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Simulated Characteristic Model of Artificial Neuron in VHDL

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Abstract: *In this paper the behaviour of a biological neuron has been modelled in VHDL and shows how nervous impulses, the so-called spikes, are transmitted through the body of the neuron, from the dendrites to the axon. And with this knowledge, to emulate this behaviour with the target getting a system, in VHDL, that works exactly in the same way that a biologic neuron. To implement this, it is important to know how, why and in what circumstances a neuron is fired.*

Keywords: *Neuron, HDL (Hardware Descriptive Language), ANN (Artificial Neural Network), Feedback Network, Feed-Forward Network, Artificial Neuron, Biological Paradigm, Pattern Recognition, Simulation.*

1. Introduction

The human nervous system has been treated by numerous studies. Not only from a medical point of view, as treatments for prevention of diseases, but also, from a technological point of view, trying to emulate the behavior of the biological neuron. And based on this, modeling an artificial neuron can be used to develop future applications in computational neuroscience, as well as in artificial intelligence. Artificial neural networks simplify the behavior of the human brain, so, their applications are used in different fields as industrial automation, medicinal applications, robotics, electronics, security, transport, military, etc.

Applications in pattern recognition like recognition of fingerprints or control of missiles use systems based on neural networks among other techniques. The following research is based exactly in this issue, to understand the real behavior of a biological neuron and according to this being able to model an artificial neuron that works in a similar way. When this artificial neuron will be developed, it will be used in future applications through complete neural networks for applications as commented previously. A neuron can be compared to a black box composed of few inputs and an output. Like an electrical circuit that makes the addition of the different signals that receives from other units and obtain in the output according to the result of the addition with relation to the threshold. The artificial neuron is an electronic device that responds to electrical signals.

An example of the use of artificial neurons in the industry is, for example, CCortex, building by CorticalDB, which is a massive spiking neural network simulation of the human cortex and peripheral systems. CCortex represents up to 20 billion neurons and 20 trillion connections [27].

According to the manufacturer, the development of CCortex will enable a wide range of commercial products that will transform and enhance global business relationships, with advanced capabilities in pattern recognition, verbal and visual communication, knowledge acquisition, and decision-making capabilities. These products will have widespread applications in the fields of artificial intelligence, communications, medical modeling, and database and search technologies. These are only a little sample of the abilities that can be implemented starting with the development of the artificial neuron.

2. Biological Backgrounds

First of all, we must study and understand the different parts and the behavior of neurons. Functionally, a neuron can be divided in three parts: Soma: The body of the neuron, Dendrites:

Branches that transmit the action potentials from others neurons to the soma. Axon: A branch that transmits the action potential from the neuron to other cell.

