Suppression of Pulse Interference

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Abstract The issues of suppression of impulse (non-Gaussian) disturbances in the receiving devices are considered. The analysis of the generalized-Gaussian distribution law was made. The amplitude characteristics of non-linear elements are calculated. A comparison of the effectiveness of pulse interference suppression was made. It is shown that the amplitude characteristics of non-linear devices should relate to the density of the noise distribution.

Keywords: *non-Gaussian interference, distribution law, non-linear suppressors, measures of maximum likelihood, kurtosis*

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1. Introduction

Transport radio communication systems operate in a difficult jamming environment. A source of interference can be, for instance, a contact network on electrified sections of a railway. As a rule, such interference is of a pulsed nature and manifests itself in the form of clicks in the analog speech paths of the equipment. In digital communication systems, pulsed interferences can lead to error tracks. The temporal realization of impulse noise contains abnormal surges and is shown in Figure 1.

To suppress impulse noise, the most widespread are schemes with a limiter, called WLN schemes (wide band - limiter - narrow band), first proposed by the Soviet radio engineer A.N. Shchukin [1]. The block diagram of a nonlinear receiver with a limiter is shown in Figure 2.
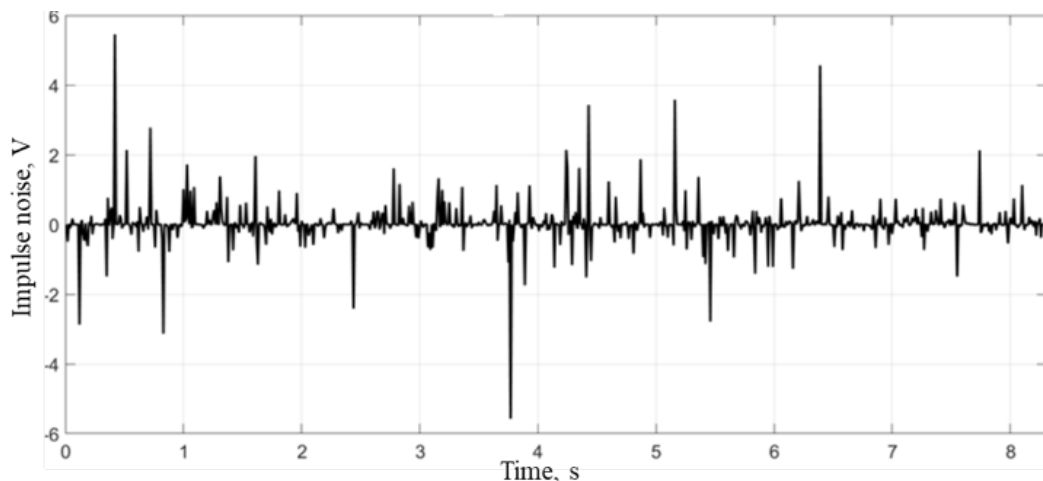

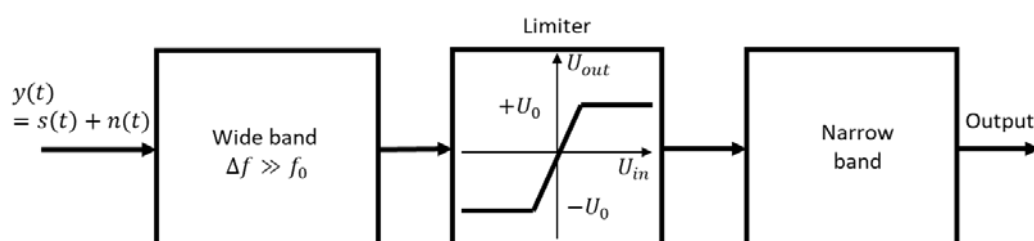**Figure 1.** Time realization of impulse noise

