Investigation of the quality of functioning of a quadrature signals receiver of a continuous automatic cab signaling on records of real signals and interference

Ruslan R. Yusupov[1], *Alexey* S. Khokhrin[1], *Alexander* L. Zolkin[2*], *Avaz* M. Merganov[3], and *Mikhail* G. Grigoriev[4]

[1]Department "Automation, telemechanics and communication on railway transport", Samara State Transport University (SSTU), Svobody Street 2V, Samara, 443066, Russia
[2]Computer and Information Sciences Department, Povolzhskiy State University of Telecommunications and Informatics, Samara, 443010, Russia
[3]Tashkent State Transport University, 1 Temiryplchilar, Tashkent, 100167, Uzbekistan
[4]OPTIMUM LLC, 17 Butlerova Street, Moscow, 117342, Russia

Abstract. Ensuring a safe transportation process is impossible without the use of complex systems for interval regulation of train traffic. In particular, such a system is a continuous automatic cab signaling (CACS) where signals are affected by various kinds of interference, leading to system failures. To reduce the number of system failures, the authors previously proposed a quadrature signal receiver of CACS (QSR of CACS). The article presents the methodology and results of an experimental study of the quality of the functioning of the QSR of CACS on records of real signals and interference. A simulation model of the test facility has been developed in the Simulink simulation environment. The study showed that the QSR of CACS provides reliable reception of CACS code signals with a low level of interference. However, it needs to apply additional measures in it to reduce the influence of impulse noise.

1 Introduction

One of the priority areas for the development of JSC Russian Railways is to increase the efficiency and safety of the transportation process. The efficiency and safety of the transportation process is directly affected by failures of signaling, centralization and blocking devices, through which interval regulation of train traffic is carried out. Locomotive safety devices (KLUB-U [1], DKSV-M, BLOK [2]), which implement the functions of the CACS system.

According to the data of the Automation and Telemechanics Service of the Kuibyshev Railway, the number of system failures caused directly by the influence of interference from year to year does not decrease (and in general there is a tendency to reduce the total number

* Corresponding author: alzolkin@list.ru

of failures in the operation of the CACS). In this regard, a need to improve the stability of the functioning of the CACS is remaining.

2 Problem statement

Several directions can be distinguished in solving the problem of increasing the stability of the operation of the CACS channel: improving the quality of the CACS signals generated by outdoor transmitting equipment; improving the quality of the technical content of inductive rail lines through which CACS signals are distributed; increasing the noise immunity of the locomotive receiver of the CACS channel.

In the framework of the latter direction, the authors previously proposed a correlation receiver with quadrature channels (quadrature receiver) of CACS signals [3].

3 Research questions

The result of studying the quality of operation of a quadrature receiver at various signal levels is presented in [4]. There is an interest to study the quality of operation of a quadrature receiver under operating conditions close to real ones.

In accordance with the above mentioned, the purpose of the study performed by the authors was to evaluate the quality of the functioning of the quadrature receiver of CACS signals on records of real signals and interference.

To achieve this goal, it is necessary to solve the following tasks:

- develop a testing facility;
- develop a methodology and conduct an experiment to assess the quality of the functioning of the quadrature receiver of CACS signals on records of real signals and interference;
- analyze the results and draw conclusions.

4 Materials and methods

4.1 Development of a research facility

Since the proposed quadrature receiver currently does not exist physically, it is advisable to use the computer simulation method to assess the quality of its operation [5,6,15,16,17,18]. In this case, the experimental setup is virtual and is implemented on the basis of a personal computer and specialized software.

To assess the quality of the operation of the quadrature receiver, the recordings of signals from the locomotive receiving coils obtained during real trips on locomotives has been used. Recording of signals and interference has been carried out using a laptop with specialized software. The line input of the laptop has been connected using an adapter in parallel with the locomotive receiving coils. The recording has been made using the SpectraLab software in the. wav format with a sampling rate of 11025 Hz and a resolution of 16 bits.

The block diagram of the virtual experimental setup is shown in Figure 1.

Fig. 1. Structural diagram of the testing facility.

