

Electrically programmable floating gate MOS transistor as a radiation detector

- diploma thesis -

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Presented at: Tyndall National Institute

27. Nov. 2019.

Content

Introduction

Floating gate

EPAD technology

EPAD programmer

Experiment

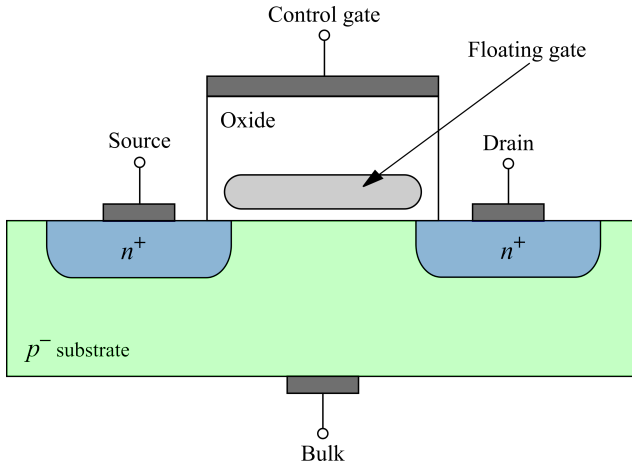
Results and Discussion

Future work

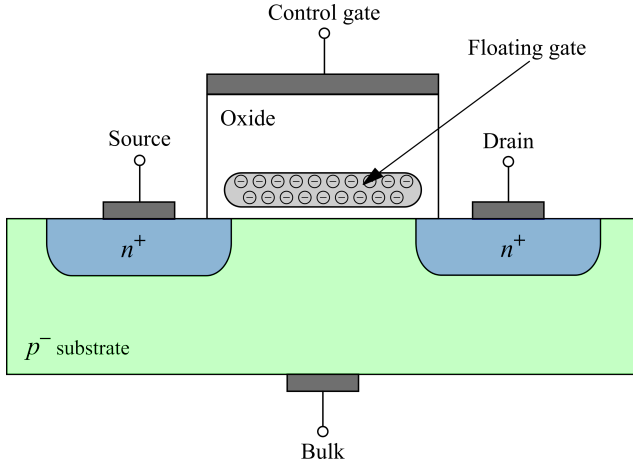
Introduction

- The aim of this thesis is to investigate the feasibility of using a commercial floating-gate MOS transistor as a radiation detector.
- For the first time, the dynamic bias of control gate during irradiation is presented.
- There is a lot of radiation detectors and dosimeters on the market. Future idea is to design semiconductor device that can be CMOS compatible, with high and linear sensitivity and very low fading.
- For now we can only investigate with Commercial Off The Shelf components.

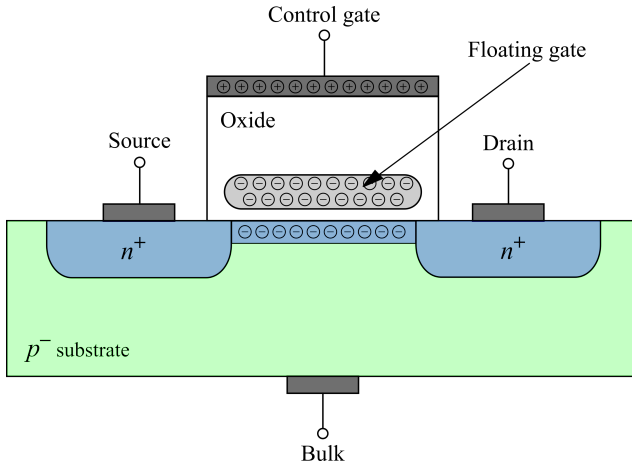
MOS transistor with floating gate



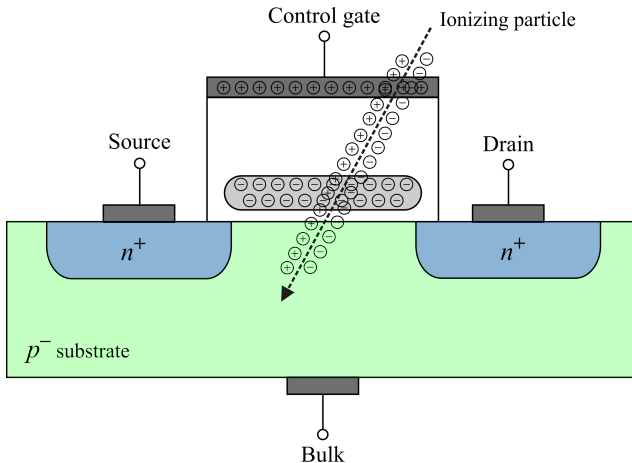
MOS transistor with charged floating gate



MOS transistor with floating gate - channel formation

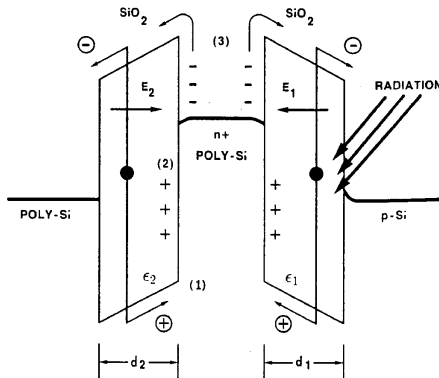


MOS transistor with floating gate during irradiation

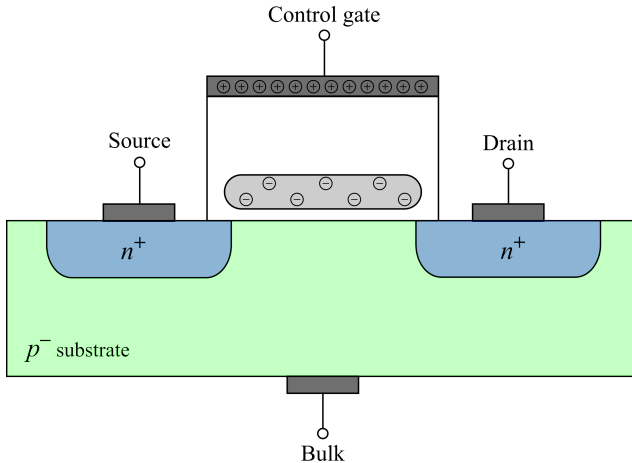


Energy band diagram of MOS transistor with floating gate

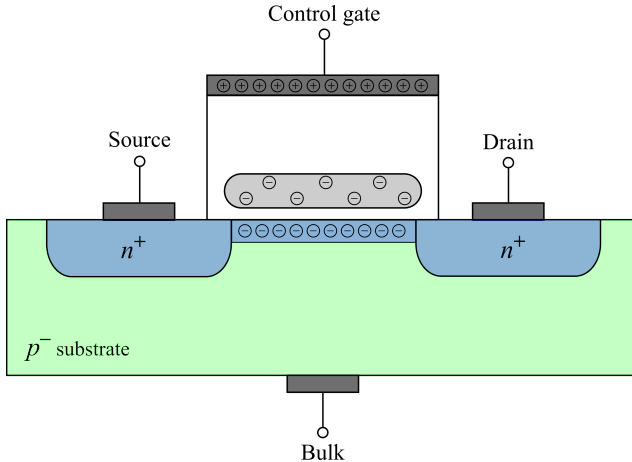
Three mechanisms which could cause a threshold voltage decrease during irradiation: holes injected into the floating gate (1), holes trapped in the oxides (2) and electron emission over the poly-silicon/oxide barriers (3).



