Design and development of a highly integrated and radiation-tolerant Software-Defined Radio (SDR) platform for space applications

Institute of Space Systems - Avionics Systems Department

Final Conference and Industrial & RADNEXT Public Kick-Off

17th – 20th May 2021

Jan Budroweit

Knowledge for Tomorrow

DLR

RADSAGA

CERN

About the speaker

Jan Budroweit

- Studied Communication and Information Technologies in Hamburg
- Since 2013 at DLR as scientist and engineer
- Responsible engineer for the communication subsystem at the Eu:CROPIS mission (launched in 2018 – second satellite mission fully supported by DLR)
- PhD candidate at TU Hamburg-Harburg

- Research activities
  - Future radio systems for space missions (communications and payload)
  - Radiation effects on electronics and systems

Outline

- Background and Motivation
- Risk Assessment Approach for COTS Usage in Space
- Radiation Testing on RFIC
- System-Level Verification
- Conclusion

Background and Motivation

Knowledge for Tomorrow

State of the art radio systems for space missions

- Radio systems for spacecraft/satellites are usually designed and develop for one specific application:
  - ➢ GPS-Receiver
  - ➢ TV-Broadcast
  - ➢ Satellite communication (TM/TC)
  - ➢ Radio and RF Payloads (e.g. AIS, ADS-B, …)
  - ➢ …

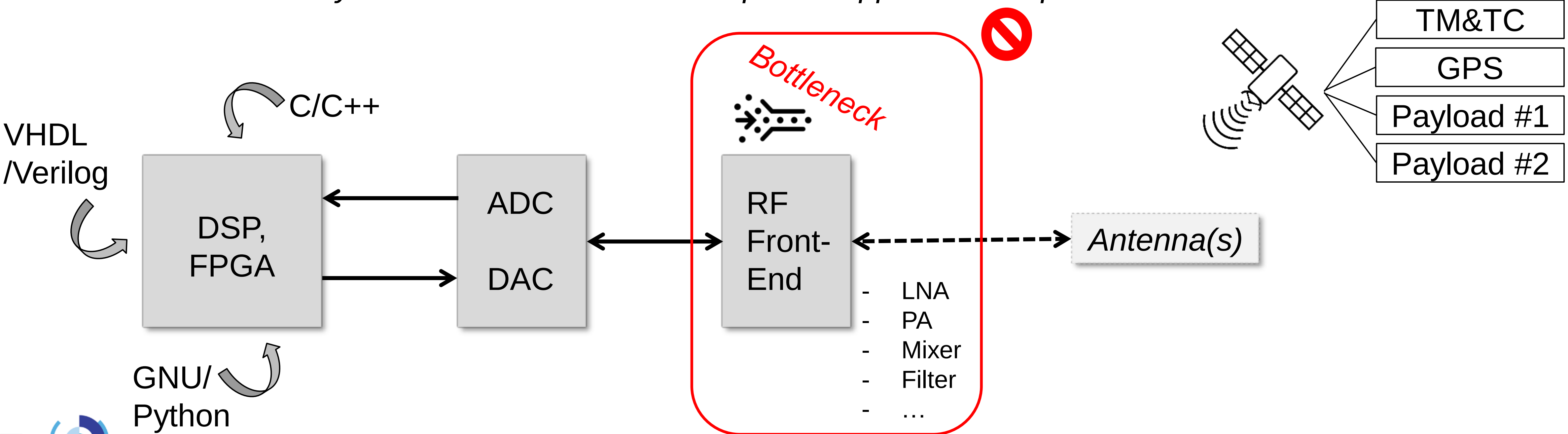
- In the beginning, such radio system were designed discretely
  - ✓ Very robust and reliable
  - – No flexibility
  - – Very large systems

- Software-Defined Radio (SDR) systems already established over the past decades in space
  - ✓ More flexibility in terms of data/signal processing adaption
  - ✓ Smaller systems
  - – Just for a single application (e.g. GPS Receiver)

What is a Software-Defined Radio (SDR)?

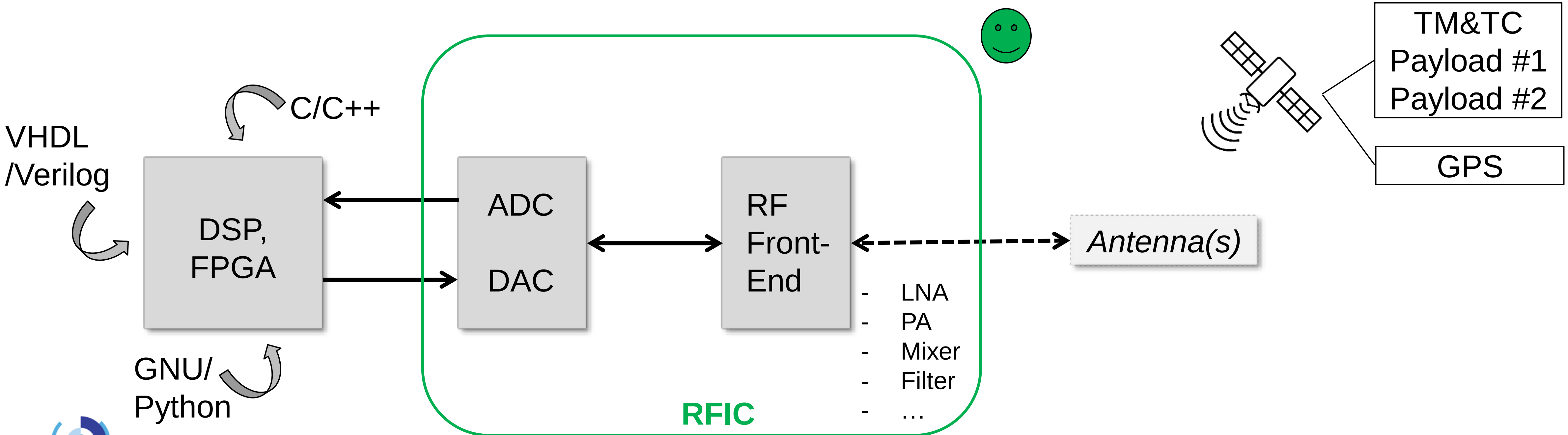
- A SDR usually defines the signal processing in software:
  - Implementation on a DSP or FPGA
- Also consist of:
  - ADC and DAC
  - RF Front-End

➢ *RF Front-End mostly untouched and tailored to specific application requirements*



The Generic Software-Defined Radio (GSDR)

- RF Front-Ends can now be configures by software thanks to RF Integrated Circuits (RFIC)
  - ➢ A single hardware (radio) for operating multiple applications (two/three/four in one)
    - ▪ 10%: TM&TC SatCom <-> 90%: RF Payload (ADS-B Receiver, AIS Receiver, Spectral Monitoring, …)
  - ➢ **Better utilization of limited resources (size, weight, power, …) on a spacecraft**



Constraints with RFICs

RFICs (AD9361) for SDR systems

Pros
- ✓ Frequency selection: 70 MHz to 6 GHz
- ✓ Adaptive sample rates: up to 64 MSPS
- ✓ Integrated RF technology (e.g. amplifiers, filter, ...).
- ✓ Small device
- ✓ “Low” power consumption

Cons
- – Limited availability and manufacturers
- – Very complex and highly integrated ICs
- – High requirements (power, noise, stability, …)
- – Compatibility to FPGAs or Processors
- – **Not designed for the use in space!**

→ Use of COTS Devices for space applications?

