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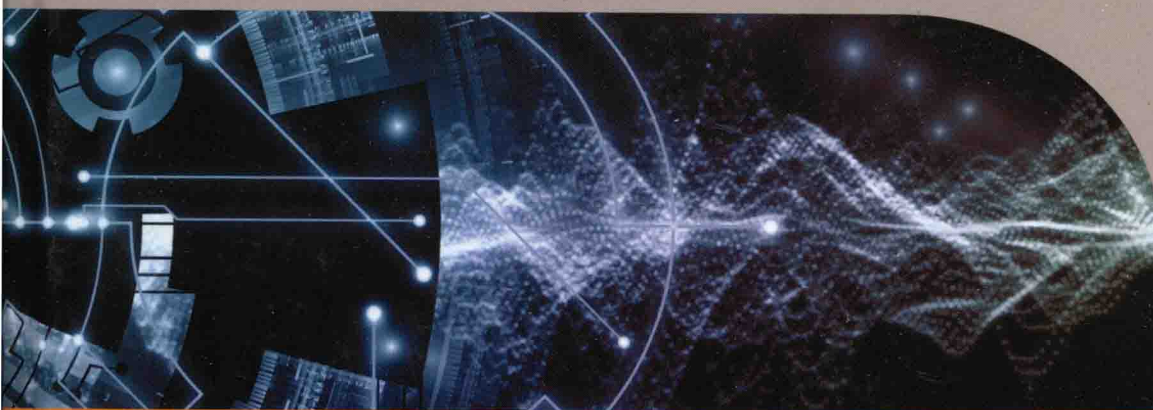

Oscillator Circuits

Frontiers in Design, Analysis and Applications

Edited by
Yoshifumi Nishio

Oscillator Circuits
Frontiers in Design, Analysis and Applications

An electronic oscillator is an electronic circuit that produces a periodic (often a sine wave, a square wave, or a pulse trains) or a non-periodic (a double-mode wave or a chaotic wave) oscillating electronic signal. Oscillators convert direct current from a power supply to an alternating current signal, and are widely used in many electronic devices. This book surveys recent developments in the design, analysis and applications of this important class of circuits.

Topics covered include an introduction to recent developments; analysis of bifurcation in oscillatory circuits; fractional-order oscillators; memristive and memcapacitive astable multivibrators; piecewise-constant oscillators and their applications; master-slave synchronization of hysteresis neural-type oscillators; multimode oscillations in coupled hard-oscillators; wave propagation of phase difference in coupled oscillator arrays; coupled oscillator networks with frustration; graph comparison and synchronization in complex networks; experimental studies on reconfigurable network of chaotic oscillators; fundamental operation and design of high-frequency tuned power oscillator; ring oscillators and self-timed rings in true random number generators; and attacking on-chip oscillators in cryptographic applications.

Providing an overview of the state-of-the-art in oscillator circuits, this book is essential reading for researchers, advanced students and circuit designers working in circuit theory and modelling, especially nonlinear circuit engineering.

Yoshifumi Nishio is a Professor at the Department of Electrical and Electronic Engineering at Tokushima University, Japan, where his research interests are in the areas of nonlinear circuits engineering. He was the Chair of the IEEE CAS Society Technical Committee on Nonlinear Circuits and Systems (2004-2005), the Steering Committee Secretary of the IEICE Research Society of Nonlinear Theory and its Applications (2004-2007), and is currently a member of the IEEE CAS Society Board of Governors (from 2012). He was an Editor or an Associate Editor of *IEICE Fundamentals Review, IEEE Transactions on Circuits and Systems I, IEEE Transactions on Circuits and Systems II, IEEE CAS Magazine and the RISP Journal of Signal Processing*. He currently serves as a Secretary for *NOLTA, IEICE* and as an Associate Editor for *IEEE Transactions on Circuits and Systems II, IEEE CAS Society Newsletter* and *International Journal of Bifurcation and Chaos*.

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Contents

Chapter 1

Introduction

Yoshifumi Nishio[1]

Oscillator circuit has been an absorbing theme of great interest for long time [1]. The researchers of oscillator circuit have been working in order to develop various electrical engineering systems from radio communication circuits to clock generators for microprocessors.

At the same time, synchronization of oscillator circuits has attracted attentions of many researchers not only in the electrical engineering field but also in the fields of mathematics, physics, chemistry, biology, medical science, neuroscience, social science, and so on. Oscillation waves (periodic or non-periodic) are the most basic and the most important signals in natural and artificial systems, and hence developing new oscillators and investigating synchronization and related phenomena in coupled oscillators are essential topics for many researchers in various fields. Oscillator circuits are good models of various systems generating oscillations in the sense that they are real physical systems realized easily and handled easily. This is the reason why oscillator circuits have been a common subject for researches in diverse fields.