MOS transistor with floating gate after irradiation

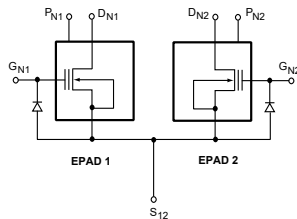
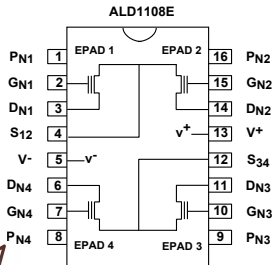


MOS transistor with floating gate as a radiation detector

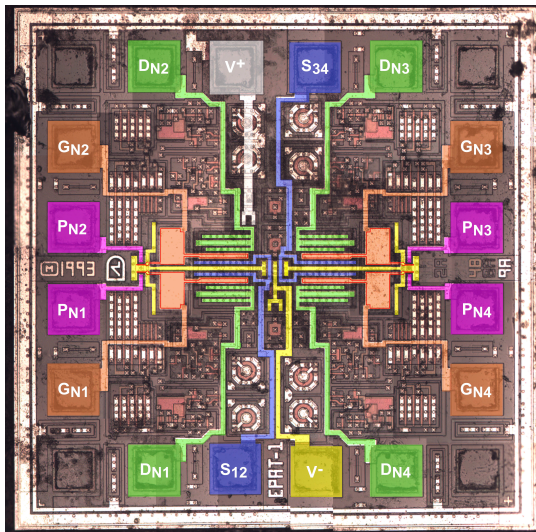


EPAD technology

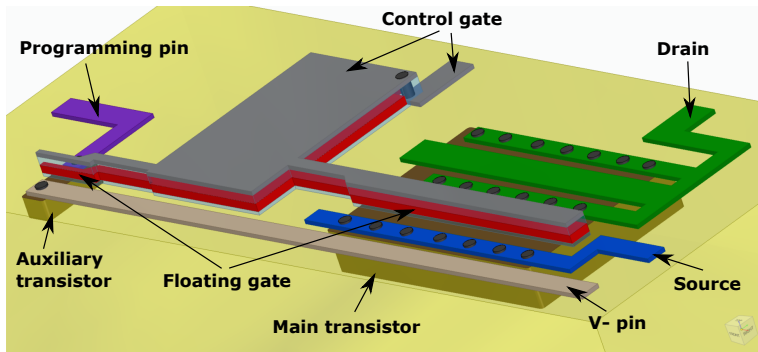
EPAD (*Electrically Programmable Analog Device*) is manufactured by *Advanced Linear Devices*. EPAD is a commercial component designed for completely different purposes, such as current sources, current mirrors and anywhere where precise threshold voltage adjustment is required.



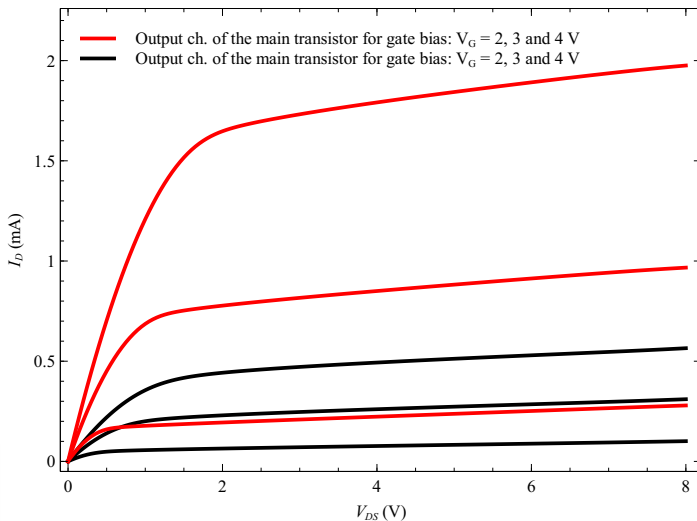
Composite picture of IC ALD1108E



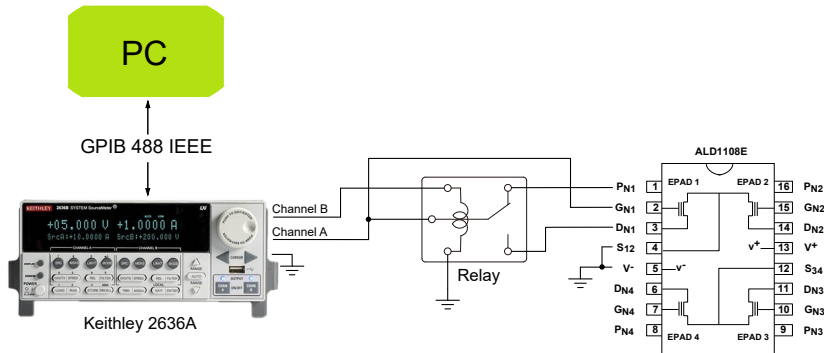
3D representation of the structure of a single EPAD



Output characteristics of main and auxiliary transistors



Second-generation EPAD programmer



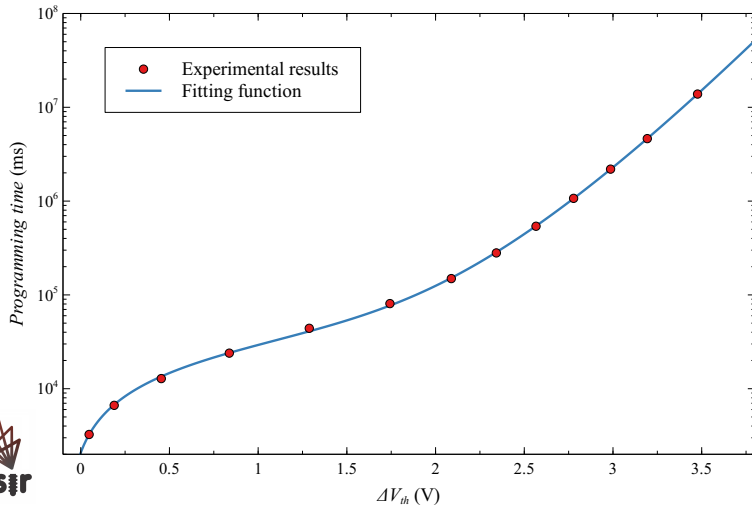
EPAD programming function

$$t_{prog} = a_1 \Delta V_{th} e^{b_1 \Delta V_{th}} + a_2 \Delta V_{th} e^{b_2 \Delta V_{th}} + a_3 \Delta V_{th} + b_3$$

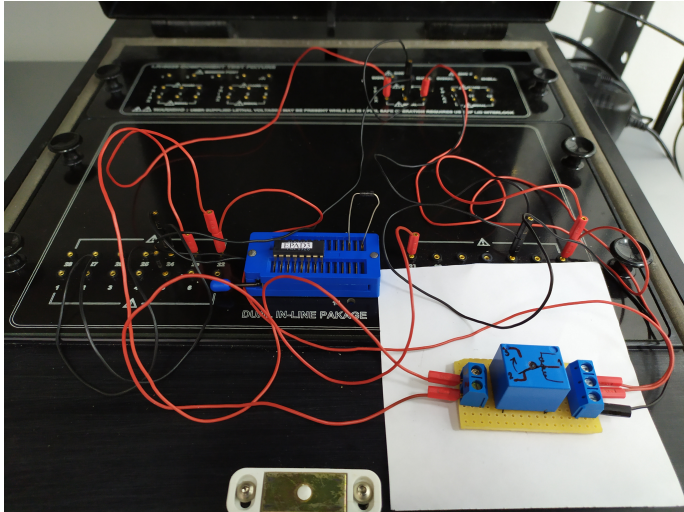
Table: Function parameters

Parameter	Value
a_1	220.512
b_1	2.488
a_2	1.000
b_2	4.259
a_3	24469.893
b_3	2075.736

