative characteristics of information and telecommunication systems to ensure their invariance to the obstacle have been determined by analytical means, which is confirmed by simulation results and experimental data.

Keywords: information and telecommunication system, invariance, error probability, adaptive obstacle, additive impediment, noise immunity.

Introduction

The main criterion of the effective functioning of modern information and communication systems (ICS) is the quality of data reception and transmission in all modes of their functioning, including critical ones. In practice, this problem has to be solved comprehensively, since in these systems, the useful signal and interference cannot substantially be completely separated.

The search for appropriate methods is acceptable only when the probability of transmitting information is guaranteed [1], and in critical modes (the action of concentrated interference) the property of system invariance is guaranteed to unpredictable disturbances.

The peculiarity of the problem of invariance of ICS is that the role of the invariant plays not the instantaneous value of the original value, but some of its statistical characteristics [2].

In ICS, obstacles acts as interference-suppressersand as a characteristic of a system, which must be an invariant of the interference is its noise immunity, expressed quantitatively, for example, because of the probability of error when it comes to discrete information transmission systems [3, 4].

The required error probability value depends on the type of information transmitted and ranges from 10^{-2} to 10^{-6}. If the error probability exceeds the acceptable values, then the transmission of messages becomes impossible due to unacceptably poor quality.

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Changes to the characteristics of the information channel are caused by a variety of obstacles inherently:

- the additive interference consists of a useful signal, and a mixture of signals comes to the input of the receiver. The parameters of the additive interference directly determine the immunity of the ITS, and if it is a non-stationary random process, then the probability of transmitting information changes;
- non-additive interferences lead to changes in individual signal parameters and a channel that can be expressed by changes in signal parameters.

In order to ensure the acceptable quality of operation of a real digital transmission system, it is necessary to maintain the error probability at a level not exceeding a certain set value. This task can be considered fulfilled if [5]:

- the probability of error is less than the set one and remains unchanged, despite the presence of interferences that cause non-stationarity of the information channel;
- the probability of error under the influence of interference changes arbitrarily in the range of values below the set value and does not exceed this value under any circumstances.

The purpose of the article

- to receive basic analytical algorithms for constructing ICS invariant to additive or nonadditive obstacles, as well as to determine the class of obstacles for which it is possible to construct an invariant system.
- to identify ways to improve the performance of ICS to ensure its invariance to the obstacle.
- to establish the capabilities of different types of ICS in terms of achieving their invariance.

The main part

In practice, interference with spectrum-focused parameters is often present, because, unlike thermal noise power, their power is concentrated in a relatively narrow frequency band [2]. If this band is less than $1/T$, in the time interval T the focused interference can be represented as a harmonic oscillation with random amplitude, frequency and phase:

$$\xi(t) = a_n \cos(\omega_n t + \phi_n) . \quad (1)$$

If the amplitude of the useful signal is a_s compared with the amplitude of the interference a_n, then the reception of the signal becomes impossible due to frequent failures. Unmistakable reception in these conditions can be ensured by choosing a useful signal of more complex shape than interference (1).

For example, we choose a signal in the form of harmonic oscillation which changes phase by phase:

$$S(t) = sign\left(\sin\frac{\pi}{\Delta T}t\right)a_s\cos(\omega_s t + \phi_s), \qquad (2)$$

Where $\Delta T -$ duration of the element of composed signal, $\Delta T << T$.

Two signal components (2) having opposite initial phases are obtained experimentally and are shown in Fig. 1, b. We believe that the system performs phase or phase difference modulation of the signal (2). In Fig. 1, a representation of the interference (1) is presented, the case where the interference frequency coincides with the signal frequency $\omega_{ï} = \omega_{ñ}$; the interference amplitude is also selected equal to the signal amplitude ($a_n = a_c$) for ease of comparison of the results of their processing at the receiver output.

