Memristor-The Future of Artificial Intelligence

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Abstract- Due to increasing demand on miniaturization and low power consumption, Memristor came into existence. Our design exploration is Reconfigurable Threshold Logic Gates based Programmable Analog Circuits using Memristor. Thus a variety of linearly separable and non-linearly separable logic functions such as AND, OR, NAND, NOR, XOR, XNOR have been realized using Threshold logic gate using Memristor. The functionality can be changed between these operations just by varying the resistance of the Memristor. Based on this Reconfigurable TLG, various Programmable Analog circuits can be built using Memristor. As an example of our approach, we have built Programmable analog Gain amplifier demonstrating Memristor-based programming of Threshold, Gain and Frequency. As our idea consisting of Programmable circuit design, in which low voltages are applied to Memristor during their operation as analog circuit element and high voltages are used to program the Memristor's states. In these circuits the role of memristor is played by Memristor Emulator developed by us using FPGA. Reconfigurable is the option we are providing with the present system, so that the resistance ranges are varied by preprogram too.

Index Terms— Memristor, TLG-threshold logic gates, Programmable Analog Circuits, FPGA-field programmable gate array, MTL-memristor threshold logic, CTL-capacitor Threshold logic, LUT- look up table.

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1 INTRODUCTION

ACCORDING to Chua's [founder of Memristor] definition, the internal state of an ideal Memristor depends on the integral of the voltage or current over time. Therefore the use of ideal Memristor as Analog elements in programmable circuits is limited since their internal state once programmed, would change significantly due to DC component in current or voltage. Only perfect ac signals would significantly change the memristor state so that use of such devices seems to appear narrow. But experimentally realizable Memristor are not ideal. Threshold Logic Gates are interesting candidate for logic implementation using memristive-CMOS circuits. Reconfigurable TLG built with memristor can lead to changes in programmable analog circuits. Memristor based circuits could be used to replace larger combinations of Transistors, and through proper application of signals, the logic operation in foundational architecture could be easily changed among AND, OR, NAND, NOR, XOR, and XNOR to create the logic necessary to solve each individual computational problem. In the present work we are designing a Programmable analog circuit based on the reconfigurable Threshold Logic Gates using Memristor. The circuit is first designed in Xilinx using FPGA and simulated using Modelsim.

This paper is organized as follows: Basic concepts of Memristor and definitions in Sec 2. In Sec 3 we describe our approach to use Memristor in Threshold Logic Gates and in Programmable analog circuits. In Sec 4 we present a Memristor Emulator design as an electronic circuit whose response is similar to that of a Memristor. We will use this Memristor Emulator in Sec 5 to demonstrate an application of Memristor in analog circuit which includes Programmable Gain Amplifier built using Threshold Logic Gate in FPGA. Simulation results and concluding remarks are given in Sec 6.

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2 Memristor

2.1 Definition And Basic Concepts

The fourth fundamental passive element, Memristor is a concatenation of "memory resistor". The memristor was originally envisioned in 1997 by analyzing mathematical relation between pairs of fundamental circuit variables. Memristor is a two terminal device which change its resistive properties depending on the direction of current passing through the device. The amount of current a memristor allows to pass depends on how strong the current was that flowed through it in the past and how long it was exposed to it. We utilize memristor as weights in the realization of low-power Field Programmable Gate Arrays (FPGA) using threshold. Comparison with the existing CMOS look-up-table (LUT) gate and capacitor threshold logic (CTL) gates show that MTL gates exhibit less energy-delay product by at least 90 percent. Memristive behavior and memory storage have been reported in solid-state Ti02 thin films, where the change in resistance is realized by the ionic motion of oxygen vacancies activated by current flow. Memristors can represent many states instead of just two states, 'on' or 'off', as with transistor. This means new types of computing models and analog computers can be created.Memristor was originally defined in terms of a non-linear functional relationship between magnetic flux linkages that has flowed, q (t).

