REDI

Radiation evaluation of digital isolators currently available, suitable for space missions in terms of radiation tolerance (TID and SEE) including the JUICE mission

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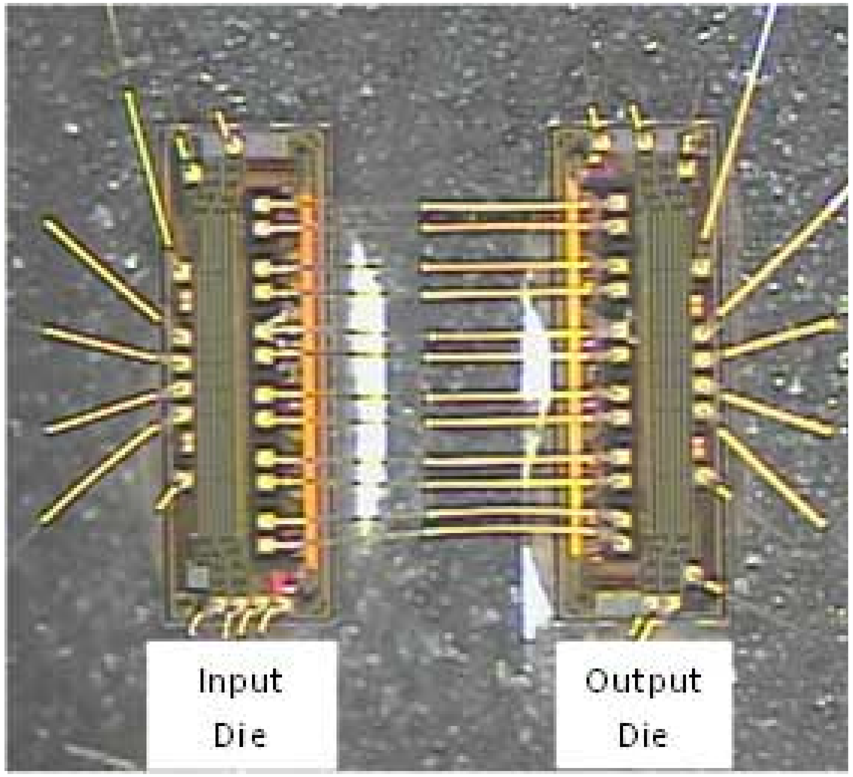
S. Metzger (INT), M. Poizat (ESA), M. Steffens (INT)

ESA-CNES Final Presentation Days on Space Environments and Radiation Effects on EEE Components

9th March 2016, ESA-ESTEC, Noordwijk



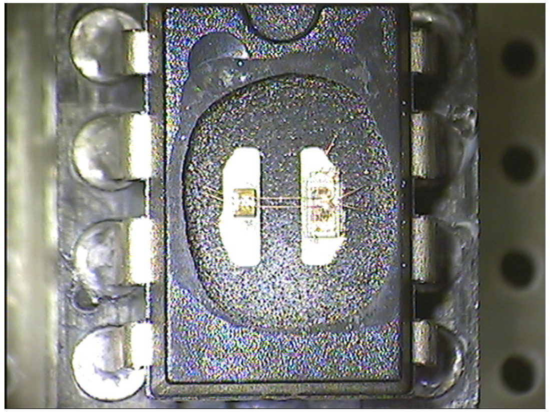
Motivation and Objectives

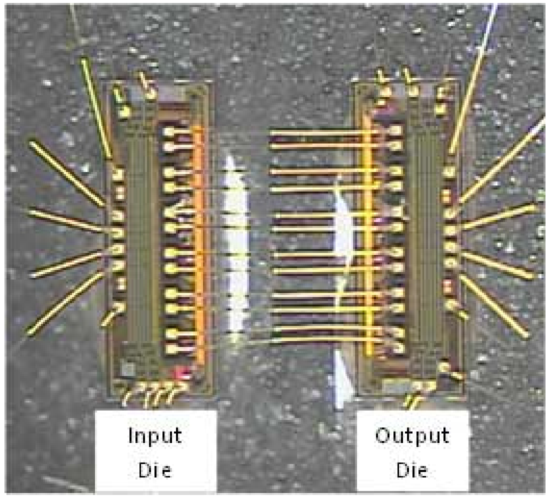
Motivation

- offer new options on safety isolations
- show advantages over optocouplers (integration, power efficiency, cost, performance, etc.)

Objectives

- identify DIs currently available that are of interest for space missions
- perform a detailed radiation evaluation (TID and SEE)