Risk Assessment Approach for COTS Usage in Space

Knowledge for Tomorrow

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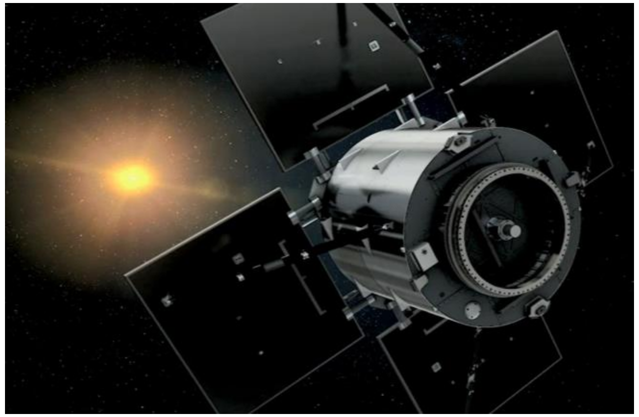
Space mission survey

Traditional space missions

- High costs
- Low risk acceptance
- Intense QA
- Avoidance of COTS usage
- Long development time
- Standardization (ECSS)
  - ➢ High success rate

CubeSat space missions

- Low costs
- High risk acceptance
- No QA
- COTS usage (only)
- Fast development time
- No standardization
  - ➢ Low success rate



Eu:CROPIS, source: DLR

Huge gap between both mission approaches

Qtum’s CubeSat , source: Qtum Foundation

Space mission survey

<u>Traditional space missions</u>

- High costs
- Low risk acceptance
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- Avoidance of COTS usage
- Long development time
- Standardization (ECSS)
  - ➢ High success

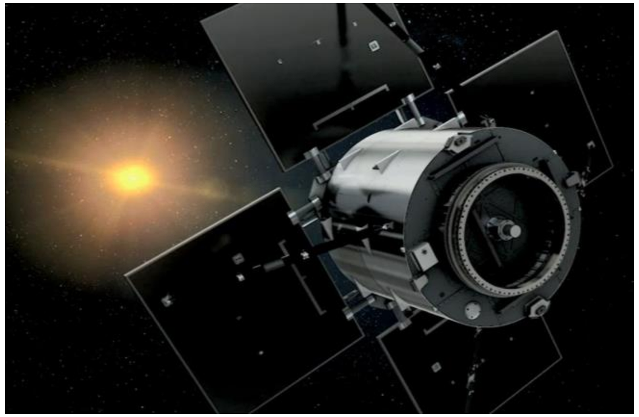
<u>NewSpace missions</u>

- *Lower costs*
- *Medium risk acceptance*
- *COTS usage preferred*
- *Faster development time*

New Approach, no standards defined yet

<u>CubeSat space missions</u>

- Low costs
- High risk acceptance
- No QA
- COTS usage (only)
- Fast development time
- No standardization
  - ➢ Low success



Eu:CROPIS, source: DLR

Huge ga

SpaceX StarLink Satellite(s), source: GunterSpace

roaches

Qtum’s CubeSat , source: Qtum Foundation

Considerations for the Use of COTS

STRENGTHS	WEAKNESSES
Functional performance	Poor control of supply chain
Latest technologies	Obsolescence and counterfeit
Availability on stock	Limited technology insight
Fast proof-of-concept	Testability of devices
Competitive market	Limited qualification from manufacturer
Low costs compared to space EEE parts	Up-screening efforts (RHA, RLAT)
ITAR free	

Radiation Hardness Assurance (RHA) for COTS

- Using COTS in space is not new, but becomes more and more important due to NewSpace
- Usually, for traditional space missions, those COTS devices were completely up-screened (e.g., according to ECSS)
  - ➢ *Not unlikely that up-screening costs are higher than a comparable space-qualified EEE part*
- To avoid the expensive up-screening, RHA can be mainly considered since radiation is the most critical environmental stress.

✓ Certain publications were published for RHA on COTS (also given as guidelines from NASA).

  - RHA approaches mainly based on engineering judgment or does not cover a system-point of view (in terms of failure propagation)

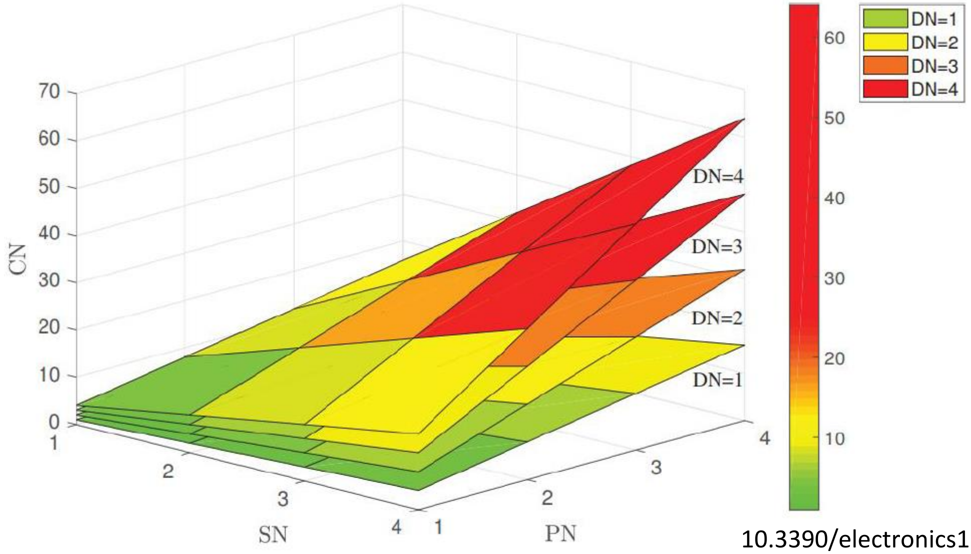
  - ➢ **A numerical-based criticality analysis for RHA would be beneficial**
  - ➢ **A RHA approach that also covers the system perspective of view**
  - ➢ **A guidance on how to select between COTS and RadHard / space-qualified EEE parts**