Facility contains the followings:

- "RRD" - device for reproducing recordings of CATS signals and noise;
- «QR CATS» - Quadrature receiver of CATS signals;
- «RVD» - registration and visualization device (multi-channel oscilloscope MCO).

Simulation modeling of devices as a part of a virtual experimental setup has been carried out in the environment of dynamic interdisciplinary modeling of complex technical systems and model-based design Simulink [7].

5 Results

Record player provides data reading from record files and their transfer to the quadrature receiver input. Since the recording of signals and interference was carried out with a sampling frequency of 11025 Hz, and the simulation model of the quadrature receiver of CACS signals functioned with a sampling frequency of 2 kHz, it became necessary to change the sampling frequency of the reproducible record. The block diagram of the record player simulation model is shown in Figure 2.

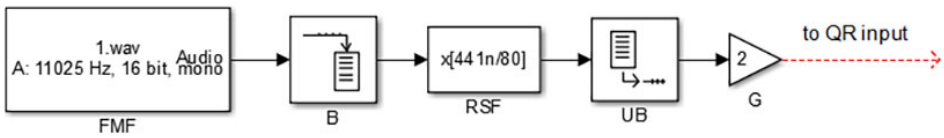

Fig. 2. Block diagram of the player of records of CACS signals and interference.

Record player model contains of the following:

- " FMF " block, which reads a signal record from a multimedia file of *.wav format.
- block "B", which buffers (accumulates) signal samples and thereby generates a vector signal;
- block " RSF ", which is a digital non-recursive filter that resamples the input vector signal from a frequency of 11025 Hz to a frequency of 2000 Hz;
- block " UB ", which converts the input vector signal into the output scalar one;
- block "G", which is an amplifier necessary for scaling the signal in amplitude.

The output of block "G" is also the output of record player.

Figure 3 shows an oscillogram of a signal fragment from the record player output, which is a signal record from locomotive receiving coils, recorded on the Moscow-St. Petersburg railway section.

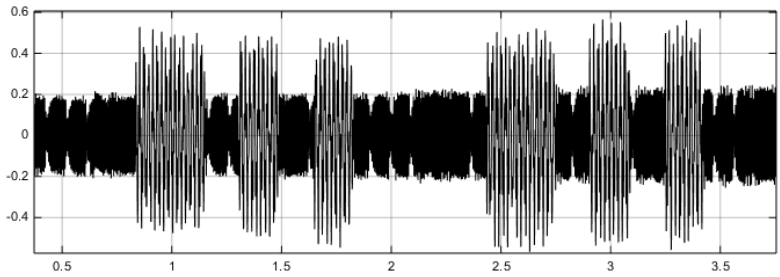

Fig. 3. A fragment of the record of the signal from the locomotive receiving coils reproduced on record player.

On this and all subsequent oscillograms, the horizontal axis shows the time in seconds, and the vertical axis shows the signal voltage in volts.

From the oscillogram shown in Figure 3, it can be seen that both the CACS signal (code combination "3") and the integrated continuous automatic cab signaling signal are present in the record.

From the output of the record player signal is fed to the input of the quadrature receiver, the block diagram of the simulation model of which is shown in Figure 4. A detailed description of the simulation model of the qudrature receiver is presented in [1].

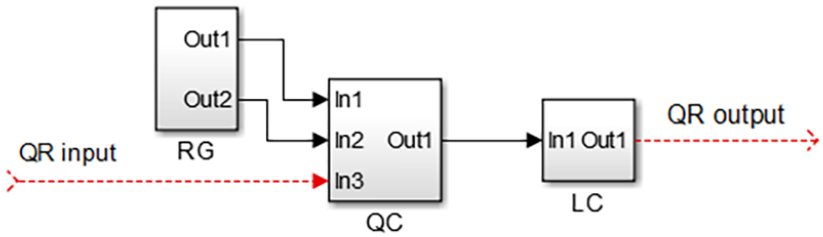

Fig. 4. Block diagram of the simulation model of the quadrature signal receiver of CACS

Quadrature receiver model contains:

- reference generator (RG) , which generates two reference harmonic oscillations with initial phases differing by 90° for two quadrature channels;
- quadrature correlator (QC), which generates at its output the instantaneous values of the envelope of the received CACS code signal;
- a threshold logic controller (LC) with dynamic decision threshold.

