

A NEW HYPERCHAOTIC GENERATOR: CIRCUIT REALIZATION AND ANALYSIS

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Abstract. This paper proposes a new circuit of the generator with hyperchaotic behavior. All component values are presented. NIs MultiSim was used for analysis of the main properties of hyperchaotic theory such as attractors for different projections, time series and spectral characteristics for four hyperchaotic signals. This hyperchaotic generator can be used in modern telecommunication systems for information security.

Keywords: hyperchaos, generator, MultiSim, telecommunications, information security

NOWY GENERATOR HIPERCHAOTYCZNY: REALIZACJA OBWODU I ANALIZA

Streszczenie. W niniejszym artykule zaproponowano nowy obwód generatora o zachowaniu hiperchaotycznym. Przedstawiono wartości wszystkich elementów. Do analizy głównych właściwości teorii hiperchaotycznej, takich jak atraktory dla różnych projekcji, szeregi czasowe i charakterystyki spektralne dla czterech sygnałów hiperchaotycznych, wykorzystano oprogramowanie NI MultiSim. Generator hiperchaotyczny może być stosowany w nowoczesnych systemach telekomunikacyjnych do zapewnienia bezpieczeństwa informacji.

Słowa kluczowe: hiperchaos, generator, MultiSim, telekomunikacja, bezpieczeństwo informacji

Introduction

In modern nonlinear dynamics, the concept of hyperchaos occupies an important place, as it reflects a new level of complexity in the behavior of dynamical systems [3, 12, 14, 23, 24, 31, 32, 34]. While ordinary chaos is characterized by the presence of a single positive Lyapunov exponent, which indicates an exponential divergence of close trajectories, hyperchaotic oscillations are marked by the presence of two or more such exponents. This means that the system demonstrates instability simultaneously in several independent directions of the phase space, which leads to even greater unpredictability, complexity, and multidimensionality of its dynamics [2, 13, 19, 30, 35].

The concept of hyperchaos was first introduced in 1979 by Otto Rossler while studying the modification of his own chaotic system [26]. Since then, hyperchaotic modes have been found in many physical, biological, chemical, and technical systems, from laser generators and electronic circuits to plasma processes and control systems. Such oscillations are the result of the interaction of several nonlinear elements and feedbacks that form complex attractors with a branched structure [4, 7, 25].

Hyperchaotic oscillations are of considerable scientific interest not only from a theoretical point of view but also because of a wide range of practical applications. Due to their extreme sensitivity to initial conditions and the complexity of time series, they are used for secure information transmission, generation of random signals, modelling of complex natural processes, and synthesis of new types of nonlinear control systems.

The study of hyperchaos opens up new possibilities for understanding multidimensional dynamics, transitions between different modes of oscillation, and ways to control complex systems [10, 18]. In this context, hyperchaotic oscillations are not only a continuation of the traditional chaos theory, but also an important step towards a deeper understanding of patterns in seemingly completely unpredictable processes.

Hyperchaotic oscillators are one of the most interesting areas of modern nonlinear electronics and dynamical systems theory. They are devices or mathematical models capable of generating signals with a high level of complexity, characterized by hyperchaotic behaviour, i.e., the presence of two or more positive Lyapunov exponents. This property means that the system exhibits instability in several independent directions of the phase space, creating multidimensional, highly unpredictable dynamics.

The idea of creating hyperchaotic oscillators originates in the development of chaos theory. While traditional chaotic oscillators, such as the Lorentz [8, 11, 21], Chua [9, 17, 27], or Rossler systems, provided complex but one-dimensional instability, hyperchaotic circuits were the next stage of develop-

ment – they expanded the concept of chaotic oscillations by introducing additional degrees of freedom and nonlinear relationships between variables. The first experimental realizations of such generators appeared in the 1980s and 1990s, when the development of electronic technologies made it possible to implement multidimensional nonlinear systems with precise parameter control.

Hyperchaotic oscillators play a special role in modern communication and cryptography systems, where their complex signals are used to mask information and protect data transmission channels. The high entropy and lack of periodicity in the time series of hyperchaotic signals makes them ideal for creating pseudorandom sequences, encryption keys, and noisy carriers. In addition, they are used in sensor systems, neural networks, laser physics, biomedical research, and the control of nonlinear processes [5, 6, 15, 20, 22, 29, 36].

