INCREASING NOISE IMMUNITY OF THE RECEIVING DEVICE AT RECEPTION OF DIGITAL SIGNAL DUE TO USE OF ADDITIONAL CHANNEL WITH PHASE CONVERTER

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The rapid development of digital information transmission systems using radio signals has led to the need to improve receiving systems. This article considers the possibility of using an improved theory of narrow-band noise to increase the sensitivity of the receiving device when receiving digital signals. It is generally admitted that the task of detection is to make a decision about the presence or absence of a useful signal against the background of interference and noise, which is fundamentally impossible to get rid of. The narrow-band random process structurally is close to the amplitude-modulated oscillation with suppressed carrier and represents a beating signal of two sidebands. It follows from the theory of vibration beats that the phase of the high-frequency component changes by π when the signal envelope passes through 0. Consequently, phase jumps are explained by the fact that narrow-band noises are beating signals of two sidebands. It has been shown that by using the structural differences in the mixture of useful signal and noise and simply narrow-band noise, it is possible to significantly increase the reliability of receiving a digital signal in the field of small signal-to-noise ratios. The article describes in details the mathematical models of the receiving device with an additional receiving channel that uses the phase features of the useful signal and noise mixture and simply narrow-band noise for signal detection. A diagram of a receiving device with an additional channel for the implementation of the receiver on laboratory equipment is given in order to obtain real experimental data. In addition, comparative detection characteristics are presented for a classic single-channel receiver and a receiver with an additional receive channel.

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The rapid development of digital information transmission systems using radio signals has led to the need to improve receiving systems [5-6]. It has been established that the reliability of receiving a radio impulse depends mainly on the signal-to-noise ratio at the input of the receiving device. However, in most cases, the transmitter power is limited and the creation of signal power at the input of the receiving device that significantly exceeds the noise power is impossible for technical reasons. Therefore, it is relevant to search for ways to receive radio pulse signals at low signal-to-noise ratios [1-4].

It is known that the essence of the detection task is to make a decision about the presence or absence of a useful signal against the background of interference and noise, which is fundamentally impossible to get rid of [8].

The optimal receiver for receiving a radio impulse against the background of interference and noise, according to Kotelnikov's theory, consists of an optimal linear filter and a threshold device. It has been established that the practical implementation of the optimal filter matched with the spectrum of the useful signal, as a rule, has a complex design, and in some cases is not realizable. Therefore, in real receivers, a quasi-optimal linear filter and a threshold device are used. In this case, the reliability of detection does not depend on the parameters of the signal but depends only on its energy. In the case when the ratio of signal energy to noise energy is less than three, the probability of errors in signal reception turns out to be unacceptably large. The information transmission system, in this case, is not operational[9-16].

The paper [1] shows the possibility of using structural differences between a mixture of a radio impulse and narrow-band noise and simply narrow-band noise to solve the problem of increasing the sensitivity of a radio receiver.

The backbone of the idea of increasing sensitivity is as follows: in systems with heterodyne reception, due to their narrow-band, the following condition is met:

$$\Delta F << F_{np}, \tag{1}$$

Where ΔF – input signal spectrum width; F_{np} –intermediate frequency of the receiving-recording system.

Systems that meet this condition are called narrow-band systems. When such systems are exposed to broad-band noise, the output signal is a narrow-band process, which, in the general case, can be represented as a harmonic oscillation with a random change in amplitude and phase:

$$\xi(t) = A(t)\cos\left[\omega_0 t + \varphi(t)\right] \tag{2}$$

where $A(t)$ and $\varphi(t)$ – interchangeable, slowly varying functions compared to $\cos\omega_0 t$, representing the envelope and random phase of a narrow-band process.

If normal broad-band noise is applied to the narrow-band system input, the output process and envelope will also be normal with a zero average value [1], since the output signal is a linear conversion of the input normal process.

Since $A(t)$ – is a normal random process with a zero average value, then there is no zero term in the expansion [4].