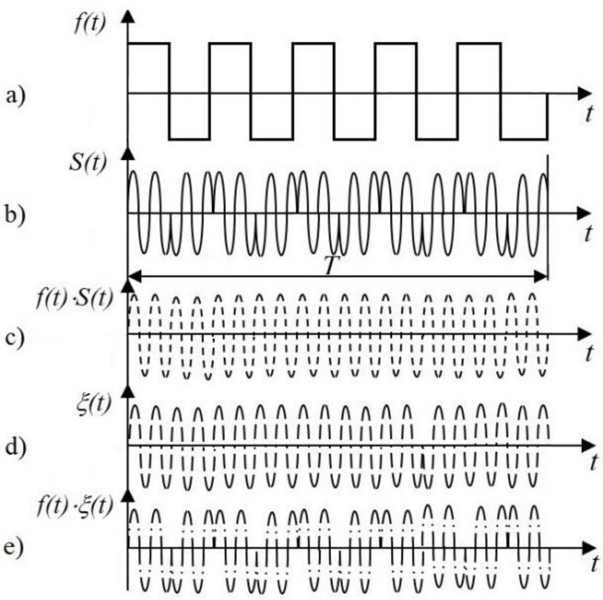

Fig. 1. Experimental data of harmonic signal and obstacle realization

Let us now follow the signal transformations and the interference in the receiver. The receiver (Fig. 2) consists of two sequentially included multipliers M_1 and M_2, which multiply the received signal

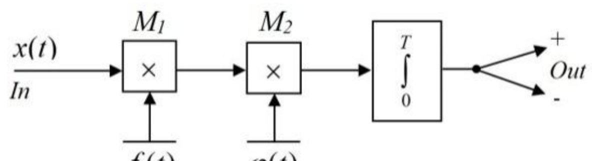

Fig. 2. Schematic diagram of the receiver of the sequential composite signal

$$x(t) = S(t) + \xi(t), \qquad (3)$$

On the reference oscillations $f(t) = sign\sin\frac{\pi}{\Delta T}t$ and $\phi(t) = a_s\cos(\omega_s t + \phi_s)$, and integrator. Since the scheme is linear, one can consider separately the signal conversion and interference. The results of multiplication at output M1, respectively for the signal and interference are presented in Fig. 1, c, d.

As a result of multiplication, the broadband signal was turned into a narrowband and narrowband interference into a broadband signal. Since the next part of the circuit is a correlator consistent with the narrowband signal, the effect of broadband interference on the output of the integrator is negligible.

The Fig. 3 shows the output signal voltages (solid lines) and interferences (dashed lines) are obtained. Although the signal power is equal to the power of the interference, the effect of the interference at the output of the receiver is many times less than the effect of the signal.

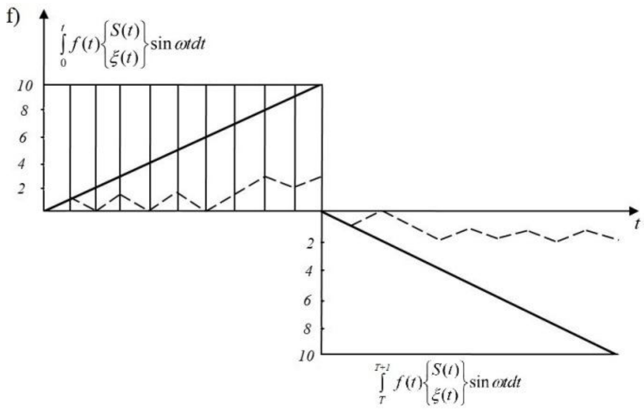

Fig. 3. Output signal voltage and interference

With the selected amplitude of the obstacle, no realization of it can lead to failure, that is, the system under consideration is completely invariant to the spectrum-limited obstacle with limited amplitude. This is achieved by the redundancy of a signal consisting of ten elements carrying the same information. By increasing the number of elements of a signal, its redundancy, it is possible to reduce the effect of the interference or, in the same way, to ensure the invariance of the system to interference with a large range of change in amplitude.

To provide invariance to amplitude interference $a_n \le \max a_n = A_n$ it is necessary that the number of elements m of the composite signal (2) be not less than

$$m = 2 \div 3\frac{A_n}{a_s}. \qquad (4)$$

If relation (4) is being held, then the probability of error in this system is zero and thus,

$$p = in\,\mathrm{var}\,\xi.$$

Following a given rate of information transmission, an increase in the redundancy of the signal m leads to a proportional broadening of its spectrum, which is a charge for the achieved invariance of the system to a spectrum-focused interference [5].

In real broadband systems, it is complicated by the fact that, in addition to concentrated interference, they have fluctuating noise.

The noise immunity of the system with respect to fluctuation noise is determined by the ratio of the signal energy Q to the spectral density of the noise power σ_0^2, the magnitude

$$h^2 = \frac{Q}{\sigma_0^2} = \frac{P_s T}{\sigma_0^2} = \frac{P_s}{P_n} \Delta f T\ , \tag{5}$$

where P_s – signal power, P_n – average interference power, T – signal duration, Δf – bandwidth of the channel, which does not depend on the shape of the signal, including the number of elements of the compound signal with a fixed energy.