Figure 2. Block diagram of the WLN impulse noise suppression system

If the limiting thresholds $\pm U_0$ are higher than the maximum level of the sum of the signal and interference y(t), the receiver operates in a linear mode. In the case of impulse interference at the input of the receiving device, it is limited in level and does not pass further into the narrowband path of the equipment. It should be noted that the use of the limiter yields the maximum gain, from the point of view of the noise immunity of the receiving device, when exposed to impulse noise at the input with a probability distribution density (PDF) that takes the form of a Laplace distribution law [2]. However, in the general case, it is more efficient to utilize non-linear elements, as opposed to a limiter, due to the relationship between their amplitude characteristics and the analytical expressions of the distribution laws acting in the interference communication channel, as shown below.
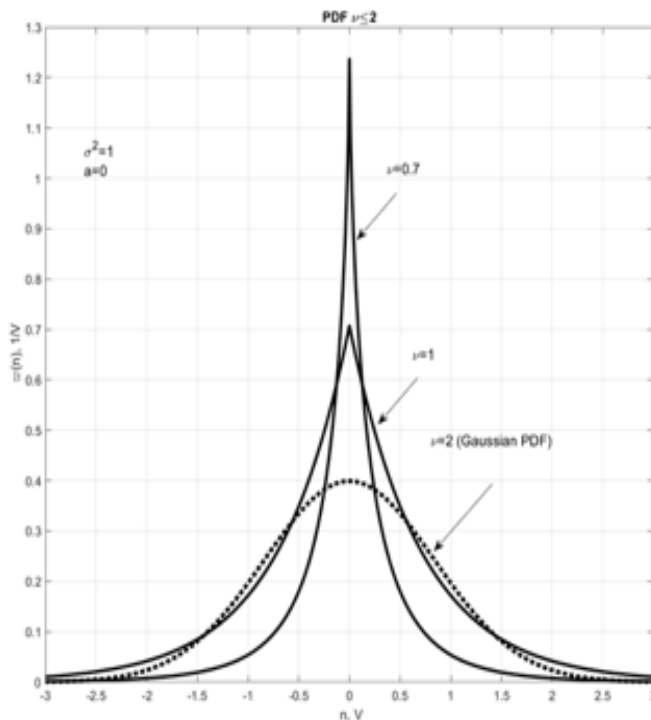
2. Analytical Description of Pulse Interference

To describe a non-Gaussian noise as a random process, it is convenient to apply a generalized Gaussian distribution law [3] with a probability distribution density (DGDD) of the form:

$$w(n) = \frac{v\eta(\sigma,v)}{2G\left(\frac{1}{v}\right)} e^{-\left[\eta(\sigma,v)|n|^v\right]},$$

$$(\sigma,v) = \sqrt{\frac{G\left(\frac{3}{v}\right)/G\left(\frac{1}{v}\right)}{\sigma^2}} \qquad (1)$$

where

$$G(x) = \int_0^\infty e^{-t} t^{x-1} dt \qquad (2)$$

represents the gamma function for real and positive values of the argument x and v is the distribution parameter. At $v = 2$, DGDD turns into a Gaussian distribution. The graph of the gamma function in the range of argument from 0.1 to 3 is shown in Figure 3.
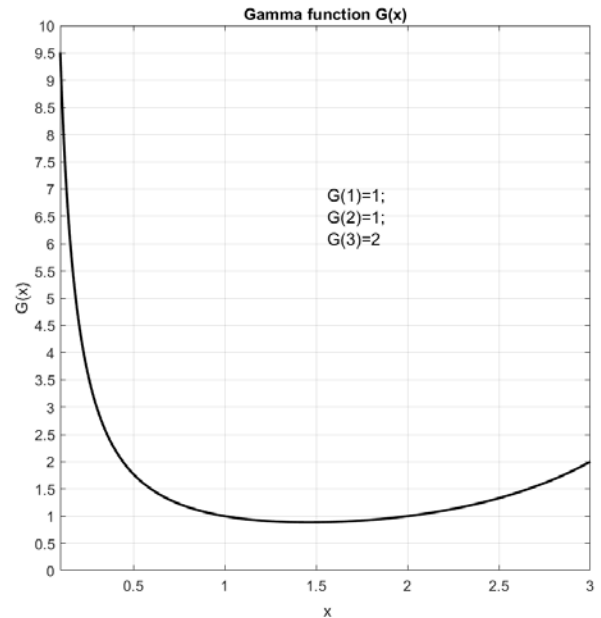