$$f(\Phi_m(t), q(t))=0 \qquad (1)$$

The variable Φ_m(magnetic flux linkage) is generalized from the circuit characteristic of an inductor. It does not represent a

magnetic field here. The symbol Φ_m may be regarded as the integral of voltage over time. In the relationship between Φ_m and q, the derivation of one with respect to the other and so each memristor is characterized by its memristance function describing the charge-dependent rate of change of flux with charge.

$$M(q) = d\Phi m/dq \qquad (2)$$

Substituting the flux as the time integral of the voltage, and charge as the time integral of current, the more convenient form is

$$Mq(t) = V(t)/I(t) \qquad (3)$$

To relate the memristor to the resistor, capacitor, and inductor, it is helpful to isolate the term M(q), which characterizes the device, and write it as a differential equation.

TABLE I.
Comparison Of Passive Components

Device	Characteristic property	Differential equation
Resistor	Resistance(V per A, or ohm, Ω)	R= dV /dI
Capacitor	Capacitance(C per V, or Farads)	C=dq/dV
Inductor	Inductance (Wb per A, or Henrys)	L=$d\Phi_m$/Di
Memristor	Memristance (Wb per C, or ohm)	M=$d\Phi_m$/dq

It can be inferred from this that memristance is charge-dependent resistance. If M(q(t)) is a constant, then we obtain ohm's law R(t)= V(t)/I(t). If M(q(t)) can vary with time produces

$$V(t) = M(q(t)\, I(t)) \qquad (4)$$

This equation reveals that memristance defines a linear relationship between current and voltage, as long as M does not vary with charge. Nonzero current implies time varying charge. Alternating current, however, may reveal the linear dependence in circuit operation by inducing a measurable voltage without net charge movement-as long as the maximum change in q does not cause much change in M. The memristor is static if no current is applied. If I(t)=0, we find V(t)=0 and M(t) is constant. This is the essence of the memory effect. The power consumption characteristic recalls that of resistor, I^2R.

$$P(t) = I(t)V(t) = I^2(t)M(q(t)) \qquad (5)$$

As long as M (q(t)) varies little, such as under alternating current, the memristor will appear as a constant resistor. If M (q(t)) increases rapidly, however, current and power consumption will quickly stop.

3 MEMRISTOR IN TLG AND PROGRAMMABLE ANALOG CIRCUITS

3.1 MEMRISTOR IN THRESHOLD LOGIC GATES

Threshold Logic Gates are single node Artificial Neural Networks (ANNs) designed specifically to implement a logic operation. The Logic gates produce a binary output by passing a weighted summation of several binary inputs ($X=[X_1, X_2 \ldots X_n]$) through a hard limiting activation function f,

$$Y = g(X) = f\left(\sum_{i=1}^{N} w_i x_i + w_0\right) \qquad (6)$$

Where w_o is the threshold level. In this paper we are considering two input logic operations AND, OR, NAND, NOR, XOR, XNOR. These logic operations are linearly and non-linearly separable can be realized by the architecture given in figure 1.

The same network structure can be used for multiple logic operations, simply by changing the weights w_i. The weights necessary to implement any given TLG are not unique. Here the Synaptic weights (including bias) are controlled by Memristor. Each time when the resistances of memristor changes, the weight values are changed, accordingly Threshold output is varied. According to the Threshold value, the operation of the logic functions is changed.

$\Psi(\upsilon)$ defines the output of a neuron in terms of the induced local field υ. Here we identify a type of activation function necessary to implement Threshold logic gate, i.e. threshold function.