From a technical point of view, hyperchaotic oscillators can be implemented as analogue electronic circuits (based on operational amplifiers, diodes, transistors, or other nonlinear elements), digital systems (in the form of microcontrollers or FPGAs), and hybrid models that combine both approaches. Their design requires an accurate selection of parameters that ensure the emergence of a hyperchaotic mode, as well as the analysis of attractors, phase portraits, spectral characteristics, and Lyapunov parameters.

Thus, hyperchaotic oscillation generators are a key tool for studying the complex dynamics of nonlinear systems and, at the same time, an important practical tool for developing the latest technologies for processing, transmitting, and protecting information [16, 28, 33]. Their research opens the way to creating more reliable, flexible, and high-performance engineering solutions based on the principles of chaos and hyperchaos.

1. Electronic circuit with hyperchaotic behavior

The principle of operation of hyperchaotic oscillation generators is based on the creation and maintenance of nonlinear dynamics that leads to the emergence of a hyperchaotic regime – a state where the system has at least two positive Lyapunov exponents. This means that the system is sensitive to initial conditions simultaneously in several independent directions of the phase space, forming a complex, multidimensional trajectory that cannot be predicted analytically.

Hyperchaotic oscillators are created by introducing additional degrees of freedom and nonlinear feedbacks into the basic chaotic system. Traditional chaotic oscillators (e.g., Lorentz or Chua systems) contain three variables that describe the state of the system in time. To achieve hyperchaos, it is necessary

to increase the model's dimensionality to at least four variables. This is what ensures the emergence of the second independent instability.

In most schemes, hyperchaotic oscillations are created using:

- one or more nonlinear elements (diodes, transistors, varistors, etc.),
- active components (operational amplifiers, comparators, current generators),
- feedback loops that delay or modify the signal,
- capacitive and inductive elements that create energy exchange between variables.

These components form a system of differential equations whose behavior describes the evolution of voltages and currents over time. Under the influence of nonlinearities, the system moves from a stable state to chaos, and under certain parameters to a hyperchaotic mode.

Hyperchaotic fluctuations occur in several stages.

1. Linear mode – the system has a stable equilibrium; the oscillations are damped.
2. Chaotic mode – when parameters change, one positive Lyapunov exponent appears, indicating chaotic behavior.
3. Hyperchaotic mode – further increase of the system complexity (for example, adding a new feedback or delay element) leads to the appearance of another positive Lyapunov exponent. In this state, the system trajectory has several independent directions of instability, which makes the signal behavior extremely complex and unpredictable.

Nonlinear transfer functions and parametric interactions between variables play a key role in this process. They ensure the transition from periodic oscillations to hyperchaos through a sequence of bifurcations, i.e., changes in the qualitative nature of the system's dynamics.

Hyperchaotic oscillators are characterized by a wide range of frequency components and high energy density of the signal. This is due to the fact that the dynamics of the system covers several independent modes of oscillation. As a result, the resulting signal has a spectrally blurred but stable statistical structure, which is valuable for applied tasks, such as secure communication, encryption, generation of pseudorandom sequences, etc.

Despite the complexity of their dynamics, hyperchaotic oscillators can be synchronized with other systems using special control algorithms. This opens up the possibility of building covert information transmission systems, where the message is transmitted in the form of small perturbations in the hyperchaotic signal. Such methods make it possible to achieve high resistance to interception and decoding by third-party means.

Thus, the principle of operation of hyperchaotic oscillation generators is to create a multidimensional nonlinear system in which the interaction between components and the presence of feedback leads to the emergence of highly complex, multi-dimensional behaviour. As a result, hyperchaotic oscillators have become an important tool for modelling complex physical processes, as well as a practical tool in modern communication, encryption, and control technologies.

In Figure 1 shows a circuit of a generator with hyperchaotic behaviour. It contains two multipliers AD633, three op-amps TL082, four capacitors ($C1 \div C4 = 100 \text{ nF}$), twelve resistors ($R1, R2 = 10 \text{ k}\Omega$; $R3 = 100 \text{ k}\Omega$; $R4 = 10 \text{ k}\Omega$; $R5 = 2 \text{ k}\Omega$; $R6 = 510 \Omega$; $R7 = 2 \text{ k}\Omega$; $R8 \div R10 = 10 \text{ k}\Omega$; $R11 = 27 \text{ k}\Omega$; $R12 = 20 \text{ k}\Omega$). The operational amplifier is built on two in one case, so the circuit shows five, but indicated three only. For powering was used bipolar $\pm 15 \text{ V}$ power supply.