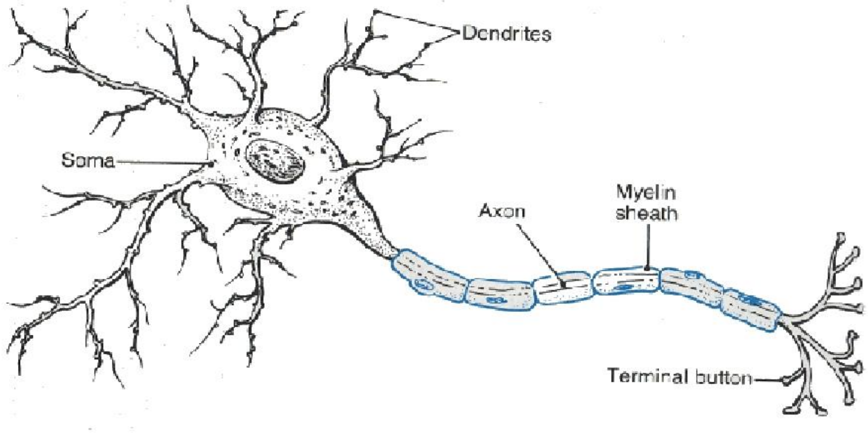

Figure1. *Parts of a neuron.*

All main parts of a neuron can be appreciated in this picture, dendrites, soma and axon. The soma is the central unit of the neuron, it receives signals from others neurons across the different dendrites. If the addition of these signals is over of a certain threshold an output signal, a spike, is generated. The spike is propagated by the axon to other neurons. The contact site between the axon of the first neuron and the dendrites of the next neurons is called synapse. The spikes are short electrical pulses. The amplitude of theses spikes, are about 100 mV and they have duration of 1 or 2 ms [28]. A spike train is a chain of action potentials emitted by a neuron, the importance of action potentials is in the timing and the numbers of spikes, the form of the action potential does not carry any information, since they all look almost the same. The spike is the elementary unit of signal transmission. When a neuron is fired, it generates a action potential, this action potential is transmitted and processed in the soma of the next neuron, where action potential from others neurons are arriving. The soma considers all the input from the different neurons and makes a non-linear addition of these signals. The sum of this addition gives the membrane potential of the neuron, which is transmitted along the axon to target neurons.

During the summation process, not all the inputs have the same relevance, thus, some are more important (represented as higher weight values) whereas other inputs are less important (lower weight values). One of the characteristics of the biological as well as artificial neuronal network is their capacity of learning, for that, the inputs has adaptive weights.

3. MODELING OF NEURON

The implementation of this neuronal model will be carried out in VHDL language. VHDL language is a combination of VHSIC (Very High Speed Integrated Circuit) and HDL (Hardware Description Language) [32]. For the developing of the system we have used a system based in an artificial neuron with only three dendrites as inputs, actually, the numbers of simultaneous spikes, in a short period of time, needed to excite a neuron are about 50 but we think that 3 dendrites are enough to show how a neuron works. To get that these 3 dendrites will be able to fire the output, we will have to increase the value of the weights, associated with the dendrites. They are defined like variables, can let the possibility of change the values to make a dendrite more significant than others. One of the most important characteristics of the neural networks is the ability of learning. For neurons, learning is the modification of the induced behavior for the interaction with the environment and like result of experiences that drives to establishment of new response models to extern stimulus. As mentioned earlier, we have defined 3 variable weights as inputs, every weight is associated with a dendrite to let that the global neuronal network let the ability of learning.

To first view our system will have:

- 3 inputs referred to the dendrites from others neurons.
- 1 output referred to the axon. When the output would be fired, the output will have to generate a pulse to propagate it to others neuron through the axon.

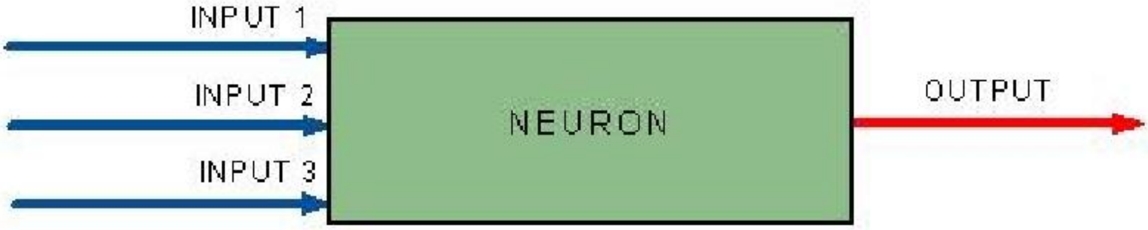

Figure2. *Neuron with 3 inputs.*

When a spike arrives, the soma has basically two functions, to generate the potential action according to the input and to compare if the addition of all potential actions in this instance of time is over a threshold, in that case, it will have to generate a pulse through the axon. We are going to consider these actions as: (i) Potential generator. When receive a pulse starts to increase the potential, (ii) Addition and comparison. Add all the potential and compare with the threshold.