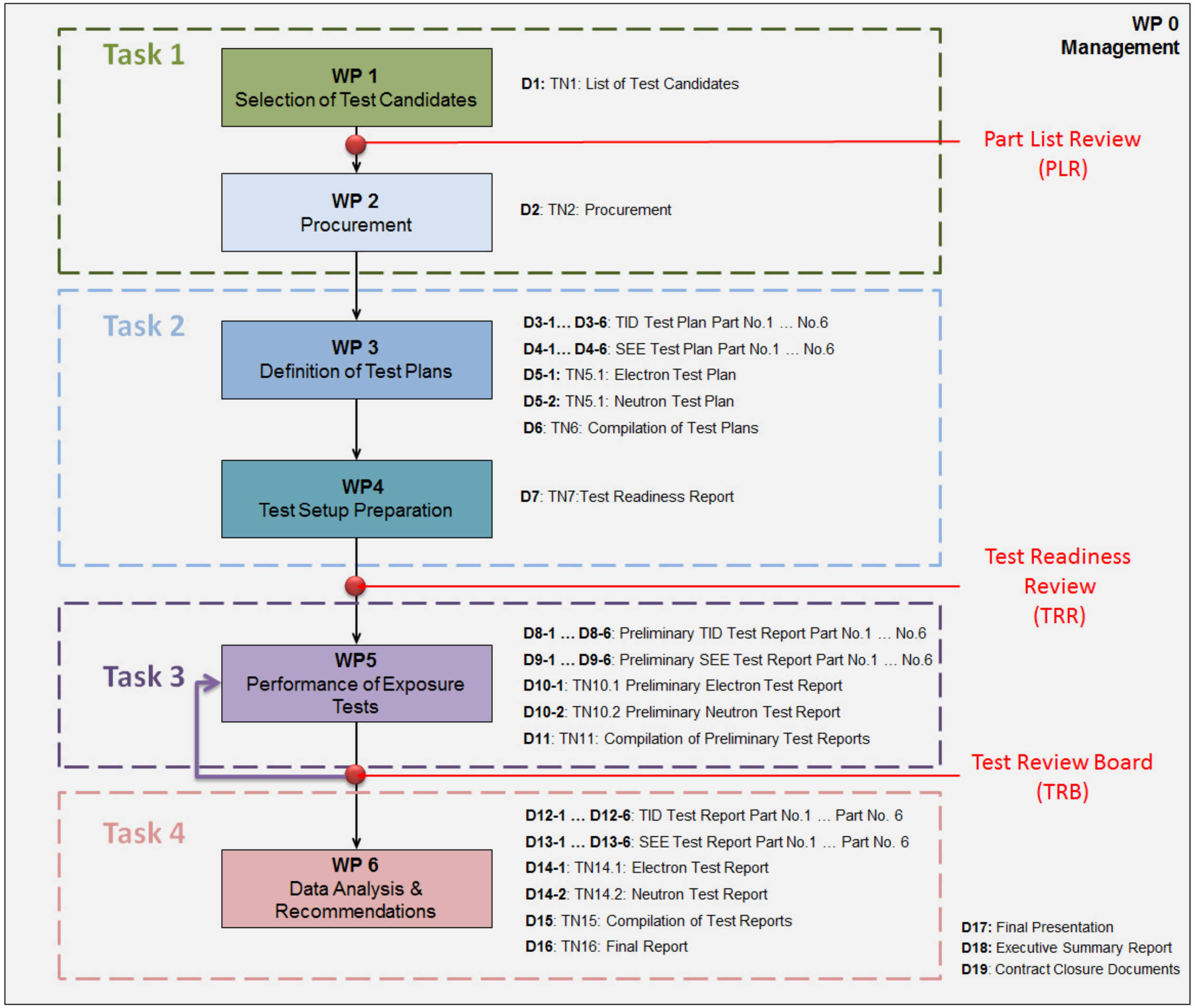




Contents

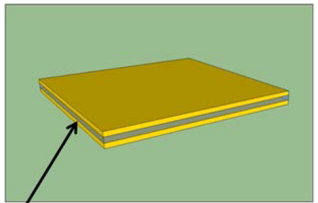
Project Work Flow

SEIBERSDORF LABORATORIES

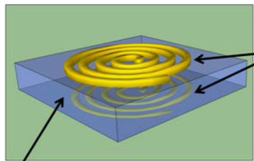


Test Candidates - Technologies

Technology	Capacitive Coupling				Monolithic Transformer		GMR
Manufacturer	TI Texas Instruments		Maxim Integrated	Silicon Labs	Analog Devices		NVE* IsoLoop
Investigated Part	ISO7220MDR	ISO15DW	MAX14850SE+	Si8261ACC-C-IP	ADUM1201ARZ	ADUM1100URZ	IL715-3E
Lot Code	4286983TW4 4662957TN4	4043232TN4	0001755035	1333CF600U	1TAK96092.9	AJ60138.5	132361, 135210
Date Code	-/1419	-	1406	-	-	1351	-
Purchased Quantity	100	100	100	100	100	100	100