Programming time dependence on required threshold voltage shift

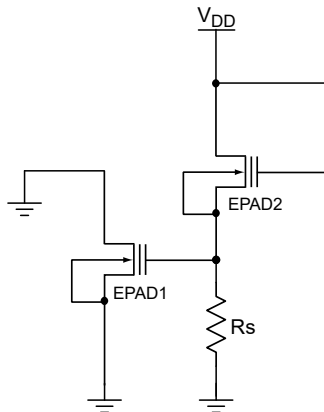


EPAD programming on a test fixture

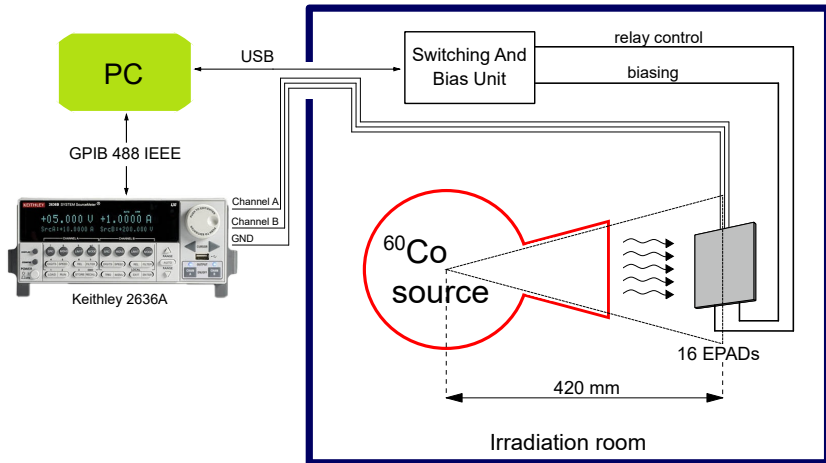


The idea behind the experiment

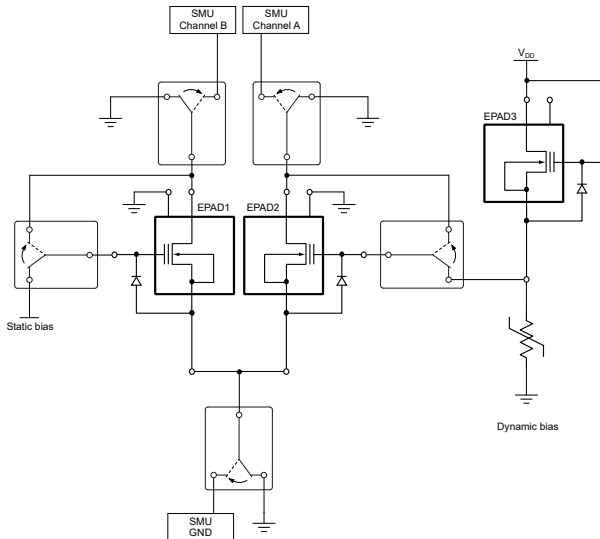
Idea: Using dynamic bias to achieve a linear dependence of the threshold voltage shift with absorbed dose. And compare zero, static and dynamic bias.



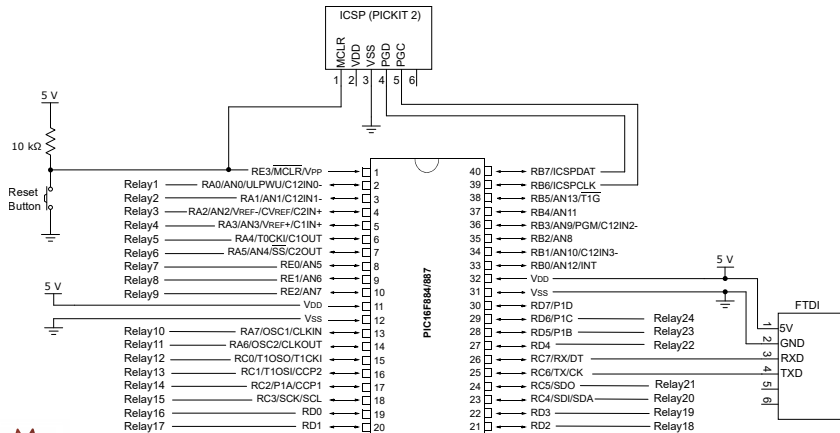
Experiment setup



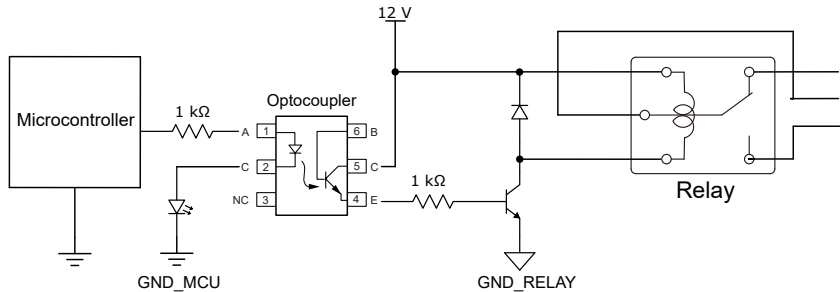
Automation of measuring system



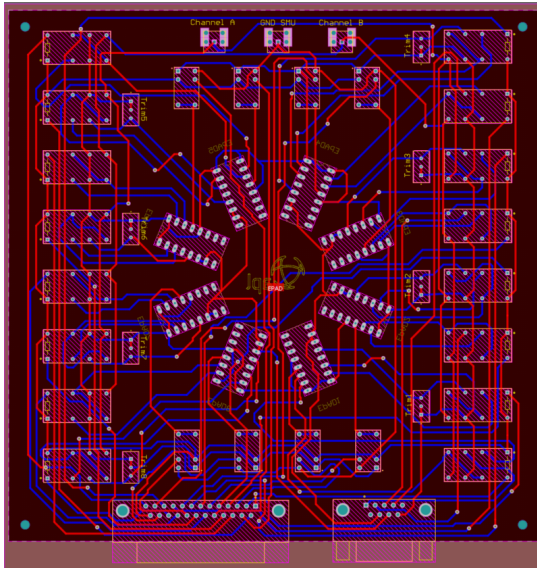
PIC16F887 microcontroller with ICSP and FTDI outputs



