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Radiation Reduction in the Axon-Hillock Neuromorphic Circuit

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***Abstract*— Nowadays, implementing neuromorphic circuits, the main goal of which is to mimic neuron behavior, has drawn attention. The aim of the present research is to design robust neuromorphic circuits for environments exposed to radiation. After research samples were examined in radiation laboratories, it was found out that radiation causes a change in the threshold voltage of MOSFET transistors. Accordingly, the parameters of the neuromorphic axon-hillock circuit were measured before and after exposure to radiation. According to the results, the presence of radiation causes a change in the threshold voltage of this transistor and increases the short-circuit current in the circuit, leading to an increase in the dynamic power consumption. Hence, using techniques for reducing the short-circuit current and adding a transistor to the circuit led to a decrease in the short-circuit current. All the simulations were performed in HPSICE software.**

***Keywords*— neural network, neuromorphic, radiation, MOSFET**

I. INTRODUCTION

Neuromorphic architectures are hardware systems that aim to utilize the operational principles of brain neural networks in order to perform their tasks. The advantages of neuromorphic systems include their ability to create decentralized operations with large parallelization using simple processing units [1]. Some of the applications of these systems are machine vision, machine learning, pattern recognition, and learning with low power consumption. Many researchers and research teams around the world are attempting to create a brain similar to that of humans by developing neuromorphic architectures [2]. There are circuits operating in satellites outside the Earth's atmosphere due to the thinning of the ozone layer or in robots operating and experimenting in other planets. Such environments are known as harsh environments. These factors lead to a daily increase in our harsh environments. The topic of circuits that can resist a reduction in radiation effects has always been popular, and progress has been made in this field with advances in electronic instruments. Radiative environments include cosmic rays, solar energetic particles, particles trapped in the magnetic fields of planets, and radiation belts around the Earth (in space) and neutrons present in the atmosphere, alpha particles, and man-made radiation (on Earth) [3]. Nowadays when the neuromorphic architecture is a popular topic, attention is being paid to radiation in these circuits albeit with insufficient advances [4]. The aim of this research is to reduce radiation effects on neuromorphic circuits.

II. RELATED WORKS

A. Radiation effect

Radiations are divided into ionizing and non-ionizing depending on their nature and effects. Ionizing radiation ionizes matter. Non-ionizing radiation does not change the atomic structure of matter after being absorbed. Radiative environments include cosmic rays, solar energetic particles, particles trapped in the magnetic fields of planets, and radiation belts around the Earth (in space) and neutrons present in the atmosphere, alpha particles, and man-made radiation (on Earth) [3].

In this section, we would like to investigate the effect of radiation on the threshold voltage of a MOS transistor. Electrical circuits have a large number of oxides and insulators due to their use of MOS transistors. In environments exposed to radiation, the entrance of these materials into transistors causes a change in the electron-hole structure. Electrons and protons outside the Earth's atmosphere can create an ionizing dose. This traps some charges in the gate oxide. This process changes the threshold voltage and leakage current of the transistor [5]. The presence of radiation disturbs the operation of these circuits. Sometimes, radiation causes a change in the threshold voltage of transistors [6,7]. This change in the threshold voltage increases the short-circuit current and power consumption. Fig. 1 displays the change in the threshold voltage at various radiation doses. In a research paper, M.Marcisovska et al. have studied the results of investigations on 2 ASICs in 180-nm technology. They placed the designed sample circuits in a chamber and examined the radiation effect on the threshold voltage. It is observed in Fig. 1 that the changes in the NMOS transistor are less than 10%. However, a remarkable change in the threshold voltage is observed for the PMOS transistor. When the radiation dose reaches kGy10 to kGy100, an approximate change of 30% occurs in the threshold voltage [8].

