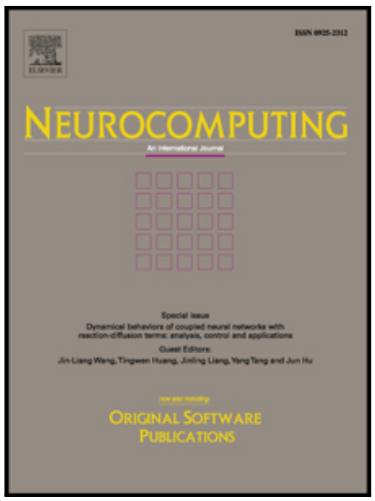

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A neuromorphic real-time VLSI design of Ca^{2+} dynamic in an astrocyte

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Abstract

Neurophysiological experiments have illustrated that astrocytes, the most abundant subtype of the glial cells, have the potential to dynamically regulate and control synaptic transmissions in neural networks. As these cells are able to provide energy substrates for neurons, they play an important role in human brain processing. This paper proposes an analogue implementation of an astrocyte model that can describe the contribution from activation pathways, by modeling the calcium dynamics of astrocyte with different bias currents. The proposed VLSI circuit has been designed using 0.35 μm CMOS standard technology in HSpice software. Simulation results demonstrated that the proposed astrocyte circuit has the advantages of low power consumption and compactness. Furthermore, it is a real-time VLSI design that uses a number of transistors operating in the subthreshold region; therefore, it is believed that the proposed design can be used for implementations of dense arrays of neural networks in several applications.

Keywords

Neuromorphic VLSI, Astrocyte, real-time

1. Introduction

Understanding the computational principles underlying the interactions of subsystems of the human brain is essential for developing innovative computing frameworks. For many years, researchers from various fields have attempted to explore, describe, and understand the principles of brain information processing. *Biological* scientists have found that glial cells are very important for support of the nervous system; furthermore, these cells have an important role in neuronal dynamics and information processing [1],[2],[3]. Neuromorphic engineers have typically attempted to implement various models of neurobiological systems in electronic circuits for the last two decades [4],[5],[6]. The implementation of the practical neural networks has some advantages such as very high degree of parallelism and their deep physical realizations. A large number of neurons, synapses, and learning rules are implemented as electronic circuits, e.g. [7], [8] ,[9],[10],[11],[12],[13]. Furthermore, many studies have focused on the communication processes between neurons, astrocytes and astrocyte–neurons [14],[15],[16],[17],[18],[19], and also on circuit implementations for various mathematical models of neuron-astrocyte networks. e.g. [20],[21],[22], [23] ,[24],[25]. In [24] the proposed analog circuit of the astrocyte can activate the analog neuron or change spiking frequency of the neuron through bidirectional communication. In [23], the neuron-astrocyte interaction can be effect on synchronous/asynchronous patterns in neural responses. Therefore, it enables building a new circuit with astrocyte actively contributing in neural information processing. The main contribution of this study is to design and introduce a new astrocyte analogue circuit which possesses some critical capabilities that have not been demonstrated in previous circuit implementations. This circuit not only can replicate the exact behavior of the astrocyte model, which has been proposed in [26], but also it has the advantage of real-time operation unlike related previous papers [22], [23] ,[24].

The rest of this paper is organized as follows. In Section 2, an overview of mathematical model of the astrocytes is given. Section 3 presents a description of the proposed circuit operation. Section 4 is dedicated to simulation results where we demonstrate the capabilities of our proposed circuit. Finally, Section 5 concludes the paper.