Design of Radiation Hardened RADFET Readout System for Space Applications

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Agenda

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6. Self-Adaptive Multiprocessor System-on-Chip
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DSD Paper

- **The concept outlined in this presentation has been accepted for publication at Euromicro Conference on Digital Systems Design (DSD), 2020**

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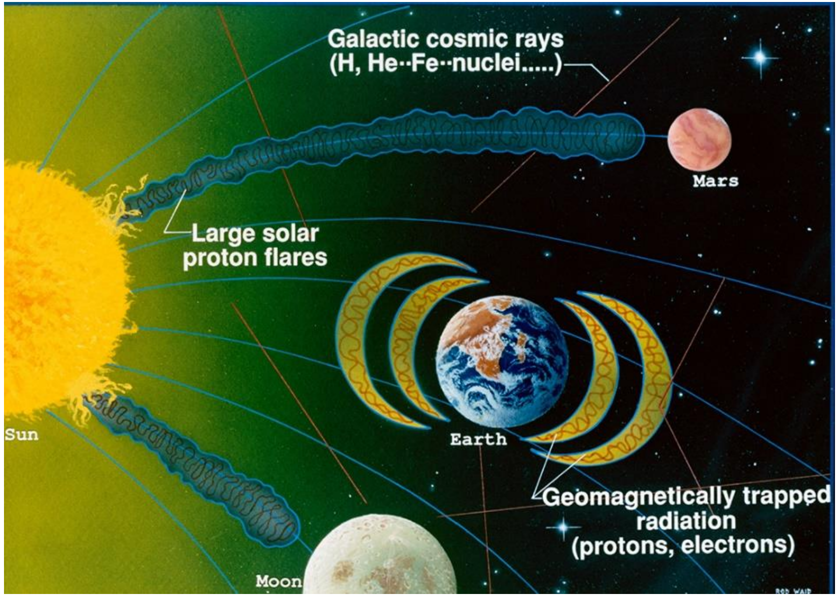
"Design of Radiation Hardened RADFET Readout System for Space Applications"

1. Motivation

- **Space radiation environment**
  - Complex (wide range of sources and energies)
  - Dynamic (variable radiation intensity)



[Illustration from https://www.nasa.gov]

- **Radiation effects**
  - Lethal for humans
  - Source of failures in electronics
    - Total Ionizing Dose (TID) effects
    - Single Event Effects (SEEs)

- **Space mission requirements**
  - Radiation dosimetry – *adsorbed dose and dose rate measurement*
  - Radiation-hardened electronics – *robust to TID and SEEs*

1. Motivation

- **Common radiation dosimeters in space applications**
  - Diodes – *measure dose rate in terms of radiation-induced current*
  - RADFETs – *measure absorbed dose in terms of threshold voltage shift*

- **RADFET's advantages**
  - Operation in passive mode (without bias)
  - Storage of dosimetric information

- **Limitations of existing RADFET readout solutions**
  - Measuring only absorbed dose – *other sensors required for dose rate monitoring*
  - Static radiation hardening – *not optimal under dynamic radiation conditions*

2. Contribution

- **Proposed solution: A RADFET readout system for real-time measurement of absorbed dose and dose rate with a self-adaptive multiprocessing system-on-chip**

- **Measurement of absorbed dose and dose rate with a single RADFET**
  - No need for additional radiation sensors
  - Simplified and cheaper design

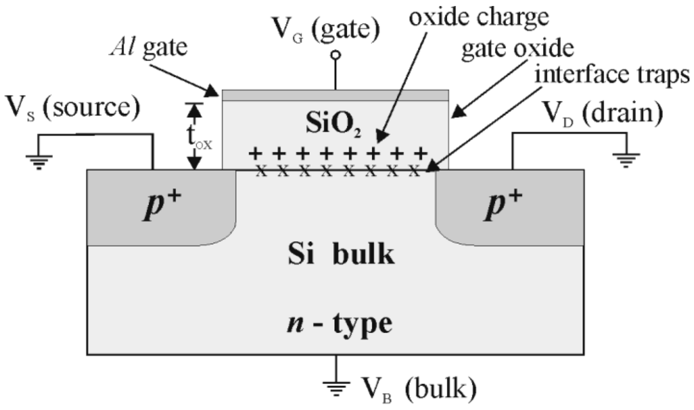
- **Self-adaptive fault-tolerant multiprocessing platform**
  - Provides fault tolerance only when required
  - Can perform additional onboard functions
  - Enables high level of integration

