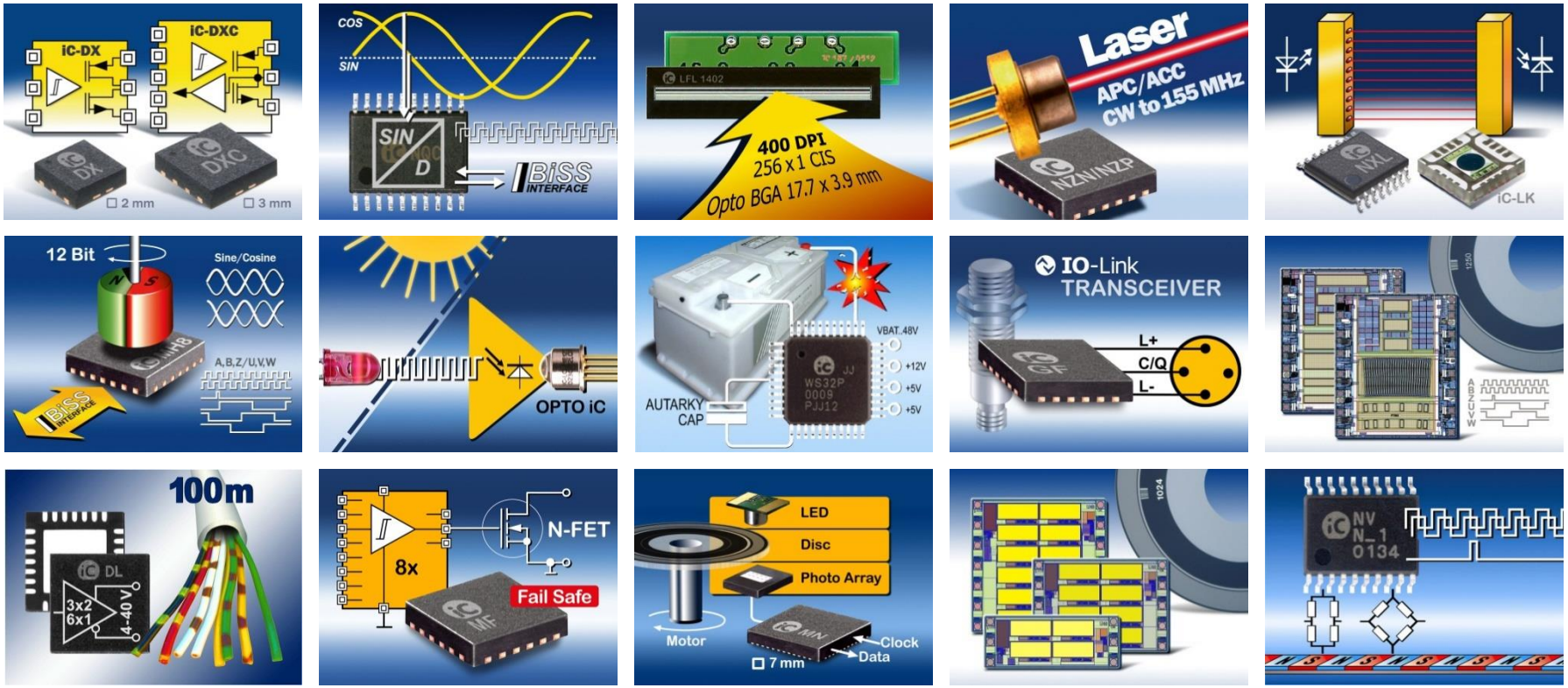

FGDOS® : Floating Gate DOSimeter for Space applications. Introduction. Tests and results. Moon Flyby

Joan Cesari Bohigas
Electronics Engineer

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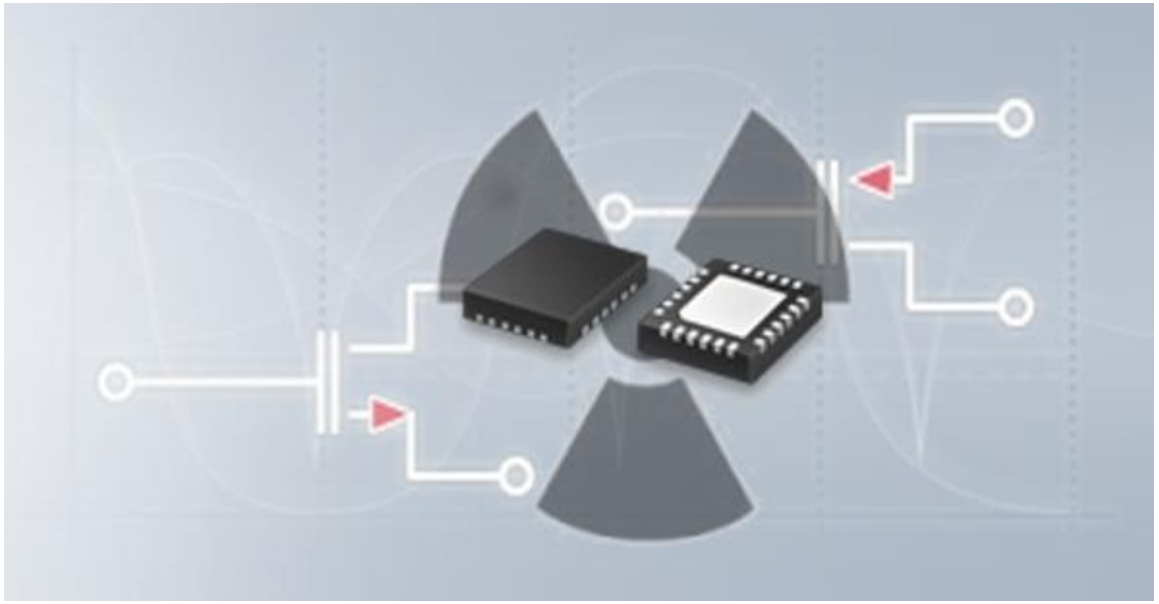