3.2 THRESHOLD ACTIVATION FUNCTION

For this type of activation function we have,

$$\psi(\upsilon) = \begin{cases} 1 & \text{if } \upsilon \geq 0 \\ 0 & \text{if } \upsilon < 0 \end{cases} \qquad (7)$$

In engineering literature, this form of Threshold function is commonly referred to as a HEAVISIDE FUNCTION. Correspondingly, the output of neuron k employing such a Threshold function is expressed as,

$$Y_K = \begin{cases} 1 & \text{if } \upsilon \geq 0 \\ 0 & \text{if } \upsilon < 0 \end{cases} \qquad (8)$$

Where υ_k is the induced local field of the neuron;that is

$$Y = g(X) = f\left(\sum_{i=1}^{N} w_i x_i + w_0\right) \qquad (9)$$

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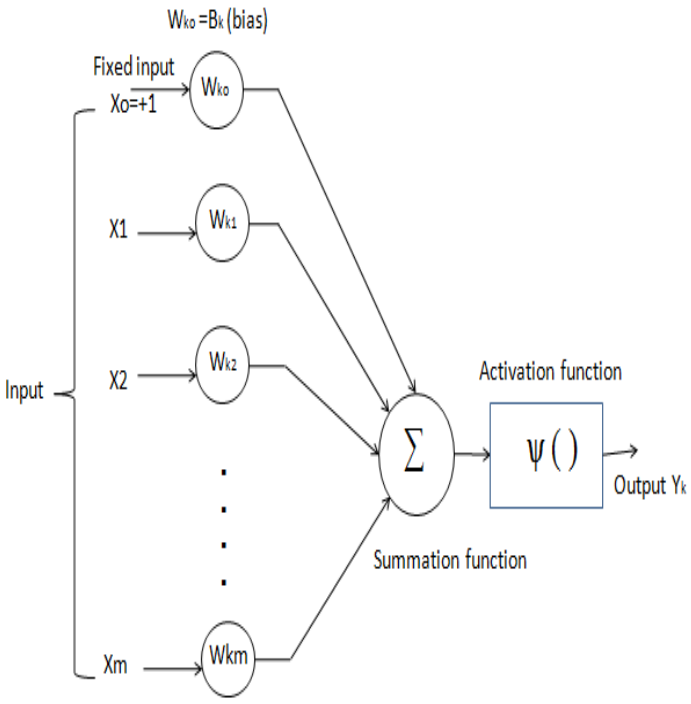

Fig 1.A nonlinear model of neuron with M input synapses

3.3 MEMRISTOR IN PROGRAMMABLE ANALOG CIRCUIT

The memristor can be used to implement programmable analog circuits, leveraging memristor's fine-resolution programmable resistance without causing perturbations due to parasitic components. The resistance programming can be achieved by controlling the input pulse width and its frequency. In analog circuits memristor is based on threshold type behavior, hence we implement Threshold logic gate based programmable analog circuit. Circuit is designed in such a way to use low voltages in analog mode of operation and high voltage pulses in order to program the memristor's state. In this way, we obtain a circuit element whose mode of operation is close to that of a digital potentiometer but its realization is much simpler. This scheme represents an important application of a new class of emerging systems called memory circuit elements (memelements).

4 MEMRISTOR EMULATOR

Memristor Emulator imitates the behavior of a TiO_2 Memristor. As of today Memristors, are not yet available on the market to implement memristor based programmable circuits, we have built a Memristor Emulator. The latter is a simple electronic scheme which can simulate a wide range of memristive systems. In particular, we have recently used it to simulate the behavior of synapses in simple neural networks. Two or more emulators can be connected in series, parallel or hybrid with identical or opposite polarities. With a simple change of connection, each memristor emulator can be switched between a decremental or incremental configuration.

