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SOME ADVANCES IN DOSE MEASUREMENT WITH MOSFET FOR PORTABLE INSTRUMENTATION

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AGENDA

- Research group
- Introduction
- Low cost pMOS as dosimeter
- Procedures of measurement
  - Pulsed biasing (PB)
  - Two currents method (2CM)
  - Three currents method (3CM)
- Portable dosimetry system
- Conclusions
- Aknowledgements

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RESEARCH GROUP

- **Interdisciplinary spanish group**:
  - PhDs in Physics
  - PhDs in Electronic Engineering
  - PhD. students in Telecommunications Eng.
  - Several Hospitals in Spain (Granada and Málaga)
- **Main topics in dosimetry:**
  - MOSFET electrical and thermal characterization
  - Monte Carlo simulation of radiation-matter interaction
  - Measurement science
  - Design and testing of electronic instrumentation
- **We offer our experience for collaboration**

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INTRODUCTION

- **Scope**: Dose verification systems (DVS) based on MOSFETs mainly for medical use.
- High reliable commercial available DVS:
  - Best medical Canada systems (BM)
  - REM Oxford Ltd. (REM)
  - One Dose by Sicel Tech.? (OD)
- Some little disadvantages
  - Wired sensors for bias purposing (BM, REM)
  - Short dose range (OD)
  - Expensive RADFETs (BM, REM, OD)

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INTRODUCTION

- **Our approach**
  - Use of low-cost general-purpose MOSFET as dosimeters
  - Wireless and reusable sensors without bias during irradiation

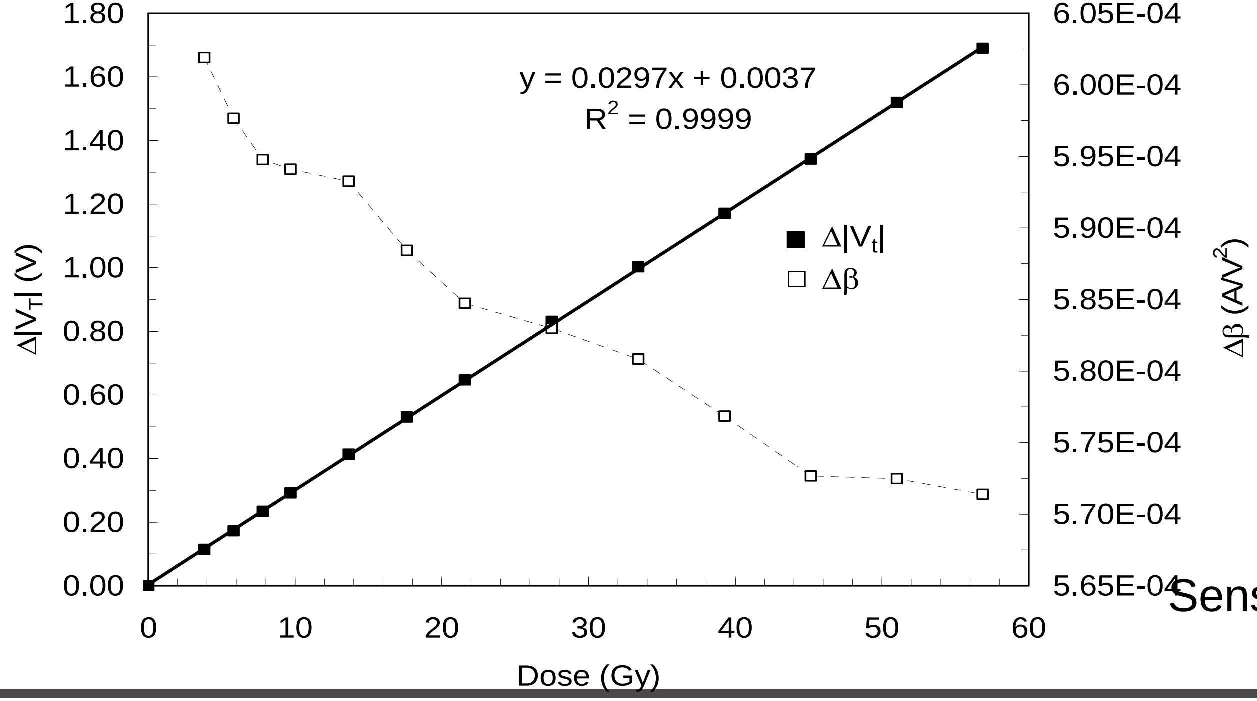
- **Drawbacks of our approach:**
  - Low sensitivity to radiation.
  - Low signal-to-noise ratio (SNR)
  - Low linear range.

