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SOME APPROACHES TO ASSESSING THE QUALITY OF MASKING NOISE INTERFERENCE OF SPATIAL NOISE GENERATORS

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ABSTRACT

The article discusses the characteristics of spatial electromagnetic noise generators and the formation of a broadband noise signal. It also describes a number of known methods and methods for assessing the quality of masking noise interference and their differences. Different approaches to measuring masking noise when evaluating its quality are proposed. The first method is based on the measurement of the instantaneous values of the amplitudes of the noise signal and the calculation of the entropy coefficient based on this method.

The second method involves searching for correlation of masking noise signals of noise generators in different frequency subbands. The third approach is to use statistical and (or) graphical methods (tests) for randomness. The completeness and objectivity of assessing the quality of masking noise interference from spatial noise generators will be achieved by combining all the methods.

Keywords: *noise generators, masking noise, TEMPEST, noise quality rating, electromagnetic radiation*

1. INTRODUCTION

Currently, electronic means are used in almost all spheres of human life, from simple communications to ensuring the security of the state. However, the use of electronic devices and computer technology carries a large number of threats to information security. The basis for solving this problem is the protection of information in the field of optics, electronics, radio engineering, acoustics, and other sciences.

The main and at the same time one of the most dangerous technical channels for information leakage at information objects is the channel of spurious electromagnetic radiation and interference (TEMPEST). Such a channel of information leakage is called electromagnetic [1-6].

Scientists have been dealing with TEMPEST for the last 50-70 years. On this subject, there are many works, standards and regulatory documents of different countries [7-42].

Protection of electronic means (EM) of processing and transmitting information from leakage through TEMPEST channels is achieved by using passive and active protection methods. Passive protection methods include shielding, grounding, interlocking and filtering, and active protection by spatial systems of electromagnetic noise and simulation (masking) interference [3, 40, 43].

The use of passive EM protection methods is the preferred method, since there are no problems with electromagnetic compatibility and detection features during their use of such devices.

However, the use of passive EM protection methods is not always possible due to the complexity of their implementation, high cost, the need for additional development work, etc.

In such cases, active protection techniques are used which reduce the signal/noise ratio at the input of the receiving device and the means of exploration and hence the monitored area for EM [1].

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Currently, energy and non-energy active protection methods are distinguished. The non-energetic (statistical) method of active masking consists in the radiation of a special masking signal (noise) with a spectrum similar to the spectrum of informative TEMPEST EM. The spectral density of masking interference should be higher than the spectral density of TEMPEST, and its level should not exceed the levels of TEMPEST [3, 40].

The difficulty in implementing the non-energy protection method lies in the need to use pulses of random amplitude, similar in shape and time-correlated radiation with pulses of informative TEMPEST. In this case, the exact determination of all informative TEMPEST for each EM sample and the creation of an individual simulator of masking interference for this sample (or identical EM) are required. As a rule, imitators or jammers are used to protect personal computers.

The essence of the energy method is the formation and emission into the surrounding space in the immediate vicinity of the operating ES of a masking broadband noise signal ("white noise") in the entire frequency range of informative TEMPEST with a spectral level exceeding the levels of these TEMPEST.

By electromagnetic noise (electromagnetic interference, radio noise, radio interference, active masking interference) is meant a time-varying electromagnetic phenomenon that does not contain information and can be superimposed on or combined with a useful signal. In the context of this article, they are intended to worsen or distort the normal operation of the enemy's electronic equipment. Active masking interference creates a background at the input of the enemy's receiver, which makes it difficult to detect informative TEMPEST, their recognition, and the determination of parameters [44, 45].

It follows that the use of spatial electromagnetic noise generators (NG) should prevent or lead to the impossibility of intercepting informative TEMPEST for their subsequent analysis and restoration of the initial information, or significantly complicating process.

The objectives of this work are:

- definition of the main characteristics of the NG;

- a review of existing methods for assessing the quality of masking noise interference and identifying their shortcomings;

- development of our own method for assessing the quality of masking noise interference;

- a description of the methods for measuring masking noise interference;

- determination of the quality of masking noise interference of some NG;

- search for correlation of noise signals and the use of statistical methods (tests) for randomness as alternative methods for assessing the quality of masking noise interference.

2. SPATIAL ELECTROMAGNETIC NOISE GENERATORS

Currently, a large number of NG with various technical characteristics and type of execution are presented on the market [1, 46]. Noise generators come in the form of a separate device or as a PCI card for a personal computer. NG usually consists of a broadband signal generator and one or more antennas.

The main characteristics of GS include [1, 46,]:

- range of generated noise frequencies (operating frequency range);

- noise power spectral density;

- suppression ratio;

- protective attitude;

- noise structure (entropy coefficient of noise quality, entropy of the probability density of the instantaneous values of noise amplitudes, entropy power of real noise);

- type of radiated interference (noise, pulse, synchronous, signal-like, coded, broadband, deterministic, etc.);

- level of generated noise (by electric and magnetic component of the electromagnetic field);

- dynamic range of output signal adjustment;

- type of antennas (by electric field, by magnetic field);

- antenna polarization (vertical, horizontal);

- antenna parameters (directional coefficient, gain, side lobe level or background level);

- lack of exposure to acoustoelectric transformations;

- lack of exposure to high-frequency imposition;

- lack of exposure to high-frequency radiation;

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- compliance of the level of generated noise with the permissible values established by regulatory documents (for electromagnetic compatibility or industrial radio interference, sanitary and epidemiological requirements, etc.).

At the same time, the goal of spatial electromagnetic noise is considered to be achieved if the ratio of the information signal/noise at the input of the receiver located on the border of the controlled area of the object does not exceed some acceptable value calculated by special methods for each frequency of the information TEMPEST EM (Figure 1) [1, 3, 4, 40, 47].

Also, some manufacturers of NG in the description of NG indicate the following information [46]:

- quality factor of the electromagnetic field of noise;

- spectral radiation density;

- the values of the spectral density of the magnetic and electrical components of the normalized electromagnetic noise field in decibels to 1 μV/(m^kHz) generated by the generator at a distance of l m;

- spectral voltage density of the noise signal;

- spectral density of the electric field of noise;

- spectral density of the magnetic field of noise;

- signal level at a load of 50 ohms in the entire frequency range;

- coefficient of directional action of the radiating antenna;

- polarization coefficient of the radiating antenna;

- entropy (normalized) noise quality factor;

- stability of the parameters of the electromagnetic field of noise in the conditions of round-the-clock operation;

- rms spectral density of the electromagnetic field of noise;

- automatic control of NG performance;

- normalized spectral density of interference;

- the rms spectral density of the tension generated by the NG at a distance of 1 m from the emitter.

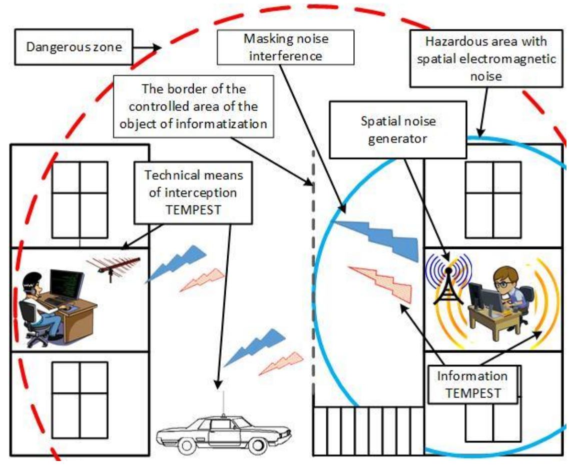

Figure 1: Spatial Electromagnetic Noise

3. SCHEMES FOR GENERATING A BROADBAND NOISE SIGNAL

One of the most important requirements for NG is the wide-width spectrum of the noise signal and the high uniformity of the spectral density of the noise power. For this reason, noise generators mainly use three schemes for generating a broadband noise signal [44]:

1)classic method of generating direct noise interference. In this case, it is possible to use several noise sources operating in different frequency ranges. Noise resistors, diodes, transistors, Zener diodes and other elements forming noise similar in their characteristics to "white" can be used as the primary sources of noise in such NG;

2) use of a digital noise generator, the "digital" noise of which is a temporary random process that is close in its properties to the process of physical noise and is called a "pseudo-random process". Such generators form chaotic (pseudorandom) sequences of binary symbols and convert them into a sequence of rectangular pulses of pseudorandom duration with pseudorandom intervals between them. Noise sources in such NG can be microband elements, various integrated circuits, digital signal processors, programmable logic integrated circuits, and other elements [52-55];

3) use of a stochastic or chaotic method of generating a noise signal [52, 56]. The signal from the harmonic signal generator is fed to a power amplifier operating in a non-linear mode and loaded onto a non-autonomous non-linear dynamic system in the form of a parallel non-linear oscillatory circuit in which the amplified signal is converted into stochastic noise.

