# The Application of SRAM Chip as a Novel Neutron Detector

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## ABSTRACT

SRAM chips were used to design a fast response, highly sensitive neutron detector. We have conducted experiments with SRAMs at the DESY Research Centre in Hamburg, Germany. Memory contents (number of SEU) were recorded as a function of neutron expose time. The chips were exposed to a neutron field from an Americium-Beryllium neutron source ($^{241}$AmBe). The second experiment was accomplished in the 450 MeV electron linac (Linac II) tunnel. Another batch of SRAMs was irradiated with $^{60}$Co-gamma rays to a dose, of about 60 Gy, no SEU was registered. This validates, that gamma radiation has no substantial effect to produce SEU in the SRAM. The proposed detector could be ideal for the detection of pulsed neutron radiation produced by high-energy electron linear accelerators and synchrotron facilities, which are currently in operation and planned for the near future.

***Key words:*** Single Event Effect, Single Event Upset, Total Ionizing Dose, Static Random Access Memory, Beam Loss Monitoring System

## 1 INTRODUCTION

Bremsstrahlung gamma radiation and photoneutrons are generated during the operation of high-energy linear accelerators [1, 2]. These parasitic radiations could run the risk of radiation damage to electronic systems placed in the accelerator's neighborhood.

One can use different types of detectors to monitor the neutron and gamma radiation level and deliver prompt warnings, when the radiation exceeds the pre-set alarm level [3]. Large varieties of presently available sensors such as, Photo-multipliers, Compton diodes, Ionization chambers, Scintillation counters, Aluminium cathode electron multipliers and PIN diodes are used for the detection of gamma radiation [3]. On the other hand, no neutron detector with a fast response time and the interface capability to a computerized radiation monitoring is available. The primary criterion of a neutron detector for a pulsed radiation field produced by a high-energy accelerator; such as the newly installed X-Ray Free-Electron Laser at DESY [1, 4], is the fast-response time. The common BF3 chamber-based neutron detectors suffer from long response time and pulse pile-up effect, therefore could not be used to detect pulsed neutrons in real time.

SRAM memories, susceptible to neutron induced Single Event Upsets (SEUs), are selectively sensitive to neutrons and give practically no gamma response. Hence, these devices are good candidates for neutron detection within a radiation field contaminated with a strong gamma background [1]. The SEU plays the most important role in the neutron detection. They are induced by heavy charged particles (i.e. alpha particles, recoil nuclei) losing their energy in the interface region of the MOS structures (Fig. 1) of memory cells [1, 5].

Dynamic Random Access Memories (DRAMs), previously used by other investigators for neutron detection, require frequent refreshing of the memory content [6]. On the other hand, the present device runs without the memory refreshment. This paper highlights a novel, inexpensive and reliable neutrons detector based on SEU of SRAM chips.

The design of a reliable refreshing circuit, which often is intended to be used in a high radiation (neutrons and gamma) environment, makes a device more complicated, therefore, less reliable. Most of research was done using densely ionizing particles like alpha particles or protons [7]. The number of generated errors in the memory increases with the time and depends on the neutron dose. The SRAM-based neutron sensor described in this paper posses a linear response, hence, could be used as a neutron counter. This application requires the use of the high-density memory in order to increase the sensitivity.

## 2 NEUTRON PRODUCED IN LINAC ENVIRONMENT

The X-FEL free electron laser operating in X-ray regime uses a 20 GeV accelerated electron beam [8, 9]. Bremsstrahlung photons and photoneutrons are produced during the operation of such a high-energy electron linac [18]. The first type of radiation effects concerns accidental electron beam losses. The beam energy is lost and thereby an intense field of photoneutrons and Bremsstrahlung gammas are produced [4, 10].

The second type of effect concerns unavoidable beam losses, which are localized in the collimator, limiting the beam profile [11]. Radiation in the accelerator tunnel is produced when of the electron beam interacts with high-Z materials, such as collimators or scrapers. High-energy neutrons are produced when the incident electron beam energy exceed the threshold limit [10]. Systems capable of detecting a sudden beam loss in the accelerator facilities are urgently recommended by accelerator users' community [12].

## 3 THE INFLUENCE OF RADIATION ON ELECTRONIC DEVICES

The two main groups of radiation effects on SRAM devices can be classified as: Cumulative Effects (CEs) and Single Event Effects (SEEs).

The SEE plays a more important role when considering the beam loss phenomenon in the high-energy accelerator environment. Static SEE, called Single Event Upsets (SEUs) could be induced only by charged particles (alpha particles or recoil nuclei) losing its entire energy near the interface region in MOS structures of the memory cells [5, 6, 7, 13, 16] and affect random access memories (SRAMs and DRAMs), registers, buffers and programmable devices. Moreover SEU could be observed in the SRAM devices placed in the neutron environment because of inelastic and elastic nuclear reaction, e.g. proton or alpha particles recoil reactions, which can deposit locally enough energy [1]. SEU occur mainly in the nearest surrounding of the sensitive area of memory cells due to a shallow depth penetration of neutrons. Fig. 1 depicts the SEU phenomenon in a MOS structure induced by neutrons.

