


PS-BBICS: Pulse Stretching Bulk Built-in Current Sensor for On-Chip Measurement of Single Event Transients

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innovations
for high
performance
microelectronics

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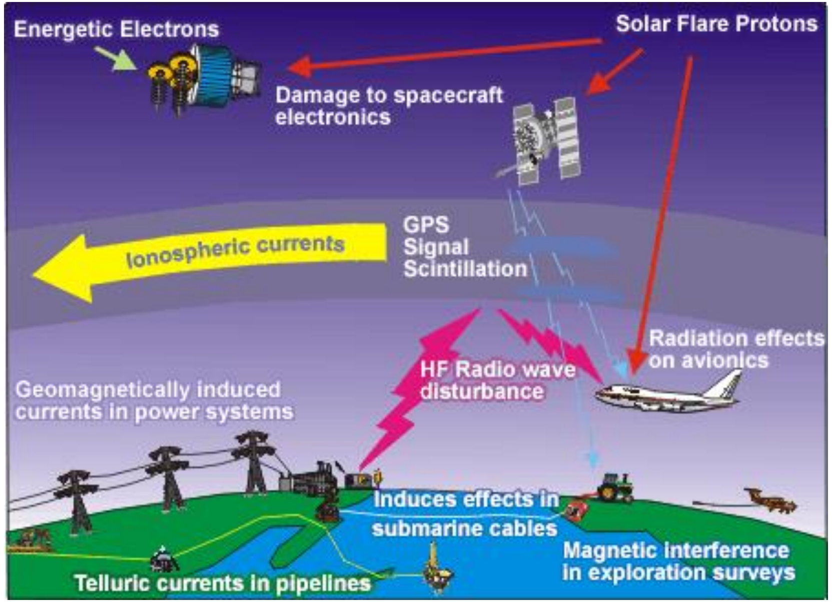
Outline

1. Background

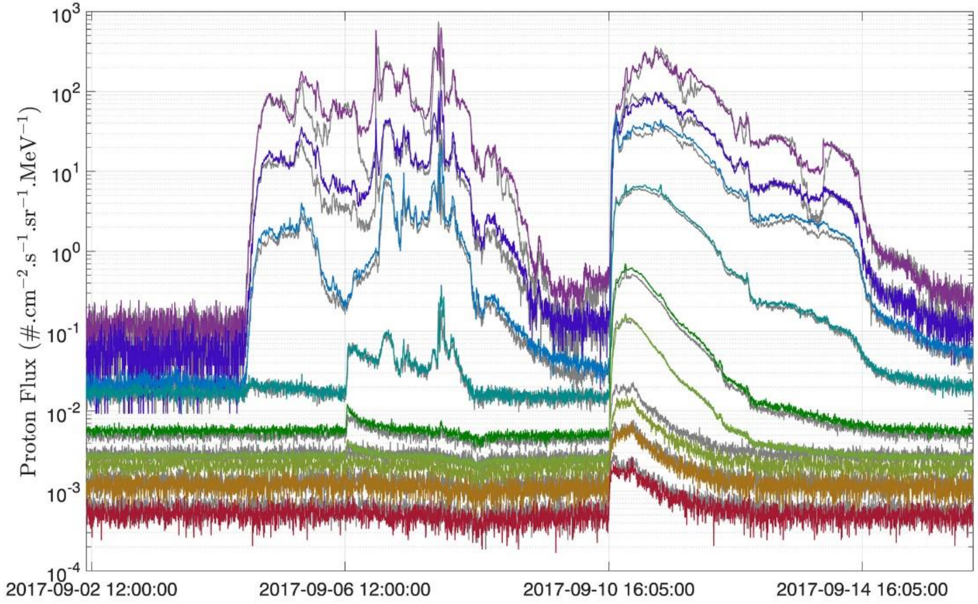
- **Ionizing radiation in space**
  - Different types and variable intensity
  - <u>May cause damage and failure in electronics</u>
- **Radiation sources**
  - Radiation trapped in Earth's magnetic field (Van Allen belts)
  - Galactic Cosmic Rays (GCRs)
    - *From deep space*
  - Solar Particle Events (SPEs)
    - *Solar flares and coronal mass ejections from the Sun*



[Source: NASA]

1. Background

- **Due to Solar Particle Events, the particle flux in space may increase by 2 – 6 orders of magnitude during a period of several hours or days**



Particles with lower Linear Energy Transfer (LET) have higher flux

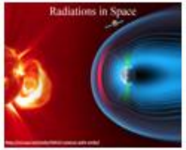
P. Jiggens et al., "In Situ Data and Effect Correlation During September 2017 SPE," Space Weather, 2018.