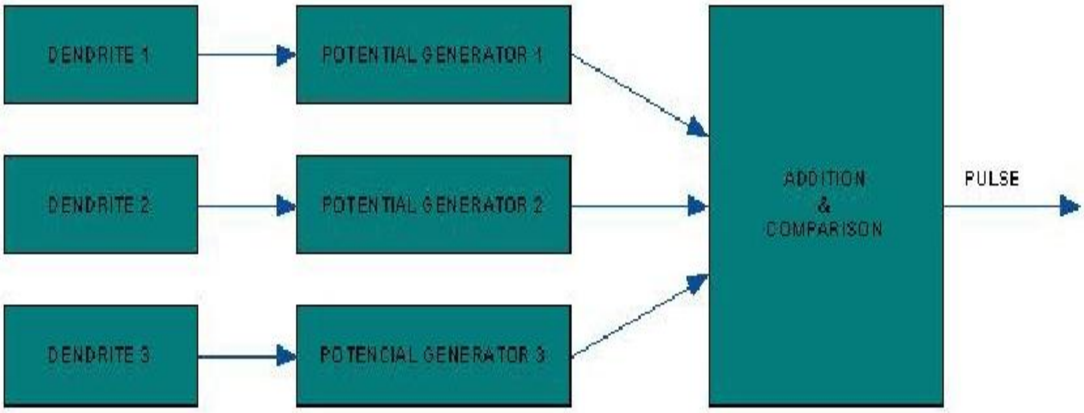

Figure3. *Functions of a neuron.*

The functions of the processor unit of a neuron are to generate a potential according to the arriving of spikes and evaluate these potential to generate an output potential.

4. Global Neuron Systems

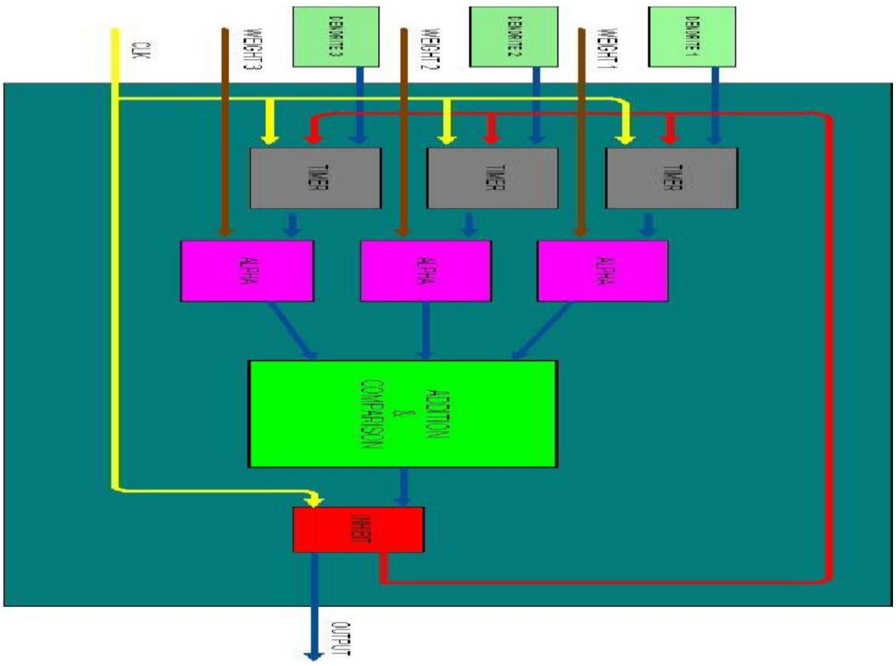

Figure4. *Global neuron system*

Global system is represented in the following figure4. We can observe the 3 inputs from the dendrites and their respective weights. The other input showed in the figure is the "clk" input, needed to synchronize the counter of the timer and inhibit blocks. The complete block diagram of the global neuron system is given below.

5. Simulation Results for the Neuron System

With the aim of simulating the right behavior of the main program, we need a testbech. A testbench is a virtual environment used to verify a model or a design. We have designed a program that emulates a possible case that could be happened, it represents the possible changes in the different inputs and observe the output to check if the system meets with the requirements.