A complete block diagram of the simulation model of the facility for studying the quality of the operation of a quadrature receiver on records of real signals and interference is shown in Figure 5.

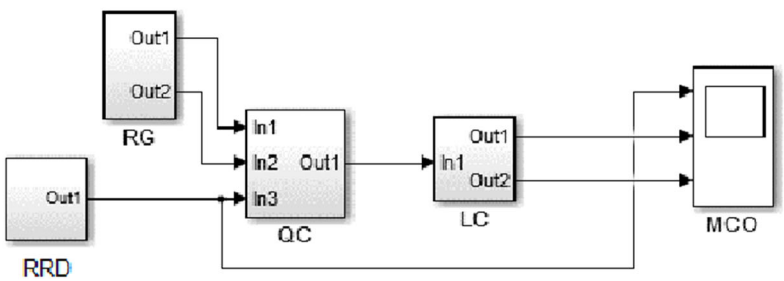

Fig. 5. Block diagram of the simulation facility for the study.

6 Findings

6.1 Methodology and conduct of the experiment

On the developed simulation model of the installation, a study was made of the quality of the functioning of the quadrature receiver of CACS signals on records of real signals and

interference. Records of the real CACS signal and noise recorded during trips on locomotives were fed to the input of the receiver model. The operation of the receiver was observed using a multichannel MCO oscilloscope, the inputs of which were connected to the inputs and outputs of individual receiver blocks. The quality of the receiver operation was analyzed and evaluated visually according to the received oscillograms. The total duration of the signals and noise recordings used in the study was more than 50 hours. Below are some of the received and analyzed waveforms.

In Figure 6 and below, all presented oscillograms show graphs from top to bottom:

- signal at the input of the quadrature receiver;
- the envelope signal at the output of the quadrature correlator (1) and the floating decision threshold signal (2);
- a signal at the output of the receiving and distribution devise (logical pulses of the code signal CACS at the output of the receiver).

The upper oscillogram of Figure 6 shows the distortion of the CACS signal at the receiver input in the interval 393-393.7 s, caused by impulse noise that occurred while passing through railroad switch while moving along a short isolated railroad switch section. These distortions led to the appearance of a short false pulse in a long interval of the CACS code cycle.

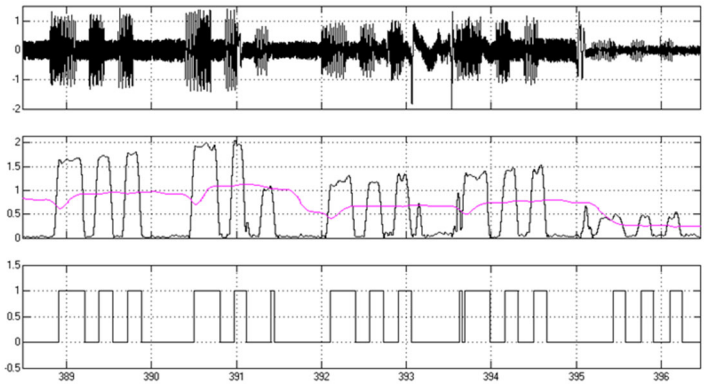

Fig. 6. Oscillograms of the CACS signal, distorted while passing through a short railroad switch section, and signals at the outputs of the receiver blocks.

On the upper oscillogram of Figure 7, impulse noise is visible in the long interval of the signal of the code combination "3".

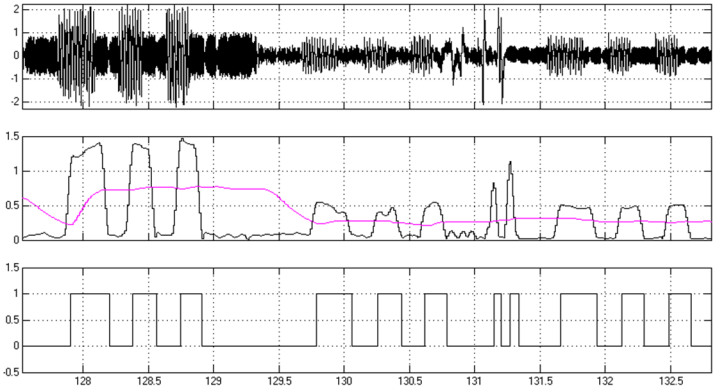

Fig. 7. Oscillograms showing the impact on the quadrature receiver of impulse noise.