1. Background

Single Event Effects (SEEs)

- Major reliability threat for Integrated Circuits (ICs) used in space applications
- Caused by a single energetic particle (e.g. proton, neutron, heavy ion)
- *Soft SEEs*: temporary impact (data loss)
- *Hard SEEs*: permanent physical damage
- Soft SEEs are critical for nanoscale ICs:
  - **Single Event Transients (SETs)** – voltage glitches in combinational logic
  - **Single Event Upsets (SEUs)** – bit flips in memory and sequential logic

Radiation environment



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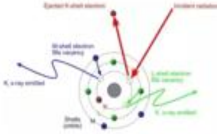
Particle-matter interaction



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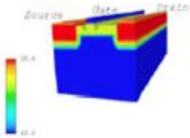
Charge collection and current pulse formation



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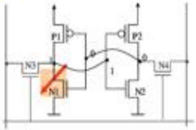
Soft or hard SEE on cell level



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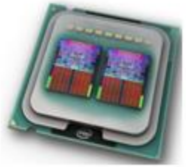
Erroneous response of the system



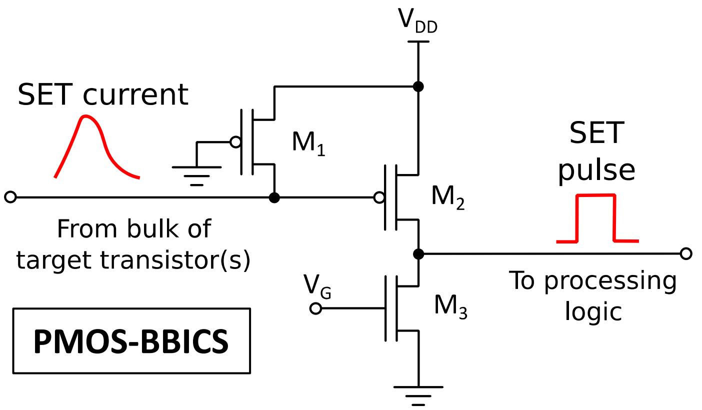
1. Background

- **Soft Error Rate (SER)**
  - Number of soft errors (due to SETs and SEUs) in a given time interval
  - Depends on particle flux and Linear Energy Transfer (LET)
- **Self-adaptive fault-tolerance for dynamic control of SER**
  - Activation of fault-tolerant mechanisms only under critical radiation levels
  - Trade-off between performance, power consumption and radiation hardness
  - Particle detectors are needed to monitor radiation intensity
- **Semiconductor particle detectors**
  - Diode-based detectors
  - SRAM-based detectors
  - Bulk built-in current detectors
  - Acoustic wave detectors
  - 3D NAND flash detectors
  - Pulse stretching detectors

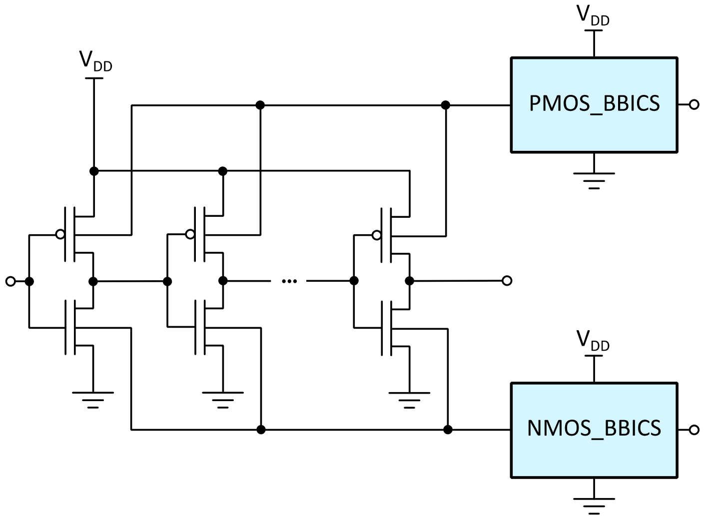
There is no a detector that can detect strike location and measure particle flux and LET with fully digital readout

