Global Journal of Researches in Engineering: F
Electrical and Electronics Engineering
Volume 15 Issue 7 Version 1.0 Year 2015
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Simulation of the Stochastic Resonance Effect in a Nonlinear Device

By Okcana Kharchenko
National Technical University, Ukraine

Abstract- The possibility to separate a useful signal from the realization of the random process representing the sum of the harmonic signal and Gaussian noise, using the method of stochastic resonance, is shown. The results of calculation of the signal-to-noise ratio at the output of a nonlinear device, creating an effect of stochastic resonance, are given. It is shown that the nonlinear device, described by the equation of stochastic resonance, operates as a stochastic low-pass filter. A simulation model of a non-linear device possessing effect of SR is constructed.

Keywords: stochastic resonance (SR), nonlinear device, signal-to-noise ratio (SNR), filter.

GJRE-F Classification : FOR Code: 280204

Simulation of the Stochastic Resonance Effect in a Nonlinear Device

Okcana Kharchenko

Abstract- **The possibility to separate a useful signal from the realization of the random process representing the sum of the harmonic signal and Gaussian noise, using the method of stochastic resonance, is shown. The results of calculation of the signal-to-noise ratio at the output of a nonlinear device, creating an effect of stochastic resonance, are given. It is shown that the nonlinear device, described by the equation of stochastic resonance, operates as a stochastic low-pass filter. A simulation model of a non-linear device possessing effect of SR is constructed.**

Keywords: stochastic resonance (SR), nonlinear device, signal-to-noise ratio (SNR), filter.

I. Introduction

It is considered that noise in a system is a negative factor and the fight against noise is one of actual problems of radio engineering systems. Low-noise devices and methods of noise reduction are developed, noiseproof codes, digital communication, signals with the necessary correlation properties are created.

However, research conducted recently in the field of theoretical and experimental physics has shown that in some cases an input weak signal can be amplified and optimized with the assistance of noise (Anishchenko *et al*, 1999;, Geraschenko, 2003). The integral characteristics of the process at the system output, such as the spectral power amplification (SPA), the signal-to-noise ratio (SNR) have a well-marked maximum at a certain optimal noise level.

The notion of stochastic resonance (SR) determines a group of phenomena wherein the response of a nonlinear system to a weak input signal can be significantly increased by appropriate tuning of the noise intensity. SR refers to a generic physical phenomenon typical for nonlinear systems.

This article discusses the simulation of the effect of SR in the case of additive sum of a harmonic signal and Gaussian noise at the nonlinear device input.

II. Characterization of Stochastic Resonance

A weak input signal significantly increases with increasing intensity of noise and reaches its maximum at a certain noise level in nonlinear systems in which SR occurs.

Author: National Technical University "Kharkiv Polytechnic Institute», Kharkiv, Ukraine. e-mail: okcana1304@mail.ru

Consider the equation describing the model of nonlinear systems in which SR occurs (Anishchenko *et al*, 1999;, Kharchenko*et al*, 2015):

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

where $x(t)$ – input signal;

$\eta(t)$ – output signal.

This formulais Abel's equation of the first kind and has no analytical solution(Kamke, 1961). It is also impossible to find two-dimensional probability density of the output signal by using the exact solution of the Fokker – Planck equation even in the absence of an input harmonic signal (Middleton, 1996).

Therefore, the signal correlation functions and spectral density at the nonlinear system output can't be defined exactly. Naturally, there are additional difficulties in the analytical description of actual effects, if there is an additive sum of harmonic signal and Gaussian noise.

III. Signal-to-Noise Ratio at the Nonlinear System Output

Unlike linear systems, in which the energy spectrum at the output follows input energy, output spectrum of the non linear system has amore complicated structure (Levin, 1969, Volochuk, 2005). Signal and noise are independent in ali near system. The output of the non linear device forms new spectral components due to the interaction of the components of the input process.

Moreover, the type of non-linear transformation and the statistical characteristics of the input signal determine the type and intensity of the additional component.

If the input processisan additivesum of the unmodulated carrier and noise, there are three main parts in the output power spectrum of the non linear device:

$F_{SxS}(\omega)$ – corresponds to the beats between the components of the signal and its harmonics (a discrete part of the spectrum);

$F_{NxN}(\omega)$ – is formed by beats of noise components (continuous component of the spectrum);

$F_{SxN}(\omega)$ – is formed by mutual beats of signal components and noise(continuous component of the spectrum).

The discrete part of the spectrum is complemented by the spectrallineat zero frequency, representing the DC component at the output, which is also determined by the beats of the signal components and noise. Consequently, the energy spectrum of the output of the nonlinear device is determined as (Levin, 1969, Voloshchuk, 2005):

$$F(\omega) = F_{SxS}(\omega) + F_{SxN}(\omega) + F_{NxN}(\omega).$$

Practically the most convenient power indicator of the output signal is the signal–to–noise ratio (SNR). Since the output process is an in separable mixture of an input signal and noise, it is impossible to specify components, which would depend only on the signal and, accordingly, only on noise.