Radiation tests in collaboration with:

Moon FlyBy thanks to:

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Company Presentation iC-Málaga

Who we are

- SME founded in 2002 as part of the iC-Haus network
- Current facilities: Alaró (Mallorca, Spain)
- Certified for ISO 9001 and ISO 166002

What we do

- Integrated circuit design for industry, automotive and medical applications
- ASiC/ASSP manufacturer (fabless)

FGDOS® Current Applications

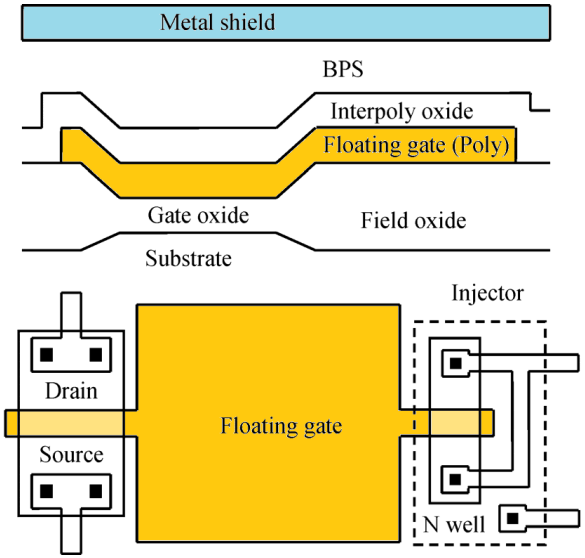
- FGDOS® is an **smart dosimeter on-chip** and overcomes some drawbacks of traditional RadFETs.
- FGDOS® **100 to 500 times more resolution** than RadFETs.

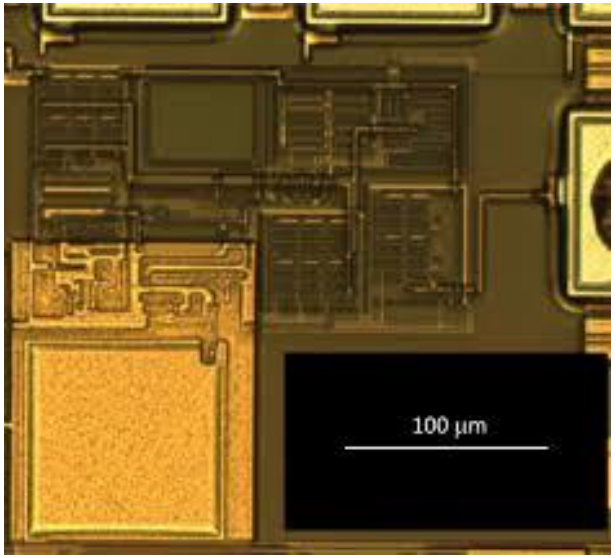
- The FGDOS® is **being tested at CERN** to be used as radiation dosimeter in some LHC areas.
- Nowadays being **used as a detector in private space missions** to monitor the radiation.

