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A Frequency Synchronized Oscillatory Neural Network using Two-Stage Ring-Oscillators

Shang-Kai Wei, Mohammad R. Haider, Nasim Uddin
University of Alabama at Birmingham – USA, Email: {joseph83, mrhaider, nuddin}@uab.edu

Abstract

In this work, an oscillatory neural network circuit is designed and implemented using two-stage ring oscillators. The ring oscillator comprises of two differential operational transconductance amplifiers (OTA) with positive feedback connections. An ONN is then formed by serial connecting several ring oscillators where each oscillator works as a network node. In the proposed network, each oscillator is connected in serial fashion to their neighbors through Metal Oxide Semiconductor Field Effect Transistor (MOSFET) based switches. The dimensions of the coupling MOSFETs work as coupling weights of the network and can store associative memory pattern. For a range of coupling weights the network goes to frequency synchronization. Different coupling weights result different frequency of synchronization and the corresponding memory pattern.

1. Introduction

Artificial neural network is a novel and creative research field as it has attracted tremendous level of attention for different applications, for instance, image processing, structural health monitoring, natural language processing, pattern recognition, and sensor network [1]-[8]. Inspired by the human brain where billions of slow and noisy neurons can outperform the modern computer, the oscillatory neural network (ONN) can perform computation and signal processing in an efficient way. By utilizing the network dynamics such as frequency of synchronization and time of synchronization, ONN can perform the pattern recognition task in an efficient way than the conventional digital processor. In this work, an oscillatory neural network circuit is designed and implemented using two-stage ring oscillators. The ring oscillator comprises two differential operational transconductance amplifiers (OTA) with positive feedback connections. The gain of the OTA block is carefully selected for sustained oscillation and the oscillation frequency is tuned by the capacitors connected at the output terminals of each OTA stage. An ONN is then formed by serial connecting several ring oscillators where each oscillator works as a network node. In the proposed network, each oscillator is connected to their neighbors through MOSFET based switches and the serial connection of the network leads to frequency synchronization. By changing the coupling MOSFETs W/L ratios different frequency of synchronization can be achieved. The dimensions of the coupling MOSFETs work as coupling weights of the network and can store associative memory pattern. Different coupling weights result in different frequency of synchronization and the corresponding memory pattern.

The organization of the paper is as follows. Section 2 highlights the architecture of the oscillatory neural network, OTA based ring oscillator and the oscillatory node formation. Section 3 shows the simulation results of ONN under different coupling weights and coupling capacitors. The effects of supply voltage on synchronization frequency is also shown in section 3. Finally, section 4 draws the conclusion of this work.

