FPAA Implementation and Investigation of Analog Neurons

Emil Dimitrov Manolov, Mihail Hristov Tzanov and Filip Todorov Koparanov

Abstract – **The paper considers the FPAA implementation of analog neurons. To this aim, the classical block diagram of the artificial neuron is presented and analyzed. The FPAA model of analog neuron is proposed and different test-experiments with the designed prototype are carried out. The experiments confirm the preliminary theoretical assumptions. The results from the investigations can be used in the prototype design of low and medium size analog artificial neural networks.**

Keywords – **Field Programmable Analog Array, FPAA, Analog neuron, Artificial neural networks**

I. Introduction

Artificial neural networks are a contemporary approach for distributed parallel information processing. They enhance the computational capability of the electronic instruments. The hardware implementations of the neural networks guarantee high speed and functionality of the developed circuits and systems [1].

In [2] is pointed out that the analog implementations of neural circuits are very appropriate for learning algorithms with high fault-tolerance and requiring low or moderate precision. In [1] and [2] are discussed and presented transistor based topologies of basic analog blocks for building analog neurons and networks. These solutions are suitable when the designed neural networks are a part of full custom VLSI integrated circuits with high-run production. For short-run production, the most correct solution is to use some of the fast prototyping devices as Field Programmable Analog Arrays (FPAAs).

The FPAAs are the perfect solution for fast implementation of analog prototypes [3]. They allow high-level description, design and programming of the functions of the blocks and interconnections inside the chip. In this way the FPAAs give the possibilities to implement systems with various functionalities [4]. Nowadays the most popular FPAAs are the chips of Anadigm Inc. [5].

In [6] is presented an analog neuron (the Morris-Lecar model), which is implemented on FPAAs. The FPAA FitzHugh-Nagumo model is shown in [7]. The both neurons are built by using analog modeling method for presenting the differential equations, which describe the circuit's functionality.

The papers [8] and [9] discuss the possibilities to implement analog neural networks on FPAA. An analog neural circuit for two-parameter space classification is proposed in [10]. In [11] is proposed the FPAA implementation of Threshold Logic Circuits.

E. D. Manolov, M. H. Tzanov and F. T. Koparanov are with the Department of Electronics, Laboratory of Semiconductor Devices and Integrated circuits, Room 1437, Faculty of Electronic Engineering and Technologies, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mails: edm@tu-sofia.bg, mzep@abv.bg, fkop@abv.bg

The paper presents the results from FPAA implementation and investigation of analog neurons. To this aim, the typical block diagram of the artificial neuron is analyzed and the way for its FPAA modeling is described. The FPAA electronic model of the classical analog neuron is proposed and the test circuit for its examination is developed. The results from investigation of analog neurons with different transfer characteristics of the activation block are presented. The obtained results show very good agreement with theoretical assumptions.

II. Classical Block Diagram of Analog Neuron

Fig.1 shows the classical artificial neuron block diagram. The inputs $\boldsymbol{x_i}$ are multiplied by a synaptic weight $\boldsymbol{w_i}$ and the intermediate results are summed up with the input constant $\boldsymbol{b}$. After, the obtained sum $\boldsymbol{y}$ is passed into an activation function $\boldsymbol{F}$, which generates the neuron's response. Depending on the application of the neuron, the activation function possesses specific transfer characteristics.

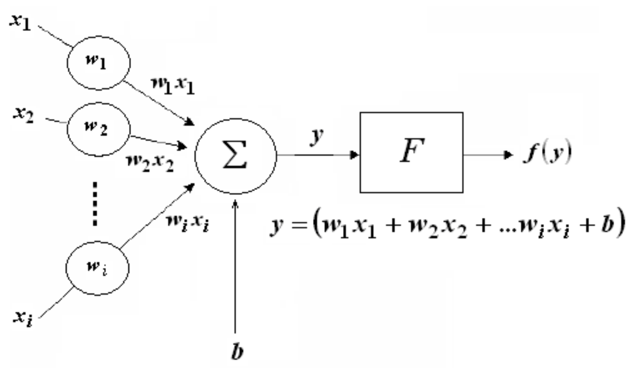


Fig.1. Classical block diagram of artificial neuron.

The analog implementation of the above circuit needs: *Multipliers* to obtain the weighted input terms $\boldsymbol{w_ix_i}$, *Multiple Input Summing Block* to obtain the value of $\boldsymbol{y}$, and *Programmable Function Block* to perform the different activation functions $\boldsymbol{F}$. All these blocks can be implemented on FPAA of Anadigm Inc.

