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Signal Detection by Coupled Chaotic Circuits

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Abstract — **We investigate the system that combined two or more simple chaotic circuits by a resistor. When the multiplexed input signals are added, the coupled system responds to each input signal. We make the multiplexed input chaotic signal generated from other chaotic circuits, and investigate the response of the system. As the result, the example of the signal detection with coupled chaotic circuits can be shown.**

1 INTRODUCTION

Studies on engineering application of chaos, such as chaos communication systems and chaos cryptosystems, attract many researchers attentions. Because chaotic signals process infinite information, it could be possible to create novel engineering systems with great advantages. However, at this moment, there are only a few systems with some kinds of advantages over conventional engineering systems. Hence basic researches on chaotic phenomena with future engineering applications in mind are still quite important.

On the other hand, the authors have researched about many oscillatory circuits connected by a resistor [1]-[3]. Using this connection of circuits, chaotic signals generated from chaotic circuits change the state of synchronization to minimize the total of currents flowing in coupled resistor. Moreover, we confirm the phenomena of the coupled chaotic circuits when sinusoidal input is added [4]-[5]. The coupled system changes the state of synchronization against the input signal with very limited range of angular frequency. Therefore this coupled system is useful for signal processing of input signals.

In this study, as the basic research for future application of the chaotic signals by electronic circuits, we investigate the system that combined two or more simple chaotic circuits by a resistor. In this system, input signals are detected with the synchronization state of chaotic signals generated from the coupled chaotic circuits. When the multiplexed input signals are added, the coupled system responds to each input signal. Considering various types of coupled systems, we can make the system that will react to input signal when a certain multiplexed signal is inputted. Specifically, we make the multiplexed input chaotic signal generated from other chaotic circuits, and investigate the response of the system. As the result, the example of the chaotic signal detection can be shown.

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2 COUPLED CHAOTIC CIRCUITS

At first, the coupled system with chaotic circuits investigated in the previous research is explained [4]. Figure 1 shows the circuit model. The circuit in Fig. 1(a) is a three-dimensional autonomous circuit generating chaotic signal and was proposed by Inaba and Mori [6]. In the circuit in Fig. 1(b), two Inaba's circuits are coupled by one coupling resistor and an input signal is added to the coupling resistor as a current $_3$.

We assume the $-$ characteristics of the diodes in the circuit by the two-segment piecewise linear function as Eq. (1).

$$_d(\ _k) = 0\ 5(\ _d\ _k + \quad - |\ _d\ _k - \quad |) \qquad (1)$$

By using the variables and the parameters in Eq. (2), the circuit equations are normalized as Eq. (3).

$$
\begin{aligned}
&_k = \sqrt{\quad}\ _1 \quad _k \qquad _k = \sqrt{\quad}\ _1 \quad _k \\
&_k = \quad _k \qquad = \sqrt{\ }\ _1 \qquad = \frac{1}{2} \\
&= \sqrt{\quad}\ _1 \qquad = \sqrt{\quad}\ _1 \qquad = \ _d\sqrt{\quad}\ _1
\end{aligned} \qquad (2)
$$

$$
\begin{aligned}
&_k = (\ _k + \ _k) - \ _k - \sum_{j=1}^{3}\ _j \\
&_k = \{\ (\ _k + \ _k) - \ _k - \ _d(\ _k)\} \\
&_k = \ _k + \ _k \\
&(\ = 1\ 2)
\end{aligned} \qquad (3)
$$

In previous research, we have considered the case that a simple sinusoidal signal and chaotic signal are inputted. Namely, we use the following sinusoidal function with the normalized amplitude $_m$ and the normalized angular frequency as the sinusoidal input $_3$.

$$ {}_3(\quad) = \quad {}_m \sin \qquad (4) $$

In this study, we use the chaotic input signal which is generated from same chaotic signal used coupled chaotic circuits. The differential equations of chaotic circuits generating chaotic input signal are shown as Eq. (5). $\quad {}_3$ is inputted to coupled chaotic circuits as chaotic input signal. $\quad$ is the parameter for the frequency of oscillation of chaotic circuits.

