



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

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innovations
for high
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microelectronics

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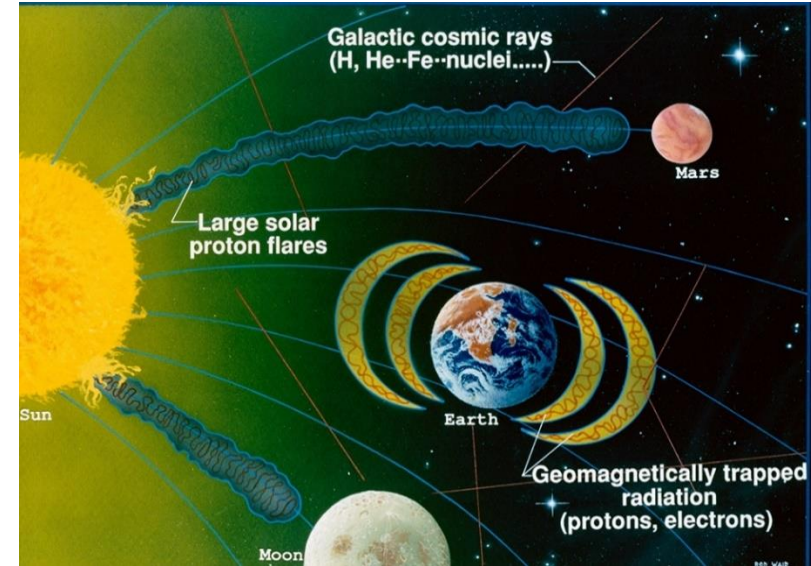
1. Background

■ Space ionizing radiation

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

■ Radiation sources in space

- 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*

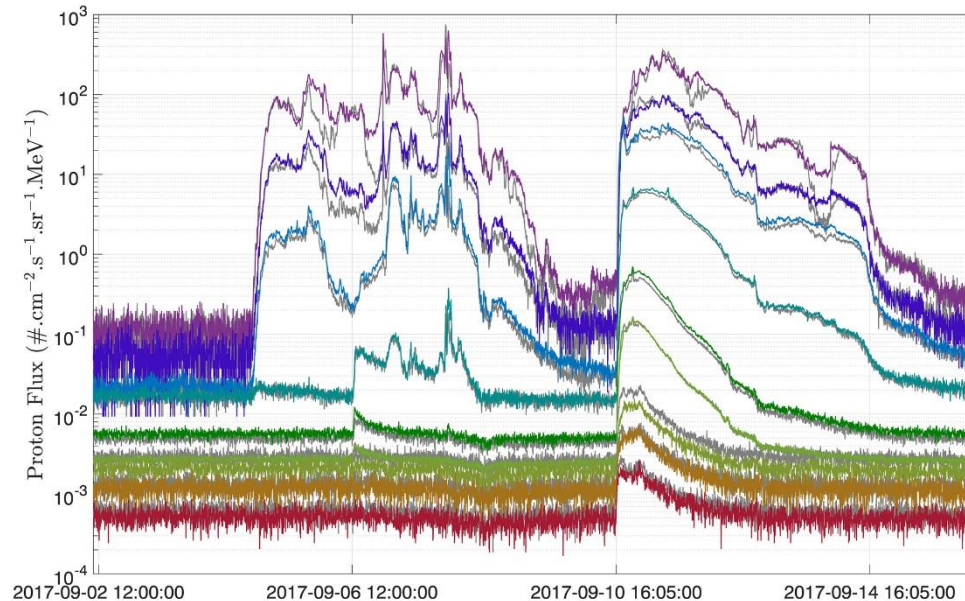


[Illustration from <https://www.nasa.gov>]

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**

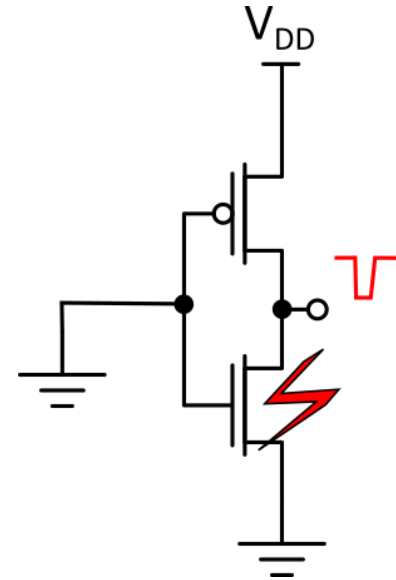
P. Jiggins et al., "In Situ Data and Effect Correlation During September 2017 SPE," Space Weather, 2018.

