Modern instruments and technologies for measuring random signal characteristics

I I Sytko
Saint-Petersburg Mining University, 2, 21st Line V. O., St. Petersburg, 199106, Russia
E-mail: ivan-sytko@yandex.ru

Abstract. Based on modern computer technologies developed by National Instruments, a virtual device has been developed to adjust, control and study noise characteristics of various radio-electronic devices. Examples of distribution laws for random signals based on smoothness or sharpening, asymmetry and uncertainty were provided. It is shown that the method identifies the laws of distribution of random signals in comparison with other methods, and the virtual instrument technology and the electronic device with a data acquisition board monitor the technical state of electronic devices by their noise characteristics.

1. Introduction
Probability measuring instruments are widely used: various electronic devices influenced by random noise; dynamic characteristics of automatic control and regulation systems according to their response to random influences; noise-resistant electronic equipment; telemetry information processing quality; indicators of detection quality and measurement of parameters of weak signals against natural and artificial interference; means of technical diagnostics and control of the technical condition of electronic devices.

Methods for determining the probabilistic characteristics of random signals are based on the probability density curve displayed on the indicator screen, the distribution law, the average value and the rms value. The common name for such measuring instruments is instruments for studying probabilistic characteristics of random processes. All known measurement methods do not ensure simultaneous operational control of smoothness, sharpening, asymmetry and uncertainty, as well as identification of the probability distribution law of random signals.

The practical solution to the problem of the operational measurement of the probabilistic characteristics of random signals, taking into account metrological requirements, creates prerequisites for more widespread use of these measuring instruments in various industries.

The operational measurement of probabilistic characteristics of random signals taking into account metrological requirements is an urgent task.

2. Purpose of research
The article aims to develop mathematical models for measuring probabilistic characteristics of random signals, as well as hardware-software based on computer technologies of virtual instruments by National Instruments (NI). Procedures for identifying the laws of probability distribution using information about second and higher order moments were developed; characteristics of uncertainty were identified; a working model was built, and the scope of its application was determined.
3. Materials and methods

A priori and a posteriori information about counterexcess, asymmetry and entropy coefficient is used as signs for determining the type of symmetric distribution, for example, Beta, Nakagami, Gamma and Rayleigh [1–3]. The issues of measuring the characteristics of random signals are discussed in [4–6].

It is always difficult to identify the type of the distribution law with a limited observation time [7–8]. To identify the laws of distribution of random signals, the counterexcess, the asymmetry, and the entropy coefficient are used [3, 5]. The analytical expressions of the parameters that are used to identify the laws of probability distribution are given in Table 1.

The results of computer calculations in the Mathcad environment showed that completely different symmetric distribution laws can have the same values of counterexcess (from 0.05 to 0.882) and the entropy coefficient (from 0.09 to 2.066) and overlap in the areas of flat-top and peaked distributions. Symmetric distributions have a zero asymmetry.

For the asymmetric Beta, Nakagami, Gamma, and Rayleigh distribution laws, the counterexcess values are vary from 0.327 to 0.655, the entropy coefficient varies from 1.288 to 3.458 and the asymmetry varies from –0.51 to –2.015. For example, in the Beta distribution, the counterexcess values vary from 0.628 to 0.655, the entropy coefficient varies from 3.268 to 3.458 and the asymmetry varies from –0.51 to –0.071 and from 0.071 to 0.51 at $\beta = 1.5–3$ and $\alpha = 3$, and $\alpha = 1.5–3$ and $\beta = 3$.

### Table 1. Analytical expressions of the random signal distribution parameters

| No | Distribution parameter | Analytical expression |
|----|------------------------|----------------------|
| 1  | Counterexcess          | $\chi = \frac{\int (x-x_0)^2 p(x) dx}{\int (x-x_0)^2 p(x) dx}$ |
| 2  | Asymmetry              | $S = \frac{\int (x-x_0)^3 p(x) dx}{(\int (x-x_0)^2 p(x) dx)^{3/2}}$ |
| 3  | Entropy coefficient    | $K_\alpha = \frac{\exp(-\int p(x)\alpha np(x) dx)}{2\int (x-x_0)^3 p(x) dx}$ |

The mathematical model, the graph of the probability distribution density, the shape parameters $\alpha$ and $\beta$, as well as the values of counterexcess, entropy coefficient and asymmetry of Beta and Nakagami distributions were analyzed in [5–6].

