http://doi.org/10.35784/iapgos.6703

received: 14.10.2024 | revised: 13.02.2025 | accepted: 07.03.2025 | available online: 31.03.2025

PULSE CHAOTIC GENERATOR BASED A CLASSICAL CHUA'S CIRCUIT

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Abstract. *This article presents circuit realization of the pulse chaotic generator that can be used in digital modern telecommunication systems for masking and decrypt of the information. This generator based a classical Chua's circuit. The results of computer simulation of a nonlinear element that realizes the chaotic behavior of the classical Chua's circuit are presented. For modelling was used a modern software MultiSim. Also, such basic results as chaotic attractor and time distributions of signals were obtained.*

Keywords: chaos, pulse, MultiSim, Chua's circuit

IMPULSOWY GENERATOR CHAOTYCZNY OPARTY NA KLASYCZNYM OBWODZIE CHUY

Streszczenie. *W artykule przedstawiono realizację obwodu impulsowego generatora chaotycznego, który może być stosowany w nowoczesnych cyfrowych systemach telekomunikacyjnych do maskowania i deszyfrowania informacji. Generator ten bazuje na klasycznym obwodzie Chuy. Przedstawiono wyniki symulacji komputerowej nieliniowego elementu realizującego chaotyczne zachowanie klasycznego obwodu Chuy. Do modelowania wykorzystano nowoczesne oprogramowanie MultiSim. Uzyskano również takie podstawowe wyniki jak atraktor chaotyczny i rozkłady czasowe sygnałów.*

Słowa kluczowe: chaos, impuls, MultiSim, obwód Chuy

Introduction

Chaotic oscillations are some complicated, unpredictable phenomena in systems capable of oscillatory motion. Consequently, such oscillations occur in physics and engineering [5, 12, 18, 20, 29, 30]. The mark of chaotic oscillation is the sensitivity of the initial conditions that even small changes can result in extremely different outcomes [21, 24, 28].

Some of the principal characteristics of chaotic oscillations are as follows:

1. Nonlinearity: Many chaotic systems possess nonlinearity, which means their equation of motion is not linear and does not obey the superposition principle.
2. Bifurcations: Chaotic systems also can make bifurcations, in other words, variation of parameters of the system, a small variation of the value of the parameter induce an abrupt qualitative change of behaviour.
3. Strange Attractors: Chaotic systems have attractors in phase space that can be fractals; strange attractors represent the long-run behaviour of the system.
4. Applications: These oscillations appear in different systems, such as weather conditions, population dynamics, electrical circuits, and many others.

Most of the time, explanation of chaotic oscillations needs mathematical preciseness by high-order theories such as chaos theory, dynamical systems, and nonlinear dynamics.

In particular, such systems are a good tool for testing the performance of parametric identification systems. Of particular interest are systems that allow simple circuit implementation [6–8, 14, 16, 23], since they allow both to study the adequacy of the corresponding mathematical models without significant costs and to synthesize the identification criterion based on physical principles. For example, Chua's nonlinear dynamic system contains only one nonlinear element – the "Chua diode" [1–4, 10, 22, 25]. However, the circuit implementation of this element requires the presence of several operational amplifiers, not counting many passive elements. This complicates both the creation and debugging of the device and the verification of the adequacy of the mathematical model. Therefore, the task of creating chaotic generators containing a minimum number of active elements and allowing their behaviour to be described by simple mathematical models is relevant [11, 13]. Also, chaotic signals used in cryptography [9, 15, 17, 19, 26, 27].

This paper describes a pulse conversion of an analog nonlinear signal. A classical Chua chaos generator was used as the main component to generate the nonlinear signal. The electronic circuit and nominal components are shown. The MultiSim software was selected to analyse and demonstrate the computer modelling results.

1. Electronic circuit for pulse transformation

Analog signals are continuous in time; they are defined at all moments in time.

Discrete signals are signals represented by a sequence of readings, i.e. signal values at discrete moments in time.

Digital signals are discrete in time (or space) and quantized by level. Computational procedures in a computer are performed in digital signals.

In order for a computer to process a signal, it is necessary to convert the signal from analog to digital form.

Analog-to-digital converter (ADC) is a device that converts an input analog signal into a discrete code (digital signal), which quantitatively characterizes the amplitude of the input signal.