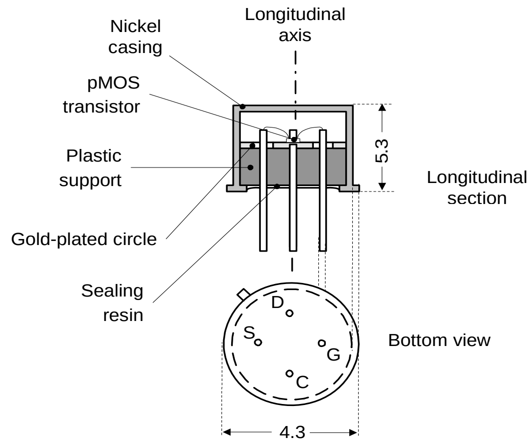
- **Objective:** overcoming the above problems

LOW COST pMOS

- **3N163 (Vishay-Siliconix, USA)**
  - Response to radiation from I_D-V_{GS} curves

$$I_D = -\frac{\beta}{2}\left(\left|v_{GS}\right| - \left|V_t\right|\right)^2$$





Sensitivity 30 mV/Gy

PROCEDURES OF MEASUREMENT
State of the art

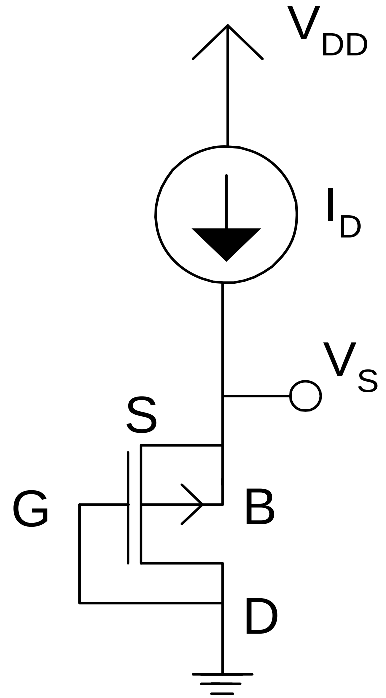
- Ionizing radiation creates charge in the oxide: Threshold voltage, V_t ,is the dosimetric parameter

$$\Delta |V_t| > 0$$
$$\Delta \beta < 0$$

- Measurement of V_t at constant drain current (V_{GD} = 0). (BM, REM, OD)

$$I_D = -\frac{\beta}{2}\left(|v_{GS}| - |V_t|\right)^2$$

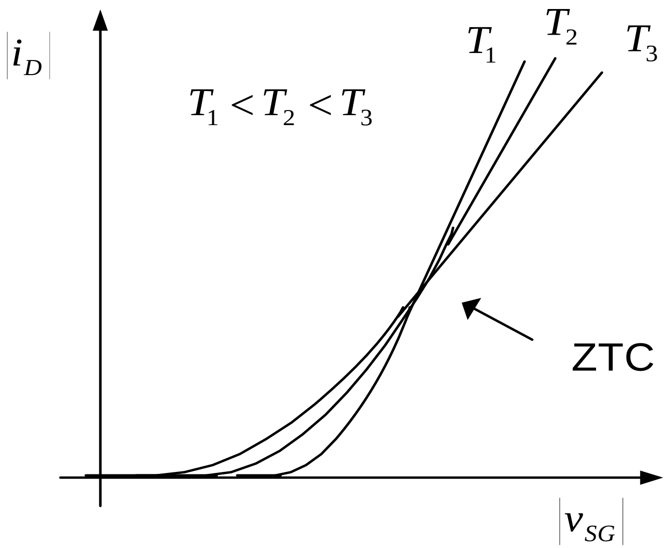
$$\beta \approx cte \quad \Rightarrow \quad \Delta|V_t| \approx \Delta|V_S|$$



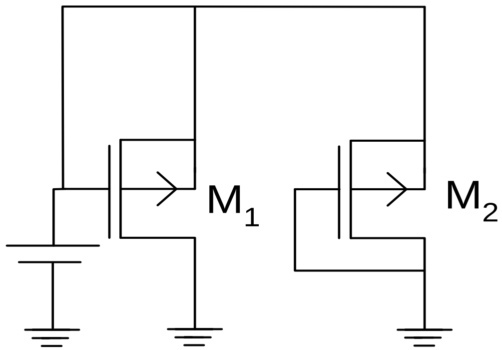
PROCEDURES OF MEASUREMENT
State of the art

- **Thermal compensation techniques**

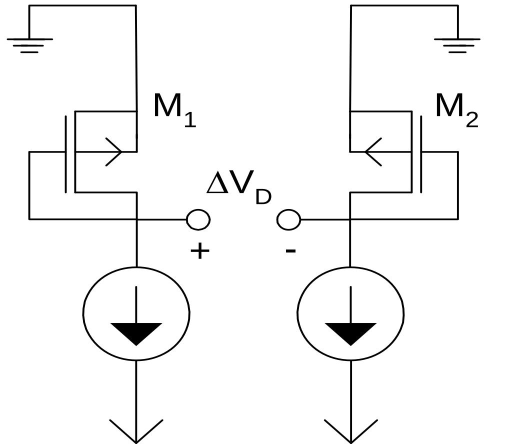
Biasing the pMOS at I_{ZTC} (REM, OD)