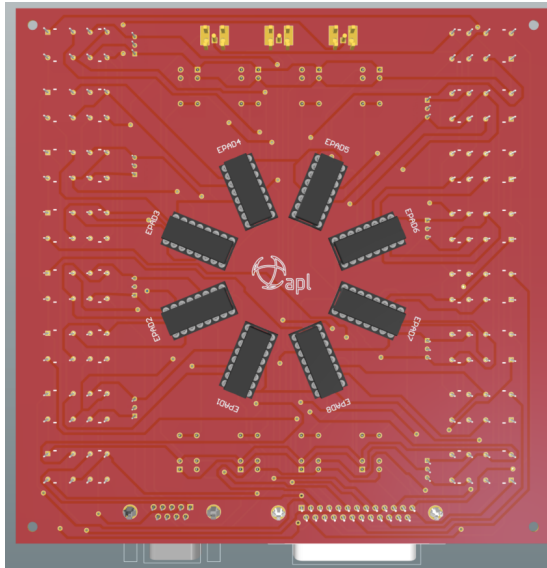
Relay control via optocouplers



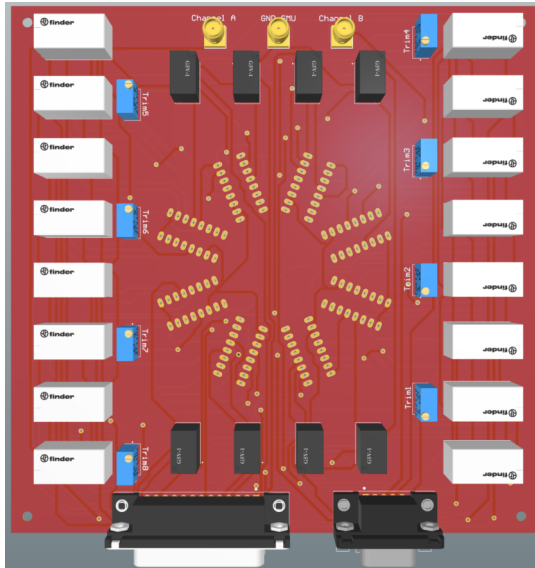
PCB Design: 2D View



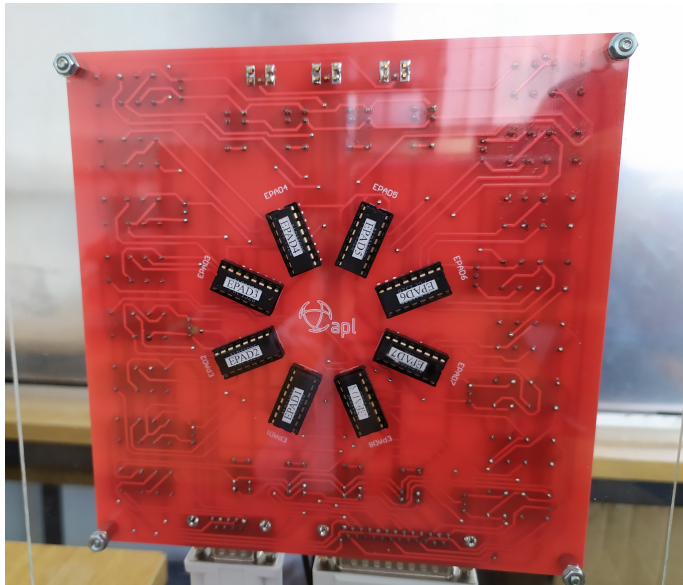
PCB Design: 3D Bottom View



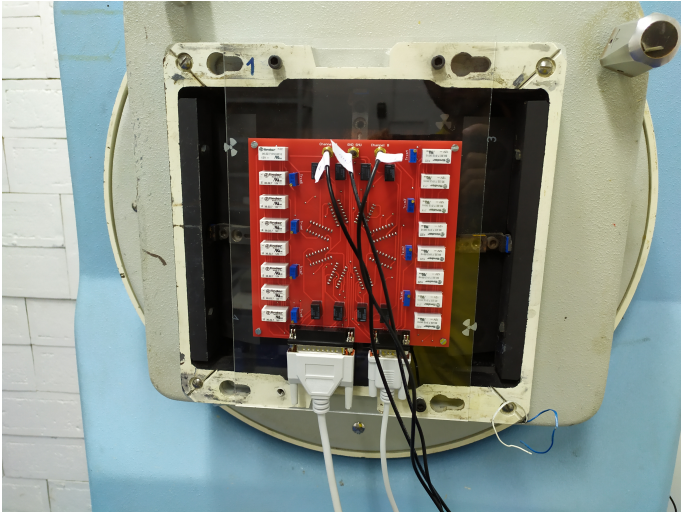
PCB Design: 3D Top View



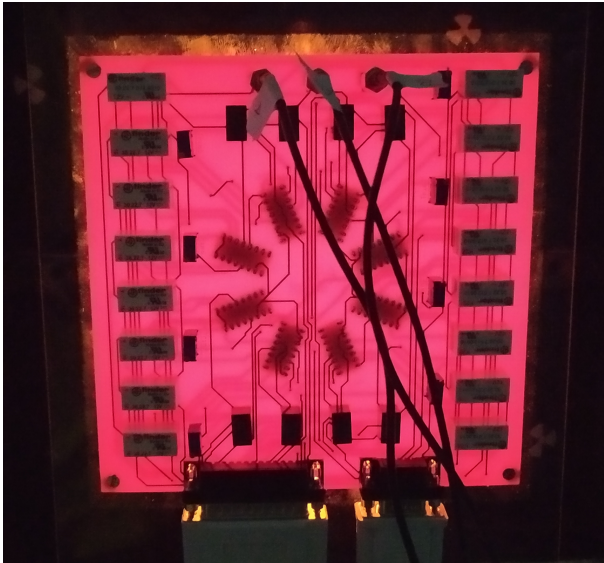
PCB with EPADs on acrylic glass



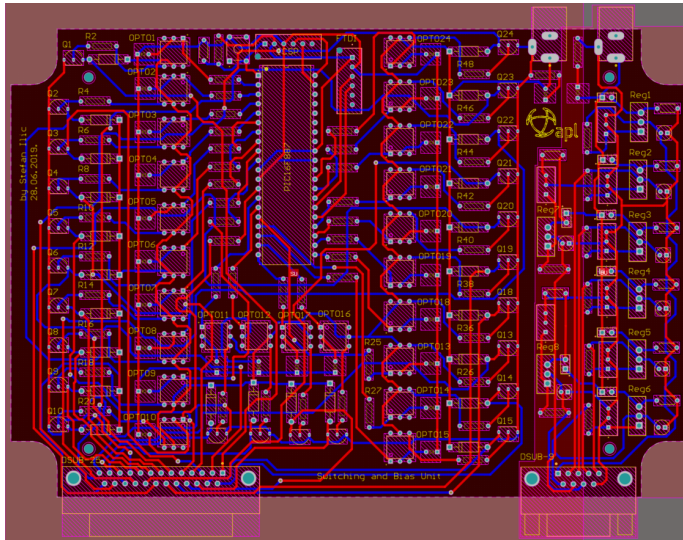
PCB with EPADs in the irradiation room



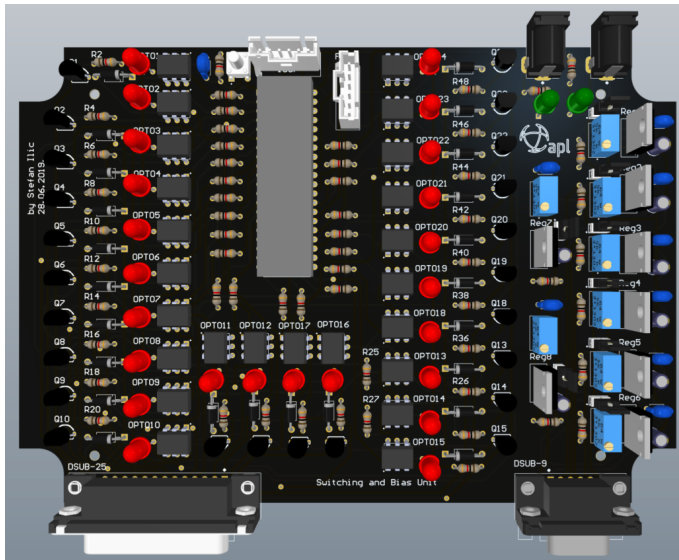
Positioning the PCB in front of the collimator