In order to evaluate the SNR at the output of the nonlinear system, it is necessary to determine the portion of the spectrum $F_{SxN}(\omega)$.

We can calculate SRN at the output ofthe nonlinear system in two ways as:

a) if the beats between signal components and noise are attributed to noise:

$$SNR = \frac{\int_0^\infty F_{SxS}(\omega)d\omega}{\int_0^\infty [F_{SxN0}(\omega) + F_{NxN}(\omega)]d\omega},$$

b) if the beats between signal components and noise are attributed to signal:

$$SNR = \frac{\int_0^\infty [F_{SxS}(\omega) + F_{SxN}(\omega)]d\omega}{\int_0^\infty F_{NxN}(\omega)d\omega}.$$

SNR is calculated using the last formula in case of the SR, as a high valueof this parameter is predetermined by the component $F_{SxN}(\omega)$, i.e. by the interaction between signal and noise.

IV. Snrat the Output of the Nonlineardevicehas the Effect ofSR

Consider the case where the input signal of the nonlinear device is an additivesum of the sinusoidal signal and Gaussian noise

$$d\dot{\eta}/dt = \eta(t) - \eta^3(t) + A\cos(2\pi ft + \varphi) + \xi(t) \quad (2)$$

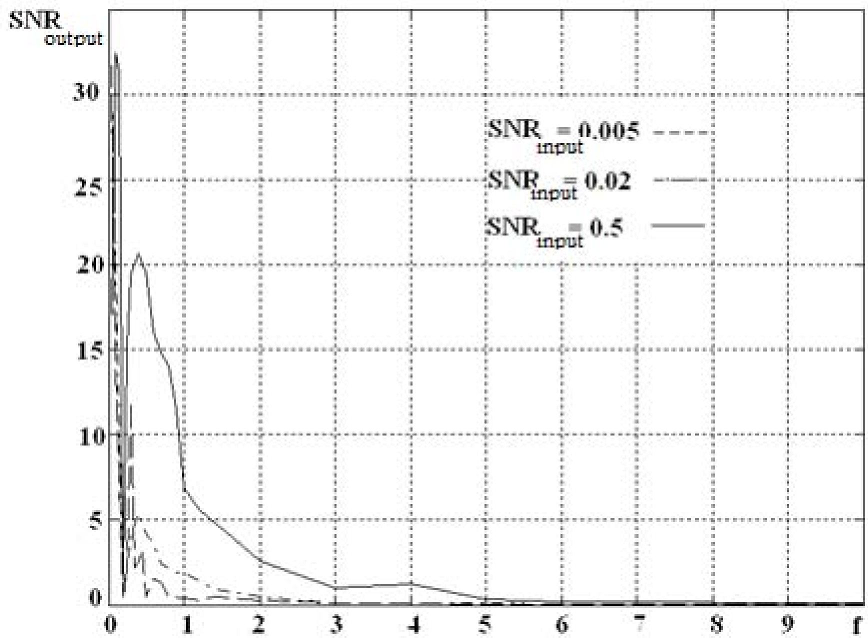
where $\xi(t)$ – Gaussian noise with a zero average and variance D,

$\eta(t)$ – the process at the nonlinear device output.

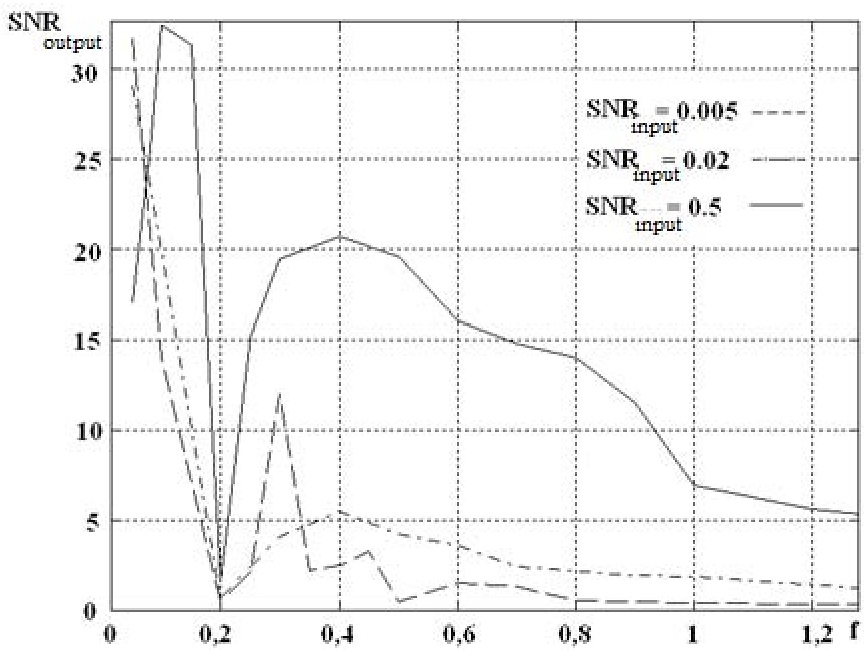
Having solvede quation (2) numerically, let'sde fine the SNR at the output of the nonlinear device (SNR_{output})as a function of frequency and SNR at the input (SNR_{input}). We can calculate SNR_{input}as