Figure 3. Gamma values

In expression (1), and in further formulas, zero mathematical expectation is taken. The DGDD plots plotted for different values of the parameter v are shown in Figure 4.
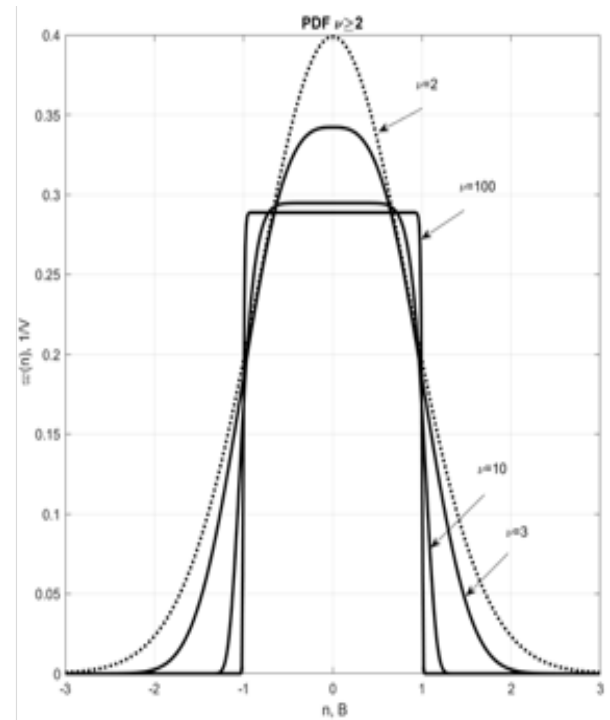

Figure 4. PDF plots for different values of the parameter v

In Figure 4, the dotted line shows the PGD for the Gaussian law. In the case of impulse noise, the parameter ν should be less than 2. At large values of ν, distribution (1) tends to be bound within ± σ. As seen from Figure 4, impulse noise has a peaked distribution of instantaneous values. A measure of the severity of the distribution peak is the excess coefficient, known as the kurtosis coefficient, calculated by the formula:

$$\kappa = \frac{m_4}{m_2^2} = \frac{m_4}{\sigma^4} \quad (3)$$

where m_2, m_4 are the second and fourth moments of distribution.

The fourth point is determined by the formula:

$$m_4 = \int_{-\infty}^{\infty} n^4 w(n) dn \quad (4)$$

For a Gaussian distribution, the kurtosis coefficient is 3. To bring the kurtosis coefficient to zero for a Gaussian distribution, expression (3) is written as:

$$\kappa = \frac{m_4}{m_2^2} - 3. \quad (5)$$

In this case, an impulse noise with a sharp peak in its distribution will have a positive kurtosis, and a noise with a flat PDF will have a negative excess coefficient.

Let us calculate the kurtosis parameter for DGDD, substituting (1) into (3):

$$\kappa = \frac{G\left(\frac{5}{\nu}\right) G\left(\frac{1}{\nu}\right)}{G^2\left(\frac{3}{\nu}\right)} \quad (6)$$

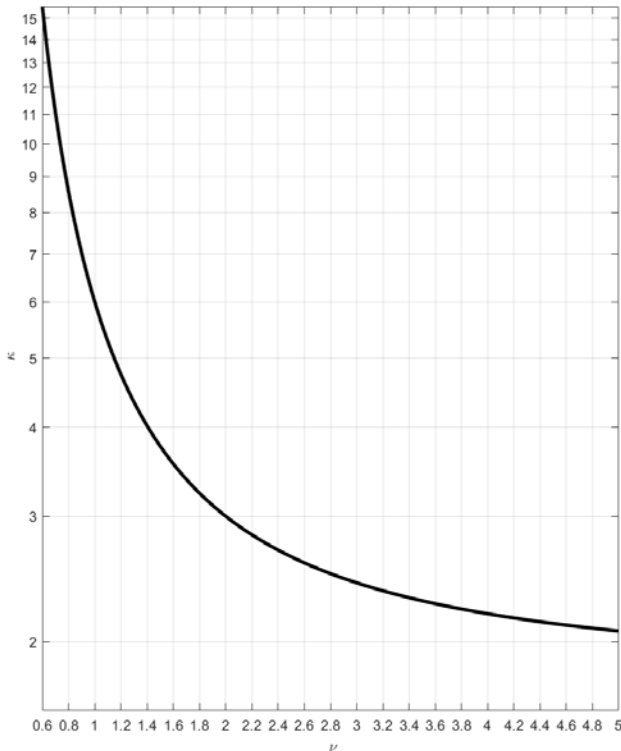The plot of κ versus ν is shown in Figure 5.

