EXPERIMENTAL METHODS AND PROCESSING OF DATA

NON-LINEAR FILTERING OF PULSE SIGNALS IN CASE OF HIGH INTENSITY NOISE

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Signal standing out from the high-intensity noise is a main task in diagnostics of power beam plasma systems. Pulse signals detection from wide-band noise under low value of the signal-to-noise ratio is considered. Stochastic resonance effect as a method of investigation scrutinized. The algorithm and program for the numerical solution are developed. The comparative analysis of ranges of the useful signal on an output of stochastic and linear filters is carried out. Estimates of quality of filtering in case of pulse width modulation signals are calculated. Criteria of non-linear filtering of pulse signals in case of high intensity noise are formulated.

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INTRODUCTION

In modern conditions the providing of reliable communication of data at presence of interferences is considered one of major problems. Error-correcting codes, optimal filters are created, and are used by the detection method of accumulation, the probabilistic approach to suppressing random disturbances. etc. [1].

At the same time, researches in experimental and theoretical physics at the end of the XX century [2, 3], resulted in paradoxical conclusions. The noise on the input of the nonlinear systems possessing the effect of the so-called stochastic resonance (SR), allows to stand out a weak (as compared to the noise) signal from additive signal – white noise mixture. The SR effect characterizes the response of the nonlinear system on a weak input signal. Thus data-output of the nonlinear system, such as signal-to-noise ratio, at certain terms have the distinctly expressed maximum [2, 3].

CONCEPT OF STOCHASTIC RESONANCE

The response of the nonlinear system on a weak external signal in case of SR noticeably increases with the height of the noise intensity in the system and arrives at a certain maximum at some level.

Consider the nonlinear system with SR, described by the equation [2]:

$$d\eta / dt = \eta(t) - \eta^3(t) + x(t)\,, \tag{1}$$

where $x(t)$ – is an input process being additive mixture of desired signal and white noise; $\eta(t)$ – is a process on the output of the nonlinear device.

This equation is Abel equation of the first kind and does not have an analytical solution [4]. It is also impossible to find the two-dimensional probability density of the output signal meaning of an exact solution of the Fokker-Planck equation even in the absence of an external harmonic signal [5]. Consequently, the correlation functions and the spectral densities of the output signal are not exactly determined. Naturally, with the inclusion of a periodic external force, additional difficulties arise in the analytical description.

Consider the case where the input signal is an additive mixture of a harmonic signal $s(t)$ and white noise $n(t)$:

$$x(t) = s(t) + n(t)\,. \tag{2}$$

The numeral simulation of response at affecting input of the system of additive mixture of harmonic signal and white noise illustrating model (1), resulted on Fig. 1. The signal frequency is 1/8 Hz, the signal-to-noise ratio (SNR) is 3 dB.

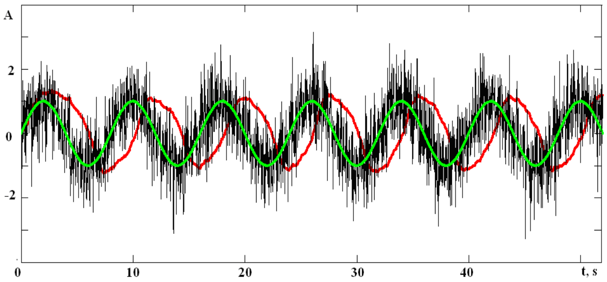

Fig. 1. Standing out of signal from additive signal-noise mixture (input harmonic signal (green), signal-noise mixture(black), output signal (red)

As it is seen from Fig. 1, mixture’s processing according to expression (1) provides to drastically reduce a noise component.

Spectra of input and output signals are shown on Fig. 2. From here we can see output noise power is reduced, and the frequency of harmonic oscillation does not change. Thus effective suppression of noise and standing out of the useful signal is provided.

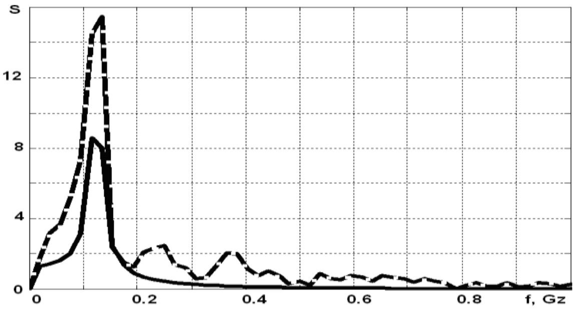

Fig. 2. Amplitude spectrum of input signal (dot) and output signal (solid)

We can note also that the ratio between signal powers on an input and an output practically does not change, i.e. in the device there is no gain of an input signal that contradict the results given in [2].

