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Strange Phase Synchronization of Chaotic Circuits

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1. Introduction

Coupled oscillatory systems have attracted a great deal of attentions in various fields. In our past studies, we have investigated synchronization phenomena in coupled Wien-Bridge oscillators by both circuit experiments and computer simulations using SPICE. We observed the synchronization state with 143 degrees phase difference. The phase difference of 143 degrees is very strange, because in-phase, anti-phase, or N-phase synchronization is typical.

In this study, phase synchronization phenomena in two coupled chaotic circuits are investigated. By computer simulations and circuit experiments, we confirm that the synchronization state with 143 degrees phase difference in two coupled chaotic circuit is observed.

2. Circuit Model

In this study, we consider a simple coupled system of two chaotic circuits to investigate the generation of the 143 degrees synchronization. The circuit model is shown in Fig. 1. In this model, two chaotic circuits are coupled by one resistor R.

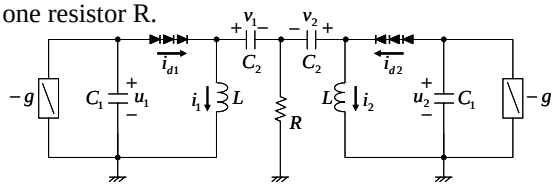

Fig. 1. Circuit model.

The characteristics of the nonlinear resistor consisting of diodes are approximated by the following function.

$$i_{dk} = G\left(u_k - L\frac{di_k}{dt} - E \right), (k = 1,2).$$

The circuit equations are given as follows.

$$\begin{cases} C_1 \dfrac{du_k}{dt} = gu_k - i_{dk} \\ C_2 \dfrac{dv_k}{dt} = i_{dk} - i_k \\ L\dfrac{di_k}{dt} = v_k + R\left(i_{d1} - i_1 + i_{d2} - i_2\right) \end{cases} \qquad (k = 1, 2).$$

3. Simulation and Circuit Experiment Results

We investigate phase synchronization phenomena in two coupled chaotic circuits by computer simulations using the Runge-Kutta method. Figure 2 shows the simulated results. Figs. 2(a) and (b) show the chaotic attractor of each sub circuit. The phase difference and the time waveforms are shown in Figs. 2(c) and (d), respectively. From these figures, the two coupled chaotic circuits are synchronized with around 143 degrees phase differences same as the two coupled RC oscillators.

We also confirm the generation of the same synchronization states in circuit experiments as shown in Fig.3.

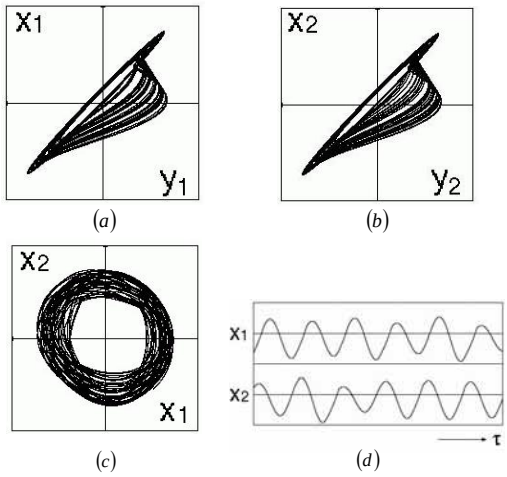

Fig.2 Computer simulation result. (a) Chaotic attractor. y_1 vs. x_1. (b) Chaotic attractor. y_2 vs. x_2. (c) Phase difference. x_1 vs. x_2. (d) Time waveform. α =0.33, β =0.43, γ =14.0, and δ =0.05.

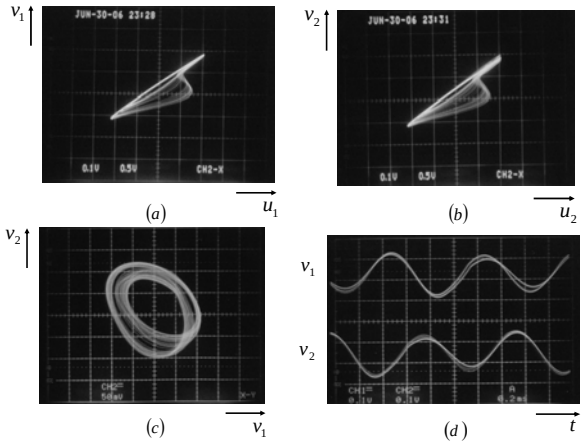

Fig.3 Circuit experimental result. (a) Chaotic attractor. u_1 vs. v_1. (b) Chaotic attractor. u_2 vs. v_2. (c) Phase difference. v_1 vs. v_2. (d) Time waveform. C_1 =100nF, C_2 =33nF, L =100mH, and R =100Ω.

4. Conclusions

In this study, we have investigated phase synchronization phenomena in two coupled chaotic circuits. By computer simulations and circuit experiments, interesting synchronization phenomena were observed.