1-7

Switching Synchronization State of System Including Time Delay in One Direction

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1. Introduction

The generation of chaos has been reported in all self-excited oscillation systems containing a time delay [1].

In this study, we devise coupled systems that take advantage of the features of time-delayed chaotic circuits. The novel coupled systems utilize the characteristics of circuits having time-delayed feedback. We investigate the synchronization state in coupled time-delayed chaotic circuits. By carrying out computer simulations, it is shown that the time delay of subcircuits changes the synchronization state.

2. Circuit Model

The circuits in this study employ characteristic time delay methods. We have devised the coupled system shown in Fig. 1. This system is coupled by resistors R. This system includes a time delay in one direction. The normalized circuit equations of the system are given as follows:

(A) In the case that the switch is connected to the negative resistor

$$\begin{cases} \dot{x}_n &= y_n \\ \dot{y}_n &= -x_n + 2\alpha y_n + \gamma(y_{n-1} - 2y_n + y_{n+1}) \end{cases} \quad (1)$$

(B) In the case that the switch is connected to the positive resistor

$$\begin{cases} \dot{x}_n &= y_n \\ \dot{y}_n &= -x_n - 2\beta y_n + \gamma(y_{n-1} - 2y_n + y_{n+1}) \end{cases} \quad (2)$$

where $n = 1, 2, 3$ and $y_0 = y_3$, $y_4 = y_1$. Generally, switching synchronization can be observed when the system including a time delay in one direction is coupled by resistors R. The amplitude alternately diverges and converges with different divergence and convergence times.

3. Simulation Results

The result shown in Fig. 2 can be obtained from the difference in the coupling strength γ and the time delay T_{dn}. The time waveform in Fig. 2(a) shows in-phase synchronization and the amplitude of x_n is switched sequentially. However, when γ is larger than 0.05, the switching synchronization state is lost and a full in-phase synchronization state can be observed. Furthermore, the synchronization state is changed by time delay. The cycle of synchronization state shows in Fig. 3. When the time delay T_{dn} are asymmetric, the cycle approaches stable regardless of the time delay.

4. Conclusions

In this study, we investigated the synchronization state of novel coupled systems of time-delayed chaotic ring circuits coupled by various methods. As a result, some special synchronization states were observed. In the case of a ring circuit coupled by resistors, we observed an in-phase synchronization state. Switching of the amplitude of the voltage in addition to the in-phase synchronization state was observed from the difference of coupling strength and time delay. Furthermore, the cycle of switching synchronization state is changed by combination of the time delay.

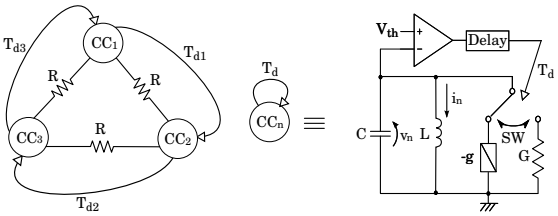
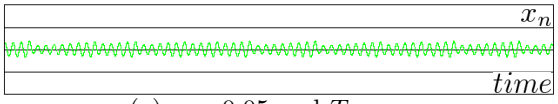
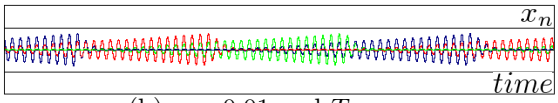


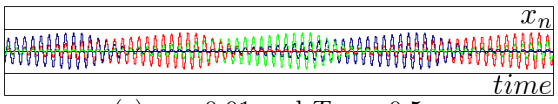
Figure 1: System including time delay in one direction.



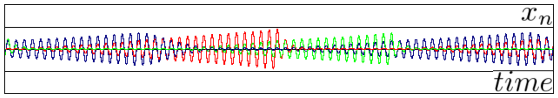
(a) $\gamma = 0.05$ and $T_{dn} = \pi$.



(b) $\gamma = 0.01$ and $T_{dn} = \pi$.



(c) $\gamma = 0.01$ and $T_{dn} = 0.5\pi$.



(d) $\gamma = 0.01$, $T_{d1} = 0.5\pi$ and $T_{d2} = T_{d2} = \pi$.

Figure 2: Time waveform $\alpha = 0.015$, $\beta = 0.5$.

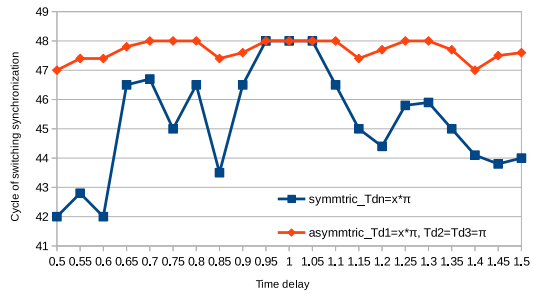


Figure 3: Cycle of switching synchronization.

Reference

[1] T. Maruyama, N. Inaba, Y. Nishio and S. Mori, "Chaos in an Auto Gain Controlled Oscillator Containing Time Delay," Trans. IEICE, vol. J 72-A, pp. 1814-1820, Nov. 1989.