Faculty of Power and Aeronautical Engineering
WARSAW UNIVERSITY OF TECHNOLOGY

Design and On-orbit Performance of Low-cost, COTS-based Total Ionizing Dose Sensor for CubeSat Applications

Grzegorz Gajoch[1], Michał Gumiela[2]

[1] AGH University of Science and Technology in Krakow, grzegorz@gajoch.pl
[2] Warsaw University of Technology, michal.gumiela@gmail.com

Introduction

Destructive ionising radiation influence on electronics is a major concern in most of the space missions, especially in the days of increasing role of commercial off-the-shelf (COTS) parts. In this work, we describe the design and on-orbit evaluation of the total ionising dose radiation (TID) sensor, suitable for small sats LEO missions. Real-life TID measurement data would significantly help the future missions in radiation-related risk mitigation as well as they provide valuable scientific data about radiation environment.

The main objectives of the work were to find and evaluate COTS MOSFET transistor for dosimetric purposes, develop complete readout circuit and test flight instrument aboard PW-Sat2 satellite.

Operation principles

The total ionising dose sensor is based on radiation-sensitive field-effect transistors which radiation-induced threshold voltage shift (ΔV_{Th}) can be measured in order to determine an actual TID value (D), where A, n are sesitivity and linearity coefficients, respectively:

$$\Delta V_{Th} = A \cdot D^n$$

Quanta of ionizing radiation possess enough energy to induce electron-hole pairs in transistor oxide regions. Holes transportation through the oxide is much slower and some of them can be trapped in long-term sites in the oxide region producing positive charge build-up causing shift in threshold voltage (Fig. 1).

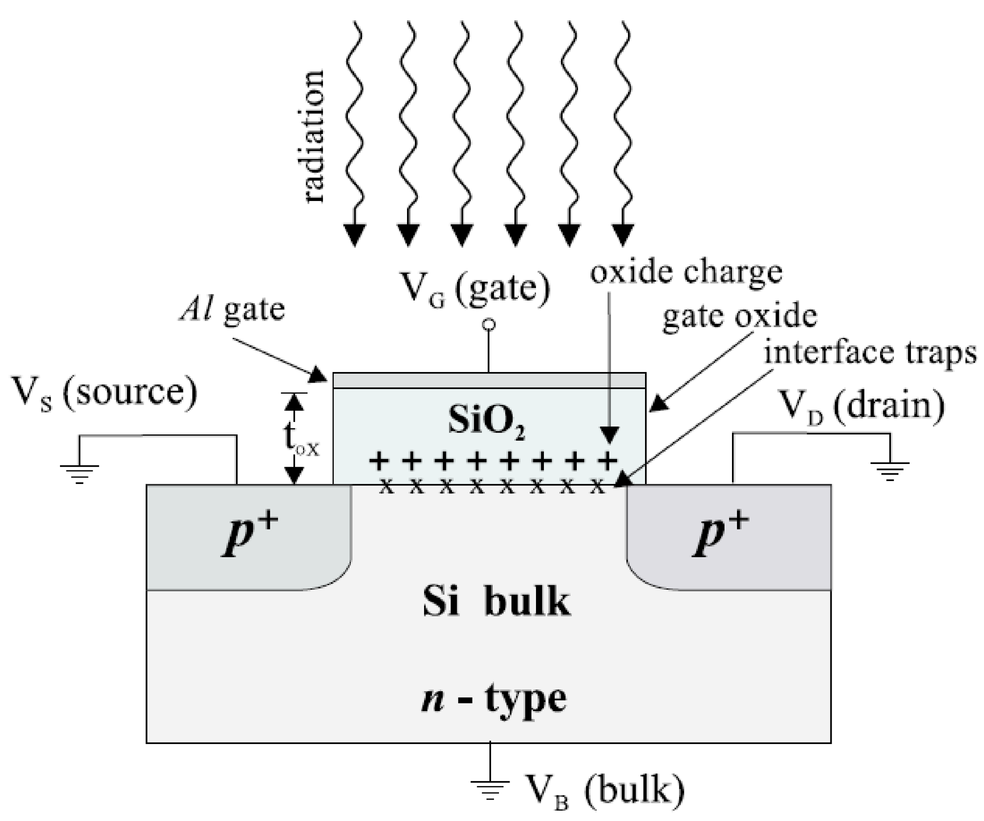

Fig. 1 MOSFET transistor during irradiation. [1]

Radiation dose integration takes place continuously, even without any bias or power supply. Active operation of the sensor is needed during readout phase making the sensor a very low-power.