Main parameters of ADC:

1. Input signal range (measurement range).
2. Conversion frequency [Hz] – frequency of analog-to-digital conversions. In DSP terminology, the ADC conversion frequency is called the sampling frequency of the signal in its digital representation.
3. Conversion period [s] = [1/Hz] – a value inverse to the conversion frequency. In DSP terminology, the ADC conversion period is the period of signal conversion in its digital representation. For asynchronous ADCs, the conversion time is standardized.
4. ADC bandwidth [Hz]…[Hz]. This is the range of signal frequencies that the converter passes at a signal level of -3 dB.
5. ADC bit depth – the number N of binary digits of the converter, while the number of signal quantization levels in the digital representation of the ADC is 2N.
6. Signal-to-noise ratio of the ADC conversion channel [dB].
7. ADC technology. Typical representatives: successive approximation ADC, sigma-delta ADC.
8. Interchannel pass-through [dB].

The ADC must generate a binary position code corresponding to the value of the input analog signal. Such a conversion is performed in three stages:

At the first stage, the continuous analog signal is replaced by a set of samples taken at discrete moments in time. This stage is called "Discriptization of an analog signal in time". The time interval between two adjacent samples is called the sampling period and is designated: According to Kotelnikov's theorem, in order to preserve the properties of the signal, the frequency of taking a sample of the signal must be greater than or at least equal to where Fmax is the maximum frequency in the spectrum of the original analog signal.

At the second stage, "Quantization of samples by level" The values of the samples are compared with the level of the disk scale and rounded to one of the values of this discrete scale. Let us round to the nearest lower value of the level. During the operation of the circuit, the voltage conversion remains unchanged.

The third stage forms a binary position code corresponding to the value of the quantized value.

The electronic circuit to pulse transformation with components: one operational amplifier TL082, one transistor 2N2222A, resistors *R1, R2, R4* = 1 kΩ, *R3* = 5,6 kΩ, *R5* = 2.2 kΩ, voltages + 5 V and ± 9 V is displayed in Fig. 1.

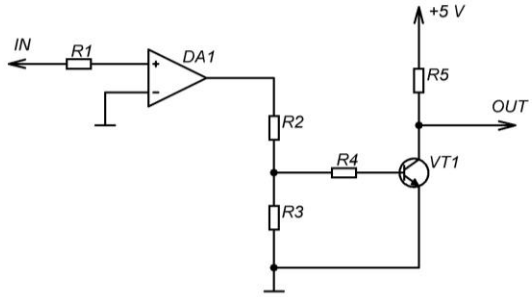

Fig. 1. The electronic circuit to pulse transformation

The simplest electronic circuit that demonstrating chaotic behaviour was invented by Leon Chua in 1983 (Fig. 2).

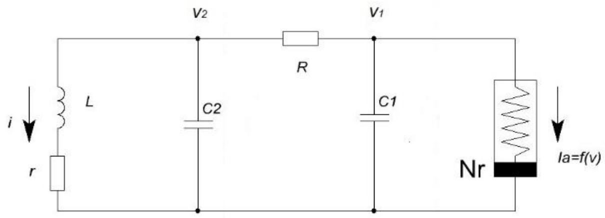

Fig. 2. Chua circuit

This circuit consists of one nonlinear element with characteristic $f(v)$ called a Chua diode, inductor L, two capacitors ($C1$, $C2$), and passive resistors (R, r). This is described by the following equations

$$\begin{cases} \dfrac{dv_1}{dt} = \dfrac{1}{C_1}\left(\dfrac{1}{R}\left(v_2 - v_1\right) - f\left(v\right)\right) \\ \dfrac{dv_2}{dt} = \dfrac{1}{C_2}\left(\dfrac{1}{R}\left(v_1 - v_2\right) + i_L\right) \\ \dfrac{di_L}{dt} = -\dfrac{1}{L}\left(v_2 + ri_L\right) \end{cases} \tag{1}$$

$$f\left(v\right) = \begin{cases} G_b v_1 + \left(G_b - G_a\right)E_1, & if\ v_1 \le -E_1 \\ G_b v_1, & if\ \left|v_1\right| < E_1 \\ G_b v_1 + \left(G_a - G_b\right)E_1, & if\ v_1 \ge E_1 \end{cases} \tag{2}$$

The function $f(v)$ – the volt-ampere characteristics of Chua's diode; iL – current through inductor L; v_1 & v_2 – voltages across capacitors C_1 and C_2, respectively.