They led to a significant distortion of the shape of the envelope at the output of the quadrature detector (Graph 1) and the appearance of two false logic pulses at the output of the receiver. The correlation receiver was unable to effectively suppress these interference pulses.

7 Discussion

Figure 8 shows oscillograms demonstrating the situation when the impact of impulse noise led to a significant distortion of the signal shape at the input of the quadrature receiver, noticeable distortions of the signal envelope, but did not lead to the appearance of erroneous symbols at the output of the receiver. In this case, the noise pulses had a long duration and, consequently, a low-frequency energy spectrum, which was effectively suppressed by filters in the quadrature correlator.

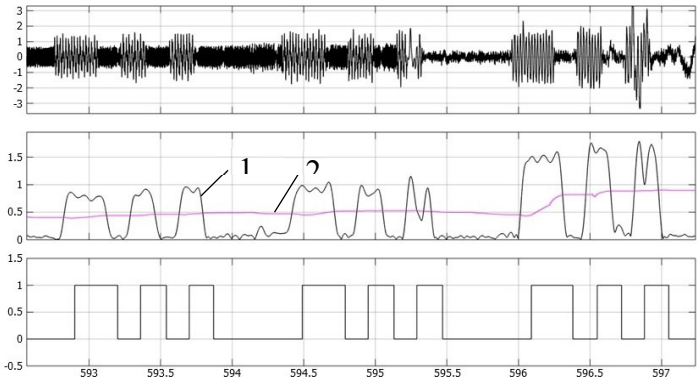

Fig 8. Oscillograms showing the situation when the impact of impulse noise did not lead to errors during reception.

Figure 9 shows oscillograms demonstrating the impact of a burst of impulse noise in a long interval of the code combination “3”. They caused envelope spikes at the output of the quadrature correlator, which led to the appearance of false logic pulses at the output of the receiver.

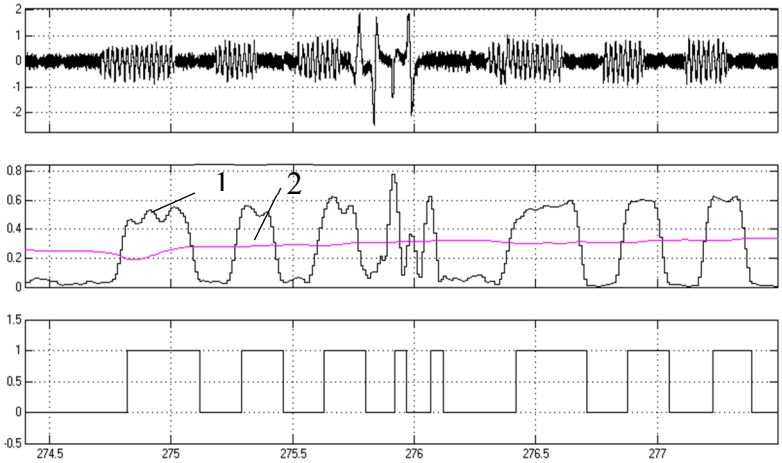

Fig. 9. Oscillograms showing the impact of a burst of impulse noise.

Figure 10 shows oscillograms that demonstrate the difference in the effect of the CACS signal on interference pulses of different durations. The first interference pulse with an amplitude of 2.4 V at a time mark of 114.5 s caused splitting of the first logical pulse in the code combination "3" at the receiver output. The second interference pulse with a larger amplitude of 2.8 V at a time mark of 116.1 s did not distortion of the envelope signal at the output of the quadrature correlator and did not lead to the appearance of a false logical pulse at the output of the receiver. This is due to the fact that the second interference pulse has a much longer duration and, accordingly, a lower frequency energy spectrum and is more strongly suppressed in the quadrature correlator.