Considering this, the narrow-band noise process can be represented as follows:

$$\begin{aligned}\xi(t) &= \left(\sum a_k \cos(k\Omega t)\right)\cos\left(\omega_0 t - \varphi(t)\right) = \\ &= 0,5\sum a_k \cos\left(\omega_0 t - k\Omega t + \varphi_c(t)\right) + \\ &+ 0,5\sum a_k \cos\left(\omega_0 t + k\Omega t + \varphi_p(t)\right)\end{aligned} \tag{3}$$

where $\varphi_c(t) = \varphi_k + \varphi(t)$, $\varphi_c(t) = \varphi_k - \varphi(t)$..... .

Based on this expression, a narrow-band random process in its structure is close to amplitude-modulated oscillation with a suppressed carrier. Thus, it is nothing more than a beating signal of two sidebands. It follows from the theory of oscillation beats that the phase of the high-frequency component changes by π when the signal envelope passes through 0[7-11]. Consequently, phase jumps are explained by the fact that narrow-band noises are signals of beats of two sidebands. In this case, the frequency of phase jumps of the high-frequency oscillation is determined by the bandwidth of the narrow-band filter. This conclusion is well consistent with the known provisions of information theory and the theory of random processes.

the modulated oscillation differs in its structure from the beat signal only in case when the envelope reaches the zero level with amplitude-modulated oscillation, the phase of the high-frequency component of the signal does not change, and the phase of the high-frequency component of the beat signal changes by π. This circumstance provides means for verifying the main propositions stated above in connection with the structure of narrow-band noise.

If a useful signal is present at the receiver input, the narrow-band process structure changes. As shown in paper [1], even at small values of the energy of the radio impulse, the structure of the mixture of the signal and narrow-band noise changes and becomes comparable to the structure of the amplitude-modulated signal with the carrier. Structural differences, as shown [1], can be successfully used to increase the sensitivity of the receiver by using nonlinear transducers. In particular, phase converters change phase at each reaching amplitude of the envelope of zero value.

The study of the efficiency of using a receiving device with an additional receiving channel using differences in the structures of the input process in the presence or absence of a useful signal was carried out for the case of detecting a single radio impulse.

Therefore, the purpose of this work is to study the possibility of using receivers with an additional receiving channel for the task of receiving digital radio signals against the background of high-intensity interference.

To solve the problem, at the first stage, packages of specialized programs were used. Such software products include software packages specially designed for research and development of students by the company (K and H), and specialized equipment (KL-96001 Main Unit, (KL-94005 ASK Unit, KL-93007 FDM Unit , KL-94003 FSK Unit and KL-96008 Multi - Function Unit).

A mathematical model of a two-channel receiver shown in Figure 1 was built using the above programs:

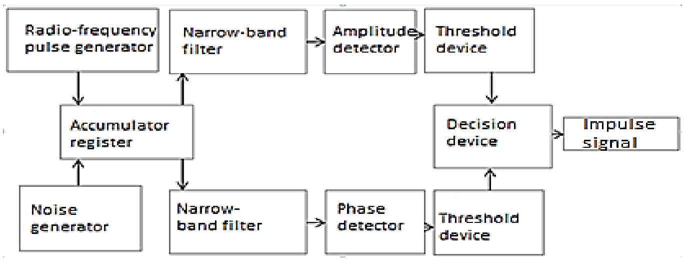

Figure 1. Block diagram of signal and noise mixture through the cascades of the receiving device

The study of a two-channel receiver was carried out by a combined method to ensure the correctness of the results obtained. For example, the noise generator was implemented in software in order to be able to generate noise with various characteristics, and the digital signal was generated using a real device included in the laboratory setup (Fig. 2).

Figure 2. Main signal generator

The practical part was carried out using the same methods used in Matlab: impulse signal is first generated, i.e. a digital signal with a frequency signal, the magnitude of which can be controlled, and also its amplitude, power, and frequency can be amended, as shown in Figure 3.

Figure 3. Test generation of analog and digital signals

At the second stage of the research, the virtual noise generator was replaced by a real source of interference. The impulse signal was generated by the AD633, which performs the process of multiplying the two signals. Then the signal was mixed with noise through a collector circuit with a noise generator, the receiving antenna was used for this purpose. The antenna signal was fed to a radio frequency amplifier with the possibility of changing the gain. Through this process, the possibility of taking detection characteristics at different signal-to-noise ratios was realized (Fig. 4).