Risk Assessment for the Use of COTS

FMECA-based RHA approach

- The proposed RHA approach is based on the Failure Mode, Effects and **Criticality** Analysis (FMECA)
- Well known tool in space quality assurance for criticality analysis
- Based on three parameter:
  - Severity Number (**SN**)
  - Probability Number (**PN**)
  - Detection Number (**DN**)

$$CN = SN \times PN \times DN$$



10.3390/electronics10091008, source: Budroweit et. al

Severity Level	Severity Number (SN)	Severity Category	Failure Effect
1	4	Catastrophic	Propagation of failure to other systems, assemblies or equipment
2	3	Critical	Loss of functionality
3	2	Major	Degradation of functionality
4	1	Negligible	Minor or no effect

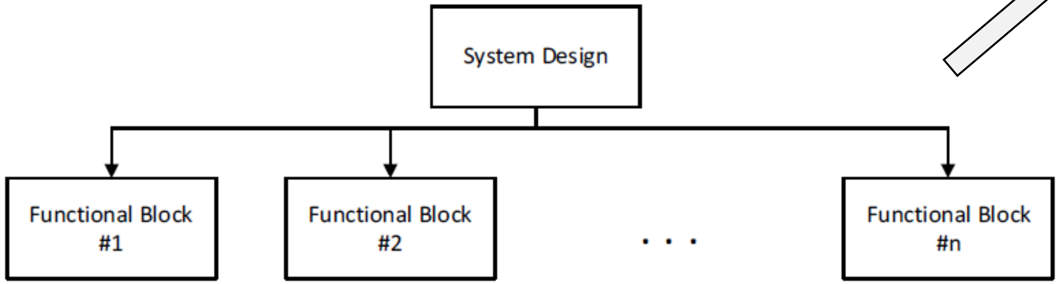
PN Level	PN Limits	PN
Very likely	$P > 1 \times 10^{-1}$	4
Likely	$1 \times 10^{-3} < P \leq \times 10^{-1}$	3
Unlikely	$1 \times 10^{-5} < P \leq \times 10^{-3}$	2
Very unlikely	$P \leq 1 \times 10^{-5}$	1

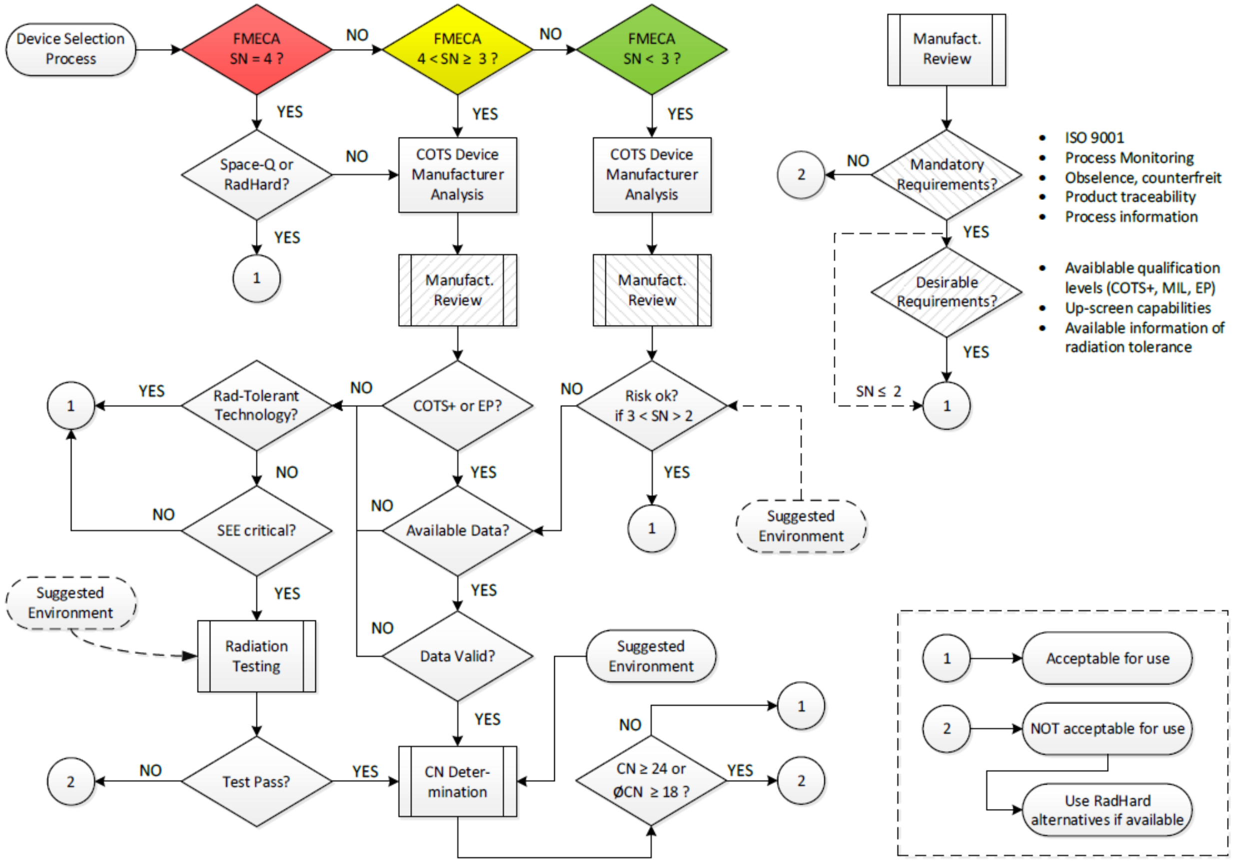
DN	Definition
4	Very unlikely
3	Unlikely
2	Likely
1	Very likely

Risk Assessment for the Use of COTS

FMECA-based RHA approach

- The FMECA-based RHA approach follows the following stages:
  - *Step 1*: System level breakdown structure into functional block design
  - *Step 2*: FMECA-based severity analysis performed on functional blocks
  - *Step 3*: Technology assessment and rating on functional blocks
  - *Step 4*: Evaluation of the FMECA-based criticality of selected devices.