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At the same time, noisy informative TEMPEST can be filtered and in case of poor-quality masking, the enemy can gain access to the protected information [57].

In NG, a scheme for dividing the entire frequency range into subbands using a frequency multiplier can be used to generate a broadband noise signal [1, 58]. In such cases, the generated noise in different subbands will be correlated, i.e. have the same parameters except for the frequency.

This circumstance will allow the subtraction of noise in different ranges in which informative TEMPEST has a large amplitude (power) and the further restoration of the protected information. It should be noted that the presence of additional factors in the form of repeatability of the informative signal, the level of its amplitude (power), etc. is also important [59].

In addition, in the absence of complete randomness of the generated noise, statistical analysis methods are used, through which it is possible to identify patterns of noise formation, including their frequency.

4. ASSESSING THE QUALITY OF THE NOISE SIGNAL GENERATED

In this regard, an important problem arises related to assessing the quality of the noise signal generated by NG.

To determine the estimated characteristics of masking noise, information (non-energy or statistical) and energy methods are used. Information methods consider the statistical parameters of noise signals in the time domain and directly determine the numerical coefficient of noise quality. Based on the calculation of the mathematical expectation, variance, and entropy of the instantaneous values of time samples and their envelopes, the degree of approximation to some reference distributions is calculated. They are aimed at finding the degree of uncertainty in the instantaneous values of noise signals, expressed, for example, through the entropy coefficient of quality of masking noise. When using this method of active masking, NG emits a special masking signal (interference) with a spectrum similar to that of informative TEMPEST. In this case, the spectral density of the masking noise should be higher than the spectral density of the TEMPEST, and its level should not exceed the levels of the TEMPEST.

The energy method for protecting information uses the postulate of the need for excess noise energy over TEMPEST in the entire frequency range. Therefore, in order to check the noise quality, integral indicators are used that take into account the excess of the noise level over the level of the informative signal [40, 57].

4.1 Methods For Assessing The Quality Of Masking Noise

Currently, a number of methods for assessing the quality of masking noise are known:

1) a method for assessing the quality of masking frequency-modulated noise interference [60];

2) a method for assessing the quality of masking amplitude-modulated noise interference [61];

3) a method for assessing the quality of masking direct noise interference [62];

4) a method for assessing the quality of masking acoustic (vibroacoustic) noise [63];

5) a method for assessing the quality of masking noise [64];

6) the use of a universal indicator for assessing the effectiveness of masking and imitation radio interference [47].

Figures 2-8 shows the algorithms of these methods for assessing the quality of masking noise.

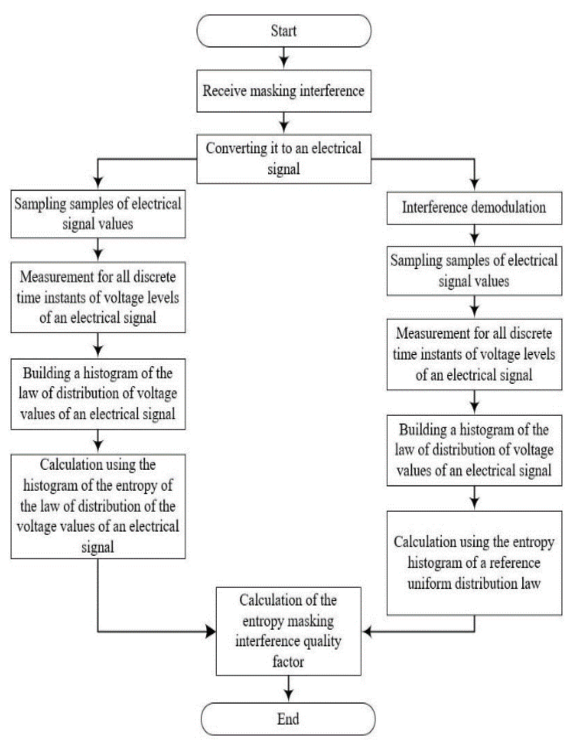

Figure 2: The Algorithm For Evaluating The Quality Of Masking Frequency-Modulated Noise Interference

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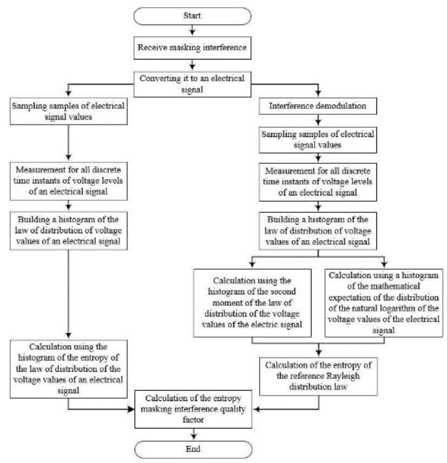

Figure 3: The Algorithm For Evaluating The Quality Of Masking Amplitude-Modulated Noise Interference

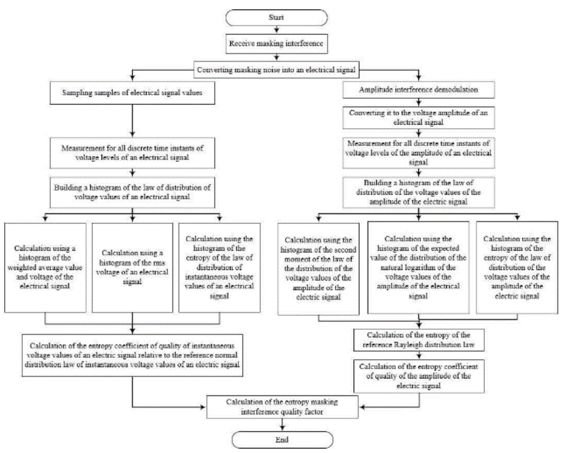

Figure 4: The Algorithm Of The Method For Assessing The Quality Of Masking Direct Noise Interference

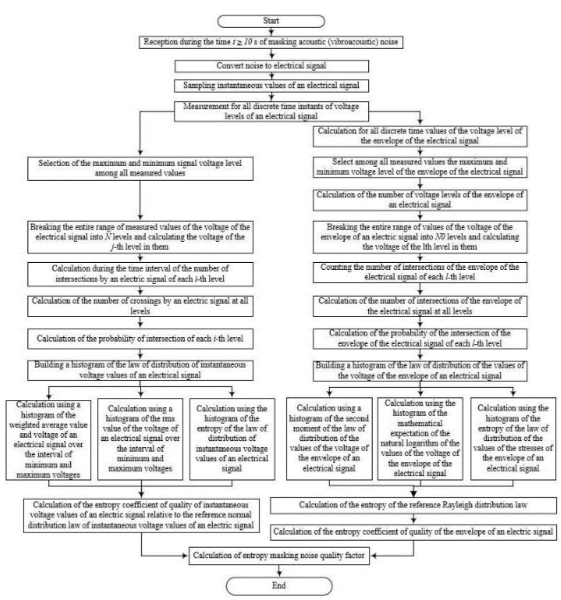

Figure 5: The Algorithm For Evaluating The Quality Of Masking Acoustic (Vibroacoustic) Noise