2. Analysis of the hyperchaotic generator

NI MultiSim is one of the most popular software environments for modelling, analyzing and researching electronic circuits. This program combines a user-friendly graphical interface with powerful analytical capabilities, allowing engineers, researchers and students to efficiently create, test and optimize a variety of electronic devices without the need for physical manufacturing.

MultiSim provides modelling of analogue, digital and mixed circuits and supports a wide range of virtual instruments, including oscilloscopes, multimeters, signal generators and more. This allows experiments to be conducted in conditions that are as close as possible to a real laboratory environment.

Thanks to SPICE simulation support, users can analyze time characteristics, amplitude-frequency dependencies, signal spectra, and other system parameters. MultiSim is widely used not only in education, but also in scientific research, in particular for studying nonlinear dynamic systems, chaotic and hyperchaotic oscillations, developing signal encryption schemes, and creating intelligent electronic devices.

Thus, the use of MultiSim makes it possible to model complex processes, verify the performance of circuit solutions, and reduce the time and resources spent on the design and research stages.

Methods for analysing hyperchaotic oscillations encompass both classical approaches to nonlinear dynamics and modern numerical, statistical, and spectral tools that allow for detailed investigation of the structure, stability, and degree of chaos in systems with more than two positive Lyapunov exponents.

The main methods are phase space, time series and signal power analyses:

Construction of phase trajectories. Visualization of system behavior in phase space (e.g., in coordinates $x(t)$, $y(t)$, $z(t)$, $w(t)$) allows us to observe complex attractors of hyperchaotic systems, which have a higher dimension and more complex topology compared to chaotic ones.

Projections of the attractor. For ease of analysis, two- or three-dimensional projections of the phase portrait are used. They demonstrate the interaction between variables and allow the structure of the hyperchaotic attractor to be revealed.