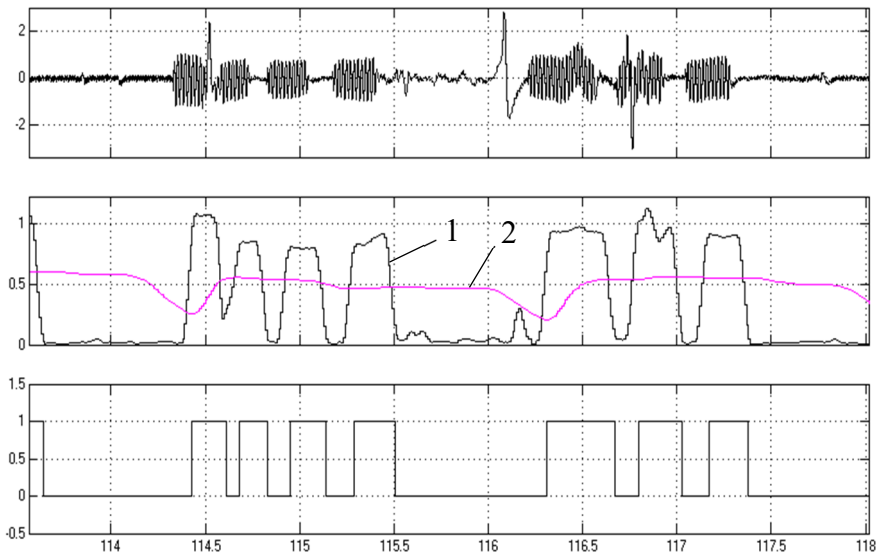

Fig. 10. Oscillograms showing the difference in the impact of interference pulses of different durations of the interpulse intervals were noted.

8 Conclusion

According to the results of the study of the quality of the functioning of the quadrature receiver of CACS signals on the records of real signals and interference, it can be concluded that the quadrature receiver provides reliable reception of CACS code signals at a noise level lower and comparable to the signal level. However, it needs to use additional measures to reduce the influence of essentially non-Gaussian (in particular, impulse) noise.

It is possible to increase the noise immunity of a quadrature receiver of CACS signals under the influence of non-Gaussian noise (pulse, harmonic), for example, by introducing a nonlinear processing of a mixture of signal and noise [8].

When exposed to interference with an arbitrary distribution law, it is possible to achieve an increase in the noise immunity of the receiver by using robust, adaptive [9,10], adaptive-robust methods [11], nonparametric statistics methods [12, 13], and the stochastic approximation method [14].

To approximate the instantaneous noise values $n(t)$, the generalized Gaussian distribution of the following form [15] is widely used

$$W_{noise}(n,\nu)=\frac{\nu}{2\sqrt{2}\Gamma(1/\nu)\sigma}\exp\left[-\frac{|n|^{\nu}}{2^{\nu/2}\sigma^{\nu}}\right], \quad (1)$$

where $\Gamma(\bullet) = \int_0^\infty z^{x-1} e^{-z} \mathrm{d}z$ is the gamma function; v is a distribution parameter that takes values from 0.5 to 10 or more in various situations; σ is the standard deviation of the noise.

At $v = 2$, distribution (1) becomes Gaussian; at $v < 2$, it approximates the density distribution of the probability of impulse interference of the type of shock excitation of the circuit quite well, and at $v > 2$, it approximates the density of the distribution of the probability of harmonic interference.

In the case of an exponential (Laplacian) distribution ($v = 1$), the non-linear transformation block is an ideal limiter (the WLN (wide band filter, limiter, narrow band filter) scheme).

To describe the mixture of fluctuation noise and impulse noise, the following distribution is also used widely:

$$W_{noise}(n) = \left(1 - P_{imp.noise}\right) W\left(n_{fluct.noise}\right) + P_{imp.noise} W\left(n_{imp.noise}\right),$$

where $W(n_{fluct.noise})$ - Gaussian distribution density of the fluctuation component of the interference;

$W(n_{imp\ noise})$ is the distribution density of the impulse component of the noise, usually with a dispersion significantly exceeding the dispersion of the fluctuation component;

$P_{imp.noise}$ - weighting factor, $P_{imp.noise} \leq 1$.