This book is a collection of recent researches on oscillator circuits. Design, analysis, and applications of oscillator circuits are described by different authors.

In Chapter 2, bifurcation analysis of oscillator circuits is described with some example circuits. It is important to know what kinds of bifurcations exist in the circuits and how the oscillation states change as circuit parameters in order to understand the features of the circuits and to use the circuits for real applications. The authors of this chapter classify the bifurcations and describe how to calculate the parameters at which the bifurcations occur.

Because of the recent development of circuit devices and nonlinear theory, several researchers have been proposing novel oscillator circuits. In this book, three types of oscillator circuits are introduced by different authors.

In Chapter 3, fractional-order oscillator circuits are described. Fractional-order calculus is a mathematical theory dealing with non-integer order differentiation [2]. The authors describe how to realize oscillator circuits with fractional-order circuit elements and their advantages with a possible application in biomaterial characterization.

[1]Department of Electrical and Electronic Engineering, Tokushima University, Tokushima, Japan

In Chapter 4, oscillator circuits including memristive devices are described. After the first nanoscale device was reported in 2008 [3], many researchers have been trying to produce different kinds of circuits including memristive devices. In this chapter, the authors concentrate on the floating memristor emulator, which extends the application possibility of memristive devices, and utilize it to realize oscillator circuits.

In Chapter 5, piecewise-constant oscillator circuits are described. The circuits are extremely simple and are also realized very easily. The most important advantage of the circuits is that rigorous analysis using exact solutions becomes possible. In spite of their simplicities, the circuits exhibit a rich nonlinear phenomena. The authors show two example oscillator circuits with theoretical analysis using exact solutions.

Coupled systems of oscillator circuits have been an important subject in relatively wide range of research field. Basic coupled oscillator circuits were investigated in 1960s [4,5] and they are extended to larger systems in 1970s [6–8]. Since then, many different types of coupled oscillator circuits have been reported and investigated.

In Chapter 6, a new type of master–slave synchronization method is described. Namely, common non-periodic pulse is injected to oscillator circuits as an external force. Complete and stochastic synchronizations are achieved according to the features of the external force. This method may offer a simple control method to attain synchronization of engineering systems such as power-grid networks, communication networks, and so on. Also, the investigation of the synchronization mechanism may help to understand the behavior of a group of small animals.

Oscillator circuit containing a nonlinear resistor whose voltage–current characteristics are described by a fifth-power nonlinear polynomial equation is known to exhibit hard excitation [9,10]. Namely, the origin is asymptomatically stable and proper initial values are necessary to generate oscillation. Such an oscillator circuit is often called as a hard oscillator or said to have a hard nonlinearity. In Chapter 7, coupled oscillator circuits with hard nonlinearities are investigated. Multimode oscillation, one of typical oscillation phenomena observed in such circuits, is described in detail. The authors extend their circuits to one-dimensional ring structure and report propagating waves.

In Chapter 8, the authors report the wave propagation of phase difference between adjacent circuits in one-dimensional and two-dimensional arrays of inductively coupled oscillator circuits. They describe the physical mechanism of the wave using the relationship between the instantaneous frequency and the phase difference.

In Chapter 9, a concept of frustration in coupled oscillator circuits is introduced, which is a kind of difficult situation for circuits to generate apparent stable synchronization patterns. The authors investigate coupled polygonal oscillator networks as an example of oscillator circuit networks with frustration and describe the calculation method of synchronization states by using power consumption under some assumptions.

Synchronization of complex networks has been intensively investigated in these two decades. In Chapter 10, the authors describe the method to achieve global synchronization of complex networks composed of coupled oscillator circuits using the topological information of the network. The method is explained to be especially useful for networks with growing topologies. Successful practical applications are expected in near future.

In Chapter 11, a lot of interesting nonlinear phenomena observed from oscillator networks, more specifically coupled Chua's circuits which are the most famous chaotic oscillator circuits, are reported. It should be emphasized that almost all results in this chapter are obtained from real circuit experiments, which are not easy for large-size networks.

There have been many different engineering applications of oscillator circuits. In this book, two different applications are introduced.

In Chapter 12, an application to power electronics is described. The author has developed a design method of tuned power oscillators satisfying the class-E conditions, which achieves high-power conversion efficiency at high frequencies. This chapter describes how to design the class-E tuned power oscillators.

In Chapters 13 and 14, an application of ring oscillators to true random number generators is described, which is one of key technologies in data security systems. In Chapter 13, the authors introduce different types of ring oscillators and how to construct true random number generators with those ring oscillators. The characteristics of different true random number generators are explained with their advantages and disadvantages in detail. In Chapter 14, a possible attacking on a true random number generator based on a ring oscillator is described. Improving and attacking are a kind of two wheels of one car to develop a robust security system. In the next step, the authors may add an innovative idea to ring oscillators to make true random number generators robust against electromagnetic field.

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