2. Modelling and analysis of nonlinear element

A nonlinear element is a system or a circuit that possesses a nonlinear characteristic, i.e., the output is not directly proportional to the input. In linear elements, such as resistors or capacitors, this relationship between voltage and current can be expressed by a simple linear equation, as shown explicitly for the case of a resistor by Ohm's law. For a nonlinear element, however, this relationship becomes more involved, depending on a number of factors.

Examples of nonlinear elements are as follows:

1. Diode: One of the most straightforward nonlinear element examples, it conducts current in only one direction when a threshold voltage is crossed and does not depend linearly on the input voltage.
2. Transistor: Also nonlinear since its collector current depends nonlinearly on the base voltage or base current. That permits transistors to be used for signal amplification, control, and switching.
3. Thyristor: semiconductor element whose current passes when voltage oversteps some critical value and when is 'on' it stays in conducting status as long as current is passing through it. Nonlinear behavior of it allows use thyristor for power electrical circuit's control.
4. Non-linear magnetic elements: For instance ferrite where nonlinear dependence between magnetic flux and magnetic field strength would be observed – magnetohysteresis.

Main properties of nonlinear elements:

1. Nonlinear dependence: Complicated interaction of input and output signals, not according to a linear law. For example, the volt-ampere characteristic can be exponential or quadratic.
2. Saturation: Most nonlinear elements have a saturation effect whereby, after a certain level of input signal is attained, the output does not change anymore. This is typical for magnetic and semiconductor devices.
3. Hysteresis: This is an effect where the state of the system depends on anything other than just the present value of the input signal; it depends also on previous values. As an example, magnetic materials exhibit hysteresis because there is a lag between a change in magnetic field and the resulting change in magnetisation.
4. Complex harmonic signal response: The nonlinear element may generate harmonics, i.e., output frequencies being integer multiples of the input frequency or even chaotic behaviour in the system.
5. Application of nonlinear elements: In signal processing nonlinear elements serve in a wide array of signal conversion circuits, such as microwave detectors, frequency mixers, amplitude modulators, etc.
6. Amplifiers and Generators: Non-linear gain of amplifiers with the help of nonlinearities of transistors or tubes; signal generators can be built.
7. Overload Protection: Electrical circuits are protected against short circuits and over-voltages by nonlinear elements, such as thyristors.

Non-linear elements play a fundamental role in many electronic circuits; their rich behaviour extends the range of functions compared to the linear systems.

The circuit realization to modelling and analysis of the non-linear element with components is displayed in Fig. 3.

Fig. 4 shows the result of the modelling of the nonlinear element. The nonlinear characteristic was modelled by the following parameters: E = 6.5 V, f = 2 kHz, R = 3 kΩ, $U1$ = 2 V/div, $U2$ = 2 V/div.

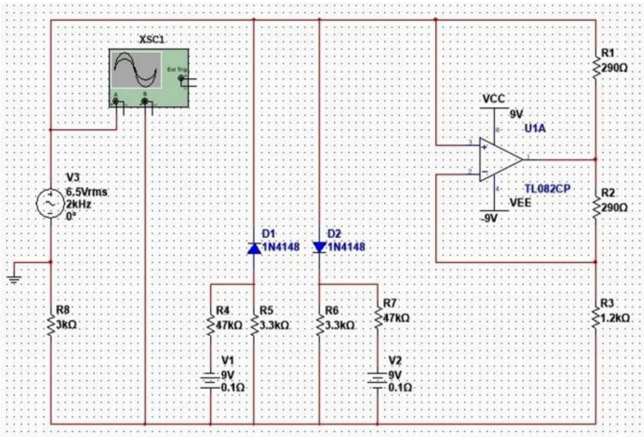

Fig. 3. Circuit realization to modeling and analysis of the nonlinear element

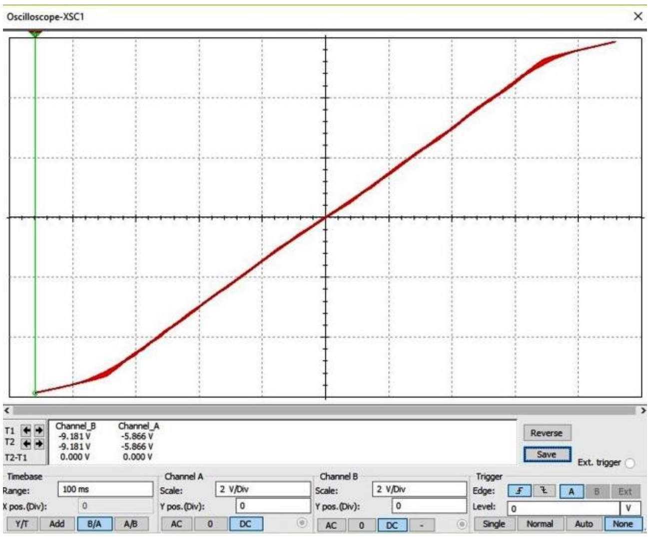

Fig. 4. V/I characteristic of the nonlinear element

3. Modelling and analysis of the classical chaotic Chua's generator

Fig. 5 shows scheme of the classical chaotic Chua's generator.

