Suppression of Chaos Propagation in Ladder Chaotic Circuits by Local Switching of Coupling Strength

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***Abstract*— Various phenomena have been observed in coupled chaotic circuits. One of the phenomena in chaotic synchronization is the chaotic propagation. It has been investigated what kind of frustrations affect the chaotic propagation. These have been investigated for both simple and complex networks. In this study, the chaos propagation in the ladder-coupled chaotic circuits is studied by computer simulation, using the voltage difference between the adjacent circuits as the threshold for switching the coupling strength.**

***Keywords;* Chaotic circuit; Chaos propagation**

I. INTRODUCTION

Various phenomena have been observed in coupled chaotic circuits. The collapse of the chaotic synchronization [1] and the clustering phenomena [2] have attracted attention and have been studied. However, it is believed that there are still many unexplained phenomena in chaotic synchronization. Therefore, it is important to discover, model, and investigate such phenomena in order to understand and utilize them.

One of the synchronous phenomena observed in coupled chaotic circuits is chaos propagation, which occurs when one chaotic circuit is set to generate chaos and the others are set to generate a three-period attractor. The propagation time and the propagation rate have been considered by the coupling strength [3], changing the network structure, and the location where the chaos is generated [4]. In the past, a method to change the network topology by probability [5] has been proposed as one of the frustrations to the chaos synchronization.

In this study, we utilize this method to investigate the effect of switching the coupling strength on the propagation of chaos in ladder chaotic circuits. The chaos propagation is investigated in three different ways of changing the coupling strength by means of computer simulation.

II. SYSTEM MODEL

The chaotic circuit is shown in Fig. 1. This circuit consists of a negative resistor, two inductors, a capacitor and dual-directional diodes. The system model is shown in Fig. 2. In this system, the circuit in the one end of the system generates chaotic attractor and the other circuits generate three-periodic attractors. Ten chaotic circuits next to each other are coupled together with resistors.

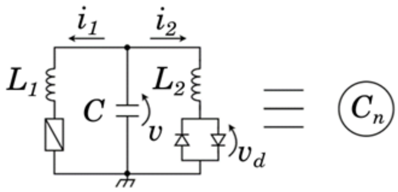

Figure 1: Circuit model.

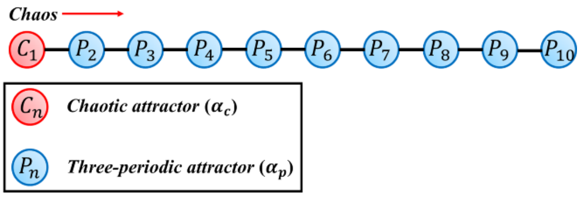

Figure 2: System model.

The parameters are described as follows:

$$\begin{cases} i_1 = \sqrt{\dfrac{C}{L_1}} V x_n, \quad i_2 = \dfrac{\sqrt{L_1 C}}{L_2} V y_n, \quad v = V z_n \\ \alpha = r\sqrt{\dfrac{C}{L_1}}, \quad \beta = \dfrac{L_1}{L_2}, \quad \delta = r_d \dfrac{\sqrt{L_1 C}}{L_2}, \\ \gamma = \dfrac{1}{R}, \quad t = \sqrt{L_1 C}\tau. \end{cases}$$

The normalized circuit equations are described as follows:

$$\begin{cases} \dfrac{dx_n}{d\tau} = \alpha x_n + z_n \\ \dfrac{dy_n}{d\tau} = z_n - f(y_n) \\ \dfrac{dy_n}{d\tau} = -x_n - \beta y_n - \gamma_{n,n-1}(z_n - z_{n-1}) \\ \qquad -\gamma_{n,n+1}(z_n - z_{n+1}) \\ (n = 1,2,\cdots,N) \end{cases} \quad (1)$$

where

$$\gamma_{1,0} = \gamma_{N,N+1} = 0$$
$$f(y_n) = \frac{\delta}{2}\left(\left|y_n + \frac{1}{\delta}\right| - \left|y_n - \frac{1}{\delta}\right|\right).$$

For the computer simulations, we calculate Eq. (1) using the fourth-order Runge-Kutta method with step size $h = 0.005$. We set the parameters of this circuit model as follows; $\alpha_c = 0.460$, $\alpha_p = 0.413$, $\beta = 3.0$ and $\delta = 470.0$.

III. Results

A. Fixed the couplings strength

Chaos propagation is researched in ladder chaotic circuits, when the coupling strength is fixed at $\gamma = 0.002, 0.004,$ 0.006, and 0.008. The horizontal axis is the value of x_n representing the current flowing in L_1, and the vertical axis shows the value of z_n representing the voltage applied to C.