Sensor design

Major design consideration is a selection of radiation-sensitive transistor. As a first candidate Vishay 3N163 was considered due to high radiation sensitivity of 30 mV/Gy. Considering many drawbacks (initial Vth as high as 4.5 V, high price and low availability) and poor long-term stability of Vth, we have finally decided to use a Texas Instruments CD4007 integrated circuit comprising 3 MOS complementary pairs (Fig. 2). Low initial threshold voltage (2.4 V), small TSSOP14 package, cheap and wide in-market availability come at a price of lower TID sensitivity - 5 mV/Gy (Fig. 3) in unbiased mode.

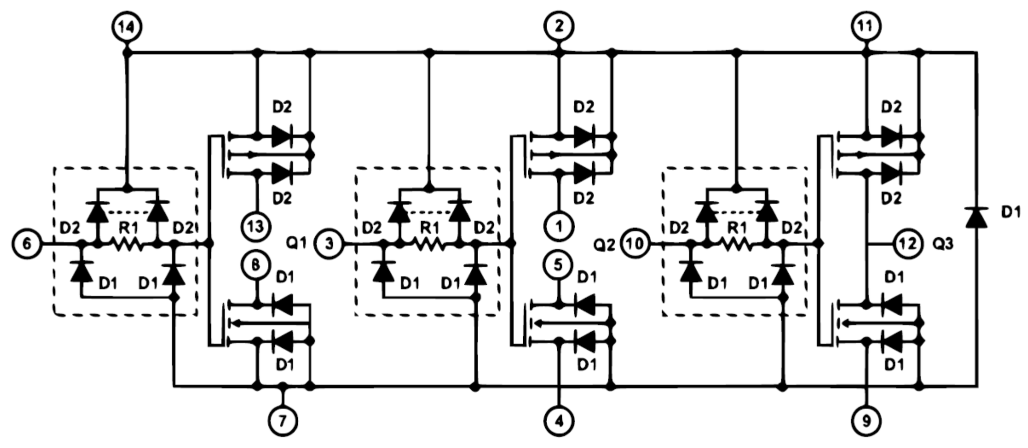

Fig. 2 A schematic of a Texas Instruments CD4007 integrated transistor array consisting of three P-MOS/N-MOS complementary pairs. [2]

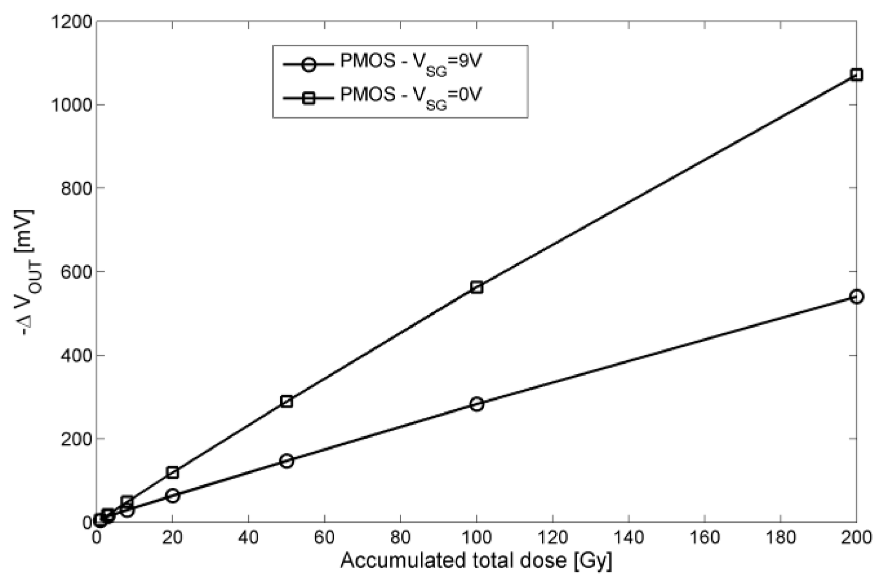

Fig. 3 Threshold voltage variation vs. total dose (irradiated using Co-60 source). [3]