Two identical pMOS with different sensibilities (BM)



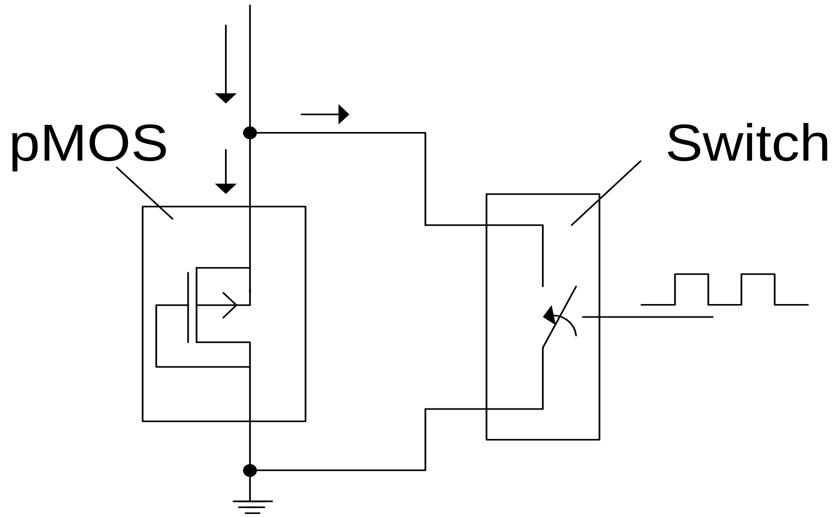
During irradiation



Read-out configuration

PROCEDURES OF MEASUREMENT
Pulsed biasing (PB)

- **SNR improvement**
  - Read-time instabilities caused by low frequency noise (LFN) (due to near-interface and interface states)
  - How can LFN be reduced? Chopping the drain current as in other experimental techniques (i.e. spectroscopy) and averaging



PROCEDURES OF MEASUREMENT
Two currents method

- **Linear range improvement**
  - Reducing $\Delta\beta$ effect in ΔV_t

$$I = \frac{\beta}{2}\left(V_S - |V_t|\right)^2$$

  - pre- and post-irradiation parameters at constant current *I*:

$$|V_t| = V_S - \sqrt{\frac{2I}{\beta}} \Rightarrow \begin{cases} |V_t^{post}| = V_S^{post} - \sqrt{\dfrac{2I}{\beta^{post}}} \\ |V_t^{pre}| = V_S^{pre} - \sqrt{\dfrac{2I}{\beta^{pre}}} \end{cases} \quad \Delta|V_t| = \Delta V_S - \sqrt{2I}\left(\sqrt{\frac{1}{\beta^{post}}} - \sqrt{\frac{1}{\beta^{pre}}}\right)$$

PROCEDURES OF MEASURMENT
Two currents method (TCM)

- **Linear range improvement**
  - Using two drain currents for read-out:

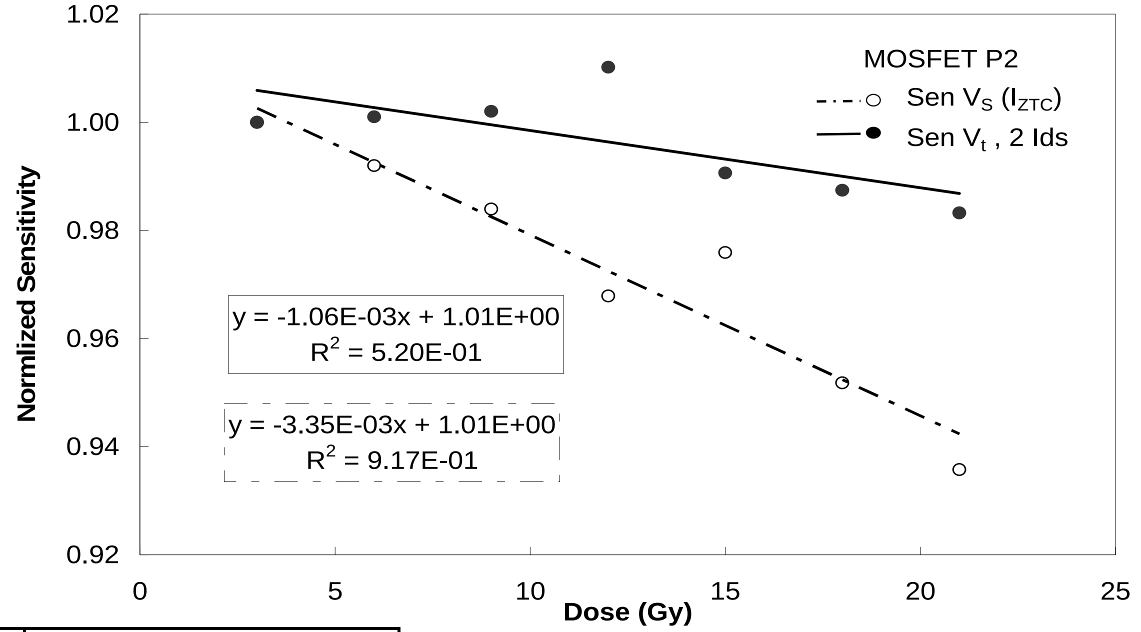
$$\Delta|V_t| = \Delta V_{S1} - \sqrt{2I_1}\left(\sqrt{\frac{1}{\beta^{post}}} - \sqrt{\frac{1}{\beta^{pre}}}\right) \qquad \Delta|V_t| = \Delta V_{S2} - \sqrt{2I_2}\left(\sqrt{\frac{1}{\beta^{post}}} - \sqrt{\frac{1}{\beta^{pre}}}\right)$$