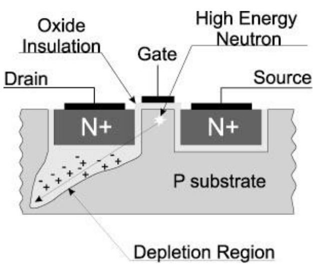


Figure 1: Ionization of a MOS structure as an effect of interaction with particle.

Primary and secondary ionizing particles create electron-hole pairs in the silicon device [7, 17]. Due to the existence of strong electric fields, the charge carriers are moved and collected near the MOS electrodes. The charge accumulated near the MOS drain could result in a single memory cell or a flip-flop state change [13]. The SEU affecting a standard 6T SRAM cell is shown in Fig. 2. In the picture above transistors $T_1$ and $T_4$ are conducting, therefore, the output line Data line is equal to logic state "1" and the complementary Data Line is "0". When the particle interacts with the sensitive area of transistor $T_3$ the state of the flip-flop will change and the state of data lines will change respectively: Data line is equal to "0" and complementary Data line equal to "1" (on the assumption that the pass transistors are conducting).

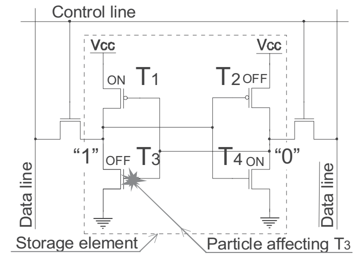


Figure 2: SEU generated in a standard 6T SRAM cell

The deposition of energy should occur in a silicon volume of a collecting node, which is called the Sensitive Volume (SV) [5]. According to current publications on the subject, deactivated transistors (e.g. $T_2$, $T_3$) could be changed mainly by charged particle interaction [14].

The SEU, also called a "Soft Error", is a non-destructive phenomenon. The initial state of the memory can be achieved by rewriting its contents [16].

Long-lived, Cumulative Effects are caused by electrons, neutrons, protons, alpha particles, gamma rays and heavy ions. Energy deposited by gamma radiation and charged particles cause ionization in the material. Because of those changes excitation, charge transport, bonding, and decomposition properties of the material are modified, which has an influence on device's parameters. This phenomenon is called Total Ionizing Dose (TID) [1].

SRAM devices, subjected to gamma radiation, could be damaged because of the charge integration near the Si-$SiO_2$ interface in Metal Oxide Semiconductors (MOS) structures. The threshold voltage shift and leakage current increase are the indicators of TID effect. This is a detrimental effect and plays a crucial role in the SRAM's lifetime [4].

## 4 RESULTS

Three experiments with SRAM were carried out at the DESY Research Centre in Hamburg. During the first stage the memory sensor was irradiated with an Americium-Beryllium ($^{241}$Am/Be) neutron source [2].

The second experiment was accomplished in the Linac II tunnel. The chip was connected to a PC; therefore, the number of induced errors was registered in real time. The final measurement was carried out using gamma source in order to prove that gamma radiation in the linac environment will impose minimum effects to create SEU. The 128kB SRAM, manufactured by Samsung, was used. The memory was powered by a 5V supply.

### 4.1 Neutron Exposure with $^{241}$AmBe source

For the first measurement, a $^{241}$AmBe neutron source was used. The energy spectrum [2] of the neutron source is shown on Fig. 3.

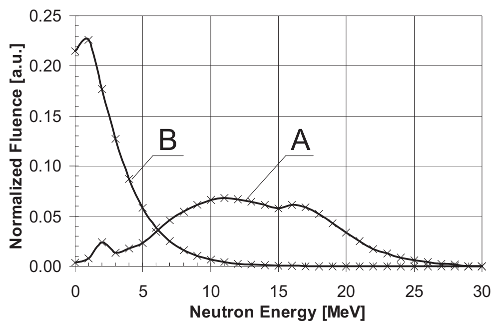


Figure 3: Spectrum of the $^{241}$AmBe neutron source.

The 'A' curve represents the $^{241}$AmBe source spectrum and the 'B' the photoneutron spectrum of Linac II. The area under both spectra (A and B) was normalized to unity. The distance between the active part of the memory and the source was 10 mm. The memory was connected to a PC to facilitate reading and writing of its contents in real time. A bit-pattern was written in the memory before irradiation. The contents of the device was read every minute and compared with the reference. A SEU was registered every time when the contents of the irradiated memory differed from the reference value. The memory chip was irradiated for 24 hours. The memory contents changed in a given time frame depending on the absorbed neutron dose in the chip, as shown in Fig. 4. Evidently, the computer was not subjected to any radiation expose as it was installed in an adjacent room and separated by a thick concrete shielding wall. The figure shows a linear relationship between SEU induced in the memory and time. The neutrons source used during the experiment provides a constant number of neutrons therefore one can conclude that the amount of generated SEU is dependent on the absorbed dose of radiation. The neutrons fluence for 24 hours was calculated to be $2.3\times10^{10}$ neutron·cm$^{-2}$. This corresponds to 480 upsets (SEU). For one hour ($9.7\times10^{8}$ neutron·cm$^{-2}$) the number of upsets (SEU) was equal to 20.

