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ДОСЛІДЖЕННЯ ФАЗОВИХ ПОРТРЕТІВ ШУМУ ЕЛЕКТРОННИХ ПРИСТРОЇВ

INVESTIGATION OF PHASE PORTRAITS OF NOISE OF ELECTRONIC DEVICES

Експериментально досліджено шуми електронних приладів для їх динамічної ідентифікації. Проведено моделювання фазових траєкторій за допомогою осциляторної моделі. Аналіз часових змін амплітуди шумів підтвердив їх фрактальну природу. Параметри фазових портретів спектральних компонент шуму дають можливість автентифікації електронних приладів. Експериментально зафіксований ефект формування часових структур у спектрі шумів.

Ключові слова: ідентифікація в кіберпросторі, автентифікація електронних приладів, фазовий портрет шумів, дивний атрактор, граничний цикл.

The article deals with the experimental studies of noise for dynamic identification of electronic devices. The simulation of phase trajectory was carried out using the oscillator model. Analysis of the noise temporal characteristics confirms their fractal nature. Parameters of phase portraits of spectral noise components enable us to conduct the electronic devices authentication. Experimental studies have shown that there is the effect of temporary structures formation in the behavior of the noise spectrum.

Key words: identification in cyberspace; authentication of electronic devices; phase portrait of noise; strange attractor; limit cycle.

Introduction

Modern networks and computer systems are exposed to several thousands of different attacks everyday. A significant part of the attacks is due to an access violation when the attacker becomes a legitimate user. This is made possible by weak authentication attributes of legal entity. Biometrics techniques were developed for the admission of people. For electronic devices also need to develop similar techniques that would make it possible to uniquely identify a particular device in a critical facility management system, the Internet of Things, telemedicine, etc.

Electronic device noise in the first approximation can be regarded as white noise. Individuality of noise for each electronic device is manifested to differences from the white noise model. The article deals with the noise of the electronic device as a computer audio card.

The purpose of this study is to show the possibility of using of the natural noise of electronic devices for problems the identification and authentication of devices in cyberspace. This requires choosing the noise parameter which does not depend on a particular time series, but only from the physical characteristics of the electronic device.

The challenge is to develop methods of recognition, which would provide unambiguous information on the specific unique device. Many researchers have come to the conclusion that such information may be inherent noise signals [1–4].

Any electronic device consists of a set of elements that are different in the parameters within limit variations. Nobody can make exactly the same elements at the micro-level, so that these differences are manifested in deviations of parameters at the macro level of devices: linear gain tract characteristics, resonant frequencies, noise ratio and others.

The authentication process of the electronic device is determined by measuring a parameter. Thus, impulse noise is used to identify the chip by implementing physical unclonable function [5]. Authentication accuracy is determined by quality measure which depends on the technical equipment, measurement methodology and the selected identifier. Therefore, comprehensive approach is needed to meet the challenges of authentication of electronic devices.

Experimental research of the noise characteristics

Experimental study noise of audio card was performed by the modeling its behavior. The noise of audio card was researched via Oscillometer program. The sampling frequency was equal to 44.1 kHz. Minimum frequency in the Fourier transform and the distance between adjacent spectral components was set using the window length. Shift between adjacent windows was equal (1/44100) sec. The amplitude of the signal output from the audio card was measured using Oscillometer program and no signal is input to audio card, Figure 1. At the beginning of the measurements transition process was observed, that was not considered in the calculations.

The noises of audio cards have a discrete nature as time-dependent analysis shows to a larger scaled. Audio card consists of several blocks such as input and output mixers, Analog-to-digital converter (ADC) and Digital-to-analog (DAC) converters, Processor, Synthesizer, Bus PCI and Connectors. Only the DAC, a Mixer and Connectors are involved in the formation of the noise of audio cards for our experiment. DAC and Mixer are complex electronic devices which are composed of triggers, and various resonant circuits. It is known from the radio that the complex wireless devices can form distribution circuit with strong capacitive and inductive coupling. Triggers are bistable system, their presence in the radio circuit leads to several points of stable equilibrium. Contacts are the source of thermal noise and specific contacts noise. These elements produce noise near the resonance frequencies. Noise spectrum is limited to sampling frequency, which can be observed. Experimental studies have shown the effect of the formation of temporary structures in the behavior of the noise spectrum. The number of temporary structures is not dependent on the number of spectral components.