- Other applications as:
  - Medical
  - Personal dosimetry

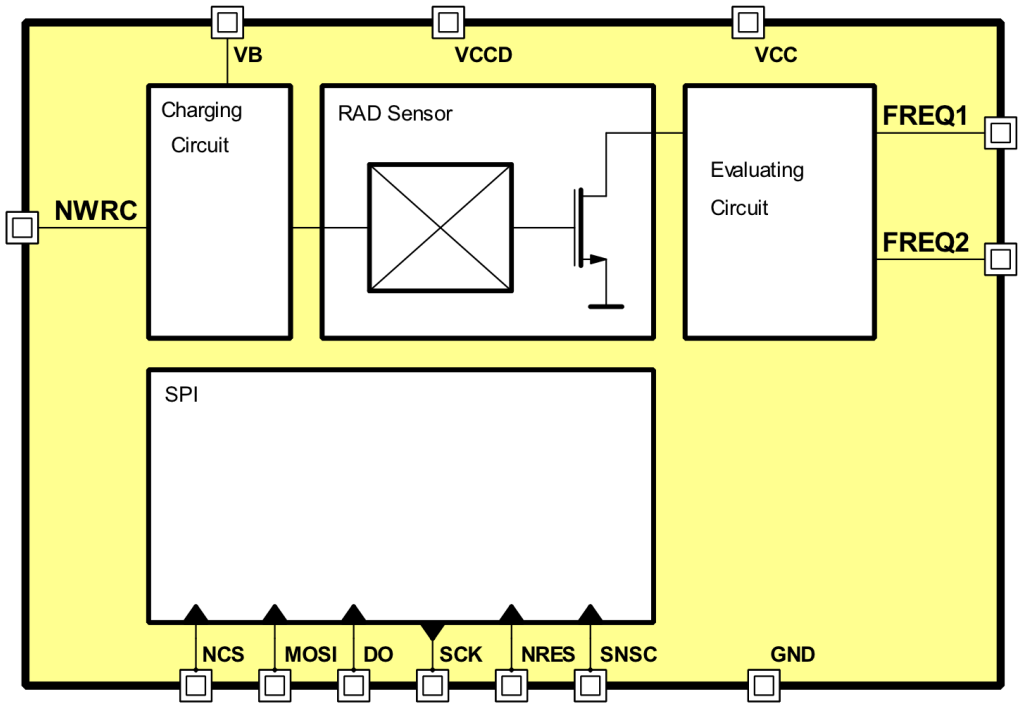
FGDOS® Basic Structure

- Floating gate (FG) structure on **standard CMOS.**
- Permits to **detect ionizing radiation by injecting** charge on the FG capacitor.
- When irradiated the FG is **discharged.**





- As smart sensor on-chip includes:
  1.- Charging circuitry
  2.- FG sensor
  3.- Evaluating circuitry
  4.- SPI interface

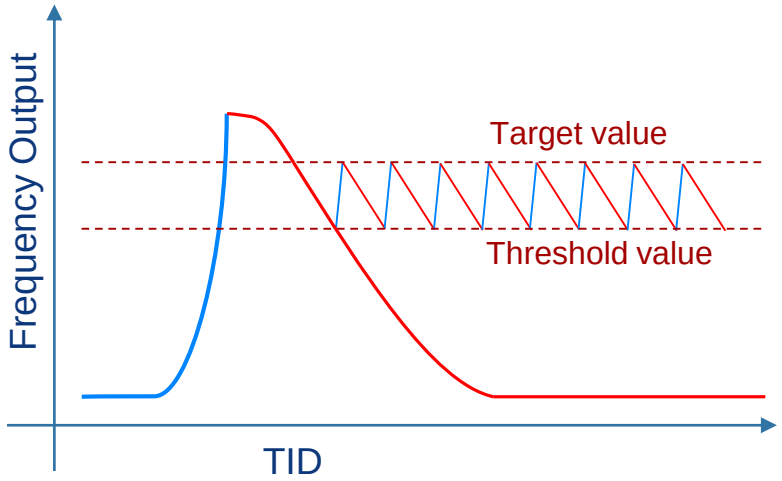


FGDOS® Working Principle

- FG dosimeter system **function principle**:

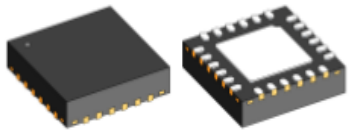
  Step 1: recharge the FG up to **the target** value
  Step 2: discharge the FG due to radiation down to the **threshold**

- The dosimeter keeps the sensor working inside the **Linear Dynamic Range.**



FGDOS® Application Example [1]

- 5 mm x 5 mm QFN package. **Redundancy.**
- 5V power supply
- Different sensing modes: **Active**, **semi-passive** and **passive modes**.
- Micro-controlled based application. **SPI interface**.
- **Ultra low power** applications (by using passive mode)
- **Digital output**. Sampling rate from 1 second up to 125 milliseconds.