1. Background



■ Single Event Transient (SET)

- One of the most common radiation-induced effect
- Occur when a single high-energy particle interacts with a radiation-sensitive component in a target circuit
- Induced in combinational circuit (off-state transistors)
- Manifests as a current pulse flowing through the affected component: SET voltage pulse formed, propagate through circuit, result in data corruption and malfunction of the circuit or entire system



1. Background



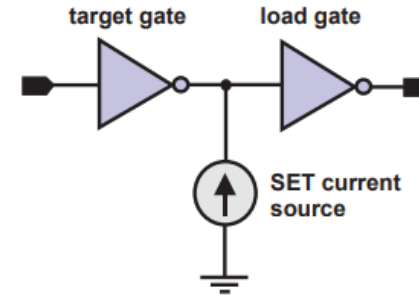
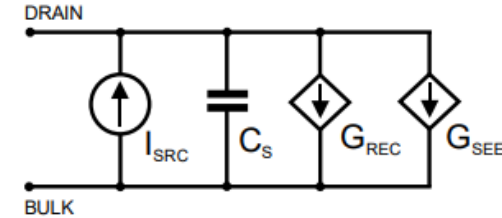
■ Single Event Transient (SET)

- The shape of the SET pulse depends on radiation conditions, design parameters and operating parameters
- A particle-induced voltage pulse is considered as an SET pulse if its amplitude exceeds $V_{DD}/2$
- A minimum particle-induced charge which can cause an SET is known as the critical charge
- The deposited energy is expressed in terms of **Linear Energy Transfer (LET)**, i.e. the energy lost by a particle as it passes through the material
- The minimum LET required to cause an SET is known as the **threshold LET** (LET_{th}), and it is linearly proportional to critical charge

1. Background

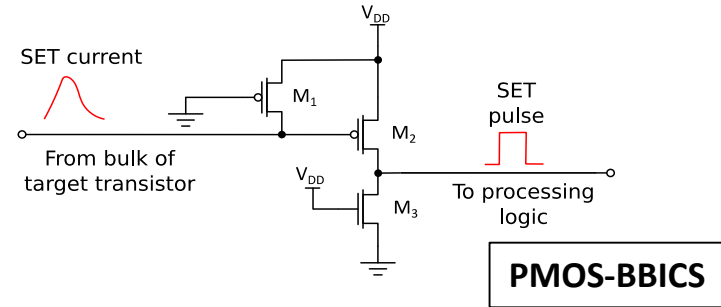
■ Single Event Transient (SET) model

- SET model by Kaupila: one of the most advanced compact SET current models, providing a realistic shape of the current pulse as a function of LET
- The model is composed of a bias-independent double-exponential current source, two voltage-controlled current source, and a capacitor that stores particle-induced charge
- The model is defined by three parameters which can be varied in simulations: LET, rise time of current pulse, and fall time of current pulse



2. Bulk Built-in Current Sensor (BBICS)

- Connected to transistors' bulk terminal
- Detection of particle-induced current pulse
- Detected current pulse is transformed into transient voltage pulse (alarm signal)



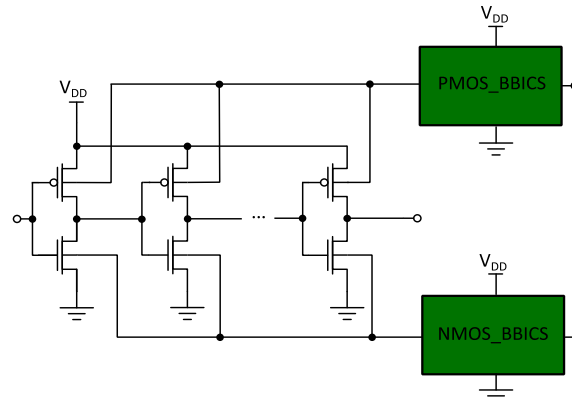
G. Wirth et al., Microelectronics Reliability, 2008