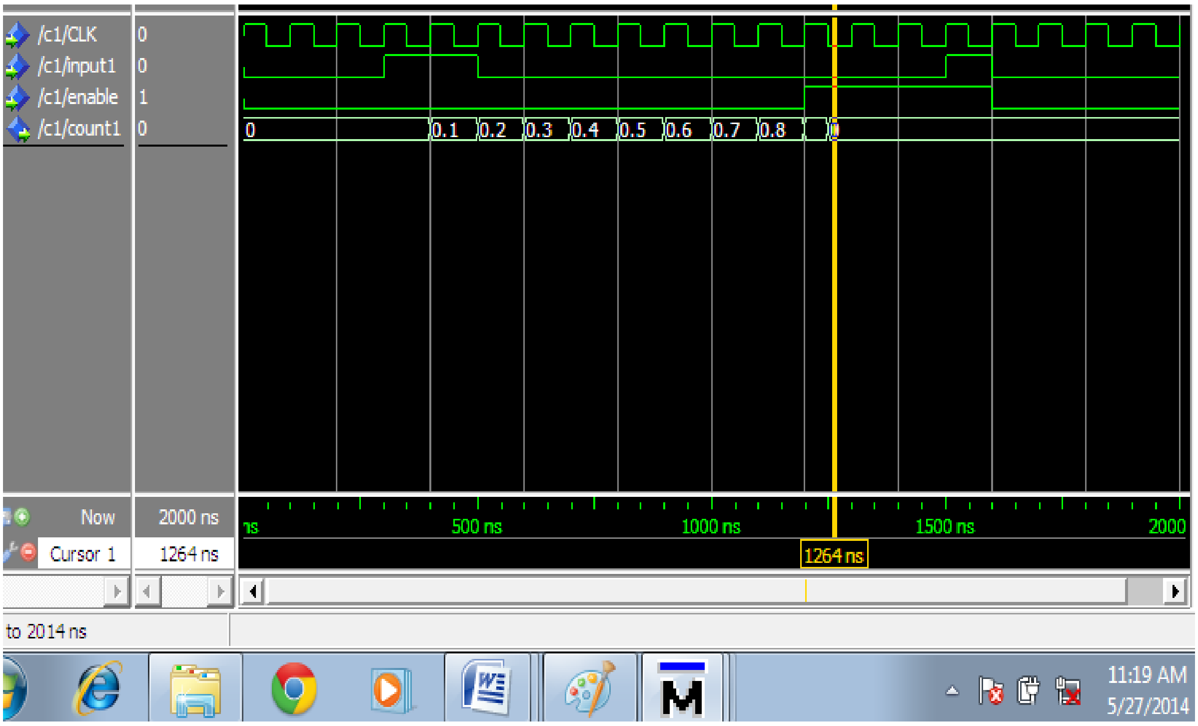

Figure 6.1. *Timer block simulation*

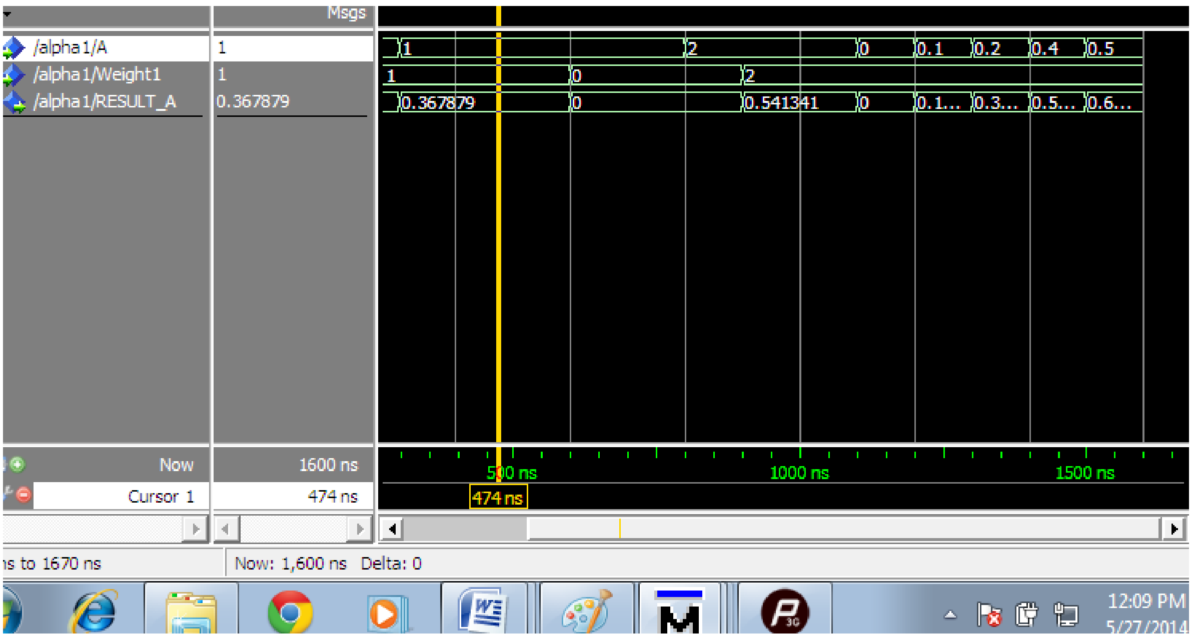

Figure 6.2. *Alpha block simulation*

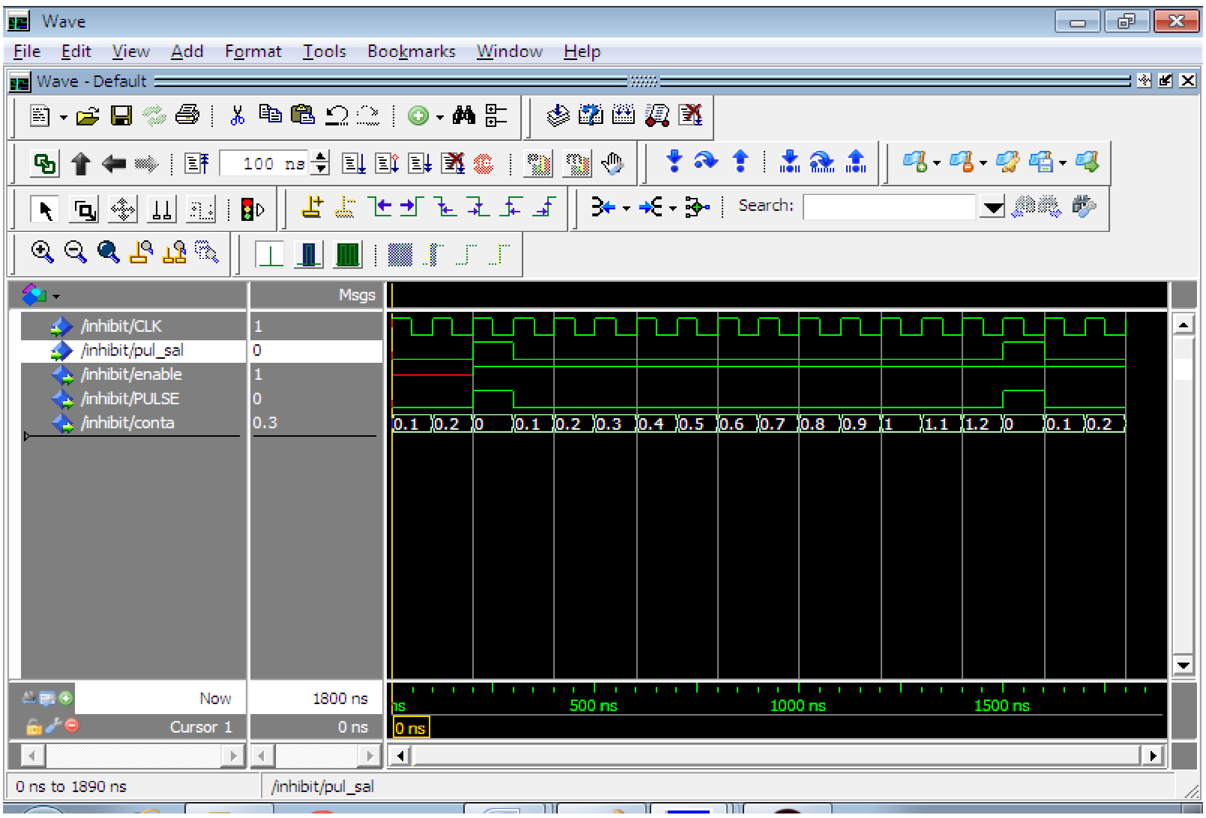

Figure 6.3. *Inhibit block simulation*

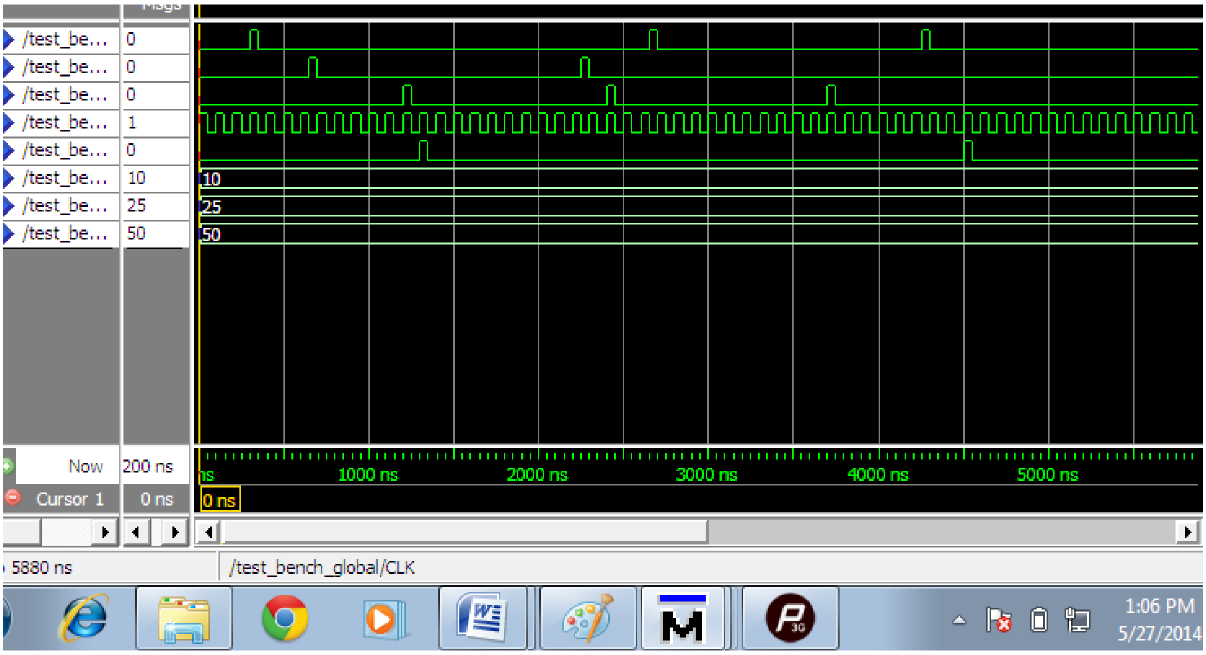

Figure 6.4. *Global Block Simulation*

6. CONCLUSIONS

During several weeks going thought the biological neuron system, we have concluded some important things, as the following ones. The basic behavior of the biological neuron can be emulated in an artificial neuron. A biological neuron with their dendrites, soma and axon can be characterized in an artificial neuron as a black box with inputs and an output. To implement the system the electronic pulses or spikes transmitted through neurons are replaced by digital signals or pulses. We can get to emulate the potential actions in the presynaptic and postsynaptic reactions using timers and multiplier blocks.

Therefore, according to the results obtained, we can say that we have designed a system whose performance leads to the achievement of the objectives and at the same time could work as the main base to develop future applications.

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