Figure 5. Dependence of the kurtosis of the generalized Gaussian distribution on the parameter ν

As seen from the Figure 5. for a small ν value, the kurtosis parameter has large values. As a result, an alternative to the kurtosis coefficient for measuring a non-Gaussian distribution, called the counter-kurtosis, is occasionally used and calculated by the formula [4]:

$$\kappa_c = \frac{1}{\sqrt{\kappa}} \quad (7)$$

The plot of the dependence of the counter excess parameter on ν for DGDD is shown in Figure 6.
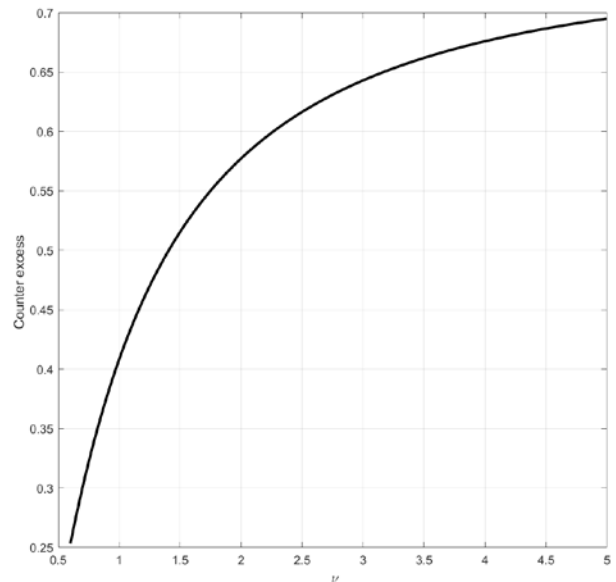

Figure 6. Dependence of the counter excess of the generalized Gaussian distribution on the parameter ν

3. Calculation of Nonlinear Devices for Suppressing Pulse Interference

As shown in [5,6], with a small signal-to-noise ratio and no correlation between the input samples y (t), the amplitude characteristic of the nonlinear element (NE) at the input of the receiver is calculated by the formula:

$$Z_1(n) = -\frac{d}{dn} \ln w(n). \quad (8)$$

Substituting (1) in (8) we get the expression:

$$Z_1(n) = \frac{\nu}{\sigma^\nu} \left[\frac{G\left(\frac{3}{\nu}\right)}{G\left(\frac{1}{\nu}\right)} \right]^{\frac{\nu}{2}} |n|^{\nu-1} sign(n) \quad (9)$$

The graphs of the amplitude characteristics of the NE, in accordance with (9), are shown in Figure 7.

For ν = 2, which corresponds to the Gaussian law of noise distribution, the characteristic in Figure 7 becomes linear. For ν = 1 (Laplace distribution law), the characteristic corresponds to the limiter, as in the SHOU circuit in Figure 2. When exposed to non-Gaussian noise with large kurtosis parameters (for ν ν<1), small values of n(t)=y(t)-s(t) are amplified.
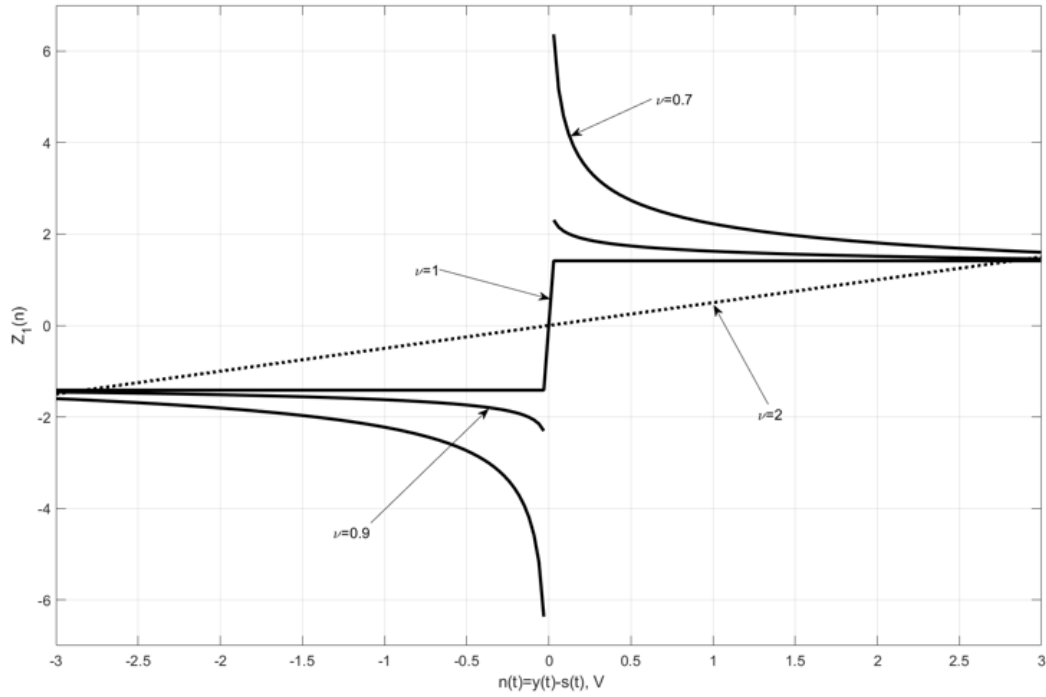
Figure 7. Amplitude characteristics of nonlinear elements depending on the parameter ν

