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A new method for identification of RTS noise

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Abstract. In the paper a new method, called the Noise Scattering Pattern (NSP) method, for RTS noise identification in a noise signal is presented. Examples of patterns of the NSP method are included.

Key words: Noise Scattering Pattern method, RTS noise identification.

1. Introduction

Random Telegraph Signal noise (RTS noise) is fluctuation in the current or voltage with random discrete impulses of equal heights. RTS noise is observed as two- or multi-level impulses. The two-level RTS noise is presented in Fig. 1. RTS noise occurs in the inherent noise of electronic devices as a non-Gaussian component. This kind of noise is specially important in semiconductor devices. An analysis of RTS noise is typically applied to improve the performance of semiconductor devices and their technology and quality. With downscaling of an area of semiconductor devices the contribution of RTS noise sources becomes again more pronounced. RTS noise in sub-micron devices usually dominates over all the other noise sources, for example thermal, shot, 1/f, generation-recombination noise (sources with Gaussian distribution of instantaneous values of noise) and becomes a major component in low frequency noise.

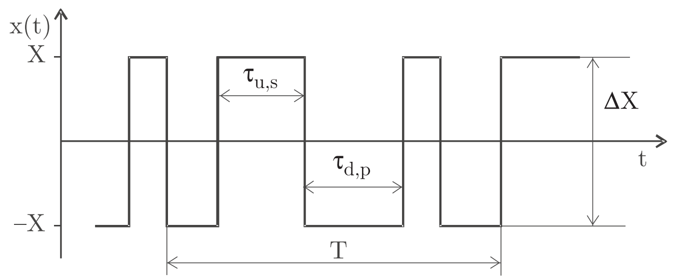

Fig. 1. Typical two-level RTS noise $\tau_{u,s}$ – the s-th duration of an impulse in the up time, $\tau_{d,p}$ – the p-th duration of an impulse in the down time, ΔX – the amplitude of RTS noise, T - observation time

Typically the analysis of RTS noise is carried out in the time domain or in the frequency domain or in both.

In the time domain usually a noise signal is observed and the probability density function of the noise signal is calculated. From the analysis in the time domain the following parameters of RTS noise can be evaluated: – $\overline{\tau_u}$ – mean time of $\tau_{u,s}$, where s = 1,2,...,S observed in time T, evaluated as:

$$\overline{\tau_u} = \frac{\sum_{s=1}^{S} \tau_{u,s}}{S},$$

– $\overline{\tau_d}$ mean time of $\tau_{d,p}$, where p = 1,2,...,P observed in time T, evaluated as:

$$\overline{\tau_d} = \frac{\sum_{p=1}^{P} \tau_{d,p}}{P},$$

– ΔX amplitude of RTS noise, and also the calculated f_{RTS} frequency, equal to:

$$f_{RTS} = \frac{1}{\overline{\tau}} = \frac{1}{\overline{\tau_u}} + \frac{1}{\overline{\tau_d}}.$$

In the frequency domain, usually the $S(f)$ power spectral density function and the product of $f \cdot S(f)$ are estimated. From an analysis in the frequency domain the following parameters can be evaluated:
– ΔX amplitude of RTS noise,
– f_{RTS} frequency.

The presented method allows to identify RTS noise in a low frequency noise signal and to evaluate the amplitude and the relation between $\overline{\tau_u}$ and $\overline{\tau_d}$ of RTS noise. The analysis is based on instantaneous values of the noise signal. This method can be applied to different noise signals, for example to inherent noise of semiconductor devices, in particular to nano- and mezoscopic devices.

2. The idea of the Noise Scattering Pattern (NSP) method

The Noise Scattering Pattern method proposed in papers [1,2] enables to detect RTS noise in a time only a little longer than the time required for noise signal acquisition. A schematic diagram of the measurement system for low frequency noise measurements based on the NSP method is presented in Fig. 2.

The low frequency noise signal x'(t) is digitized in an A/D converter and a sequence {x(n)}, where n = 1,2,..., N (N is an even number), is stored in a computer memory.