Since the effect of fluctuation noise is entirely determined by the value of h, it is considered that the system is invariant to the interference from h is not changed under the influence of ξ.

As an invariant, we consider not the influence of the ξ, but a function $p(h)$.

In the broadband system under consideration, this function is not a strict invariant of influence but with a large redundancy of the composite signal, the function $p(h,\xi)$ is little different from function $p(h,0)$ and, therefore, it is possible to speak about partial relative invariance of the system to interferenceξ.

Mathematical notation corresponds to the concept of invariance relativity

$$p(h) \approx in \operatorname{var} \xi\ . \tag{6}$$

The redundancy of composite signals is estimated to be the magnitude of their base, which is understood to be the product of the duration of a T signal on the width of its spectrum Δf . Because $\Delta f \approx 1/\Delta T$, then, the base of the signal is approximately equal to the number of elements of the compound signal: $\Delta f T = m$. By increasing the base of the signal, one can approximate function $p(h,\xi)$ to function $p(h,0)$, that is, the relative invariant system to absolute invariance.

In the case of both interference – fluctuation noise and concentrated interference, relation (4) can be considered as a necessary but insufficient condition of invariance.

To obtain a sufficient condition, it is necessary to determine the dependence of the loser in the noise immunity (compared to the case of no obstacle ξ) from $\Delta f T$.

The noise immunity loss can be conveniently expressed as the equivalent increase in signal energy required to compensate for this loss. Let us estimate the energy loss caused by the appearance of a concentrated interference at the output of a coherent receiver, which calculates the convolution of the received signal $x(t)$ (3) and the reference oscillation $S(t)$:

$$J[x(t)] = \int_0^T x(t) S(t) dt\ . \tag{7}$$

The integral (7) is decomposed into two components:

$$J[x(t)] = \int_0^T S^2(t) dt + \int_0^T \xi(t) S(t) dt\ , \tag{8}$$

the first is equal to the energy of the useful signal, and the second is the effect of the interference. By decomposing the signal and the interference in the Fourier series at the interval [0, T] and confining ourselves to only additives with frequencies inside the bandwidth of the channel, we obtain:

$$J[x(t)] = P_s T + \frac{T}{2} \sum_{k=k_1}^{k_2} a_k \alpha_k + b_k \beta_k\ , \tag{9}$$

where a_k, b_k – signal decomposition coefficients,

α_k, β_k – interference decomposition factors,

$k_2 - k_1 + 1 = \Delta f T$ – the basis of the signal.

If there was no ξ obstacle, the system's noise immunity would be determined by the signal energy $Q = P_s T$. In the presence of concentrated interference, the signal energy in the worst case, when the results of signal processing and interference have different signs, is reduced by

$$\gamma = \frac{T}{2} \sum_{k=k_1}^{k_2} a_k \alpha_k + b_k \beta_k$$

and gets equal:

$$Q_{ekv} = Q - |\gamma|\ . \tag{10}$$

Let's define the extremum of magnitude $|\gamma|$ by considering that the signal has a uniform spectrum and that $a_k = b_k = c$.

Then

$$\gamma = \frac{cT}{2} \sum_{k=k_1}^{k_2} \alpha_k + \beta_k\ . \tag{11}$$

Having calculated the Fourier coefficients α_k and β_k for the obstacle (1), we get

$$\sum_{k=k_1}^{k_2} \alpha_k + \beta_k =$$

$$= \sum_{k=k_1}^{k_2} \cos\phi_n \frac{\sin \Delta\omega_k T}{\Delta\omega_k T} + \sin\phi_n \frac{\cos \Delta\omega_k T - 1}{\Delta\omega_k T}$$

$$- \sin\phi_n \frac{\sin \Delta\omega_k T}{\Delta\omega_k T} + \cos\phi_n \frac{\cos \Delta\omega_k T - 1}{\Delta\omega_k T},$$

where $\Delta\omega_k = \omega_n - k\frac{2\pi}{T} = 2\pi(f_n - k/T)$.

Considering that

$$\left|\begin{matrix}\sin(\Delta\omega_k T+\phi_n)+\cos(\Delta\omega_k T+\phi_n)- \\ -\sin\phi_n-\cos\phi_n\end{matrix}\right|<3,$$

we get $\left|\sum_{k=k_1}^{k_2}\alpha_k+\beta_k\right|<3a_n\sum_{k=k_1}^{k_2}1/\Delta\omega_k T$,

since $\Delta\omega_k=\omega_n-k\frac{2\pi}{T}$ and $k_1\frac{2\pi}{T}\le\omega_n\le k_2\frac{2\pi}{T}$.

