

Simulation and circuit implementation of 12-scroll chaotic system



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ABSTRACT

Based on the typical Chua's circuit and the latest research results of multi-scroll system, a model of the new system is constructed to produce multi-scroll chaotic attractors, replacing the typical Chua's diode with the combination of sign function. The major method is to make equilibrium point located in the center of two adjacent breakpoints, and keep scrolls and bond orbits alternated with each other. The chaos generation mechanism is studied by analyzing the symmetry and invariance, the existence of the dissipation and attractor, the system equilibrium and stability. The fractal dimension, the K-S entropy, the time domain waveform and the initial value sensitivity are applied to verifying the chaotic behaviors. The numerical simulations show that the system generates n -double ($n = 1, 2, 3, 4, 5, 6$) scroll chaotic attractors. Finally, the design of the hardware circuit produces at a maximum of 12-scroll hardware experimental results. Theoretical analysis, numerical simulation and hardware experimental results are full matched, which further proves the existence of the system and the physical realization.

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1. Introduction

As an emerging discipline, Chaos has a long history, the origin of which can be traced back to the 19th century. With the development of computer technology, chaotic dynamical systems study has a major breakthrough. In the 1970s, the U.S. weather experts put forward the famous Lorenz system, revealed the basic characteristics of chaotic motion, and laid the foundation for the application of chaos [1]. In 1983, the U.S. electrical expert Cai ST made famous Chua's circuit, which became an important milestone of chaotic development history and lead chaotic from theory to practical application stage [2]. Studies show that simple low-dimensional chaotic encryption systems can be deciphered, and the behavior of complex high

dimensional multi-scroll is difficult to be deciphered. Compared with the traditional single-scroll and double-scroll chaotic system, the multi-scroll chaotic system has more complex structure and dynamic behavior. The multi-scroll chaotic system has better confidentiality, so around the generation of multi-scroll chaotic system and its circuit implementation have more practical significance and application value.

The group of Yalcin, Suykens, Vandewalle proposed some effective methods for generating n -scroll attractors with simple circuits [3–6]. By introducing a piecewise linear characteristic with multiple breakpoints, they are able to create the circuit realization maximum of 5-scroll chaotic attractors [3]. Also, the nonlinear characteristics can be systematically designed by adding comparators, and a 5-scroll attractor circuit realization is shown [4]. Josephson junctions are used in order to generate n -scroll and n -scroll hypercube attractors [5]. Recently, multiscroll chaotic attractors from a hysteresis based time-delay

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differential equation is presented, and the maximum of 5-scroll realization is given [6]. Altogether, they used different nonlinear function to produce the maximum of 5-scroll circuit realization.

In recent years, it has further proposed the forced Chua's circuit, driven memristive Chua's circuit, time-delayed Chua's circuit, the dual Chua's circuit, distortion and other forms of Chua's circuit [7–13]. More recently, some methods to generate multi-scroll chaotic attractors have been proposed, such as hyperbolic functions, colpitts oscillator, switching piecewise linear controller, wavelet-based neural network, switched fractional systems, bond graph technique, Julia process fractal and so on [14–25]. Altogether, computer simulation of more than 10-scroll chaotic attractors is not surprising, but it is not easy to produce more than 10-scroll chaotic attractors of the actual hardware circuit.

In this paper, a model of the new system is constructed to produce multi-scroll chaotic attractors, replacing the typical Chua's diode with the combination of sign function. The chaos generation mechanism is studied by analyzing the symmetry and invariance, the existence of the dissipation and attractor, the system equilibrium and stability. The fractal dimension, the K-S entropy, the time domain waveform and the initial value sensitivity are applied to verifying the chaotic behaviors. The numerical simulations show that the system generates n -double ($n = 1, 2, 3, 4, 5, 6$) scroll chaotic attractors. Finally, the design of the hardware circuit produces at a maximum of 12-scroll hardware experimental results. Notably, this paper presents a maximum of 12-scroll hardware circuit experimental result, moreover, the result is a rare experimental result.