Strengths:

- ❖ Fully digital processing
- ❖ Detection of strike location

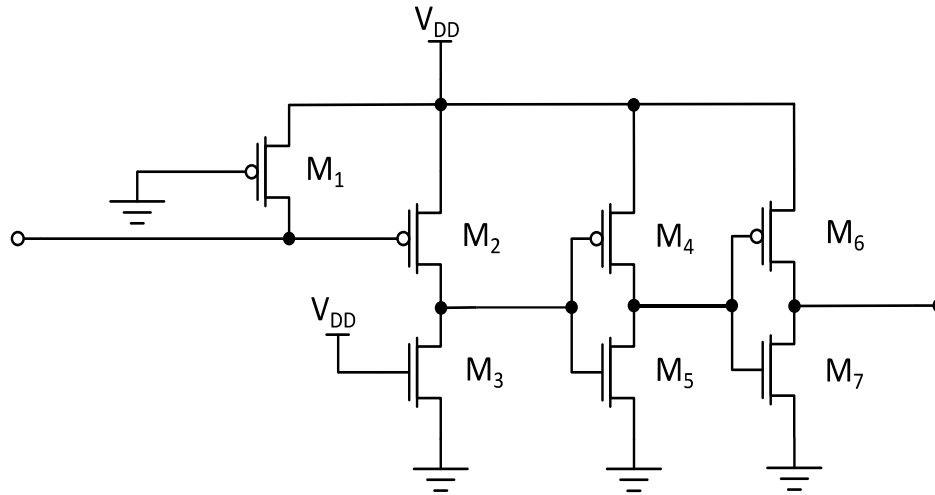
Weaknesses:

- ❖ Sensitivity depends on the detector design
- ❖ Cannot detect particle LET



Two BBICS are required for each circuit, for PMOS bulk and NMOS bulk

3. Proposed Pulse Stretching BBICS (PS-BBICS)



$$\begin{aligned} W_{M_4} &= W_{M_7} \\ W_{M_5} &= W_{M_6} \\ W_{M_5} &> W_{M_4} \\ W_{M_6} &> W_{M_7} \end{aligned}$$

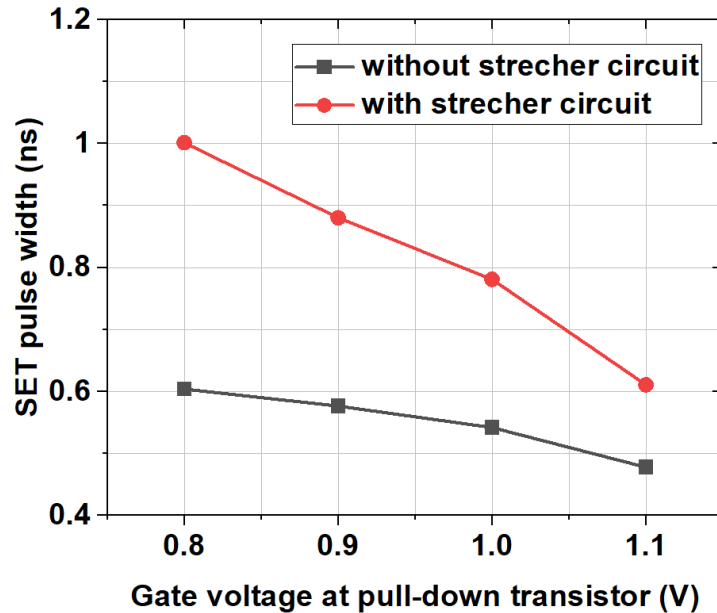
- ❖ Modified the standard BBICS design by adding a custom-sized pulse stretcher
- ❖ To extend short SET pulse and thus facilitate their propagation through the sub-sequent processing logic