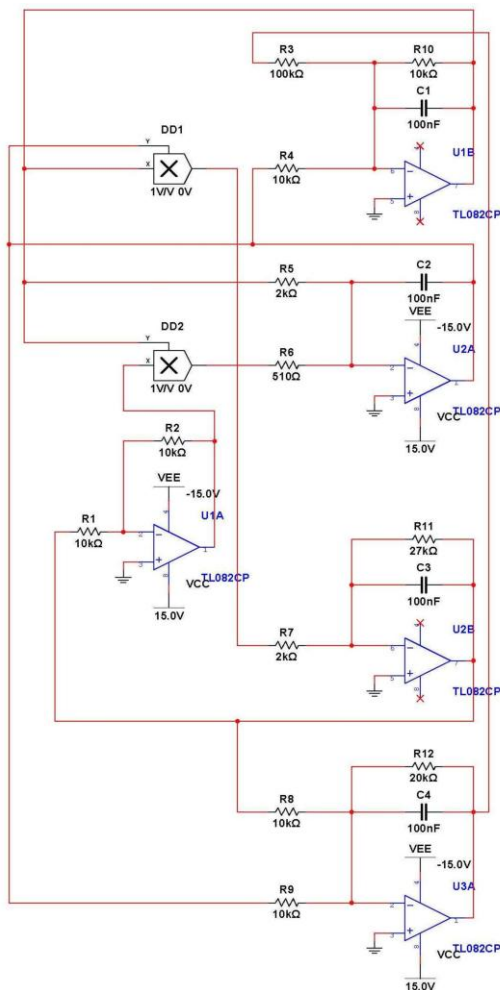


Fig. 1. Circuit of a generator with hyperchaotic behavior

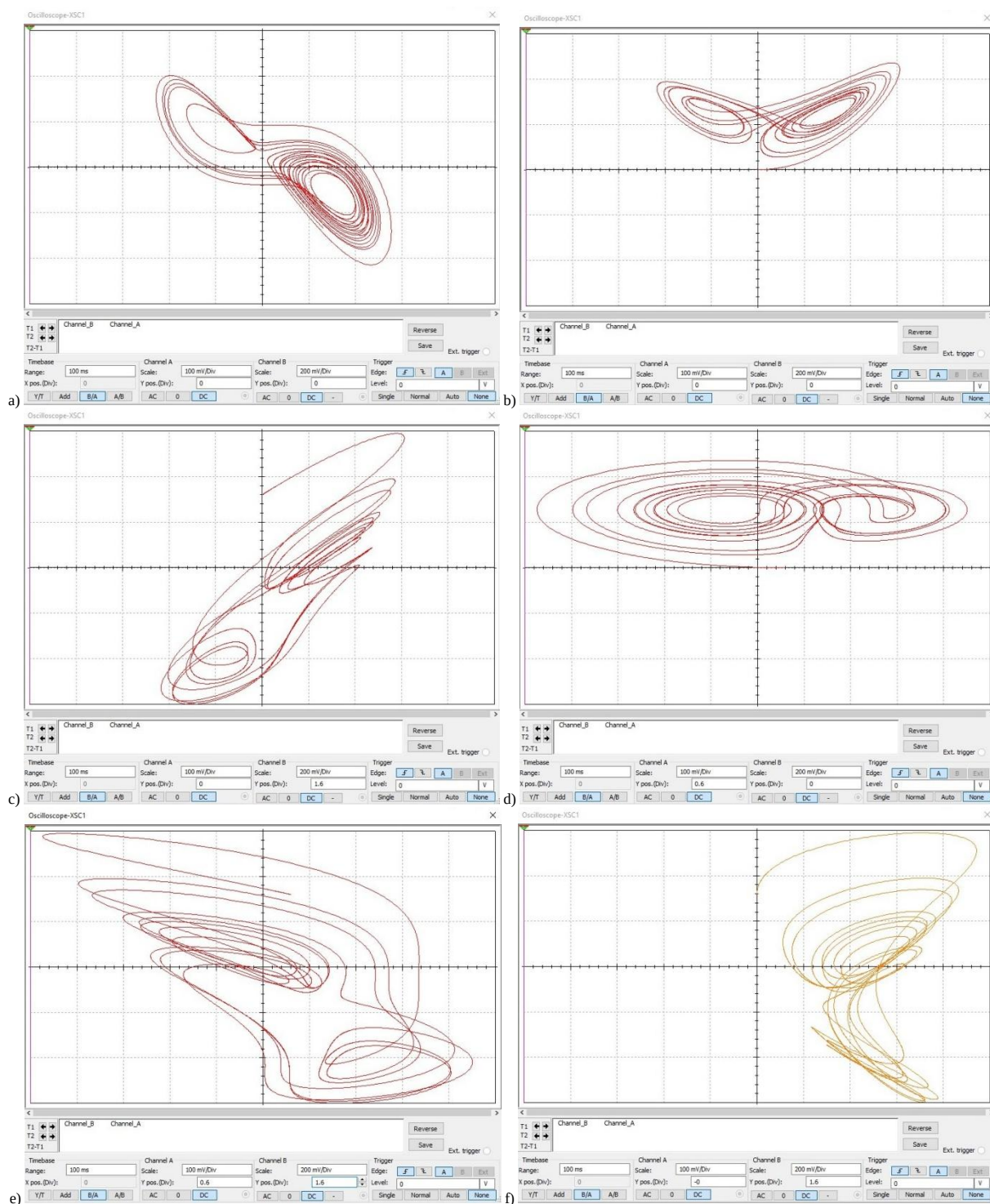


Fig. 2. Hyperchaotic attractors for: (a) XY; (b) XZ; (c) XW; (d) YZ; (e) YW; (f) ZW projections

Time series analysis. Allows you to evaluate changes in amplitude, periods, and energy characteristics of oscillations.

Signal power analysis (Power Spectral Density, PSD). Performed using fast Fourier transform (FFT). For hyperchaotic signals, the spectrum is usually broad and without clear harmonics, indicating aperiodicity and a complex frequency structure.

In Figure 2 shows hyperchaotic attractors in different projections. Parameters for modelling: voltage A = 100 mV/div; voltage B = 200 mV/div; time scale = 100 ms.

Figure 3 presented time series for all four signals. Parameters for modelling: voltage = 1 V/div; time scale = 100 ms/div. Signal X corresponds to output op-amp U1B, signal Y – output U2A, signal Z – output U2B and signal W – output U3A.

Figure 4 shows spectral characteristics for four hyperchaotic signals.

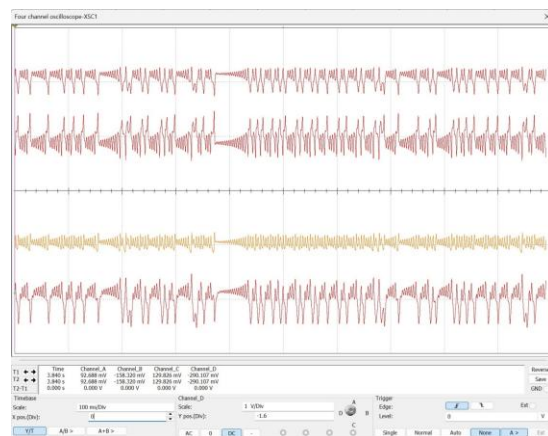


Fig. 3. Time series for four hyperchaotic signals X, Y, Z and W (top to bottom)