2. Bulk Built-in Current Sensor (BBICS)

- Connected to transistors' bulk terminals
- Detection of particle-induced current pulse
- Current pulse is transformed into transient voltage pulse (alarm signal)
- Two BBICSs are needed (for PMOS and NMOS)



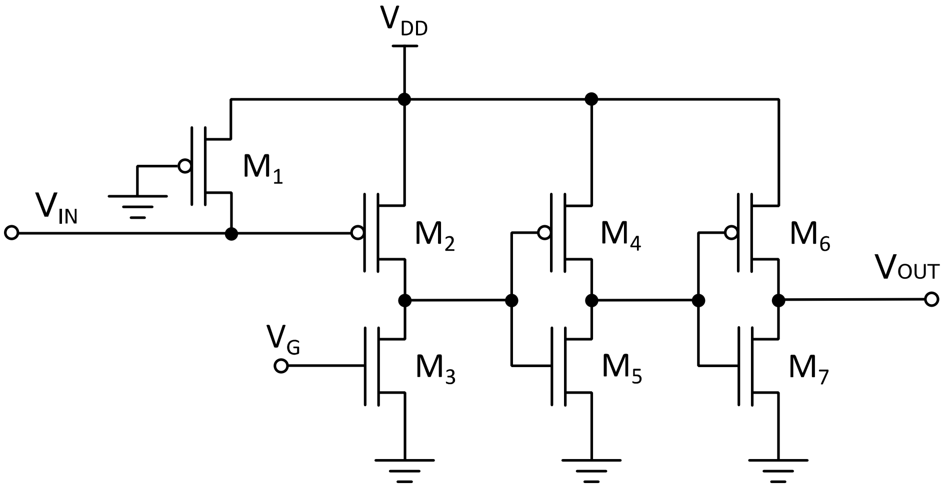
G. Wirth et al., Microelectronics Reliability, 2008



- **Detects location of particle strike**
- **Fully digital readout**
- **Sensitivity decreases with the number of transistors**
- **Cannot measure SET pulse width (particle LET)**

3. Proposed Pulse Stretching BBICS (PS-BBICS)

- Modification of standard BBICS by adding a two-inverter custom-sized pulse stretcher
- Pulse stretcher extends short SETs to facilitate their propagation through the processing logic



$$W_{M_4} = W_{M_7}$$
$$W_{M_5} = W_{M_6}$$
$$W_{M_5} > W_{M_4}$$
$$W_{M_6} > W_{M_7}$$

4. SET Response of PS-BBICS

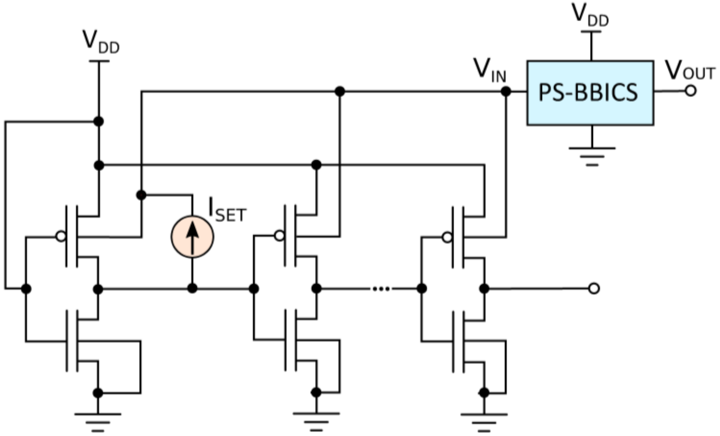
Simulation setup

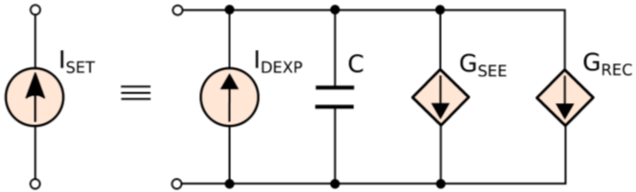
- Use of PS-BBICS to detect SETs in inverter chain
- SET is simulated in SPICE, using a bias-dependent current source
  - Double-exponential current source and two voltage-dependent current sources