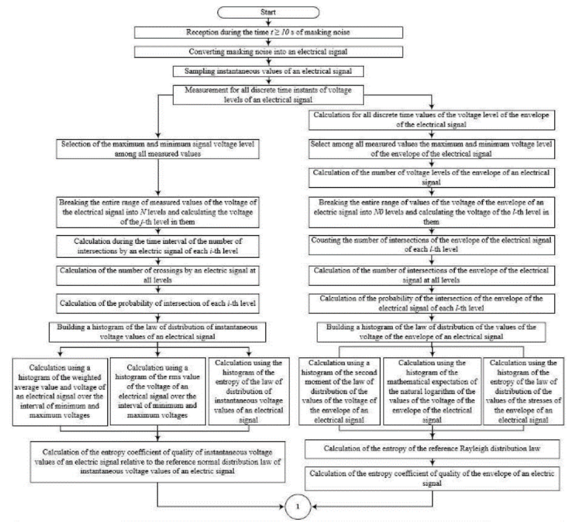

Figure 6: The Algorithm For Evaluating The Quality Of Masking Noise (Part 1)

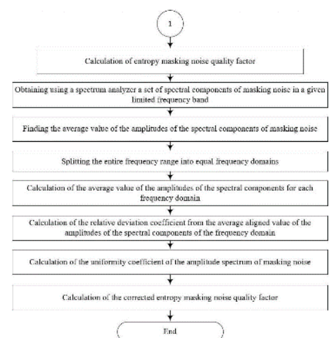

Figure 7: The Algorithm For Evaluating The Quality Of Masking Noise (Part 2)

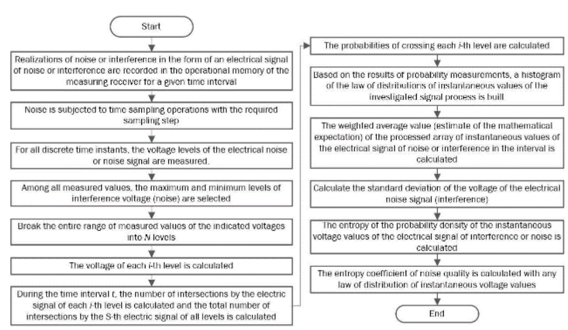

Figure 8: Algorithm For Applying A Universal Indicator For Evaluating The Effectiveness Of Masking And Imitation Radio Interference

4.2 Entropy Coefficient Of Quality Of Masking Noise

The main criterion for evaluating the quality of noise in all these methods is the entropy coefficient of quality of masking noise (interference). The entropy coefficient is calculated based on the results of reception (measurement) for a certain period of

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time of the noise signal (for statistics) and its conversion to voltage with further mathematical operations.

The proposed methods accept instantaneous voltage values of the noise signal with their discretization in time. Further, to calculate the entropy coefficient of quality of the masking noise, the RMS value of the voltage of the electric signal, the second moment of the distribution law of the voltage values of the amplitude of the electric signal, the mathematical expectation of the natural logarithm of the voltage values of the electric signal and other parameters are used.

Thus, the following basic parameters are used to calculate the entropy quality factor of masking noise (interference):

- the RMS value of the voltage of the electrical signal;

- the entropy of the law of distribution of instantaneous voltage values of an electrical signal (its envelope);

- the second moment of the law of distribution of the voltage values of the electrical signal (its envelope);

- the mathematical expectation of the natural logarithm of the voltage values of the electrical signal (its envelope).

The first four methods for assessing the quality of noise involve the evaluation of a certain type of noise interference (frequency-modulated, amplitude-modulated, direct noise, acoustic (vibroacoustic)). Below we consider the frequency-modulated, amplitude-modulated, and direct noise interference.

The method [64], when calculating the entropy coefficient, considers the uniformity coefficient obtained by a set of spectral components of masking noise in a given limited frequency band.

The method [47] involves taking into account the energy, probabilistic and information-energy properties of interference by applying indicators that take into account useful signals and standard white Gaussian noise.

4.3 Frequency-Modulated, Amplitude-Modulated And Direct Noise Interference

From the theory of protection against interference, it is known that the voltage of the frequency-modulated noise interference at the input of the receiver can be represented as follows:

$$u_N(t) = U_N \cos\left[2\pi f_0 t + 2\pi \int_0^t \Delta f(\xi) d\xi + \varphi_0\right] \quad (1)$$

where U_N – vibration amplitude; f_0 – average value of high frequency; $\Delta f(t)=k_F\Delta U_{mod}(t)$ – random change in vibration frequency; k_F – steepness of modulation characteristic.

One of the main parameters of frequency-modulated oscillations is the effective value of the frequency deviation index, equal to the ratio of the effective value of the frequency deviation to the effective value of the spectrum width of the modulating voltage.

The quality factor of the frequency-modulated noise interference to a large extent depends on the ratio between the width of the interference spectrum and the passband of the receiver of the suppressed electronic means [65].

Amplitude-modulated noise interference is an undamped harmonic vibration, amplitude-modulated noise. The interference signal at the input of the receiver can be recorded as follows:

$$u_N(t)=U_N[1+k_a\Delta U_{mod}(t)]\cos\omega_0 t \quad (2)$$

where k_a – steepness of transmitter's modulation characteristic; $\Delta U_{mod}(t)$ – modulating voltage that comes from the noise generator.

If the modulating noise has a constant spectral density ranging from zero frequency to F_{max}, then the spectral density of the modulated oscillation will also be constant, and the width of the spectrum is:

$$\Delta F_N = 2F_{max} \quad (3)$$

The interference spectrum includes oscillations at the carrier frequency and side components [65].

Forward noise is closer to normal noise. Two ways of creating noise interference can be applied. The first of these is the use of a microwave generator. The oscillations formed at the output of such a generator are amplified in power and radiated into space. Microwave discharge lamps, for example, are suitable as primary noise sources. The noise generator consists of a gas discharge tube, a segment of a transmitting high-frequency line, and a matching device. Depending on the type of high-frequency line used, the generators are coaxial and waveguide. Waveguide-type noise generators are created for waves from 0.2 to 10 cm, and coaxial noise from 10-12 to 120-140 cm. Gas discharge tubes are very wide-range sources of high-frequency noise and are characterized by high uniformity of the spectrum.

The second way to create direct noise interference is to use the heterodyning method to

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transfer the noise of a low-frequency generator to the high-frequency region. At low frequencies, the role of primary noise sources is played by direct-heating diodes, thyristors in a magnetic field, and photoelectronic multipliers.

The quality factor of direct noise interference would be equal to unity if it were not for the amplitude-limited oscillation that occurs in any physically feasible amplifier path. The amplitude limitation leads to a change in the interference spectrum and the law of distribution of its instantaneous values, as a result of which the quality of the interference decreases [65].

A typical block diagram of the formation of direct noise interference from the theory of electronic warfare is shown in Figure 9 [66].

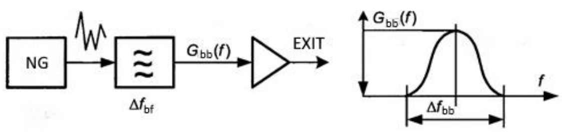

Figure 9: The Formation Of Noise Interference

NG generates noise vibration with a wide uniform spectrum. The band-pass filter generates a Gaussian noise at the output with a power spectrum $G_N(f)$ in the band$\Delta f_{bf} = \Delta f_{bb}$. After amplification by power at the output, a Gaussian direct noise interference with the energy spectrum is created [66]:

$$G_N(f) = G_0 K_g K^2(f) \quad (3)$$

where $G_0 = const(f)$ – spectral noise density at the NG output; K_g – output amplifier gain;$K(f)$ – amplitude-frequency characteristic of the forming band-pass filter.