  - Threshold voltage shift without $\Delta\beta$ interference

$$\Delta|V_t| = \Delta V_{S1} + \frac{\Delta V_{S2} - \Delta V_{S1}}{1 - \sqrt{\frac{I_2}{I_1}}}$$

PROCEDURES OF MEASUREMENT
Results (PB+TCM)

- **Linearity improvement**



Sensitivity decay coefficient, mean sensitivity and the linear limit (up to 5%).

	DC modes		PB	
	I_{ZTC}	TCM	I_{ZTC}	TCM
m (mV/Gy^2)	-0.153	-0.095	-0.113	-0.057
Mean Sensitivity (mV/Gy)	20.6	19.7	20.0	19.2
Linear Range (Gy)	6.8	10.3	8.8	16.8

20 % reduction of SD

$$\sigma_{Vs}^{DC} = 45.8\,\mu V$$

$$\sigma_{Vs}^{PB} = 36.4\,\mu V$$

PROCEDURES OF MEASUREMENT
Three currents method (ThCM)

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- **Thermal compensation**
  - Starting hypothesis:

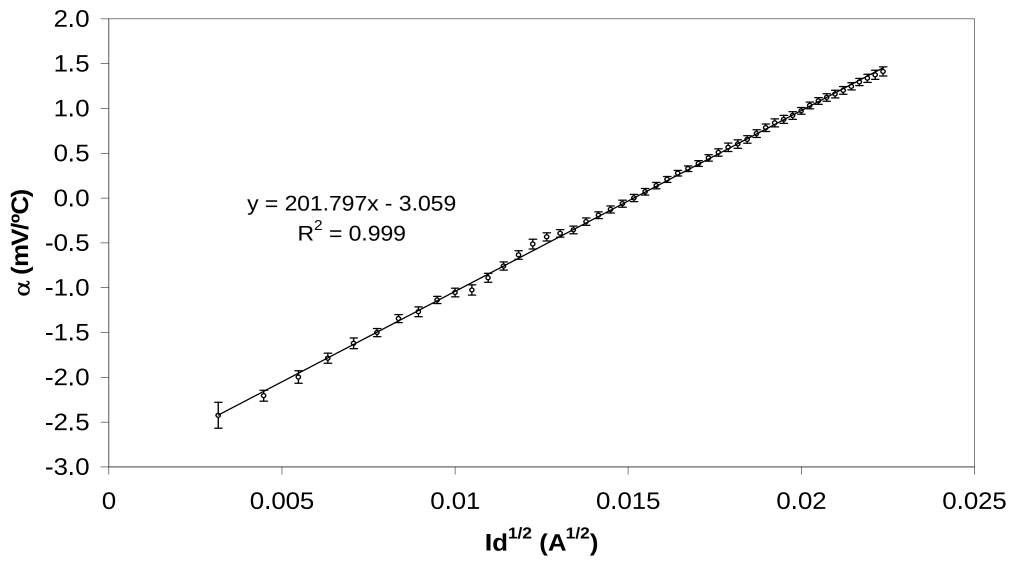
$$\Delta|V_t| = \Delta V_{S1} + \frac{\Delta V_{S2} - \Delta V_{S1}}{1 - \sqrt{\frac{I_2}{I_1}}}$$

$$\Delta V_{S1}(T) = \Delta V_{S1}^0 + \alpha_1 \Delta T$$

$$\Delta V_{S2}(T) = \Delta V_{S2}^0 + \alpha_2 \Delta T$$

$$\Delta|V_t|(T) = \Delta|V_t^0| + \alpha_{|Vt|}(T - T_0)$$

$$\Rightarrow \quad \alpha_i = \alpha_{|Vt|}\left(1 - \sqrt{\frac{I}{I_{ZTC}}}\right)$$



  - Experimentally verified

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PROCEDURES OF MEASUREMENT
Three currents method (ThCM)