Dynamics of changes in the imaginary part of the Fourier component of noise series with the numbers 62 is shown in Fig. 1. The dynamics of the real part of the Fourier components has a similar view.

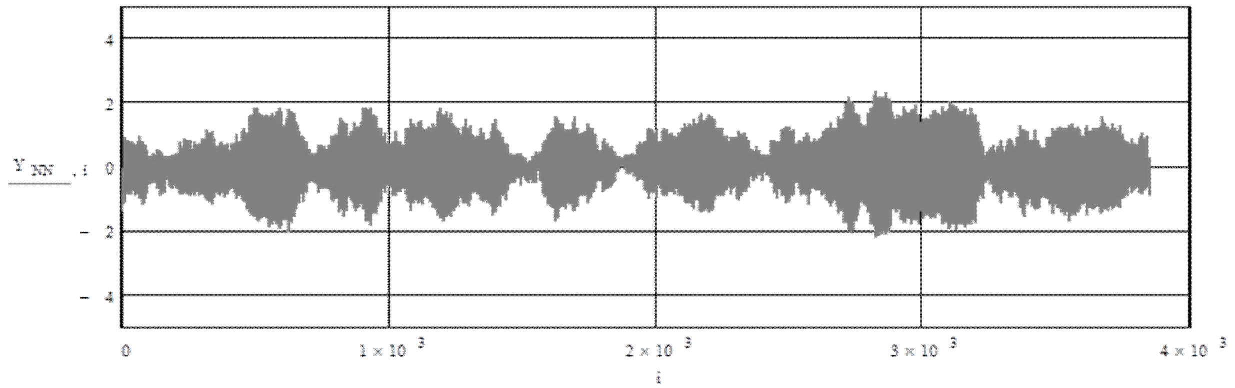


Fig. 1. The time dependence of the imaginary part of the Fourier components of noise series for the audio card desktop computer for n=62. Source: own.

Window length was 4410 samples. Fourier transform for 512 point was used. All mathematical operations were performed using Mathcad program. Chart shows the formation of temporary structures. The repeatability of temporary structures is about 300 samples. Temporary structures are approximately the same.

Temporary structure is shown in Fig. 2 on a larger scale. Type structure resembles a short-term sine process that develops, lasts for some time, and then dies.

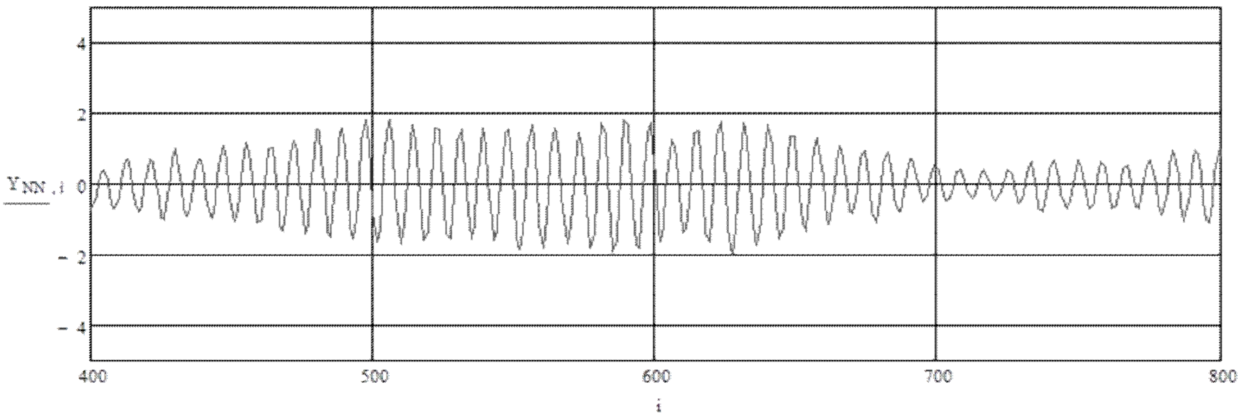
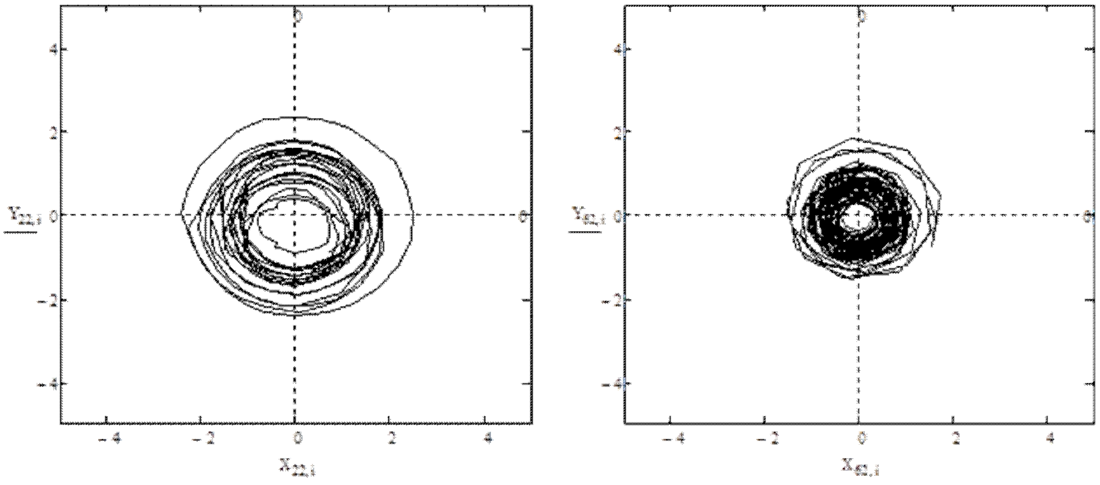