4. Assessment of Immunity Improvement

The criterion for the efficiency of the nonlinear receiving device can be the coefficient μ_0^2, which shows how many times the signal/noise ratio at its output increases in comparison with the optimal linear receiving device [5]:

$$\mu_0^2 = \sigma^2 \int_{-\infty}^{\infty} \left[Z_1(n) \right]^2 \omega(n)\, dn$$
$$= \sigma^2 \int_{-\infty}^{\infty} \left[d/dn \ln w(n) \right]^2 \omega(n)\, dn. \tag{10}$$

Substituting (1) in (10), we obtain the expression for the suppression coefficient in the case of inference with DGDD:

$$\mu_0^2 = \frac{\nu^2 G\left(\frac{3}{\nu}\right) G\left(\frac{2\nu-1}{\nu}\right)}{G^2\left(\frac{1}{\nu}\right)} \tag{11}$$

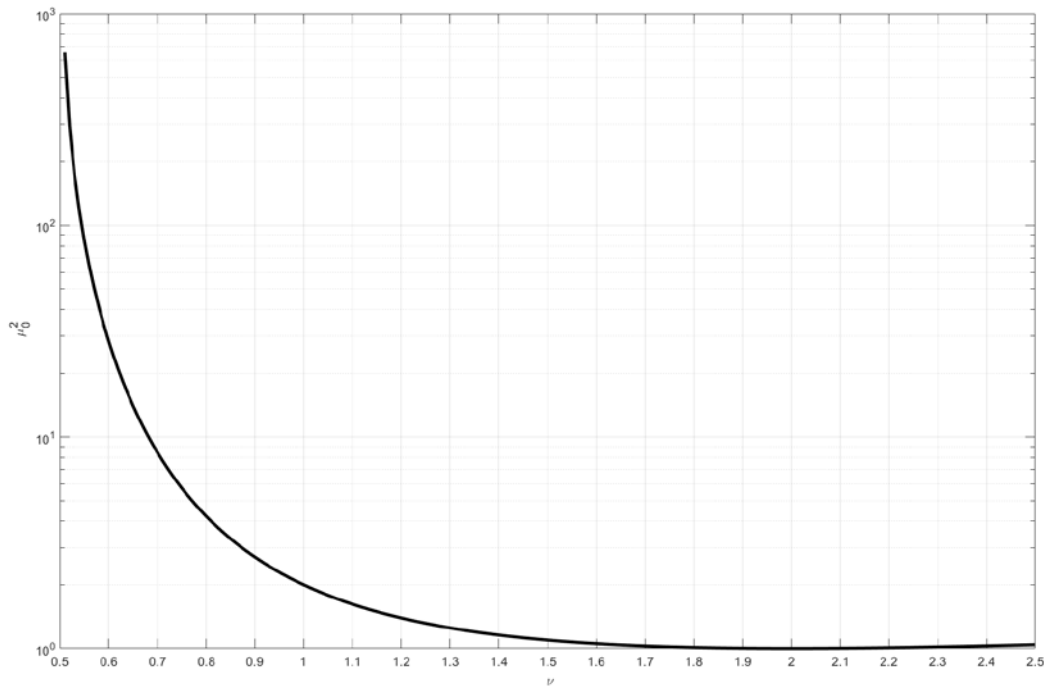The μ_0^2, graph, calculated by formula (11) is shown in Figure 8.