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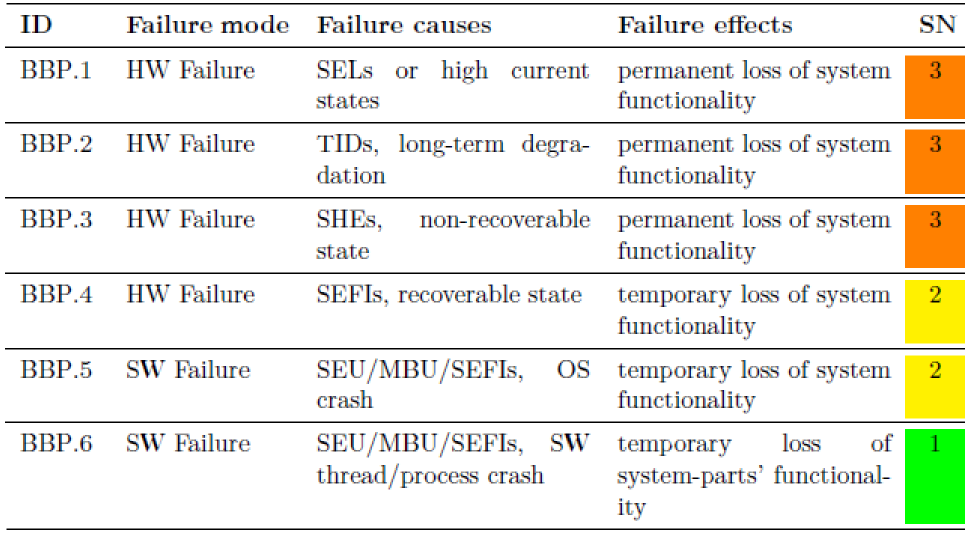
Risk Assessment for the Use of COTS

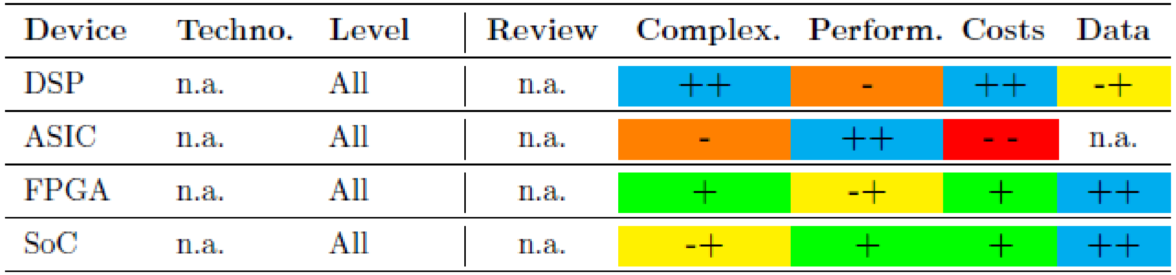
FMECA-based RHA approach: Example on a baseband processor

Step 2: Severity analysis

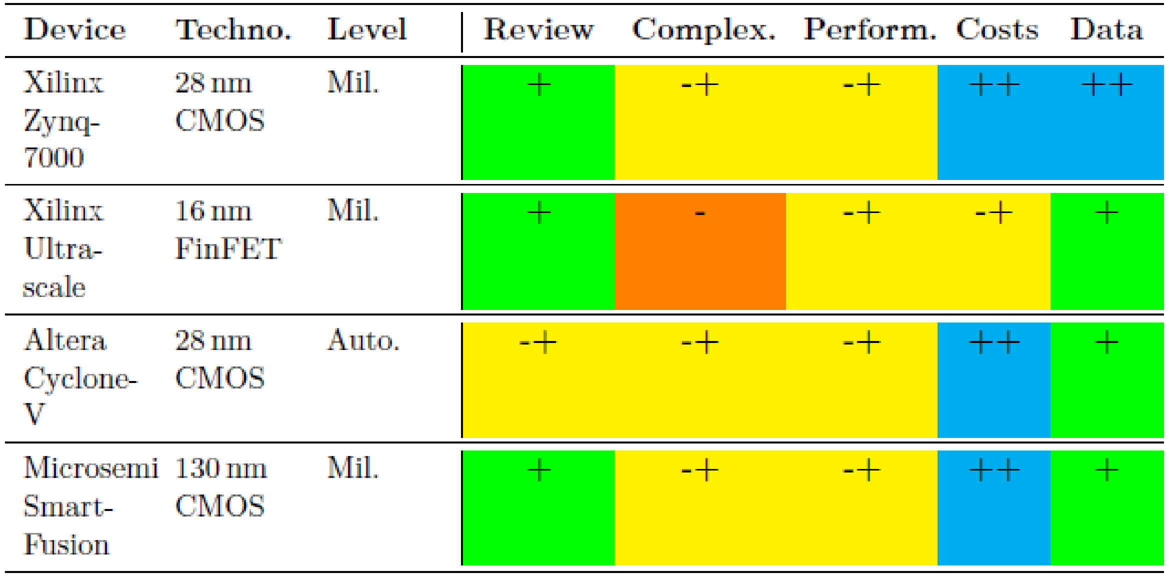


ID	Failure mode	Failure causes	Failure effects	SN
BBP.1	HW Failure	SELs or high current states	permanent loss of system functionality	3
BBP.2	HW Failure	TIDs, long-term degradation	permanent loss of system functionality	3
BBP.3	HW Failure	SHEs, non-recoverable state	permanent loss of system functionality	3
BBP.4	HW Failure	SEFIs, recoverable state	temporary loss of system functionality	2
BBP.5	SW Failure	SEU/MBU/SEFIs, OS crash	temporary loss of system functionality	2
BBP.6	SW Failure	SEU/MBU/SEFIs, SW thread/process crash	temporary loss of system-parts' functionality	1

Step 3: Technology and device survey



Device	Techno.	Level	Review	Complex.	Perform.	Costs	Data
DSP	n.a.	All	n.a.	++	-	++	-+
ASIC	n.a.	All	n.a.	-	++	- -	n.a.
FPGA	n.a.	All	n.a.	+	-+	+	++
SoC	n.a.	All	n.a.	-+	+	+	++



Device	Techno.	Level	Review	Complex.	Perform.	Costs	Data
Xilinx Zynq-7000	28 nm CMOS	Mil.	+	-+	-+	++	++
Xilinx Ultrascale	16 nm FinFET	Mil.	+	-	-+	-+	+
Altera Cyclone-V	28 nm CMOS	Auto.	-+	-+	-+	++	+
Microsemi Smart-Fusion	130 nm CMOS	Mil.	+	-+	-+	++	+