4. SET Response of PS-BBICS

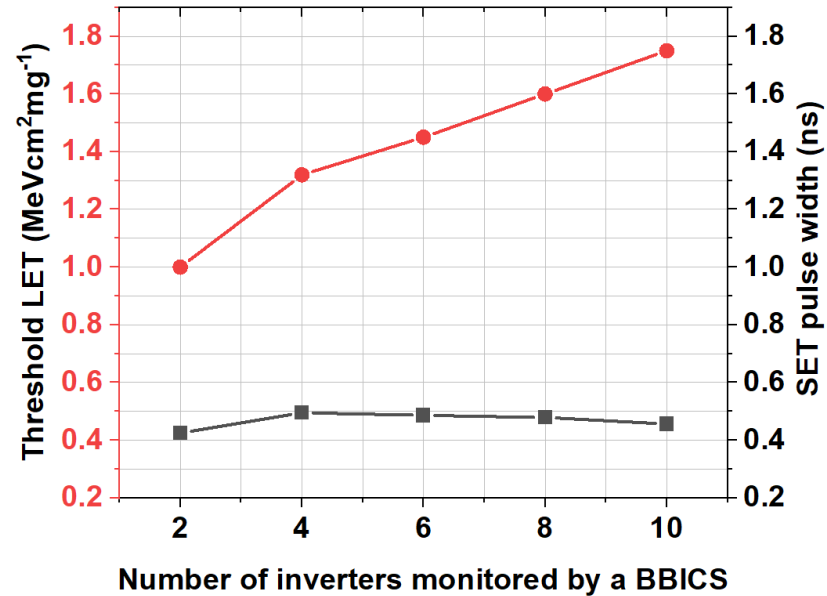
LET _{TH} (MeVcm ² mg ⁻¹)	W/L (μm/μm)		
	M1, M2	M3, M4, M7	M5, M6
0.7	0.6/0.13	0.15/0.13	0.35/0.13
0.8	0.9/0.13		1.5/0.13
0.9	1/0.13		2.75/0.13
1.0	1.2/0.13		4/0.13
2.0	3.25/0.13		12.5/0.13

The primary requirement for a particle detector is to have as low threshold LET as possible

4. SET Response of PS-BBICS

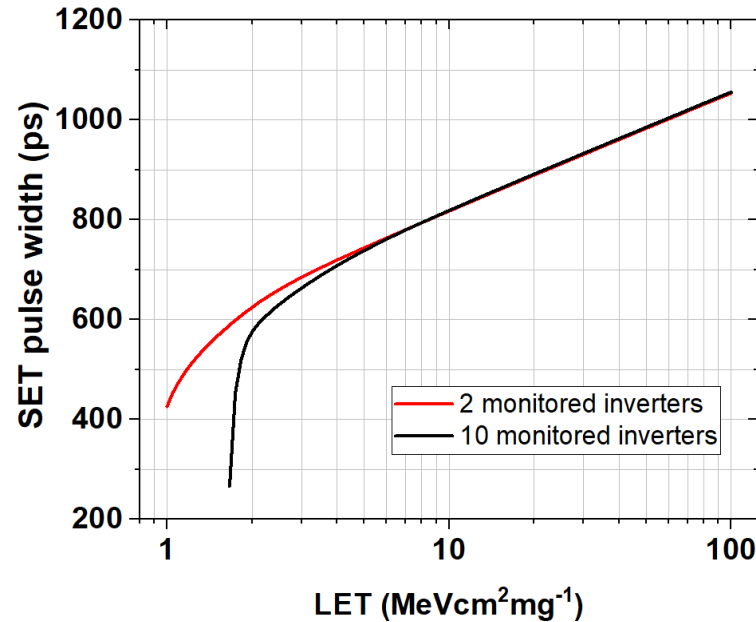


SET pulse width as a function of gate voltage at pull-down transistor M3, for $LET = 60 \text{ MeVcm}^2\text{mg}^{-1}$, with and without pulse stretcher