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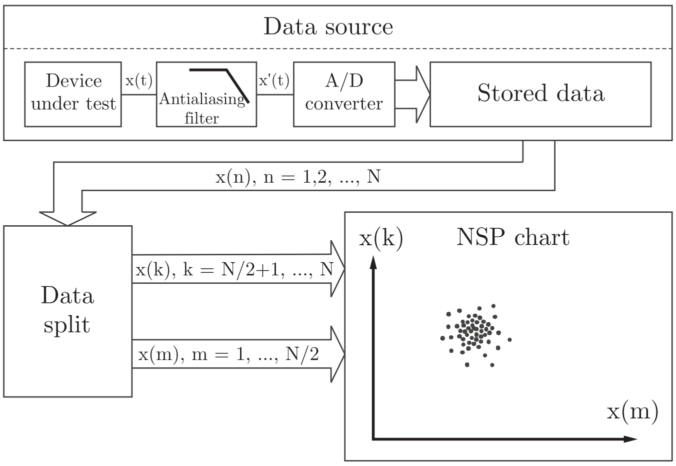

Fig. 2. Schematic diagram of the measurement system based on the NSP method; x(t) – noise signal, x'(t) – noise signal after antialiasing (lowpass) filtration, x(n) – stored data, x(k), x(m) – subsequences after splitting sequence x(n)

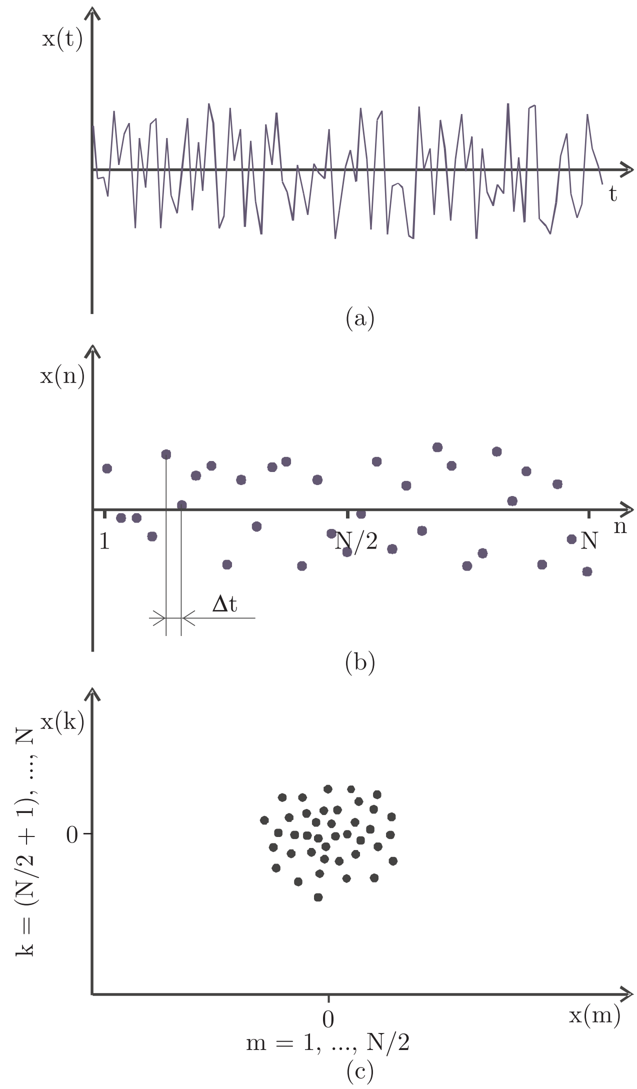

Fig. 3. Illustration of the NSP method results for a noise signal containing only Gaussian noise (without RTS noise), (a) – noise signal, (b) – sampled signal data, (c) – data in XY plane, $\Delta t = 1/f_s$ sample period, the reciprocal of the sampling frequency

