ACCEDE | ESCCON 2025
Seville - Spain
25 to 27th March

ALTER | esa

ZES
ZERO-ERROR SYSTEMS

ZES Unprecedented Solutions toward SEL and µSEL

Wei Shu, CTO
25 Mar, 2025

Agenda

- ❑ About ZES (Zero-Error Systems)
- ❑ Technology Evolution for Power Reliability
  - ❖ LCL (Latching Current Limiter)
  - ❖ LDAP (Latchup Detection And Protection)
  - ❖ AI-SLDAP (Artificial Intelligence System Latchup Detection And Protection)

ZES at-a-Glance

ZES
ZERO-ERROR SYSTEMS

OUR COMPANY

Founded in **2019**

2 Locations
USA
SG(HQ)

28 patents

7 Strategic Business Partners

OUR R&D

38% Ph.D
23% Master's
>60% Engineers overall

OUR SOLUTIONS

Semiconductors
LDAP
DC-DC
PoL
Voter

IP Design Services
RHBD Library Cells

Laser Test

System Solutions

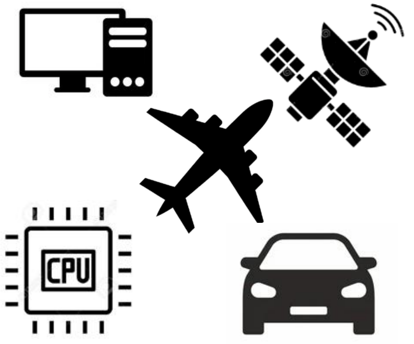
OUR FOCUS

Space
5G/6G, IoT
Automotive

Our Original Innovation: Hardware Reliability and Data Integrity

ZES
ZERO-ERROR SYSTEMS

Radiation in space



Radiation can impact electronics everywhere

Radiation on earth

Impacts

Hardware Damage

Radiation results in COTS'
- *Reduced lifetime*
- *Non-functionality*

SEL
Single Event Latch-Up

Two types of impacts from radiation

Soft Error

Radiation results in COTS 'bit flipping'

SEU
Single Event Upset

Consequences

Loss of Space Assets
Satellites and satellite payloads will stop working or suffer reduced lifetime

Car Safety
The safety of cars and autonomous vehicles is compromised

Service Interruption
Critical applications for communication or earth observation will have reduced quality of service

Incorrect Computing
Corrupted data for decision making

Space – Value Proposition

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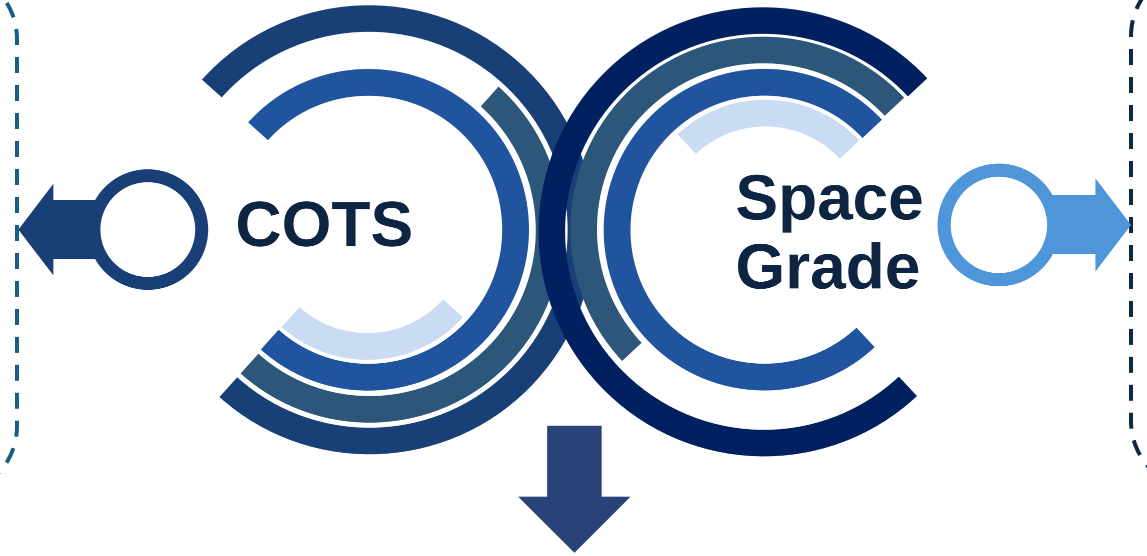
Market Trends Suggest a need for Convergence of COTS and 'Space-Grade'

COTS Merits
- High Functionality
- Low-Cost
- Readily available
- Rapid system development

Shortcomings
- Susceptible to radiation effects



Space-Grade Merits
- Not susceptible to radiation effects

Shortcomings
- Low Functionality
- Prohibitively expensive (e.g., QML)
- Not readily available

Acronyms
COTS: Commercial off-the-shelf
SEL: Single Event Latch-Up
SEU: Single Event Upset

ZES Solutions Converges COTS IC's/SOC's to 'Space-Grade'

Merits
- **Power Reliability and Data Integrity by protecting COTS from SEL and SEU**
- **Longer product lifetime than COTS**
- **Lower system cost than that of Space-Grade**

Enabling COTS in Space: ZES Components Use Case

ZES
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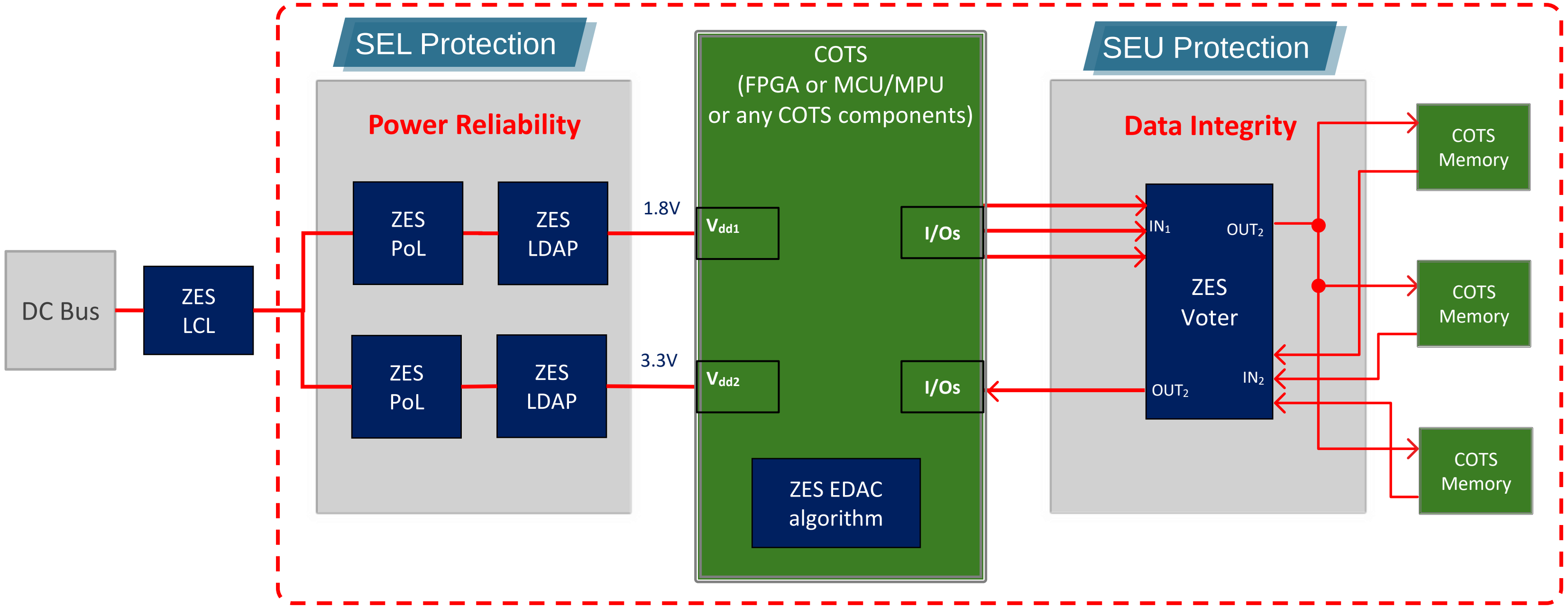
Architecture of OBC/Payload/Subsystem protected by ZES