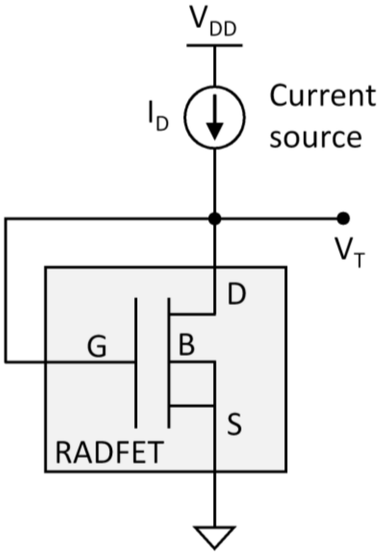
3. RADFET Dosimetry

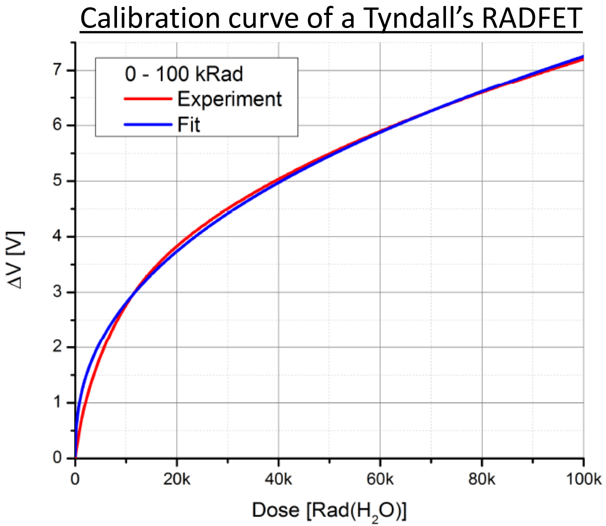
Absorbed Dose Measurement

- Radiation results in charge accumulation in oxide layer
- Threshold voltage shift ΔV_T increases with dose D

$$\Delta V_T = a - \frac{a}{1 + b \cdot D^c}$$







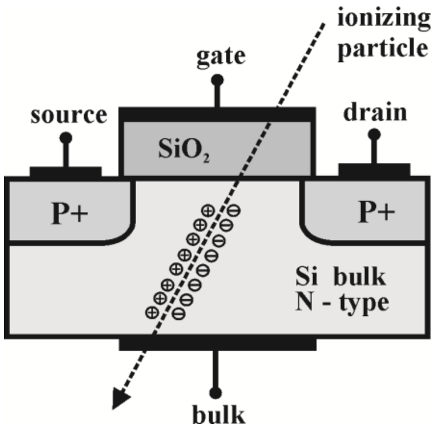
3. RADFET Dosimetry

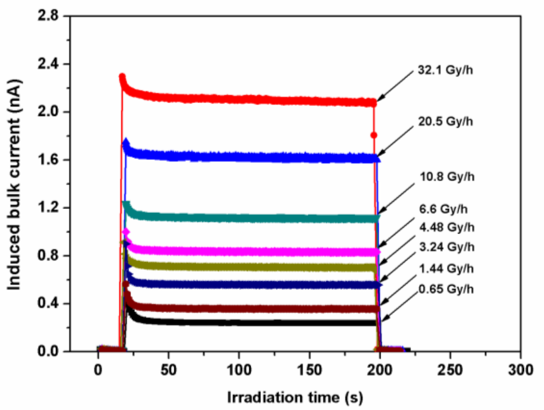
Dose Rate Measurement

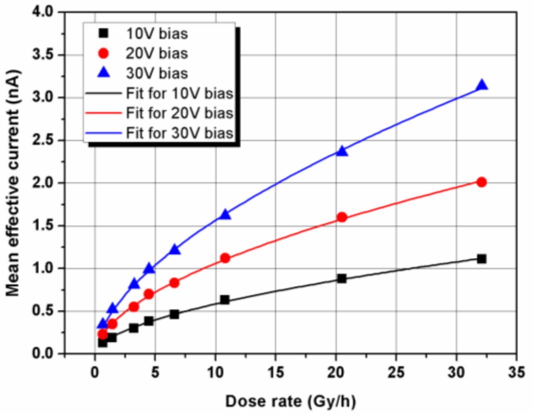
- Radiation generates stable bulk current at medium and high dose rates (e.g. 0.65 – 32 Gy/h)