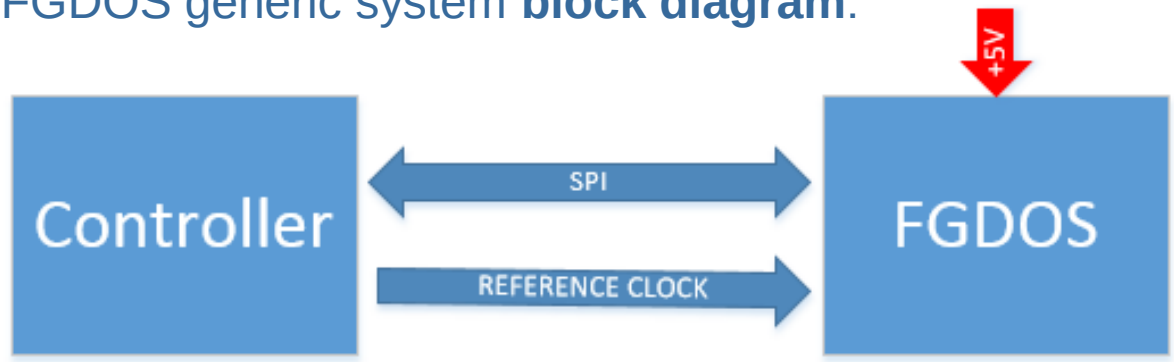
5 mm x 5 mm QFN package

2 sensors, for redundancy

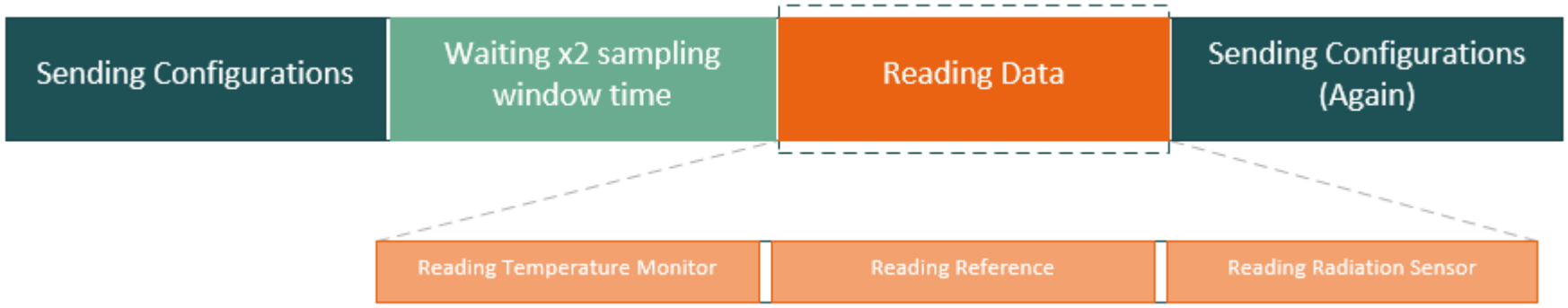
FGDOS® Application Example [2]

R. Ferraro *et al* "Design of a radiation tolerant system for total ionizing dose monitoring using floating gate and RadFET dosimeters", *JINST* **12** C04007, April 2017

FGDOS generic system **block diagram**:



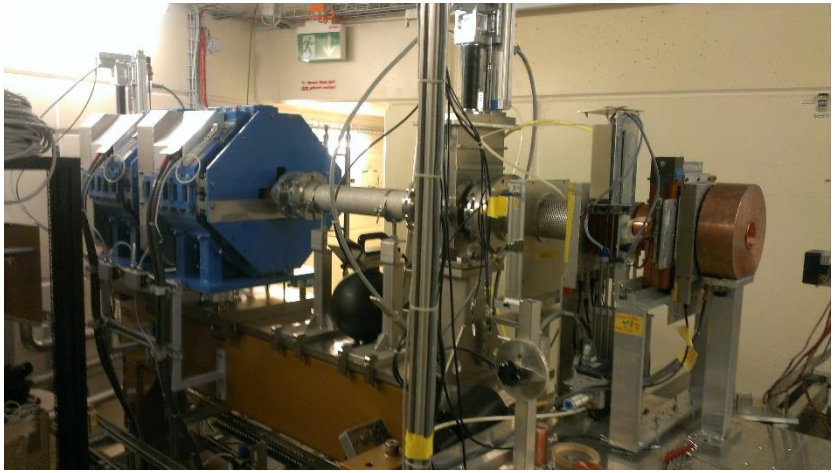
Example, FGDOS SPI **communication flow**:

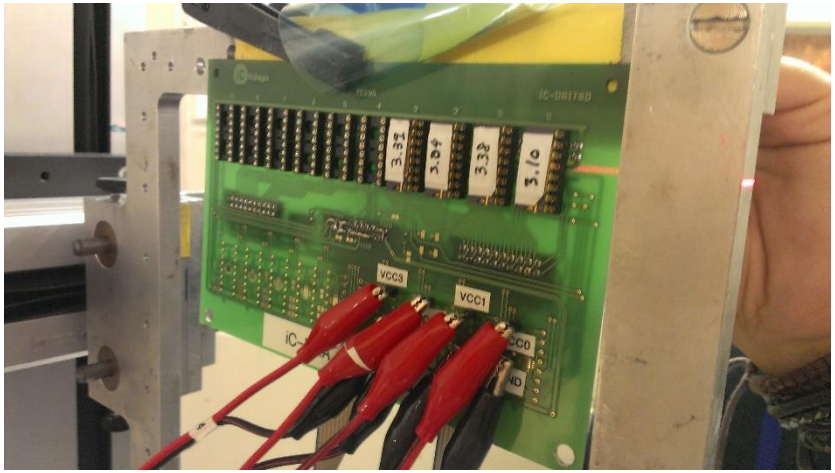


FGDOS® Proton Tests

S. Danzeca, J. Cesari, M. Brugger, L. Dusseau, A. Masi, A. Pineda, and G. Spiezia, “Characterization and Modeling of a Floating Gate Dosimeter with Gamma and Protons at Various Energies,” *IEEE Trans. Nucl. Sci.*, vol. 61, no. 6, pp. 373–378 3451 - 3457, Dic. 2014.