PhD thesis, source: Budroweit

FMECA-based RHA approach: Example on a baseband processor

Step 2: Severity analysis

ID	Failure mode	Failure causes	Failure effects	SN
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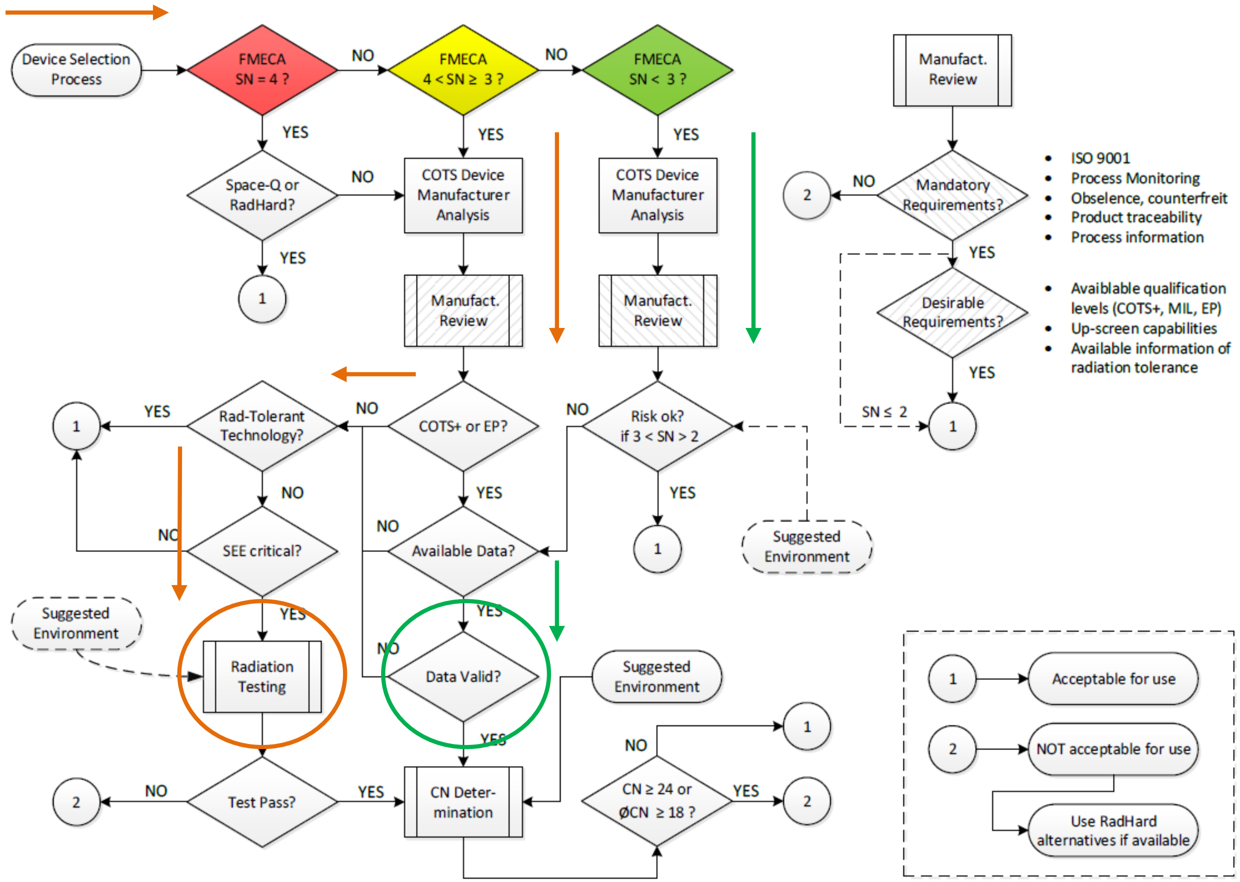
BBP.3	HW Failure	SHEs, non-recoverable state	permanent loss of system functionality	3
BBP.4	HW Failure	SEFIs, recoverable state	temporary loss of system functionality	2
BBP.5	SW Failure	SEU/MBU/SEFIs, OS crash	temporary loss of system functionality	2
BBP.6	SW Failure	SEU/MBU/SEFIs, SW thread/process crash	temporary loss of system-parts' functionality	1