- **Thermal compensation**
  - $\Delta|V_t|$ thermal compensated

$$\Delta|V_t| = \Delta V_{S1}^0 + \frac{\Delta V_{S2}^0 - \Delta V_{S1}^0}{1 - \sqrt{\frac{I_2}{I_1}}}$$

  - Additional current: I_3

$$\Rightarrow \Delta V_{S1}^0 = \Delta V_{S1} + (\Delta V_{S3} - \Delta V_{S1})\frac{\sqrt{I_1} - \sqrt{I_{ZTC}}}{\sqrt{I_1} - \sqrt{I_3}}$$

$$\Delta V_{S2}^0 = \Delta V_{S2} + (\Delta V_{S3} - \Delta V_{S2})\frac{\sqrt{I_2} - \sqrt{I_{ZTC}}}{\sqrt{I_2} - \sqrt{I_3}}$$

  - Simplification $I_1 = I_{ZTC}$

$$\Delta|V_t| = \Delta V_{S,ZTC} + \frac{\Delta V_{S2}^0 - \Delta V_{S,ZTC}}{1 - \sqrt{\frac{I_2}{I_{ZTC}}}}$$

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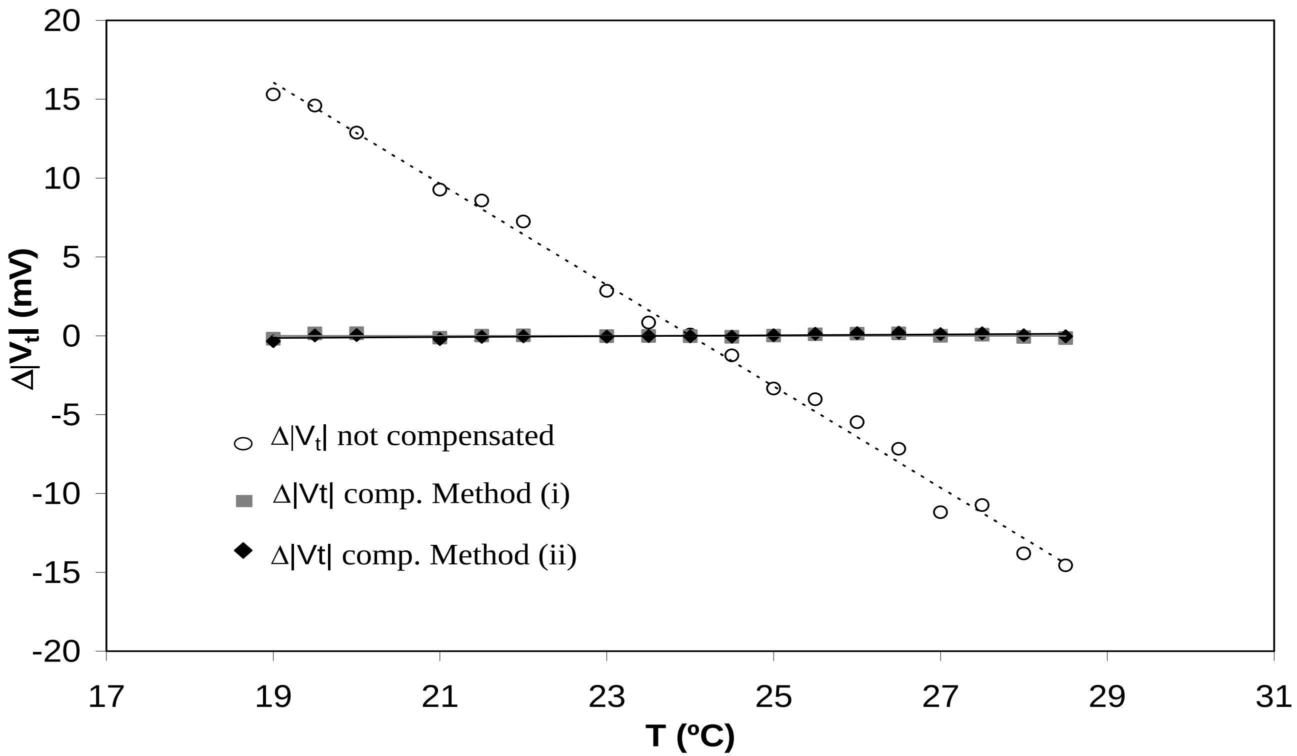
PROCEDURES OF MEASUREMENT
Results (ThCM)