$$I_{DEXP}(t) = \frac{Q}{\tau_{fall}-\tau_{rise}}\left(e^{\frac{-t}{\tau_{fall}}} - e^{\frac{-t}{\tau_{rise}}}\right)$$

$$Q = 1.035 \times 10^{-2} \times l \times LET$$

- Analysis of SET pulse width dependence on the number of monitored inverters, supply voltage, temperature and process corners





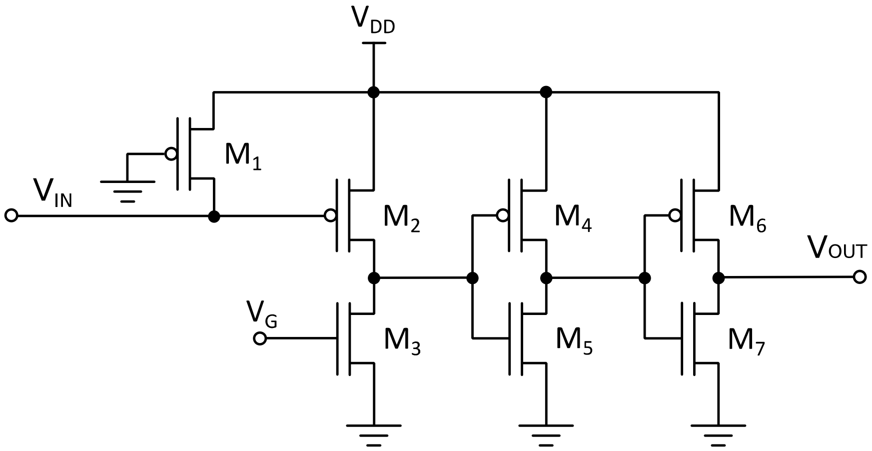
J. S. Kaupilla et al., IEEE TNS, 2009.

4. SET Response of PS-BBICS

Transistor sizing

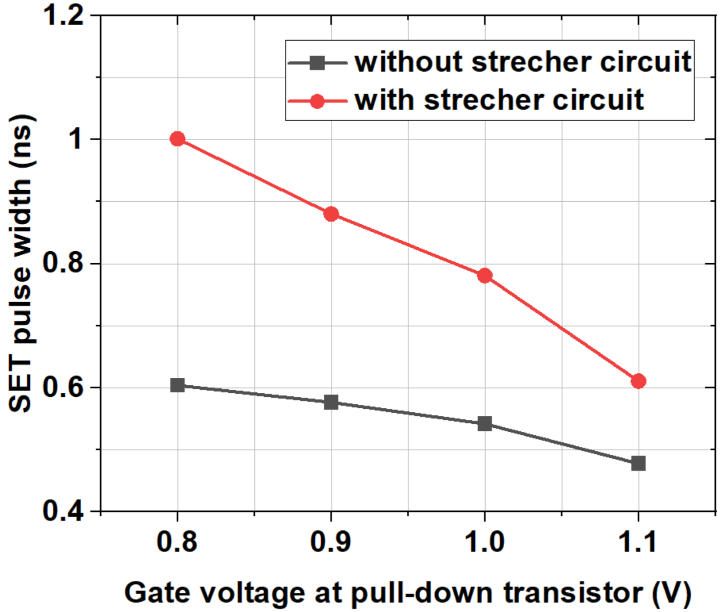
- Primary requirement for a particle detector is to have as low threshold LET as possible
- LET_{TH} = 1 $MeVcm^2mg^{-1}$ is chosen as optimal value, as most particles in space have greater LET