III. Circuit for Testing of Analog Neuron

Fig.2 presents a test circuit for two-input artificial neuron (2-input neural cell). The input signals are denoted as $\boldsymbol{x_1}$ and $\boldsymbol{x_2}$. The corresponding weights are $\boldsymbol{w_1}$ and $\boldsymbol{w_2}$. The output of the *Ramp Generator* is applied to the input $\boldsymbol{x_1}$ and to the input of the external sweep signal *EXT INP* of the oscilloscope. In this way the input and the output of the neural circuit are synchronized with the sweep of the oscilloscope. All the rest inputs are connected to *DC*

Voltage sources *DC1÷DC4*. They can be regulated in order to excite the neuron in different conditions. The output of the neuron is applied to channel *CH1* and the internal output ***y*** – to *CH2*.

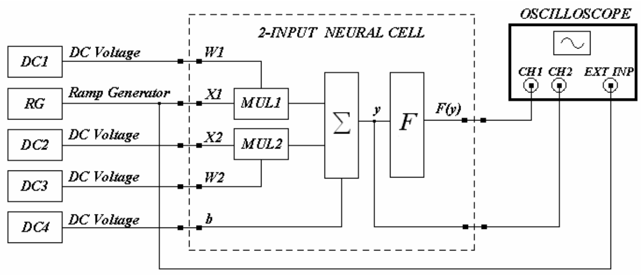


Fig.2. Test circuit for analog neuron

IV. FPAA IMPLEMENTATION OF ANALOG NEURON

Fig.3 presents the proposed FPAA implementation of the 2-input analog neuron. Fig.4 presents a picture of the experimental test-bench. Two series connected AN221K04 FPAA Evaluation Boards from Anadigm Inc. are utilized to build the circuit. The configuration allows programming of both AN221E04 FPAA chips via the serial port of the personal computer. To this aim AnadignDesigner2 software is used.

The circuit on Fig.3 corresponds to the classical block diagram on Fig.1. The multiplication of the input signals is fulfilled by *Multiplier_1* and *Multiplier_2* blocks. The summing is implemented by *Sum_Inv* and *Gain_Inv* amplifiers. The *Transfer_Func* block performs the activation function in the neuron. It is based on the Look-up table and can be programmed to execute various transfer functions. The *Ramp generator* (Fig. 2) is implemented as *Periodic Wave* oscillator with frequency of the signal about 1kHz (Fig.5). The *Hold* blocks are used to agree the appearance of the signals at the outputs of the different functional blocks. Their inputs are sampled synchronously with the phase Φ_1 of the internal clock system of FPAA.

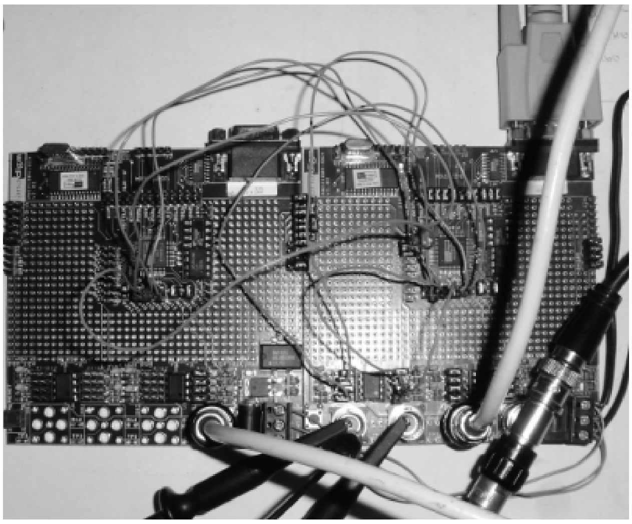


Fig.4. Picture of the experimental test-bench.

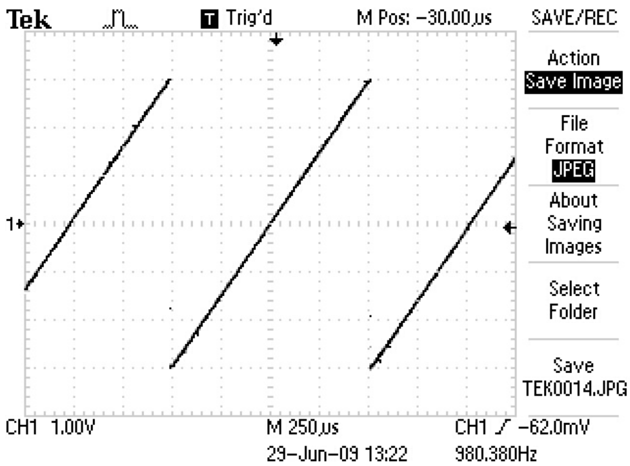


Fig.5. The output signal of the ramp generator

The output of the circuit, denoted as ***f(y)***, is connected to the lower output of the FPAA1. The output of the summing block ***y*** is connected to the upper output of the FPAA1.