$$ {}^3 = \ {}_3 \ (\ {}_3 + \ {}_3) - \ {}^2_3 \ {}_3 - \ {}_3 \quad {}_3 $$

$$ {}^3 = \quad \{ \ {}_3 \ (\ {}_3 + \ {}_3) - \ {}_3 \ {}_3 - \ {}_d(\ {}_3)\} \qquad (5) $$

$$ {}^3 = \ {}_3 + \ {}_3 $$

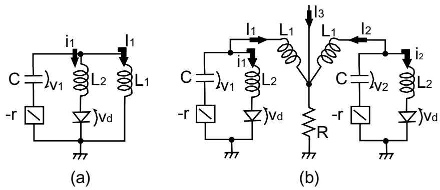

Figure 1: Chaotic circuit and the coupled chaotic circuits. $\ = 7\ 0$, $\ = 0\ 14$ and $\ = 100$.

2.1 Response to sinusoidal signal

In previous research, we have investigated the synchronization of coupled chaotic circuits to input sinusoidal signal. In order to investigate the synchronization, we define the phase difference of the two chaotic signals. By using the time when the chaotic signals take extrema as shown in Fig. 2, the phase difference $\quad$ [deg] is defined as follows.

$$ = \frac{\ {}_{20} - \ {}_{10}}{\ {}_{11} - \ {}_{10}} \times 360 \qquad (6) $$

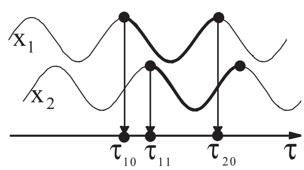

Figure 2: Definition of the phase difference $\quad$.

Figure 3(a) shows the results for the case that the angular frequency of the input is fixed as $\quad = 1\ 037$ and the amplitude $\quad {}_m$ is varied continuously. In the figure, 1500 data of $\quad$ are plotted after the system settles to the steady state for each $\quad {}_m$. Figure 3(b) shows the average of $\quad$ in Fig. 3(a). Because the fluctuation caused by chaotic feature is averaged, we can see the variation of $\quad$ more clearly. The results in Fig. 3 suggest that it is possible to distinguish the amplitude of the input sinusoidal signal by the phase difference between the two chaotic signals.

Next, we fix the amplitude of the input signal as $\quad {}_m = 1\ 17$ and vary the angular frequency $\quad$. Figure 4(a) shows 1500 data of $\quad$ and Fig. 4(b) shows their average. In this case the coupled system responds to the input clearly only for very limited values of angular frequency. Namely, as we can see from Fig. 4(b), the two chaotic signals almost synchronize at anti-phase for wide parameter region and they synchronize to the input signal at three-phase only around $\quad = 1\ 037$. The results in Fig. 4 suggest that the coupled system could be useful as a filter to distinguish the frequency of the input sinusoidal signal.

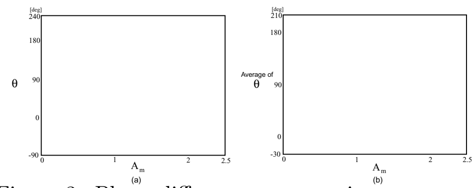

Figure 3: Phase difference $\quad$ as varying $\quad {}_m$. $\quad = 7\ 0$, $\quad = 0\ 14$, $\quad = 0\ 03$, $\quad = 100$ and $\quad = 1\ 037$. (a) $\quad$. (b) Average of $\quad$.