TABLE II.
Comparison Of Solid State Memristor And Memristor Emulator

Parameter	Real Memristor	Memristor emulator
Resistance range	Determined by the structure	50Ω to 1000kΩ (also can be extended)
Frequency	Any	≤50MHZ
Response	Determined by the structure	Determined by pre-programing
Applied voltage	Less than breakdown voltage of the structure	0, +5v or -2.5, +2.5v
Supply voltage	Not needed	0, +5v or -2.5, +2.5v

4.1 VLSI IMPLEMENTATION SCHEME

The Memristor Emulator is developed using FPGA TQ 100. It consists of a Analog to Digital Converter and a memory element with resistance values. The A/D converter is used to convert the input Analog signal into digital signal. The FPGA is used to update the resistance value of the memory element i.e. the Memristor. The action is implemented as follows.

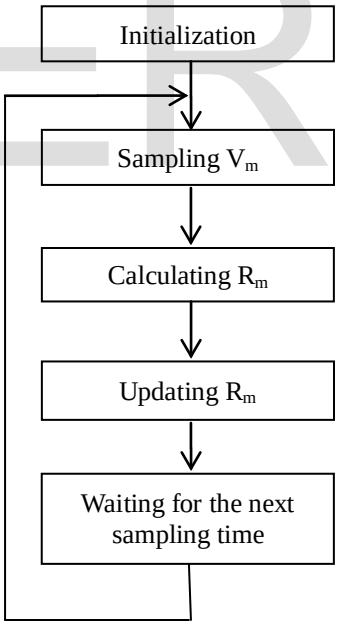

fig 2.Block Scheme of Memristor Emulator Algorithm

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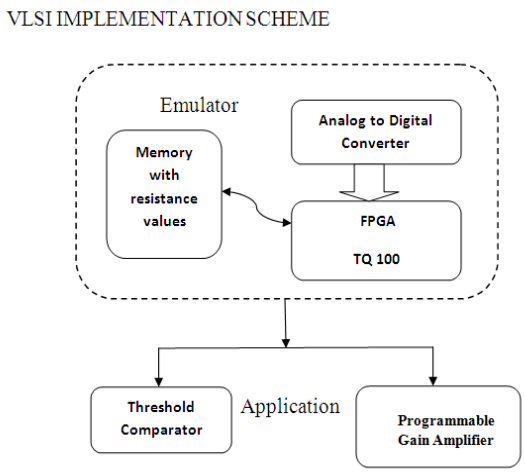

Fig 3. VLSI Implementation Scheme of Memristor Emulator

The characteristic curve of Memristor Emulator is shown in the following figure 4. The curve is plot between current in mA and the voltage of memristor in volts. The graph shows the difference between the ideal memristor and the memristor emulator developed by us.

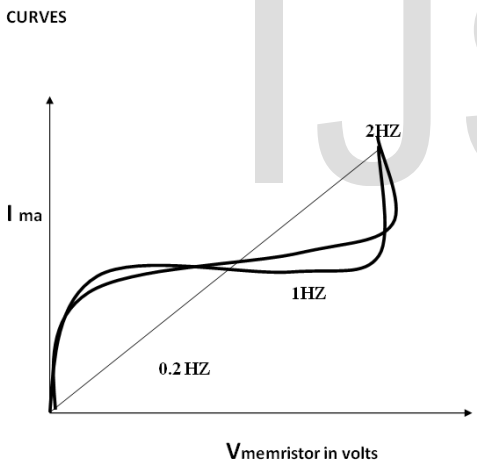

Fig 4. Characteristic Curve of Memristor

5 PROGRAMMABLE ANALOG CIRCUITS

The memristor can be used to implement programmable analog circuits, leveraging memristor's fine-resolution programmable resistance without causing perturbations due to parasitic components. The resistance programming can be achieved by controlling the input pulse width and its frequency. In analog circuits memristor is based on threshold type behavior, hence we implement Threshold Logic Gates to build programmable analog circuits. Main idea is to use low voltages in analog mode of operation and high voltage pulses in order to program the memristor's state. In this way, we obtain a circuit element whose mode of operation is close to that of a digital potentiometer but its realization is much simpler. This scheme represents an important application of a new class of emerging systems called memory circuit elements (memelements).