Radiation Qual:
LET = 110MeV·cm²/mg
TID = 100krad

Latching Current Limiter

ZES LCL

- Over Current Protection
- 15V, 28V and 60V
- Space Enhanced Plastic Packaging

Point of Load

ZES PoL

- Saving Energy at Low Power
- Redundancy Ideal for Reliability in Space
- Small Form Factor

Latchup Detection & Protection

ZES LDAP

- Unique Identification of SEL Transient
- Fast to React (~0.1µs)
- Ease of Use & fast implementation

Voter

ZES Voter

- Protect Memories from Data Corruption
- High Speed Memory Support
- Enabling Multi-Bits Error Correction
- EDAC algorithm

Power Reliability: Technology Evolution

ZES
ZERO-ERROR SYSTEMS

- Application
  - Satellite/payload bus
- Feature
  - Over-current protection
- Limitation
  - SEL/µSEL unprotected

Gen-1

LCL

Latching Current Limiter

- Application
  - Component powerlines
- Feature
  - Over-current and SEL/µSEL detection & protection
- Limitation
  - Hardware overheads

Gen-2

LDAP

Latchup Detection And Protection

- Application
  - Payload bus
- Feature
  - AI-Protection for all current anomalies including over-current, SEL/µSEL, etc.
  - Plug-and-play

Next Gen

AI-SLDAP

Artificial Intelligence System Latchup Detection And Protection

Power Reliability: Technology Evolution

ZES
ZERO-ERROR SYSTEMS

- Application
  - Satellite/payload bus
- Feature
  - Over-current protection

Gen-1

LCL

Latching Current Limiter

- Application
  - Component powerlines
- Benefit
  - Over-current and SEL/µSEL protection

Gen-2

LDAP

Latchup Detection And Correction

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Next Gen

AI-SLDAP

Artificial Intelligent System Latchup Detection And Protection

Radiation Hardened Latching Current Limiter (LCL)

Industry's 1st Radiation Hardened Plastic-Packaged LCL with built-in MOSFET

Over-current protection for major satellite powerlines

ZES7xx Series (18V/28V/60V)

- Key Features
  - ECSS-E-ST-20-20C standards compliant
  - Space Enhanced Plastic (SEP) QFN-package
  - Latched or Re-triggerable
  - Integrated MOSFET switch
- TID: >100Krad(Si) & SEE: >99Mev·cm^2/mg
- >50% Cost-Savings vs traditional space-grade
- >50% smaller form factor

** ECSS-E-ST-20-20C standards compliant in QFN-package*

Power Reliability: Technology Evolution

- Application
  - Satellite/payload bus
- Feature
  - Over-current protection
- **Limitation**
  - **SEL/µSEL unprotected**

Gen-1

LCL

Latching Current Limiter

- Application
  - Component powerlines
- Benefit
  - Over-current and SEL/µSEL protection

Gen-2

LDAP

Latchup Detection And Correction

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Next Gen

AI-SLDAP

Artificial Intelligent System Latchup Detection And Protection

Power Reliability: Technology Evolution

- Application
  - Satellite/payload bus
- Feature
  - Over-current protection
- Limitation
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Gen-1

LCL

Latching Current Limiter

- **Application**
  - **Component powerlines**
- **Feature**
  - **Over-current and SEL/µSEL protection & protection**

Gen-2

LDAP

Latchup Detection And Protection

- Application
  - Payload bus
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Next Gen

AI-SLDAP

Artificial Intelligent System Latchup Detection And Protection

Why SEL/µSEL protection is insufficient today?

SEL/µSEL is NOT Over-Current!

- The state-of-the-art detection methods are insufficient:
  - SEL detection is based on 4x-5x nominal current
    - Unable to detect µSELs
    - Unsafe current levels/over-heating may occur

- Why µSELs are difficult to detect?
  - µSEL currents are indeterminate
    - Depends on operating current, functionality, device type, etc.

- ZES objective is to:
  - Detect every occurrence of µSELs
    - Ensuing the current does not reach unsafe levels
  - Completely eliminate SELs/µSELs

Why detection and elimination of μSELs is imperative?

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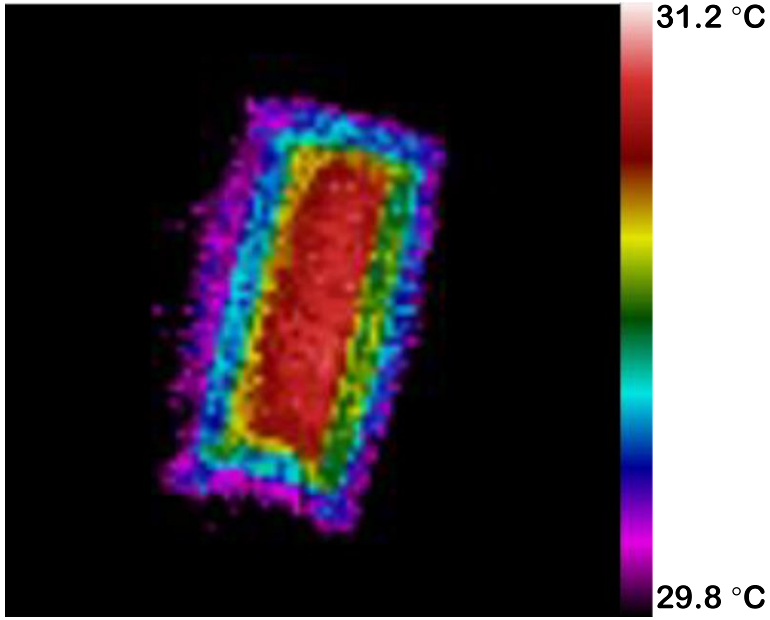
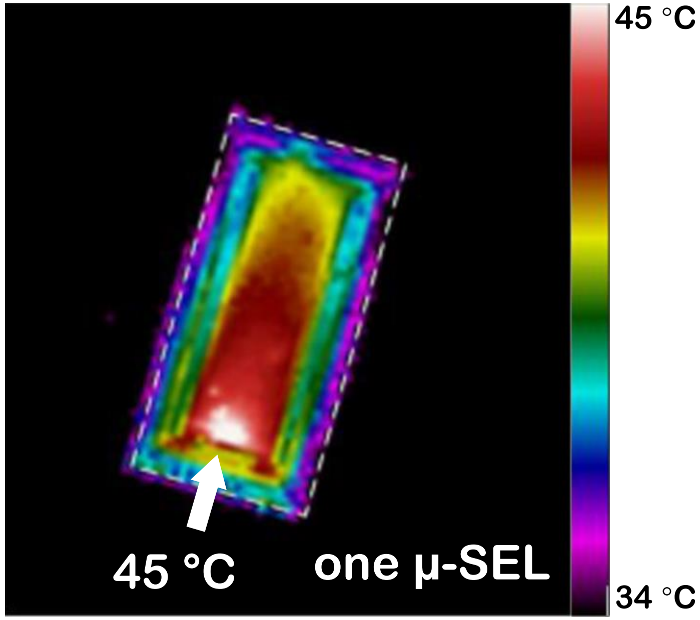
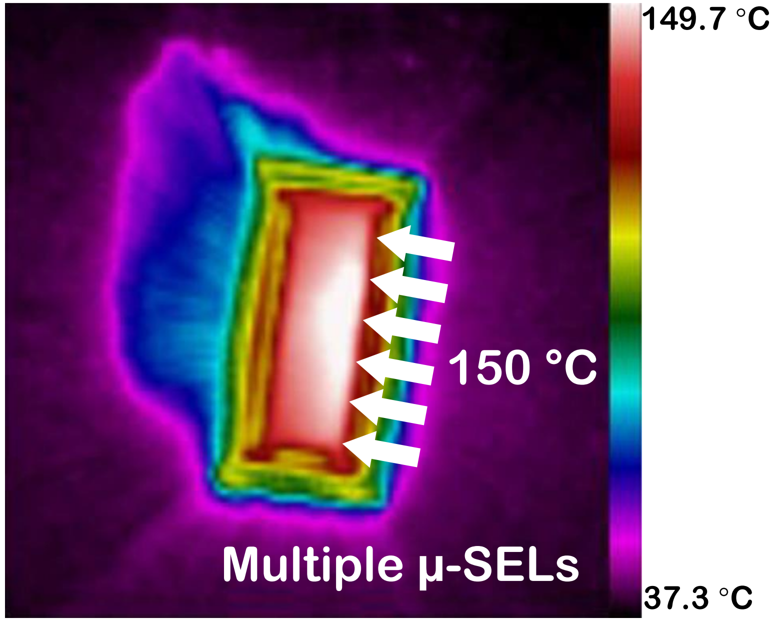