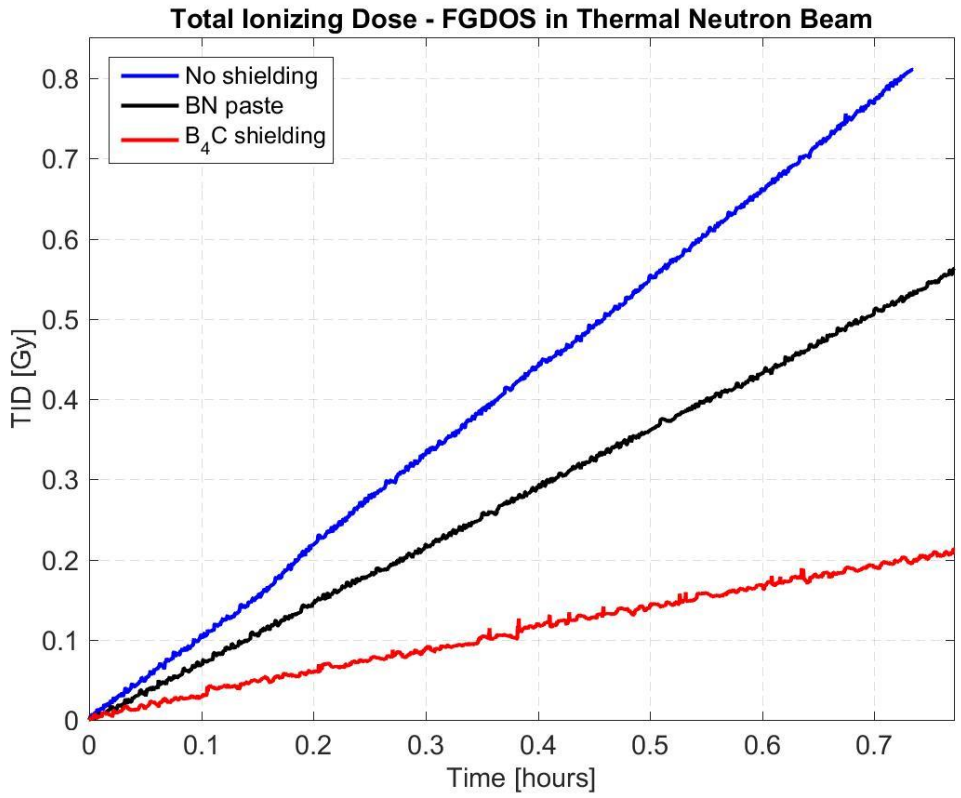
- Tests carried out at Paul Scherrer Institut (PSI) with CERN.
- PSI proton accelerator. Proton energies from 60 to 230 MeV.
- No SEU registered up to a fluence of 5.60×10^{11} ions/cm^2 for 230 MeV.





FGDOS® Neutron Tests

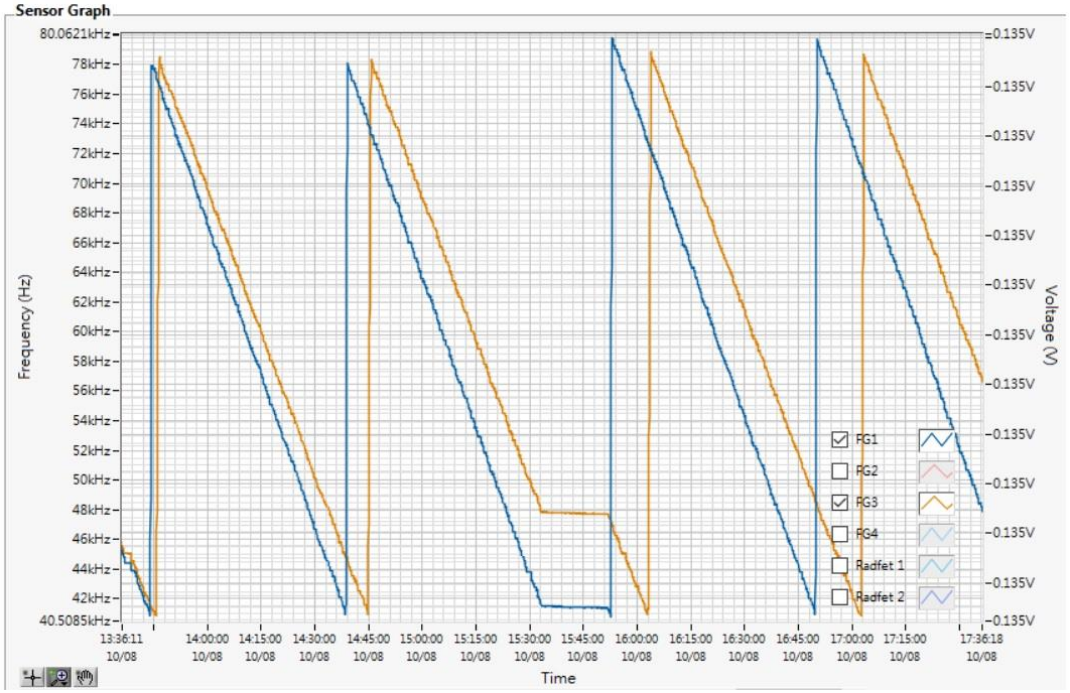
- Test carried out at ILL facility at Grenoble by CERN.
- No shielding, boron carbide and boron nitride coatings
- New publication in 2018, with more details on FGDOS® neutron response



FGDOS® Gamma Tests

- M. Álvarez, C. Hernando, J. Cesari, A. Pineda, and E. Garcia-Moreno, “Total Ionizing Dose Characterization Prototype Floating Gate MOSFET Dosimeter for Space Applications,” *IEEE Trans. Nucl. Sci.*, vol. 60, no. 6, pp. 4281–4288, Dec. 2013.
- M. Brucoli, S. Danzeca, M. Brugger, A. Masi, A. Pineda, J. Cesari, and L. Dusseau, “Floating Gate Dosimeter Suitability for Accelerator-Like Environments”, *IEEE Trans. Nucl. Sci.*, vol. 64, no. 8, pp. 2054–2060, March 2017.