2. Proposed System Architecture

2.1 The Proposed Oscillatory Neural Network

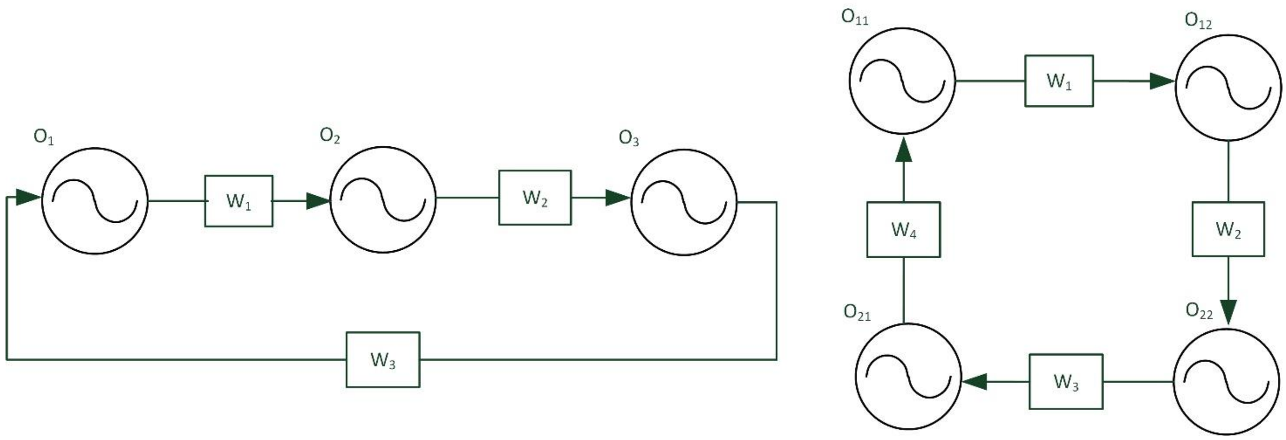

Fig. 1: Proposed Serial Oscillatory Neural Network.

A serial oscillatory neural network (ONN) is considered as shown in Fig. 1. In this paper, the coupling is made by using NMOS switches between the neighbouring serial connected oscillators. The signal of previous oscillator couples through the gate of NMOS and provides output current to next oscillator. Size of NMOSs is a critical factor in this design. As the sizes of NMOSs increase, synchronize frequency also increases due to the increased output current. Small size of NMOSs may not provide enough output current to next oscillator and cause out of synchronization. At the beginning, all the oscillators oscillate with different initial frequencies. However, due to the serial network connection, one oscillator drives current to the next one, the next oscillator drives current to the previous one and causes negative feedback. This system is more stable and has the ability to adjust themselves. More oscillators take more time to synchronize since every oscillator has it's own initial frequency.

2.2 Voltage Control Oscillator

Oscillators in this work are designed by two-stage Voltage Control Oscillators (VCO). Two-stage VCO is made of two operating transconductance amplifier (OTAs). This OTA design includes eight transistors, four PMOSs and NMOSs. In fig. 2, NMOSs (M1, M2, M3, and M4) latch produce delay by positive feedback. PMOS (M5, M6, M7, and M8) can control the frequency of VCO. C1 and C2 are capacitors that can decrease frequency.

3. Simulation Results

3.1 Relationship Between Voltage and Injected Capacitors

While supply voltage decreases, the frequency of VCO would also decrease. While injected capacitors increase, frequency of VCO decrease. Fig. 3 shows the different frequencies in different capacitors and voltages. Injected capacitors can be used to delay the frequency. In 1.4 V the frequencies of oscillators drop rapidly and unstable. The reason is big injected capacitor would cause more serious current injection, which happened when the latch of I phase and Q phase lock each other and promote these oscillators strongly to oscillate. However, if there are more oscillators, the I/Q phases inject each other, each oscillator would provide enough signal to the next one and make it synchronize. This phenomenon would not cause serious problem.

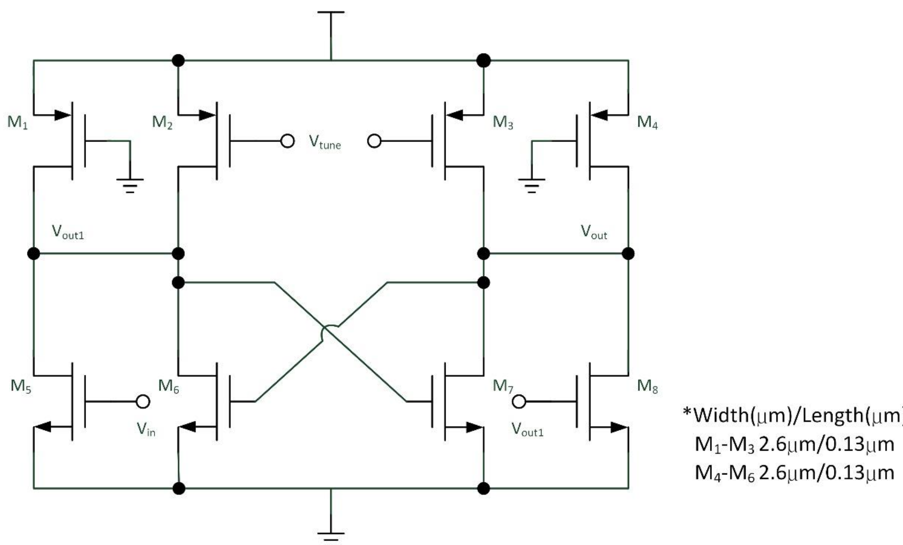

Fig. 2 Topology of operational transconductance amplifiers in 130 nm.