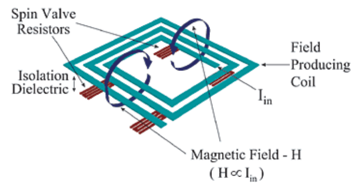


Thin SiO_2 Insulation



Primary & Secondary Coils

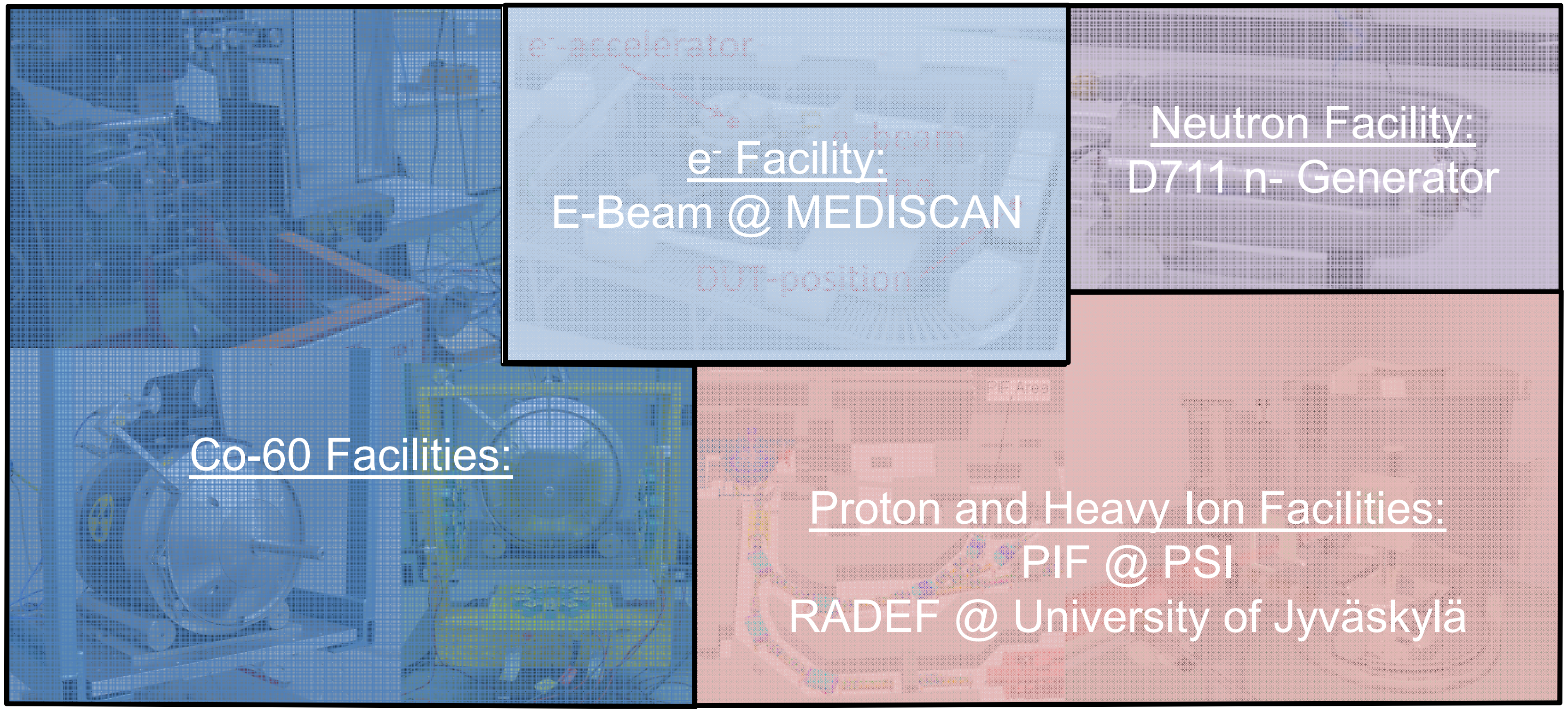
20 to 32 µm Thick Polyimide Insulation



Performed Radiation Testing

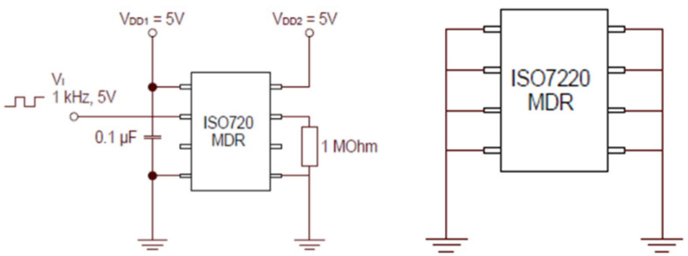
Test	Test Facility	Source
TID testing with **gamma**	Accredit Standard Radiation Laboratory Seibersdorf Laboratories (SL), Austria	Cobalt-60
TID testing with **gamma**	TK1000A, Fraunhofer INT Euskirchen, Germany	Cobalt-60
TID testing with **electrons**	MEDISCAN, E-Beam Technology Kremsmünster, Austria	10 MeV electrons
Displacement damage testing with **neutrons**	D711 n-generator, Fraunhofer INT Euskirchen, Germany	14 MeV neutrons
SEE testing with **protons**	Proton Irradiation Facility (PIF), Paul Scherrer Institute (PSI), Villigen, Switzerland	24 to 200 MeV protons
SEE testing with **heavy ions**	Radiation Effects Facility (RADEF) University of Jyväskylä, Finland	Heavy ions: N, Si, Fe, Kr, Xe LET: 1.87 to 60.0 MeV cm²/mg

Radiation Testing Facilities



Co-60 TID Testing

Exposure Circuitry (Biased & Unbiased):



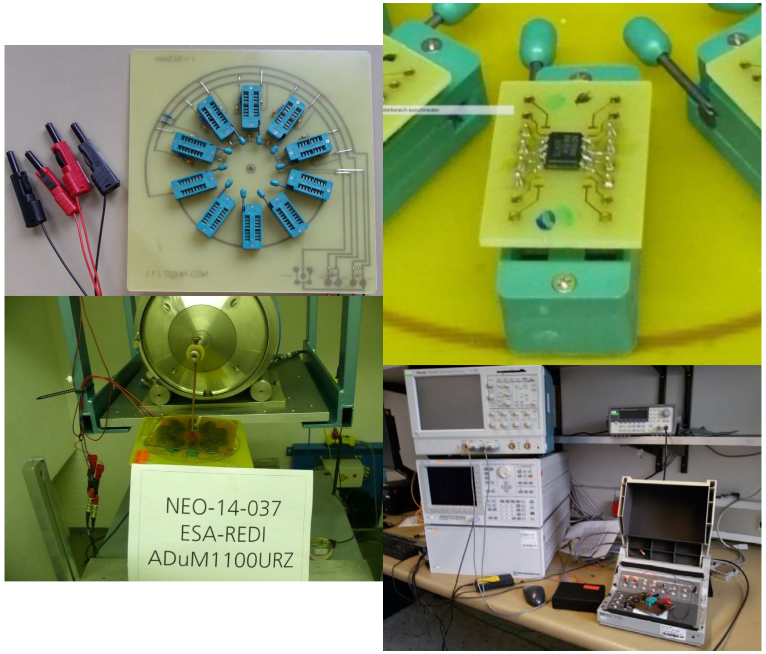
Irradiation Sequence

- Dose Level: 300 $krad_{(Si)}$
- Dose Rate: 3.2 – 5 $rad_{(Si)}/s$
- Dose Steps: 10, 20, 30, 50, 100, 300 $krad_{(Si)}$
- Annealing: 24 h at RT, 168h at 100°C