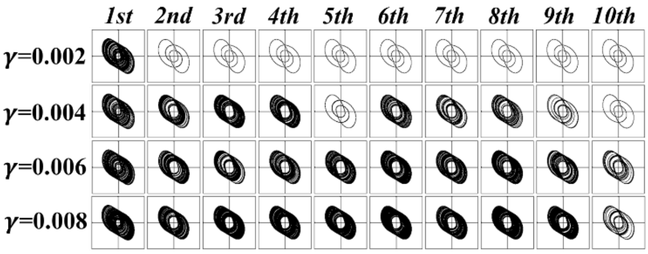

Figure 3: Chaos propagation under fixed coupling strength

The propagation state at almost the same time is shown in Fig. 3. As the coupling strength increases ($\gamma = 0.004, 0.006,$ and 0.008), the number of circuits for chaotic propagation becomes larger. In particular, no propagation was observed in case of a coupling strength $\gamma = 0.002$.

B. Switching coupling strength

The chaos propagation is changed by switching the coupling strength with the difference of z_n and z_{n+1} as a threshold. The first method is to switch all the couplings simultaneous, and the second method is to switch each coupling at a certain. How to switch the coupling strength is shown in Fig. 4.

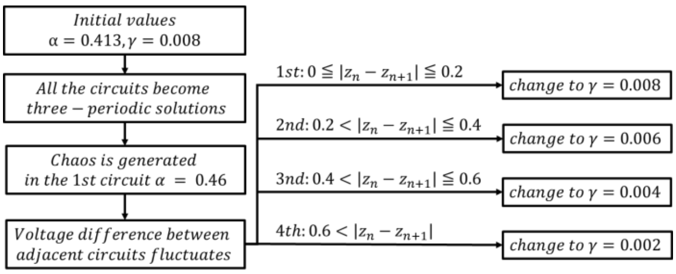

Figure 4: The algorithm for controlling chaotic propagation by coupling strength (The threshold widths are all 0.2).

(1) *Switching all couplings simultaneous*

When the voltage difference at one coupling exceeds the threshold, all couplings switch. In Fig. 5, the maximum number of circuits propagated chaos is fifth, when the third threshold width is 0.1. For the other threshold widths, that is fourth. In a few seconds, the coupling strength decreased from 0.008 to 0.002 and then remained at 0.002.

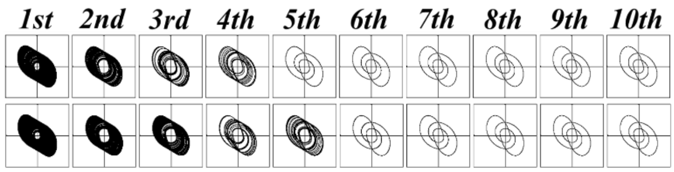

Figure 5: Chaos propagation after a certain time. (Same time as Fig. 3)

(2) *Switching each coupling*

When the coupling strength is switched for each coupling, propagation can be classified into four patterns as shown in the Fig. 6.

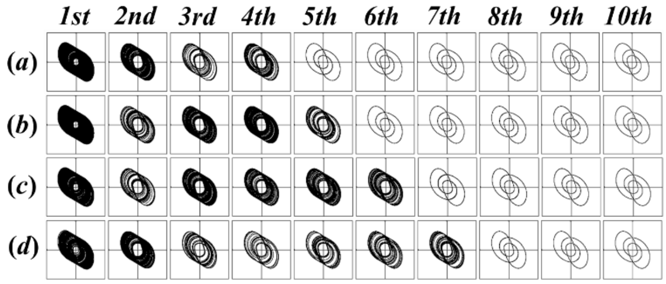

Figure 6: Four patterns of chaos propagation.

When the first threshold width is $0 \leq |z_n - z_{n+1}| \leq 0.2$, the chaos propagation can be suppressed as shown in the Fig. 6(a)-(c). As the second threshold width increases to 0.1, 0.2 and 0.3, the number of circuits for chaotic propagation becomes larger to 4th, 5th and 6th as well as when the first threshold widths are 0.1 and 0.3. However, when threshold widths are 0.1, 0.1 and 0.4 from 1st to 3rd step in the algorithm, the number of circuits propagated chaos becomes the largest as shown in Fig. 6(d).

IV. Conclusion

In this study, chaos propagation in a ladder-coupled chaotic circuit was studied when the coupling strength was switched. The propagation was regulated in three ways: fixed coupling strength, simultaneous switching of all the couplings, and switching at each coupling. The results show that the propagation of chaos can be controlled locally, and even in the case of switching at each coupling, the propagation can be suppressed as well as in the method of switching all the couplings at the same time by considering the decision criteria. In the future, we would like to focus on the propagation process such as recovery from chaos and indirect propagation.

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