Fig. 6 shows the result of computer circuit simulation. Coordinate X on the circuit corresponding voltage $UC2$, coordinate Y – voltage $UC1$. The simulation parameters: $U1$ = 500 mV/div, $U2$ = 1 V/div.

In Fig. 7 the time series of both x- and y-signals appear. Shows time series of the coordinates X (top) and Y (bottom) respectively (the channels' settings were for channel A, 1V/div and for channel B, 5V/div.

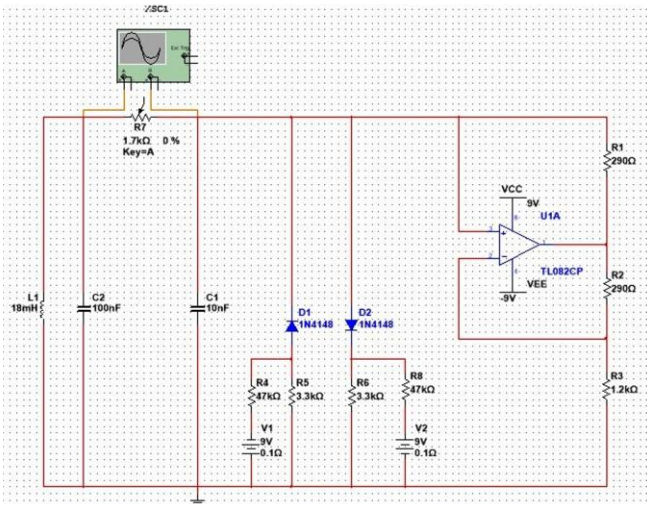

Fig. 5. The classical chaotic Chua's generator

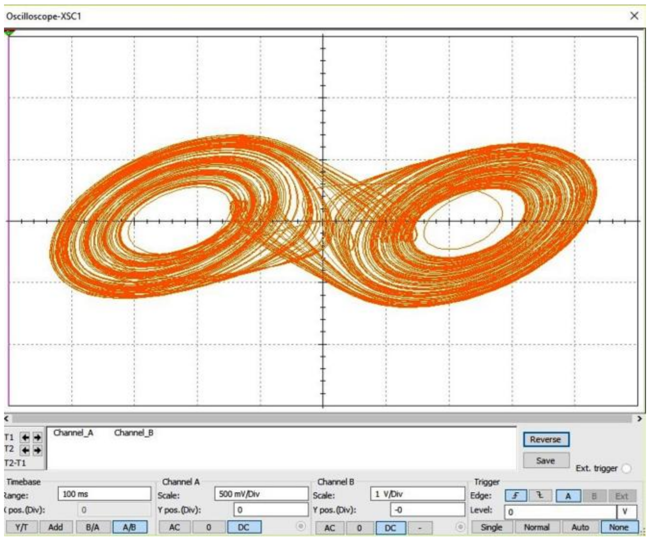

Fig. 6. Chaotic attractor

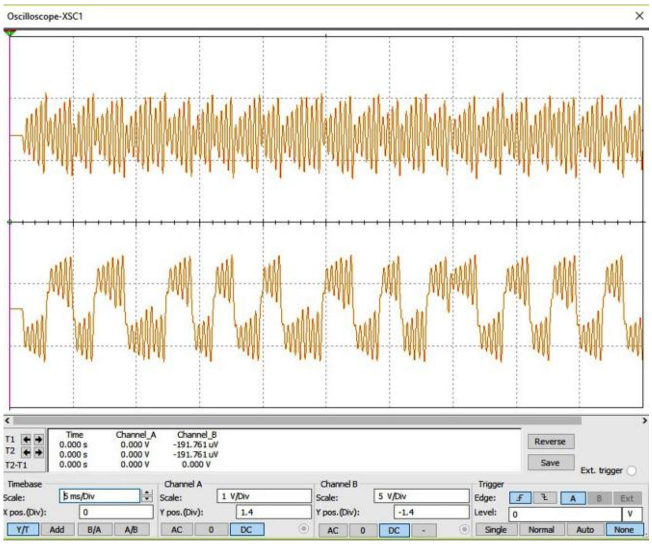

Fig. 7. The x-signal (upper) and the y-signal (lower) time series

4. Computer modelling of the process of the pulse transformation

The electronic circuit with component values is displayed in Fig. 8.