COTS IC without any μ-SEL



COTS IC with one μ-SEL



COTS IC with multiple μ-SELs

"The majority of the COTS components are rated for operation between -25°C and 70°C."

NASA (Richard L. Patterson, *et al.*)

⇨

"If left unchecked, μ-SELs will cluster, degrading the long-term reliability and shortening the lifetime of the COTS IC".

(N. J. Pieper, *et al.*, RADECS 2021)

Why SEL/µSEL detection is insufficient today?

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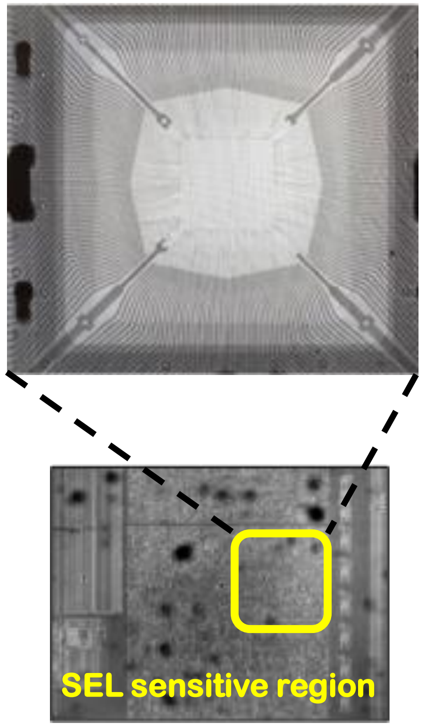
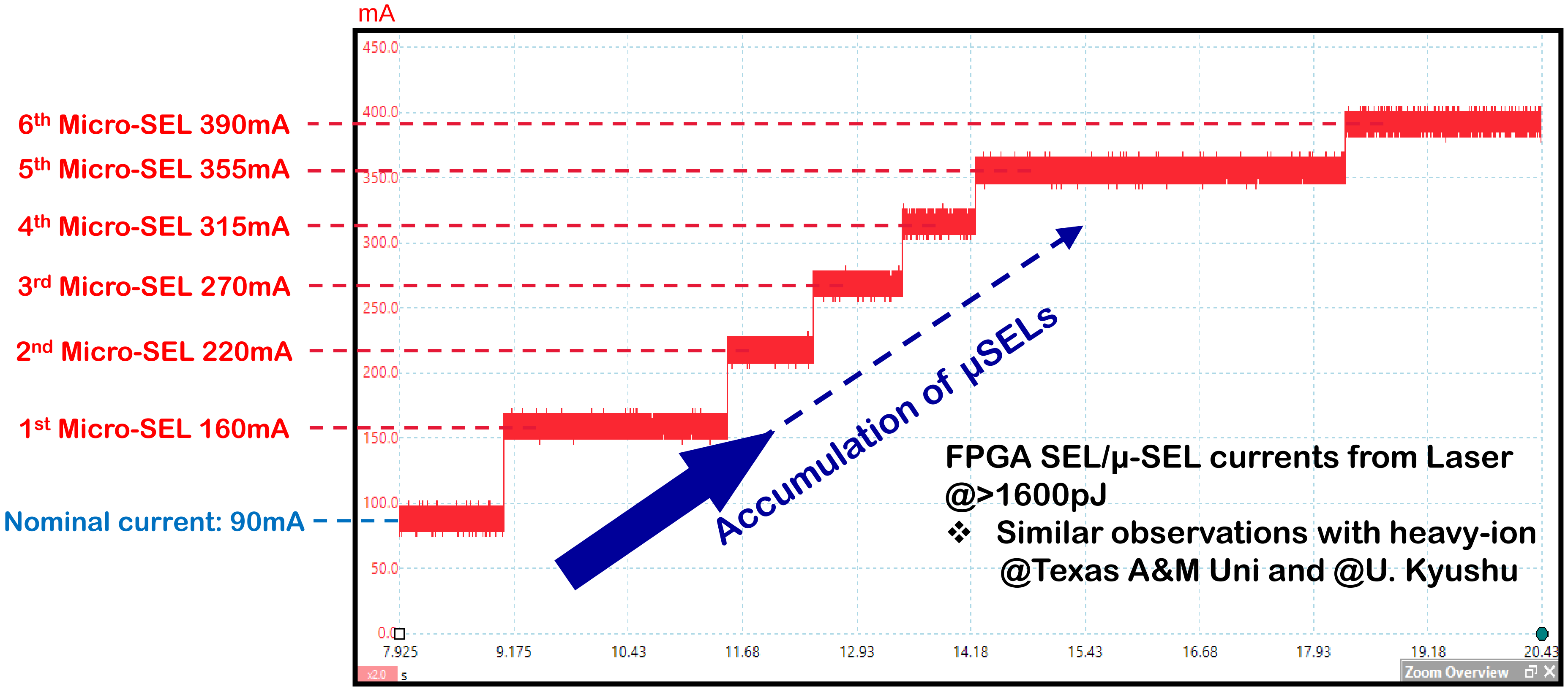
ZERO-ERROR SYSTEMS