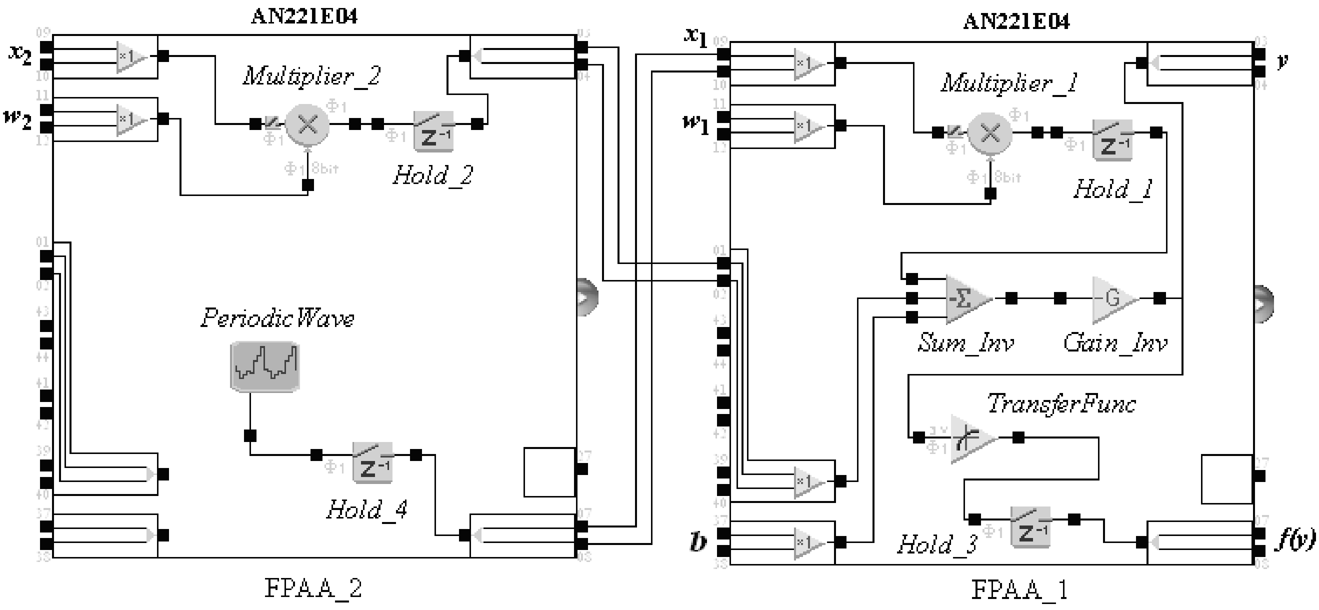


Fig. 3. FPAA implementation of 2-input analog neuron

V. EXPERIMENTAL RESULTS

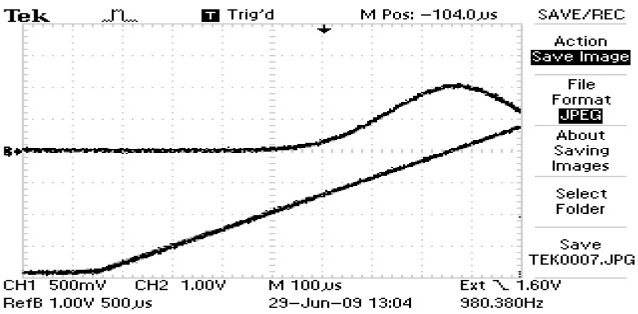
The presented neuron configuration is examined for various activation functions with different combinations of input signals.