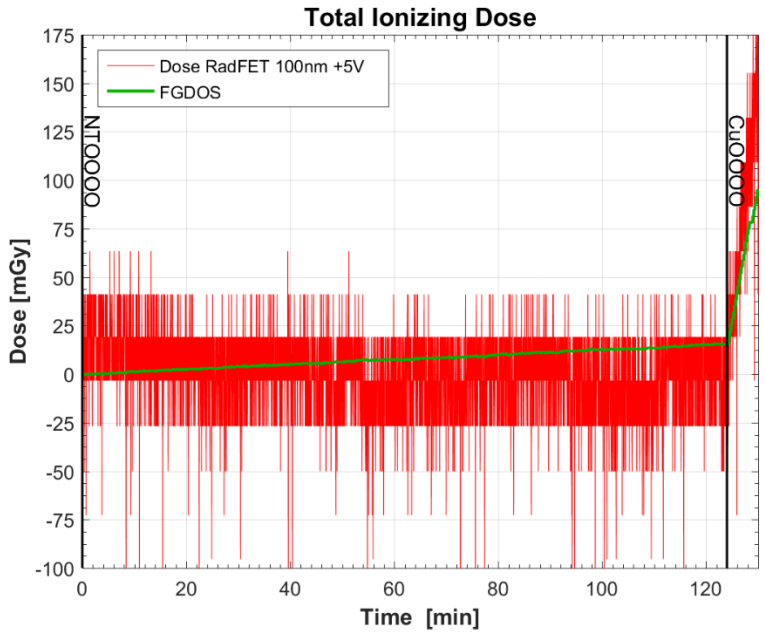
- Tests at CC60 at CERN, using a 60-Co gamma source
- Minimum detectable dose 200 µGy (20 mrad)
- Lifetime up to 300 Gy (30 Krad)
- Linearity up to 98%

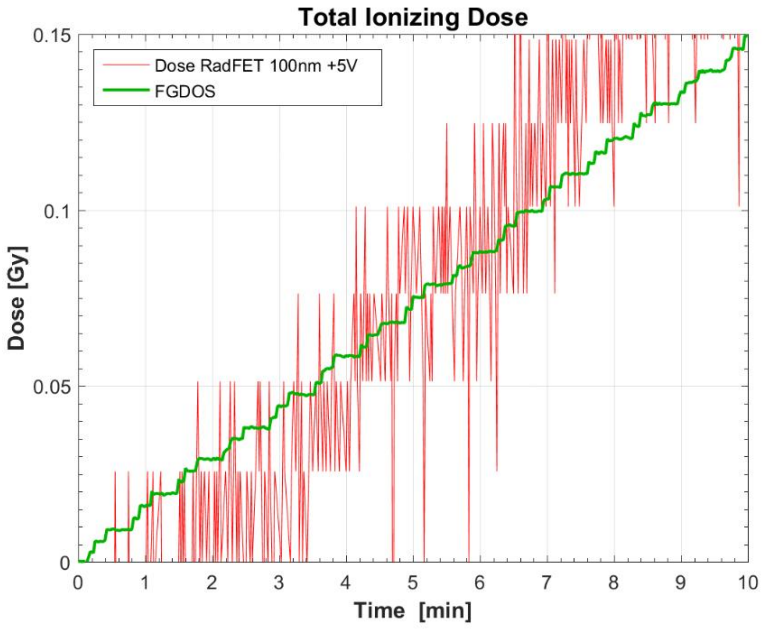


FGDOS® Mixed Field Tests

J. Mekki, M. Brugger, R. G. Alia, A. Thornton, N. C. Dos Santos Mota, and S. Danzeca, "CHARM: A Mixed Field Facility at CERN for Radiation Tests in Ground, Atmospheric, Space and Accelerator Representative Environments",

- Tests at CHARM facility at CERN, different spectra and particles cocktails (pions, muons, neutrons, protons, etc.).
- FGDOS® detects the **spill from the beam**.
- RadFETs comparison, more resolution, lower noise.
- FGDOS® **beam detection with no target**, and **beam detection with target**.