Parameters Tested

Index	Characteristics	Symbol
1	Input Supply Current at logical low	$I_{DD1(L)}$
2	Output Supply Current at logical low	$I_{DD2(L)}$
3	Input Supply Current at logical high	$I_{DD1(H)}$
4	Output Supply Current at logical high	$I_{DD2(H)}$
5	Output voltage at logical low	V_{OL}
6	Output voltage at logical high	V_{OH}
7	Rise time	tr
8	Fall time	tf
9	Propagation delay Low? High	t_{pLH}
10	Propagation delay High? Low	t_{pHL}
11	Pulse Width Distortion	PWD
12	Leakage Current	I_{I-O}

Co-60 TID Test Set-Ups



SEIBERSDORF LABORATORIES

TID Results – Overview

Technology		Capacitive Coupling				Monolithic Transformer		GMR
Manufacturer		TI Texas Instruments		Maxim Integrated	Silicon Labs	Analog Devices		NVE* (IsoLoop)
Investigated Part		ISO7220MDR	ISO15DW	MAX14850SE+	Si8261ACC-C-IP	ADUM1201ARZ	ADUM1100URZ	IL715-3E
TID	Parametric failure level	> 300 krad(Si)	10 krad(Si)	50 krad(Si)	30 krad(Si)	20 krad(Si)	20 krad(Si)	30 krad(Si)
	Functional failure level	> 300 krad(Si)	> 300 krad(Si)	100 krad(Si)	168 h @100°C	100 krad(Si)	N/A	> 300 krad(Si)
	Dielectric withstand	100 krad(Si)	100 krad(Si)	> 300 krad(Si)	> 300 krad(Si)	>300 krad(Si)	> 300 krad(Si)	FAIL at 0 krad(Si)
	Recovery @	No	No	No	No	168 h @100°C	N/A [6]	partially yes

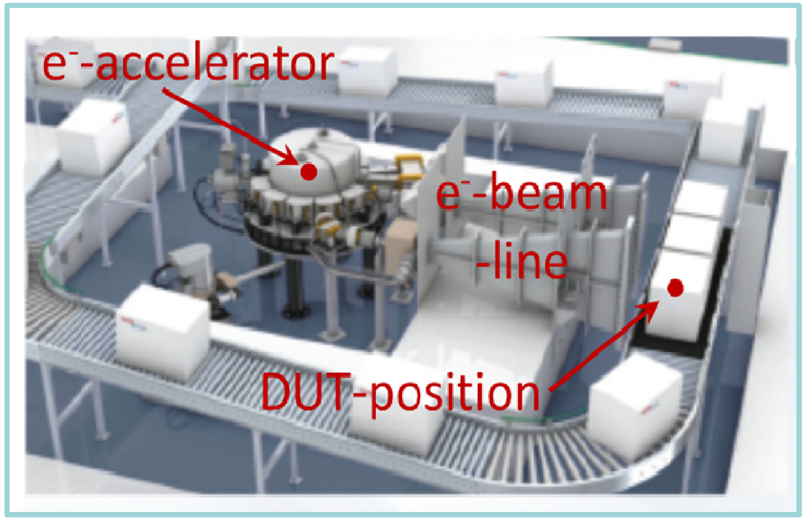
TID Electron Testing

- Tested Part: **ISO7220MDR**
- **Radiation facility:** MEDISCAN, E-Beam, Kremsmünster, Austria

- **Irradiation Sequence**
  - Total Dose Level: 285 $krad_{(Si)}$
  - Dose Rate: 5 $krad(Si)\cdot s^{-1}$
  - Dose Steps: 23, 47, 95, 285 $krad_{(Si)}$

- Biased and unbiased exposure (identical to Co-60)
- Characterized are electrical parameters, timing and switching related parameters

- Parametric failure level: 47 $krad_{(Si)}$
- Functional failure level: 95 $krad_{(Si)}$
- Recovery after 24 h RT anneal



Technology		Capacitive Coupling
Manufacturer		TI Texas Instruments
Investigated Part		ISO7220MDR
Electrons	Parametric Failure	47 $krad_{(Si)}$
	Functional Failure	95 $krad_{(Si)}$
	Recovery @	24h @ RT

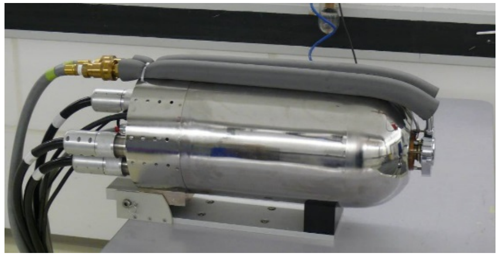
DD Neutron Testing

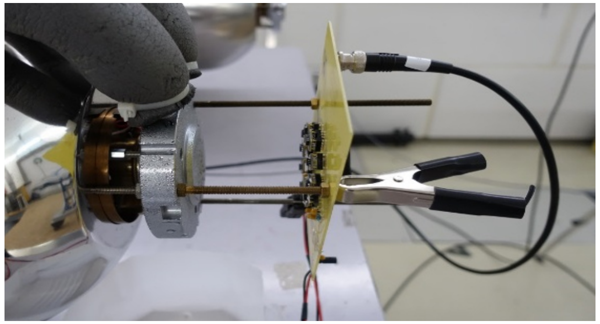
- Tested Part: **ISO7220MDR**
- **Radiation facility:** D711 n-generator, Fraunhofer INT

- **Irradiation Sequence**
  - Total Fluence Level: $9 \cdot 10^{11}$ n(1MeV) cm^{-2}
  - Flux: $1.35 \cdot 10^{7} – 3.70 \cdot 10^{7}$ n(14MeV) $cm^{-2} \cdot s^{-1}$
  - Fluence Steps:
    $1.8 \cdot 10^{10}$, $9 \cdot 10^{10}$, $1.8 \cdot 10^{11}$, $9 \cdot 10^{11}$ n(1MeV) cm^{-2}

- Biased an unbiased exposure (identical to Co-60)
- Characterized are electrical parameters, timing and switching related parameters

- **No** parametric nor functional **failures** observed!