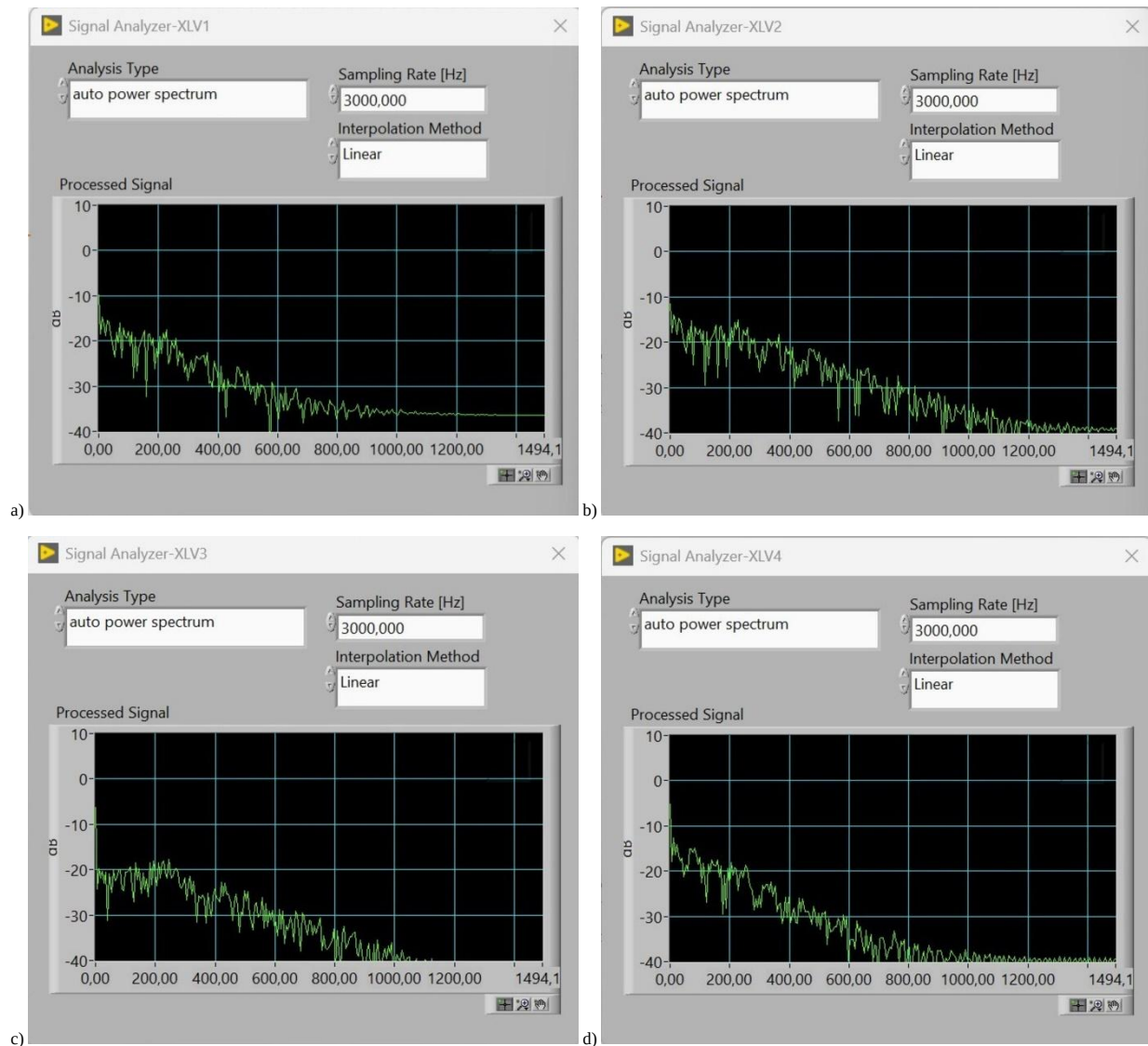


Fig. 4. Spectral characteristics for: (a) X; (b) Y; (c) Z; (d) W signals

3. Conclusion

A circuit of the new generator with hyperchaotic behaviour is presented. The analysis of the main properties of hyperchaotic theory such as attractors for different projections, time series and spectral characteristics for four hyperchaotic signals was conducted. For this purpose, we used NIs MultiSim software. This hyperchaotic generator can be used in modern telecommunication systems as a main block for information security.

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