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Research progress of multi-scroll chaotic oscillators based on current-mode devices

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ABSTRACT

Compared to the traditional single scroll and double scroll chaotic systems, multi-scroll chaotic systems present more complex structure and dynamic behavior, possess good application prospect in information security and secure communications. Therefore, theoretical research and circuit implementation of multi-scroll chaotic attractor generation has become a hot spot in the research field of chaos at present domain. In this paper, we briefly overview the recent progress that has been reported in the study of multi-scroll chaotic oscillators based on current-mode devices. Multi-scroll chaotic oscillators are listed according to their electronic implementations. Finally, we list multi-scroll chaotic oscillators based on current-mode devices, and prospect development trends of multi-scroll chaotic oscillators based on current-mode devices in the future.

1. Introduction

In recent decades, chaos in information security, secure communication, digital watermarking and random number, has been widely studied and applied. However, the generation of chaotic attractors with complex topological structure and dynamic behavior is an important prerequisite for the application of chaos in information security and secure communication [1]. Since the single direction multi-scroll chaotic system successfully constructed by Suyken and Vandewalle [2], people have been constructed different nonlinear functions in a variety of different chaotic systems to generate multi-scroll chaotic attractors with more complex dynamic behaviors [3,4], but the multi-scroll chaotic attractors generated only in one direction, and a limited number of scroll. With respect to the general single direction multi-scroll chaotic attractors, multi-direction multi-scroll (MDMS) chaotic attractors are their further extension and expansion, the nonlinear behaviors are more complex, difficult to predict, and more secure.

Over the last two decades, the theoretical design and hardware implementation of various complex multi-scroll chaotic attractors has been a subject of increasing interest [3–10]. Recently, Lü et al. [5] introduced the step and saturated functions series approaches for generating 1-D n-torus, 2-D $n \times m$-grid torus, 3-D $n \times m \times l$-grid torus, and 4-D $n \times m \times l \times p$-grid torus chaotic attractors, with rigorously mathematical proof and physical realization for the chaotic behaviors. Zhang and Yu then [6] proposed a approach to generating two types of grid multi-scroll chaotic attractors from canonical Chuas circuit by constructing hysteresis series and step series. Chen [7] also introduced $n \times m$-scroll attractors with smooth polynomial and non-smooth step function by using Chuas circuit. Yu et al. [8] investigated a systematic methodology for generating various grid multi-wing hyperchaotic attractors by switching control and constructing super-heteroclinic loops from the piecewise linear hyperchaotic Lorenz system family. Compared to the chaotic attractor, a hyperchaotic attractor is characterized as a chaotic attractor with more than one positive Lyapunov exponents, and indicates that the dynamics of the system is expanded in more than one direction. Wang et al. [9] proposed an approach for constructing a high-order Chua's circuit. Based on a dual-port RCL network, MDMS chaotic attractors could be realized by introducing a RC structure and suitable nonlinear functions. Last but not least, Wang et al. [10] proposed a general Chuas system for creating multi-block MDMS chaotic attractors.

Although the successful implementation of multi-scroll chaotic attractors report abound in a variety of different chaotic systems by using different nonlinear functions, but further studies show that, the existing literatures on circuit to realize multi-scroll chaotic oscillators are mostly composed by independent active

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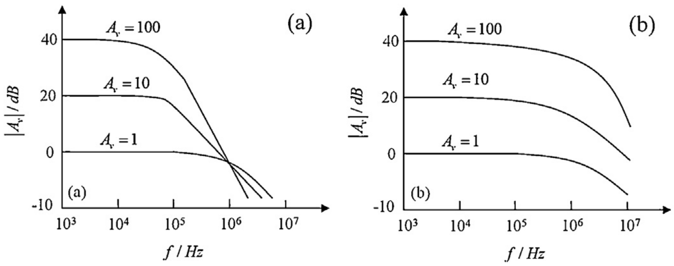

Fig. 1. Gain frequency characteristic curves of active devices (a) μA741 and (b) AD844.

devices, of which the main active devices are operational amplifiers (Opamp) [2–10]. Opamp is a voltage-mode device with a low conversion rate and narrow dynamic range [11], and its gain bandwidth product is finite, and the tradeoff between gain and bandwidth must be made in the design of the circuit. As shown in Fig. 1(a), the gain bandwidth product of universal operational amplifier μA741 is about 1 MHz. When the circuit's amplification is 100, the bandwidth of the circuit is only 10 kHz, which greatly limits the operating frequency of the circuit. And the circuit structure has got some defects, such as high power consumption and large area, all of which have restricted it from the application of low-voltage low-power consumption, high frequency and chip implementation, that it is difficult to produce really adapt to secure communication high frequency multi-scroll chaotic signal. The gain frequency characteristic of a typical current feedback operational amplifier (CFOA) AD844 is shown in Fig. 1(b), it can be seen that the current-mode devices have good frequency gain characteristics. The bandwidth of these kind of devices are almost independent of gain, so there are no need to weigh the gain and bandwidth in the design circuit, which can improve the working frequency of the circuit. Meanwhile, an amplifier composed of a current-mode device is more than a current output terminal of an amplifier composed of a voltage-mode device, so the circuit structure composed of the current-mode device is simpler, the function is stronger, and the use is more flexible [12].