Fig. 2. The imaginary component n=62 on a larger scale. Source: own

The dynamics of the amplitude spectral component of the noise was investigated in the phase plane. The real and imaginary Fourier components lay along the x and y axes. The phase portrait of the spectral components of n = 22 and n=62 is shown in Fig. 3. The hypothesis is made that the phase portraits are strange attractors [6].



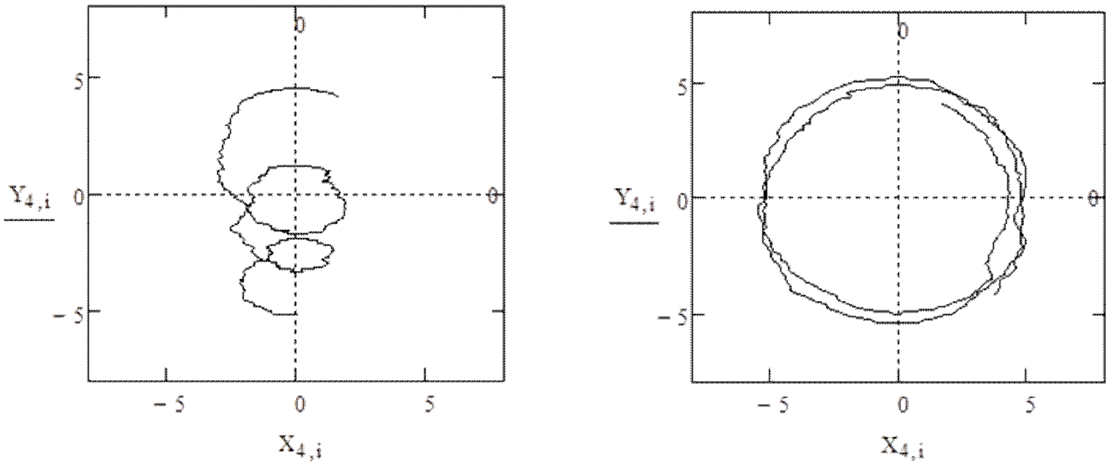
a *b*

Fig. 3. Phase portrait of the Fourier components for 500 samples: a – for n=22, b – for n=62. Source: own

Phase portraits of low-frequency Fourier components were used for further analysis since more marked features of phase portraits is observed. Analysis of phase portraits for the low-frequency Fourier components shows the following behavior: first phase portrait resembles the limit cycle - pseudo limit cycle, with time cycle goes astray and a new cycle begins. This goes on all the time. Each pseudo limit cycle is shifted with respect to the coordinate zero. The shift for each cycle there is different. Fragments of the phase portrait for the fourth Fourier component are shown in Fig. 4.

Motion of phase trajectory takes place clockwise. Phase portrait occupies a limited area on the phase plane. The motion of trajectory occurs in a spiral as long as the phase portrait becomes identical to the limit cycle. Then, the phase trajectory moves in a spiral again and achieves its highest point. Further there is a downward spiral, the limit cycle is repeated. Formation of the phase portrait is completed downwards spiral.