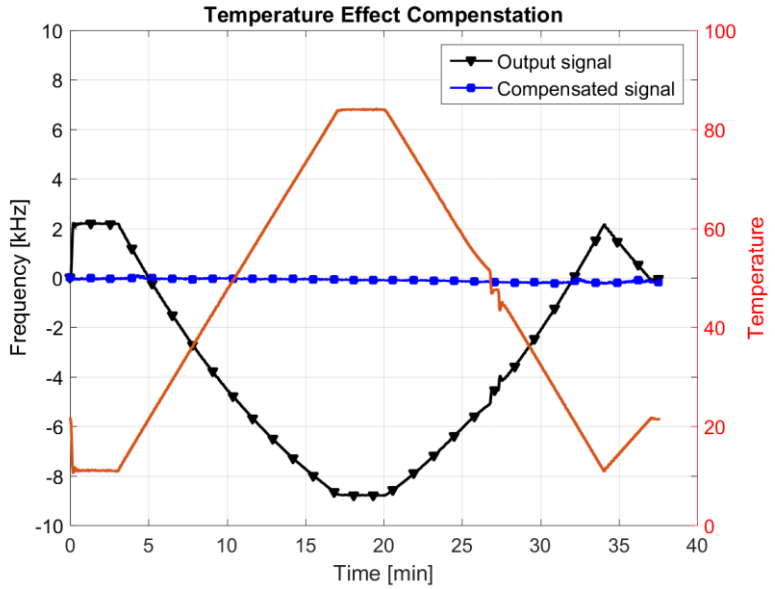


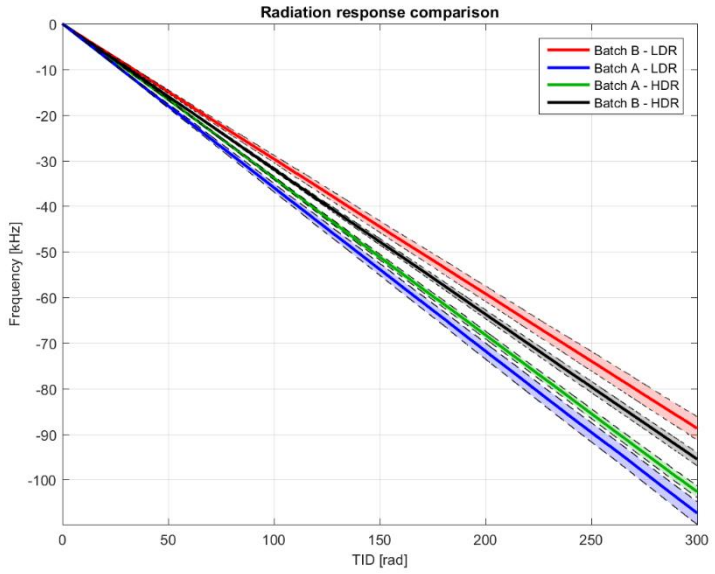


FGDOS® Limitations and Effects

M. Brucoli, S. Danzeca, J. Cesari, M. Brugger, A. Masi, S. Gilardoni, A. Pineda, L. Dusseau and F. Wrobel, “Investigation on the Sensitivity Degradation of Dosimeters based on Floating Gate Structure”, submitted to IEEE Trans. Nucl. Sci.,Sep. 2017.

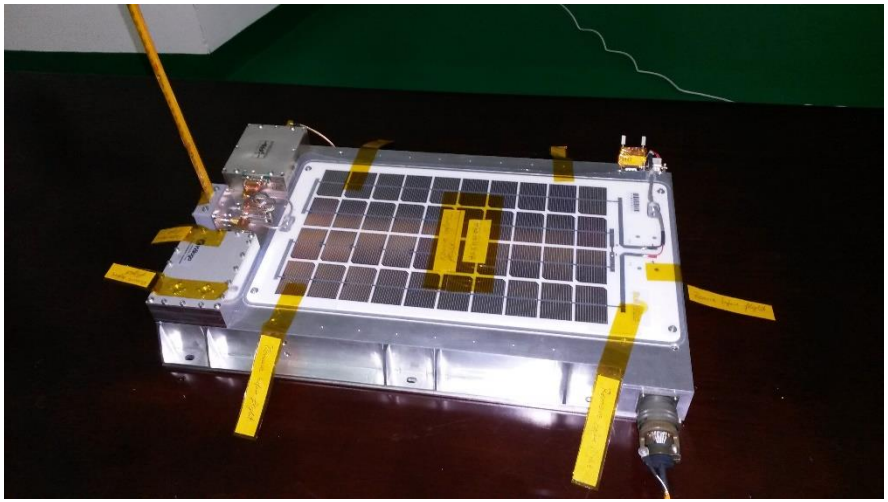
- Sensitivity Degradation during the dosimeter lifetime. (≈ 10 % @ 100 Gy).
- TID Lifetime (≈300 Gy).
- Sample to sample variation. Due to fabrication process.
- Dose rate Dependence (30% less from 5 Gy(Si)/h to 300 Gy(Si)/h).
- Temperature Compensation needed via a reference embedded on-chip.