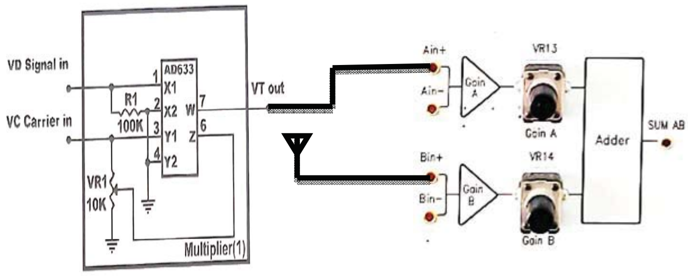

Figure 4. Practical models of impulse signal and noise generators

An arbitrary digital signal with an active pause (fig. 5) was used as a useful signal. When conducting mathematical modeling, we assumed that there is a possibility of correlation between the carrier oscillation of radio impulses and the high-frequency filling of narrow-band noises, since the formation of the above processes was carried out by the same package of programs. Therefore, for the reliability of the obtained results in the second stage of research, we used a real receiving antenna as a source of noise.

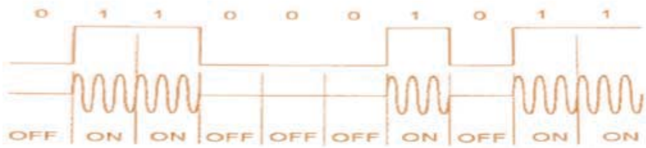

Figure 5. Impulse signal modulator

When transmitting a code combination, reliable reception is possible if the number of errors in the recognition of signals 1 and 0 do not exceed the corrective capabilities of the code. Therefore, when calculating the parameters of a digital information transmission channel, the initial value is the probability of missing the and the probability of false alarm. The dependences of the above probabilities on the signal-to-noise ratio are known to be called detection characteristics [12-14].

In order to confirm the correctness of the operation of the mathematical model and the experimental setup, the detection characteristics were taken for a single-channel receiver consisting of a quasi-optimal linear filter, an amplitude detector, and a threshold device.

Oscillograms of signal and noise mixture at the output of the quasi-optimal filter for different signal-to-noise ratios are shown in Figure 6.

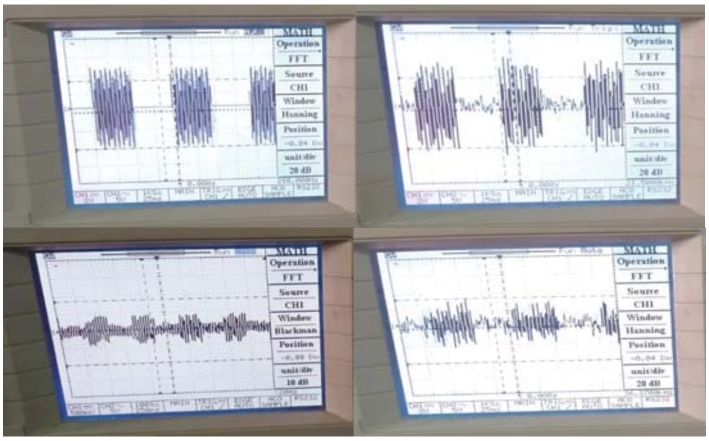

Figure 6. Oscillograms of signals at the output of a quasi-optimal linear filter for various signal-to-noise ratios

The obtained detection characteristics coincided with the characteristics described in the literature and thus allowed us to conclude that it is possible to conduct studies of a receiving device with an additional receiving channel.

The main idea of increasing the noise immunity of the receiving device in the area of low signal-to-noise ratios ,presented in paper [1], was to use an additional receiving channel with a phase converter.

Due to the phase converter, the structural differences in the mixture of the useful signal and narrow-band noise and simply narrow-band noise are converted into spectral differences. Only by noise on spectral differences with a certain degree of probability it is possible to conclude that the receiver installed at the input. This information in the form of an electrical signal is fed to the decision device and blocks the decision about the presence of the signal made by the main receiver. This significantly reduces the probability of false alarms [1].