A variable gain amplifier or voltage-controlled amplifier is an electronic amplifier that varies its gain depending on a control voltage. A voltage controlled amplifier can be realized by first creating a voltage controlled resistor (VCR), which is used to set the amplifier gain. Thus the voltage controlled resistor is replaced by Memristor.

The recent work on finding the world's simplest and cheapest Memristor, scientists have discussed possibilities and efficiencies gained by using Memristor in analog circuit design, such as reduction in area and power of a circuit. Using the simplest Memristor Emulator developed by us, we now demonstrate how we can make simplest and energy efficient programmable amplifier, that would considerably reduce the power consumption.

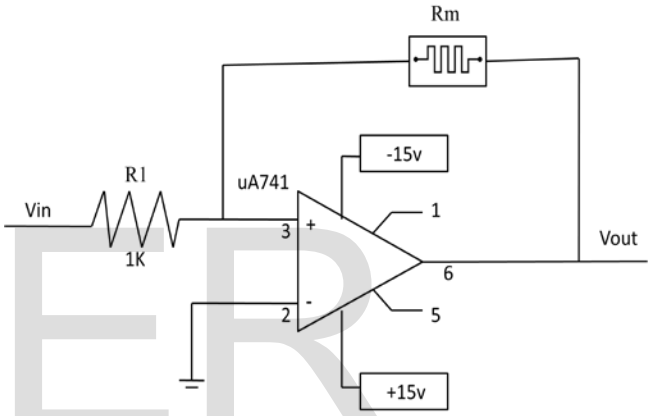

Fig 5. Circuit of Gain Amplifier Using Memristor

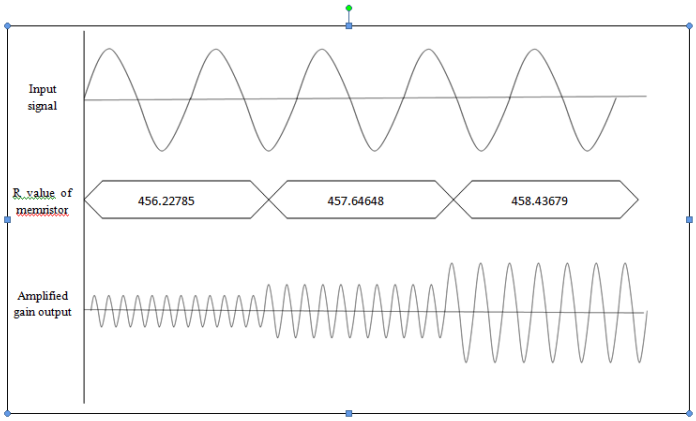

Fig 6. Model Graph of Gain Amplifier

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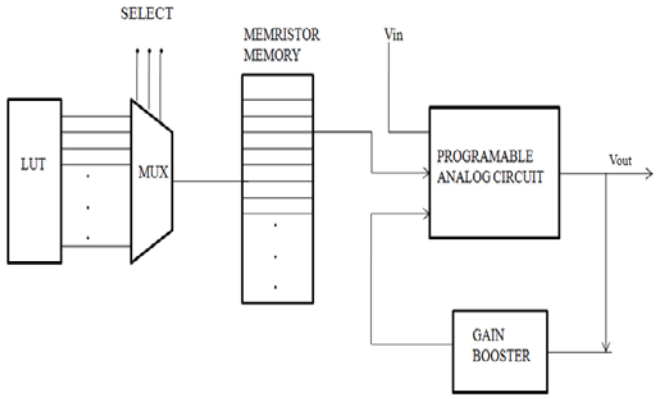