LET_{TH} ($MeVcm^2mg^{-1}$)	W/L (µm/µm)		
	M1, M2	M3, M4, M7	M5, M6
0.7	0.6/0.13	0.15/0.13	0.35/0.13
0.8	0.9/0.13		1.5/0.13
0.9	1/0.13		2.75/0.13
1.0	1.2/0.13		4/0.13
2.0	3.25/0.13		12.5/0.13

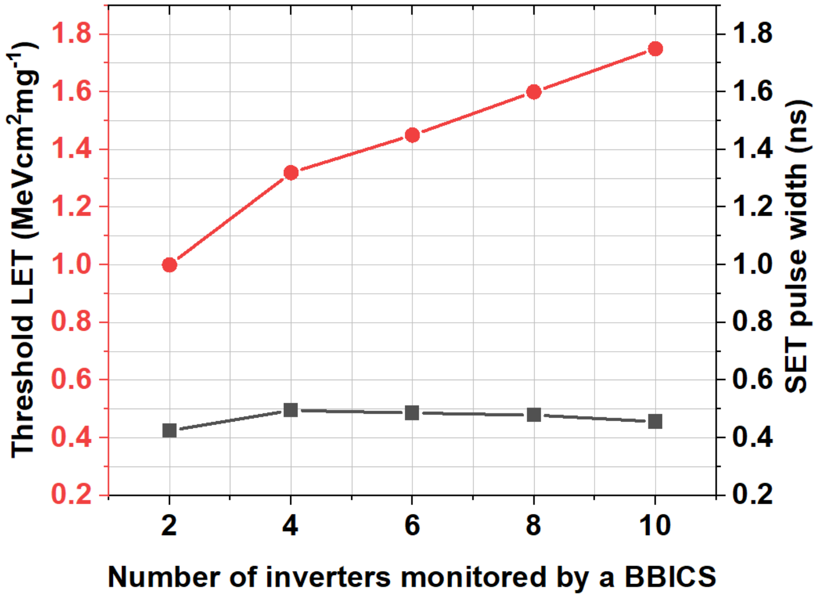


4. SET Response of PS-BBICS

SET pulse width as a function of gate voltage at pull-down transistor M3, for LET = 60 $MeVcm^2mg^{-1}$



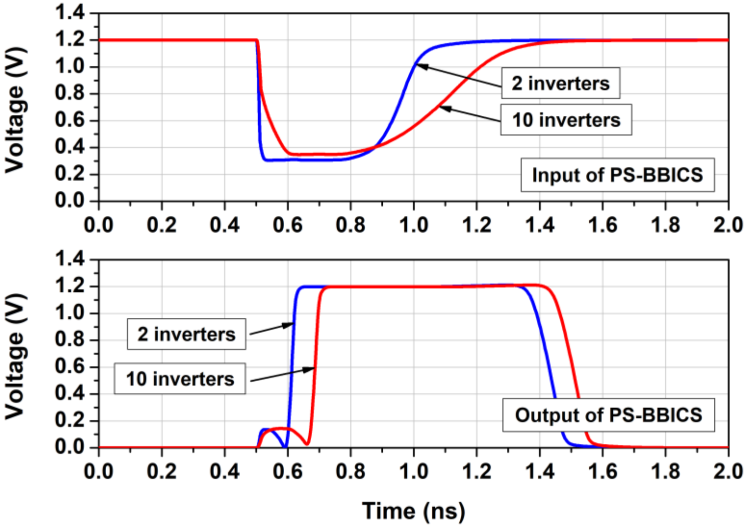
Threshold LET and corresponding SET pulse width as a function of number of monitored inverters