In [6] stochastic resonator output SNR depending on the input harmonic signal frequency and the input SNR is calculated. Input SNR 0.005; 0.02; 0.5 (on power) we accept equal respectively. Results of calculation are given in Fig. 3.

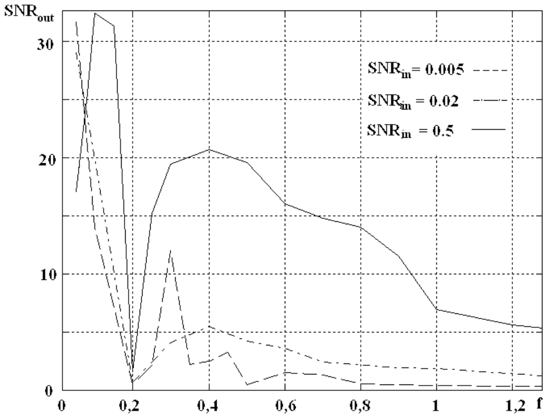

Fig. 3. The output SNR dependence (SNRoutput) on the frequency of the periodic input signal for various values of the input SNR (SNRinput)

The figures show that the phenomenon of SR is best expressed at low frequencies, thus a nonlinear device, having the effect of SR, is a stochastic low-pass filter. In addition, there is a minimum SNR at the output at a frequency f =0.2 Hz, and this effect is observed at any input SNR. Output SNR is a nonlinear function of the external noise and the input harmonic signal.

STANDING OUT OF PULSE SIGNALS

It is known that the model of a rectangular pulse is basic in theories of information and coding [7, 8]. We will consider a case of a so-called passive pause (though it not essentially) when zero is provided by zero voltage. The analysis of SR effect for the harmonic signal standing out from the signal-high intensive noise mixture has been carried out in [9]. It is shown that modification of the equation (1) by changing of the first item sign the right member of equation (1), provides more effective standing out of the harmonic signal. Thus, the equation of SR has the form

$$d\eta / dt = -\eta(t) - \eta^3(t) + x(t)\,. \qquad (3)$$

Consider a pulse sequence as the useful input signal. Numerical solution of the equation (3) illustrates effective standing out of pulse signals from the signal-high intensive noise mixture (Fig. 4). The SNR becomes much higher at the output of a SR filter than at its input.

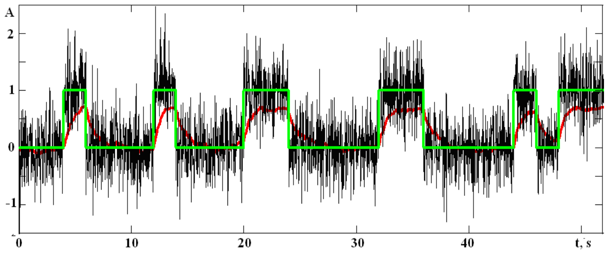

Fig. 4. Digital signal without noise (green), signal-noise mixture (black), output signal (red).pulses durations – 4 and 8 s, the SNR – 8 dB

We use a concept of squareness coefficient k_r for assessment of a pulse-shape distortion. Squareness coefficient is defined as duration relation (ΔT) at the given level γ and at the level of 0.707 of the maximum value [10, 11].

$$k_r = \Delta T_\gamma \,/\, \Delta T_{0.7}\,.$$

In practice the conditional level is selected equal to one of values: 0.1; 0.01; 0.001. It is obvious that for an ideal rectangle pulse $k_r = 1$ [10, 11].

We calculate dependence of squareness coefficient of pulse on an output of the non-linear filter from the input SNR. The comparative analysis of equal duration pulses shows that the first pulse is distorted more considerably owing to transient phenomenon.

Fig. 5 shows that the maximum value of squareness for coefficient of a certain pulse duration takes place in case of a certain SNR. In this case this relation is equal 8 dB.