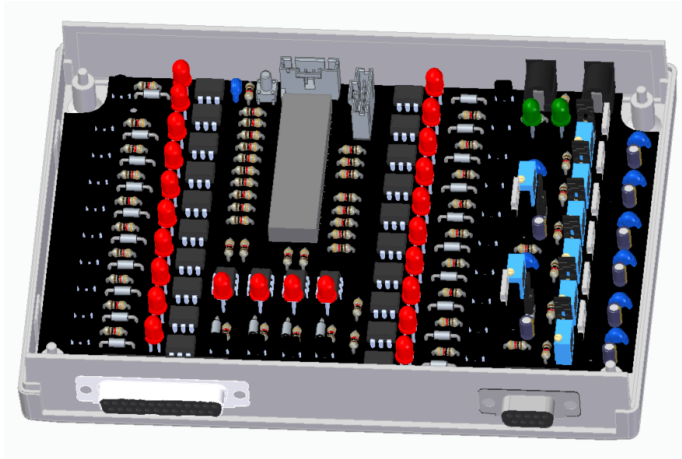
Switching And Bias Unit Design: 2D View



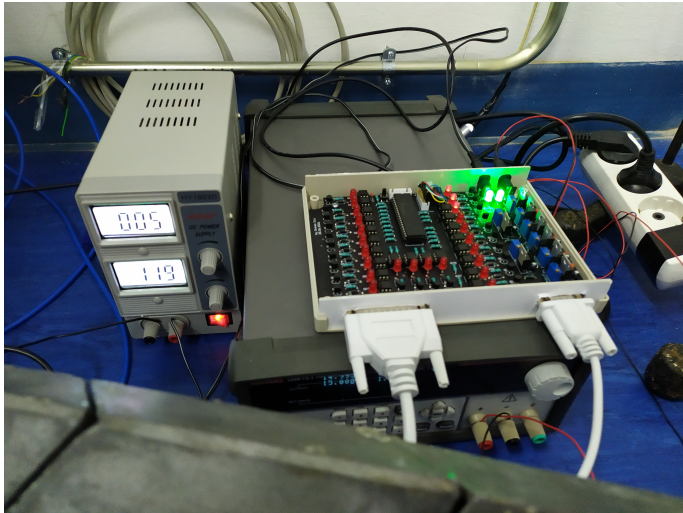
SABU Design: 3D View in Altium Designer



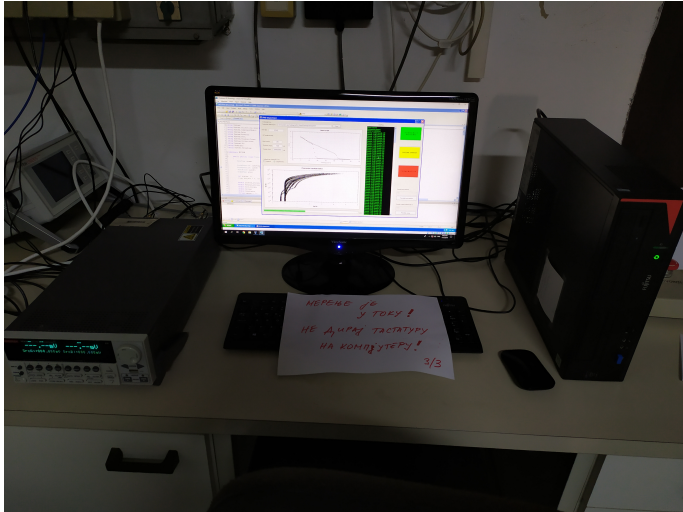
SABU Design: 3D View in Solid Edge



SABU in the irradiation room



Computer and Keithley 2636 outside the irradiation room



Transfer characteristics of EPADs for different temperatures

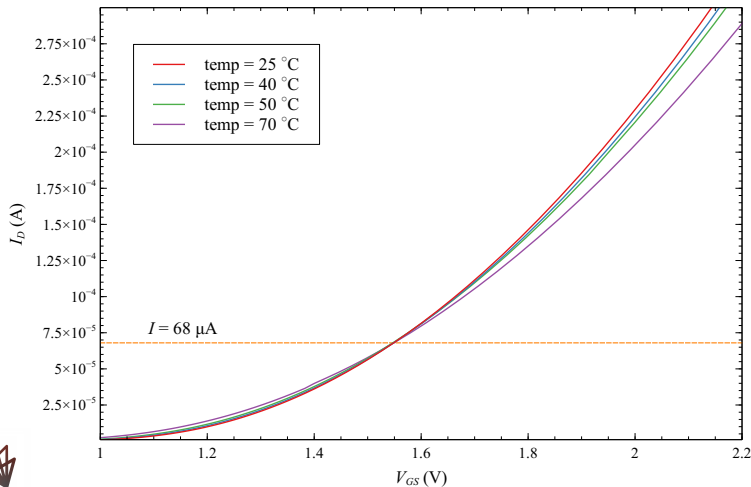
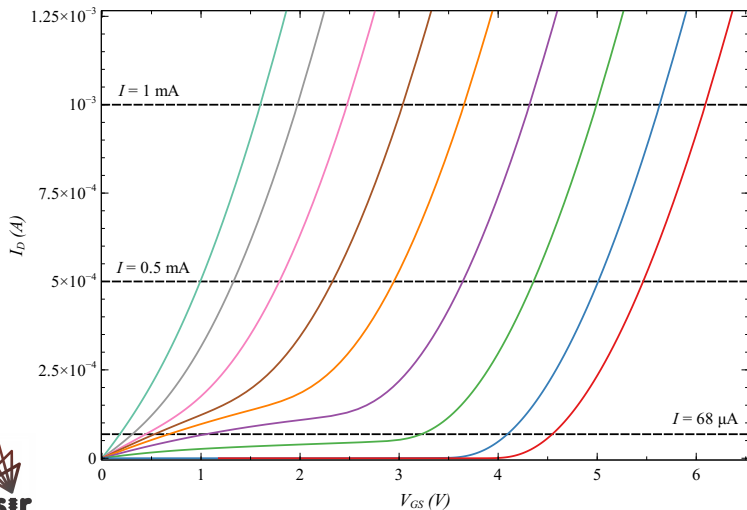


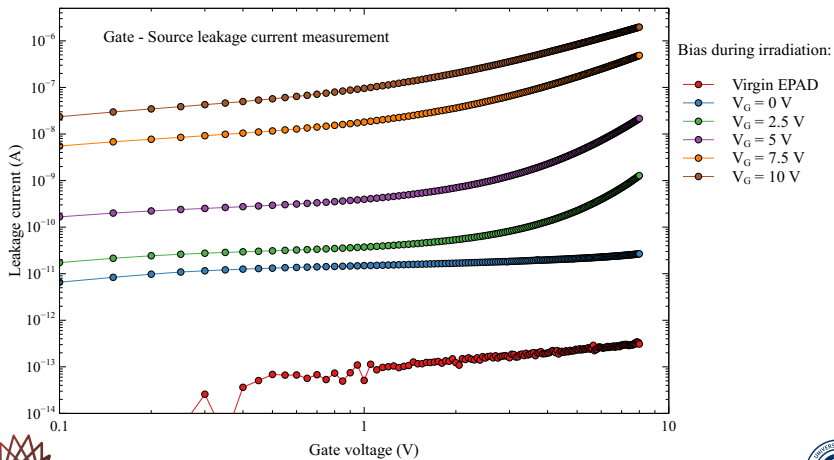
Table of EPAD parameters for experiment

Name	Bias	Dynamic par.	Initial V_{th}
EPAD1	(0.51 - 2.28) V	6 V, 1 k Ω	$V_{th} = 4$ V
EPAD2	2.5 V		$V_{th} = 4$ V
EPAD3	(0.81 - 3.17) V	6 V, 2.5 k Ω	$V_{th} = 4$ V
EPAD4	5 V		$V_{th} = 4$ V
EPAD5	(1.10 - 3.88) V	6 V, 6 k Ω	$V_{th} = 4$ V
EPAD6	7.5 V		$V_{th} = 4$ V
EPAD7	(1.61 - 4.93) V	6 V, 50 k Ω	$V_{th} = 4$ V
EPAD8	10 V		$V_{th} = 4$ V
EPAD9	(5.20 - 8.00) V	12 V, 3 k Ω	$V_{th} = 4$ V
EPAD10	0 V		$V_{th} = 1$ V
EPAD11	(5.92 - 8.95) V	12 V, 6 k Ω	$V_{th} = 4$ V
EPAD12	0 V		$V_{th} = 2$ V
EPAD13	(6.61 - 9.86) V	12 V, 15 k Ω	$V_{th} = 4$ V
EPAD14	0 V		$V_{th} = 3$ V
EPAD15	(7.40 - 10.9) V	12 V, 100 k Ω	$V_{th} = 4$ V
EPAD16	0 V		$V_{th} = 4$ V

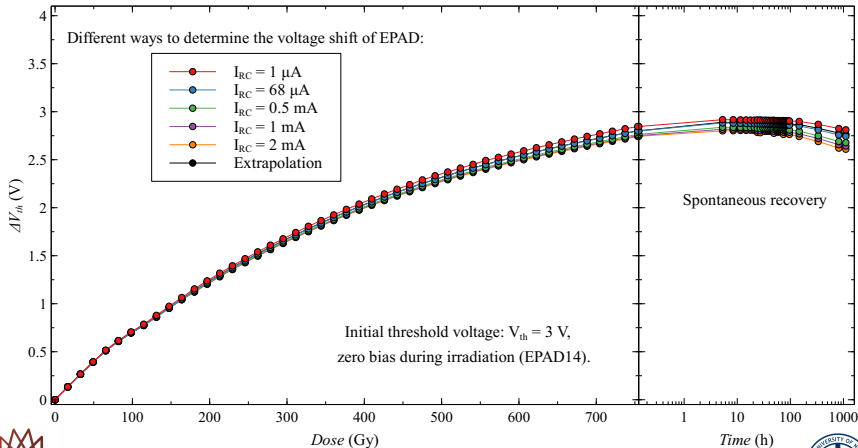
Degradation of transfer ch. for different absorbed doses



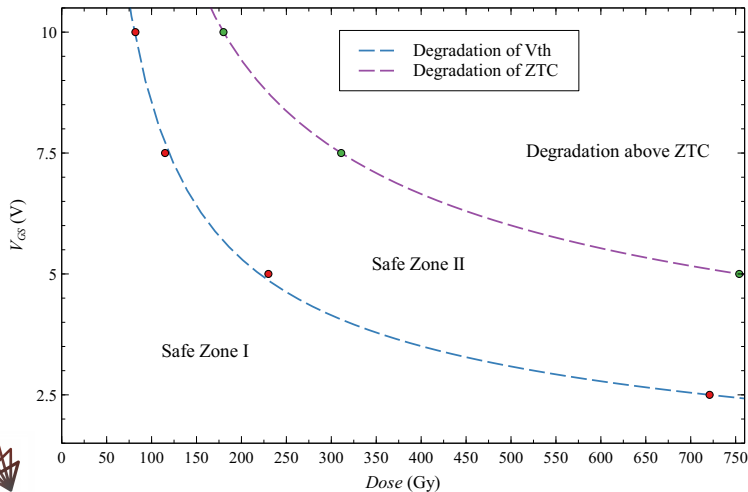
Gate - Source leakage current for different biases during irradiation



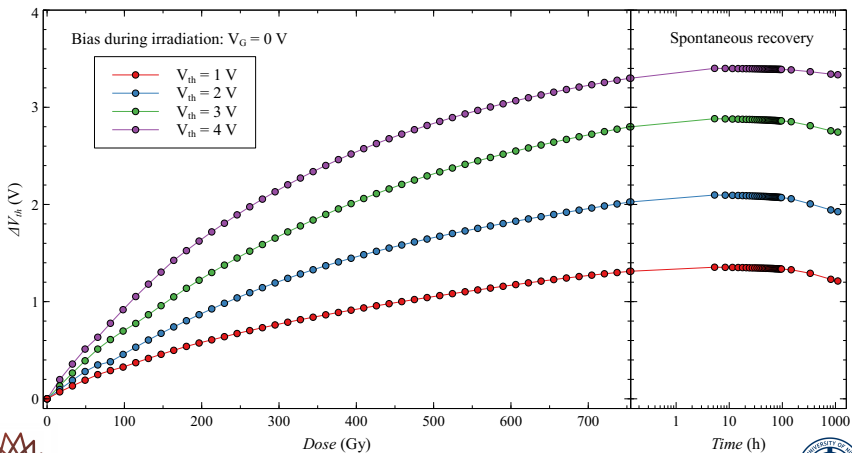
Good example of different Reader Circuit values