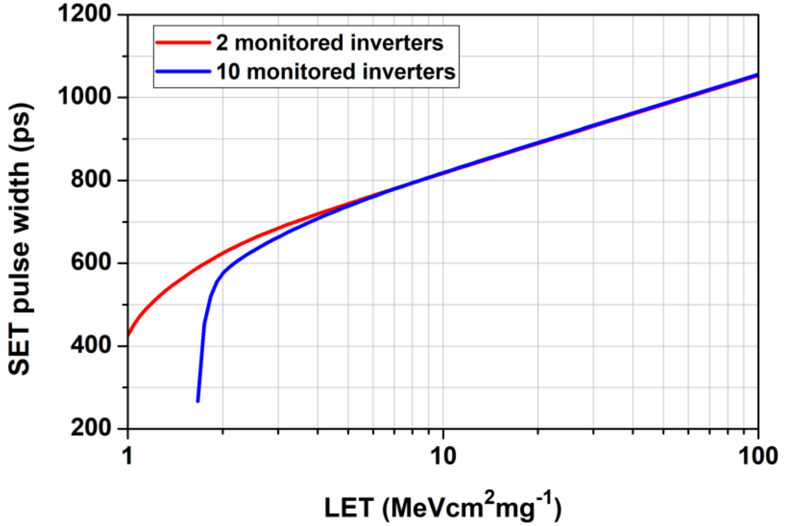


4. SET Response of PS-BBICS

SET pulse width as a function of LET, for 2 and 10 load inverters

- For LET > 4 MeVcm^{2}mg^{-1}, the SET pulse width is independent of the number of monitored inverters