It should be noted that for high-frequency Fourier components shifts of phase portraits are not observed visually.



a *b*

Figure 4. Formation of limit cycles for fourth Fourier component: a – samples from 1 to 400, b – samples from 400 to 800. Source: own

Placement in the plane of phase portraits of low spectral components depends on the spectral detail: for the 128 component of the Fourier transform image is tilted to the right with respect to the y-axis, while the symmetry about the center is maintained. For the 512 component of the Fourier transform image is positioned vertically.

Simulation of the phase portraits of noise

Today it has become known a growing number of relatively simple examples of spontaneous appearance of temporary structures in disordered systems [7]. It is a testament to the self-organization processes in irreversible processes. For electronic devices the presence of self-oscillatory systems is characteristic. Spontaneous pattern formation takes place in trigger-type systems [8]. A limit cycle is characterized by constant amplitude. The trajectory describes the stationary harmonic oscillations. Nonlinear oscillator model is used in the research of noise in radio frequency integrated circuits [9].

Let us consider the two-frequency oscillator model as

$$f(t) = sin(2\pi i\nu 0/44100) + sin(2\pi i\nu 1/44100)$$

Frequencies ν0 and ν1 we call a low frequency and the basic frequency. This choice of model signal frequencies is due to the following. The length of the measurement window is 0.1 seconds. The period of signal is not visible guaranteed in the Fourier spectrum, if the frequency is below 15 Hz. Simulations have shown that a signal with a frequency close to the minimum frequency Fourier transformation is a cause of the limit cycle shift in the phase plane, as can be seen in Fig. 5.

Position of the limit cycles centers for the basic frequency is sensitive to the value of the lower frequency. Increasing the lower frequency at the 1Hz leads to shift of the phase trajectories; each of them is shifted differently. The addition to the model of third oscillator with a high frequency explains the slight unevenness in the phase portrait or low Fourier components. Figure 6 shows fragment of phase portrait for fourth Fourier component, n=600. The simulation showed that the signal processing (discrete Fourier transform) significantly affects the outcome, even if the signal is the sum of sine waves. An important processing parameter is the length of the window, which determines the minimum frequency of the discrete spectrum. Features of the noise signal can be studied by changing processing parameters.

Changing the window width determines the presence of frequency that is lower or similar to the frequency of first discrete component. A study of low-frequency discrete spectrum proved more informative than its high-frequency part. Thus, the phase portraits of high-frequency component cease to feel the presence of low frequency, their center coincides the origin of coordinates. Lower frequency changing by 1 Hz results in a significant shift of the characteristic points of the phase portrait. Thus, measurement of the mutual disposition of characteristic points makes it possible to determine the lower frequency.

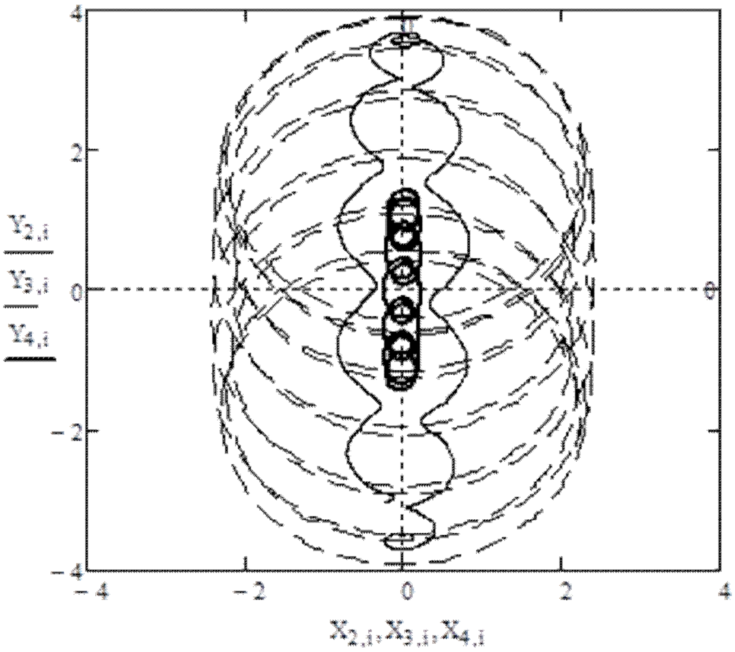


Fig. 5. Phase portrait for the three Fourier components of the signal model.
Thin solid line - the second component, dashed line – the third component,
fat solid line – the fourth component, n=3000. Source: own

The analysis of low frequency Fourier components of noise shows that the average value of the imaginary part there is less than zero. This shift can be explained by the presence of low-frequency (slow) component in the noise spectrum. The shift of center of each pseudo limit cycle is linear function of frequency ν0 as simulation of two-frequency oscillator model shows, Fig. 6.