Time series and pulse transformation for chaotic coordinate X are shown in Fig. 9. The simulation parameters: $U1$ = 5 V/div, $U2$ = 5 V/div, time scale 2 ms/div.

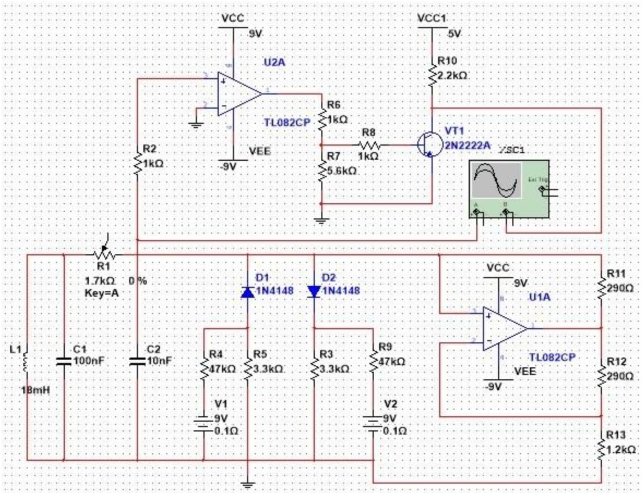

Fig. 8. Circuit realization of the process of pulse transformation

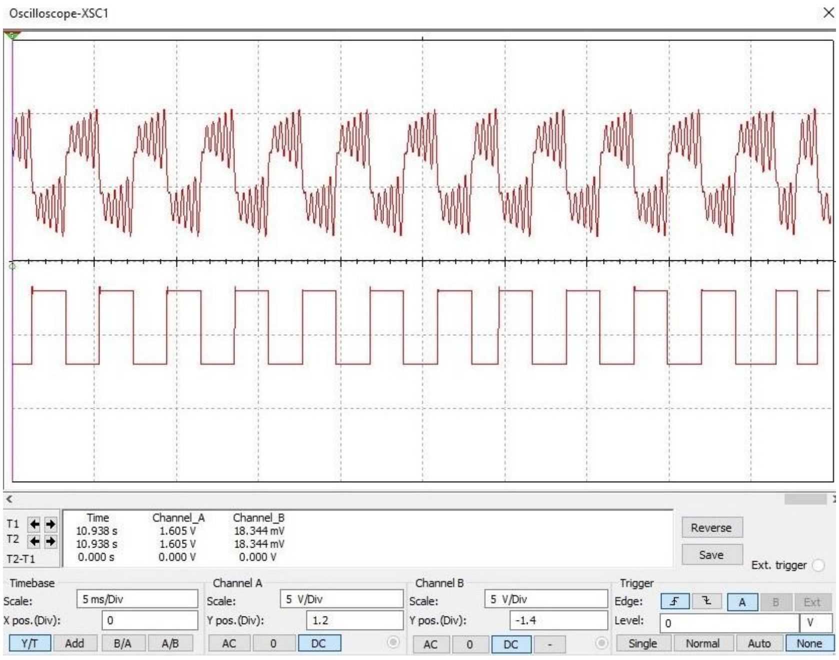

Fig. 9. Time series and pulse transformation

5. Conclusion

There are many circuits that realize generators that exhibit nonlinear operation. A circuit realization to pulse transformation of analog nonlinear oscillation is shown. Computer modelling results and component values are shown.

Using the MultiSim software, a scheme technical analysis circuit of a nonlinear device consisting of one operational amplifier with two diodes and a generator realizing chaotic behaviour was performed. It was submitted by means of a chaotic attractor and a time series of two chaotic coordinates.

A classical chaotic Chua's generator was used as the main part generating the nonlinear signal to demonstrate of this process.

The circuit that generates the chaotic oscillations can be used for masking and decoding information carriers. The process of pulse transformation of analog nonlinear oscillations can be used in modern digital communication systems.

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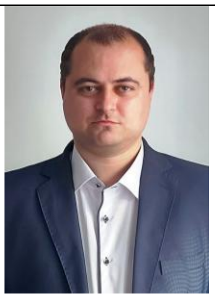

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