2. Dynamic characteristics of the multi-scroll chaotic system based on sign function

2.1. Construction of the multi-scroll chaotic system

Typical Chua's circuit is capable of generating double-scroll chaotic attractors. The system has rich dynamical characteristics. The circuit implementation is shown in Fig. 1, in which the volt ampere characteristic of Chua's diode is shown in Fig. 2.

The state equation of the above Chua's circuit based on the circuit state analysis is given by

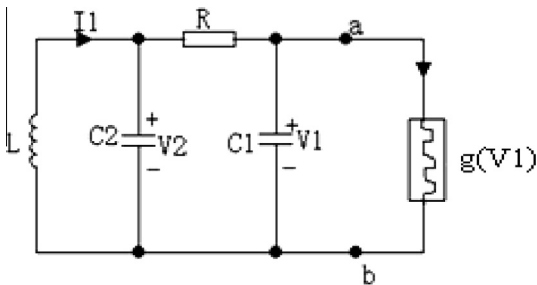


Fig. 1. Typical Chua's circuit.

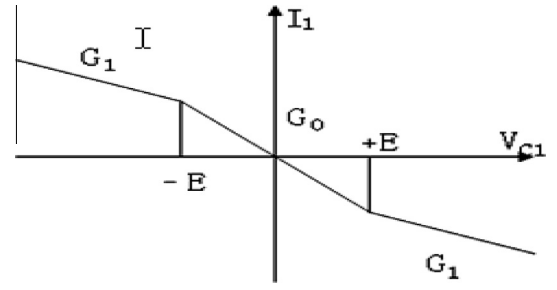


Fig. 2. The volt-ampere characteristic of Chua's diode.

$$\begin{cases} \frac{dV1}{dt} = \frac{V2-V1}{RC1} - \frac{1}{C1}g(V1) \\ \frac{dV2}{dt} = \frac{V1-V2}{RC2} + \frac{I1}{C2} \\ \frac{dI1}{dt} = -\frac{V1}{L} \end{cases} \quad (1)$$

From Fig. 2, we can see that the resistance characteristic of the Chua's diode can be represented by $g(V1) = G_1 V1 + 0.5(G_0 - G_1)(|V1 + E| - |V1 - E|)$. Here, E is the turning point voltage.

Now, consider another dynamical system with the sign function $f(x)$. This system is considered because the Chua's diode is piecewise linear and the sign function can be employed for modeling the piecewise linear function. It is worth noting that every equilibrium points are located in the middle between two adjacent turning points and keep scrolls and bond orbits alternated with each other. Since Eq. (2) is a three dimensional autonomous system, it can be represented as follows

$$\begin{cases} \frac{dx}{dt} = A[y - bx - 0.5(a - b)f(x)] \\ \frac{dy}{dt} = x - y + z \\ \frac{dz}{dt} = -By \end{cases} \quad (2)$$

where controls parameter $a = -\frac{2}{7}$, $b = \frac{2}{7}$, $A = 20$, $B = 30$ and the nonlinearities function is the combination of sign function $f(x) = \sum_{i=1}^{N-2} [\text{sgn}(x + 2i) + \text{sgn}(x - 2i)]$. N denotes the control factor of the scrolls, and N equals to the number of scrolls. This system can generate n -double ($n = 1, 2, 3, 4, 5, 6$) scroll chaotic attractors. Furthermore, this system can generate a 12-scroll chaotic attractors if $N = 12$.

2.2. The chaos generation mechanism

2.2.1. Symmetry and invariance

The proposed system shown by Eq. (2) is transformed by

$$(x, y, z) \rightarrow (-x, -y, -z) \quad (3)$$

Eq. (2) remains unchanged.

The transformation can be expressed as

$$x \rightarrow px, \quad p = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \quad (4)$$

$P: R^3 \rightarrow R^3$, it meets with $g(PX) = Pg(X)$, so the proposed system is symmetric about the origin. Furthermore, the symmetry for all parameters is established.

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