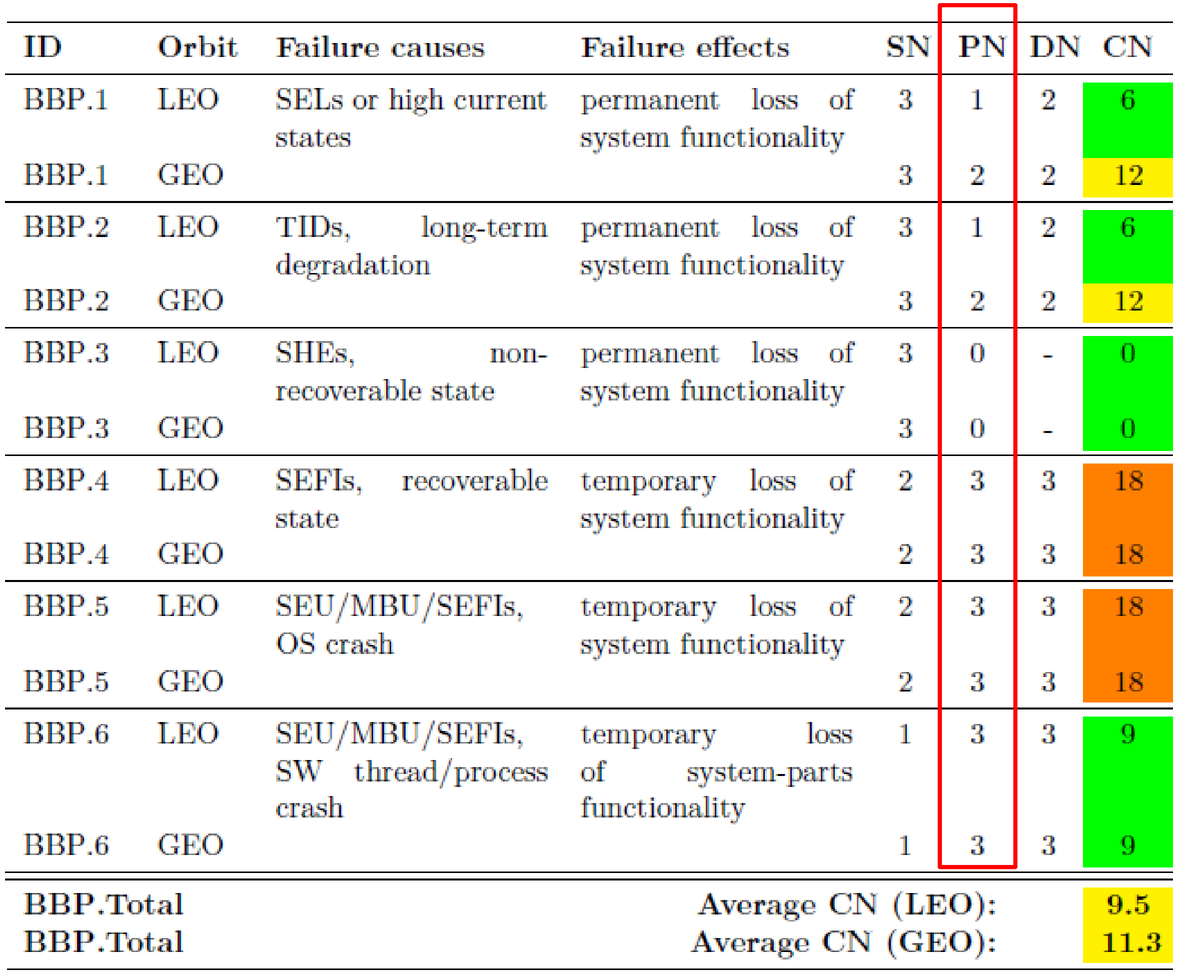
PhD thesis, source: Budroweit

FMECA-based RHA approach: Example on a baseband processor

__Step 4: Criticality analysis__

SEE Type	Orbit	LET threshold [MeV·cm²/mg]	Limit cross-section [cm²/bit;dev]	Events/day (nominal)	Events/day (worst)
SEL	GEO	$1.23 \times 10^{+1}$	2.98×10^{-4}	5.02×10^{-5}	5.66×10^{-3}
SEL	LEO	$1.23 \times 10^{+1}$	2.98×10^{-4}	2.01×10^{-5}	1.41×10^{-3}
CRAM	GEO	1.00×10^{-3}	1.60×10^{-9}	1.36×10^{-8}	3.23×10^{-6}
CRAM	LEO	1.00×10^{-3}	1.60×10^{-9}	1.04×10^{-8}	7.67×10^{-7}
BRAM	GEO	1.00×10^{-3}	5.31×10^{-9}	2.37×10^{-8}	5.80×10^{-6}
BRAM	LEO	1.00×10^{-3}	5.31×10^{-9}	1.83×10^{-8}	1.38×10^{-6}
OCM	GEO	1.00×10^{-3}	2.40×10^{-9}	4.96×10^{-8}	1.38×10^{-5}
OCM	LEO	1.00×10^{-3}	2.40×10^{-9}	4.34×10^{-8}	3.26×10^{-6}
Sobel	ISS	-	6.61×10^{-9}	-	1.2×10^{-2}
Processor	ISS	-	5.70×10^{-9}	-	1.4×10^{-2}

PhD thesis, source: Budroweit

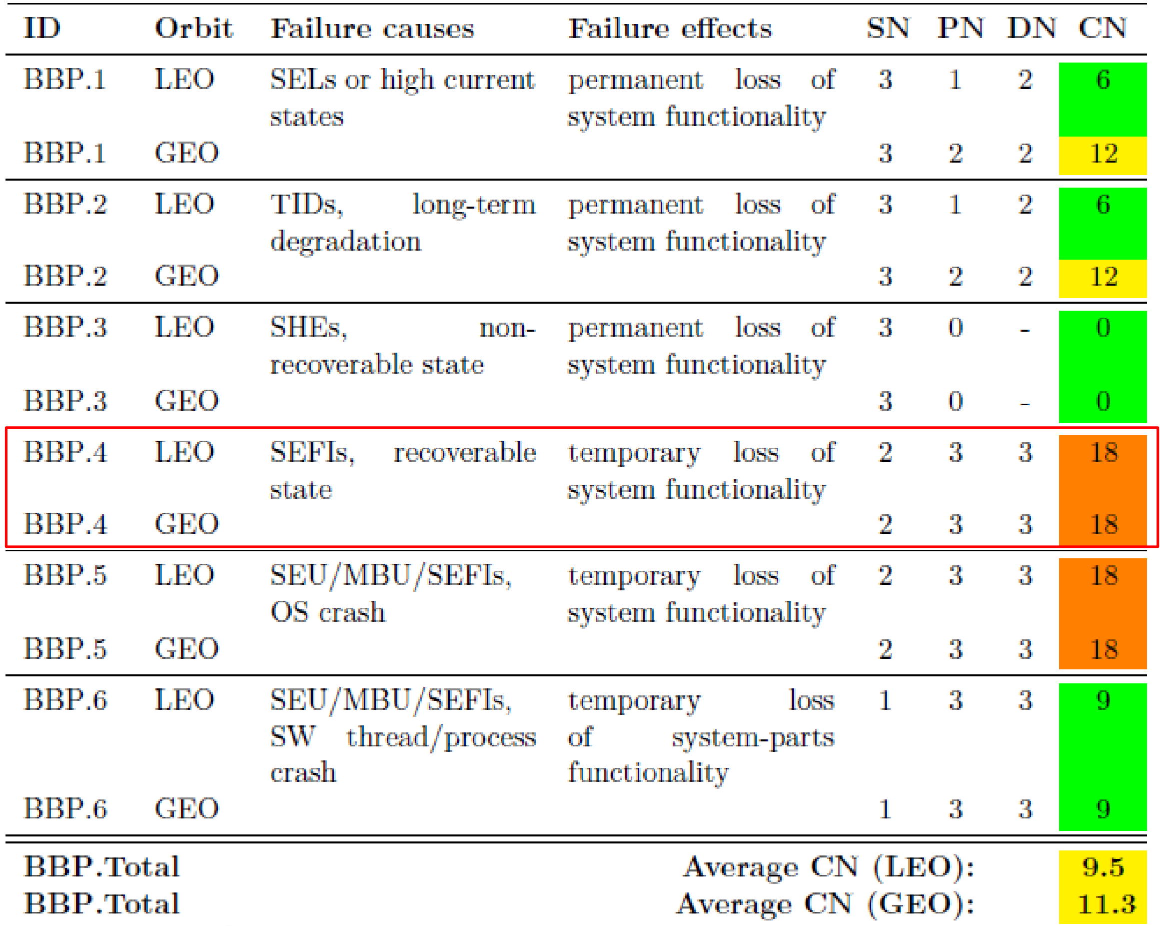


ID	Orbit	Failure causes	Failure effects	SN	PN	DN	CN
BBP.1	LEO	SELs or high current states	permanent loss of system functionality	3	1	2	6
BBP.1	GEO			3	2	2	12
BBP.2	LEO	TIDs, long-term degradation	permanent loss of system functionality	3	1	2	6
BBP.2	GEO			3	2	2	12
BBP.3	LEO	SHEs, non-recoverable state	permanent loss of system functionality	3	0	-	0
BBP.3	GEO			3	0	-	0
BBP.4	LEO	SEFIs, recoverable state	temporary loss of system functionality	2	3	3	18
BBP.4	GEO			2	3	3	18
BBP.5	LEO	SEU/MBU/SEFIs, OS crash	temporary loss of system functionality	2	3	3	18
BBP.5	GEO			2	3	3	18
BBP.6	LEO	SEU/MBU/SEFIs, SW thread/process crash	temporary loss of system-parts functionality	1	3	3	9
BBP.6	GEO			1	3	3	9
BBP.Total			**Average CN (LEO):**				**9.5**
BBP.Total			**Average CN (GEO):**				**11.3**