Under $P_{imp.\ noise}$, for example, the average relative time of the duration of the noise pulses or the probability of the occurrence of noise pulses can be understood. Moreover, even in the case when $W(n_{imp.noise})$ is Gaussian, $W_{noise}(n)$ will be non-Gaussian. In this case, the non-linear conversion block is described by a feature that can be approximated by the feature of the blanking device.

Further studies of the quadrature receiver will be aimed at improvement of its noise immunity when it is exposed to non-Gaussian (pulse, harmonic) noise.

References

1. V.I. Astrakhan, V.I. Zorin, G.K. Kiselgof et. al, *Unified integrated locomotive safety device (CLUB-U)*: Textbook; Ed. V.I. Zorin and V.I. Astrakhan (Moscow, GOU "Educational and methodological center for education in railway transport", 2008), p. 177
2. E.E. Shukhina, V.V. Viskov, A.V. Guryanov, *Automation, communications, informatics* **4**, 18-19 (2011)
3. R.R. Yusupov, A.S. Khokhrin, Transport of the Urals **3(74)**, 49-54 (2022)
4. R.R. Yusupov, A.S. Khokhrin, V.B. Leushin, assessment of the quality of functioning of the quadrature receiver of CACS signals at different signal levels **1**, 374-379 (2022)
5. R. Shannon, *System simulation - art and science* (Moscow, Mir Publishing House, 1978)
6. Averill M. Law, *Designing and Analyzing Simulation Experiments* (Industrial Engineering, March 1991), pp. 20-23.
7. I.A. Stefanova, *Modeling Telecommunication Systems in MATLAB + Simulink* (Samara, Publishing House of Povolzhskiy State University of Telecommunications and Informatics, 2018), p. 112
8. A.G. Isaicheva, M.V. Basharkin, A.L. Zolkin et al., Journal of Physics: Conference Series **2094**, 052058 (2021). https://www.doi.org/10.1088/1742-6596/2094/5/052058

9. K.K. Venskauskas, V.V. Krestianinov, *The ship electromagnetic environment and methods of improving EMC characteristics of ship radioelectronics equipment,* In: Proceedings of 1984 International Symposium on EMC (Tokyo, 1984), pp. 178-183
10. A.V. Stafeev, *Development and research of noise-immune adaptive-robust digital demodulators of discrete signals*. Thesis for a candidate degree technical sciences (Moscow, 1992), p. 245
11. B.R. Levin, *Theoretical Foundations of Statistical Radio Engineering*. - 3rd ed., revised and added (Moscow, Radio and communication, 1989), p. 656
12. P.S. Akimov, F.F. Evstratov, S.I. Zakharov, et al., *Detection of radio signals* / Ed. A.A. Kolosov (Moscow, Radio and communication, 1989), p. 288
13. M.B. Nevelson, R.Z. Khasminsky, *Stochastic approximation and recurrent estimation* (Moscow, Nauka, 1972), 327
14. *Development and analysis of methods for improving the stability of the functioning of microprocessor receivers AB-CHK under the influence of destabilizing factors*: Report on research (conclusion) / MIIT; supervisor is V.M. Lisenkov. - VF-3-83; GR 01820087667; Inv. 0285 (Moscow, 1994), p. 197
15. L. Han, C. Lu, A. Yumashev, D. Bahrami, R. Kalbasi, M. Jahangiri, A. Karimipour, S.S. Band, K.-W. Chau, A. Mosavi, Engineering Applications of Computational Fluid Mechanics **15(1)**, 1746-1760 (2021). https://doi.org/10.1080/19942060.2021.1984991
16. M.A. Chirkov, T.A. Lachinina, M.S. Chistyakov, Free thought **5(1683)**, 37-44 (2020). https://www.doi.org/10.24411/0869-4435-2020-00003
17. S. Abduvakhitov, A. Merganov, AIP Conference Proceedings. – AIP Publishing LLC, **2432(1)**, 030048 (2022)
18. M. Khadjimuhametova, A. Merganov, R. Egamberdiev, AIP Conference Proceedings. – AIP Publishing LLC **2432(1)**, 030046 (2022)