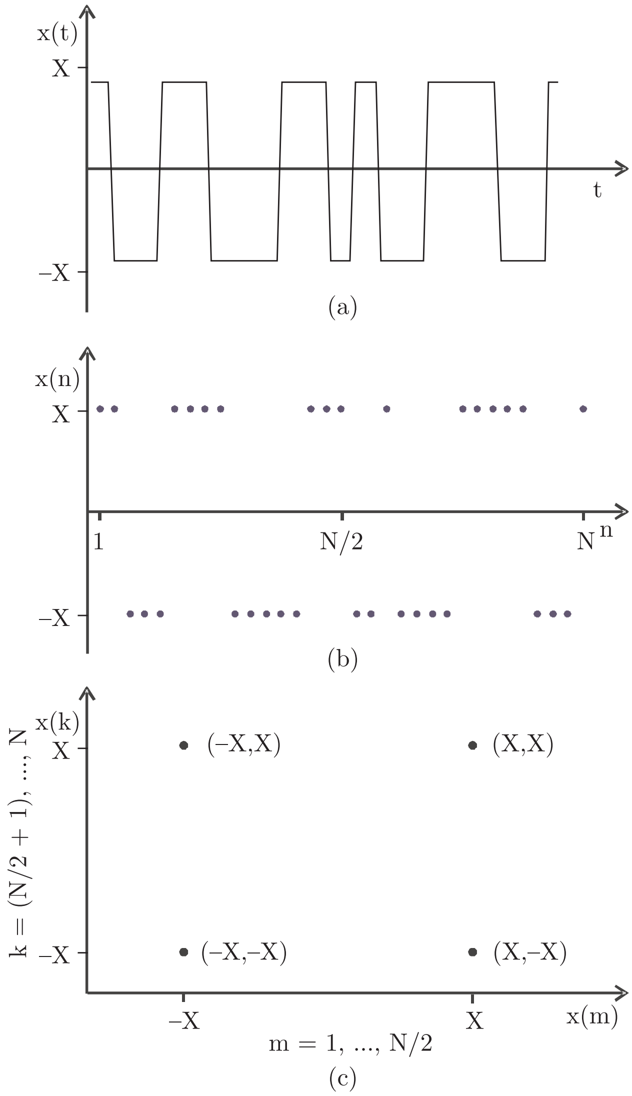

Fig. 4. Illustration of the idea of the NSP method for inherent noise signal which contains only RTS noise: (a) – noise signal, (b) – sampled signal data, (c) – data in XY plane

The sequence {x(n)}, where n = 1,2,..., N is divided (split) into two subsequences:
– {x(m)}, where m = 1,2,..., N/2,
– {x(k)}, where k = (N/2) + 1, (N/2) + 2,..., N.

The data of both subsequences are put on the XY plane. The data from the subsequence {x(m)}, where m = 1,2,..., N/2, are X axis coordinates, the data from the subsequence {x(k)}, where k = (N/2) + 1, (N/2) + 2,..., N, are Y axis coordinates. By this way dots are created in the XY plane.

We assume that the low frequency noise signal contains two components: Gaussian noise and non-Gaussian noise (two-level RTS noise). For a signal containing only the Gaussian noise (without RTS noise) an illustration of the NSP method is presented in Fig. 3. For a noise signal without RTS noise, in the XY plane we receive dots around the signal mean value. Some information about the distribution of the investigated signal is contained in the concentration of dots, in the pattern of dots.

For a noise signal which contains only two-level RTS noise, in the XY plane we receive four points in the XY plane:

(X,–X), (X,X), (–X,–X), and (–X,X) (see Fig. 4). If the noise signal contains Gaussian noise and RTS noise, dots around the mentioned above four points: (X,–X), (X,X), (–X,–X), and (–X,X) in the XY plane are observed (see Fig. 5).