Risk Assessment for the Use of COTS

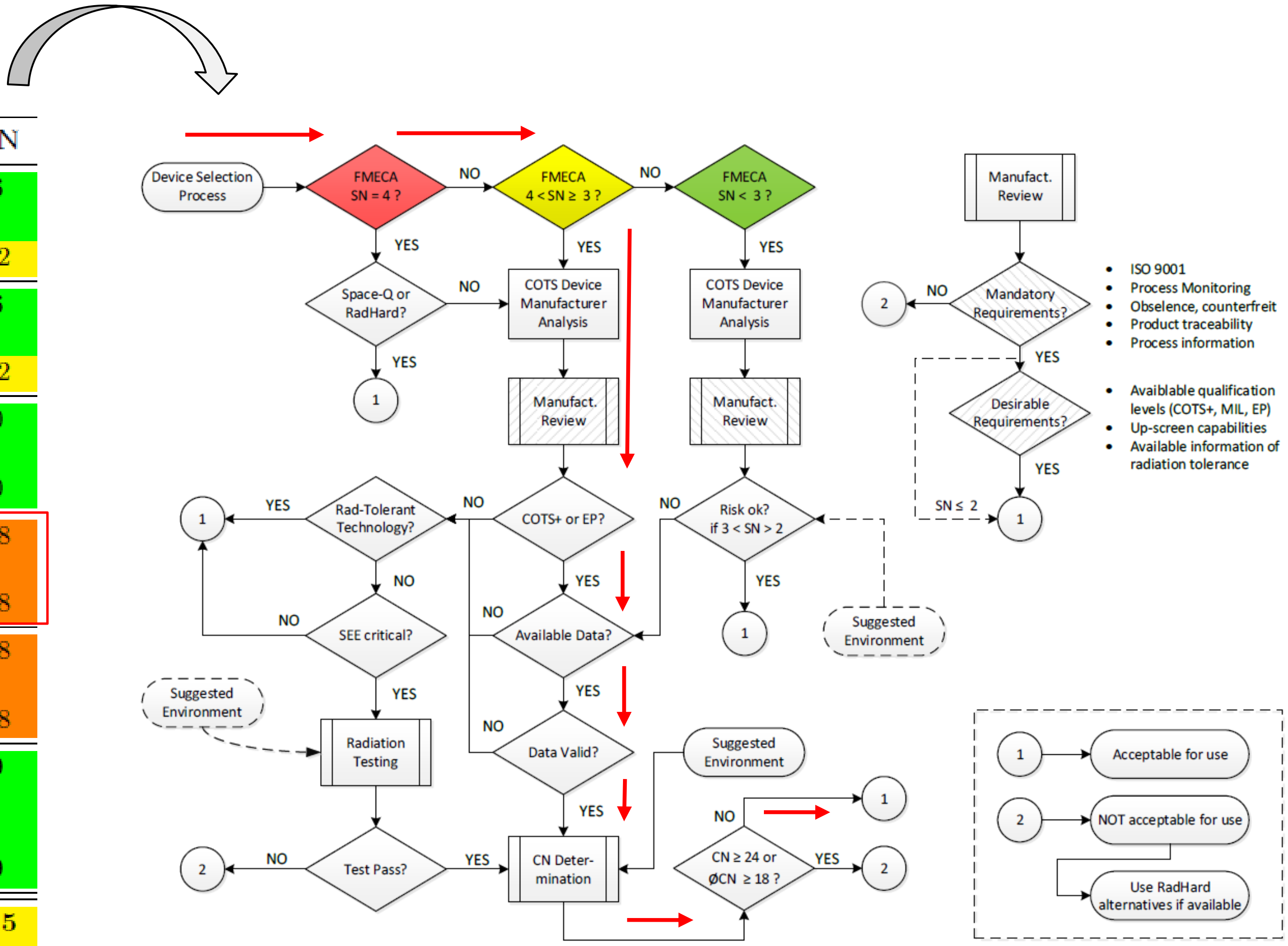
FMECA-based RHA approach: Example on a baseband processor

Step 4: Criticality analysis



ID	Orbit	Failure causes	Failure effects	SN	PN	DN	CN
BBP.1	LEO	SELs or high current states	permanent loss of system functionality	3	1	2	6
BBP.1	GEO			3	2	2	12
BBP.2	LEO	TIDs, long-term degradation	permanent loss of system functionality	3	1	2	6
BBP.2	GEO			3	2	2	12
BBP.3	LEO	SHEs, non-recoverable state	permanent loss of system functionality	3	0	-	0
BBP.3	GEO			3	0	-	0
BBP.4	LEO	SEFIs, recoverable state	temporary loss of system functionality	2	3	3	18
BBP.4	GEO			2	3	3	18
BBP.5	LEO	SEU/MBU/SEFIs, OS crash	temporary loss of system functionality	2	3	3	18
BBP.5	GEO			2	3	3	18
BBP.6	LEO	SEU/MBU/SEFIs, SW thread/process crash	temporary loss of system-parts functionality	1	3	3	9
BBP.6	GEO			1	3	3	9
BBP.Total			**Average CN (LEO):**				**9.5**
BBP.Total			**Average CN (GEO):**				**11.3**

PhD thesis, source: Budroweit



- ISO 9001
- Process Monitoring
- Obselence, counterfreit
- Product traceability
- Process information

- Avaiblable qualification levels (COTS+, MIL, EP)
- Up-screen capabilities
- Available information of radiation tolerance