µSEL is a localized and small-surge of current

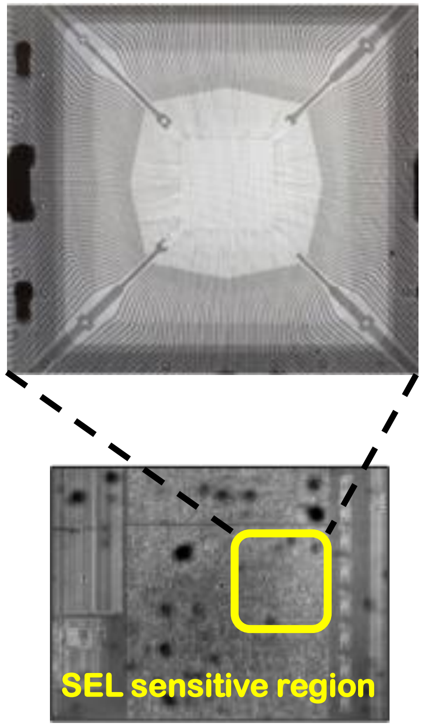


FPGA Die

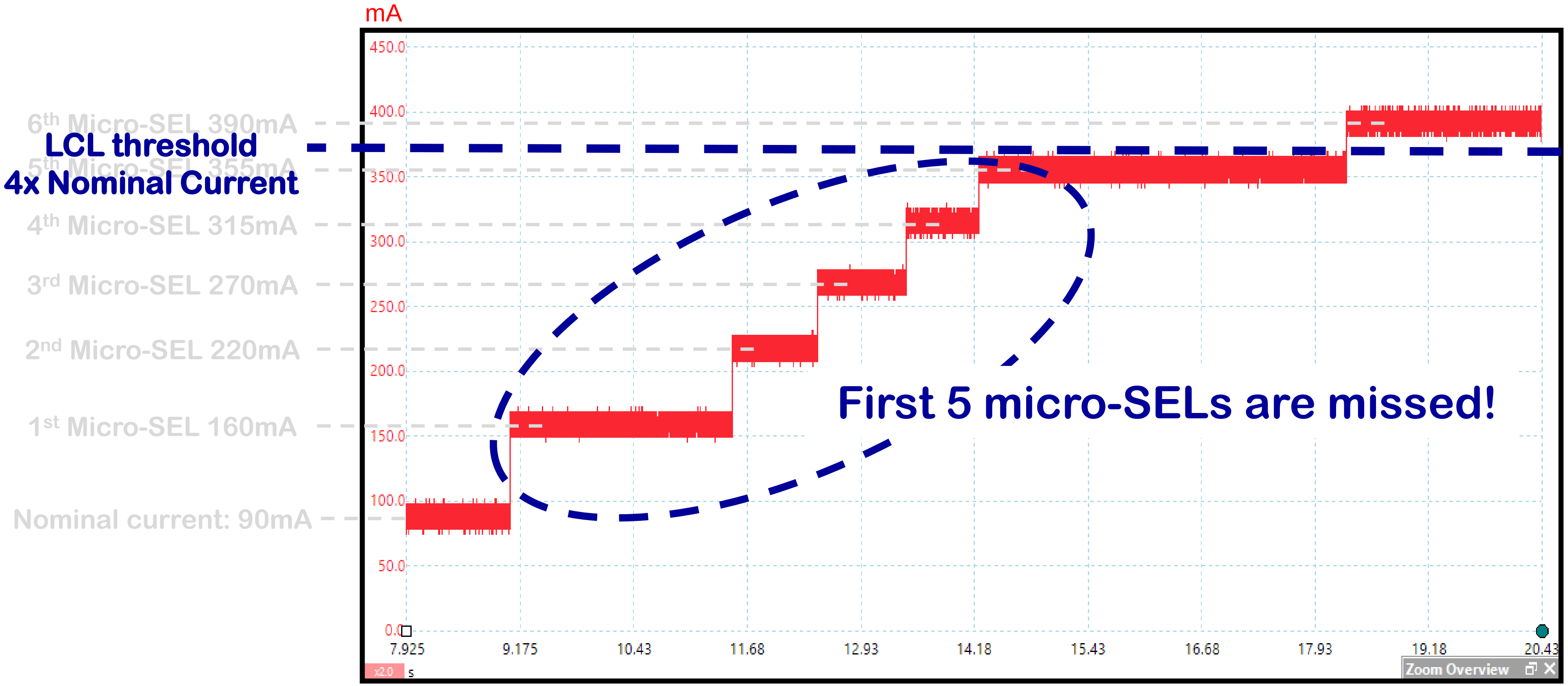


Y He, *et al.*, J Chang, RADECS Conf, Oct 2022

LCLs are unable to detect: First Reason

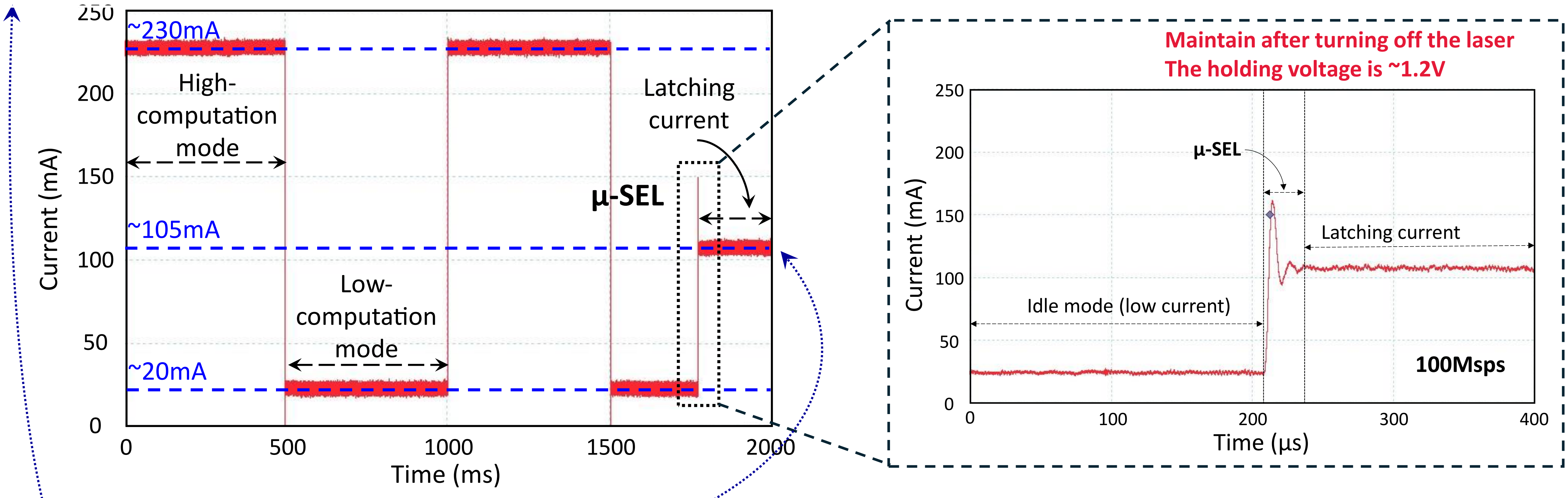


FPGA Die



Y He, *et al.*, J Chang, RADECS Conf, Oct 2022

Experimental µSEL Current Profile



- ❑ **µ-SEL current is different for different operating modes**
  - ❖ **Lower @Low computation**
  - ❖ **Higher @High computation**