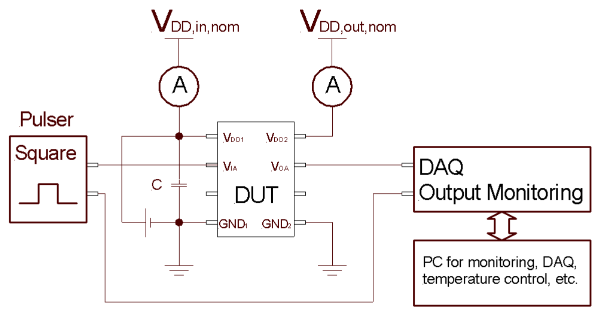
Technology		**Capacitive Coupling**
Manufacturer		**TI Texas Instruments**
Investigated Part		**ISO7220MDR**
Neutrons	Parametric Failure	> $9 \cdot 10^{11}$ n(1MeV) cm^{-2}
	Functional Failure	> $9 \cdot 10^{11}$ n(1MeV) cm^{-2}

SEE Testing

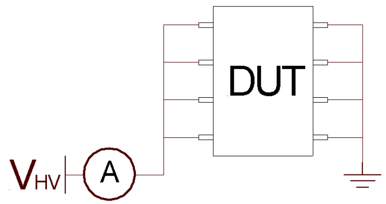
Investigated SEE effects

- Single Event Latch-Up (**SEL**)
  - Monitoring of the supply currents of both DI sides
  - Standard procedure to catch SELs
- Single Event Transients (**SET**)
  - Detect deviations from the expected DI output
- Single Event Dielectric Rupture (**SEDIR**)
  - DC high voltage of 560 V
  - $I_{leak,max}$ = 5µA

Schematic: SEL / SET



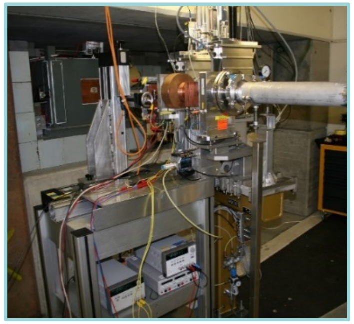
Schematic: SEDIR



Applied Radiation Environments

Radiation Environment	Test Facility	LET Range	Fluence	Flux
Proton	PIF/PSI	< 15 MeV·cm²/mg	10^{10} cm^{-2}	10^7 cm^{-2}·s^{-1}
Heavy Ion	RADEF	1.8 – 60 MeV·cm²/mg	10^7 cm^{-2}	~5 · 10^4 cm^{-2}·s^{-1}

PIF / PSI



RADEF

SEIBERSDORF LABORATORIES

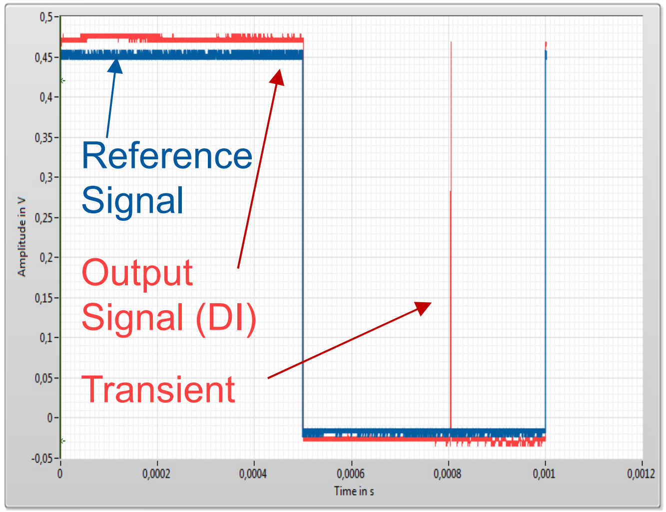
Features of SET Testing (SL)

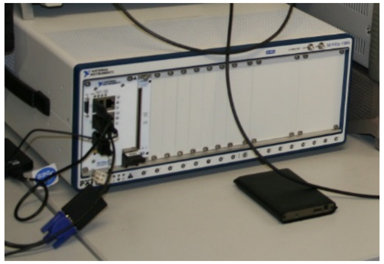
SET detection requirements

- Measure the DI output with a time resolution **< 1 ns**.
- Detect every transient with duration **> 1ns**.
  Don't miss any!
- Store SET signal trace (V_{out} vs. time) min. **100 traces**.
- Perform **trace analysis** for determination of worst case transient

Real Time NI-PXI system based FPGA solution

- Based on comparison: DI-out vs. reference
- NI-PXI Hardware, LabVIEW (SL):
  - 2 Input-Channels: comparison of signals
  - Time resolution of 0.66 ns
  - LabVIEW programmed FPGA
  - Allows for real-time analysis of the data (transient duration, transient amplitude, signal integration)
  - Every transient is counted, no dead time, no time limit
  - At least 400 transient traces for 1 ms / trace stored without interruption