Therefore, for the effect of noise on the output of the receiver the following estimate is valid:

$$|\gamma|<\frac{3ca_nT(\ln\Delta fT+1)}{4\pi}. \tag{12}$$

Let's now find a quantity $q=Q/Q_{ekv}$ that shows in how many times the energy of the signal is greater than the equivalent energy of the signal, taking into account the effect of the concentrated interference. To do this, we express the magnitude of the decomposition coefficients of the signal due to its power. Having used the correlation

$$\sum_{k=k_1}^{k_2}a_k^2+b_k^2=P_c,$$

taking into account the equation $a_k=b_k=c$ we get:

$$c=\sqrt{\frac{P_s}{2\Delta fT}}. \tag{13}$$

Substituting (13) in (12), on the basis of (10) we get

$$q<\frac{Q}{Q-|\gamma|}\approx\left[1-\frac{3}{4\pi}\sqrt{\frac{P_n}{P_s}}\frac{1}{\sqrt{\Delta fT}}\ln(\Delta fT+1)\right]^{-1}. \tag{14}$$

It follows from (14) that for any fixed ratio of interference power to the power of the signal P_n/P_s, the effect of the interference effect by increasing the signal base ΔfT can be arbitrarily arbitrary. In particular, if the condition of invariance is given the maximum permissible excess of q, then one can find a base ΔfT at which a given degree of relative invariance of the broadband system under consideration will be achieved to the concentrated interference.

As a rule, the base cannot be increased indefinitely, because with a given symbol rate of 1/T, this can only be done by extending the channel frequency band, which is always difficult. For example, in a shortwave radio channel, the bandwidth allocated to one station cannot exceed tens of kHz. Even if $\Delta f=100$ kHz, then at a manipulation speed of 300 parcels / s ($T=3/33$ ms) the base of the system is $\Delta fT=330$.

With such a base, the maximum permissible excess of interference power over the signal power is only ten (P_n/P_s=10), if it is considered possible to reduce by half ($q=Q/Q_{ekv}$) the equivalent energy of the signal (14).

As the bandwidth is widened, the likelihood of multiple narrowband interference increases, causing additional difficulties.

Therefore, the possibility of achieving invariance within systems with constant parameters is limited (which, however, does not imply that these possibilities should be neglected).

Let's consider a broadband system with a composite signal and an adaptive receiving device (Fig. 4). As elements of a compound signal, harmonic oscillations with frequencies $\omega_1,\omega_2,...,\omega_m$ are used, and the signal itself is the sum of these oscillations.

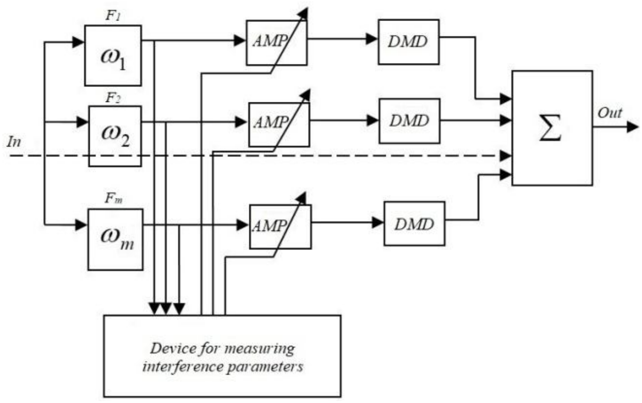

Fig. 4. Block diagram of an adaptive receiver of a parallel delivery channel

У In the receiving device (Fig. 4), the signal passes through the bandpass filter system $F_1,F_2,\ldots,F_m$ with frequencies $\omega_1,\omega_2,...,\omega_m$, resulting in separate frequency components being completely separated at the outputs of the bandpass filters. Each element of the composite signal then passes through an amplifier with adjustable gear ratio and enters the demodulator. The demodulated elements of the composite signal are jointly processed in order to decide on the transmitted information symbol. Because they carry the same information, the transmitted symbol can be defined by the "voting method" in most demodulation results of the signal elements, in this case the adder $\sum$ acts as a majority logic. In the case of the addition of analog voltages at the outputs of the demodulators, the adder is a device for adding analog signals.

In the output part of the adaptive receiver there is a processing unit of signals carrying the same information, and the resultant effect consists of partial effects on the outputs of the separation filters.