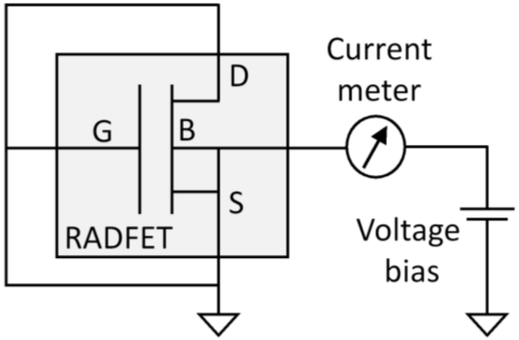
$$I = k \cdot V_{BIAS} \cdot D_R^m$$

- At lower dose rates, pulsed current is induced









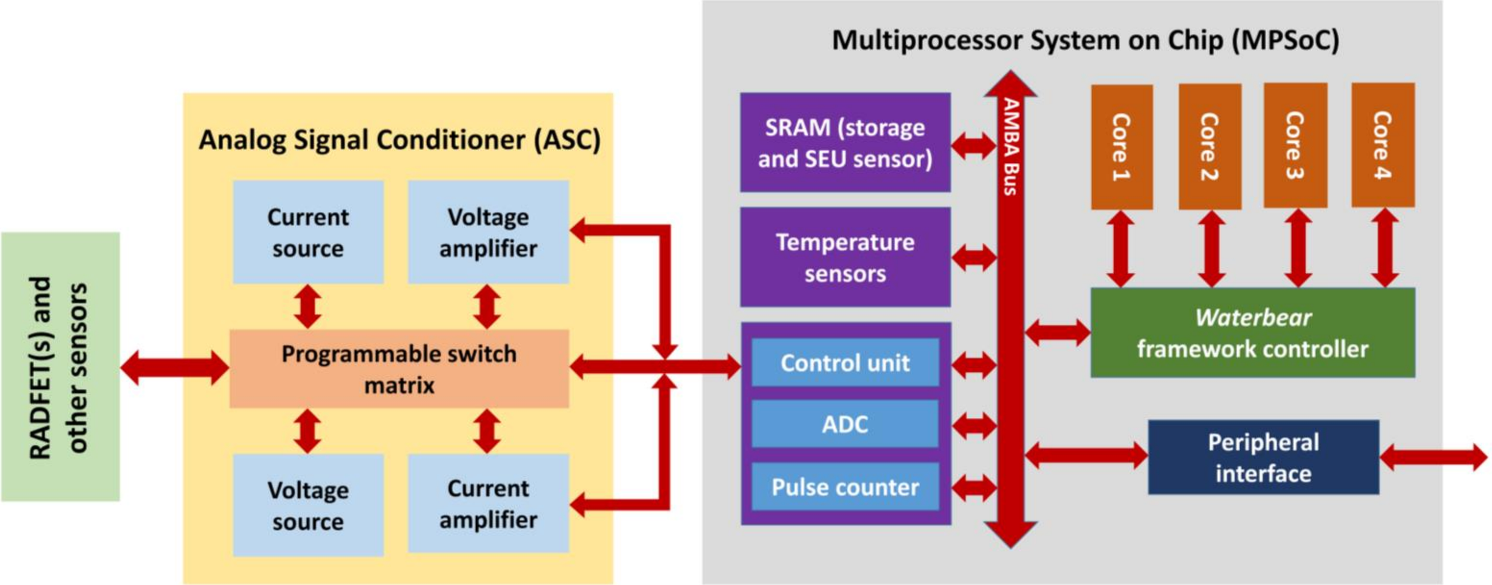
4. Rad-hard Readout System

Operating modes

- ***No readout*** – RADFET operates in passive mode
- ***Absorbed dose readout*** – voltage measurement
- ***Dose rate readout*** – current measurement

