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Field coupling benefits signal exchange between Colpitts systems

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ABSTRACT

Some evidences have confirmed that field coupling is much effective to realize signal propagation between neurons, and the biological function of synapse connection has also been modulated when field coupling is activated. These theoretical prediction and confirmation are approached on neuron model with electromagnetic induction and magnetic flux coupling is used to describe the effect of field coupling. Neuron is treated as a smart signal processor and neuronal activities can be reproduced in electric circuit by setting appropriate parameters. When time-varying current flows along the inductorium, magnetic flux across the coil is changed and induced electromotive force of the inductor is triggered. Indeed, exchange of magnetic flux between inductoriums (induction coils) can trigger modulation on magnetic field. Therefore, two nonlinear circuits can be connected to reach possible consensus of outputs by using this kind of field coupling. In this paper, two identical Colpitts oscillators are coupled by transformer which is introduced from partial inductance equivalent circuit (PEEC), and the potential differences between circuit nodes are analysed to find synchronization approach under field coupling. An unit matrix is used to derive the Master Stability Functions of the coupled systems, and the synchronization manifold of the system describes the effect of the parasitic elements on dynamical behaviour. It is also found that both of the gain of the oscillators and the coupling coefficient of transformer are important bifurcation parameters for synchronization manifold of the system. Similar investigation is as well practiced on printed circuit board (PCB) and the synchronization approach is confirmed under field coupling. This kind of field coupling provides another effective way to synchronization modulation via continuous exchange of field energy in the coupling device.

1. Introduction

Chaotic phenomena had been observed in many natural systems, such as sociology, physics, biology, etc. [1–6], and the relevant topics about chaotic problems were well addressed in numerical calculation and experiment [7–9]. By setting appropriate parameters, non-linearity is critical to trigger chaos [10,11], even mix-mode oscillations [12] in nonlinear

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dynamical system. Furthermore, multi-mode of electrical activities was found in a new Hindmarsh–Rose neuron model under electromagnetic radiation [13]. For most of the deterministic chaotic systems, positive Lyapunov exponent, wide frequency spectrum, fractional dimensional and strange attractors which are often dependent on the initials setting, can be approached from the sampled time series of observable variables even if parameters are invariable. And there also are chaotic trajectories in electron wave and electromagnetic wave [14–17]. Moreover, synchronization in chaos system is a fascinating phenomenon which is popular in biosystem [18,19], sociology [20] and nervous system [21–23], etc. For these low-dimensional chaotic and hyperchaotic systems, a variety of schemes [24–32] were proposed to control the chaotic state, estimate unknown parameters and realize synchronization consensus. Other researchers preferred to build nonlinear circuits [33–48] that the chaotic behaviour can be reproduced for further engineering application such as secure communication [49,50] and image encryption [51,52]. More interestingly, the involvement of memristor [29,31,34,48] in nonlinear circuits just opens a new window to know the information encoding and processing because its memductance is dependent on the input current. As a result, memristor-based nonlinear circuits will not only present distinct memory effect, but also the output property is dependent on the initial value setting. For example, resetting the initial value of magnetic flux across memristor can induce transition between chaotic and periodical oscillation while the parameters are fixed. Inspired by this nonlinear property of memristor, the author of this paper ever proposed a generic dynamical system [53] to detect the dynamical transition by resetting the initial value. In that work, the initial-dependent oscillators were coupled to find oscillation consensus and mode transition [54] except that the independence mechanism was discussed.

A variety of coupling methods have been proposed for synchronization control. The chemical and electrical synapse are often used to connect nodes in the neural networks [21,55–57]. And the mechanism of memory and learning are related with two kinds of synapse. In fact, autapse also can modulate the electric behaviour of neuron membrane [35,58–60]. Moreover, There are some networks such as regular and random networks in food web and electric power grid [18,61,62], etc. Without exception, the interaction between the adjacent nodes will consume chemical and electrical energy. In experiment of electric circuit, operational amplifier is usually used to couple oscillators, but the simplest coupling device is passive device such as resistor which will produce Joule heat [63–65]. Just for energy conversation, the capacitive and inductive of devices which can store energy could be the first choice.

As is well known, oscillator is a key in designing stable and reliable electronic systems. But chaos which is emerged from Colpitts oscillators was firstly found by Kennedy in 1994 [66–70]. The periodic and chaotic behaviour of the nonlinear circuits are controlled by the quality factor Q and gain g. For isolate nonlinear circuit, nonlinear circuit equations are approached to describe the flow of charge and changes of voltage for electric devices, and dimensionless dynamical equations can be built for dynamical analysis by using scale transformation simultaneously. While two or more circuit units are often connected by using voltage coupling(via resistor) and current forcing, exchange and transmission of the signal can be discussed. As mentioned in Refs. [10,71,72], field coupling provides another effective way to propagate signals between neurons and also plays an important modulation role in synapse function. However, synchronization approach can be suppressed when field coupling is applied between two chaotic circuits, the potential mechanism could be that magnetic flux-based field coupling can't change the mismatch induced by diversity in induction current [73].

Most of the researchers usually concern about design consideration to decouple or couple in electrical engineering. The best known of all these is a decoupling capacitor, one of passive device used to filter high-frequency noise and store energy. Indeed, coupling capacitor is also used to connect two circuits for blocking DC signal, such as audio amplifier [74]. In addition, mutual inductor(also named transformer) is another type coupling device used to power conversion where the magnetic field acts as an important role in interaction. In fact, this phenomenon is observed in other subjects, such as memristor [75], neuron network [76,77] where magnetic flux is used to describe the effect of electromagnetic induction by triggering appropriate induction current in the circuit or media. Furthermore, Ruehli found that interconnect lands on the layers of PCB which could lead ground bounce and electromagnetic induction (EMI) must be considered to improve signal quality [78,79]. The PEEC is applied to describe the macromodels of electric circuit substructures. In other words, this phenomenon exists in integrated circuit which obeys Moore's law. In this work, the magnetic field of ground plane caused by the PEEEC will be simulated by transformer and reaction between indistinguishable Colpitts oscillators coupled by the transformer will be discussed. Therefore, the synchronization approach will be analysed for the potential of nodes in two circuits.

In last decades, implement of chaotic circuit and synchronization stability of chaotic systems have been extensively explored. Statistical function such as error function [21], Master Stability Functions(MSFs) [80,81] and synchronization factor are often used to judge synchronization degree of coupled oscillators. It should be noted that MSFs is only available for local stability of synchronization manifold [82]. Without exception, MSFs is chosen to analyse the stability of synchronization manifold in this work. Nevertheless, the coupled term originated from magnetic-field is different from classic linearly reaction-diffusion coupled systems in dynamical equations. Therefore, MSFs will be established and stability of synchronization manifold is discussed for the distinctive system coupled by magnetic field.

2. Circuit and state equation

A generic nonlinear circuit is often build by using nonlinear electric devices such as bipolar junction transistor (BJT), memristor, etc. Memristor or resistor-based coupling can connect two nonlinear circuits by exchange of magnetic flux or