By integrating the energy spectrum $G_{bb}(f)$, we can find the output power of direct noise interference [66]:

$$P_{bb} = \int_0^\infty G_{bb}(f)df = G_0 K_g K_0^2 \Delta f_{bb} \quad (4)$$

whereK_0– resonant gain at the tuning frequency of the bandpass filter; Δf_{bb} – effective noise bandwidth determined by the passband of this filter.

Often, barrage noise interference with a spectral width Δfbb of up to 500 MHz is estimated by the maximum spectral density [66]:

$$G_{max} = G_{bb}(f_0) = \frac{P_{bb}}{\Delta f_{bb}} = G_0 K_0^2 K_g \quad (5)$$

4.4 Disadvantages Of Existing Methods For Assessing The Quality Of Masking Noise Interference

Each of the methods for assessing the quality of masking noise interference indicated in Section 4.1 has some drawbacks [67].

The disadvantage of the methods described in [60] and [61] is that all calculations are carried out in the time domain and therefore there is no possibility of taking into account the influence of the shape of the envelope of the frequency spectrum on the quality of noise interference.

The disadvantage of the method [62] is the inability to take into account the influence of the shape of the envelope of the frequency spectrum on the quality of noise interference.

It is also necessary to indicate that in methods [60], [61] and [62] for evaluating the quality of masking noise interference, it is proposed to use an X6-4 type correlation characteristics meter (Figure 10).

Figure 10: The Device For Research Of Correlation Characteristics X6-4

Devices of type X6-4 are designed for [68]:

- measurement of normalized functions of autocorrelation and cross-correlation;

- selection of a periodic signal from noise;

- measurement of probability distribution density, probability distribution function and characteristic function;

- measuring the relations of levels that make up the power spectrum of stationary ergodic random processes.

Fields of their application:

- investigation of the identity of two complex signals;

- investigation of nonlinear distortions of complex waveforms;

- separation of periodic signals from noise;

- investigation of the power spectrum of random signals.

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For discrete values of the correlation function, the following transformation algorithm is implemented:

$$S(k\Delta f) = \sum_{n=0}^{99} R(n\Delta t)F(n\Delta t)\cos 2\pi \frac{k}{m\tau} n\Delta t \qquad (6)$$

where k - is the number of the point in the spectrum; m – total number of spectrum points; n – correlation function point number; F($n\Delta t$) – "window" function.

However, X6-4 type meters, as well as other instruments designed to study the correlation characteristics (X6-3, X6-5, X6-8, X6-11/1, and X6-11/2) have long been discontinued. Accordingly, their use is not possible.

The disadvantage of the method [63] is the inability to take into account the influence of uneven amplitude spectrum of masking noise in a certain (final) frequency range when calculating the entropy quality factor, which can be characterized by dips and rises in certain areas of the frequency range.

In addition, the methods [60], [61], [62] and [63] involve the assessment of only a certain type of noise interference (frequency-modulated, amplitude-modulated, direct noise, acoustic (vibroacoustic)). This circumstance excludes the universal use of any of these methods independently. Their application requires a preliminary determination of the type of masking noise interference.

The prototype of the method [64] is the method [63]. However, in the method [64], it is additionally required to carry out measurements using a spectrum analyzer, the spectral components of the masking noise in a given limited frequency band. After that, it is necessary to calculate the average value of the amplitudes of the spectral components and the relative coefficient of deviation from the average aligned value of the amplitudes of the spectral components of a given frequency domain. Only after this is the entropy coefficient of quality of masking noise calculated.

In this regard, the method [64] is quite difficult to implement and time-consuming.

The disadvantage of the method [47] can be attributed to the need to supply to the input of the receiver, in addition to masking noise interference, a useful (information) signal. At the same time, it should be noted that the quality assessment of masking noise interference, as a rule, is carried out at the enterprises of the manufacturer or in the laboratories of certification bodies. In this case, it is not possible to supply EM information signals to the input of the receiver.

Also, in methods [64] and [47] for the use of spectrum analyzers is proposed. However, the measurement process itself is not described.

It should be noted that some parameters and indicators in the considered methods have differences in their designation or name, however, they mean identical operations or vice versa, the same designations are used for different parameters.

4.5 Alternative Method For Assessing The Quality Of Masking Noise Interference

The essence of the proposed methodology for assessing the entropy coefficient of noise quality is as follows:

1) by analyzing the spectrum of the noise signal generated by the NG, the frequency intervals of the spectrum are selected in which the most uneven frequency characteristic of the noise is observed. If several noise generation channels are used in a noise generator, then at least one such interval should be selected in each of them;

2) the spectrum analyzer is sequentially tuned to the center frequency of each of the frequency intervals. The electromagnetic noise signals received by the spectrum analyzer are converted into electrical signals and transmitted at an intermediate frequency to an oscilloscope that performs the function of an analog-to-digital converter.

3) the instantaneous values of the amplitude of the noise signal in the *.csv format from the oscilloscope are sent to the computer for further processing and calculation of the entropy coefficient of noise quality.

The following is the procedure for calculating the entropy coefficient of noise quality according to the statistics of instantaneous amplitudes of the noise signal generated by NG:

1. Statistics are collected on the instantaneous values of the amplitudes of the noise signal with a volume of at least 10 million elements.

2. The statistics are used to construct the statistical series and calculate the mean value, the variance and the mean quadratic deviation.

3. The values of the statistical series are grouped according to the selected non-overlapping intervals. It is recommended that all intervals be chosen equal in width.

4. After selecting the intervals, the number n_j of sampled values falling into the corresponding intervals is calculated. Based on the obtained values

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of n_j, the corresponding relative frequencies p_j and the relative densities of sampled values in each interval σ_j are calculated. The sum of the relative frequencies p_j must be equal to one.

5. For cases when in any of the intervals n_j is equal to 0, you should combine this interval with the interval *(j-1)* or *(j+1)*, recounting the relative frequencies and relative densities in the newly formed intervals, or change Δ so that with a new partition, at least one sample value x_j falls into each of the intervals.

6. Based on the obtained data, table 1 is compiled, which indicates the number of the interval (discharge) j, the boundaries of the discharge $[x_{j-1}; x_j]$, the number of the discharge n_j, the relative frequencies p_j and the relative densities σ_j of sampled values.

Table 1. Initial Data For Calculating The Entropy Coefficient Of Noise Quality.

Interval (discharge) number j	1	2	…	m
Discharge boundaries $[x_{j-1};x_j]$	$[x_0;x_1]$	$[x_1;x_2]$	…	$[x_{j-1};x_j]$
n_j value	n_1	n_2	…	n_m
Relative frequencies p_j	p_1	p_2	…	p_m
Relative densities σ_j	σ_1	σ_2	…	σ_m
Entropy of the discharge H_j	H_1	H_2	…	H_m
Noise signal entropy H				

Based on table 1, a histogram of the distribution of instantaneous voltage values of the noise signal is constructed.

7. For each digit of the histogram, the entropies H_j are calculated.

$$H_j = p_j \ln \sigma_j \qquad (7)$$

8. Next, the entropy of the noise signal H is calculated by the formula (8), the entropy power of the noise signal P_E by the formula (9) and the entropy quality factor of the instantaneous voltage values of the masking noise K_N is formula (10).

$$H = -\sum_{j=1}^{m} H_j \qquad (8)$$

$$P_E = \frac{e^{2H}}{2\pi e} \qquad (9)$$

$$K_N = \frac{P_E}{\sigma^2} \qquad (10)$$

The calculated value of K_N is compared with the normalized value of K_{NN} set for this type of NG.

The main advantage of the proposed method is its versatility, relative simplicity in its implementation and high reliability of the results.