The possibility of achieving invariance in the system under consideration is based on the fact that the interference-focused noise channel passes only through one of the separation filters and, therefore, affects only one of the receiver m channels. If you exclude this affected channel from further processing, the system will be completely invariant to the interference that isξ, it can be recorded as

$$p=in\,\mathrm{var}\,\xi=0.$$

The device measuring the parameters of the noise is used to determine the affected channel. The algorithms of his work can be very different [6]. Since the composite signal has a large redundancy, comparing the result of the total signal processing with the results of processing in each channel, you can identify the least "quality" channel. The interference measurement device can determine the interference level in the communication channels by comparing the output level of each filter with the average output level of all separation filters. For any algorithm of operation of the device measuring the interference, it must produce a command to set the transmission coefficients of the corresponding amplifier. For significant interference in the i-th link, the transmission ratio of the i-th amplifier is almost zero.

With the presence, in addition to the concentrated interference ξ, also the fluctuation, in the considered system with variable parameters as in the system with constant parameters, only relative invariance to the interference ξ is possible. Indeed, when one of the channels of the receiver is blocked together with the interference, some of the useful signal is eliminated, so the probability of error in the presence of a concentrated interference is somewhat higher than without it. This increase in the probability of error can be made very small by increasing the redundancy of the signal and, accordingly, the number of receiving channels.

The advantage of a variable-invariant system over a constant-parameter invariant system is that it can provide invariance (absolute or relative) to an interference with a much larger range of amplitudes. In a system with constant parameters, invariance is ensured with respect to interference with amplitude not exceeding a certain value, depending on the base (redundancy) of the composite signal. In the system under consideration with variable parameters, the maximum permissible interference amplitude is independent of the signal base and is determined solely by the ability of the bandpass filters to suppress the signals lying on the frequency outside the bandwidth. It is easy to build filters with fading hundreds of times without the bandwidth, such a system can provide suppression of great interference. A large signal base is also required to ensure small noise immunity in the case of fluctuating noise in a variable parameter system.

The system under consideration with variable parameters is invariant to the noise-focused one; Compared to similar systems with constant parameters, it is invariant to a wider class of concentrated interference.

Generally a non-additive interference causes a random change in the signal parameters. Let's consider a signal with a random frequency. The causes that cause a change in the frequency of the signal are very varied: instability of task generators, rapid movement of the source of electromagnetic oscillations or changes in the medium reflecting these oscillations (Doppler Effect). [7, 8]. We believe that the output of the demodulator with constant parameters receives a signal

$$x(t) = a\sin[(\omega_0 + \xi)t + \phi], \tag{15}$$

where ξ – a random variable equal to the deviation of the signal frequency from the mean ω_0.

Since the frequency of the signal is unknown, in the class of systems with constant parameters it is impossible to receive the signal (15) by a coherent or optimal incoherent method. Thus, autocorrelation technique should be used [6, 9].

The algorithm of autocorrelation signal reception with a single first-order phase difference modulation is of the form [10, 11]

$$I = sign\int_0^T x_n(t)x_{n-1}(t)dt, \tag{16}$$

where $I = \pm 1$ –transmitted information symbol, $x_n(t)$ i $x_{n-1}(t)$ –two consecutive signal parcels, equal, according to formula (15):

$$\begin{aligned} x_{n-1}(t) &= a\sin[(\omega_0 + \xi)t + \phi_{n-1}], (n-1)T \le t \le nT, \\ x_n(t) &= a\sin[(\omega_0 + \xi)t + \phi_n], nT \le t \le (n+1)T. \end{aligned} \tag{17}$$

The delay time τ is equal to the duration of the parcel T, but in real devices, these values are always different due to implementation errors.

As a result of carrying out a modelling the dimension of voltage at the output of signal was determined (fig. 5), the integral in the right part of the statement was calculated for this (16).It should be noted that the (n - 1) - a sending the signal after pairing it with the *n*th (by means of the delay line) will take the form

$$x_{n-1}(t) = a\sin[(\omega_0 + \xi)(t + \tau) + \phi_{n-1}].$$

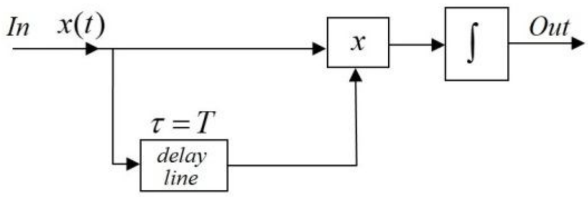

Fig. 5. Structural diagram of autocorrelation signal receiver with phase difference modulation

