Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 7, No. 1, 2023

Research on the Characteristics of Typical Chaotic Circuits

Yong Deng, Bowen Li

Southwest Petroleum University, Chengdu 610065, China

Abstract: Chaotic circuit, also called nonlinear circuit. Up to now, there is no unified definition in academic circles. The most typical chaotic circuit is the Chua's circuit invented by the Chinese scientist Cai Shaotang. In order to study the chaos characteristics of Chua's circuit, this paper studies the hardware design and software simulation of Chua's circuit. In terms of hardware, in order to verify the feasibility of the components selected in this paper, the simulation is carried out on the basis of Multisim software. In the aspect of software, based on the best display effect of the result graph, this paper chooses Simulink in MATLAB software to simulate the model. Under the software simulation, the chaos phenomenon is observed. Through the modification of various parameters, the chaos imagination corresponding to the theory is obtained. Finally, the research results are analyzed and the conclusion is obtained.

Keywords: Chaos, Chua's circuit, Simulation, Matlab, Characteristics.

1. Introduction

There is still no clear definition of chaos, which means that there is still a huge unknown waiting to be explored. As for the chaotic circuits, many improved chaotic circuits have appeared, but if we want to get more results on the chaotic circuits, we still need to keep on researching on them. The purpose of the research is to have a more complete and systematic results and conclusions for this area and to use them in practice. Chaotic circuits, which have a huge role in many applications, especially in the field of communication security, are particularly promising. In the very important area of communication security, the signals emitted by chaotic circuits have a very important characteristic, which is that they are extremely sensitive to certain conditions. Signals modulated by chaotic circuits as carriers have similar sensitivity. Therefore, even if the modulated chaotic signal is received by a non-receiver, it is very difficult to receive the correct signal, because the chaotic signal is very difficult to be cracked, which provides an important basic condition for the application of chaotic circuits to secure communications.

1. theoretical foundation

In 1983, Prof. Siu-Tong Tsai, a Chinese American scientist, invented Tsai's circuit. This is a kind of nonlinear circuit, and this circuit can exhibit the standard theoretical chaos phenomenon. The biggest advantage of this circuit is that it is simple in structure and easy to realize. It can be called the most typical chaotic circuit. The diagram of Tsai's circuit is shown below:

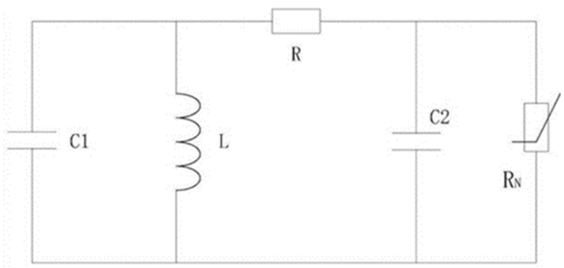

Figure 1. Circuit diagram of Tsai

The component Rn on the far right of the diagram is called a Zeiss diode and is not currently commercially available. Instead, we generally use other components. A combination of an operational amplifier and a resistor is usually used instead of a Chua's diode. The operational amplifier is not unique and is usually the TL082, but other operational amplifiers can be used. As shown in the figure below:

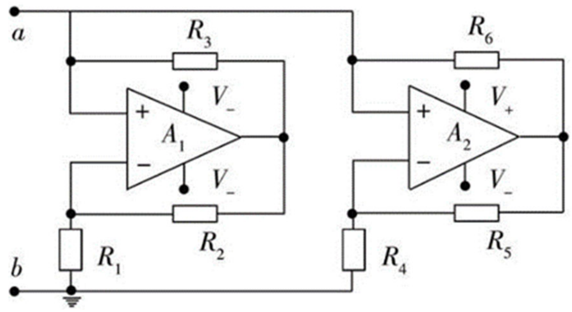

Figure 2. Chua's Diode Substitution Diagram

The equation of state for the Chua's circuit can be derived from the circuit diagram as follows:

$$C_1 \frac{dv_{c1}}{dt} = G(v_{c2} - v_{c1}) - g(v_{c1}) \quad (1)$$

$$C_2 \frac{dv_{c2}}{dt} = G(v_{c1} - v_{c2}) + i_L \quad (2)$$

$$L \frac{di_L}{dt} = -V_{c2} \quad (3)$$

Vc1 represents the current flowing across C1, Vc2 represents the current flowing across C2, Uc1 is the voltage across C1 and Uc2 represents the voltage across C2. In order to simplify the equations of the circuit and reduce the parameters, the following dimensionless equation is obtained as shown in the figure:

$$\dot{x} = a1\big(y - k(x)\big) \quad (4)$$

$$\dot{y} = x - y + z \tag{5}$$

$$\dot{z} = a_2 y \tag{6}$$

2. Hardware Circuit Simulation

MULTISIM software has been chosen to simulate the analog circuit becausethescheme is clear and the circuit model is given directly below as follows:

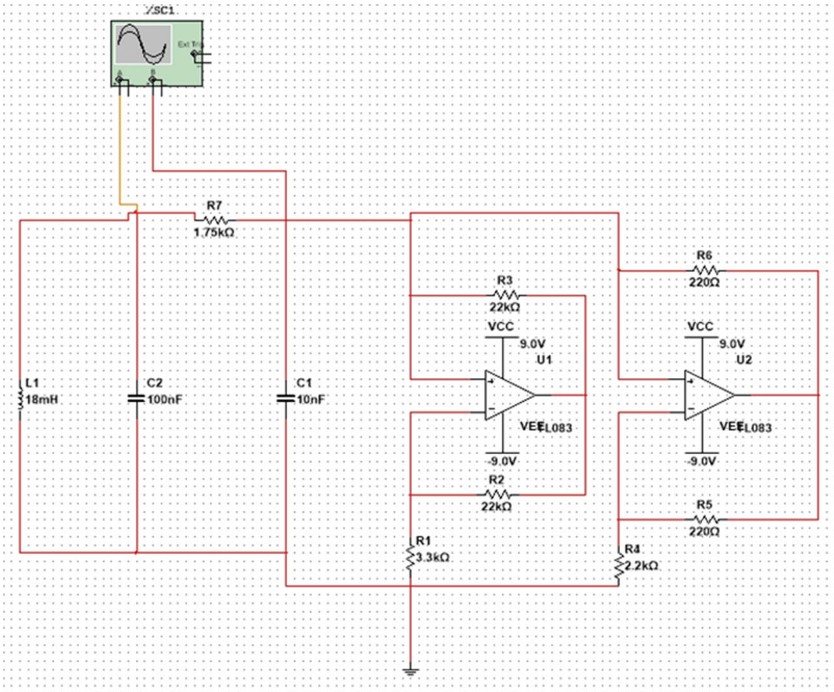

Figure 3. MULTISIM Chua's Circuit Modeling Diagram

The model building is completed and the chaotic circuit phenomenon can be observed accurately and clearly, and the results are shown below:

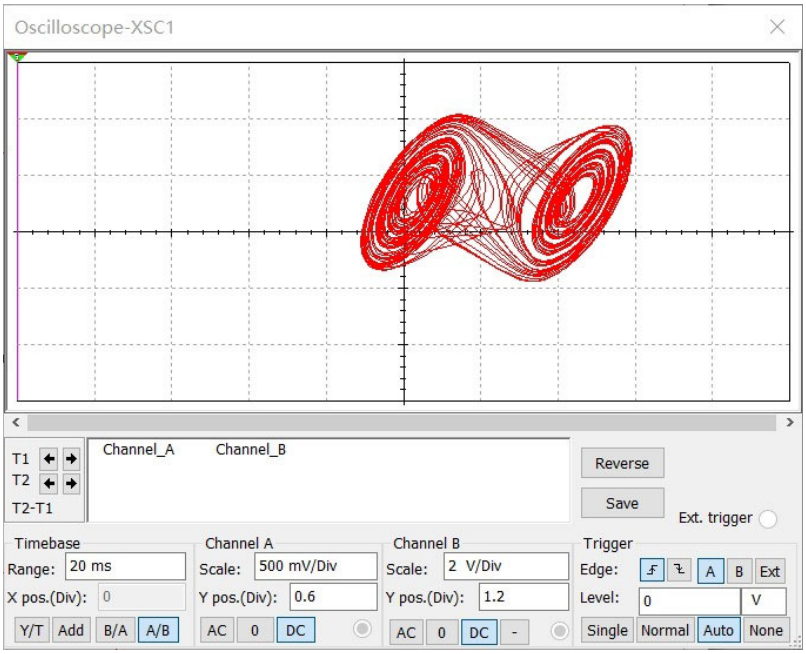

Figure 4. MULTISIM simulation result plot

3. Software Modeling

Simulink software is a powerful software from Mathworks, which is often used in combination with MATLAB software, and is usually embedded in MATLAB, equivalent to a functional module, which has powerful simulation and image display

functions, so it is also one of the reasons for choosing it for this simulation. After the selection and connection of modules, the simulation model of the Chua's circuit was finally built. The built model is shown below:

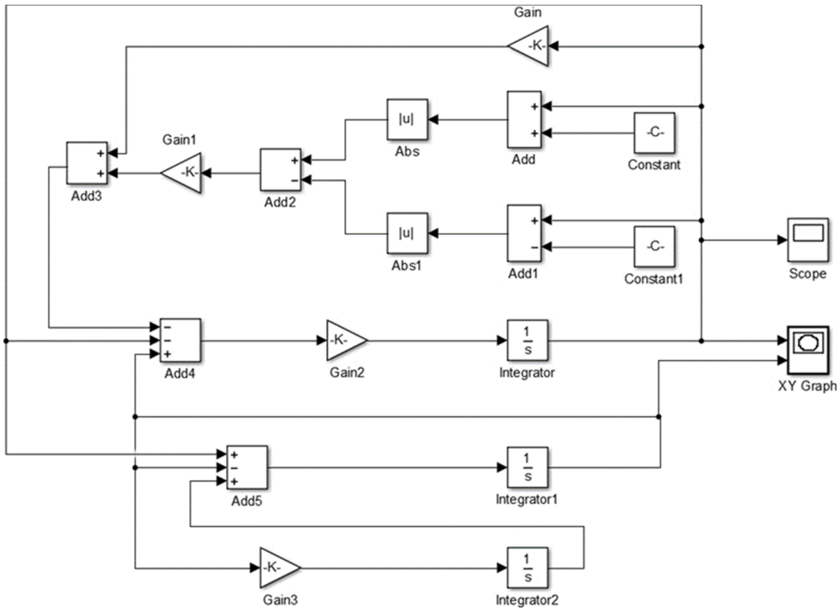

Figure 5. Chua's circuit model diagram

4. Test

4.1. Changing the capacitance value

In Chua's circuit there are two capacitors one is C1 and one is C2.C1=10nF, C2=100nF. This is fixed and generally people say that Chua's circuit is not changed by the parameters. And in this study, the fixed parameters in the Chua's circuit are only adjusted in order to observe different chaotic phenomena.

For the Chua's circuit, changing the value of capacitance only requires changing the value of capacitance C1, and the change of C1 is related to the value of the gain module in the model. In the gain module, Gain2 represents the parameter a in the dimensionless equation of the Chua's circuit, i.e., if you change a, you change the capacitance.

(1) When the capacitance value is 16.5nF, a=5.86. Run the simulation and the results are as follows:

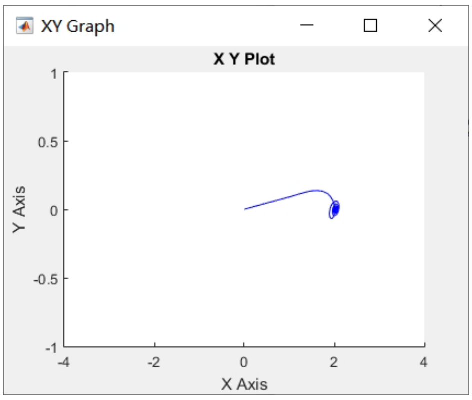

Figure 6. Stable state phase

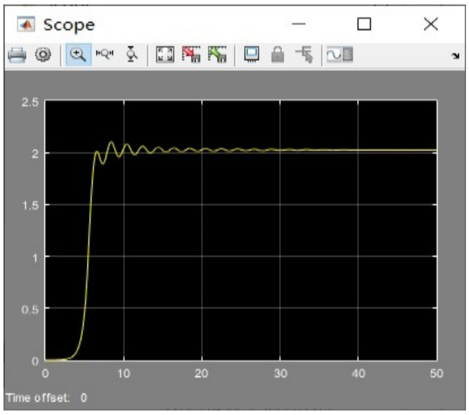

Figure 7. Stable state timing

As can be seen from the phase diagram, the chaotic phenomenon of the Chua's circuit is being stabilized at this point, as the trajectory is essentially smooth at this point, with little movement.