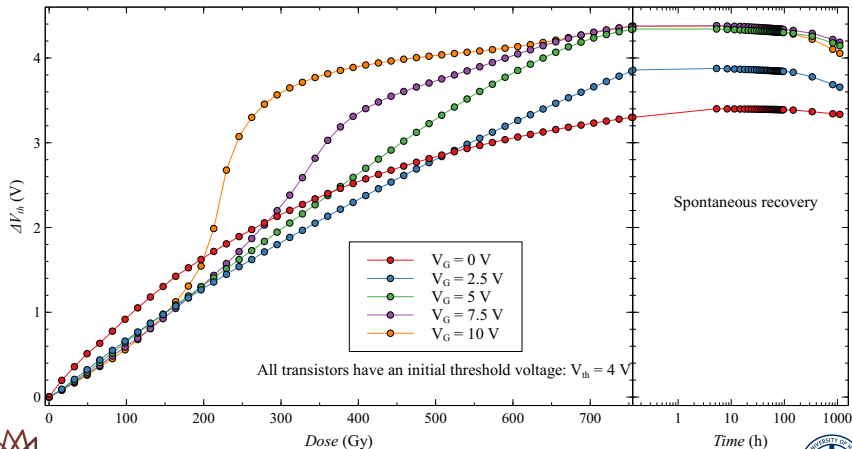
Safe operating area of EPADs



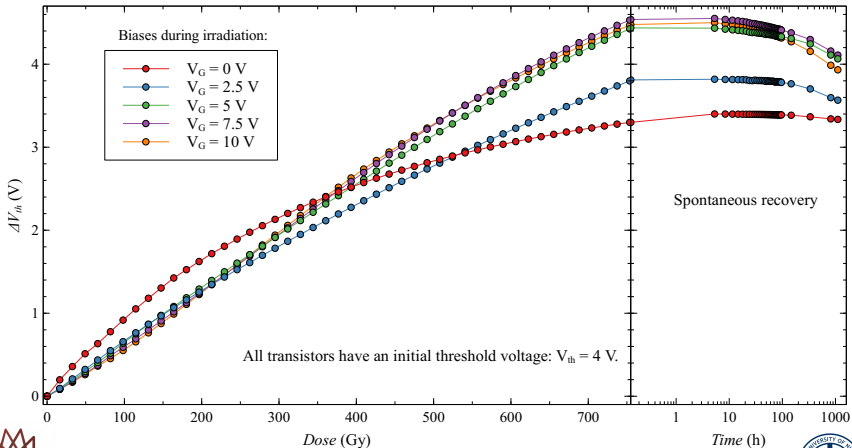
Threshold voltage shift for EPADs with zero bias



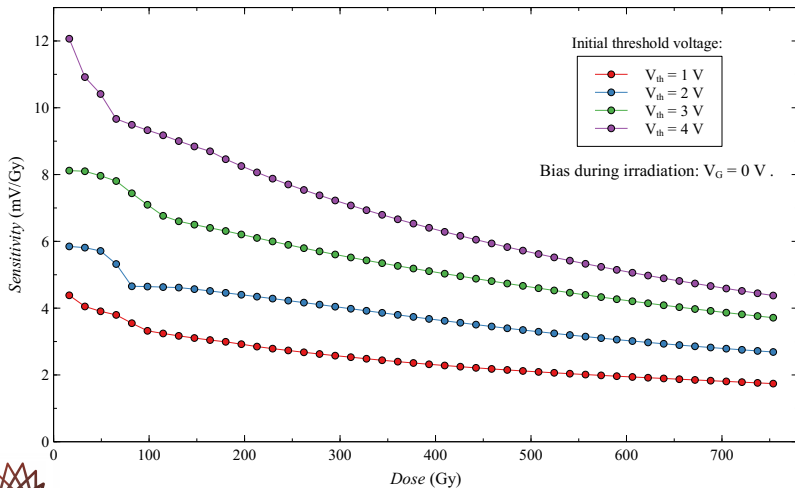
Threshold voltage shift for EPADs with static bias ZTC



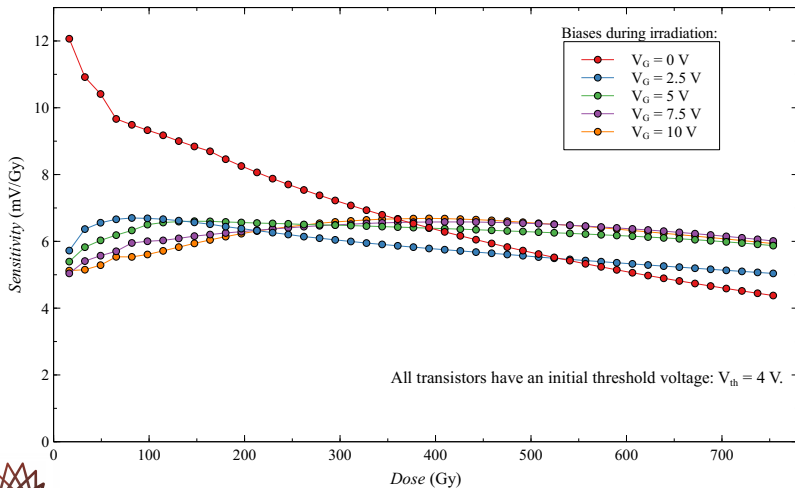
Threshold voltage shift for EPADs with static bias



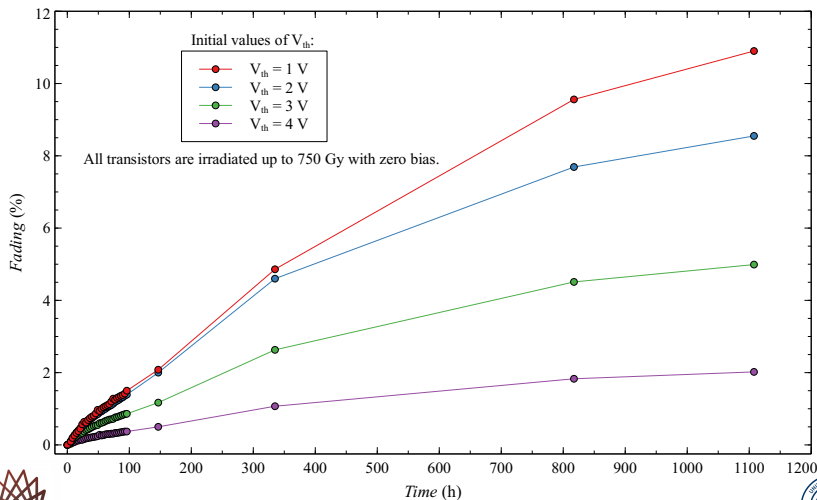
Sensitivity of EPADs with zero bias during irradiation



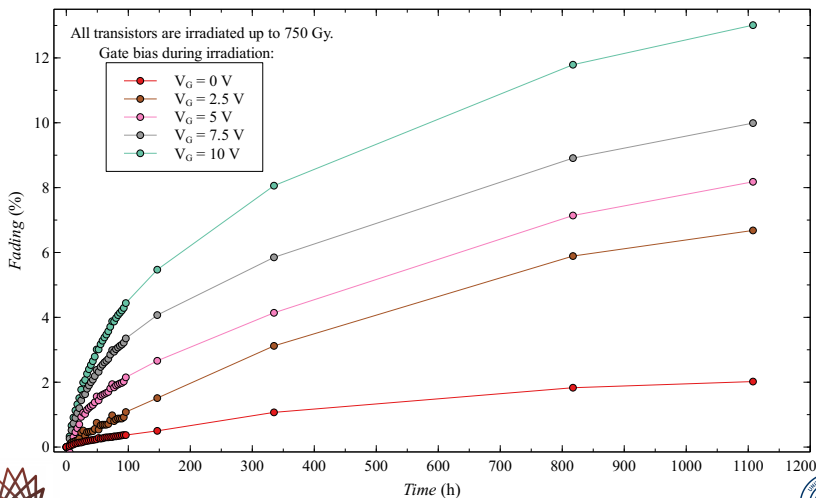
Sensitivity of EPADs with static bias during irradiation