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

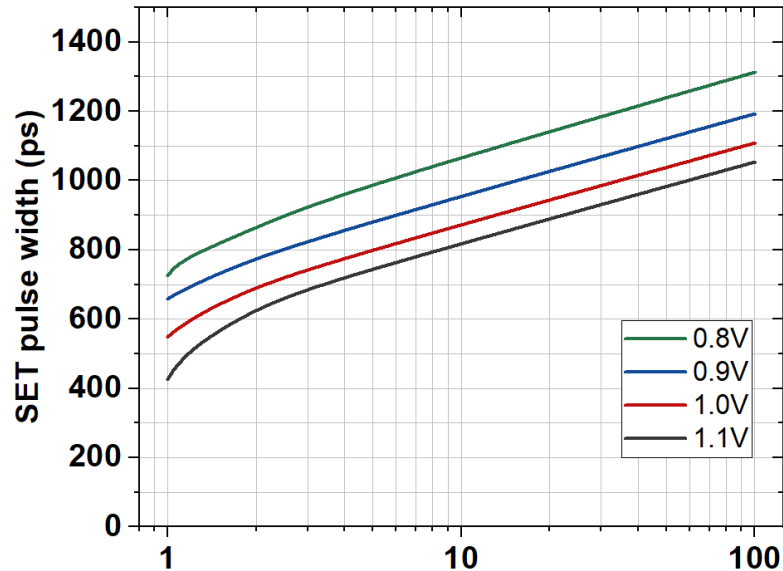
4. SET Response of PS-BBICS



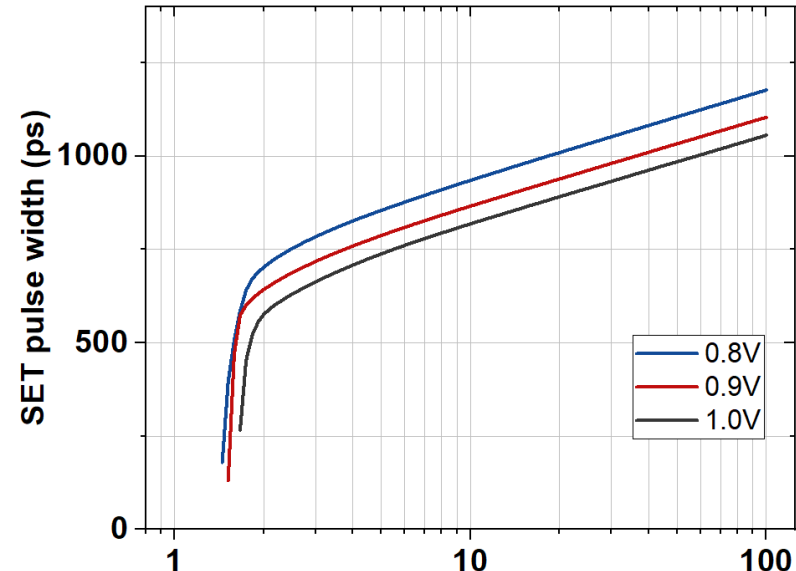
SET pulse width as a function of LET, for 2 and 10 load inverters