(2) When C1=14.5nF, a=6.95. run the simulation with the following results:

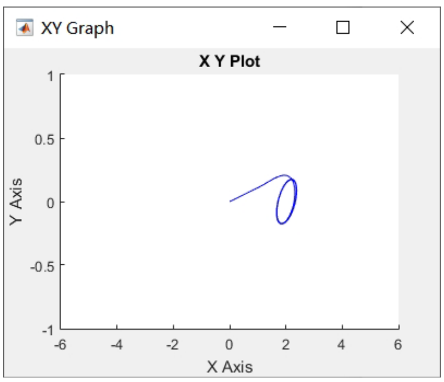

Figure 8. Single-cycle state phase

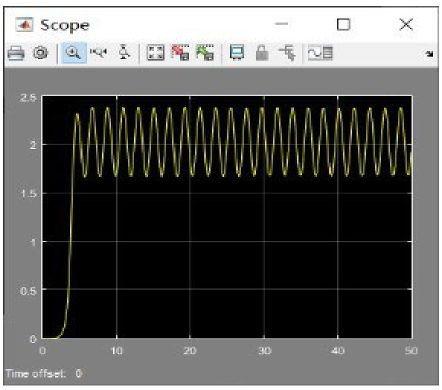

Figure 9. Single-cycle state Timing

The phase diagram at this point is a single cycle chaotic state. The phase diagramappears to be a ring, and the number of rings is not high enough to converge to one ring, so it can be determined that this is a single cycle chaotic state.

(3) when C1=13.6, a=7.35, run the simulation and the results are as follows:

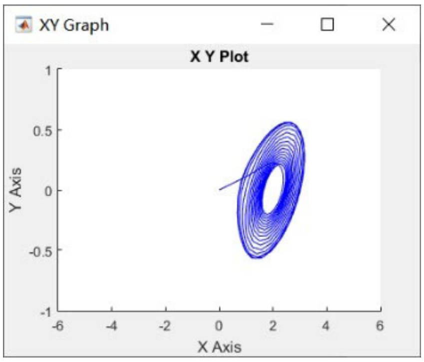

Figure 10. Multiple Cycle state phase

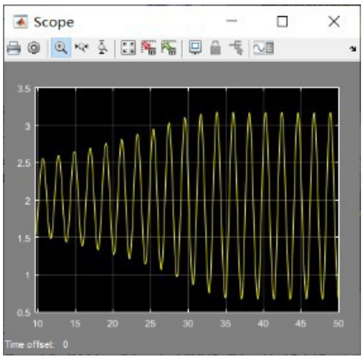

Figure 11. Multiple Cycle state Timing

The phase diagram at this time is similar to the previous one when a=6.95, both of them are in the shape of ring, but the difference is that the number of rings in the phase diagram at this time is more, and there is obvious periodicity, so it can be judged that the chaotic state at this time is a multiplicative cycle chaotic state.

(4)when C1=12.5nF, a=8, run the simulation and the results are as follows:

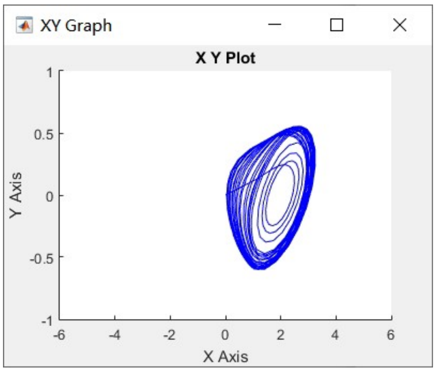

Figure 12. Single vortex state phase

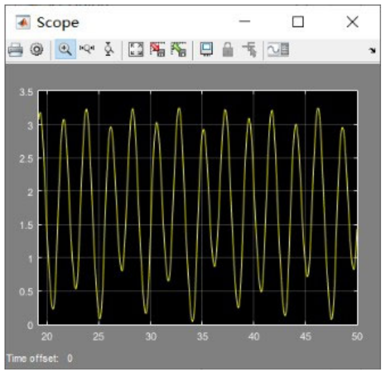

Figure 13. Single vortex state timing

As you can tell from the phase diagram, this is a single vortex chaotic state, which can also be referred to academically as a Losle shape state. One of the single vortex states actually has a distinct periodicity, so sometimes the single vortex state is also categorized as the first cycle.