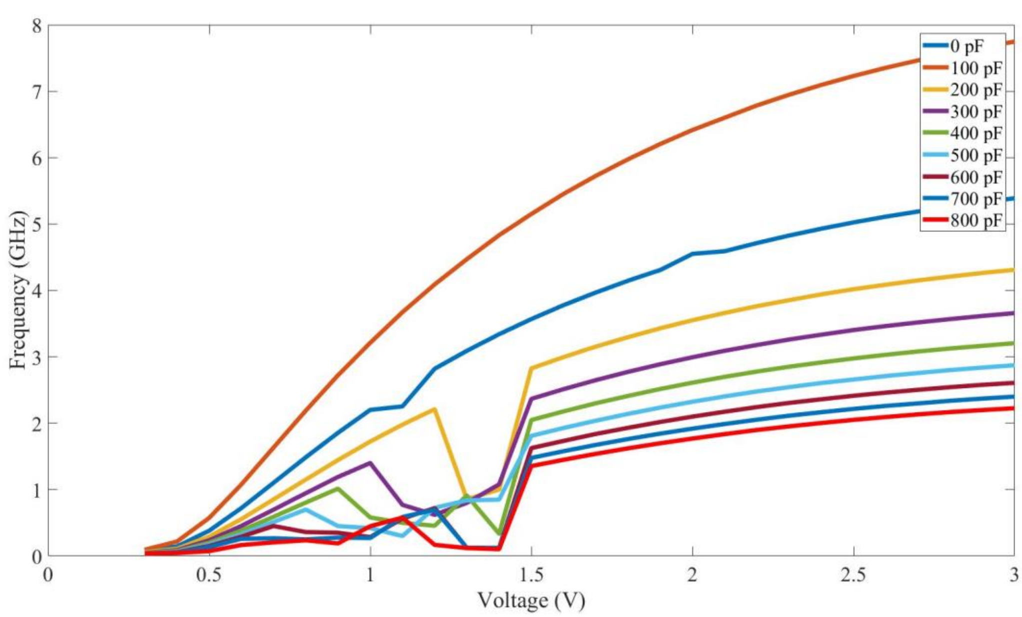

Fig. 3 Relationship of supply voltage and frequency

3.2 Effects of MOSFET Sizes and Coupling Weights

Different size of NMOSs can be presented as different weights. Synchronize frequency, which can be seen as a memory will be adjusted by changing size of NMOSs. In Fig. 4, this result is the simulation of 2 oscillators with different weights. Synchronize frequency would be changed by different injected capacitors. While the size of weight becomes bigger, the synchronizing frequency also becomes higher.