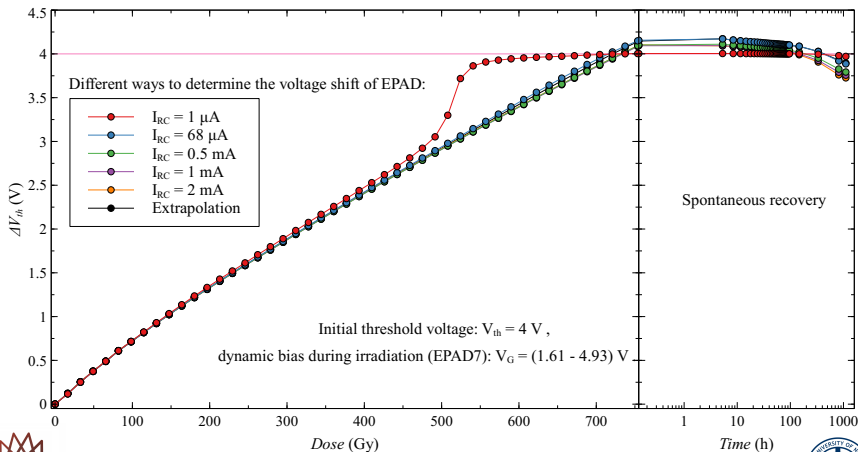
Fading of EPADs with zero bias after irradiation



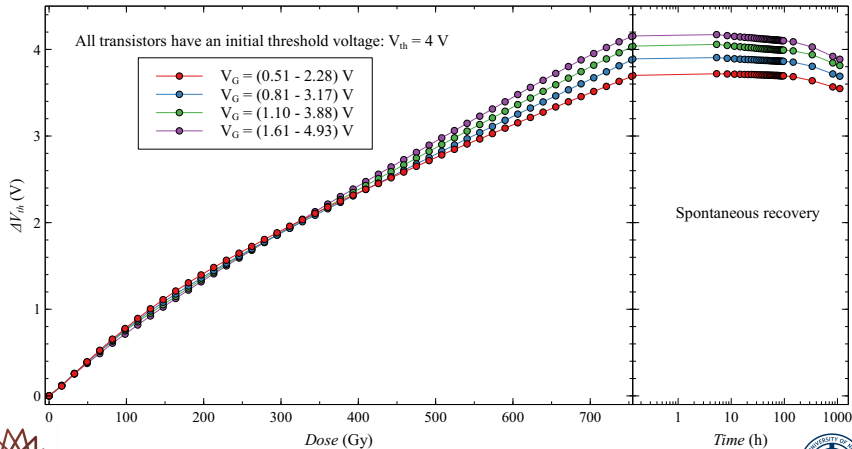
Fading of EPADs with static bias after irradiation



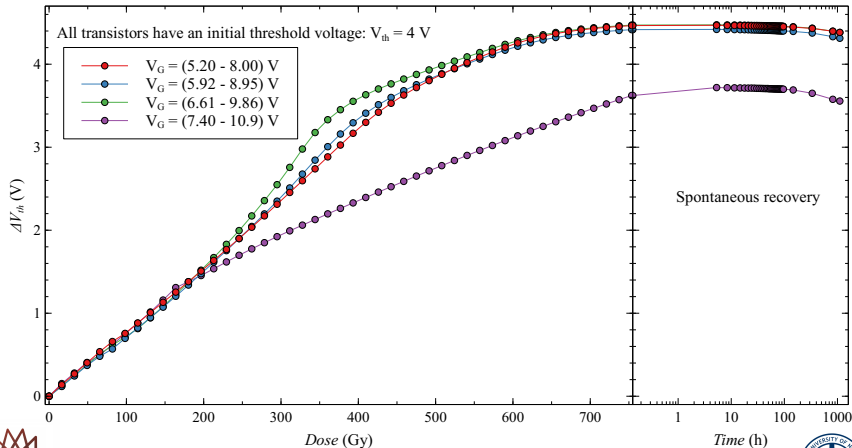
Bad example of different Reader Circuit values



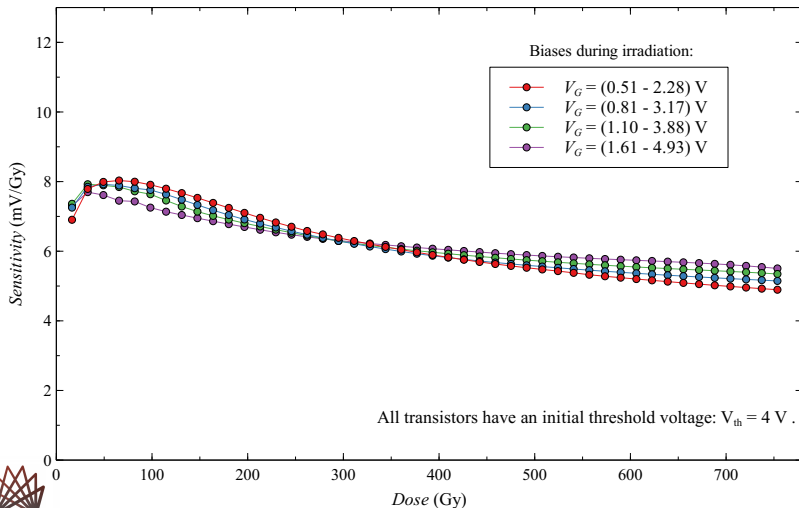
Threshold voltage shift for EPADs with dynamic bias, I



Threshold voltage shift for EPADs with dynamic bias, II



Sensitivity of EPADs with dynamic bias during irradiation, I



Discussion of the results obtained

If we want to make a radiation sensor we must somehow calibrate semiconductor component. Depending on the received dose (D) we describe observed parameter (eg. ΔV_{th}) with some function.

$$\Delta V_{th} = f(D)$$

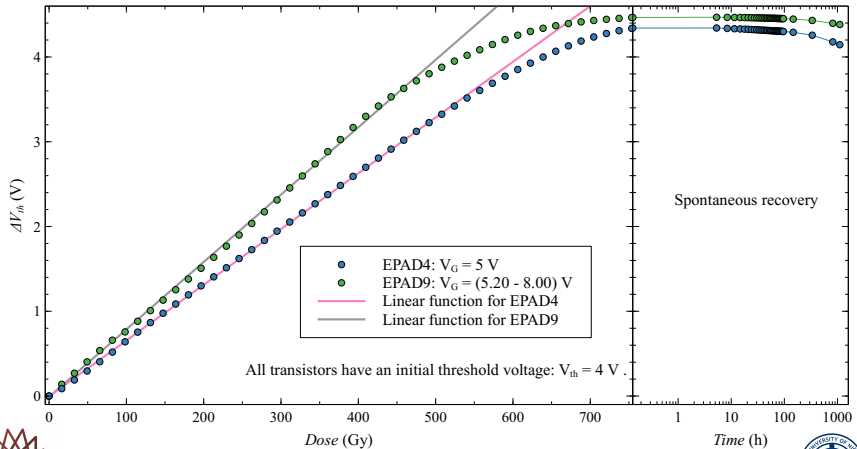
Linear function:

$$\Delta V_{th} = a + b \times D$$

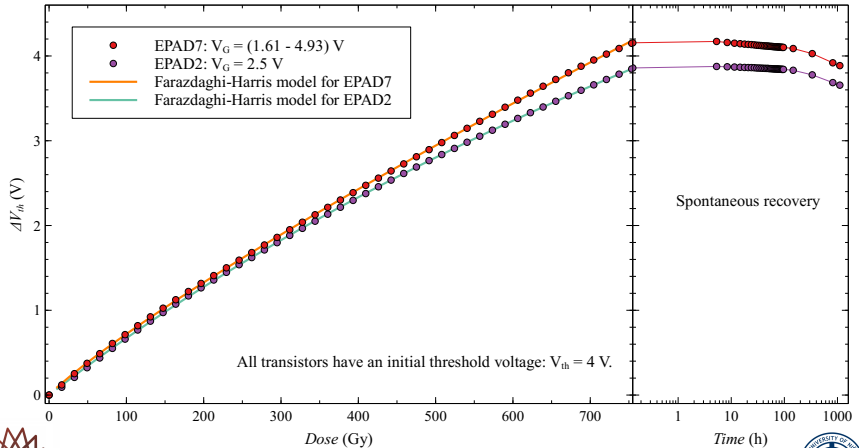
Farazdaghi-Harris model:

$$\Delta V_{th} = \frac{D}{a + b \times D^\gamma}$$

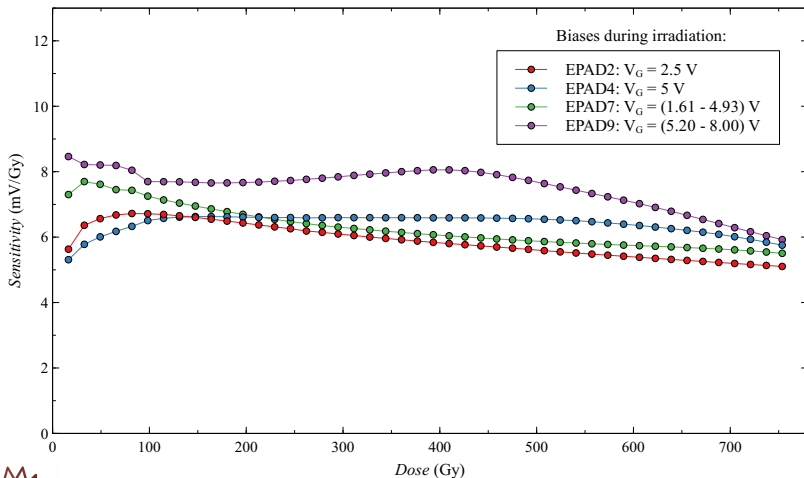
Fitting with linear function



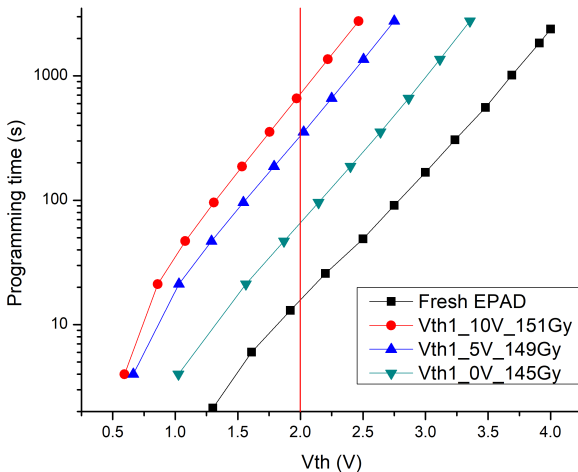
Fitting with Farazdaghi-Harris model



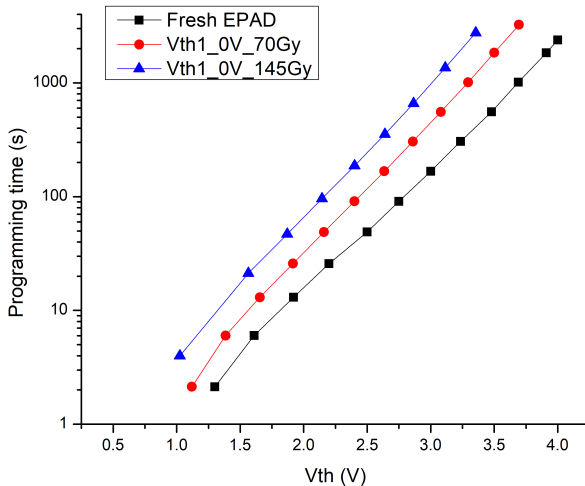
Sensitivity of four EPADs



Re-programming characteristics of EPADs ($V_{th} = 1$ V) after irradiation with a different voltage bias



Re-programming characteristics of EPADs ($V_{th} = 1$ V) with different absorbed doses



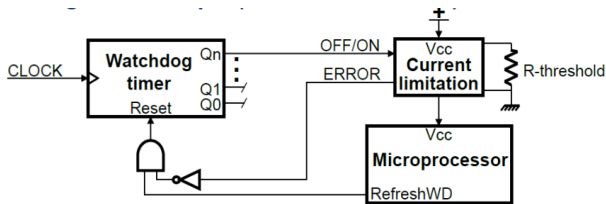
Ideas for future work

- Rad-hard reader for EPADs using COTS
 - irradiation with heavy ions (Single Event Effects)
 - gamma irradiation (Total Ionizing Dose)
 - apply hardware and software rad-hard techniques
- Third-generation programmer for EPADs
 - programming more easily controlled (no need for SMU and PC)
 - make rad-hard (if possible) and implement on rad-hard reader
 - develop for re-programming of EPADs (in radiation field)
- Stacked EPADs to increase sensitivity
- Temperature experiments with EPADs
 - thermal cycling of EPADs
 - annealing of EPADs
 - trying to discharge floating gate with bias and temperature

Rad-hard reader for EPADs

Digital circuits:

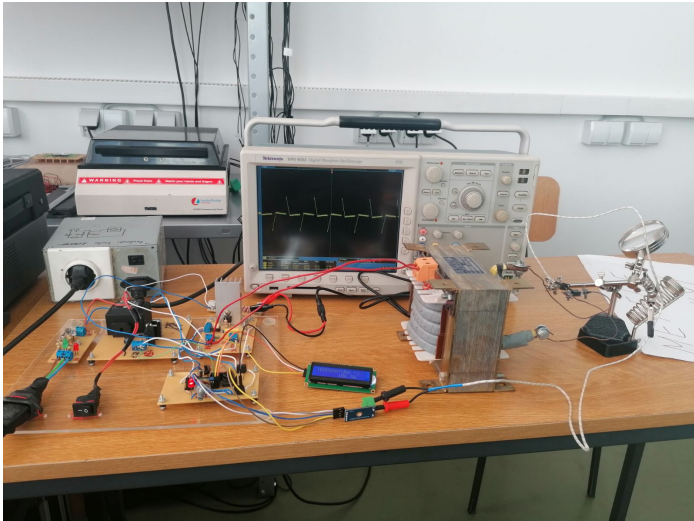
- Protection for microcontrollers from Single Event Latchups.



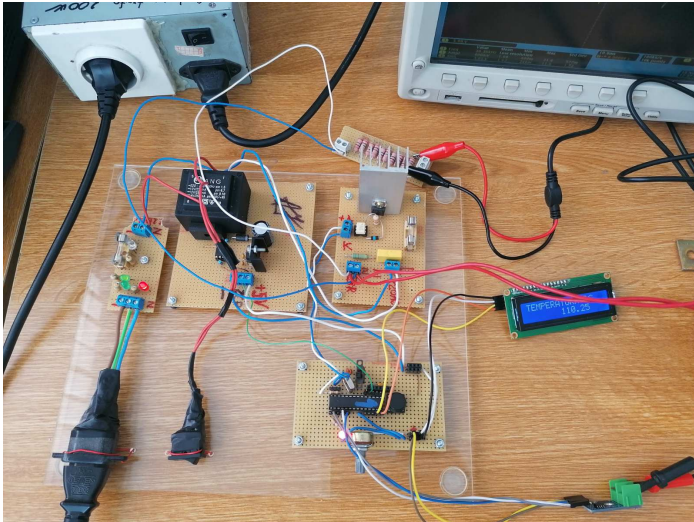
Analog circuits:

- Low pass RC filter at the end of analog block to protect from Single Event Transients.

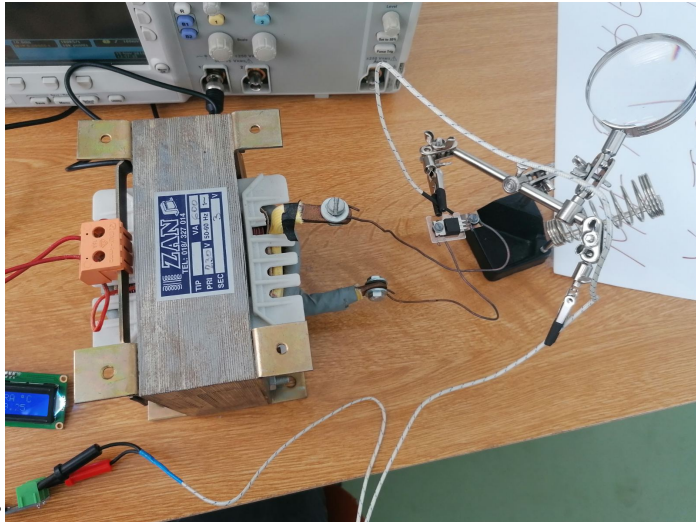
Jevta's thermal cycling machine



Jevta's thermal cycling machine



Jevta's thermal cycling machine



THANK YOU FOR YOUR ATTENTION!