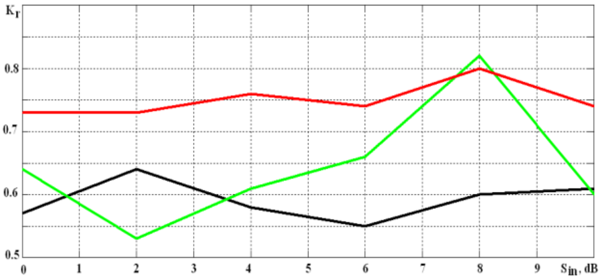

Fig. 5. Squareness coefficient dependence on the input SNR (black – the first pulse; green – the second pulse; red – the third)

Pulse fronts duration is the important characteristic of a output pulse signal. For information systems the fact that if rise and recession of each pulse happens quickly enough, then "tail" of a curve of transient phenomenon does not get to adjacent channel [12].

Figs. 6, 7 show duration dependences of pulse leading edge and pulse back edges on the input SNR. It is impossible to make some accurate conclusions on the basis of these calculations that is explained by a small data set for statistics.

The important result showing advantages of nonlinear filtering on the basis of SR can be received from the comparative analysis of quality of standing out of signals by means of the linear and non-linear filters.

Butterworth filter 8th-oder was selected in quality of the linear electoral system. The Butterworth filter provides a maximally flat response. Butterworth filter provides saving the form and increase steepness of the characteristic in the transition band in case of increase in an filter order [13, 14].

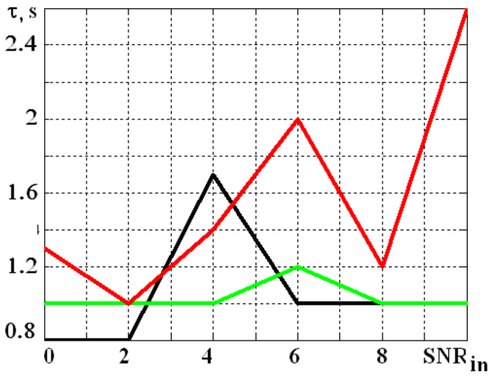

Fig. 6. Duration dependence of pulse leading edge on the input SNR (black – the first pulse; the green line – the second pulse; red – the third)

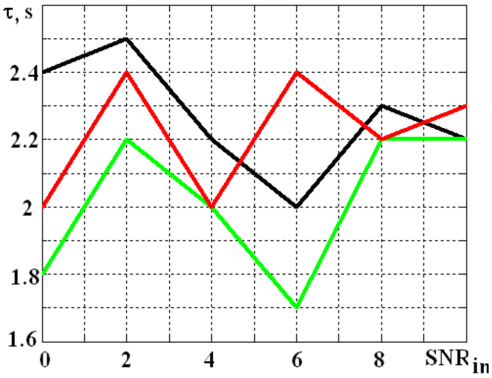

Fig. 7. Duration dependence of pulse beak edge on an input SNR (black – the first pulse; the green line – the second pulse; red – the third)

Results of numerical calculation are given in Figs. 8-11. As it is seen from Fig. 4 and Fig. 8, the non-linear stochastic filter provides more effective standing out of the pulse signal. Besides, the quality of standing out characterized by squareness coefficient also higher in case of the non-linear filter (see Fig. 9).

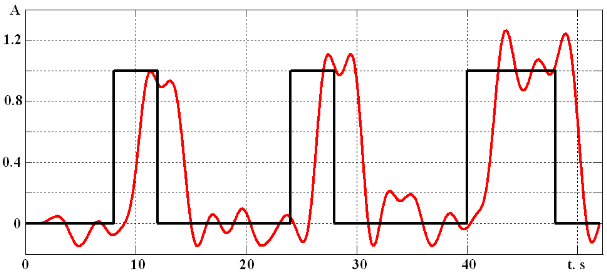

Fig. 8. Digital signal without noise (black), the output signal of the low-pass Butterworth filter (red). Duration of the first two pulses – 4 s, the third – 8 s, SNR – 8 dB

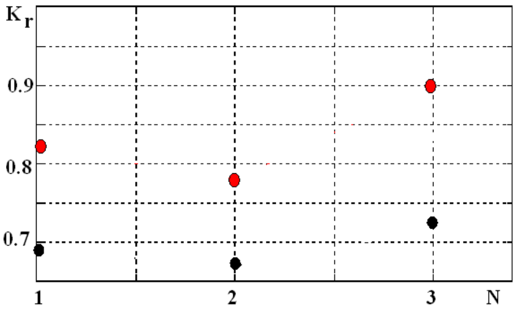

Fig. 9. Squareness coefficient dependence on the pulse number (red – SR; black – for Butterworth filter)