In the research by Faccio Federico et al., the effect of radiation on the voltage threshold of a MOS transistor in transistors with various W and L has been studied in 130-nm technology. It has been specifically shown how the main characteristics of transistors have been affected by radiation in modern technologies. The paper expects this effect to be more significant in modern technologies with smaller sizes [9]. In the research by Akturk et al., the effect of gamma radiation on the threshold voltage, leakage current, and other characteristics has been investigated. The threshold voltage

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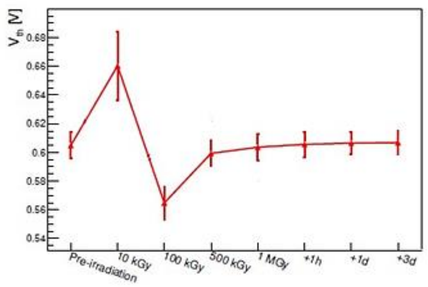
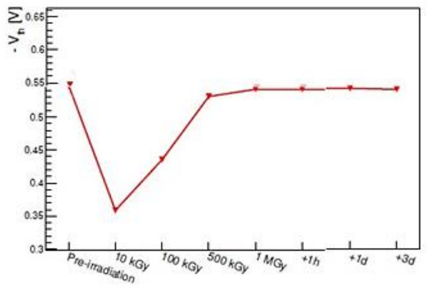
has specifically dropped. They were said to have good performance up to a dose of krad100. The transistor can be used up to a dose of krad300 using a number of limitations of the circuit and transistor. A dose larger than krad600 leads to failure [10].



(a) 180 nm SoI NMOS transistors.



(b) 180 nm SoI PMOS transistors.

Fig. 1. The change in the threshold voltage for various radiation doses [8].

B. Short circuit current in CMOS inverter

A short circuit occurs in a CMOS inverter when the pull-up network and pull-down network transistors are simultaneously on. In this state, the power consumption is connected to the ground and results in a large loss of electricity. Some techniques are employed to reduce the short circuit effect. Some techniques use a delay generator to reduce the effect of the short circuit current. In Fig. 2, the voltage first reaches the gate of the pull-up transistor, and then the voltage reaches the gate of the pull-down transistor using a delay. A smart delay generator circuit reduces the simultaneous on-time of the pull-up and pull-down transistors. Fig. 3 displays a sample delay generator from the research by Y. S. Abdalla [11]. Other techniques have been proposed for reducing short circuit at the gate-level logic [12,13]. However, most of these techniques have overhead, as seen in Fig. 3. This means that a large number of transistors has been used in them, causing an increase in their area and parasitic capacitance. The present research uses the technique by Janez Puhan et al., which has a very small overhead [14]. As shown in Fig. 4, placing a resistor between the pull-up and pull-down networks eliminates the short-circuit current, leaving only an NMOS transistor as the overhead.

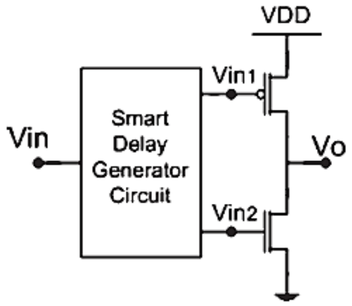


Fig. 2. General configuration of the proposed solution of short circuit current [6].

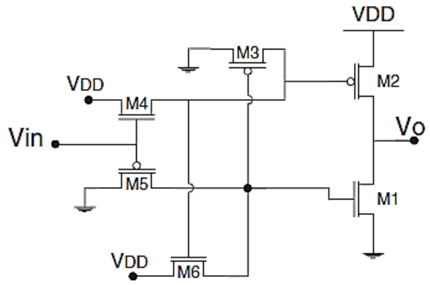


Fig. 3. Schematic of a delay generator [6].

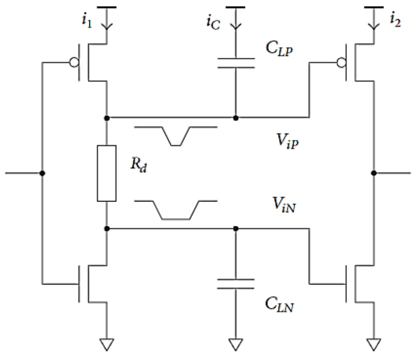


Fig. 4. Two-stage BBM buffer with RC delay implementation [9].