4.6 The Need To Assess The Quality Of Masking Noise Interference

For clarity, the application of the method for assessing the quality of GS masking noise in Figure 11 shows the histograms of the distribution of amplitudes of the noise signal. For the top histogram, the entropy quality factor is 0.9, and for the bottom 0.7. The X-axis corresponds to the number of intervals, and the Y-axis corresponds to the number of sample elements in the interval. The low entropy coefficient of quality of the masking noise interference of the NG will not be able to ensure the security of the protected information.

A low entropy quality factor can be observed with insufficient quality of the noise source (noise diode, transistor, resistor, etc.) or in other cases. Such cases include the ability to control the output level of the NG, as well as the power supply of the NG with some boundary levels. For example, some manufacturers allow the power supply of an NG within 220 V ± 10% at a mains frequency of 50 Hz. This means that the power supply of the NG is possible in the range of 187-253 V. In some NG, when they were powered in the boundary values, a significant deterioration in the entropy quality factor was observed. This circumstance directly increases the risk of leakage information protected by the NG.

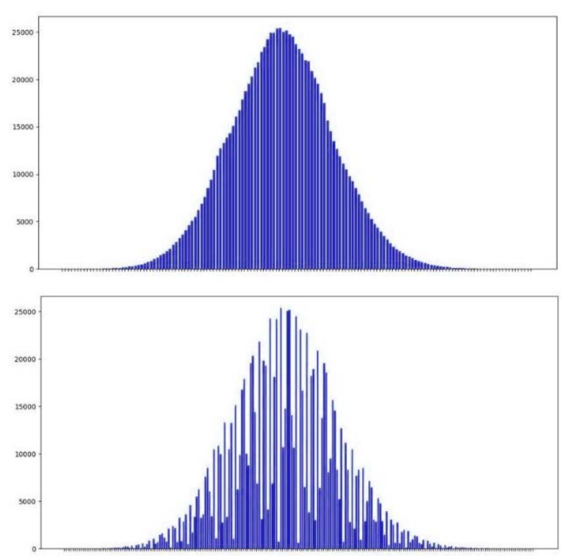

Figure 11: Histograms Of The Distribution Of Amplitudes Of The Noise Signal

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5. AUTOMATION OF CALCULATIONS BY AN ALTERNATIVE METHOD FOR ASSESSING THE QUALITY OF MASKING NOISE INTERFERENCE

Manual calculations using the proposed alternative method for assessing the quality of masking noise interference are a very time-consuming and lengthy process. This is due to the need to process a large number of values (at least 1 million elements).

In this regard, software was developed to implement automatic calculation of measurement results. The program consists of several functions and the calculation itself. The algorithm of the program is shown in figures 12-19.

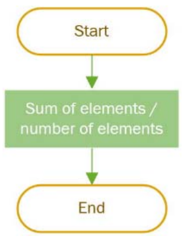

Figure 12: The Block Diagram Of The Function Of Finding The Average Value

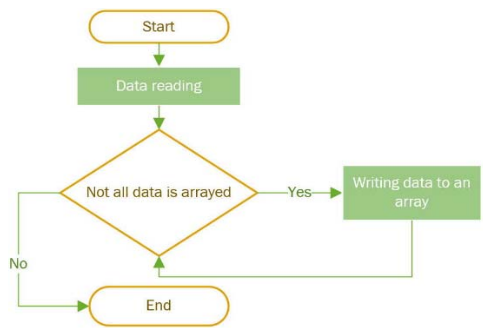

Figure 13: The Block Diagram Of The Data Reading Function

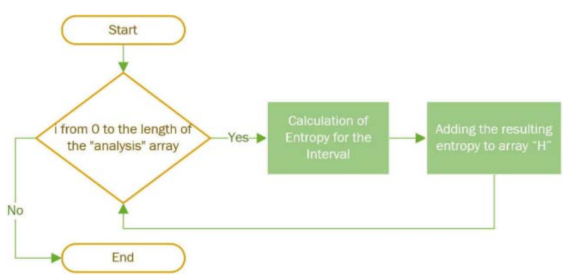

Figure 14: Entropy Calculation Function Block Diagram For Each Interval

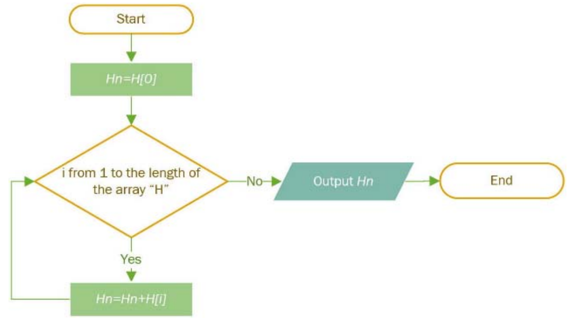

Figure 15: The Block Diagram Of The Function Of Calculating The Entropy Of A Masking Noise Signal

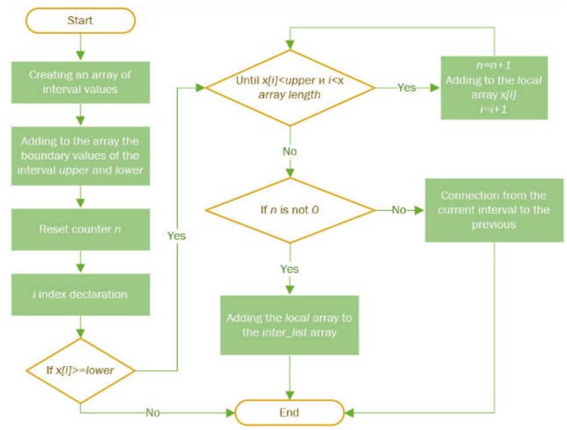

Figure 16: The Block Diagram Of The Function Of Dividing The Array Into Intervals

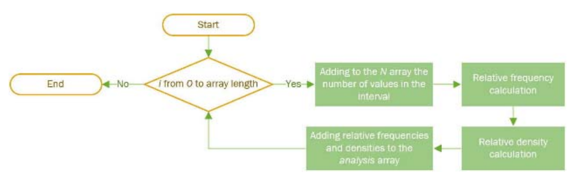

Figure 17: Block Diagram Of The Function Of Finding The Relative Frequency And Density For The Interval

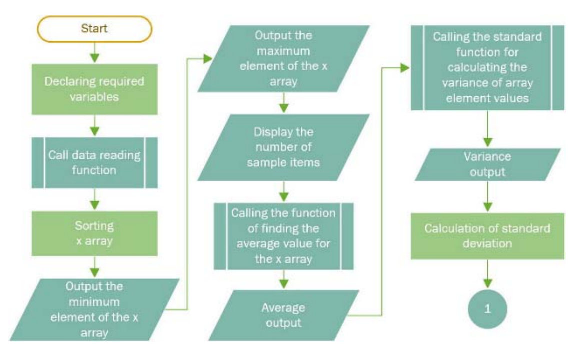

Figure 18: Block Diagram Of An Automated Calculation Program (Part 1)

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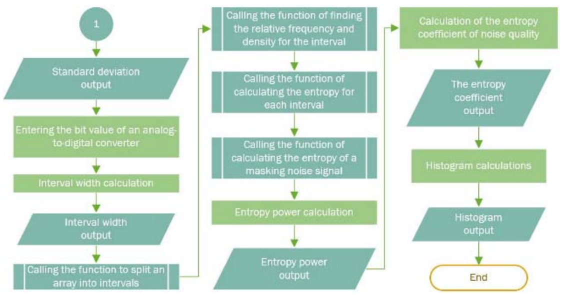

Figure 19: Block Diagram Of An Automated Calculation Program (Part 2)

Figure 20 shows an example of the result of the program.