Threshold voltage is measured in saturation regime at constant drain current of 125 μA by a high-res, 24-bit ΔΣ ADC (Fig. 4a). Readout circuit supports all three P-MOSFETs in CD4007 for better measurement statistics and reliability. Vth temperature drift compensation utilizes a body diode of N-MOS transistor built-in CD4007 (Fig. 4b). It shares the same current source and ADC with Vth extractor and allows for a precise, direct measurement of silicon die temperature. Thermal model was calibrated in a climate chamber tests.

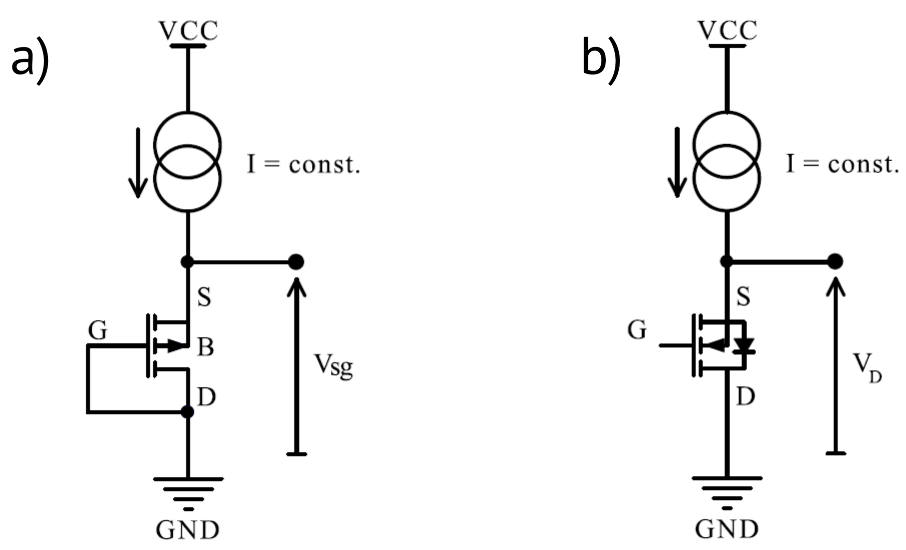

Fig. 4 Readout configurations for a) P-MOS threshold voltage, b) temperature compensation.

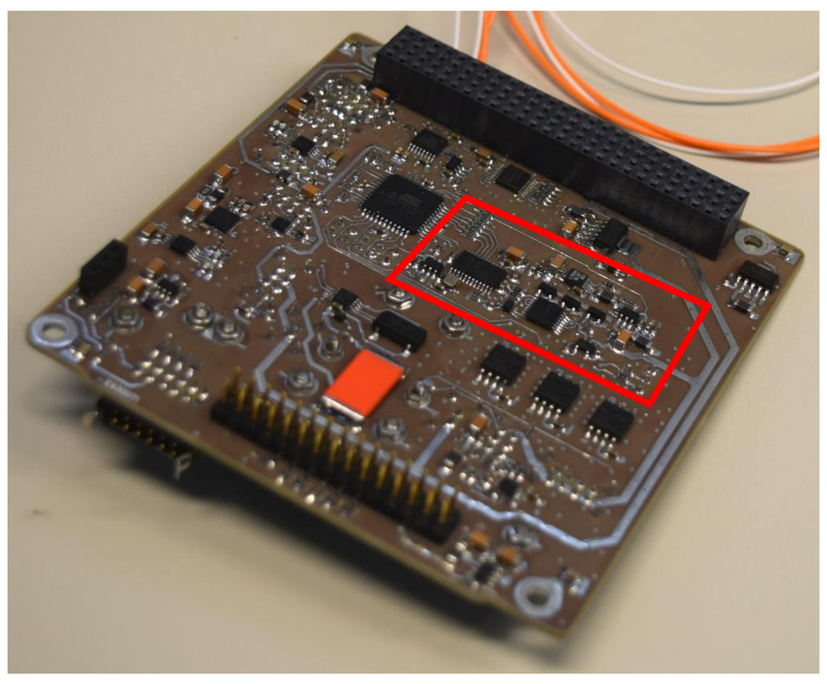

Fig. 5 Flight model of PW-Sat2 RadFET sensor (indicated within red frame) integrated with payload PC-104 board. The sensor takes less than 15 mm x 35 mm (double-sided).