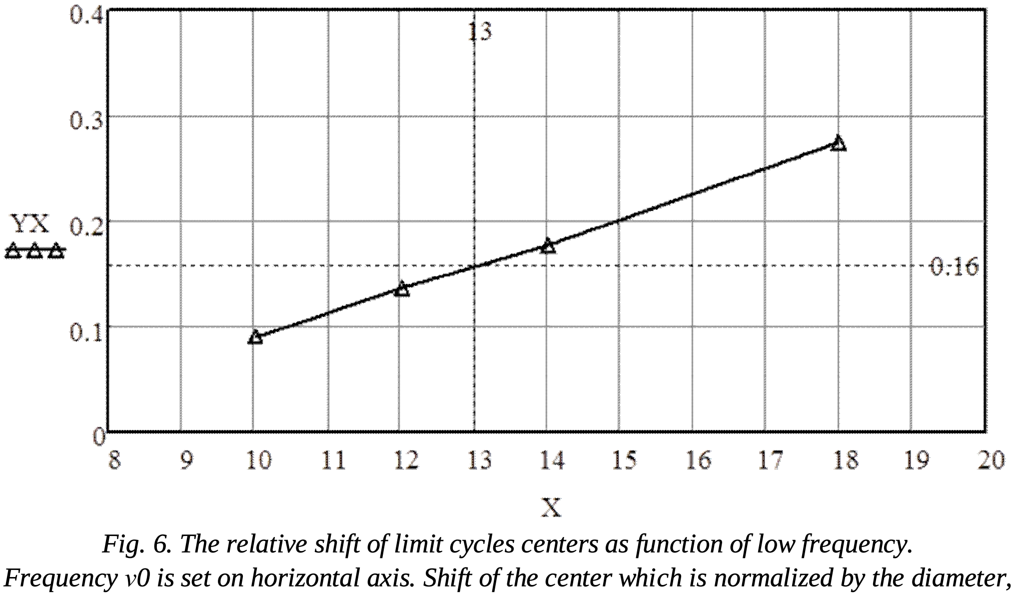


Fig. 6. The relative shift of limit cycles centers as function of low frequency.
Frequency ν0 is set on horizontal axis. Shift of the center which is normalized by the diameter,
is set on vertical axis. Source: own

It was found that the low frequency of noise can be determined by the phase portrait, if the basic frequency ν1 is known. To do this, the fast frequency of noise is determined from the plot of the Fourier component time dependence. This frequency is equal180 Hz. In the further, the frequency 180 Hz is used as the frequency of the basic component in the two-frequency oscillator model. Then, plot is setting a relationship between shift of limit cycle center and low frequency ν0.

The pseudo limit cycles, which are concentrated in the surrounding area of the origin, were taken to determine the shift of their centers. It is determined, that the frequency of the slow component of noise is equal to 13 Hz.

Similar calculations were made for other areas of noise recording. For some cases, areas have overlap, for other cases areas were spaced far enough and do not overlap. Measurements of low frequency and of basic frequency were held for the third Fourier components due to the convenience of visual determination of the basic frequency and the relative shift of the center. All measurements and calculations showed the same result, which was presented above. This leads to the conclusion that the result is not accidental, and it allows to characterize the audio card.

Thus, a simple model makes it possible to determine the frequency of the slow component of the noise for a short time recording of noise.

Conclusion

The emergence of temporary structures for noise of computers audio card shown experimentally. Analyses of these temporary structures are conveniently carried out with the use of phase portraits of the spectral components. Phase portrait for low-frequency discrete component of noise is a set of limit cycles, each of which has an individual shift relative to the origin. This shift is due to the presence in the noise spectrum of low-frequency components whose frequency is lower than the frequency of the first discrete Fourier component. The proposed model of the two oscillators explains characteristics of phase portraits of the noise spectrum. Using this model, the basic and low frequencies of noise were calculated. They were found to be 180 Hz and 13 Hz. The result is repeated for different file areas of noise recording.

Thus, shifts of limit cycles of the real noise can serve as an authentication characteristic of the electronic devices.

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