LCLs are unable to detect: Second Reason

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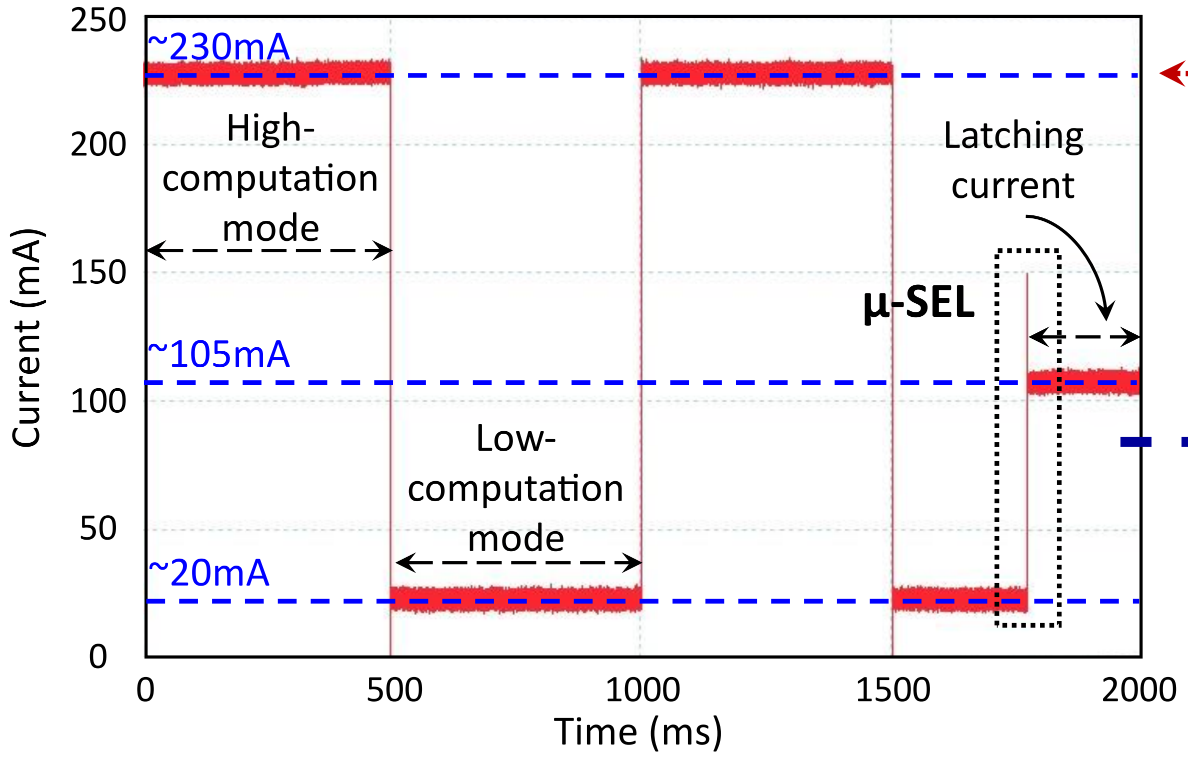
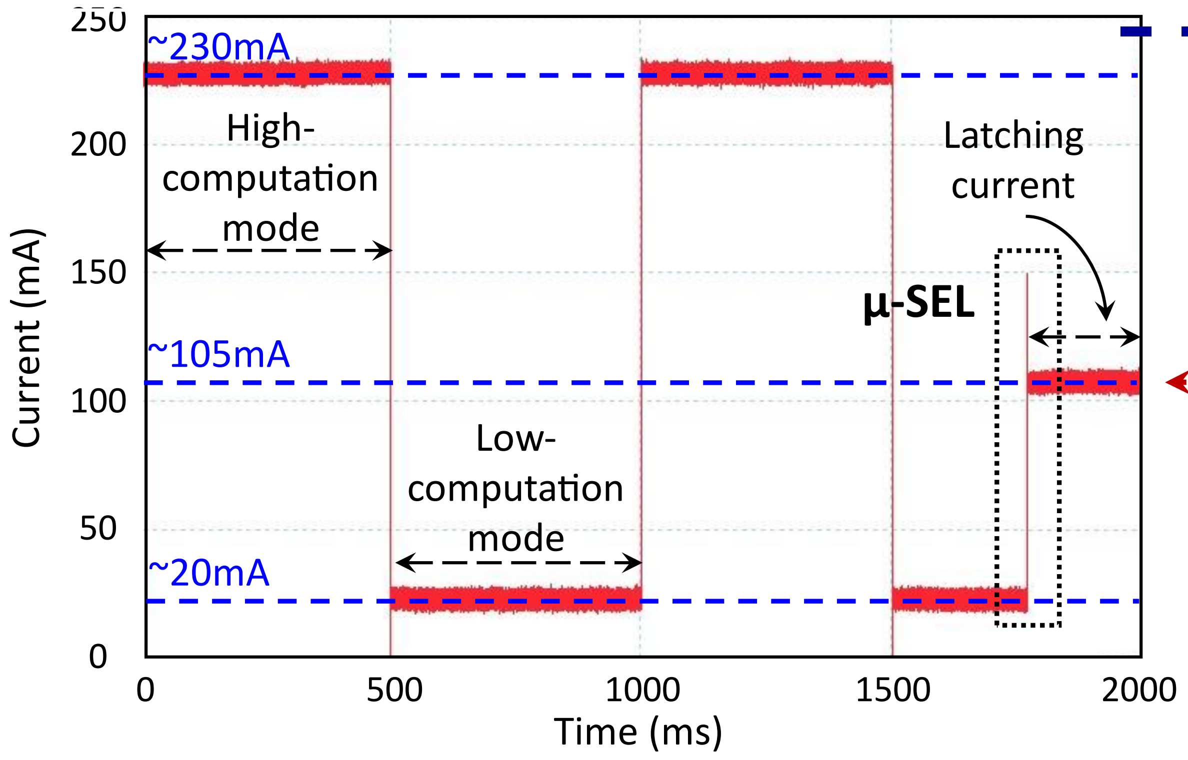
ZERO-ERROR SYSTEMS



- ❑ If SEL threshold is set LOW to detect µ-SELs @low computation
  - ❖ False positives during high-computation operation

LCLs are unable to detect: Second Reason



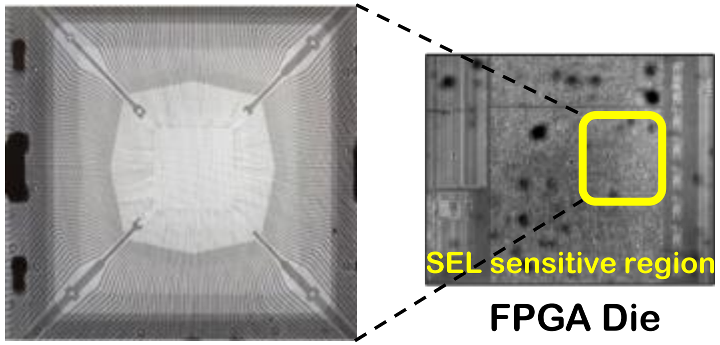
- If SEL threshold is set HIGH to detect μ-SELs @high computation
  - Unable to detect μ-SELs during <u>low-computation</u> operation

- LCLs cannot offer protection against μSELs
  - Threshold is too high – above μSEL currents
- ZES' Latchup Detection and Protection (LDAP) offers an analog solution

Latchup Detection and Protection (LDAP)

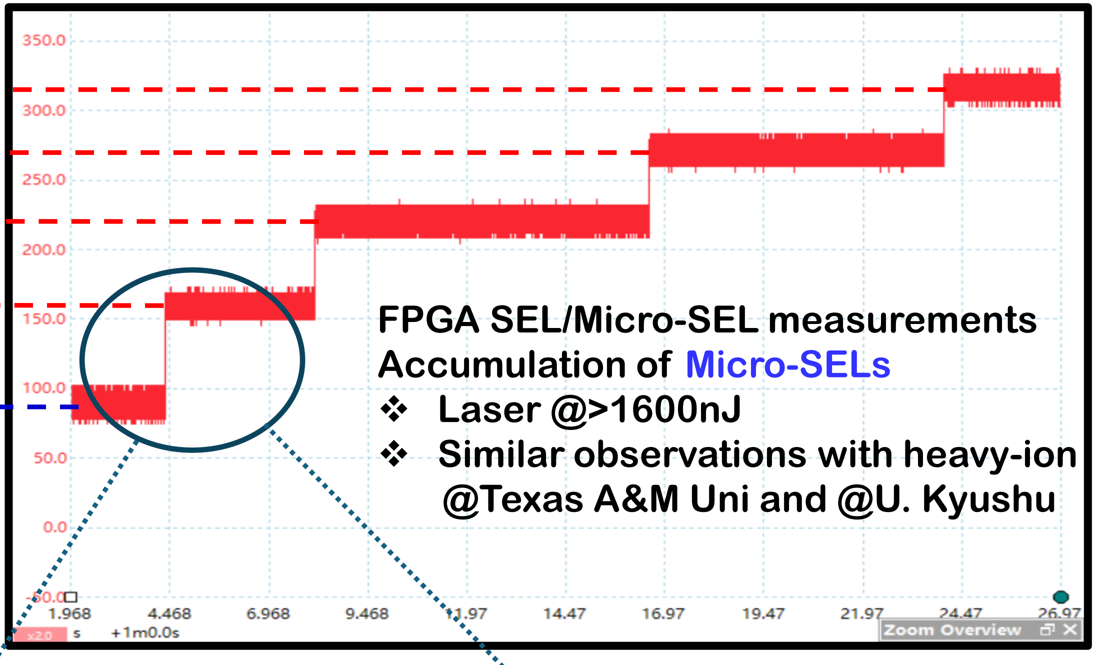
ZES
ZERO-ERROR SYSTEMS

Novel Solution for Indeterminate SEL and µSEL currents



FPGA Die

❖ **Laser test @>1600nJ**



4th Micro-SEL 315mA

3rd Micro-SEL 270mA

2nd Micro-SEL 220mA

1st Micro-SEL160mA

Nominal current 90mA

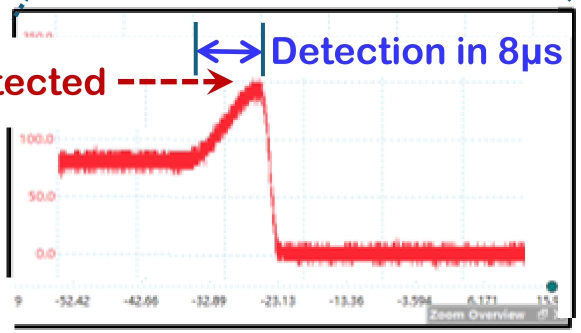
FPGA SEL/Micro-SEL measurements
Accumulation of Micro-SELs
- ❖ **Laser @>1600nJ**
- ❖ **Similar observations with heavy-ion @Texas A&M Uni and @U. Kyushu**