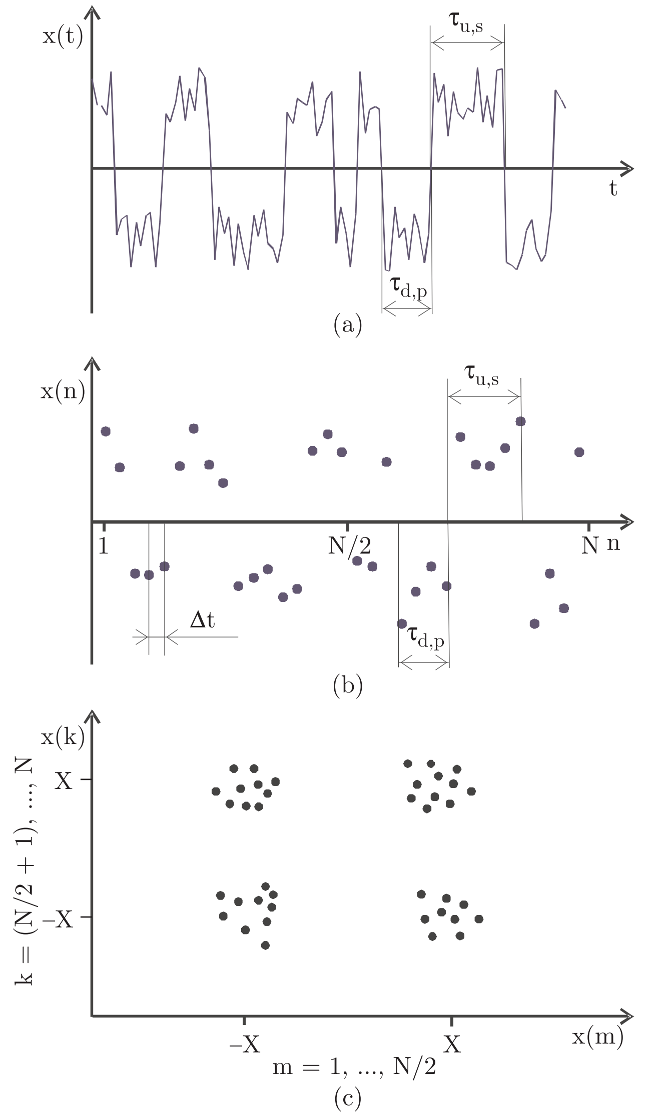

Fig. 5. Illustration of results of the NSP method for a noise signal containing Gaussian noise and RTS noise: (a) – noise signal, (b) – sampled signal data, (c) – data in XY plane

The number of dots around each point can be different. It depends on the length of mean times, $\overline{\tau_u}$ and $\overline{\tau_d}$. If $\overline{\tau_u}$ is longer than $\overline{\tau_d}$, the concentration of dots around the point (X,X) will be higher, if $\overline{\tau_d}$ is longer than $\overline{\tau_u}$, the dot concentration around the point (–X,–X) will be higher. If $\overline{\tau_u}$ is comparable to $\overline{\tau_d}$, a similar dot concentration should be observed. It means that from the concentration of dots around the four points we are able to recognize the relation between the length of mean times $\overline{\tau_u}$ and $\overline{\tau_d}$.

If the three-level RTS noise is analyzed in the XY plane we receive nine centers of dots. Dots concentration around the main nine points contains information about the relation between the length of mean times of impulses in three-level RTS noise.

We conclude that the pattern of dots for a signal without RTS noise is totally different than the pattern of dots for a signal with a RTS noise component (two-level, three-level). The NSP method enables to recognize the noise character from the scattering of dots in the XY plane which form the specific pattern.

3. Application of the NSP method

A system with the LabView virtual instrument for noise measurement in low frequency range was constructed and measurements were carried out for optocouplers (OCDs) [1]. In Fig. 6 two patterns of registered low frequency noise of OCDs are presented. In Fig. 6a the pattern suggests that the noise signal of the device does not contain RTS noise, while in Fig. 6b the pattern shows a well-pronounced centre of dot concentration around the conventional point (X,X). The pattern suggests that the noise signal of the investigated device contains RTS noise with $\overline{\tau_u}$ longer than $\overline{\tau_d}$.

