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# Synchronization of Simultaneous Oscillators Including Nonlinear Resonators

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## 1. Introduction

In this study, synchronization phenomena observed from two inductively coupled simultaneous oscillators including nonlinear resonators are reported. Note that the characteristics of nonlinear resisters are described by a third order function. We focused on the phase difference between the two oscillators for various parameter values.

## 2. Circuit Model

The circuit model is shown in Fig.1. The normalized circuit equations are given as follows.

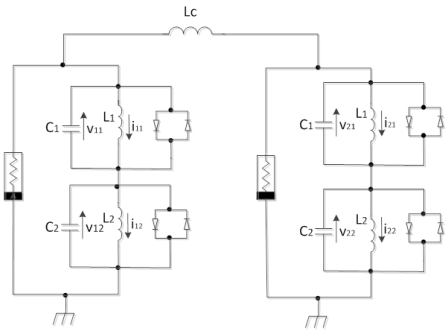


Figure 1: Circuit model.

$$
\begin{aligned}
\dot{x}_{11} &= \beta(x_{11}+x_{12})\left\{1-(x_{11}+x_{12})^2\right\} \\
&\quad -y_{11}-f(x_{11})-y_c \\
\dot{x}_{12} &= \alpha_C[\beta(x_{11}+x_{12})\left\{1-(x_{11}+x_{12})^2\right\} \\
&\quad -y_{12}-f(x_{12})-y_c] \\
\dot{x}_{21} &= \beta(x_{21}+x_{22})\left\{1-(x_{21}+x_{22})^2\right\} \\
&\quad -y_{21}-f(x_{21})-y_c \\
\dot{x}_{22} &= \alpha_C[\beta(x_{21}+x_{22})\left\{1-(x_{21}+x_{22})^2\right\} \\
&\quad -y_{22}-f(x_{22})-y_c] \\
\dot{y}_{12} &= x_{11} \\
\dot{y}_{22} &= \alpha_L x_{12} \\
\dot{y}_{12} &= x_{21} \\
\dot{y}_{22} &= \alpha_L x_{22}
\end{aligned}
\tag{1}
$$

where $y_C$ corresponds to $i_C$

$$y_c = \delta\{\alpha_L(y_{11}-y_{21})+(y_{12}-y_{22})\} \tag{2}$$

$f(x)$ corresponds to the nonlinear characteristics of the diodes.

$$f(x) = \frac{1}{\varepsilon}(x-0.5|x+\gamma|+0.5|x-\gamma|) \tag{3}$$

## 3. Simulation Results

In this article, we show only several computer simulated results obtained by giving different initial conditions for the fixed parameters as $\alpha_C$=0.3, $\alpha_L$=0.3, $\gamma$=0.1, $\varepsilon$=0.6, $\beta$=0.1, and $\delta$=0.6.

Figure 2 shows a typical example of the simulated results. We can see that each oscillator exhibits simultaneous oscillations and that the corresponding resonators are synchronized in in-phase.

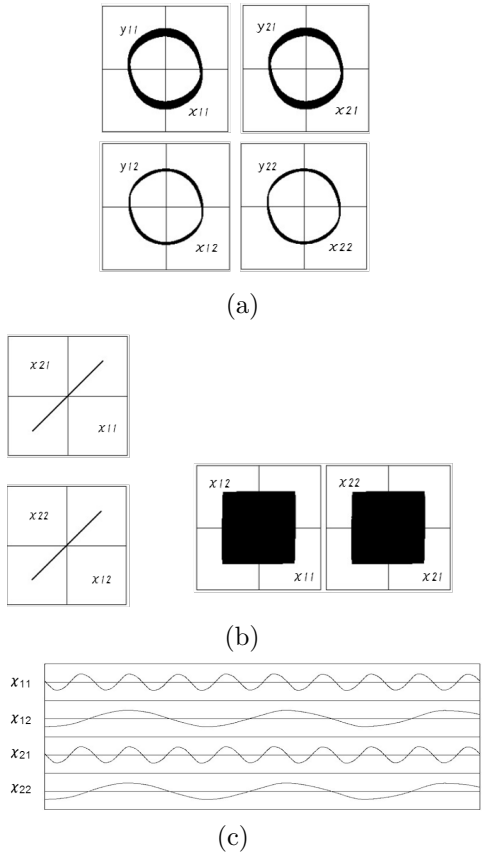


Figure 2: Computer simulated results. (a) Lissajous figures. (b) Phase differences. (c) Time waveforms.

## 4. Conclusions

In this study, we have investigated synchronization phenomena observed from two inductively coupled simultaneous oscillators including nonlinear resonators. By computer simulations, we have confirmed that the corresponding resonators were synchronized in in-phase while the oscillators exhibited asynchronous simultaneous oscillations.