SpaceCAM: A 16nm FinFET low-power soft-error tolerant TCAM design for space communication applications

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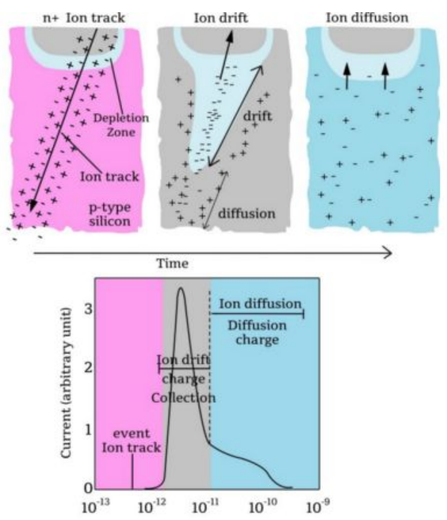
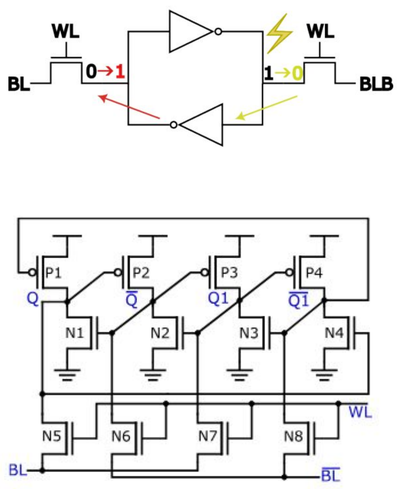
Introduction

- Energetic particles that are naturally abundant in space and terrestrial environments , pose a significant challenge to electronics, particularly memory systems.
- SpaceCAM introduces a 16nm FinFET-based content addressable memory (CAM) optimized for low-power operations, targeting applications in space communication systems.
- SpaceCAM operates efficiently at ultra-low supply voltages (as low as 350mV), consuming only 2mW at 500MHz, making it ideal for energy-constrained space applications.
- The design leverages radiation hardening and approximate matching techniques to tolerate up to 5 soft errors per row, ensuring reliable performance in the harsh radiation environment of space.

Radiation effect on memory

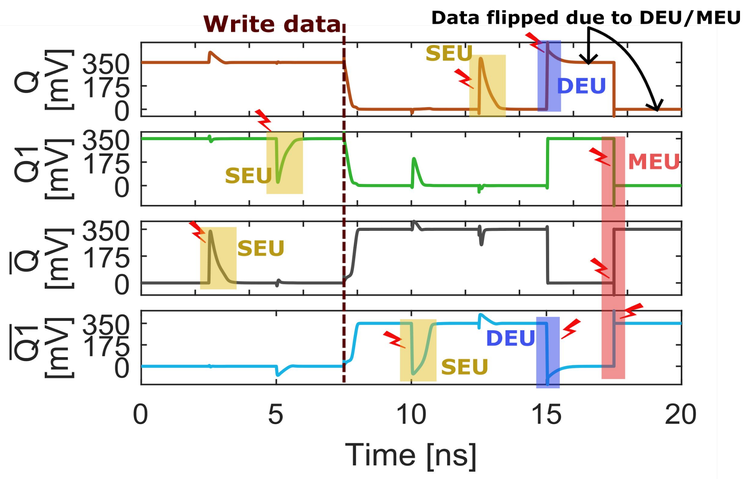
Charged particles can create electron-hole pairs in silicon, leading to a sudden spike in current and voltage, potentially causing data corruption in memory cells and transient faults in digital logic circuits

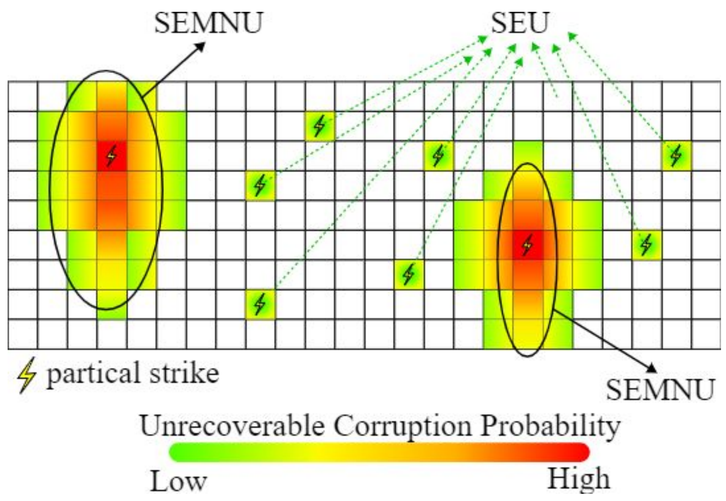




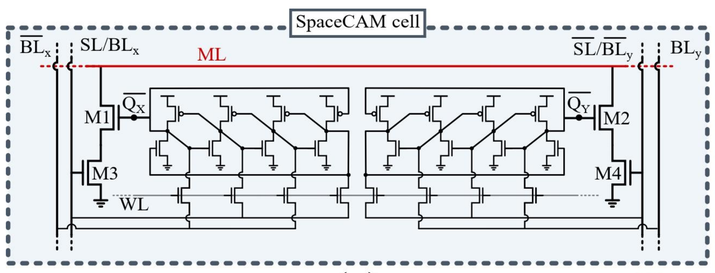
Radiation Hardening by Design

- The design aims to minimize the effects of particle strikes on memory through radiation hardening techniques, although the memory remains vulnerable to some degree of radiation exposure even after these measures are applied.
- The heatmap-like grid shows the unrecoverable corruption probability in relation to the location of the particle strike.





