Design of a Radiation Tolerant System for Total Ionizing Dose Monitoring Using Floating Gate and RadFET Dosimeters

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1. Abstract
The Total Ionizing Dose Monitor (TIDMon) is a radiation tolerant system designed to measure the effect of the TID on a new prototype of Floating Gate Dosimeter (FGDOS) and compare it against the Radiation-sensing Field Effect Transistors (RadFETS) dosimeter. In this work we present the design strategy adopted for the control of the sensors and the architecture, the radiation reliability and the performance achieved by the system.

2. Design Choices
Two parts compose the system:
- **The tester part** which is a generic radiation tolerant architecture able to acquire mixed-signals from the DUT and perform complex data processing.
- **The DUTs part** that contains the dosimeters sensors and the circuitry needed to manage them.

![Figure 1 – TIDMon board and general hardware architecture with on the right the Tester part and on the left the DUTs part](image)

The tester part is composed of:
- A **Flash-based FPGA** which offers us the possibility to improve continuously the embedded sensor controllers and to manage online different test configurations.
- A **16-bit ADC** and 0.1 Amps that allow the measuring of the DUT values: RadFET voltages, RadFET current source and floating gate current values.
- **Monitored Voltage Converters** for the powering of the DUTs and Tester elements.

Four IP cores constitute the generic tester part:
- The **CoreABC**, an assembler-based configurable softcore provided by MicroSemi which is the master of the system. The core contains in assembly-based language the reading routine of the sensors.
- The **CoreUART**, a configurable APB serial controller provided by MicroSemi.
- The **ADC Controller** which provides the measurements of the analogue values of the sensors and the reference values of the board.
- The **RadFETs Controller** performs the reading procedure for up to two RadFETs.

![Figure 2 – TIDMon FPGA architecture with in blue the generic IP provide by the tester structure and in orange the DUTs part](image)

Two IP cores are dedicated to the sensors:
- The **FGDOS Controller** performs the measurements of the frequencies and the RadFET current source of the board in order to monitor the level of degradation of the tester.
- The **RadFETs Controller** performs the reading procedure for up to two RadFETs.

3. TID Monitoring procedure
The TIDMon measures every second the TID sensors and also the voltage regulators and the current source of the board in order to monitor the level of degradation of the tester.

![Figure 5 – Functional operation of FGDOS during irradiation, the output of the sensor is provided by an embedded Voltage Controlled Oscillator (VCO) that convert the gate potential in a square wave signal](image)

- The frequency meter process used two sub processes:
  - A precise one that calculates the frequency in Hz with an accuracy of 1 Hz.
  - A fast one that calculates the frequency in 15 ms with an accuracy of 128 Hz.
- The charge process recharges automatically the sensor to a desired value when it is discharged below a defined threshold. These two values are configurable online.
- The SPI interface allows to:
  - Set the radiation sensitivity (High / Low)
  - Read the internal temperature sensor
  - Bypass the VCO, to have on the output the current of the reading MosFET of the floating gate.

![Figure 4 – FGDOs controller IP architecture](image)

- **Reading Step**: The gate and drain are shorted to the ground, and the sensor is supplied by a current source for a period of 100 ms.
- **Biasing Step**: The drain, source and gate pins are shorted to the ground. The gate can be biased to 5V in order to increase the sensibility.

4. Radiation Assurance
- A Triple Modular Redundancy (TMR) mitigation technique is applied on the FPGA IP cores at the register level by means of a commercial synthesis tool and at the memory level manually.
- The board is entirely based on **COTS components** tested against radiation effects:
  - SEE’s and TID: > 230 MeV protons (up to 9.10^11 p/cm^2)
  - Displacement damage: 1 MeV neutrons (up to 4.10^12 n/cm^2)
  - TID: Co source up to 50 krad(Si) TID

![Figure 3 – Summary of the results of the radiation test campaigns on the main analogic and digital components](image)

5. Results

- In the nominal configuration of the FGDOS with a sampling of 1 Hz, the TIDMon is able to charge the sensors in less than 1 sample, thus the blind time is reduced to the minimum.
- The TIDMon can achieve a measurable accuracy of 16 mrad(Si).
- The board worked without issues during the several test campaigns performed at CHARM mixed-field facility or with 60Co irradiation.

![Figure 6 – RadFET Dosimeter reading procedure and circuit with ADC Gains which allows the exploitation of the full range of the sensors](image)

6. Conclusions
- The TIDMon allows us to finely characterize and find the best conditioning to use the FGDOS with the maximum of performance as a TID sensor for CERN dosimetry purposes.
- The tester architecture proved to be robust against various harsh radioactive environments and can operate up to 30 krad(Si).
- The next step to consider for the Tester architecture will be to extend the lifetime of the architecture actually limited by the increase of the ADC current consumption as a result of the accumulated dose.
- The performances and the modularity of the test architecture provides us a quick and robust, ready-to-use test system able for other CERN radiation testing activities.