Figure 8. Non-Gaussian interference suppression coefficient μ_0^2 depending on the parameter ν

At small distribution parameters ν (large kurtosis coefficients), the suppression coefficient μ_0 ^ 2 increases significantly and can reach a value of several orders of magnitude. The coefficient of suppression of non-Gaussian interference μ_0^2 was obtained under the condition of consistency of the amplitude characteristic of the nonlinear element in the receiving device and the PDF of the interference acting at the input. It is of interest to calculate the suppression coefficient μ_p ^ 2, provided that a robust (stable) device limiter is used in the receiver circuit. The amplitude characteristic of the limiter is obtained by substituting the parameter ν = 1 into formula (9):

$$Z_1(n) = \sqrt{\frac{2}{\sigma^2}} sign(n) \qquad (12)$$

In formula (10), instead of $Z_0(n)$ we use $Z_1(n)$, we finally get:

$$\mu_p^2 = \frac{v^2 G(3/v)}{G^3(1/v)}. \qquad (13)$$

The μ_p^2, graph calculated by formula (13) is shown in Figure 9.

Figure 9 shows that a nonlinear element in the form of a robust limiter also has the ability to suppress non-Gaussian noise, although to a lesser extent than a NE with an amplitude characteristic consistent with the probability density of the noise.

Let us calculate the efficiency γ as the ratio of the suppression coefficients:

$$\gamma = \frac{\mu_0^2}{\mu_p^2}. \qquad (14)$$

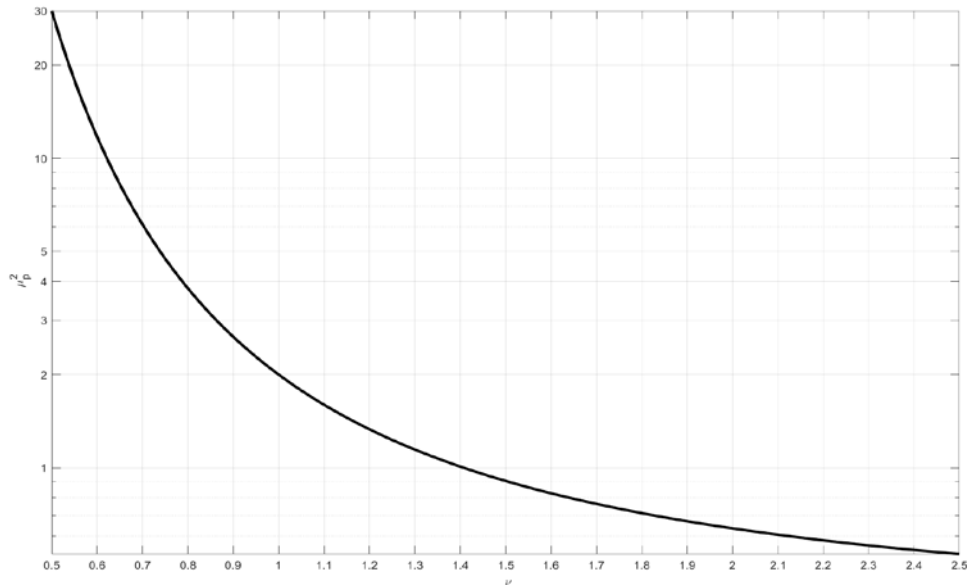The graph of the dependence of γ on the distribution parameter ν is shown in Figure 10.