C. Axon-hillock neuromorphic circuit

The axon-hillock neuron circuit is among the first circuits proposed using a neuron model [15]. The schematic diagram of this circuit is shown in Fig. 5a. The axon-neuron model has been designed using 6 transistors and 2 capacitors. The input current I_{in} is accumulated in the input capacitor C_{Mem}, and increases the voltage linearly up to the threshold voltage of the inverter. Whenever V_{Mem} exceeds the threshold voltage of the inverter, a pulse output is generated, and when V_{out} is activated, a transistor is turned on to discharge the capacitor C_{Mem}. The transistor V_{pw} is responsible for the reset current and causes V_{out} to return to zero, where we must expect the cycle to restart. Fig. 5b represents the output of the neuron circuit. The TL denotes the charging time of the capacitor C_{Mem}. The larger the input current, the faster the C_{Mem} charges, and vice versa. TH denotes the time during which the output of the neuron is 1. TH is controlled by the gate voltage of the transistor VPW [16].

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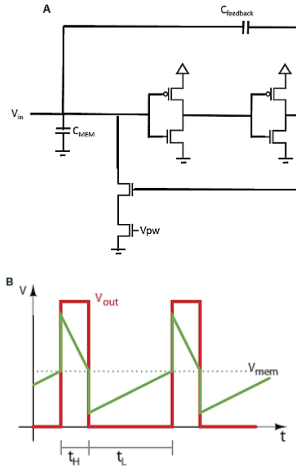

Fig. 5. Axon-hillock circuit (a) Schematic diagram; (b) Membrane voltage and output voltage traces over time [11].

III. Proposed Method

The proposed circuit is presented in this section. We have placed a resistor between transistors M1 and M2 in Fig. 6, which represents the base axon-hillock neuron circuit. To fabricate the resistor, we have used an NMOS transistor named M7 the gate of which is connected to its own drain. This prevents a short circuit in the first level. For example, if V_{in} switches from 1 to 0, transistor M1 will switch from off to on, and transistor M2 will switch from on to off. Since transistor M7 is off, no short circuit is created. M7 is turned on when its gate voltage exceeds its threshold voltage. Since the voltages have reached the next level (M3 and M4) with a delay, there is also no short circuit in this level. Fig. 7 displays a Biomimetic Real-Time Cortex (BioRC) circuit designed using CMOS technology [17]. The action potential (AP) is at the input of this circuit and is received from the axon hillock circuit. We have placed transistor M10 in this circuit, preventing a short circuit current in the AP part.

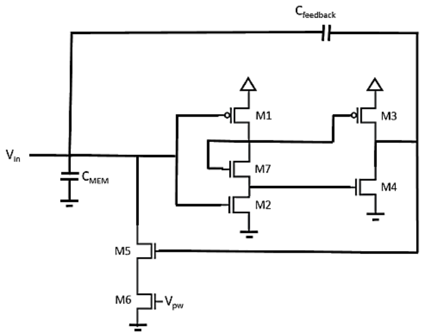

Fig. 6. Improved axon-hillock circuit.

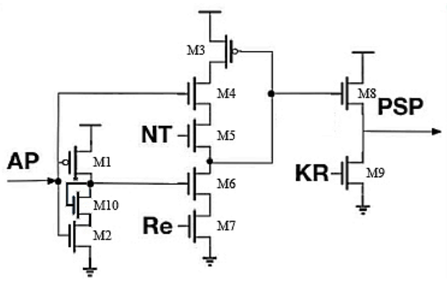

Fig. 7. Improved BioRC synapse circuit.