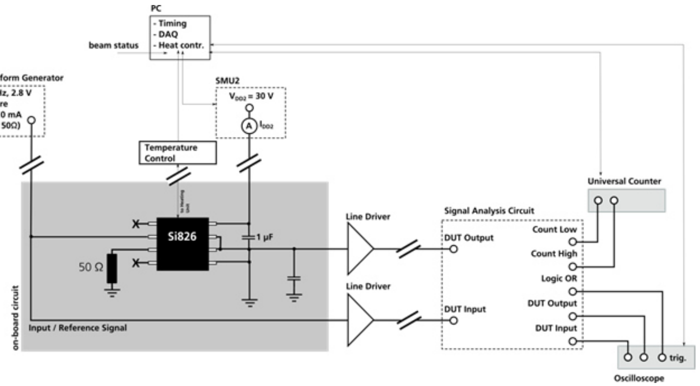


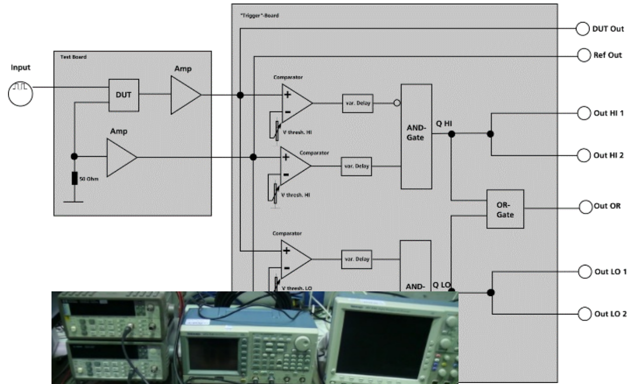


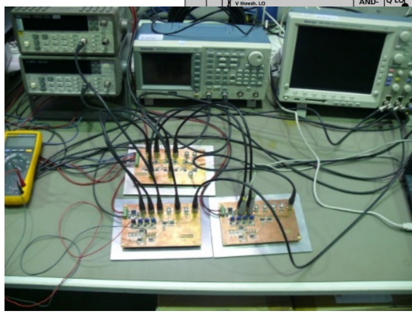
FlexRIO Hardware
NI PXIe-7976R

Adaptermodul for FlexRIO
NI 5771 Digitizer-Adaptermodul

Features of SET Testing (INT)







SET detection requirements

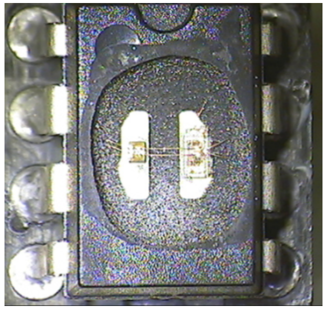
- Measure the DI output with a time resolution < **1 ns**.
- Detect every transient with duration > **1ns**.
  Don't miss any!
- Store SET signal trace (V_{out} vs. time) min. **100 traces**.
- Perform **trace analysis** for determination of worst case transient

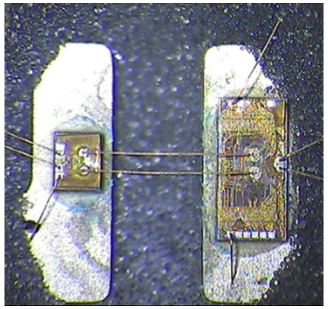
Company Internal Development

- Based on comparison: DI-out vs. reference
- Development by INT:
  - 2 input channels: Comparison of signals
  - Real time analysis of DI output, triggers fast scope for transients. Accounts and prevents signal imperfections over long cables
  - No dead time like e.g. for oscilloscopes
  - Every transient is counted, no dead time, no time limit
  - Up to 1000 transients traces for 1 µs / trace can be recorded

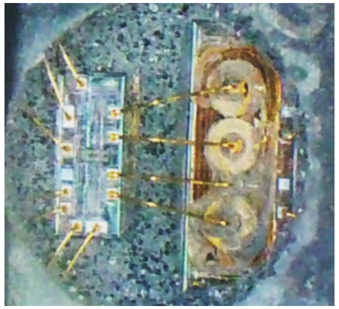
Delidding – Problems Observed

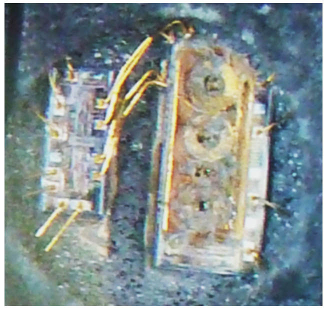
Si8261: Successful Delidding (capacitive coupling)





ADuM1201: Unsuccessful Delidding (mon. transformer)





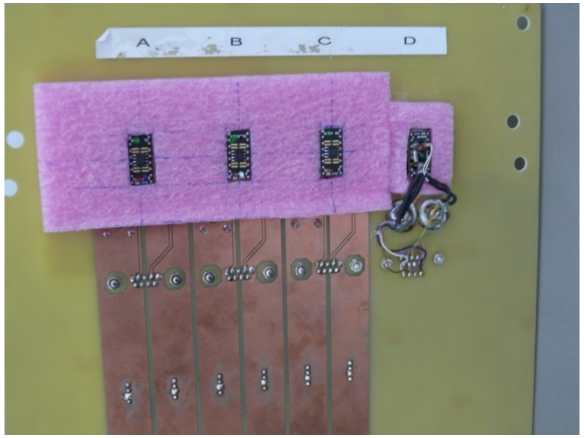
Proton Testing

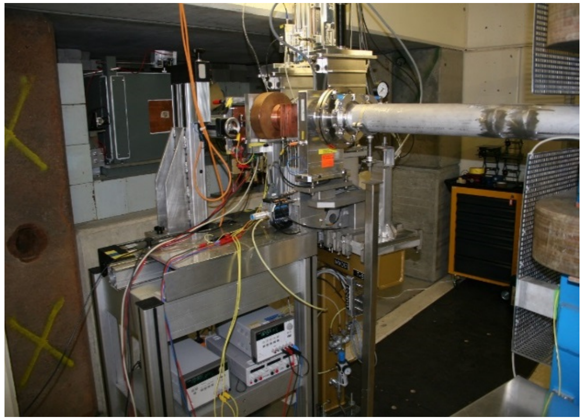
- Parts: **ADUM1201ARZ**, **ADUM1100URZ**