Fig.6 depicts the results from examination of the neuron with radial basis activation function

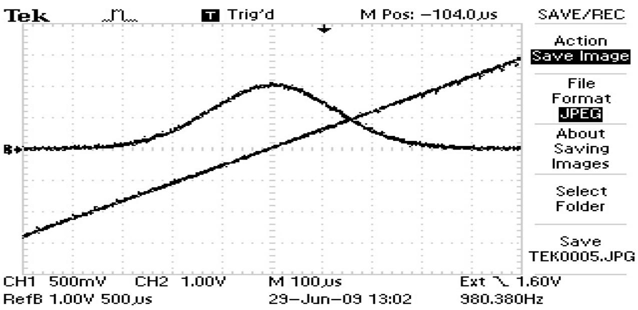
$$f = \frac{1}{exp(x^2)} \tag{1}$$

for w_1=w_2=1, x_2=0 and different values of b.

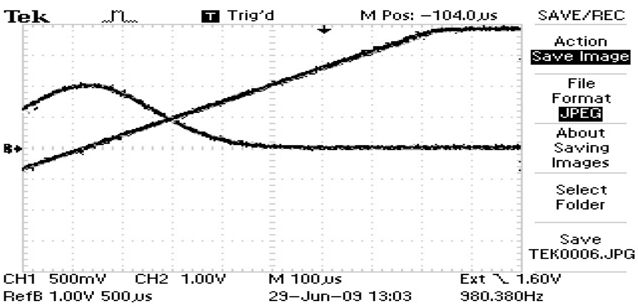
The straight line presents the value of the sum y and another curve describes the neuron's output $f(y)$. It is obvious that the position of the both lines depends on the value of b – the change of b leads to parallel shifting of the y values and shifting of the $f(y)$ on the abscissa. The saturation of y is due to the limitation of the value of output voltage of the FPAA chip between ±4 V.



b=-2



b=0



b=+2

Fig.6. Examination of neuron with radial basis activation function (w_1=w_2=1; x_2= 0)

Fig.7 presents the results from modeling the output signal $f(y)$ of the same neuron with electronic table Excel. The form and characteristics of theoretical results agree perfectly with the practical examinations. Fig.8 shows the results from another investigation of the neuron with radial basis activation function. In this case the agreement between practical and theoretical results is perfect, again.

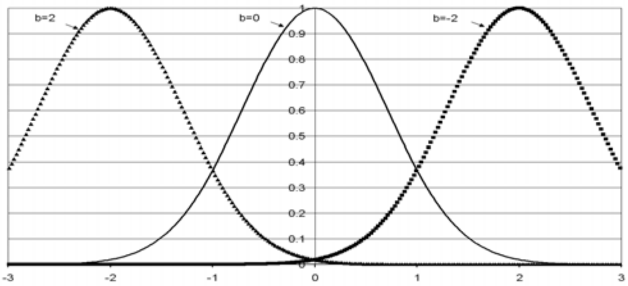
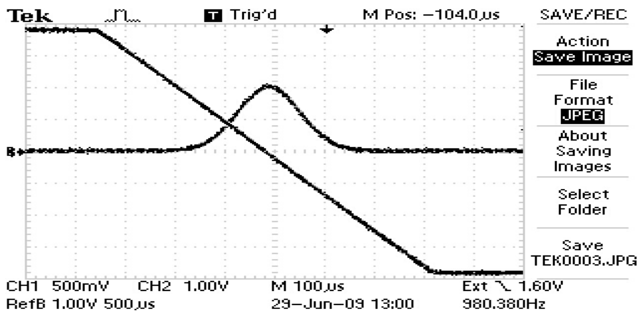
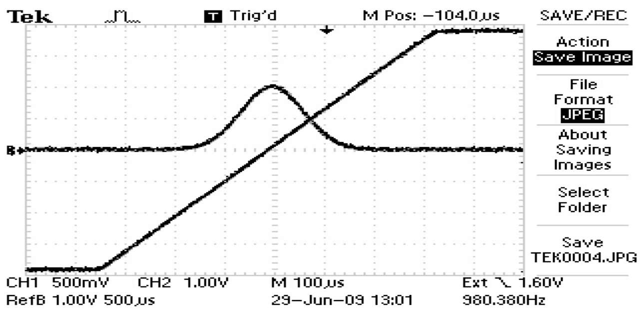


Fig. 7. Excel modeling of output signal $f(y)$ for neuron with radial basis activation function (w_1=w_2=1; x_2= 0)



w_1=w_2= -2



w_1=w_2=+2

Fig.8. Neuron with radial basis function (b=0; x_2= 0)

The results from investigation of neuron with hyperbolic tangent activation function

$$f = \frac{1-e^{-2x}}{1+e^{-2x}} \tag{2}$$

for w_1=w_2=1, x_2=0 and b=0 are shown on Fig.9.