ZES LDAP-IC
THE ONLY solution today

* To date, applicable to all COTS devices

Micro-SEL detected @140mA

Detection in 8µs



Expanded view of Micro-SEL detection

ZES Latchup Detection and Protection IC (LDAP)

Novel Solution for Indeterminate SEL and µSEL Current

ZES LDAP IC – ONLY solution today

Parameters	Performance
Response Time	~0.1µs
Current Detection	1.5x - 2x nominal
Triggering	No False Triggering
SEL and Micro-SEL	Resolved*
Protection over LCL	100x - 1,000,000x
Radiation Qualification	LET = 100MeV.cm^2/mg TID = 300kRad
Small Form factor	QFN32L (5x5mm) SEP

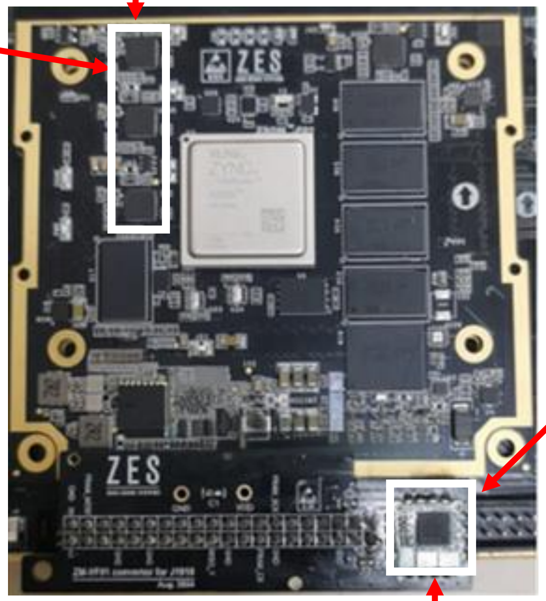
ZES LDAP IC, ZES1xx (Ground-model, Flight-model) Available

Rad. Tol. System-on-Module protecting COTS-FPGA ZSOM-F01

ZES LDAP-IC to protect COTS FPGA

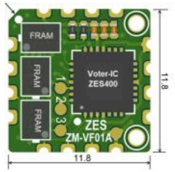
SEL protection

ZES LDAP IC ZES1xx series



SEU protection

ZES TMR Voter-module ZM-VF01A



Plug-in adaptor to existing COTS payload

- TMR-based FRAM with **ZES Rad. Hard. Voter-IC** protects data in High-speed/ embedded memory
- **ZES EDAC code** on FPGA for error-correction

Comprehensive Radiation Protection for COTS

TMR Voter-Module + EDAC

Enabling Data Integrity in Space

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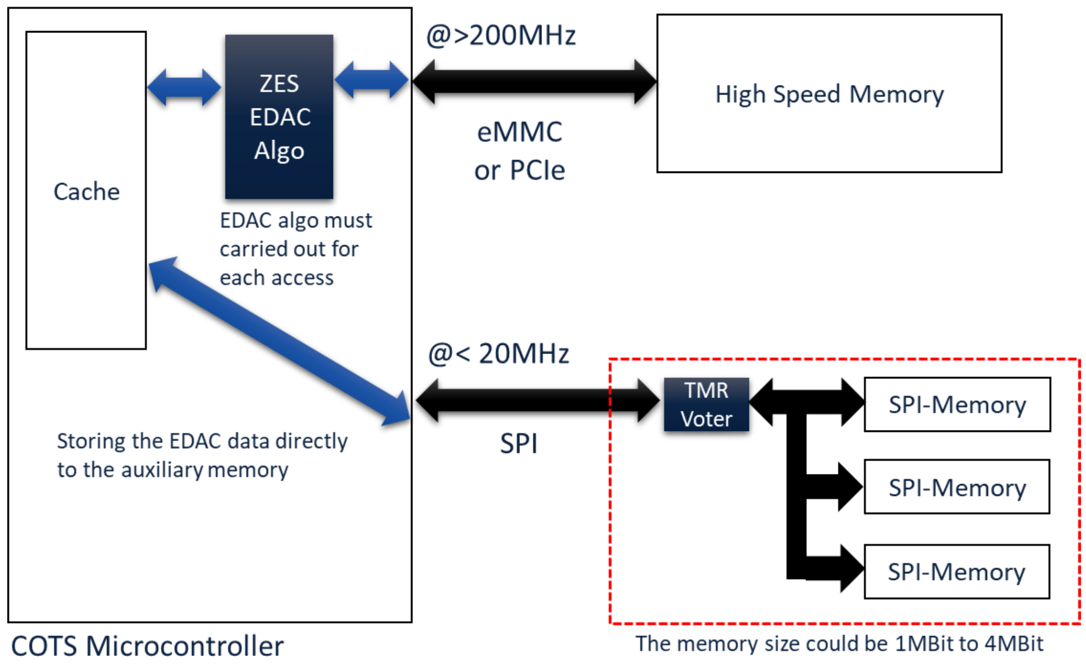
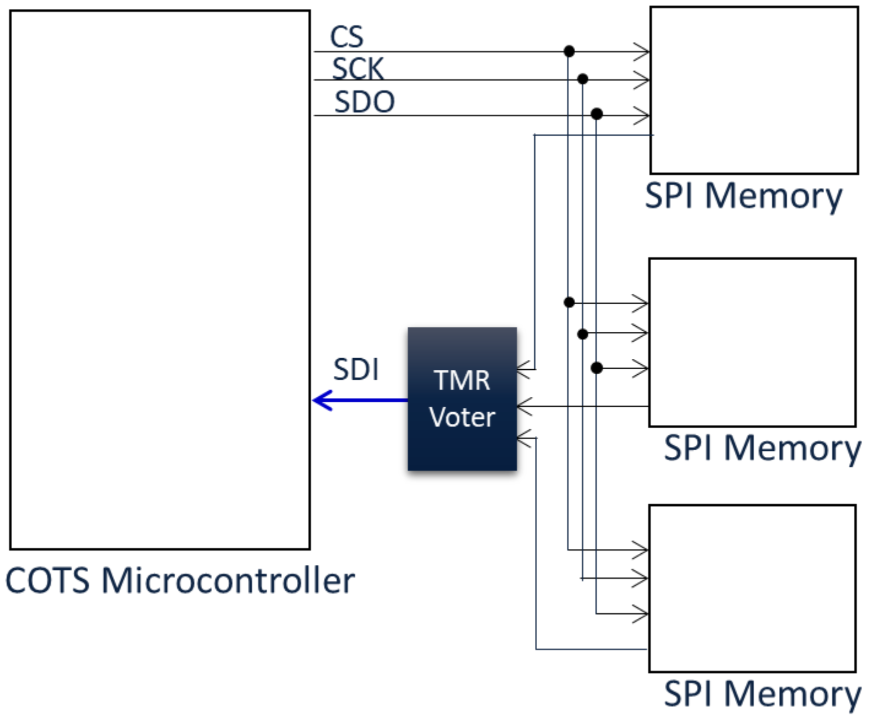
High Speed Memory Protection