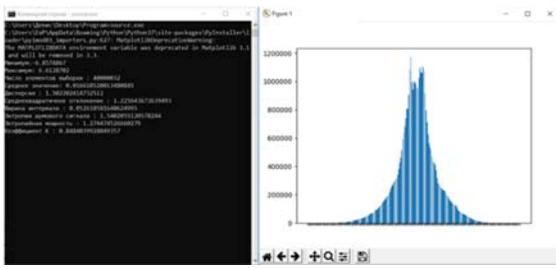

Figure 20: Results of the automated calculation program

6. CARRYING OUT MEASUREMENTS WITH FURTHER CALCULATION OF THE ENTROPY COEFFICIENT OF QUALITY OF MASKING NOISE

Taking into account the impossibility of using the X6 series instruments for the necessary measurements, it is considered advisable to use spectrum analyzers (or other measuring receivers), digital storage oscilloscopes, or mixed-signal oscilloscopes.

In this case, you should pay attention to the parameters of the selected measuring instruments: the range of operating frequencies and bandwidth.

If you select an oscilloscope with the necessary bandwidth of 2-3 GHz (the operating frequency range of the GSH) is possible, then for measurements on the air this will be an almost impossible task. This is due to the fact that even premium spectrum analyzers with the best features have less bandwidth. For example, Keysight UXA spectrum analyzers (N9040B) have a maximum bandwidth of 1 GHz (510 MHz in real-time), and the R & S®FSW 800 MHz (expandable to 5 GHz with an RTO2064 oscilloscope) [69, 70]. However, the cost of such devices is very high.

In this regard, in order to carry out measurements on the air using a spectrum analyzer, the GS operating frequency range will need to be divided into equal sub-bands that fit into the passband of the spectrum analyzer.

Carrying out measurements with a further calculation of the entropy noise quality can be carried out in two ways:

1) using a digital storage oscilloscope (a measurement stand diagram is shown in Figure 21). During measurements, the oscilloscope is connected to a special NG connector designed to measure the instantaneous values of the amplitudes of the noise signal or, in its absence, to the GS antenna output [71];

2) using a spectrum analyzer and a digital storage oscilloscope (a measurement stand diagram is shown in Figure 22). The electromagnetic noise signals received by the spectrum analyzer are transmitted to the oscilloscope at an intermediate frequency [72].

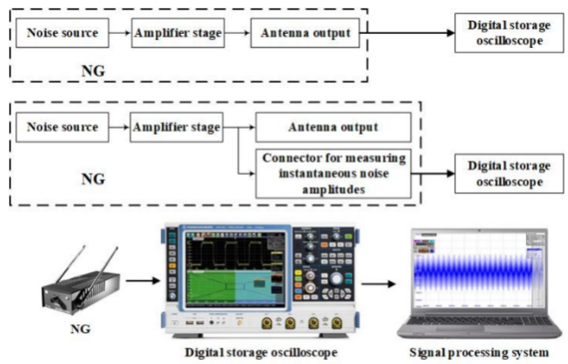

Figure 21: Schematic Of A Measuring Bench Using A Digital Storage Oscilloscope

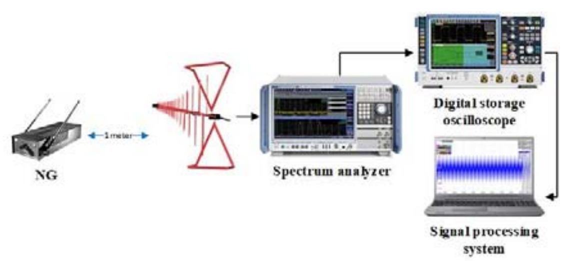

Figure 22: Schematic Of A Measuring Stand Using A Spectrum Analyzer And A Digital Storage Oscilloscope

The results of the ether measurements (using a spectrum analyzer) will be the most reliable.

In measurements using only an oscilloscope, the voltage values will be obtained from the GS connectors bypassing the antenna system, which makes its own changes to the generated noise.

In Figure 23 shows the waveforms of masking noise interference. In the top image, the oscillogram was obtained using a digital storage oscilloscope

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from the NG antenna output. In the bottom image, the waveform is obtained from a digital storage oscilloscope connected to a spectrum analyzer.

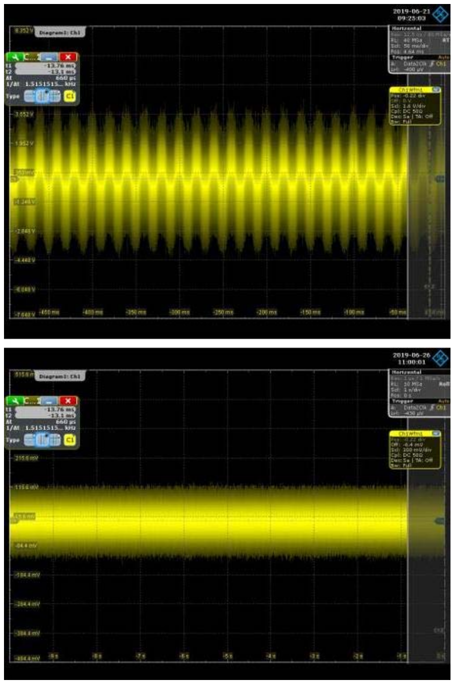

Figure 23: Oscillograms Of Masking Noise Interference

Figure 24 shows the waveform and spectrogram of noise signals with a bandwidth of 2 GHz and a sampling frequency of 2 MSa.

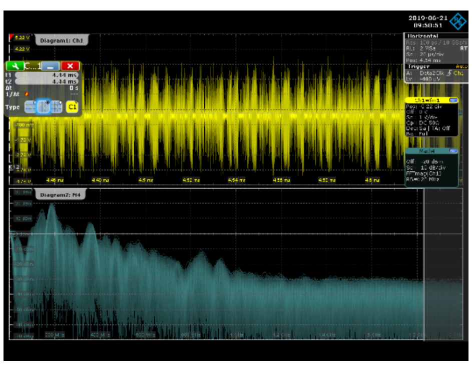

Figure 24: Oscillogram And Spectrum Of A Noise Signal

7. THE RESULTS OF PRACTICAL EXPERIMENTS TO ASSESS THE QUALITY OF MASKING NOISE INTERFERENCE BY AN ALTERNATIVE METHOD

The proposed method has been tested in measuring the entropy noise quality factor of GSh installed at computerization facilities: "LGSh-503", "Gnome-3", "Salyut 2000 B" and "Sonata-R2" (Figures 25-28).

Figure 25: Product "LGSh-503"

Figure 26: Product "Gnome-3"

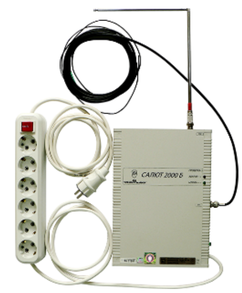

Figure 27: Product "Salyut 2000 B"

Figure 28: Product "Sonata-R2"

The tests were carried out using a laboratory complex consisting of:

- active measuring antenna AI-5.0;
- digital spectrum analyzer R&S FSW 8;
- Digital Storage Oscilloscope R&S RTO 1022;
- a signal processing complex based on a laptop.

Masking noise interference measurements were carried out according to the scheme depicted in Figure 22. Figure 29 shows the measuring stand.

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Figure 29: Measuring Stand

Figures 30-38 show the spectra of masking noise created by the noise generators “LGSh-503”, “Gnome-3”, “Salute 2000B” and “Sonata-R2”. Table 2 shows the calculated values of the entropy noise quality factor of these generators.