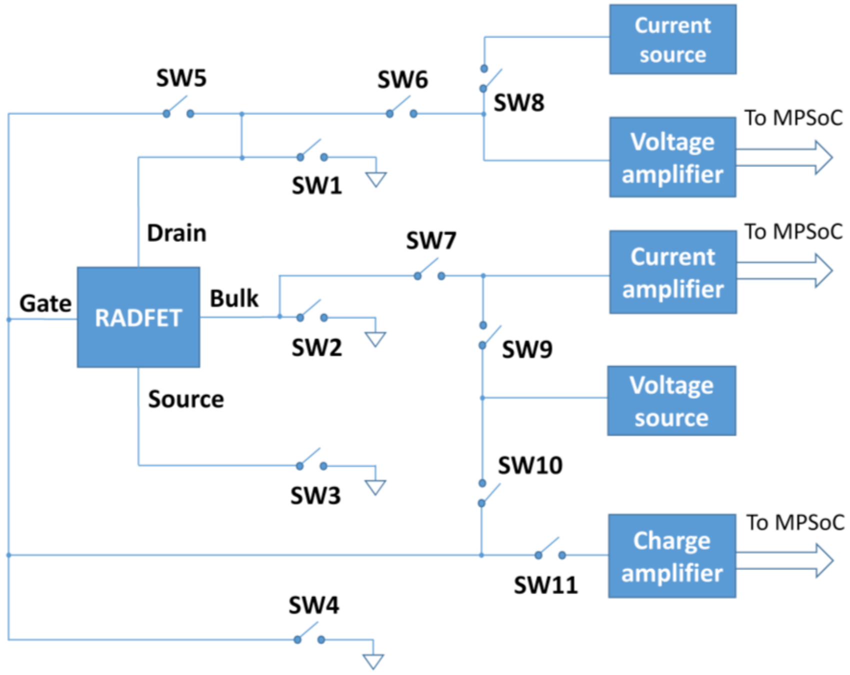
Universal architecture

(can be applied to other sensors)



5. Analog Signal Conditioner

- **Voltage and current measurement**
  - Standard voltage amplifier for threshold voltage measurement
  - Transimpedance amplifier for direct current measurement
  - Charge amplifier for pulsed current measurement
- **Switching between operating modes**
  - Controlled by MPSoC
- **Can be implemented with commercial radiation-tolerant components**



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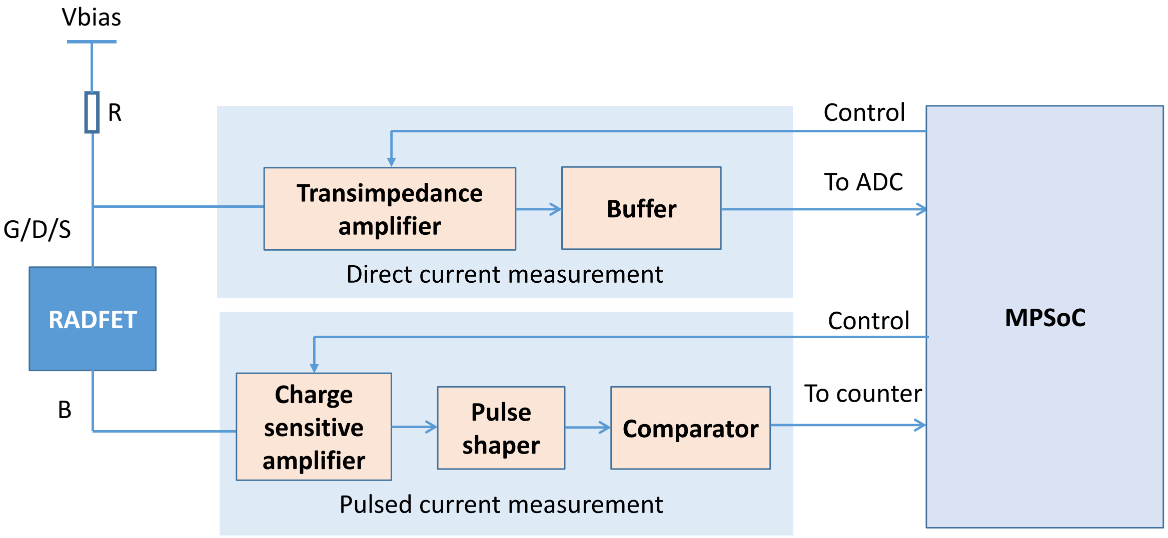
5. Analog Signal Conditioner

■ Direct and pulsed current measurement

- Open issues to be addressed:
  - *Possible interference between the two current readout modes*
  - *Possible overlapping of the direct and pulsed current ranges*