The result is

$$\begin{aligned} J &= \int_0^T a^2 \begin{pmatrix} \sin[(\omega_0 + \xi)t + \phi_n] \times \\ \times \sin[(\omega_0 + \xi)(t + \tau) + \phi_{n-1}] \end{pmatrix} dt = \\ &= \frac{a^2 T}{2}\cos(\phi_n - \phi_{n-1} + \xi\tau) + \frac{a^2}{4(\omega_0 + \xi)} \times \\ &\times \left(\sin(\phi_n + \phi_{n-1} + \xi\tau) - \sin(\phi_n + \phi_{n-1} + \xi\tau + 2\xi T)\right). \end{aligned} \tag{18}$$

When calculating expression (18), we take into account that

$$\omega_0\tau \approx \omega_0 T \approx 2\pi k.$$

For simplicity we neglect the second term in (18). This can be done if

$$\omega_0 + \xi >> 2\pi / T, \tag{19}$$

that is, in the case of a narrowband signal.

Then

$$J \approx \frac{a^2 T}{2}\cos(\phi_n - \phi_{n-1} + \xi\tau). \quad (20)$$

As can be seen from (20), with the phase difference modulation, the result of signal processing at the output of the autocorrelation receiver depends on the change in the frequency of the signal ξ. If $\xi\tau > \pi/2$, then the sign of the value J changes and according to algorithm (16) there will be an error in receiving the message.

Therefore, the phase difference modulation system is invariant to the interference that causes the signal frequency to change:

$$p \neq in\,\mathrm{var}\,\xi\,.$$

Consider a second-order phase-difference modulation system in which information is embedded in a second phase difference signal equal to

$$\begin{aligned}\Delta^2\phi &= (\phi_{n+1} - \phi_n) - (\phi_n - \phi_{n-1}) = \\ &= \phi_{n+1} - 2\phi_n + \phi_{n-1},\end{aligned} \quad (21)$$

The scheme (Fig. 6) contains two autocorrelation signal receivers. On one of them the signal is received through an additional phase shifter, which changes the phase to $\pi/2$.

The voltages at the outputs of the integrators are proportional

$$\cos(\phi_n - \phi_{n-1}) \text{ and } \sin(\phi_n - \phi_{n-1}).$$

The part of the circuit consisting of elements of memory of constant voltages (RAM), multipliers of constant voltages

$$\begin{aligned}\cos\Delta^2\phi_n &= \cos(\phi_n - \phi_{n-1})\cos(\phi_{n+1} - \phi_n) + \\ &+ \sin(\phi_n - \phi_{n-1})\sin(\phi_{n+1} - \phi_n).\end{aligned} \quad (22)$$

In general, the receiver (Fig. 6) implements such a mathematical algorithm for processing three consecutive signal parcels $x_{n-1}(t), x_n(t), x_{n+1}(t)$:

$$I = sign(X_n X_{n-1} + Y_n Y_{n-1}). \quad (23)$$

$$\left.\begin{aligned} X_n &= \int_0^T x_{n+1}(t)x_n(t)dt \\ X_{n-1} &= \int_0^T x_n(t)x_{n-1}(t)dt \\ Y_n &= \int_0^T x_{n+1}(t)x^*{}_n(t)dt \\ Y_{n-1} &= \int_0^T x_n(t)x^*{}_{n-1}(t)dt \end{aligned}\right\} \quad (24)$$

* the Hilbert transformations of the corresponding parcels are marked (this operation is performed by the phase shifter Fig. 6) [12, 13]. Carrying out calculations similar to (18) and (20) by (24), we obtain

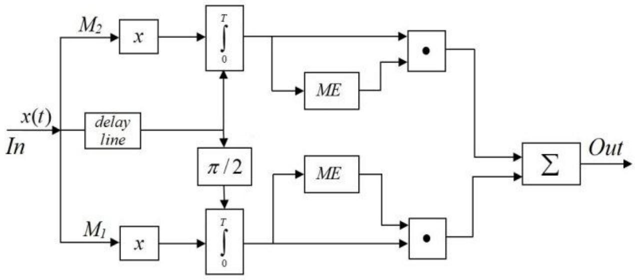

Fig. 6. Structural diagram of the autocorrelation signal receiver with second-order phase-difference modulation

$$\left.\begin{aligned} X_n &\approx \frac{a^2T}{2}\cos(\phi_{n+1} - \phi_n + \xi\tau), \\ X_{n-1} &\approx \frac{a^2T}{2}\cos(\phi_n - \phi_{n-1} + \xi\tau), \\ Y_n &\approx \frac{a^2T}{2}\sin(\phi_{n+1} - \phi_n + \xi\tau), \\ Y_{n-1} &\approx \frac{a^2T}{2}\sin(\phi_n - \phi_{n-1} + \xi\tau). \end{aligned}\right\} \quad (25)$$

where ξ – random signal frequency deviation, and τ – the duration of the signal delay in the circuit (Fig. 6), approximately equal to the duration of the parcel T.