In recent years, with the current-mode devices to realize multi-scroll chaotic oscillators have gradually become a new research direction, these current-mode devices include CFOA, second-generation current conveyor (CCII), operational transconductance amplifier (OTA), unity-gain cells (UGCs), floating-gate MOSFET (FGMOS), second-generation current controlled current conveyor (CCCII). Among them, OTA, UGCs and FGMOS can be collected into MOS integrated circuits. This paper reviews the current-mode devices advances in the research of multi-scroll chaotic oscillators, gives some of the key technical features of multi-scroll chaotic attractors achieving by current-mode devices, and prospects on the development trend of multi-scroll chaotic oscillators based on current-mode devices.

2. Multi-scroll chaotic oscillators based on current-mode devices

2.1. Multi-scroll chaotic oscillators based on CFOA

CFOA has good dynamic characteristics, due to the voltage conversion rate and linear processing signal ability than the general Opamps [13], many scholars have used CFOA to achieve multi-scroll chaotic oscillators. As early as 1997, Elwakil et al. [14] used CFOA devices to construct nonlinear function in chaotic circuits, two kind of different single scroll chaotic attractors were discovered by two chaotic oscillators. In the same year, Elwakil et al. [15,16] successfully constructed the sine wave oscillator and crystal type field effect transistor by adopting CFOA devices, two single scroll chaotic attractors oscillator have been realized. In 1998, Senani et al. [17] constructed simulated inductance and Chua's diode by using CFOA in Chua's circuit, the realization of the double scroll chaotic attractors oscillation frequency was about 4.2 kHz. Elwakil and Kennedy [18] then used a single CFOA and storage components to construct single scroll chaotic attractor in Wien bridge oscillator circuit. In 2000, Elwakil and Kennedy [19,20] improved the sine wave oscillator and Chua's chaotic oscillator, the negative impedance converter of oscillator realized by CFOA, a single scroll with the highest vibration frequency of 10 MHz and double scroll chaotic attractors with the center frequency of 522 kHz were achieved respectively. Kilic [21] used CFOA instead of the nonlinear resistors and inductors in traditional Chua's circuit, the Chua's double scroll chaotic attractors of oscillation frequency successfully increased to 2.25 MHz. In 2006, Tlelo-Cuautle et al. [22] employed two current mirrors to connect two voltage followers to realize Chua's diode with CFOA, the current-mode modified chua's circuit was successful implemented by using 0.35 μm CMOS process. Jothimurugan et al. [23] reported a non-inductive third-order autonomous Chua's circuit in 2014, the circuit of the active device was designed by using CFOA and hardware experiment showed that multi-scroll attractors oscillation frequency attained 810 kHz. In addition to Chua's circuit, the researchers also successful implemented multi-scroll chaotic circuit by using CFOA devices in other systems. Such as Srisuchinwong et al. [24] proposed a sprott chaotic oscillator based on CFOA, the Jerk nonlinear functions achieved by CFOA, so that the oscillator worked in voltage and current mode and the measured center frequency of multi-scroll oscillator was 1.21 MHz. Qing et al. [25] combined CFOA with four kinds of basic circuit elements capacitance, inductance, resistance, memory resistor ingenious to design a model of memristor chaotic circuit, the numerical simulation results showed that the circuit could have 2 kHz single scroll chaotic attractor.

The above literatures achieved just the single scroll or double scroll attractors, in order to produce more complex attractors, researchers successively put forward 3-scroll attractor [26] and grid multi-scroll attractors [27] based on CFOA. The grid multi-scroll chaotic circuit was as shown in Fig. 2 proposed by Ref. [27], wherein SNLF was a saturated nonlinear function. It can be seen that CFOA has good frequency characteristics and port characteristics, the circuit has the advantages of simple structure, high center frequency, less active devices, but because of CFOA has large static DC error, low transmission function accuracy and other shortcomings, the design of chaotic circuit would generate a certain error.

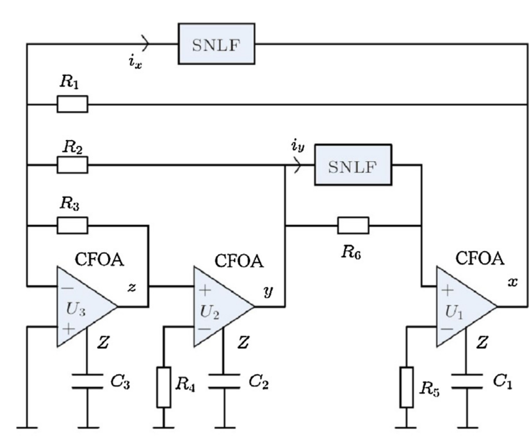

Fig. 2. The diagram of grid multi-scroll chaotic oscillator based on CFOA proposed by Ref. [27].