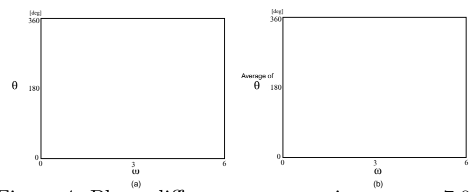

Figure 4: Phase difference $\quad$ as varying $\quad$. $\quad = 7\ 0$, $\quad = 0\ 14$, $\quad = 0\ 03$, $\quad = 100$ and $\quad {}_m = 1\ 17$. (a) $\quad$. (b) Average of $\quad$.

3 RESPONSE TO CHAOTIC SIGNAL

Similarly, when a chaotic signal is inputted, the coupled chaotic circuits exhibit the same response. The coupled system reacts for only input chaotic signal similar to the chaotic signal generating from the chaotic circuit.

Figures 5 and 6 show the response in the case that amplitude and frequency of the inputted chaotic signals are varied. A_{mc} controls the amplitude of the chaotic input signal. When $A_{mc} = 1$, the chaotic input signal has the same amplitude as the chaotic signal generating from the chaotic circuits. In order to change the frequency of the chaotic signal, we change the parameter ε of Eq. (5). If $\varepsilon = 1$, the chaotic input signal has the same amplitude and frequency of the chaotic signal generating from the chaotic circuits.

Moreover, changing the value of β of the circuit which generates the chaotic input signal, generated chaotic signal is varied. The phase difference θ of the coupled circuits is shown in Fig. 7 (a), when the state of the generated chaotic signal is varied depending on the parameter β. Poincaré section of the signal generated from the chaotic circuit is shown in Fig. 7 (b). These results mean that the coupled chaotic circuits react for only the chaotic signal generated from the chaotic circuit with the similar β values of the coupled chaotic circuits.

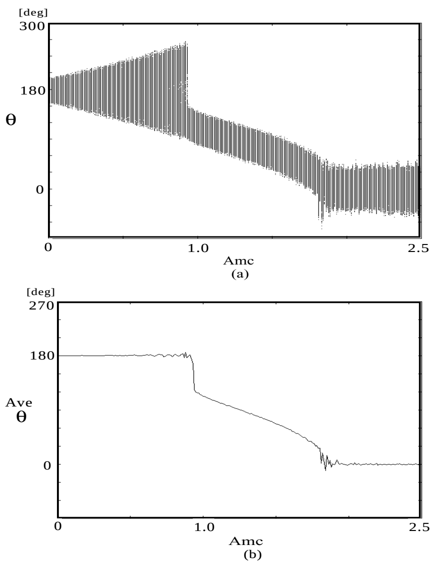

Figure 5: Phase difference θ as varying amplitude of chaotic input signal A_{mc}. $\alpha = 7.0$, $\beta = 0.14$, $\gamma = 0.03$, $\delta = 100$ and $\varepsilon = 1.0$. (a) θ. (b) Average of θ.

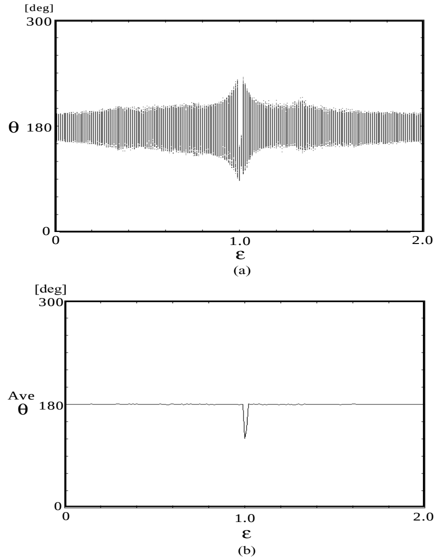

Figure 6: Phase difference θ as varying ε. $\alpha = 7.0$, $\beta = 0.14$, $\gamma = 0.03$, $\delta = 100$ and $A_{mc} = 1.0$. (a) θ. (b) Average of θ.