Substituting (25) into (23), we obtain that the magnitude of the voltage at the output of the autocorrelation signal receiver with second-order phase-difference modulation becomes

$$\begin{aligned} J[x(t)] &= X_n X_{n-1} + Y_n Y_{n-1} = \\ &= \frac{a^2T}{2}\cos(\phi_{n+1} - 2\phi_n + \phi_{n-1}) = in\,\mathrm{var}\,\xi. \end{aligned} \quad (26)$$

Therefore, the output voltage of the signal receiver with second-order phase-difference modulation is proportional to the second phase difference and does not depend on the signal frequency.

Thus,

$$p = in\,\mathrm{var}\,\xi\,.$$

A system of transmitting discrete information with second-order phase-difference modulation is absolutely invariant to the signal frequency i.

However, invariance is achieved by reducing the noise immunity of additive noise. In a second-order phase-difference modulation system, the error probability is invariant to the signal frequency, but it is greater than the error probability in the phase-difference modulation system at a constant signal frequency. This provision is illustrated in Fig. 7, which presents a qualitative picture of the relationship between the noise immunity of second-order invariant phase-difference modulation and non-invariant phase-difference modulation.

In the absence of a frequency layout ($\xi = 0$), the probability of an error in a non-invariant system is less than the probability of an error in the invariant. However, if the requirement for noise immunity of the information transmission system $p \leq p_{\ddot{a}\hat{i}\,\ddot{i}}$ (dashed line in Fig. 7), the system with second-order phase difference modulation satisfies this requirement, and the system with phase difference modulation.

For a channel with an undetermined signal frequency, it is obvious that not only a second-order phase-difference modulation system is invariant.

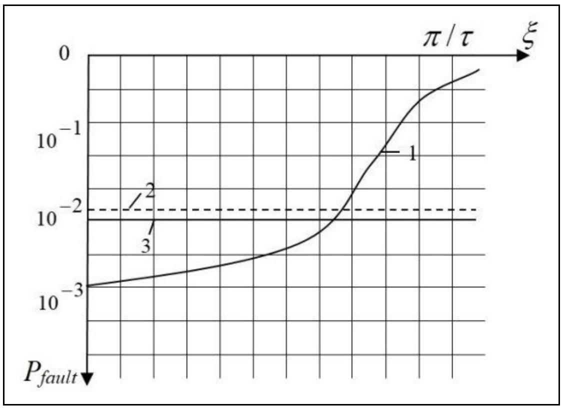

Fig. 7. Characteristics of noise immunity of invariant and non-invariant systems:
1 - probability of error in the system with phase difference modulation ($P_{fault} \neq in\,\mathrm{var}\,\xi$);
2 –valid error probability;
3 - probability of error in the system with phase-difference modulation of the second order ($P_{fault} = in\,\mathrm{var}\,\xi$)

In some cases, there are a number of invariant (totally invariant) systems to a particular interference, and the question arises as to which one to choose. If the probability of error in several systems is an invariant of some interference, then the best, optimal invariant system is the one in which this probability is less.

Let's consider additive noise and fluctuation noise. We believe that the noise power varies indefinitely $(0...\infty)$.

The mathematical model of such interference is a non-stationary Gaussian random process with unlimited variance [14].

In such a non-stationary communication channel, invariance to the non-stationary interference can be ensured by adaptive ICS.

This system changes not only the algorithm of the receiver but also, in agreement with it, the algorithm of the transmitter.

Code combinations of length n are transmitted through the direct communication channel of this system, with symbols from each combination k being informative and others $(n-k)$ valid.

The receiver's decoding device operates in error detection mode: if a fault is detected in this combination, a feedback channel sends a request to repeat the combination.

A mistaken combination is transmitted a second time; if the error is not detected, then the following combination is transmitted; if the error is detected again, a second request is sent, etc.

In such systems, one of the characteristics of fault tolerance is the probability of an undetected error $p_{\hat{i}\,\hat{i}}$, since incorrect information is given to the consumer only if the error is not detected.

Let's suppose that the system under consideration specifies the maximum acceptable probability of an undetected error $p_{d\,\hat{i}\,edm}$:

$$p_{d\hat{i}} \leq p_{d\,\hat{i}\,edm}. \tag{27}$$

We consider a system invariant to fluctuation noise if inequality (27) holds for all possible values of interference parameters.