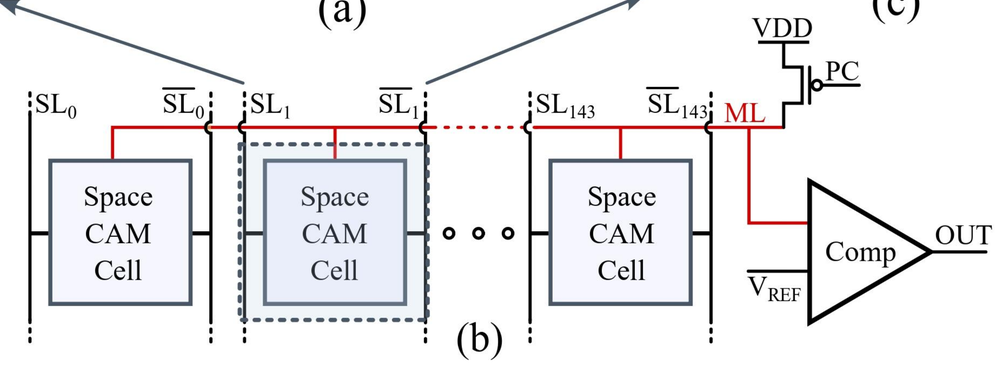
SpaceCAM Row



SpaceCAM coding

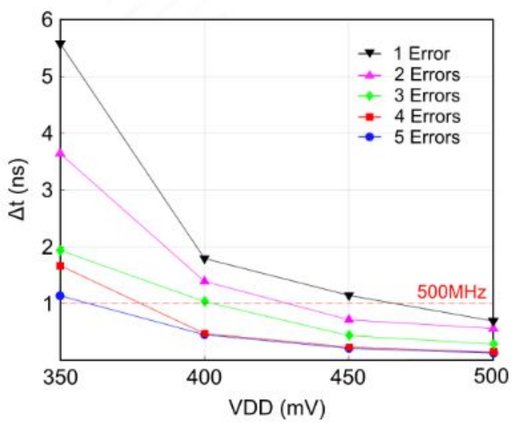
Q_X	Q_Y	Stored Value	Search SL	Search $\overline{SL}$
0	0	Illegal	0	0
0	1	0	0	1
1	0	1	1	0
1	1	X*	0	0

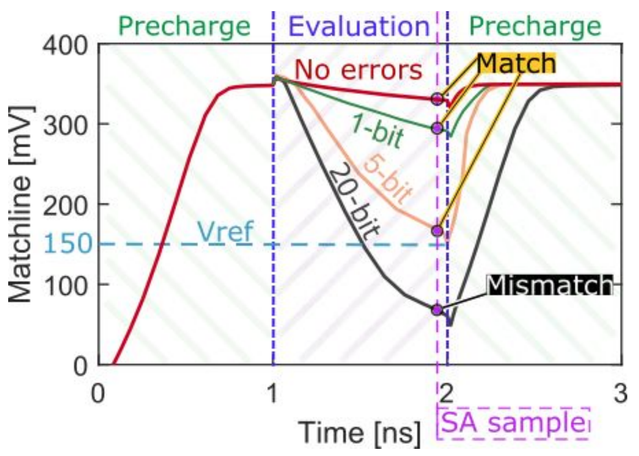
*X=don't care (c)



SpaceCAM Operation

- The Matchline (ML) is fed into a comparator that assesses its voltage level against a reference voltage, Vref. If the Matchline voltage is above the Vref at the sampling time, a match is signaled; otherwise, the comparator signals a mismatch.
- The match line voltage varies based on the number of errors in the stored data



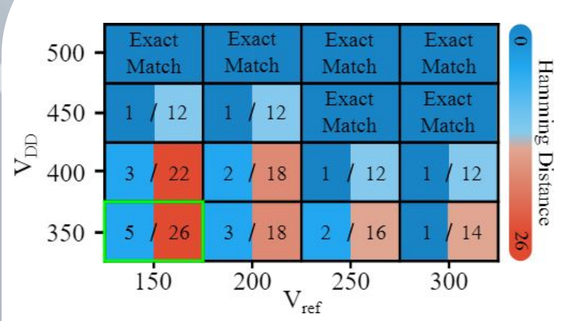


Core Mechanism

- Approximate matching in SpaceCAM is achieved by the combination of two techniques:

1. SpaceCAM implements a comparator which replaces the matchline sense amplifier.
2. Supply voltage scaling. While its primary goal is energy consumption reduction, we employ voltage scaling to control the matchline discharge pace. Specifically, reducing the supply voltage has twofold effect: not only it scales down the power consumption, it also reduces the speed of matchline discharge. This novel technique allows flexible match/mismatch decision extending beyond the capabilities of the matchline comparator.

Results



Technology	16 nm FinFET
Supply voltage (scaled)	350 mV
Operating frequency	500 MHz
Number of transistors per cell	28
SpaceCAM word size	144 bits
SpaceCAM array number of rows	512
Search time	2 ns
Worst case energy/search/bit	41 aJ