- **Thermal compensation:**
  - Reduction in a factor of 50 in the thermal drift

$$I_2 = 30\ \mu A$$
$$I_3 = 120\ \mu A$$
$$I_{ZTC} = 225\ \mu A$$

Compensated

$$\frac{\Delta V_t}{\Delta T} < 70\ \mu V/^{o}C$$



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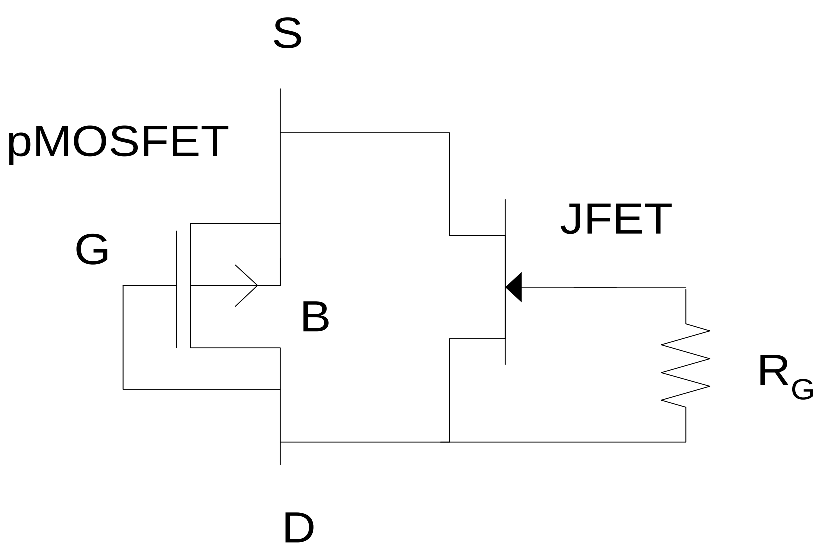
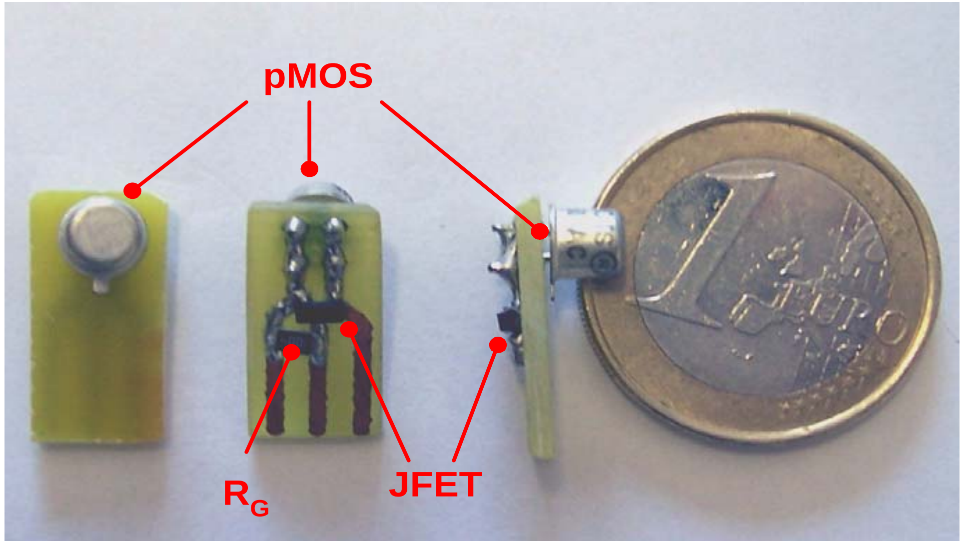
PORTABLE DOSIMETRY SYSTEM

Sensor Module

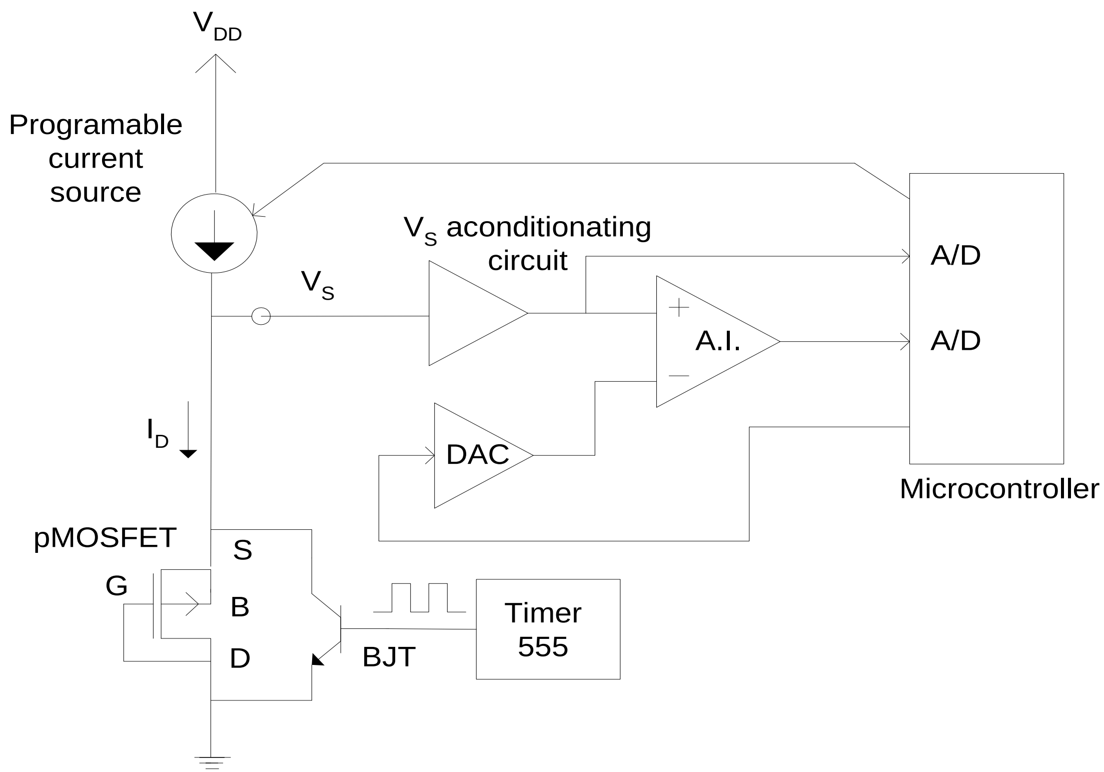
- JFET as a switch (shortcircuited during irradiation and storage and open during read-out)