If the probability of an undetected error is a monotonic function of the interference power, then the value $p_{\hat{i}\,\hat{i}}$ will be max at the maximum interference power.

With interference power going to infinity, the probability of mistakenly registering one double character code combination is to $1/2$. Then any double combination is equally likely to occur at the decoder output. An error will not be detected if a combination of code-specific combinations is made of random double characters. Therefore, the maximum $p_{d\,\hat{i}}$ is equal to the ratio of the number of code combinations (n,k) of this code to the total number of double combinations of length n, max

$$p_{d\,\hat{i}} = 2^k / 2^n = 2^{k-n}.$$

The maximum of the detected error does not depend on the characteristics of the interference, but is determined solely by the parameters of the correction code; that is, if the noise is still indicated by ξ, then max

$$p_{d\,\hat{i}} = in\,\mathrm{var}\,\xi.$$

If, $2^{k-n} \leq p_{d\,\hat{i}\,edm}$ besides, the adaptive ICS is invariant in the above value to the fluctuation noise.

The difference between the concept of invariance, which appears here, from the similar concept in the previous examples, where the probability of error did not change when changing the parameters of the interference should be emphasized; in this example, the error probability changes, but does not exceed some of the maximum permissible value under any parameters of interference. In other words, previously the invariant of the error was the probability of error, and now the invariant of the error is the acceptable maximum of this probability. However, in this case it is possible to speak about the invariance of the system, since the quality of telecommunications (in view of noise immunity) cannot be worse than the set in any circumstances.

Conclusions

The research has found a general reduction in the speed of information transmission due to the presence of interference at the entrance to the ICS and the use of code with redundancy.

As the power of the interference increases, the frequency of "rewriting" increases and the rate of information transmission slows down, and in the presence of a powerful interference the actual speed of information transmission drops to zero: in fact, in this mode the system "directs efforts" not to the transmission of information, but to "preventing" false ones combinations to the consumer.

It should be noted that, although the invariance property of a feedback system guarantees a given probability of information, it does not guarantee a predetermined rate of information transmission.

This is natural, because in this case the bandwidth of the communication channel is zero, and the only thing that can be achieved is not to receive erroneous information.

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Синтез інваріантних до перешкоди інформаційно-телекомунікаційних систем

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Анотація. Стаття присвячена розробленню аналітичних алгоритмів побудови інформаційно-телекомунікаційних систем інваріантних до перешкоди (адитивної або неадитивної). Детально розглянуті та проаналізовані основні підходи визначення класу перешкод для яких можна побудувати інваріантну систему. Встановлено, що властивість інваріантності системи зі зворотним зв'язком гарантує задану вірогідність прийому інформації, але вона не гарантує наперед задану швидкість передачі інформації. Проведені дослідження показали, що інваріантність досягається за рахунок зниження завадостійкості стосовно адитивних завад. У системі з фазорізницевою модуляцією другого порядку імовірність помилки інваріантна до частоти сигналу, але вона більша, ніж імовірність помилки в системі з фазорізницевою модуляцією при незмінній частоті сигналу. Отже, дослідження виявило загальне зниження швидкості передачі інформації через наявність перешкод на вході в систему та використання коду із надмірністю. Зі збільшенням потужності перешкод збільшується частота «переписування», а швидкість передачі інформації сповільнюється, а за наявності потужної перешкоди фактична швидкість передачі інформації падає до нуля: фактично в цьому режимі система "спрямовує зусилля" не на передачу інформації, а на "запобігання" помилковим комбінаціям споживача. У результаті проведених досліджень встановлено, що максимум невиявленої помилки не залежить від характеристик завади, а визначається винятково параметрами коригувального коду. Аналітичним шляхом визначені шляхи поліпшення якісних характеристик інформаційно-телекомунікаційних систем для забезпечення їх інваріантності до перешкоди, що підтверджено результатами моделювання та експериментальними даними. Слід зазначити, що, хоча властивість інваріантності системи зворотного зв'язку гарантує задану ймовірність інформації, вона не гарантує заздалегідь задану швидкість передачі інформації. Це природно, тому що в цьому випадку пропускна здатність каналу зв'язку дорівнює нулю, і єдине, чого можна досягти, - це не отримувати помилкову інформацію.

Ключові слова: інформаційно-телекомунікаційна система, інваріантність, ймовірність помилок, адаптаційна перешкода, адитивна перешкода, захищеність від шуму.