Fig 7.General Block Design of Analog Circuit Using Memristor Emulator

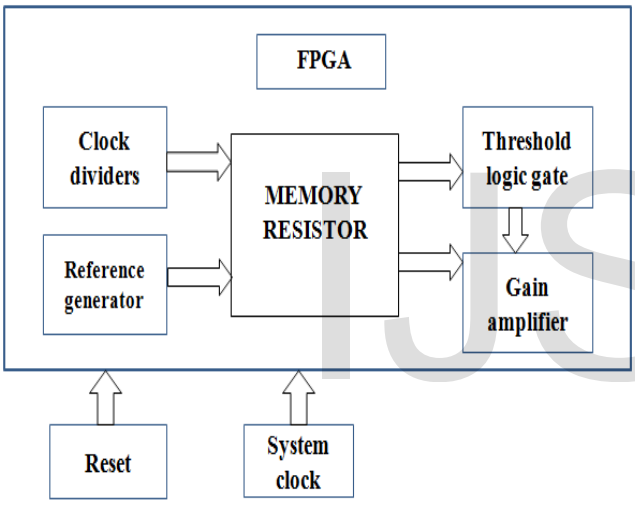
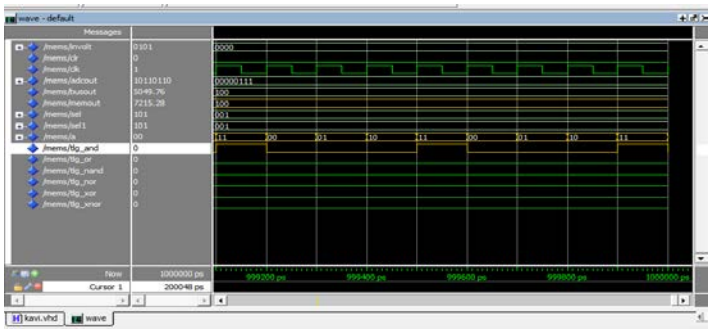


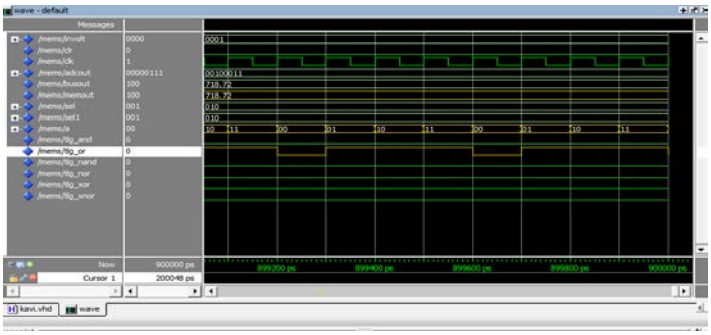
Fig 8. FPGA Implementation

6 SIMULATION RESULTS

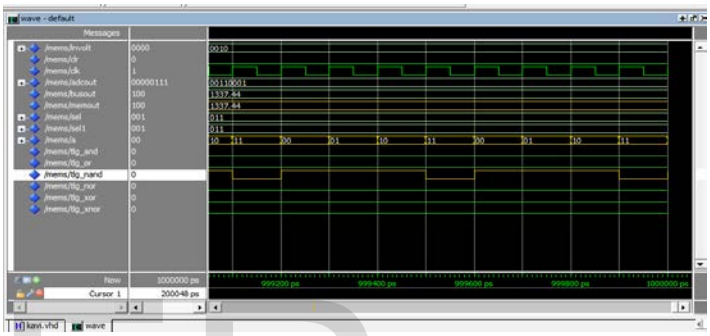
6.1 TLG as AND Gate:



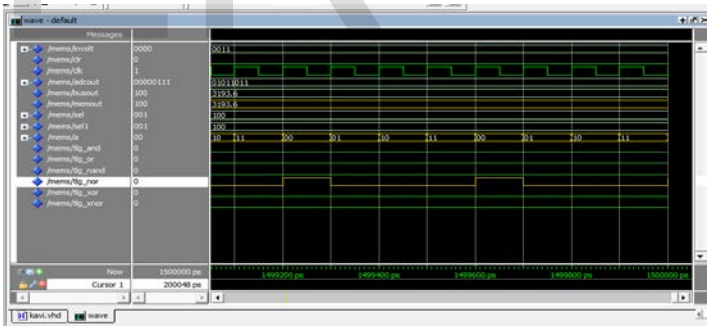
6.2 TLG as OR Gate:



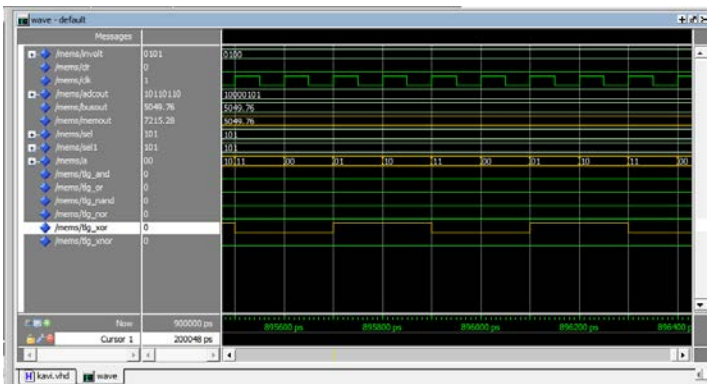
6.3 TLG as NAND Gate:



6.4 TLG as NOR Gate:



6.5 TLG as XOR Gate:



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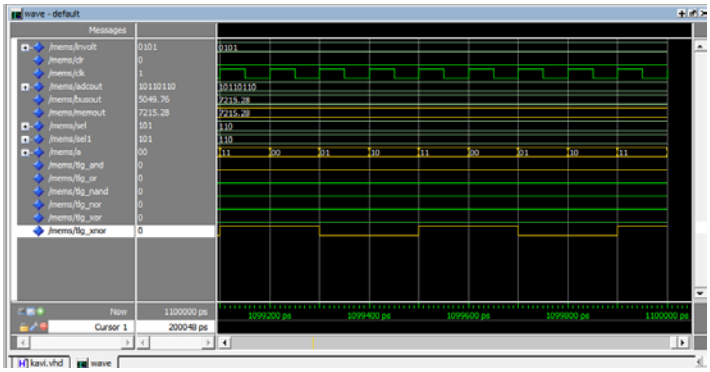
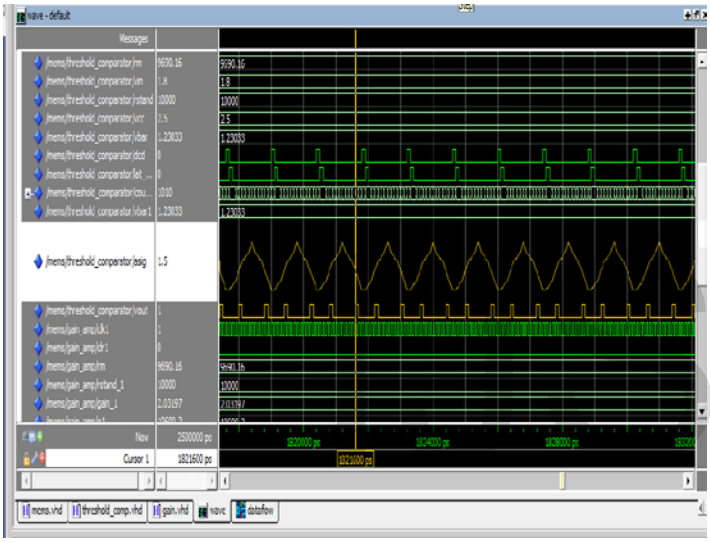
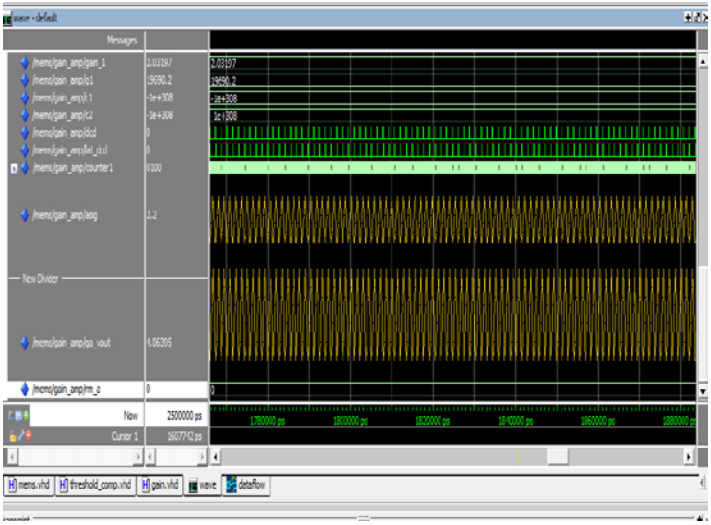
6.6 TLG as XNOR Gate:



6.7 Output of Threshold Comparator:



6.8 Output of Gain Amplifier:



7 CONCLUSIONS

By the prolonged use of memristors in analog circuits in such a way that in the analog mode of operation, only voltage of small magnitude (below the threshold) is applied to the device and high voltage is used only for programming by this way the exhaustable power is conserved . so the voltage is applied in the form of pulse which changes the resistance of memristors by discrete amount. The highly non-linear dynamic response of the device can be exploited to switch it fast between distinct resistive states and thus serve as a memory element or a programmable dynamic load. Thus by providing a simple realization of digital circuit using FPGA, we can find useful and broad-range applications in electronics. Hence by applying a train of pulses we have designed the programmable analog gain circuit with varying range of resistance which is also achieved by low power consumption. This work developed a greater understanding of the constrains involved when using memristors in complete circuits, instead of in signal analyzers. Techniques necessary to work with these memristors were also developed.

REFERENCES

[1] Adrian rothenbuhler, Thanh Tran, Elisa H.Barney smith, Kristy A. Campbell "Reconfigurable Threshold Logic Gates using Memristive Devices" journal of Low Power Electronics and Applications,2013 ISSN 2079-9268.

[2] Adhikari, S.P.; Yang, C.; Kim, H.; Chua, L.O. "Memristor bridge synapse-based neural network and its learning". IEEE Trans. Neural Netw. Learn. Syst. 2012, 23, 1426–1435.

[3] Beiu, V.; Quintana, J.M.; Avedillo, M.J. "VLSI implementations of threshold logic—A comprehensive survey". IEEE Trans Neural Netw. 2003, 14 1217–1243.

[4] C. Cagli, F. Nardi, and D. Ielmini, "Modeling of set/reset operations in NiO-based resistive-switching memory devices," *IEEE Trans. Electron Devices*, vol. 56, no. 8, pp. 1712–1720, 2009.

[5] Di Ventra, M.; Pershin, Y.V.; Chua, L.O. "Circuit elements with memory: Memristors, Memcapacitors, and meminductors". Proc. IEEE 2009, 97, 1717–1724.

[6] E. Ozalevli and P. E. Hasler, "Tunable highly linear floating-gate CMOS resistor using common-mode linearization technique," *IEEE Trans. Circuits Syst. I*, vol. 55, no. 4, pp. 999–1010, MAY 2008.

[7] G. S. Rose and M. R. Stan, Jr.," A programmable majority logic array using molecular scale electronics," *IEEE Trans. Circuits Syst. I*, vol. 54, no. 11, pp. 2380–2390, NOV 2007.

[8] K. H. Wee and R. Sarpeshkar, "An Electronically Tunable Linear or Nonlinear MOS Resistor," *IEEE Trans. Circuits Syst. I*, vol. 55, no. 9, pp. 2573–2583, OCT 2008.