A similar approach can be used to receive digital signals. However, unlike receiving a single radio impulse, while receiving a burst of radio impulses with a low duty cycle, it is more expedient to use a conventional phase detector instead of a phase converter (Fig. 1).

The operation of the additional channel, in this case,[17] will occur as follows: in the absence of a signal with a unity level at the input of the receiving device, only narrow-band noise will be present at the output of the quasi-optimal filter. As it is known from the generally accepted theory of narrow-band noise, each time the envelope reaches zero, the high-frequency filling phase jumps [2, 3, 5, 7]. In this case, a sharp change in voltage will occur at the output of the phase detector, which will correspond to a phase change of 180 degrees. Thus, the presence of one or more impulses at the output of the phase detector in the detection interval indirectly indicates the absence of a single level signal.

In the case when a radio impulse (single-level signal) arrives at the input of the receiver, a mixture of narrow-band noise of the useful signal will appear at the output of the quasi-optimal filter, which, as shown in previously mentioned work [1], will have the structure of an amplitude-modulated signal with a carrier. It is known that phase jumps for amplitude-modulated signals are not typical even with 100 percent modulation. Therefore, there will be no sudden voltage changes at the output of the phase detector.

The previous discussion makes it possible to use an additional receiving channel based on a phase detector to correct the decision about the presence or absence of a useful signal at the input of the main receiving device.

The decision device in this case will work according to the following algorithm:

– In he presence of one or more high-level signals at the output of the phase detector and any decision in the main receiving channel, a decision is made about the absence of a signal at the input of the receiver (the decision device issues a logical zero).

– In the absence of high-level signals at the output of the phase detector in the detection interval, the decision device issues a decision made by the main channel of the receiving device. (A logical one when the threshold is exceeded in the main channel and a logical zero when the threshold is not exceeded).

A fairly simple algorithm for the operation of the decision device and the use of well-known technical solutions made it possible to use an experimental setup based on standard laboratory equipment to study a receiving device with an additional phase channel (Fig. 7).

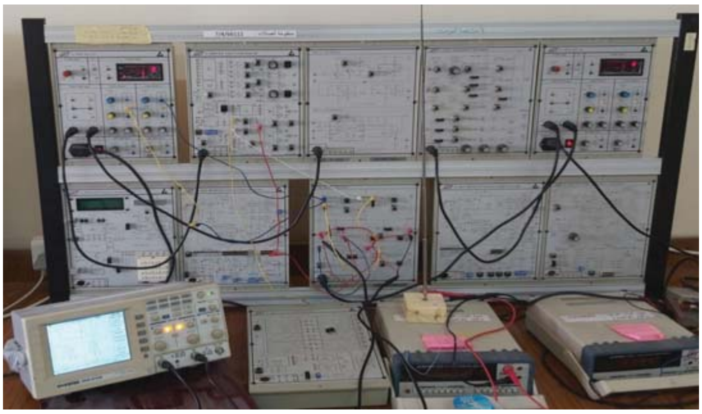

Figure 7. Laboratory setup for studying a receiving device with an additional phase channel

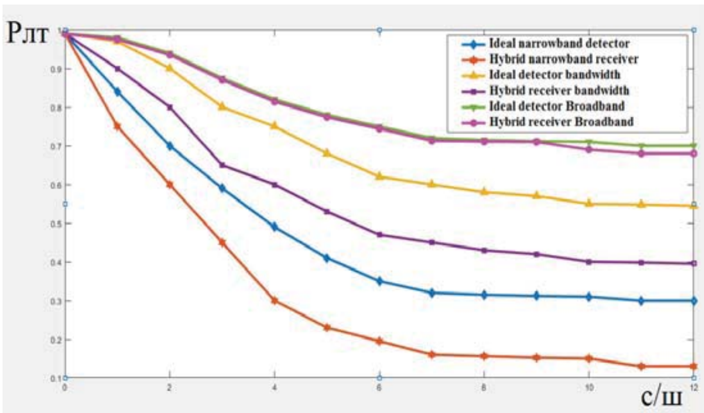

Figure 8. The probability of false positives in case of filter bandwidth change in common signal receiver and dual-channel receiver