PORTABLE DOSIMETRY SYSTEM

- **Reader Unit**



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PORTABLE DOSIMETRY SYSTEM

- **Dose measurement process**
  - Zeroing:
    - Measurement and storage of pre-irradiation V_S at the two (three) drain currents
  - Irradiation
  - Wait for short-term fading (120 -180 s)
  - Dose measurement
    - Read the pre-irradiation values
    - Measurement and storage the post-irradiation V_S at the two (three) currents
    - Dose calculation (calibration is required)

PORTABLE DOSIMETRY SYSTEM

- **Irradiation conditions**
  - Theratron-780 with a ^{60}Co source and a field of 25 x 25 cm^2
  - MOSFETs, in electronic equilibrium condition, located at 80 cm of the isocentre

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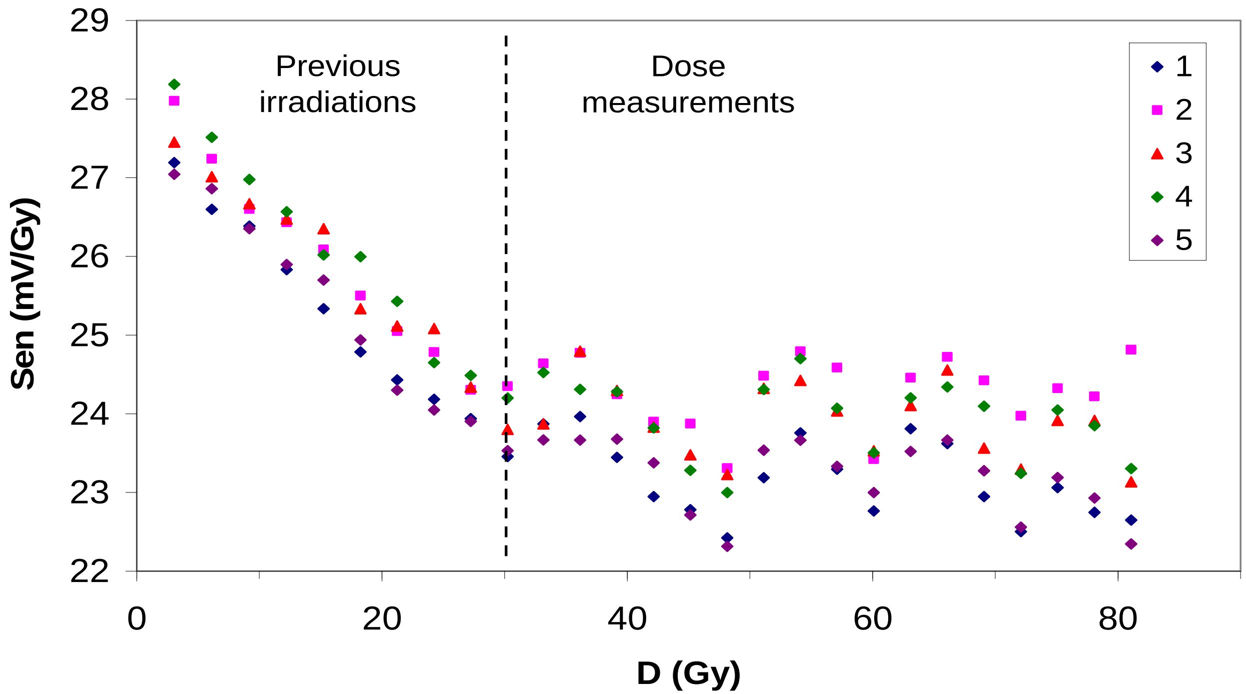
PORTABLE DOSIMETRY SYSTEM Results