$$SNR_{input} = A^2/2D.$$

The frequency is set in the range of 0.05÷10Hz. Power SNR at the input is consideredequal, respectively: 0.005; 0.02; 0.5. The calculation result sare shown in Fig. 1a and1b. Fig. 1bshowsthelowfrequencyin moredetail.



a)



b)

Figure 1 : The SNR dependence of the output of the nonlinear device(SNR_{output})on the frequency of the periodic input signal for various values of the SNR at the input(SNR_{input})

The figures show that the phenomenon of SR is best expresse dat low frequencies, thus a nonlinear device having the effect of SR, is astochasticlow-pass filter. In addition, there is a minimum SNR at the outputat a frequency of $f = 0.2$ Hz, and this effect is observedat any SNR at the input. SNR at the output is a nonlinear function of the external noise and the input harmonic signal. You can then make three-dimensional SNR graphs of the input noise power and harmonic signal amplitude. It should be noted that the numerical simulations were performed by summing the dataon limited time intervals (up to 50periods of frequency).Naturally, the time delay affects the results of (Middleton, 1996).

V. Model of the Nonlinear Device Having the Effect of CR

Let's create a simulation model of the nonlinear device according to the graphical programming environment SIMULINK (intfig.2egrated with MATLAB), described by equation (2). This system has the SR effect. An additive mixture of the harmonic signal and Gaussian noise is sent to the input. Output signal stakes from the oscilloscope. This scheme can be the basis for practical implementation of the nonlinear filter (fig.2).

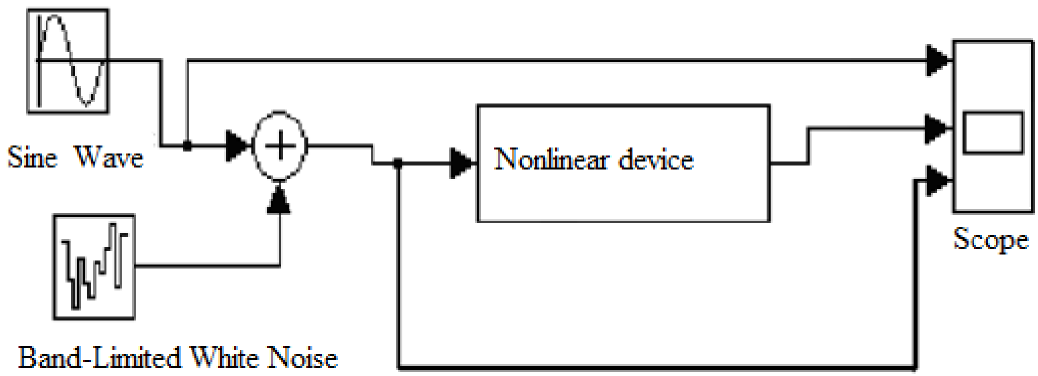
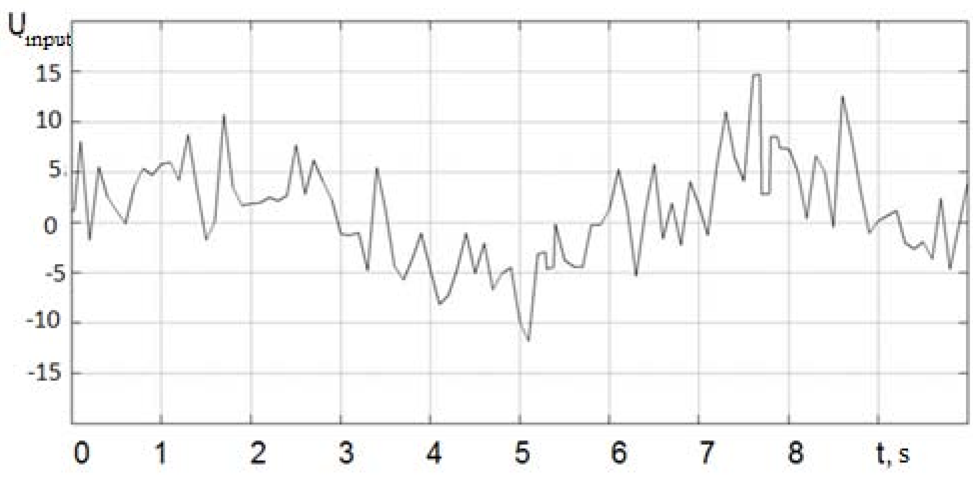
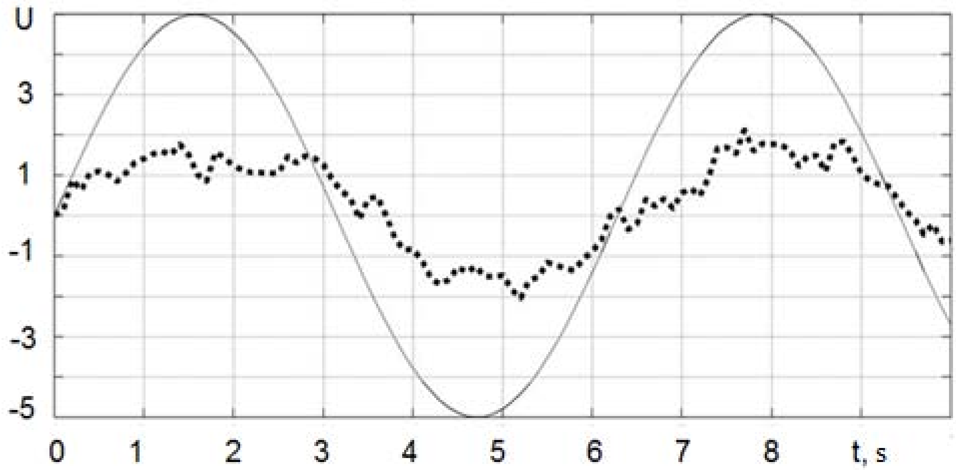