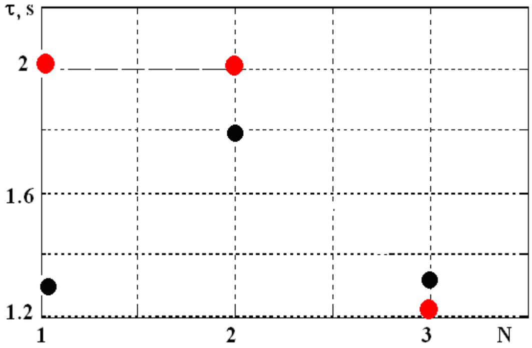

Fig. 10. Duration dependence of pulse leading edge on the pulse number (red – SR; black – for Butterworth filter)

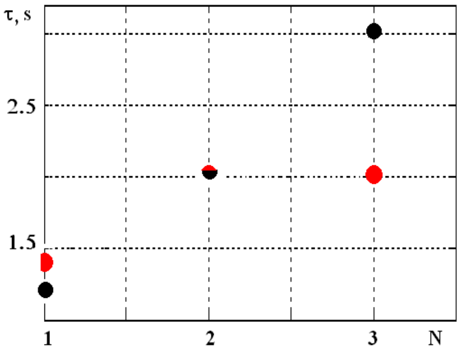

Fig. 11. Duration dependence of pulse beak edge on the pulse number (red – SR; black – for Butterworth filter)

Figs. 10, 11 show advantage of stochastic non-linear filtering. Pulses edge, are generally shorter at the non-linear filter.

CONCLUSIONS

The classic SR signature is the SNR gain of certain nonlinear systems, i.e., the output SNR is higher than the input SNR when an appropriate amount of noise. Some approach have been proposed to tune the SR system by maximizing SNR. It has been shown that certain conditions,

Use of the stochastic non-linear filter to pulse signal processing allows to increase considerably efficiency of standing out such signals from high-amplitude noise. That can be used in radio engineering and measuring systems for creation of non-linear filters.

The comparative analysis of standing out of signals in the linear and non-linear filters showed:

- noise level on the output of the stochastic non-linear filter is less than on the output of the linear filter;
- the pulse shape on the output of the stochastic non-linear filter remains better than on the output of the linear filter.

In linear systems, signal standing out is carried out by the method of accumulation and requires a fairly long time. In the case of stochastic filtering, the delay of the output signal does not exceed the pulse duration.

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НЕЛИНЕЙНАЯ ФИЛЬТРАЦИЯ ИМПУЛЬСНЫХ СИГНАЛОВ В ШУМАХ ВЫСОКОЙ ИНТЕНСИВНОСТИ

О.И. Харченко, А.М. Горбань

В диагностике мощных пучковых и плазменных систем существенной проблемой является выделение полезных сигналов на фоне высокоинтенсивных шумов. Рассмотрена задача выделения импульсных сигналов на фоне широкополосного шума в условиях низкого значения отношения сигнал/шум. В основу анализа положено явление стохастического резонанса, которое заключается в усилении периодического сигнала под действием белого шума определенной мощности. Разработаны алгоритм и программа, обеспечивающие численное решение поставленной задачи. Проведен сравнительный анализ спектров полезного сигнала на выходе стохастического и линейного фильтров. Получены оценки качества фильтрации в случае широтно-импульсной модуляции входной последовательности. Сформулированы критерии применения стохастического фильтра для выделения прямоугольных импульсов на фоне шумов высокой интенсивности.

НЕЛІНІЙНА ФІЛЬТРАЦІЯ ІМПУЛЬСНИХ СИГНАЛІВ У ШУМАХ ВИСОКОЇ ІНТЕНСИВНОСТІ

О.І. Харченко, А.М. Горбань

У діагностиці плазмових систем суттєвою проблемою є виділення корисних сигналів на фоні високоінтенсивних шумів. Розглянуто задачу виділення імпульсних потужних пучкових сигналів на фоні широкосмугового шуму в умовах низького значення відношення сигнал / шум. В основу аналізу покладено явище стохастичного резонансу, яке полягає в посиленні періодичного сигналу під дією білого шуму певної потужності. Розроблено алгоритм і програму, що забезпечують чисельне рішення поставленого завдання. Проведено порівняльний аналіз спектрів корисного сигналу на виході стохастичного та лінійного фільтрів. Отримано оцінки якості фільтрації в разі широтно-імпульсної модуляції вхідної послідовності. Сформульовано критерії застосування стохастичного фільтра для виділення прямокутних імпульсів на фоні шумів високої інтенсивності.