The law of random process distribution can be determined from the measured values of counterexcess, the entropy coefficient and the asymmetry [4–5]. The shape of the Beta density curve of the probability distribution depends on the shape parameters $\alpha$ and $\beta$, which in turn are sensitive to the asymmetry. The dependence of the parameter of the shape $\beta$ on the asymmetry $S$ for the shape index $\alpha = 3$ Beta distribution and negative asymmetry is shown in Fig. 1, a. At the positive asymmetry, the dependence of the shape parameter $\alpha$ on the asymmetry $S$ for the shape index $\beta = 3$ is shown in Fig. 1, b.

The mathematical model of the functional dependence of the shape parameter $\alpha$ ($\beta$) of the Beta distribution at $\beta = 3$ ($\alpha = 3$) is as follows

\[ \alpha = 3 \times \exp(-1.39 \times S) \quad (1) \]

\[ \beta = 3 \times \exp(1.39 \times S) \quad (2) \]
Thus, after determining the Beta distribution in accordance with expression (1), the shape parameters \( \alpha \) and \( \beta \) are determined depending on the asymmetry.

\[
\begin{align*}
\alpha &= 0.394 - 127.987 \chi + 135.135 \chi^2 \\
\beta &= 3
\end{align*}
\]

**Figure 1.** The dependence of the Beta distribution shape parameters on the asymmetry: a – at the shape parameter \( \alpha = 3 \); b – at the shape parameter \( \beta = 3 \)

The dependence of the shape parameter of the Nakagami distribution on the counterexcess with a scale parameter \( \beta = 1 \) is shown in Fig. 2.

The mathematical model of the functional dependence of the shape parameter \( \alpha \) of the Nakagami probability distribution on the counterexcess value at the scale parameter \( \beta = 1 \) and the range of asymmetry changes from 1.574 to 1.645 is as follows

\[
\alpha = 30.394 - 127.987 \chi + 135.135 \chi^2
\]  

(3)

Thus, after determining the Nakagami distribution law in accordance with expression (3), the shape parameter is determined. Computer calculations in the Mathcad environment showed that the counter-excess, the entropy coefficient, and asymmetry values for the Nakagami, Gama, and Rayleigh distributions overlap which complicates the hardware characteristics of random signals.

4. Experimental results and discussion

The studies were carried out using the NI LabVIEW 2012 programming environment and real noise recordings of electronic devices [9 and 10].

To conduct experimental studies, a virtual meter (VM) of probability characteristics was developed; Its structural diagram is shown in Fig. 3a, and the view of the front panel (F) is shown in Fig. 3b.

The meter contains: normalizing amplifier (NU) – 1; measuring channel for the the mean square value (MC MSV) – 2; asymmetry measurement channel (AMC) – 3; measuring channel for the probability distribution density and the entropy coefficient (MC PDD and EC) – 4; measuring channel for the counterexcess (MC CE) – 5; measuring channel for the parameters of the distribution form (MC PFR) – 6; decision making unit (DMU) – 7; indicator (I) – 8.

**Figure 2.** The dependence of the Nakagami distribution shape on the counterexcess
Experimental and metrological studies of measurements of the parameters of random signals and identification of the type of probability distribution were carried out and verified by semi-natural modeling on a personal computer using real-life recordings of radio electronic devices (Table 2).

The VM identifies the following types of symmetric distributions: uniform, triangular, arc-sinusoidal-I, arc-sinusoidal-II, arc-sinusoidal-III, trapezoidal-I, trapezoidal-II, trapezoidal-III, antimodal-I, antimodal-distance-II, exponential two-way exponent 1/4, two-way exponential with an exponent of 1/3, two-way exponential with an exponent of 1/2, two-way exponential with an exponent of 7, Laplace and normal, asymmetric Beta, Nakagami, Rayleigh, Gamma distributions. The indicator displays a graph of the distribution curve, as well as information about the type and distribution parameters.

**Conclusion**

It was shown that the probability characteristics meter identifies 16 types of symmetric distributions, 5 types of asymmetric distributions, measuring 7 parameters; the probability of identifying the type of distribution is not less than 0.95, and the measurement accuracy of the parameters is not less than ±1 %.

The accuracy of measurements and identification of the type of distribution increases with increasing time of observation of a random signal. The results with the known probabilistic characteristics of noise
establish a relationship between the results of measurements and identification of the data of the device measuring probabilistic characteristics and real probabilistic characteristics of noise.

Table 2. Experimental studies of random signals

| Type of distribution | Oscillogram of distribution and a random signal |
|----------------------|-------------------------------------------------|
| Normal               | ![Oscillogram of distribution and a random signal](image) |
| Gamma                | ![Oscillogram of distribution and a random signal](image) |
| Even                 | ![Oscillogram of distribution and a random signal](image) |

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