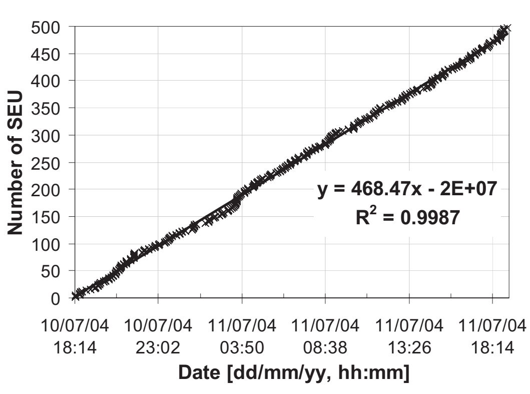


Figure 4: SEU induced in the SRAM memory irradiated with a $^{241}$AmBe neutron source.

## 4.2 On-line Measurements in Linac II

The second experiment was carried out in the linear accelerator Linac II tunnel [15]. The main source of neutrons and gamma in Linac II is the electron to positron converter. The photoneutron spectrum of Linac II is well known [2] and depicted in Fig. 3. The distance between the memory and the $e^{-}/e^{+}$ converter was about 18m. The temperature of the memory was constant during the experiment and equal to 37 °C.

The curve (Fig. 5) represents the growing number of SEU induced by neutrons present in Linac II chamber during 48 hours of the accelerator operation.

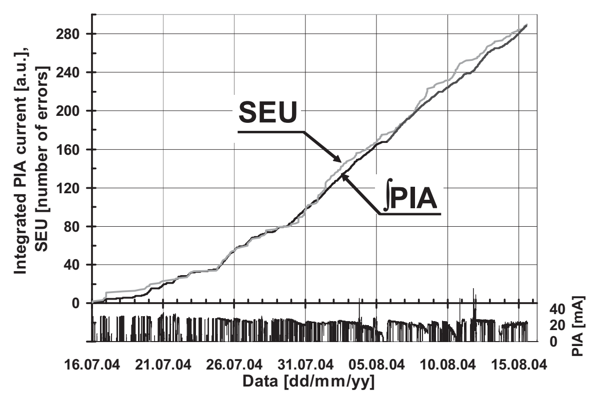


Figure 5: SEU induced in SRAM and the integrated PIA current shown as functions of elapsed time.

The curve (Fig. 5) is not linear, as compared with the curve for the SRAM irradiated with the $^{241}$AmBe source (Fig. 4). Moreover, the radiation dose absorbed in the memory was not constant. This was dependent on the accelerator's operation condition. There was no radiation sensor available, which could be able to record the relevant radiation data in real time. Therefore, it was impossible to precisely estimate the radiation dose absorbed by the memory chip. However, we had used the PIA (Positron Intensity Accumulator) current (Fig. 5) for scaling the radiation dose during the experiment.

Evidently, one can see an increase of SEU events as a function of PIA current. However, it is crucial to calibrate the SRAM chip in order to realize an efficient neutron dosimeter.

## 4.3 Gamma Irradiation using $^{60}$Co Source

No SEU was observed while the memory was irradiated with gamma radiation. A $^{60}$Co gamma source (average gamma energy: 1.3 MeV) was used. The memory chip was irradiated to 600 Gy in 120 hours. This high gamma radiation seems to have produced practically no SEU. However, it might be detrimental for the function of the memory when it exceeds the safe level because of the TID effect. Therefore, the lifetime of SRAMs must be estimated.

## 5 CONCLUSIONS

This paper presents a novel technique to design a reliable, user-friendly and low cost neutron detector. Earlier works concerned mainly the application of Dynamic memories (DRAM) that require refreshing. The design of a dependable refreshing circuit, which often is intended to be used in a high radiation environment (neutrons and gamma), makes a device more complicated and therefore less reliable. Most of research was done with ionizing particles like alpha particles or protons [6].

The number of SEU in the memory increases with time and depends on the neutron dose. Furthermore, SEU is non-destructive; the memory contents can be recovered by rewriting. The proposed SRAM-based neutron sensor reveals a good linear behaviour and can serve as a neutron detector. In order to increase the sensitivity, such a detector requires a high-density memory. However, the memory characteristic may vary due to different manufacturing condition [14], hence, the calibration of individual memory chip becomes vitally important.

The proposed sensor assures a fast response. The number of SEU is independent of gamma dose. However, as the TID effect is detrimental to the memory devices, therefore, the lifetime of the detector must be estimated for its future applications.

SRAM memories, because of the Single Event Upsets (SEUs), are selectively sensitive to neutrons, hence, are good candidates for application in a mixed neutron-gamma radiation field.

It is of overriding importance to enhance the sensitivity of the SRAM memory to SEU, thereby decreasing lowest detection level of the neutron and gamma dose. Further research concerning improvements of SRAM sensor sensitivity is still in progress in our institutions.

## ACKNOWLEDGMENTS

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