IV. Results

Fig. 1 shows the research conducted by Marcisovska et al. A remarkable change in the threshold voltage is observed for the PMOS transistor. In steps where the radiation dose reaches kGy10 to kGy100, an approximate change of 30% is observed in the threshold voltage [7]. After simulating the circuit in HSPICE, we realized that this threshold voltage change in the CMOS inverter causes a short-circuit current, resulting in an increase in the dynamic power. Figs. 5 display the base axon-hillock circuit when exposed to radiation of 10KGy. The dynamic power increases by 20% due to the generation of a short-circuit current. In the present improved circuit, the dynamic power has reduced by 16%. We have even improved the dynamic power in pre-irradiation by 10% using this method. According to Fig. 10, we have reduced the total power (static and dynamic) by 19% by implementing this technique in a neural network. In order to simulate this circuit in a neural network, a Semeion dataset with 7*7 pixel images was selected [18]. Every image of this dataset has 49 cells. According to Fig. 10, each cell is assigned to one neuron in this neural network. At the input of this neural network, there are 49 neurons, each of which has a pixel assigned to it. If the pixel is white, i.e., it is empty, the neuron output is zero, and if the pixel is black, the neuron output is 1. There are 10 neurons in the output layer, which are for identifying numbers from 0 to 9. After simulating the circuit in HSPICE software and measuring the power during pre-radiation and after the radiation, it was observed that the power has been reduced by 19% in the improved circuit.

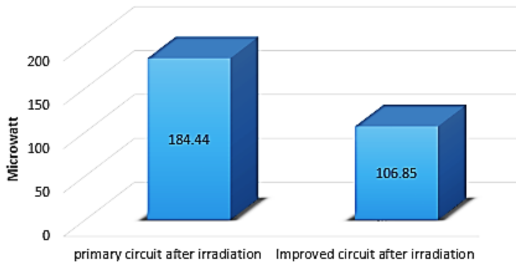

Fig. 8. Total dynamic power.

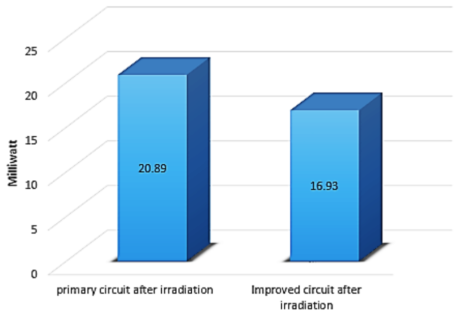

Fig. 9. total power neuromorphic circuit.

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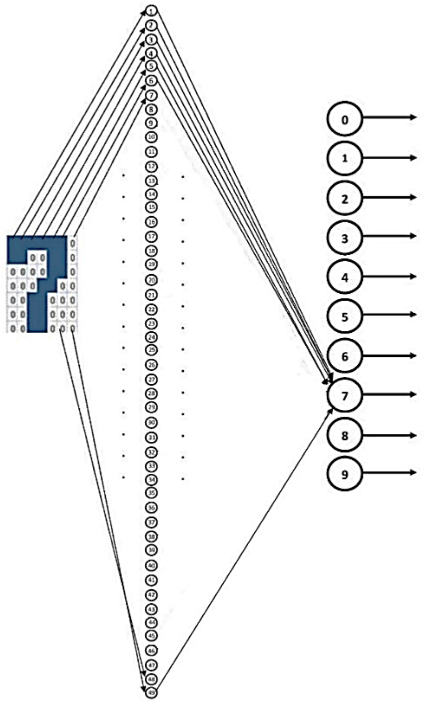

Fig. 10. A sample connection in the implemented neuromorphic circuit.

V. CONCLUSION

In this paper, we observed that when CMOS transistors are exposed to radiation, their threshold voltage changes. A change in the threshold voltage causes an increase in the dynamic power. The design of circuits that are optimal in resisting radiation is an important issue. The axon-hillock circuit was designed and simulated by placing a resistor between the transistors of the pull-up and pull-down networks. The power before and after the radiation was computed, and the short-circuit current was found to have considerably decreased with minimum overhead, which was a single transistor. Prospective research can use the idea in this research to improve the neurons and synapses of other neural networks for harsh and radiative environments.

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