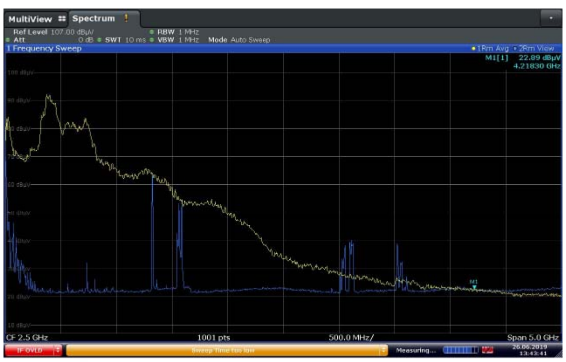

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Figure 30: The Spectrum Of Masking Noise Created By The Noise Generator "LGSh-503"

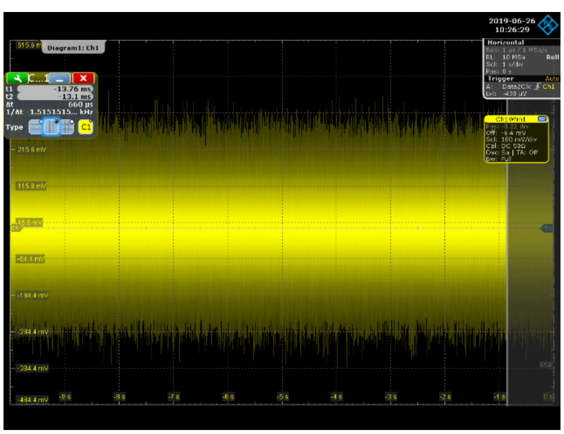

Figure 31: The Oscillogram Of Masking Noise Generated By The Noise Generator "LGSh-503"

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Figure 32: The Spectrum Of Masking Noise Created By The Noise Generator "Gnome-3"

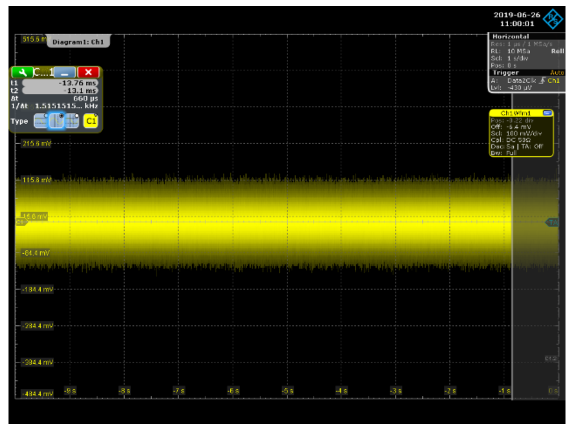

Figure 33: The Oscillogram Of Masking Noise Created By The Noise Generator "Gnome-3"

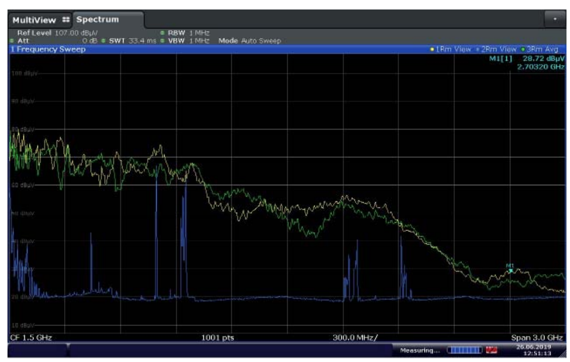

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Figure 34: The Spectrum Of Masking Noise Created By The Noise Generator "Salute 2000B"

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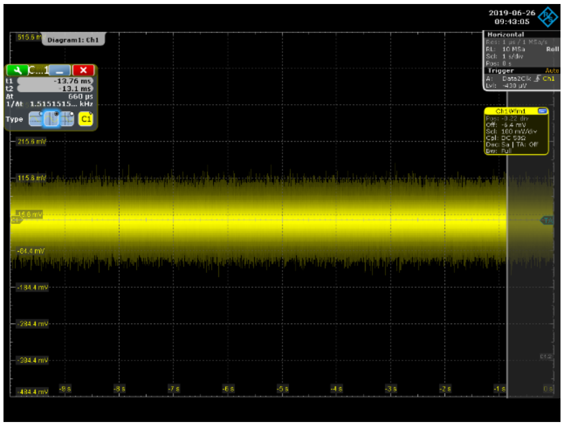

Figure 35: The OscillogramOf Masking Noise Created By The Noise Generator "Salute 2000B"

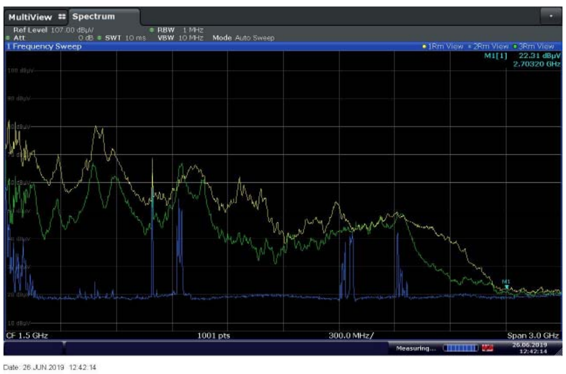

Figure 36: The Spectrum Of Masking Noise Created By The Noise Generator "Sonata-R2"At Minimum And Maximum Radiation Levels

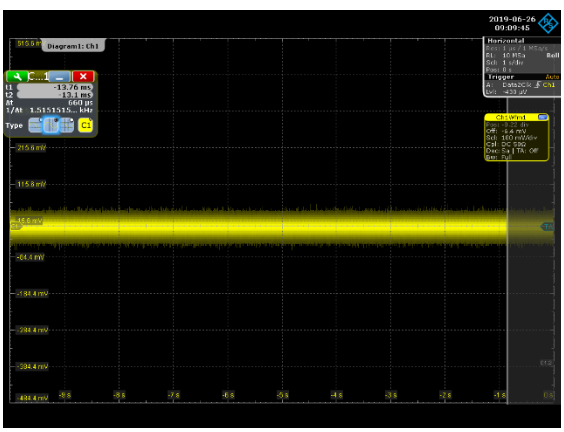

Figure 37: The OscillogramOf Masking Noise Created By The Noise Generator "Sonata-R2"At Minimum Radiation Level

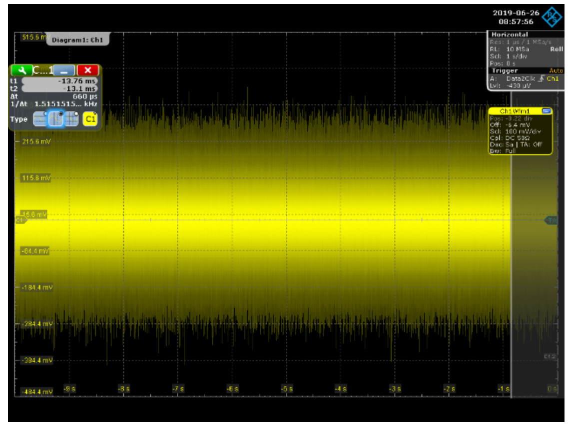

Figure 38: The OscillogramOf Masking Noise Created By The Noise Generator "Sonata-R2"At Maximum Radiation Level

The calculations were carried out using the developed automated calculation program. Due to the large amount of measured data (more than 1 million).

As can be seen from table 2, the measured values of the entropy noise quality coefficients generated by noise generators mainly correspond to their passport values.

Thus, the proposed method allows to measure the entropy coefficients of the quality of noise generated by noise generators of spatial electromagnetic noise systems without galvanic connection of measuring instruments to generators and ensures sufficient measurement accuracy.

Table 2: The Measured Values Of The Entropy Coefficient Of Noise Quality Of Noise Generators.

Type of noise generator	Spectrum analyzer tuning frequency, MHz	The Bandwidth of the spectrum analyzer, MHz	Radiation power	Measured Entropy Noise Quality Factor
LGSh-503	500	80	max	0,90
Gnome-3	500	80	max	0,97
Salyut2000B	500	80	max	0,96
Sonata-R2	500	80	min	0,88
			max	0,98

8. SEARCH FOR CORRELATION OF MASKING NOISE SIGNALS IN DIFFERENT FREQUENCY SUBBANDS

However, taking into account the rather large dimensions of the measuring instruments (spectrum analyzer, oscilloscope, measuring antenna with a tripod, computer for measuring control), the proposed methods for measuring noise quality are more applicable in laboratory conditions. For offsite events with measurements at the installation site of the NG (in real operating conditions), a compact and cheap tool will be acceptable.