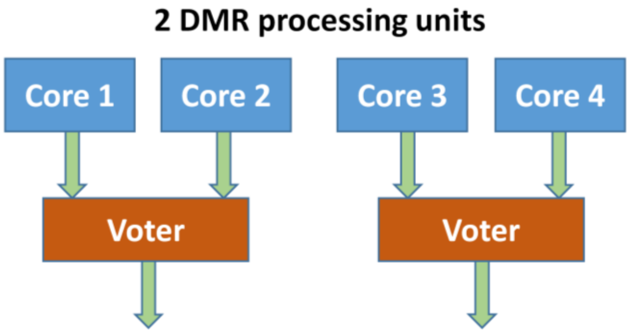


6. Multiprocessor System-on-Chip (MPSoC)

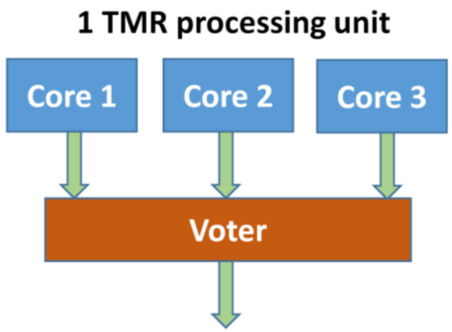
- **Main functions in readout system**
  - A/D conversion of DC voltage from ASC
  - Counting of voltage pulses from ASC
  - Control of switching matrix and amplifier gain in ASC
- **IHP's framework controller**
  - Dynamic selection of operating modes
  - Trade-off between performance, fault tolerance and power consumption
  - Flexible – can be applied to an arbitrary number of processing cores
- **Radiation hardness / fault tolerance**
  - IHP's 130 nm CMOS technology resistant to TID effect and Single Event Latchup (SEL)
  - Core-level fault tolerance enabled with embedded SRAM acting as a particle monitor

6. Multiprocessor System-on-Chip (MPSoC)

- **Self-adaptive quad-core processing platform**
  - Dynamic selection of operating modes
    - *De-stress mode* : some cores are switched off
    - *Fault tolerant mode*: cores are set into various fault-tolerant configurations
    - *High performance mode*: parallel processing



- **Core-level fault-tolerance**
  - Common configurations
    - *Supply voltage / frequency scaling*
    - *Dual Modular Redundancy (DMR)*
    - *Triple Modular Redundancy (TMR)*
  - **Use of existing on-chip resources for fault-tolerance**



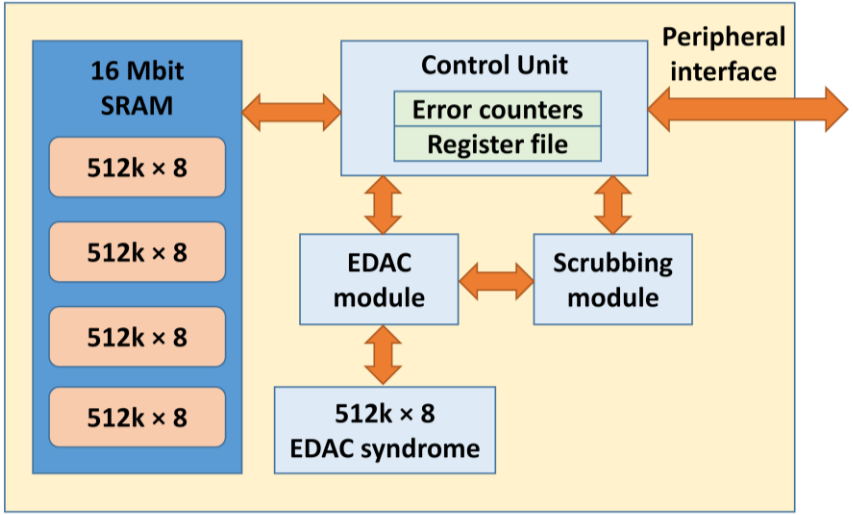
6. Multiprocessor System-on-Chip (MPSoC)

Embedded SRAM as Particle Detector

- On-chip data storage memory used also as a particle detector
- Provides information on the particle flux for triggering the fault-tolerant modes
- Flux is proportional to the number of bit errors in SRAM
- Error detection and correction (EDAC) and scrubbing logic used to detect and correct errors
- Counters store the information on the number of detected errors

Main advantage over standard SRAM-based particle monitors:

- **Negligible area and power overhead**



7. Conclusion

- **Possible further work**
  - Validation of simultaneous measurement of direct and pulsed current
  - Implementation of a complete rad-hard readout system with commercial components

Thank you for your attention!

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