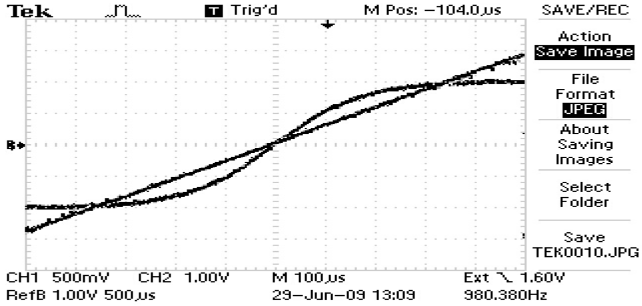
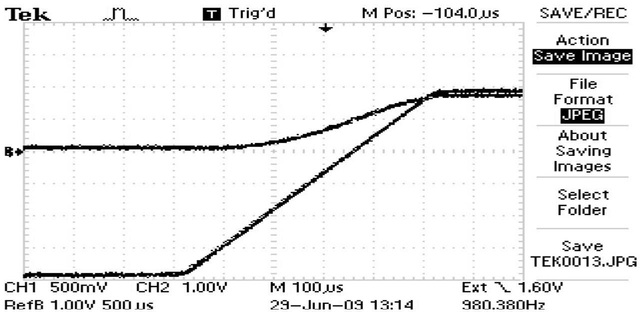


Fig.9. Examination of the neuron with hyperbolic tangent activation function (w_1=w_2=1; x_2= 0; b=0)

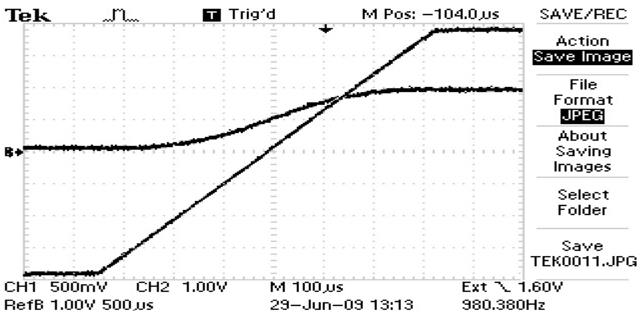
Fig.10 presents the investigation of a well-known, frequently utilized neuron with sigmoid activation function:

$$f = \frac{1}{1+e^{-x}} \qquad (3)$$

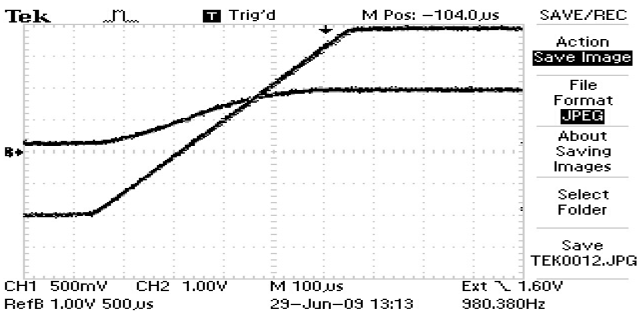
The comparison between practical results and theoretical expectations shows perfect coincidence with respect to the form and characteristics of the output signal.



b=-2



b=0



b=+2

Fig.10. Examination of the neuron with sigmoid activation function (w_1=w_2=2; x_2= 0)

VI. Conclusion

The paper presents the results from implementation and investigation of analog neurons by using Field Programmable Analog Arrays (FPAAs) of Anadigm Inc. To this aim, the classical block diagram of the artificial neuron is discussed and analyzed and the block diagram of the experimental test bench for examination of 2-input neuron cell is proposed.

Based on the presented block diagrams, FPAA implementation of 2-input analog neuron is proposed. It utilizes two series connected AN221K04 FPAA Evaluation Boards from Anadigm Inc. The configuration allows programming of both AN221E04 FPAA chips via the serial port of the personal computer. AnadigmDesigner2 software is used to this aim.

The designed circuit is used for practical examination of neurons with different activation functions and for various combinations of input signals. Results from investigation of neurons with radial basis, hyperbolic tangent and sigmoid activation functions are presented. They completely correspond to the theoretical expectations.

The presented results will be applied in the design of FPAA prototypes of small-size, small-run neural networks for learning algorithms with high fault-tolerance and requiring low or moderate precision.

VII. Acknowledgement

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