Such a tool can be made based on digital SDR receivers. For example, SDRplay RSPduo, KerberosSDR, Coherent Multi-Tuner-Receivers, HackRF One SDR, or other similar.

Based on such receivers, it is possible to manufacture a universal device for evaluating the quality of NGs noise. Such a device will be able to implement the following methods for assessing the quality of noise interference:

- calculation of the entropy coefficient of quality according to the proposed combined method;

- search for noise correlation in different frequency subbands;

- use statistical and (or) graphical methods (tests) for randomness [67, 73].

To search (identify) the presence of a possible correlation of NGs noise, it is proposed to measure masking noise simultaneously in two or more frequency ranges and compare them with each other.

The need for such a procedure is due to the fact that the frequency range of masking noise in NG is divided into subbands. Each of the frequency subbands has its own channel for generating a noise signal or a frequency multiplier is used [1, 58].

In the case when the generated noise in different subbands will have the same parameters except the frequency, it can be subtracted in the ranges in which informative signals have a large amplitude (power) with further restoration of the protected information. In this case, the presence of additional factors is also important, such as the repeatability of the initial informative signal, its amplitude (power), etc.

9. THE USE OF STATISTICAL METHODS (TESTS) FOR RANDOMNESS

At the same time, it is considered possible to use graphical and statistical methods (tests) for randomness to evaluate noise quality (for example, NIST, TEST-U01, CRYPT-X, DIEHARD, etc.).

The graphical spectral test allows you to evaluate the uniformity of the distribution of bits in the sequence based on the analysis of the height of the emissions of the Fourier transform. To use it as a tool for assessing the quality of masking noise signals, it will be necessary to obtain a certain amount of the most detailed spectrum of masking noise signals (in graphical form) emitted by noise generators, which will be interpreted as some sequences. From these graphs, it will be possible to evaluate the uniform distribution of the spectrum of masking noise signals.

Graphic tests can be very effective in detecting insufficient quality of masking noise signals (sequences). With their help, you can determine the NG, the results of which do not meet the specified criteria. However, it should be noted that graphic tests are perceived by humans, which does not guarantee their uniqueness. For more accurate results, statistical tests are used, which give a numerical characteristic of the sequence and allow us to clearly say whether the test was passed or not [74].

A method for estimating noise quality using statistical randomness assessment tests can be represented as a sequence of the following main steps (operations).

1. The entire frequency range of the masking noise signal is divided into N equal frequency regions (sub-bands) in such a way that in each frequency region there are at least l values (l>2) of the amplitude of its spectral constituents. The width of the sub-bands shall not exceed the bandwidth of the measuring receiver (spectrum analyzer(s), oscilloscope).

2. In each of the subbands, a masking noise signal is received for some time and is converted into an electrical signal.

3. Samples of instantaneous values of the electrical signal are sampled, voltage levels of the electrical signal are measured for all discrete-time instants.

In this case, the measurements of the masking noise signal can be carried out by different methods.

One of them consists in obtaining, using a spectrum analyzer, a set of spectral components in each of the subbands. In this case, the amplitudes of these components are measured, which are saved as tracepoints (frequency and amplitude) for further processing.

Of course, the more points on the curve, the better the reproduction of the original signal. The number of dots available on the display is different for different analyzers. For example, on some of them, the number of display points for curves in the frequency domain can be set from 101 to 8192 points. The top Keysight N9040B UXA signal analyzers can set 10,0001 points. An increase in the

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number of points brings the image accuracy closer to the original (Figure 39) [75].

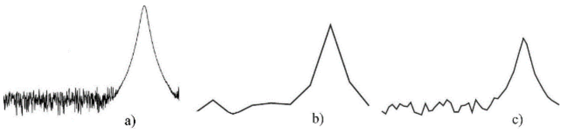

Figure 39: a) Original Signal; b) Fewer Points To Display The Signal; c) More Points To Display The Signal

However, even with this number of points, measuring the amplitude of all the frequencies of the masking noise signal for each of the sub-bands is a very labour-intensive task.

For example, 100,000 points in the path will accurately display a sub-band of frequencies whose width is 100 kHz. With a working range of 1 GHz GN, it will need to be divided into 1000 subbands, and measurements should be made for each of them.

Other methods of measuring a masking noise signal and sampling samples of its instantaneous values are described in [71] and [72].

4. Using one of the methods [71] or [72], statistics of the values of the masking noise signal are collected for each of the subbands. The collected statistics should have a volume of not less than 54x106 elements. However, the collection of such a volume of statistics may be limited by the technical capabilities of the measuring instruments used.

In this regard, a set of the required volume of elements for each of the subbands can be carried out by combining the results of repeated measurements.

5. In each of the subranges, the boundary is determined by the accumulated volume of elements (some criterion, for example, arithmetic mean value).

Software has been developed to automate the process of converting signal levels to "0" and "1". Signals exceeding this limit are assigned a value of “1”, otherwise, a value of “0” is assigned. In Figure 41 shows an example of conversion of the measured values (Figure 40) to “0” and “1”.

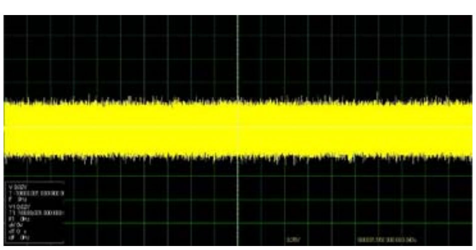

Figure 40: Measured And Digitized Values Of The Noise Signal In The Form Of An Oscillogram

6. The obtained sequence “0” and “1” of a sufficient number is evaluated using random statistical methods (tests) (for example, NIST, TEST-U01, CRYPT-X, DIEHARD, etc. tests).

7. Based on the results of assessing the quality of masking noise interference using statistical methods (tests) for randomness in each of the sub-bands, the noise quality is calculated for everything for the entire frequency range.

The proposed method for assessing the noise quality of spatial electromagnetic noise generators can be considered as an addition to traditional methods using the entropy quality factor.

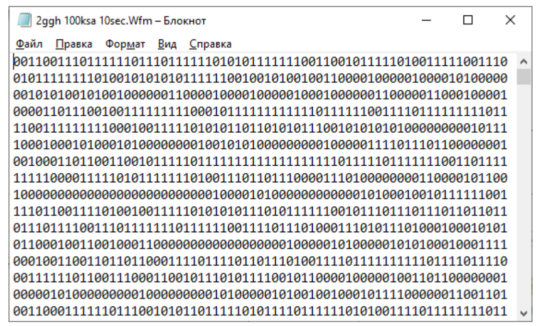

Figure 41: The Result Of Converting The Instantaneous Values Of The Amplitudes Of The Noise Signal Into Binary Numbers

CONCLUSION

This paper describes the characteristics of masking noise signals and analyzes existing methods and methods for assessing their quality. The positive aspects and disadvantages of the considered methods are described.

An alternative method for assessing the quality of masking noise interference is proposed, based on the calculation of the entropy quality factor.

To implement this method, a program for automating calculations has been developed, since manual calculations are very difficult given the large amount of input data (more than 1 million elements).

To verify the developed method, practical experiments were carried out to assess the quality of the masking noise of the NG. The results obtained are confirmed by the passport data for NG.

In addition, methods are proposed for measuring masking noise signals and the use of graphical and statistical random tests, which can also be used in assessing the quality of these signals.

Thus, using certain combinations of the considered methods (methods), it is possible to

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ensure the completeness of the estimation of the noise quality of spatial electromagnetic noise generators.

Also, it should be noted that currently there are no ready-made solutions on the market designed to assess the quality of masking noise. In this regard, the prospects for further research are related to the manufacture of universal devices for assessing the quality of noise.

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