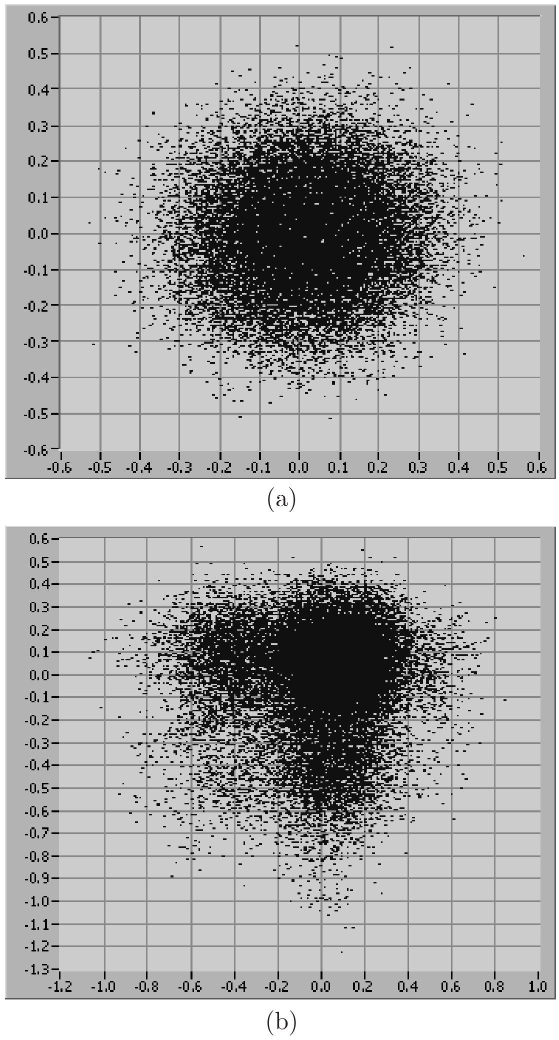

Fig. 6. NSP patterns for the inherent noise of two OCDs: (a) – Gaussian noise, (b) – Gaussian and RTS noise (after Ref. 1)

The LabView NSP virtual instrument can be fitted with a k-order median filter to partially remove the background noise from noise signal. The median filter converts the stored digital samples of noise x(n), where n = 1,2,...,N in sequence of their median $m(n)_k$ where n = 1,2,...,N:

$$(m(i)_k) = \text{med}\{\, x(i-k), x(i-k+1), \ldots, x(i), \ldots x(i+k-1), x(i+k)\}, \; i = k+1, \ldots, N-k.$$

where:
k – the order of median filter,
med – the notation of median of sub-sequence of digital samples.

The result of median filtering of data from Fig. 6b is shown in Fig. 7.

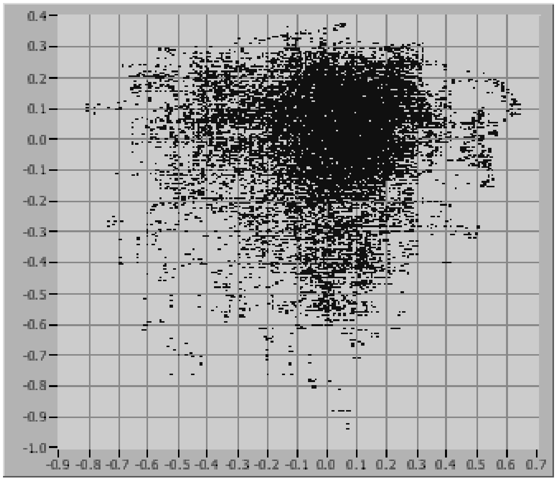

Fig. 7. The NSP pattern from Fig. 6b after median filtering (filter order k = 5) (after Ref. 1)

The median filter "is cleaning" the NSP pattern by reducing the dispersion and amount of dots. From the patterns presented in Fig. 6b and Fig. 7 the value of RTS noise amplitude can be evaluated. The amplitude is about 0.1 V and it is the center of dots concentration. Some results of the NSP method were included in [3].

4. Conclusions

The presented method enables the identification of Gaussian and non-Gaussian noise components in a noise signal. Non-Gaussian noise, for example RTS noise, can be very easily recognized from patterns in the XY plane. The RTS noise parameters as: the number of levels, amplitude and relation between mean times $\overline{\tau_u}$ and $\overline{\tau_d}$ can be evaluated from the patterns. The process of recognition is not a time-consuming procedure. The time required for taking a decision is a little longer than the time of data acquisition.

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REFERENCES

[1] J. Cichosz, A. Szewczyk, and A. Konczakowska, “The virtual instrument for RTS noise detection in semiconductor devices by Noise Scattering Pattern method”, *Proc. IV State Conference on Electronics KKE’2005*, (2005), (in Polish).

[2] J. Cichosz and A. Szatkowski, “The method for burst noise detection, particularly in semiconductor devices”, *Patent Application* P-375610, Polish Patent Office, 2005, (in Polish).

[3] J. Cichosz and A. Szatkowski, “Noise scattering patterns method for recognition of RTS noise on semiconductor components”, *Proc. of 18th Inter. Conf. on Noise and Fluctuations – ICNF 2005*, Salamanca, Spain, 673–676 (2005).