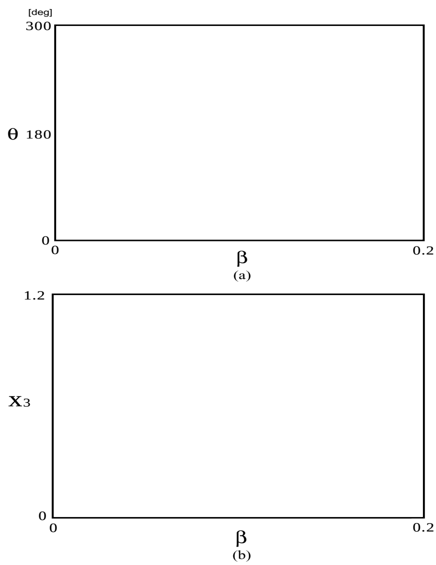

Figure 7: (a) Phase difference θ as varying β. (b) Poincaré section of x_3 of chaotic circuit as chaotic signal generator. $\alpha = 7.0$, $\gamma = 0.03$, $\delta = 100$, $A_{mc} = 1.0$ and $\varepsilon = 1.0$.

4 SIGNAL DETECTION

Next, we show the example of signal detecting by the coupled system. Figure 8 shows the simulation result for the case that N chaotic signals multiplexed and are inputted to the coupled chaotic circuits. This result means the coupled chaotic cir-

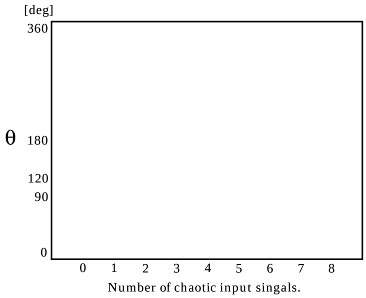

Figure 8: Phase difference θ when N chaotic signals are multiplexed as an input signal. $\Delta\omega = 0.2$, $\alpha = 7.0$, $\beta = 0.14$, $\gamma = 0.03$, $\delta = 100$ and $A_m = 1.17$.

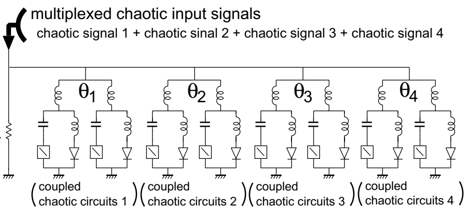

Figure 9: Connected coupled circuits.

cuits can detect the one chaotic signal from the multiplexed input signal with $N = 2, 3, 4$.

Figure 9 shows combined coupled chaotic circuits. This circuits are useful for the signal detection of multiplexed signals. Figure 10 shows simulation result using the circuit in Fig. 9. Multiplexed input signal is inputted to the coupled chaotic circuits, each pair of coupled chaotic circuits can respond to the corresponding input signals.

5 CONCLUSIONS

In this research, we have investigated that the coupled chaotic circuits could detect chaotic input signals. Simple connecting of oscillators by a resistor, we can make the chaotic signal detecting system with chaotic oscillator.

Because, the response speed of this system is slow, it is necessary to consider how to improve the speed.

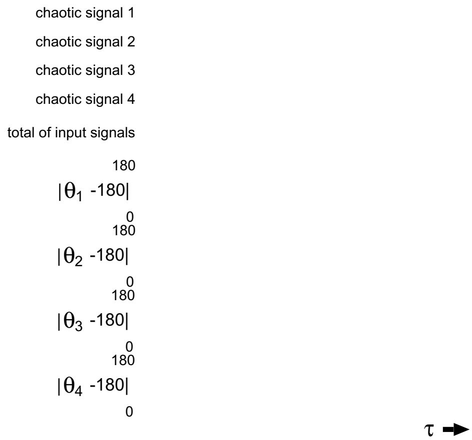

Figure 10: Simulation results of signal detection. $\alpha = 7.0$, $\beta = 0.14$, $\gamma = 0.03$, $\delta = 100$, $A_m = 1.17$ or 2.34 and $\Delta\omega = 0.05$.

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