- LET_{max} : ~ 15 MeV·cm²/mg
- Energy: E_p=24, 51, 101, 200 MeV
- Temerature: RT, 75°C

- SEE testing: **SEL, SET**
- Dielectric testing: **SEDIR**

- **No SEL, no SET** observed
- **No dielectric breakdown** observed





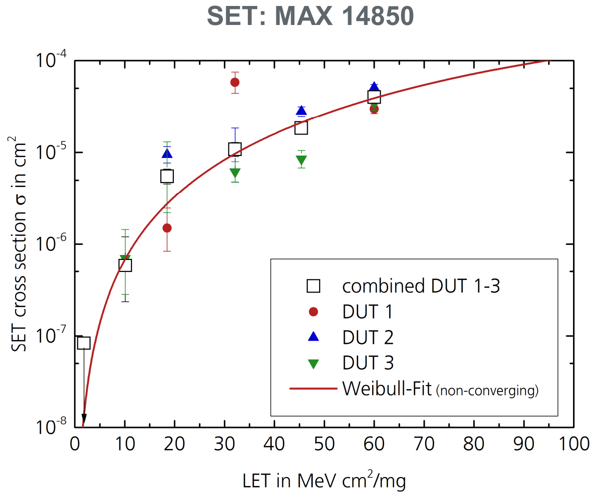
Heavy Ion Testing

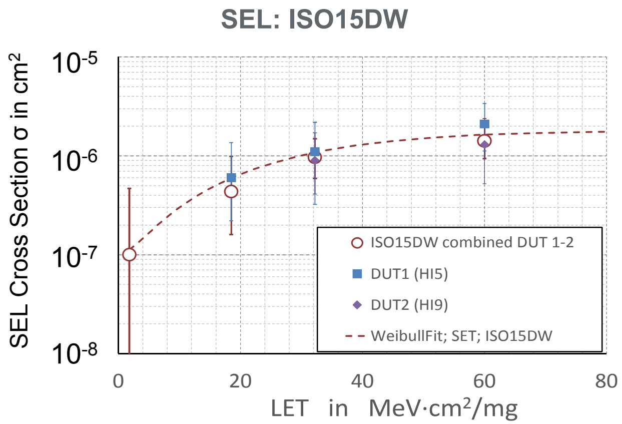
- Tested Parts: **ISO7220MDR, ISO15DW, MAX14850ASE+, Si8261ACC-C-IP**

- $LET_{surf,\ range}$: 1.8 – 60 MeV·cm²/mg
- Ions: $^{15}N^{+4}$ (1.83), $^{40}Ar^{+12}$(10.1), $^{56}Fe^{+15}$(18.5), $^{82}Kr^{+22}$(32.2), $^{131}Xe^{+35}$(60)
- Temperature: RT, 75°C

- SEE testing: **SEL, SET**
- Dielectric testing: **SEDIR**

- **No SEL** occurred for: **ISO7220MDR, MAX14850ASE+**
- **SET** occurred **for all part types** tested.





SEIBERSDORF LABORATORIES

SEE Results - Overview

Technology		Capacitive Coupling				Monolithic Transformer	
Manufacturer		**TI Texas Instruments**		**Maxim Integrated**	**Silicon Labs**	**Analog Devices**	
Investigated Part		**ISO7220MDR**	**ISO15DW**	**MAX14850SE+**	**Si8261ACC-C-IP**	**ADUM1201ARZ**	**ADUM11URZ**
SEE	Delidding						
	SEL	None	Yes $\sigma(Xe) = 10^{-6}\,cm^2$	None	Yes $\sigma(Xe)=2\cdot 10^{-4} cm^2$	None @protons	None @protons
	SET	Yes $\sigma(Fe) = 10^{-3}\,cm^2$	Yes $\sigma(Fe) = 10^{-3}\,cm^2$	Yes $\sigma(Xe)=4\cdot 10^{-5} cm^2$	Yes	None @protons	None @protons
	Dielectric withstand	N/A	N/A	Pass	Pass	Pass @protons	Pass @protons