(5)when C1=10.8nF, a=9.235, run the simulation and the results are as follows:

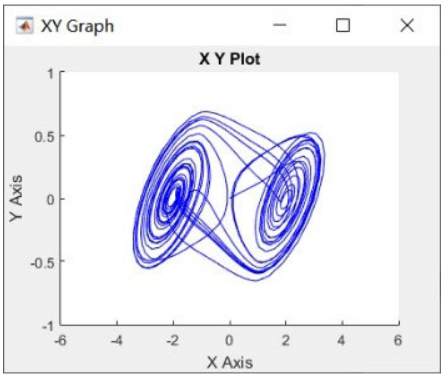

Figure 14. Double vortex state phase

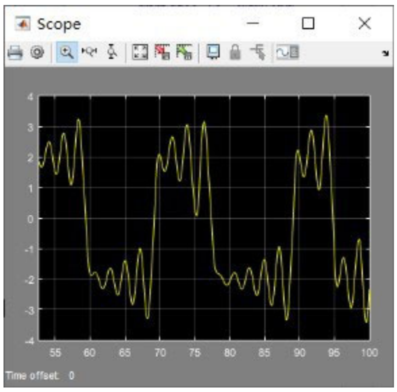

Figure 15. Double vortex state timing

The phase diagram at this point was, quite obviously, another vortex added to the phase diagram of the single-vortex state, which is academically called the double- vortex chaotic state. Although it looks chaotic, the periodicity is also more pronounced.

4.2. Changing the resistance value

For the Chua's circuit, a change in the value of the resistor R. A change in R is modeled as a change in the value of the gain module. In the gain module, Gain3 represents the parameter b in the dimensionless equation of the Chua's circuit, i.e., if you change b, you change the resistance. In a Chua's circuit, the resistance of the non-Chua's diode part tends to be around 2KΩ. So adjusting the resistance would

(1) When R=1.9KΩ, b=-20, run the simulation and the results are as follows:

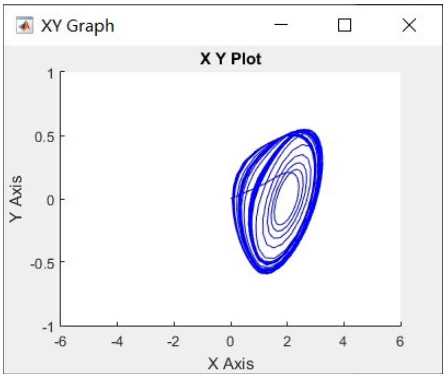

Figure 16. Stable state phase

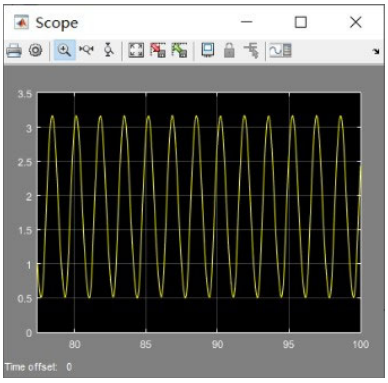

Figure 17. Stable state timing

As can be seen from the phase diagram, the chaotic state at this point is in a single vortex chaotic state, which is very similar to the phase diagram that appears when changing the value of the capacitance, although the difference is that their timing diagrams are a little different, the peaks of the timing diagrams that appear when changing the resistance are almost unchanged, while the other is periodically changing.

(2) When R=1.6KΩ, b=-16. run the simulation and the results are as follows:

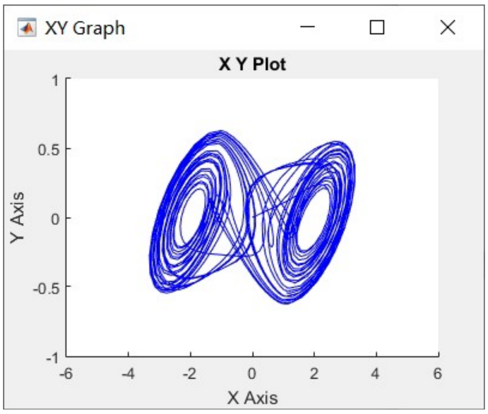

Figure 18. Double vortex state phase

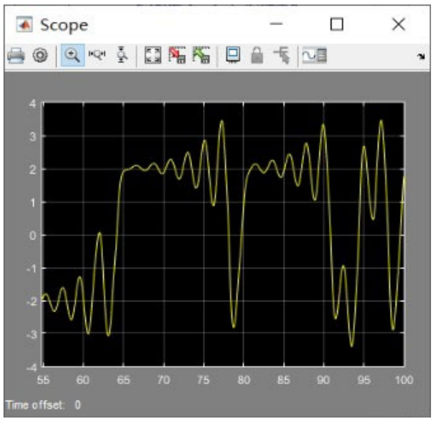

Figure 19. Double vortex state timing

From the phase diagram at this point, it is known that the chaotic state is a double vortex state. The phase diagram is also almost the same as the phase diagram when changing capacitance.

(3) When R=2.2KΩ, b=-24.2, run the simulation and the results are as follows:

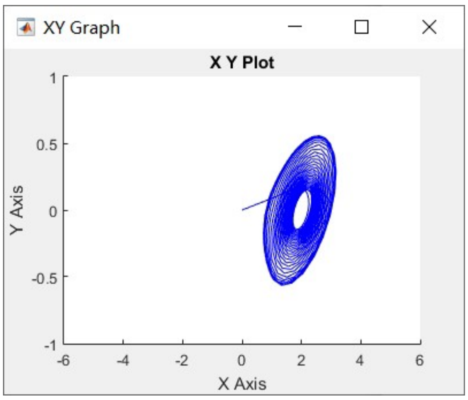

Figure 20. Multiple Cycle state phase

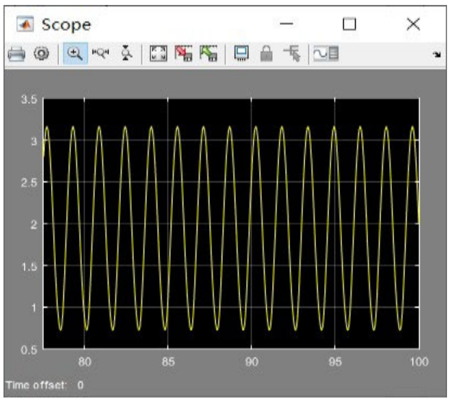

Figure 21. Multiple Cycle state Timing

At this time, the phase diagram is ring-shaped, and the periodicity is obvious, the number of rings is more, it can be judged as a multiplicative cycle chaos state.

(4) When R=2.45KΩ, b=-26.35, run the simulation and the results are as follows:

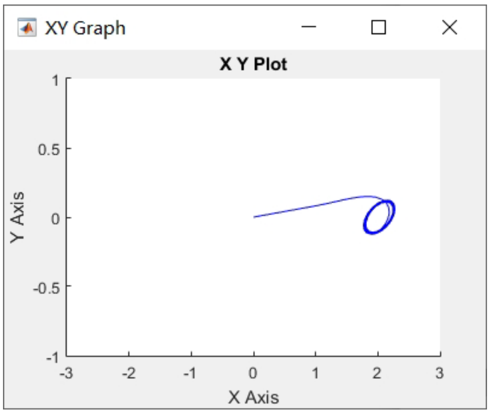

Figure 22. Single-cycle state phase

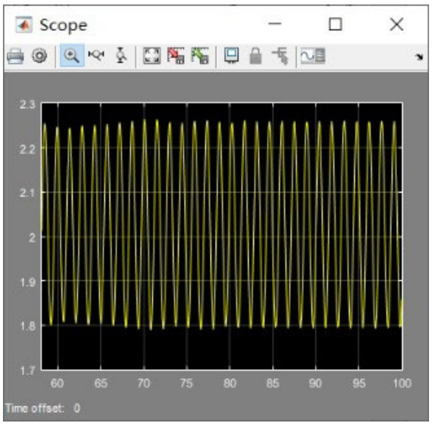

Figure 23. Single-cycle state Timing

At this time, the phase diagram is ring-shaped, the number of rings is very small, infinitely converging to 1 ring, basically can be judged as a single cycle chaotic state.