Low Speed Memory Protection



ZES Latchup Detection and Protection IC (LDAP) vs Conventional Latching Current Limiter (LCL): Heavy-ion and Flight Legacy

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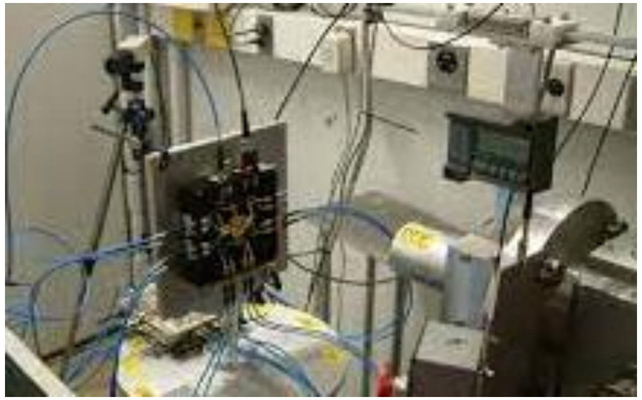
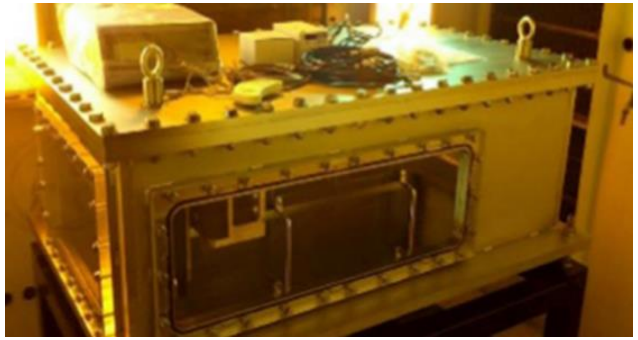
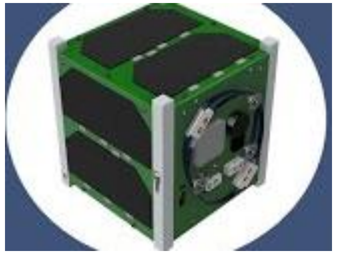
ZERO-ERROR SYSTEMS

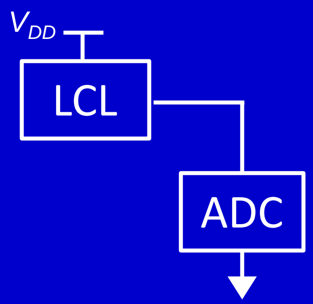
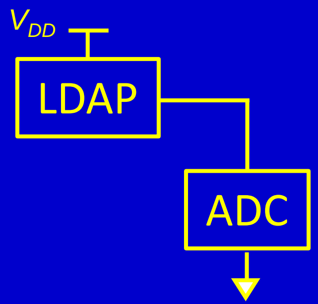
SEL and µSEL Protection: LCL vs. LDAP







J Chang, et al.,
IEEE ISCAS 2022

	Present LCL	ZES LDAP-IC
On-earth testing & Flight Legacy	 Latching Current Limiter	 ZES LDAP
On-earth Experiments: Californium-252, U. Kyoto Heavy-ion, Texas A&M U.	**NO Micro-SELs Detected** **SELs Detected**	**Micro-SELs Detected** **NO SELs Detected 'cos ALL Micro-SELs Detected**
Flight Legacy Kyutech Kyushu Institute of Technology **BIRDS-IV, Kyushu Inst. Tech 1-Year Flight (2021)**	**NO Micro-SELs Detected** **NO SELs Detected**	**41 Micro-SELs Detected** **NO SELs Detected**

Power Reliability: Technology Evolution

ZES
ZERO-ERROR SYSTEMS

- Application
  - Satellite/payload bus
- Feature
  - Over-current protection
- Limitation
  - SEL/µSEL unprotected

Gen-1

LCL

Latching Current Limiter

- Application
  - Component powerlines
- Feature
  - Over-current and SEL/µSEL detection & protection
- **Limitation**
  - **Hardware overheads**

Gen-2

LDAP

Latchup Detection And Protection

- Application
  - Payload bus
- Benefit
  - Protection for all current anomalies including over-current, SEL/µSEL, etc.
  - Plug-and-play

Next Gen

AI-SLDAP

Artificial Intelligent System Latchup Detection And Protection

Power Reliability: Technology Evolution

ZES
ZERO-ERROR SYSTEMS

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Gen-1

LCL

Latching Current Limiter

- Application
  - Component powerlines
- Feature
  - Over-current and SEL/µSEL detection and protection
- Limitation
  - Hardware overheads

Gen-2

LDAP

Latchup Detection And Protection

- **Application**
  - **Payload bus**
- **Feature**
  - **AI Protection for all current anomalies including over-current, SEL/µSEL, etc.**
  - **Plug-and-play**

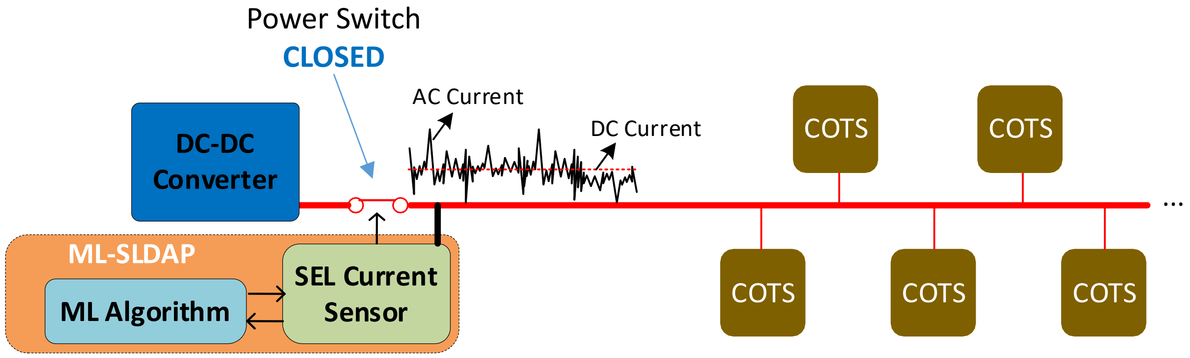
Next Gen

AI-SLDAP

Artificial Intelligence System Latchup Detection And Protection

AI-SLDAP: System Architecture

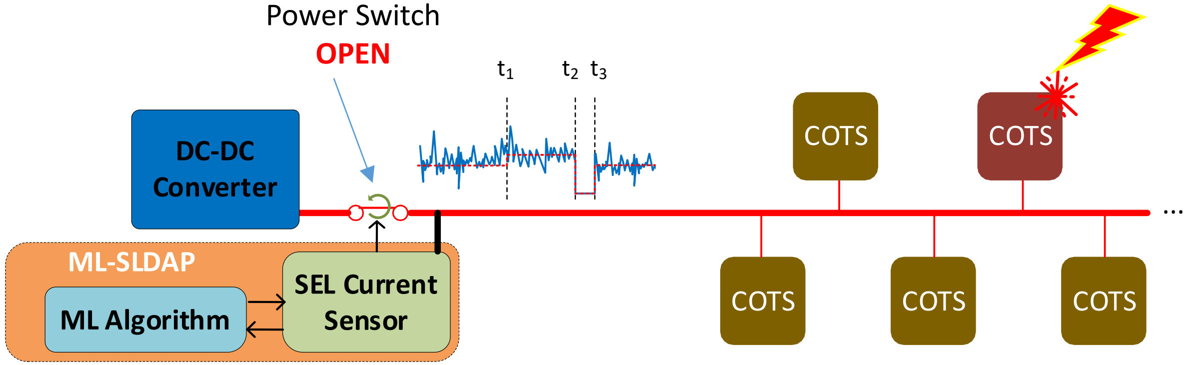
ZES
ZERO-ERROR SYSTEMS



AI-SLDAP and COTS System Circuit Board under normal operation

Normal Operation

The overall output current sensed by the SEL Current Sensor is normal (free from SEL events) and therefore the Power Switch remains closed.