Technology		Capacitive Coupling				Monolithic Transformer		Giant Magneto Resistant
Manufacturer		TI Texas Instruments		Maxim Integrated	Silicon Labs	Analog Devices		NVE[1] (IsoLoop)
Investigated Part		ISO7220MDR	ISO15DW	MAX14850ASE+	Si8261ACC-C-IP	ADUM1201ARZ	ADUM1100URZ	IL715-3E
Lot Code		4286983TW4[2] 4662957TN4[3]	4043232TN4	0001755035	1333CF600U	1TAK96092.9	AJ60138.5	132361, 135210
Date Code		-/1419	-	1406	-	-	1351	-
Numbers tested		50 / 15	44	52	57	51	57	45
TID	Parametric failure level	> 300 krad(Si)	10 krad(Si)	50 krad(Si)	30 krad(Si)	20 krad(Si)	20 krad(Si)	30 krad(Si)
	Functional failure level	> 300 krad(Si)	> 300 krad(Si)	100 krad(Si)	168 h @100°C	100 krad(Si)	N/A [4]	> 300 krad(Si)
	Dielectric withstand	100 krad(Si)	100 krad(Si)	> 300 krad(Si)	> 300 krad(Si)	>300 krad(Si)	> 300 krad(Si)	FAIL at 0 krad(Si)
	Recovery @	No	No	No	No	168 h @100°C	N/A [4]	partially yes
SEE	Delidding							N/A
	SEL	None	Yes $\sigma(Xe) = 10^{-6}\ cm^2$	None	YES $\sigma(Xe)=2\cdot10^{-4}cm^2$	None @protons	None @protons	N/A
	SET	Yes $\sigma(Fe) = 10^{-3}\ cm^2$	Yes $\sigma(Fe) = 10^{-3}\ cm^2$	Yes $\sigma(Xe)=4\cdot10^{-5}cm^2$	Yes	None @protons	None @protons	N/A
	Dielectric withstand	N/A	N/A	Pass	Pass	Pass @protons	Pass @protons	N/A
Electrons	Parametric failure level	46.9 krad(Si)	-	-	-	-	-	-
	Functional failure level	95.2 krad(Si)	-	-	-	-	-	-
	Recovery @	24h @RT	-	-	-	-	-	-
Neutrons	Parametric failure level	$> 9\cdot10^{11}$ $n(1MeV)\cdot cm^{-2}$	-	-	-	-	-	-
	Functional failure level	$> 9\cdot10^{11}$ $n(1MeV)\cdot cm^{-2}$	-	-	-	-	-	-

SEIBERSDORF LABORATORIES

Summary

- **TID** and **SEE** testing with digital isolators were **performed successfully**.
- Digital isolators based on **three technologies** have been tested:

  (1) capacitive coupling, **(2)** monolithic transformer, and **(3)** giant magnetoresistance.
- The **feasibility** of using **digital isolators in space applications** is shown for

  ISO7220MDR and MAX14850SE+ - both capacitive coupling
- Other capacitive coupled devices show high sensitivity to SEL!
- Components based on monolithic transformers
  - experienced to have **problems in deliding**:

    damage of the devices, coupling coils are covering a significant part of the die
  - proton tests indicate insusceptibility to SEE for LET < 15 MeV·cm²/mg.
- CMOS-based digital isolators are **not displacement damage sensitive** (as it is expected).

Recommendations

- **Further testing** of digital isolators is encouraged (DI offer excellent properties)
- **Low dose rate testing** is recommended (for explanation of time-dependent or rebound effects may explain some observations, e.g. functional failures after annealing at 100°C).
- **Further TID testing with electrons** is recommended using the same dose rate as for Co-60 testing (trade-off: limited availability and high costs).
- Testing with **heavy ions at higher energies** is recommended for those devices that show difficulties during delidding (trade-off: limited availability and high costs).
- Testing considering **lot-to-lot variations** is recommended.
- Testing the **part-to-part variance** within a single lot is recommended (elevated sample sizes).

Acknowledgements

The work has been carried out under ESA – Contract No. 4000112480/14/NL/SW; the support by the European Space Agency is acknowledged.

Further we acknowledge the support of the teams of the following irradiation facilities:

- Accredited Standard Radiation Laboratory, Seibersdorf Laboratories (SL), Austria
- MEDISCAN, E- Beam Technology, Kremsmünster, Austria
- TK1000A, Fraunhofer (INT), Euskirchen, Germany
- D711 n-generator, Fraunhofer (INT), Euskirchen, Germany
- Proton Irradiation Facility (PIF), Paul Scherrer Institute (PSI), Villigen, Switzerland
- Radiation Effects Facility (RADEF), University of Jyväskylä, Finland

SEIBERSDORF
LABORATORIES

RADHARD Symposium 2017 – 16th May 2017
Seibersdorf / Vienna, radhard.eu

RADHARD 2017

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RADHARD-Symposium 2017

May 16th, 2017

Seibersdorf Laboratories is organising the RADHARD-Symposium 2017, which will focus on Radiation Hardness Assurance Issues related to CubeSat space missions.

RADHARD-Symposium will focus on:

- CubeSat Space Mission
- Practical Aspects of Radiation Hardness Assurance
- Innovative Testing Developments and Future Needs

ORGANISER

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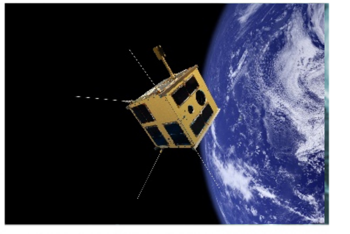

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Contact

Conference Organisation
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radhard(at)seibersdorf-laboratories.at

SEIBERSDORF LABORATORIES

RADHARD Symposium 2017 – 16th May 2017
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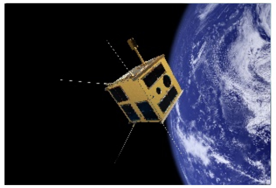
RADHARD

Preliminary Program

Update: March 06th, 2017

Tuesday, May 16th, 2017

08:30	**Registration**
09:30	**Welcome Notes by the General Manager of Seibersdorf Labor GmbH**
	Welcome Notes by the Head of Austrian Aeronautics and Space Agency
	Introduction and Scope of the Symposium
10:00	**Keynote** **CubeSat, COTS and Radiation Hardness Assurance**
10:45	Coffee Break
11:15	**Radiation Environment of CubeSat Mission**
11:45	**CubeSat Mission - RHA Experiences and Challenges I**
12:45	Lunch Buffet
13:30	**CubeSat Mission - RHA Experiences and Challenges II**
14:30	**Selected Topics in Components and System Testing**
15:00	Coffee Break
15:30	**Selected Topics in Radiation Hardness Assurance**
16:00	**Closing**
	Visit of the TEC-Laboratory



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