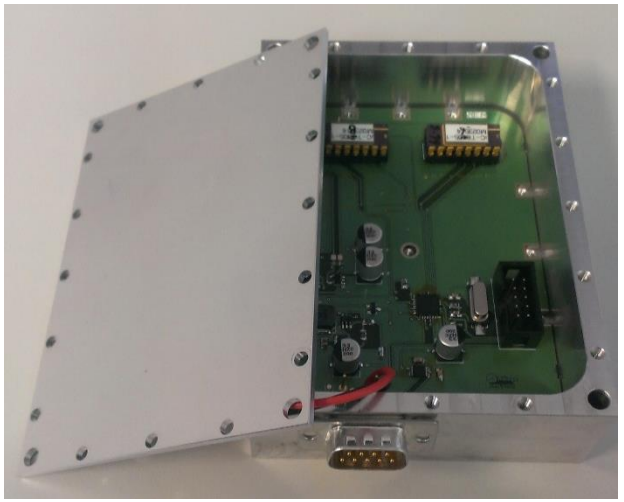




FGDOS® Moon FlyBy Overview

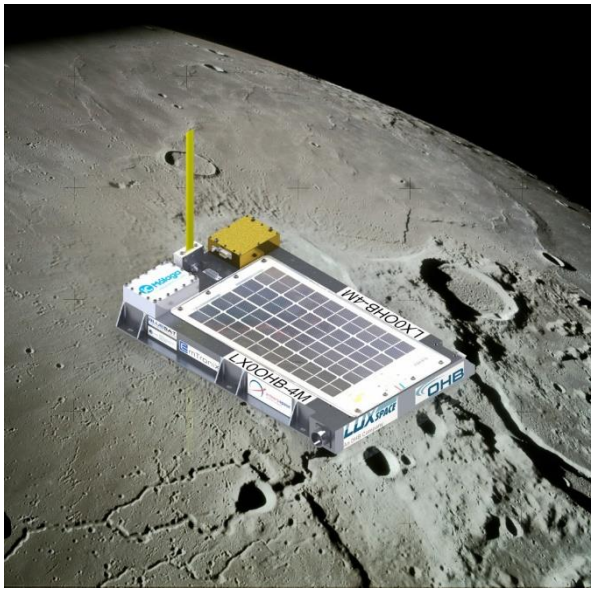
J. Cesari, A. Barbancho, A. Pineda, G. Ruy and H. Moser "Floating Gate Dosimeter Measurements at 4M Lunar Flyby Mission", The Nuclear and Space Radiation Effects Conference (NSREC) Radiation Effects Data Workshop (REDW), Boston, July 2015.



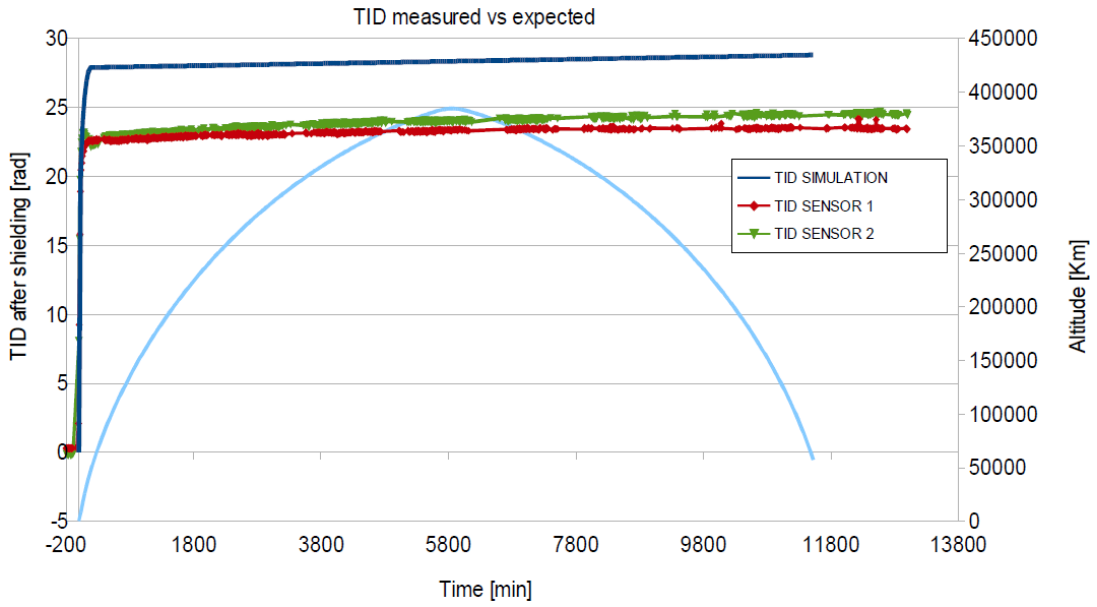


- 4M (Manfred Memorial Moon Mission) mission, first commercial mission to the Moon.
- Carried on the Chinese Chang'e 5-T1 test spacecraft.
- Launched on October 23th 2014.
- Payload attached to the third stage of Long March 3C/G2 rocket.
- Luxspace srl invited iC-Malaga to include its sensor as radiation experiment.
- Preparations from first conversations until launch, less than 5 months.

FGDOS® Moon FlyBy Results



- Data from two FGDOS® v1 retrieved
- More than 8 days receiving data from the experiment
- The radiation experiment was measuring every 5 minutes.
- The effect of the Van Allen Belts was measured
- FGDOS® measures compared with simulation results



New Applications Fields and Research

NEW APPLICATION FIELDS:

- Personal dosimetry (ring dosimeter, badge,…)
- Medical Applications (In vivo,…)
- Spot camera, pixel array sensors (100 µm x 100 µm)

NEW RESEARCH AREAS:

- Energy discrimination sensor
- Activimeter detector

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