Figure 2 : The simulation model of the nonlinear device.

Fig. 3 shows the signals taken from the oscilloscope. It can be seen clearly that the dispersion in Fig. 3ais much less than the dispersion in Fig. 3b. Thus, this model shows the increase in the SNR at the output of the nonlinear device having the effect of SR. In addition, the harmonic nature of the output signal is retained.





b)

Figure 3 : The input signal of the nonlinear device(a);time dependences of input of a harmonic signal (solid line) and the output signal of the nonlinear device (points) (b)

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.

VI. Conclusions

In this paper we discuss the work of the non-linear device having the effect of SR at the input of the additive mixture of the harmonic signal and the white noise of short duration. The results make it clear that the device works as a stochastic low-pass filter. In addition, numerical analysis of the equation describing the effect of SR showed that the SNR at the output of the nonlinear device under certain conditions exceeds the SNR at the input. Hence, the nonlinear device operates as an amplifier.

In this paper we can build a simulation model of the nonlinear device, described by equation SR. We have used an additive mixture of the harmonic signal and noise with a duration of 10 s at the input of the nonlinear device. We have used the graphical programming environment SIMULINK (integrated with MATLAB) for building a simulation model.

These results demonstrate that the signal obtainedat the output of the nonlinear device has a lower noise level as compared with the input signal.

Prospects of development schemes of nonlinear filter based on the designed model are indicated.

References Références Referencias

1. Anishchenko VS, Neiman AB, Moss F, Shimansky-Geier L,(1999). Stochasticresonance: noise-enhanced order. Phys. Usp.42: 7–36.
2. Geraschenko OV, (2003). Stokhasticheskiyresonans v asimmetrichnoi bistabilnoy sisteme". Pismav GTF, vol. 29, vyp. 6:82-86. (in Russian).
3. Kharchenko O, Tyutyunnik V, (2015).Analysison the Basis of Volterra Series Signal–To–Noise Ratioof Nonlinear Device in the Conditions of the Stochastic Resonance Effect. Journal of Electrical and Electronic Engineering. Vol. 3, No. 3: 25-29.
4. Erich Kamke. Differentialgleichungen. B.1: Gewoehnliche Differentialgleichungen. 320 p, (1942). (in German).
5. David Middleton. An Introduction to Statistical Communication Theory: An IEEE Press Classic Reissue, Wiley-IEEE Press,1184 p, (1996).
6. Levin B.R. Teoreticheskie osnovy statisticheskoi radiotekhniki, M: Sov. Radio, p. 752, (1969). (in Russian).
7. Voloshchuk Yu. I. Pidruchnik dla studentiv vich. navch. Zakladiv. Kharkiv: TOV "Kompania CMIT",T.3, 228p, (2005).(in Russian).

This page is intentionally left blank