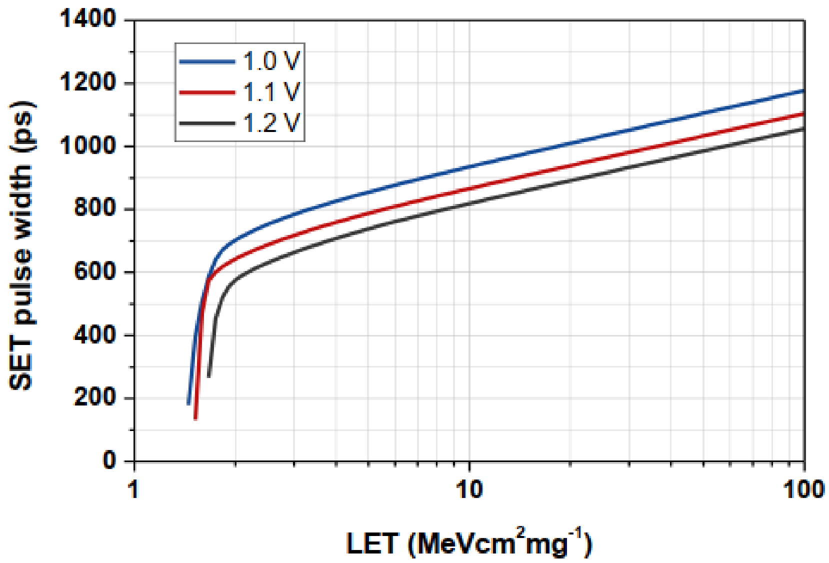




4. SET Response of PS-BBICS

SET pulse width as a function of LET and supply voltage

- SET pulse width increases when supply voltage decreases

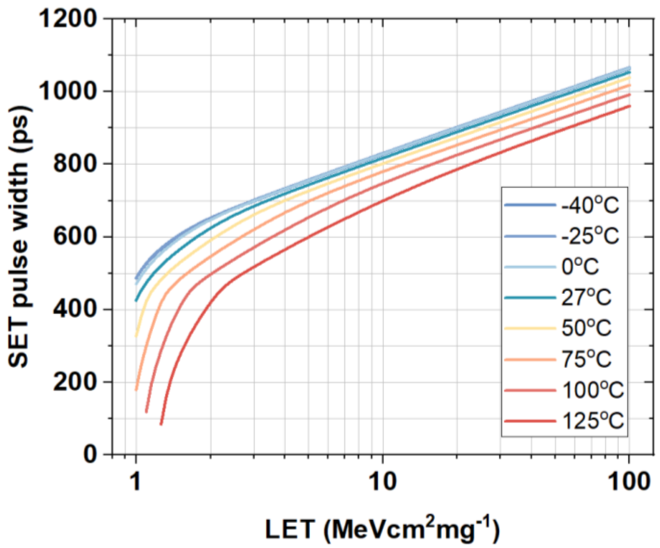


for 10 load inverters

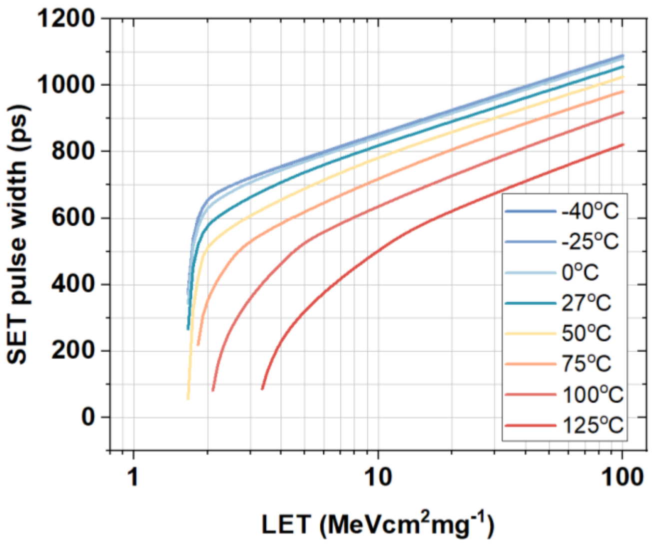
4. SET Response of PS-BBICS

SET pulse width as a function of LET and temperature

- SET pulse width increases when temperature decreases



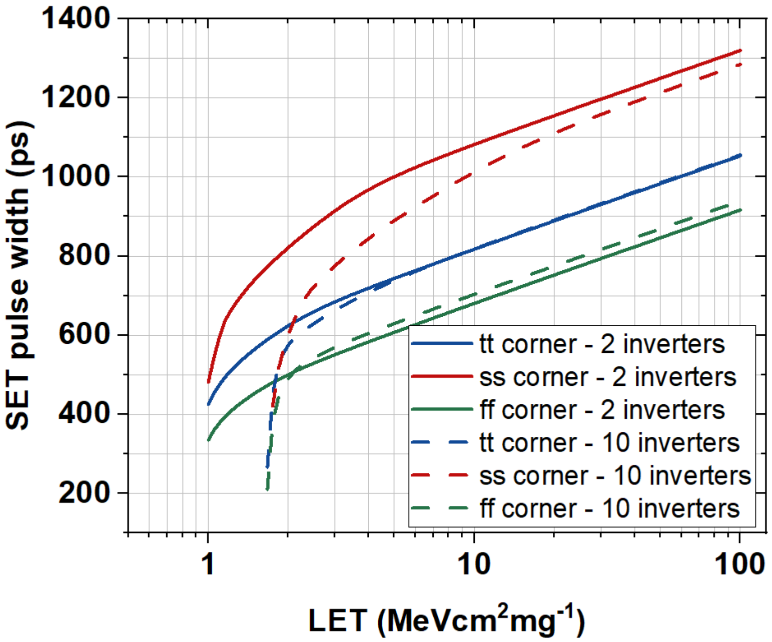
for 2 load inverters



for 10 load inverters

4. SET Response of PS-BBICS

SET pulse width as a function of LET, for three process corners (2 and 10 monitored inverters)



5. Comparison with Alternative Particle Detectors

Type of detector	Readout method	Hardware overhead	Strike location detection	LET Detection	Tested under radiation
PS-BBICS	Digital	Low	Yes	Yes	No
BBICS	Digital	Low	Yes	No	Yes
Acoustic wave detector	Mixed-mode	Medium/high	Yes	No	No
Diode detector	Mixed-mode	Medium/high	No	Yes	Yes
SRAM detector	Digital	Medium/high	No	No	Yes
3D NAND flash	Mixed-mode	Medium/high	No	Yes	Yes
Pulse streching inverter chains	Digital	Low	No	Yes	No

6. Summary

- PS-BBICS: modified BBICS supporting SET pulse width measurement
- Minimum LET that can be detected is 1 $MeVcm^2mg^{-1}$
- LET_{TH} increases with increasing number of monitored gates
- For higher LET values, SET pulse width is independent of the number of monitored gates
- Supply voltage, temperature and process variations influence the SET pulse width
- Future work:
  - To increase the sensitivity of PS-BBICS
  - On-chip implementation of sensor
  - Heavy ion testing

Thank you for your attention!

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