Figure 9. Non-Gaussian interference suppression coefficient μ_p^2 depending on the parameter ν
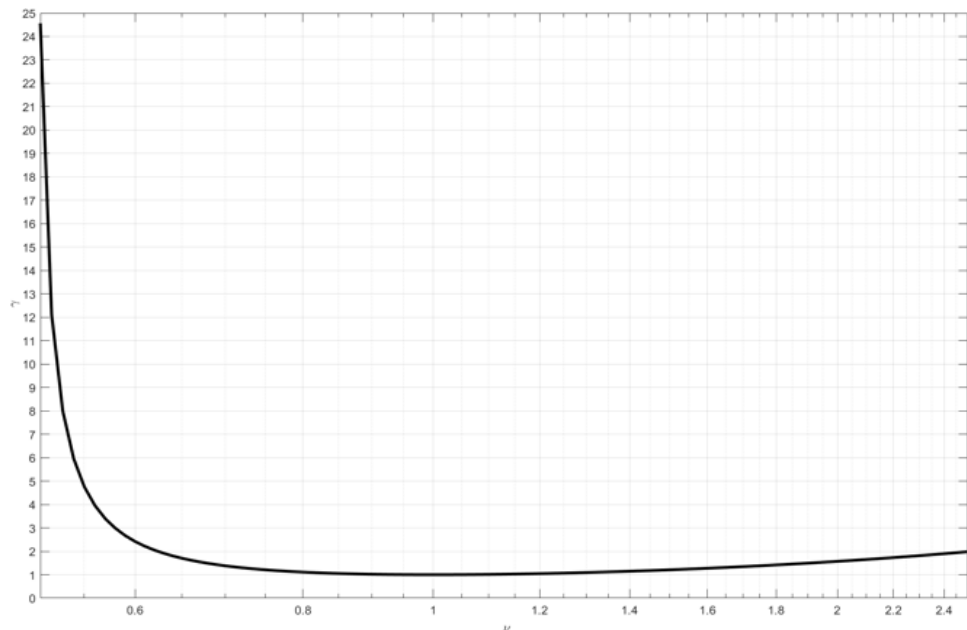

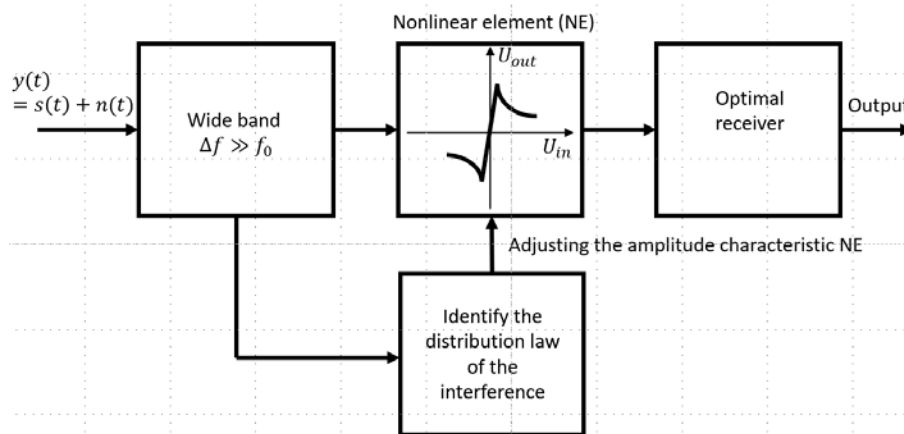**Figure 10.** Efficiency coefficient γ depending on the parameter ν

Figure 11. Block diagram of the receiving device with adjustment of the characteristics of the nonlinear element

It can be seen from Figure 10 that in the range of values of ν from 0.7 to 2, the limiter and the NE with an amplitude characteristic consistent with the probability density of the interference have approximately the same efficiency in terms of suppression of non-Gaussian interference. For small values of ν <0.7, the limiter loses to the nonlinear element that is matched with the probability density.

To adjust the amplitude characteristic of the NE, it is necessary to identify the distribution law of the interference, for example, by the excess of the distribution or other parameters [7]. The block diagram of an adaptive receiver device is shown in Figure 11.

5. Conclusions

1. For the analysis of impulse noise in communication channels, it is most convenient to use the generalized-Gaussian distribution law;
2. The parameter of kurtosis or counter-excesses of the distribution can serve as a measure of the difference between the noise and the Gaussian one;
3. The suppression of impulse noise will be the stronger, the more its distribution law differs from the Gaussian one;
4. To achieve the maximum noise immunity of the receiving device, it is necessary to analyze the distribution law of the interference acting in the communication channel. This is achieved by using adaptive reception algorithms.

Acknowledgements

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