In work [4], the results of studying the limits of application of the improved theory of narrow-band noise for the problem of increasing the noise immunity of receiving systems are presented. The fact is that relation (1) can be satisfied for receiving systems with different ratios of the bandwidth and the average tuning frequency of the linear filter. As a result of the research, the boundary of the transition from narrow-band to broad-band receiving systems was determined. Narrow-band receiving systems with extended bandwidth allow the use of shorter pulses and thus increase the rate of digital information transmission.

In this research, detection performance was obtained for a narrow-band dual-channel receiver, a dual-channel extended bandwidth receiver, and a wide-band receiver. In addition, Figure 8 shows comparative characteristics for a receiver without an additional channel.

The detection characteristics of the dual channel receiver for narrow and extended bandwidth are plotted in orange and blue curves, respectively. As can be seen from the above graphs, as the bandwidth increases, the probability of erroneous signal reception increases. However, the error probability is lower in both cases compared to a single-channel receiver. The detection characteristics for a single-channel receiver with narrow and extended bandwidth are plotted in blue and yellow curves, respectively. Thus, in the case of using narrow-band signals, the use of a two-channel scheme is justified.

The green and purple curves correspond to a single channel and a dual channel wideband receiver. As can be seen from the above graphs, the use of a two-channel scheme for receiving broadband signals does not provide any advantages compared to the classical scheme.

Conclusion

1. The possibility of using the improved theory of narrow-band noise is shown to increase noise immunity when receiving digital radio signals.
2. The use of an additional channel makes it possible to increase noise immunity of narrow-band receiving systems compared to a single-channel receiver with any ratio of the bandwidth to the average frequency of setting a linear path.
3. The use of a two-channel receiver to receive broadband digital signals is not feasible due to the noise gain is close to zero.

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ПОВЫШЕНИЕ ПОМЕХОУСТОЙЧИВОСТИ ПРИЕМНОГО УСТРОЙСТВА ПРИ ПРИЕМЕ ЦИФРОВОГО СИГНАЛА ЗА СЧЕТ ИСПОЛЬЗОВАНИЯ ДОПОЛНИТЕЛЬНОГО КАНАЛА С ФАЗОВЫМ ПРЕОБРАЗОВАТЕЛЕМ

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Аннотация

Быстрое развитие систем передачи цифровой информации с использованием радиосигналов привело к необходимости совершенствования приемных систем. В данной статье рассмотрена возможность использования уточненной теории узкополосных шумов для повышения чувствительности приемного устройства при приеме цифровых сигналов. Известно, что суть задачи обнаружения заключается в том, чтобы принять решение о наличии или отсутствии полезного сигнала на фоне помех и шумов, избавиться от которых принципиально невозможно. узкополосный случайный процесс по своей структуре близок к амплитудно-модулированному колебанию с подавленной несущей. То есть он представляет собой ни что иное, как сигнал биений двух боковых полос. Из теории биений колебаний следует, что фаза высокочастотной составляющей изменяется на π при прохождении огибающей сигнала через 0. Таким образом, перескоки фазы объясняются тем, что узкополосные шумы являются сигналами биений двух боковых поло. Показано, что за счет использования структурных отличий смеси полезного сигнала и шума и просто узкополосного шума можно существенно увеличить достоверность приема цифрового сигнала в области малых отношений сигнал/шум. В статье подробно описаны математические модели приемного устройства с дополнительным каналом приема использующего фазовые особенности смеси полезного сигнала и шума и просто узкополосного шума для обнаружения сигнала. Приведена схема приемного устройства с дополнительным каналом, для реализации приемника на лабораторном оборудование, с целью получения реальных экспериментальных данных. Приведены сравнительные характеристики обнаружения для классического одноканального приемного устройства и приемного устройства с дополнительным каналом приема.

Ключевые слова: *фазовый детектор, помехоустойчивость, радиоимпульс, узкополосный шум, широкополосный белый шум, двухканальный приемник.*

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