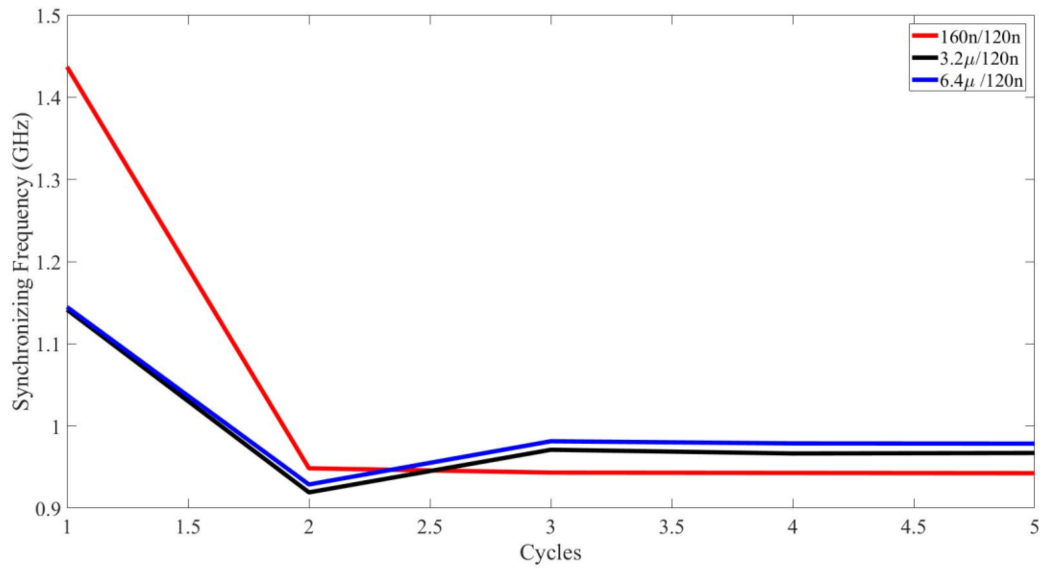

Fig. 4 Synchronizing Frequency with different size of NMOSs

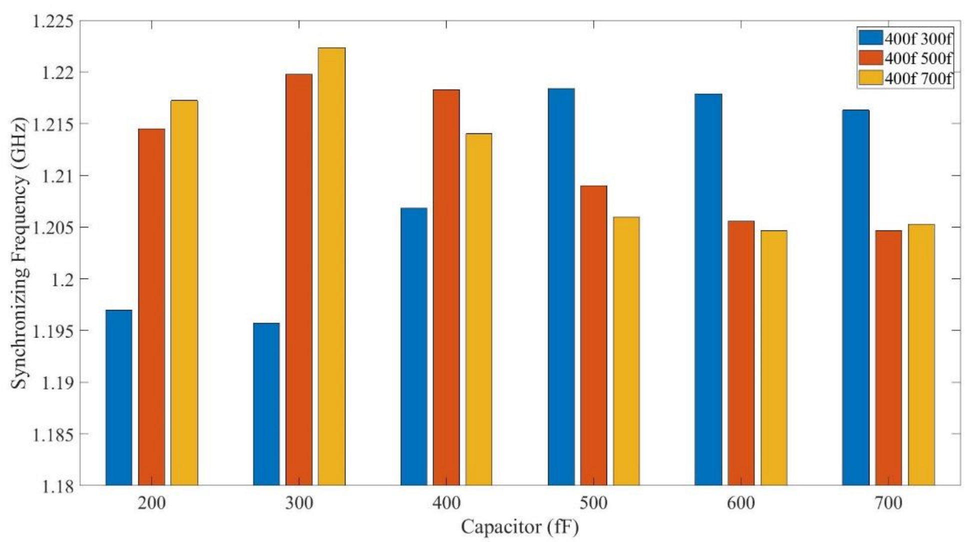

Fig. 5 Relationship between synchronizing frequency and different capacitor values working under 1 V supply

3.3 Simulation of 3 Different Oscillators

Fig. 5 shows the relationship between the synchronizing frequency and the different injected capacitors. There is three ring-oscillator with different injected capacitors and connect each other. Synchronizing frequency is adjusted by different typed oscillators. The sequence with different injected oscillator would also shows different synchronizing frequency. For example, synchronizing frequency which is 400f, 300f, and 500f is higher than 400f, 500f, 300f. As a memory, these oscillators can be represented as different parts and focus on special targets.

4. Discussion and Conclusion

This paper reports the concept of neural network based on different ring oscillator as a memory. By using different injected capacitor, different oscillators can be seen as neurons. Synchronizing frequency can be changed by different oscillators (neurons) and transfer some meaningful data. Nevertheless, weights are very essential in neural network system. Stronger size of NMOSs can increase the synchronizing frequency. Based on these two ways, synchronizing frequency can be adjusted and transfer into meaningful data.

Acknowledgment

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