- **Sensitivity per session**



$$S = \frac{\Delta |V_T|}{D}$$

A pre-irradiation of 30 Gy is required for reproducibility of S

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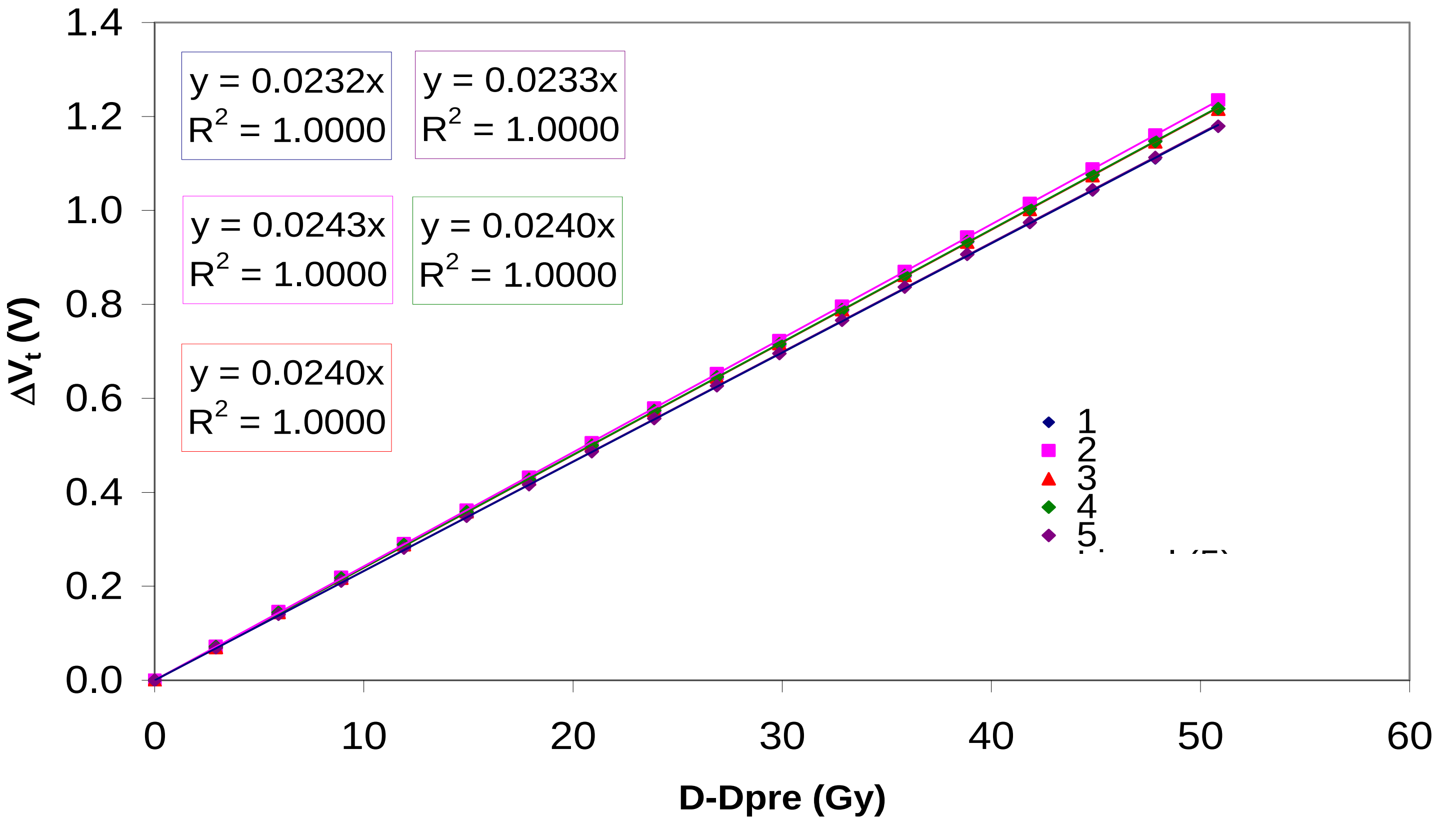
PORTABLE DOSIMETRY SYSTEM
Results

- **Radiation response**

Dpre=30 Gy



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PORTABLE DOSIMETRY SYSTEM
Technical specifications

Temperature range	10 – 40 ºC
Resolution	1 cGy
Accuracy	± 3 %
Linear range	15 Gy > 80 Gy*
Thermal drift	< 3mGy/ºC
Delay after irradiation	2 – 3 minutes

* with recalibrations every 15 Gy

CONCLUSIONS

- Procedures of dose measurement for linearity and SNR improvement and thermal drift reduction
- Portable dosimetry system based on commercial and standard MOSFET sensor
  - Wireless sensor
  - Reusable sensor (up to 80 Gy with recalibration each 15 Gy)
  - Thermal compensation without additional devices (3 mGy/ºC)

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