4. SET Response of PS-BBICS

SET pulse width as a function of LET and supply voltage



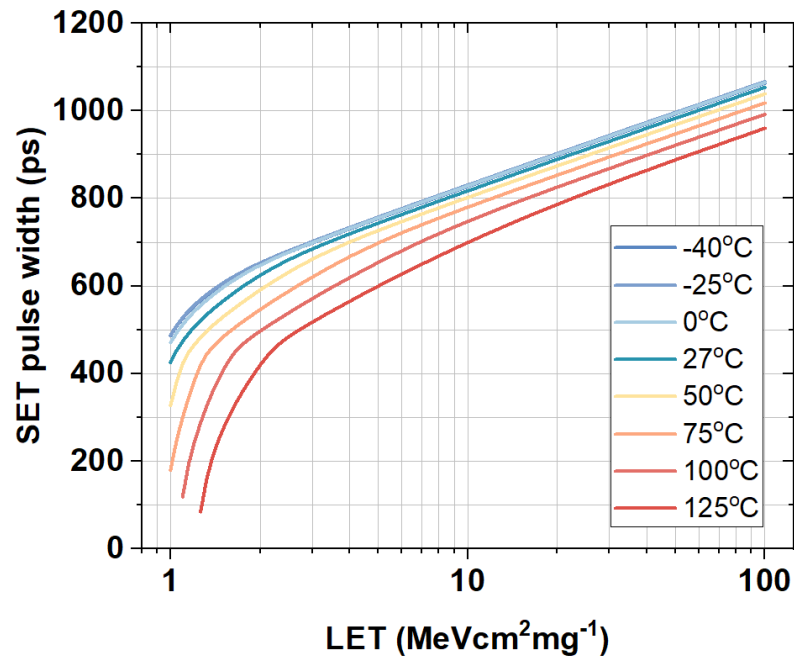
for 2 load inverters



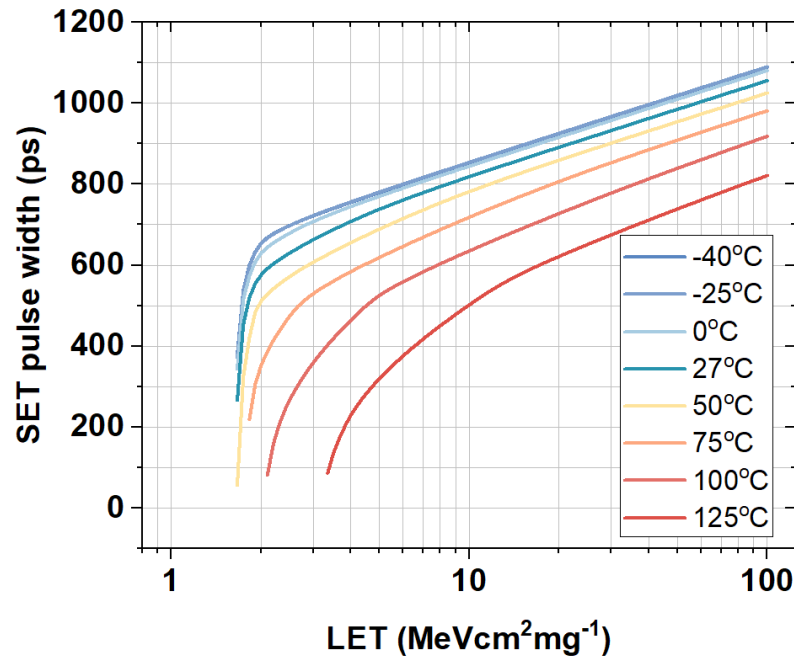
for 10 load inverters

4. SET Response of PS-BBICS

SET pulse width as a function of LET and temperature

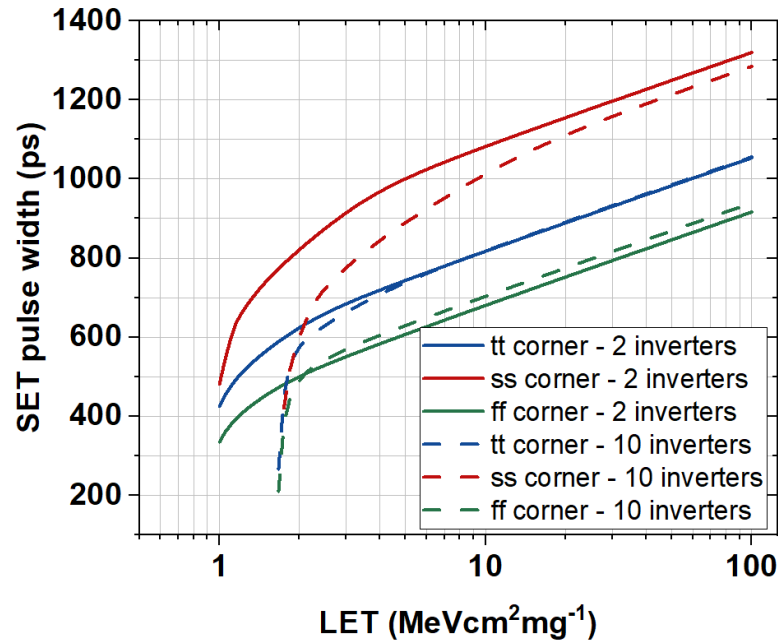


for 2 load inverters



for 10 load inverters

4. SET Response of PS-BBICS



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

5. Summary



- PS-BBICS: sensor that can measure LET
- The minimum LET that can be detected is $1 \text{ MeVcm}^2\text{mg}^{-1}$.
- LET_{TH} increases with increasing load
- For higher LET values, the SET pulse width will be the same regardless of the load
- As the supply voltage increases, the SET pulse width decreases, while the LET_{th} increases
- The increase in temperature leads to a decrease in the sensitivity of PS-BBICS
- The SET pulse width may vary by more than 300 ps due to process corners



Thank you for your attention!

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