AI-SLDAP and COTS System Circuit Board Board with µSEL

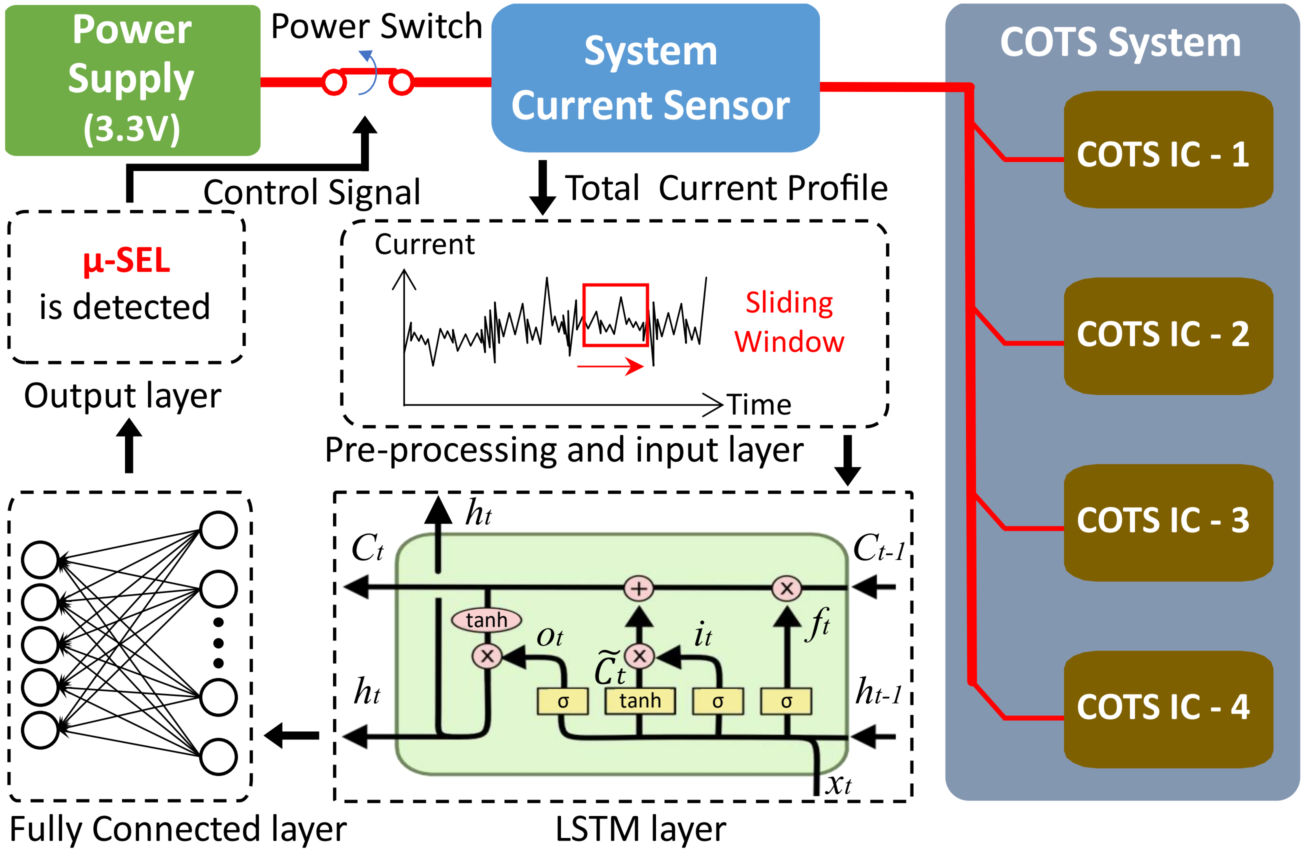
Anomaly Detection & Power Cycling

t1: When an SEL happens, the current spikes.

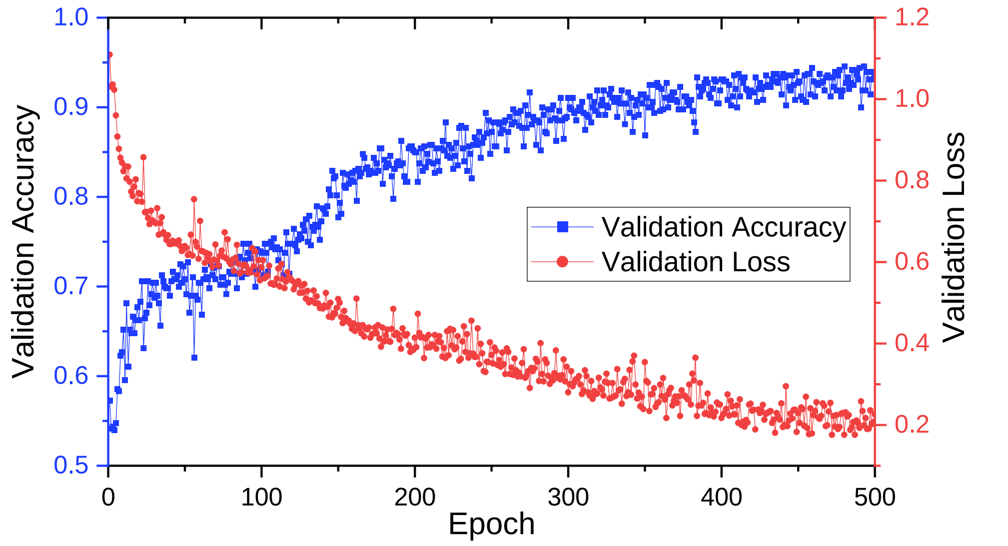
t2: The AI-SLDAP detects this, turning off the Power Switch to prevent damage and quickly dissipate current.

t3: The system then resets by Power cycling, restoring normal operation.

ZES LSTM-based Algorithm - Holistically Protects COTS



The COTS system protected by ZES LSTM-based algorithm
(without modification to the COTS system)



The training process

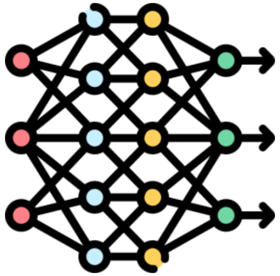
Approach	Proposed	KNN	SVM	RF	DT	NB
Accuracy	94.6%	82.6%	81.3%	79.8%	76.9%	59.3%

The first-ever attempt to holistically detect and protect a COTS system against SELs and micro-SELs.

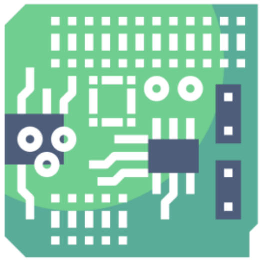
J. Zhao, *et. al.*, J. S. Chang, "An AI-powered Approach to Holistically Detect and Protect a COTS System against SELs and Micro-SELs," *European Conference on Radiation and Its Effects on Components and Systems*, 2024.

AI-SLDAP: Unprecedented Innovation

Accurate SEL/μSEL Detection by AI



Reconfigurable Protection Strategies



System-Level Protection

Summary – Power Reliability

- Application
  - Satellite/payload bus
- Feature
  - Over-current protection
- Limitation
  - SEL/μSEL unprotected

<u>Gen-1</u>

LCL

Latching Current Limiter

- Application
  - Component powerlines
- Feature
  - Over-current and SEL/μSEL detection and protection
- Limitation
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<u>Gen-2</u>

LDAP

Latchup Detection And Protection

- Application
  - Payload bus
- Feature
  - AI Protection for all current anomalies including over-current, SEL/μSEL, etc.
  - Plug-and-play

<u>Next Gen</u>

AI-SLDAP

Artificial Intelligence System Latchup Detection And Protection

ZES

ZERO-ERROR SYSTEMS

Hi-Reliability Semiconductors for Power & Data management

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