The sensor is designed to be powered from single 5 V line and features latchup protection. It communicates via I²C bus, thus it's fully compatible with CubeSat standard.

All design files, schematics, PCBs and software are available freely available under AGPL 3.0 license in our GitHub https://github.com/PW-Sat2/hardware/tree/master/PLD.

Results

The sensor was launched aboard PW-Sat2 satellite on Dec 3rd, 2018. To date, the readout procedure was carried out 21 times. All three P-MOS transistors give consistent results within measurement uncertainty. (Fig. 6) Currently, indicating over 1 Gy (100 Rad) of absorbed dose, the measurements are of the same order as SPENVIS simulations (TID, 6 mm Al sphere).

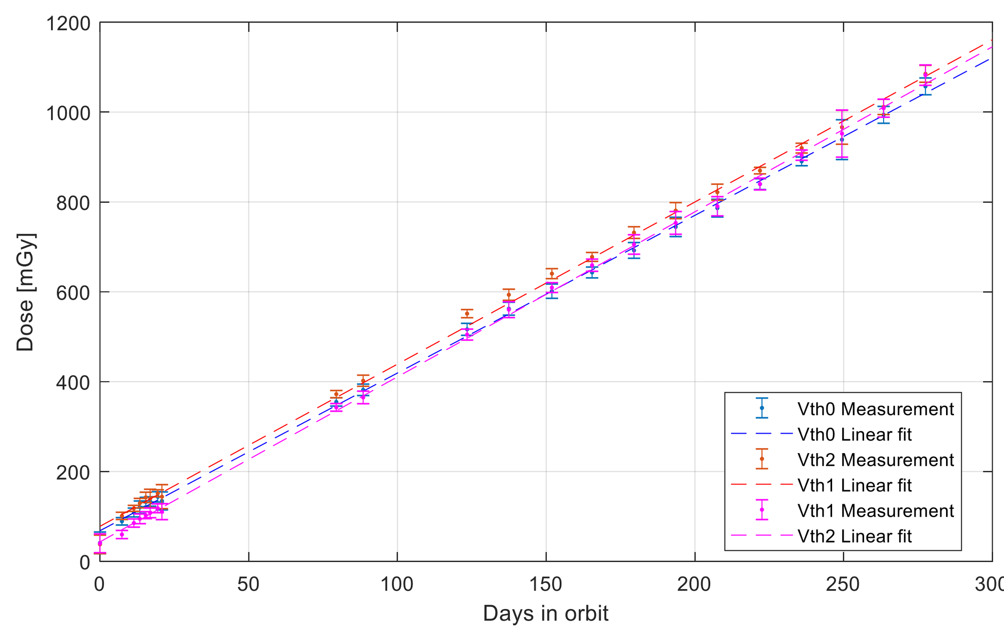

Fig. 6 Absorbed dose vs. days in orbit aboard PW-Sat2 (SSO, 580 km, 97.8° inc.).

Effective resolution as low as 20 mGy (2 Rad) was achieved, taking into account temperature-induced inaccuracies.

References

[1] Ristic G. S., pMOS dosimeters (RADFETs), Applied Physics Laboratory, Faculty of Electronic Engineering, University of Nis, 2015

[2] Analog Devices, CD4007 datasheet

[3] Siebel O. F., et al., Low power and low voltage VT extractor circuit and MOSFET radiation dosimeter, NEWCAS, IEEE 10th International. Department of Electrical Engineering, 2012

Special thanks to the Educational Office of the European Space Agency for fellowship and making possible attendance at the European CubeSat Symposium.