(5) When R=2.65KΩ, b=-35.5, run the simulation and the results are as follows:

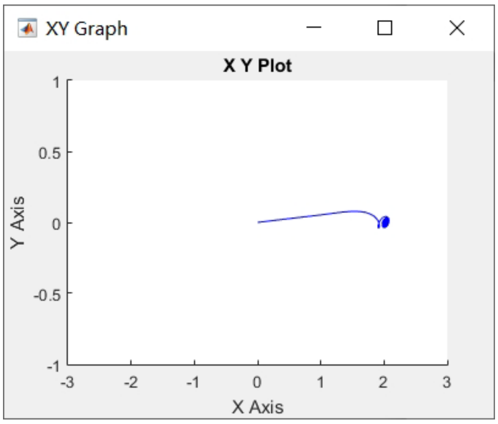

Figure 24. Stable state phase

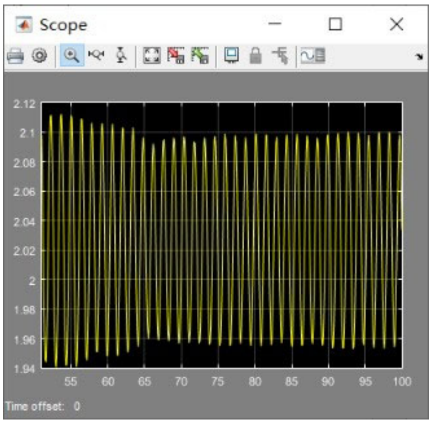

Figure 25. Stable state timing

As can be seen from the phase diagram at this point, the chaotic phenomenon of the Chua's circuit is stabilizing at this point, as the trajectory is essentially smooth at this point, with little movement.

5. Summary

In a Chua's circuit, there are two important parameters, the value of the resistanceoutside the non-Chua's diode and the value of the capacitor C1. Changes in both of these parameters affect the state of the Chua's circuit and the chaos phenomenon changes.As the value of capacitor C1 gradually varies from large to small, the value of gain a in the Chua's circuit model constructed in MATLAB also gradually varies from small to large, and the phase diagram of the chaotic phenomenon of the Chua's circuit becomes more and more divergent.

The other parameter, the non-Cai diode resistor value, as this resistor value continues to get smaller, the absolute value of the gain b will also get smaller as the resistor value gets smaller. The operating state of the Chua's circuit will also slowly transition from an apparent steady state to a periodic vortex state.

From the simulation results of this study, it seems that almost all chaotic states,except for the steady state, show significant

The periodicity phenomenon of the circuit is also observed from the time domain waveform instead of the phase diagram. When a = 10 resistance value, this time from the time domain waveform, rather than the phase diagram, can also be observed from the obvious periodic phenomenon, indicating that, not only the phase diagram, the circuit's time domain waveform is also correspondingly periodic. However, only at this point in the operation of the circuit state of the most obvious periodicity, in other resistance values, the periodicity is less obvious.

For the Chua's circuit, it is inherently very sensitive to changes in these two key parameters. So the chaotic state of the Chua's circuit is very unstable, but it exhibits a part of order and periodicity.

References

[1] V. T. Pham.A Novel Mega-stable Chaotic Circuit. [J]. Radioengineering, 2020(4).

[2] Rawid Banchuin.On the Dimensional Consistency Aware Fractional Domain Generalization of Simplest Chaotic Circuits. [J]. Mathematical Problems in Engineering.2020(3).

[3] Nestor Tsafack.Design and implementation of a simple dynamical 4-D chaotic circuit with applications in image encryption. [J]. Information Sciences.2020(3).

[4] Francisco M. Fernández Comment on: "Harmonic oscillator in an elastic medium with a spiral dislocation"[J] Physica B. Physics of Condensed Matter, 2020, 577.

[5] Taro Kanao, Hirofumi Suto, Koichi Mizushima et al. Layer-selective detection of magnetization directions from two layers of antiferromagnetically- coupled magnetizations by

ferromagnetic resonance using a spin-torque oscillator[J] Journal of Magnetism and Magnetic Materials, 2020, 495.

[6] Martin Sommerfeld, Silvio Schmalfuß Analysis and optimization of particle mixing performance in fluid phase resonance mixers based on Euler/Lagrange calculations[J] Advanced Powder Technology, 2020, 31(1).

[7] P. Tomczak, H. Puszkarski Interpretation of ferromagnetic resonance experimental results by cross-validation of solutions of the Smit-Beljers equation[J] Journal of Magnetism and Magnetic Materials, 2020, 507.

[8] Magdi S. Mahmoud, Yuanqing Xia, Sixing Zhang Robust packet-based nonlinear fuzzy networked control systems [J] Journal of the Franklin Institute, 2018.