Radiation Testing on RFIC

Knowledge for Tomorrow

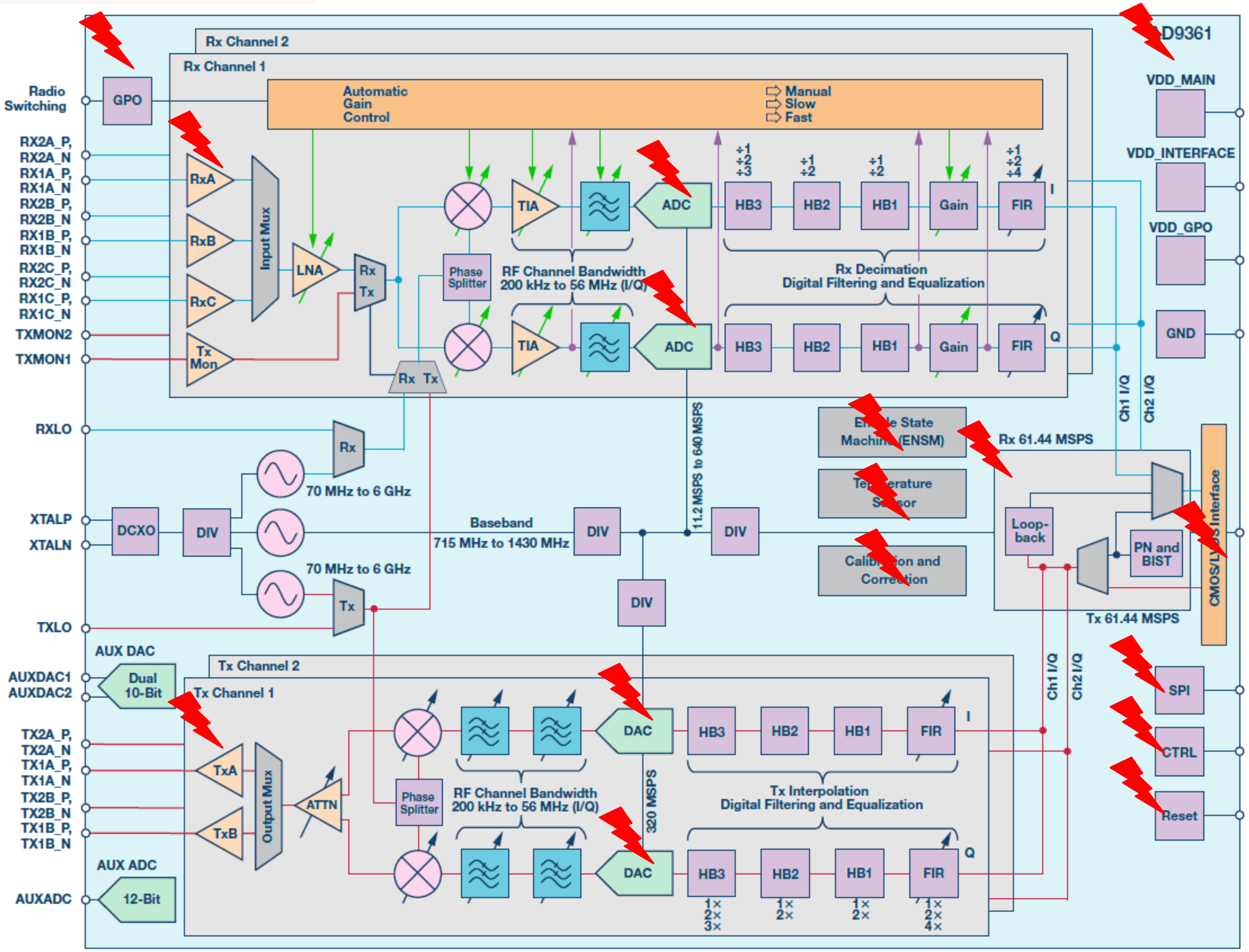
Radiation Testing on RFICs

RFIC - AD9361

- AD9361
  - Based on 65nm CMOS
  - ADC/DAC
  - Analog Technologies (e.g. Amps)
  - Synthesizer
  - Register
  - State machine
  - Digital Interfaces

- SEE susceptibility
  - SELs
  - SEUs, MBUs
  - SETs
  - SEFIs

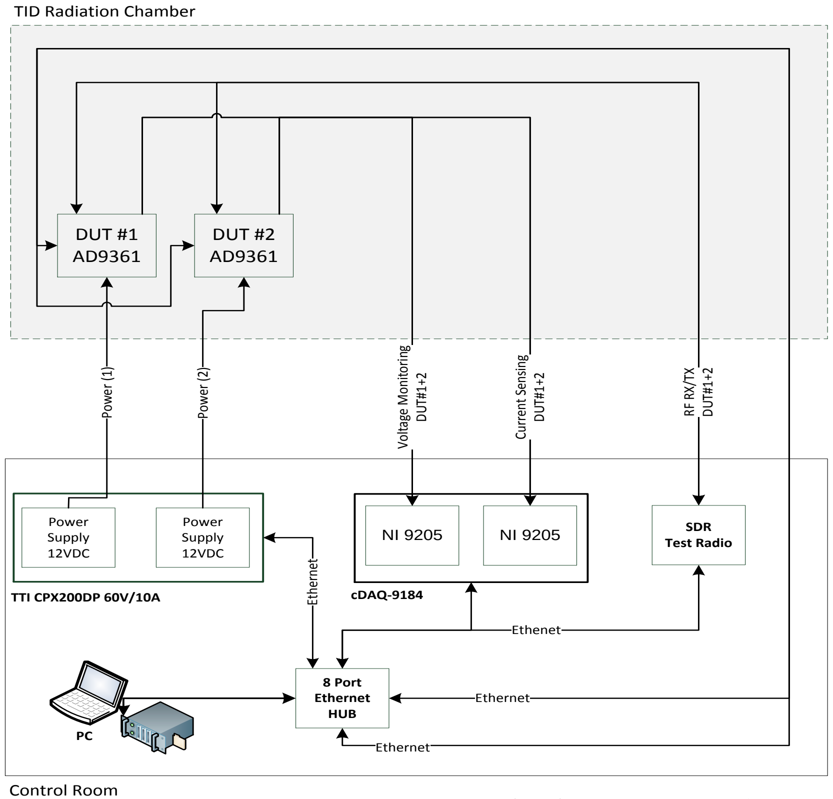
How to test such a complex device?!



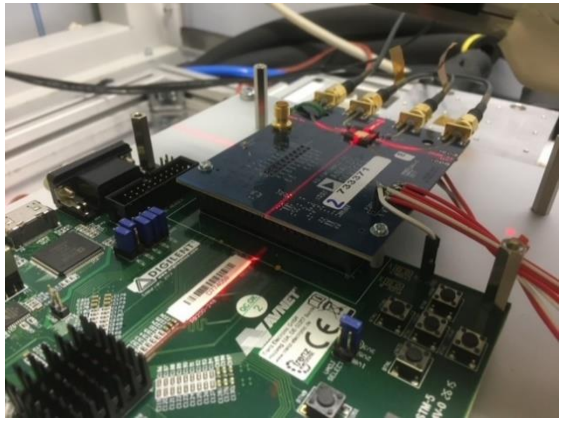
AD9361, source: Analog Devices

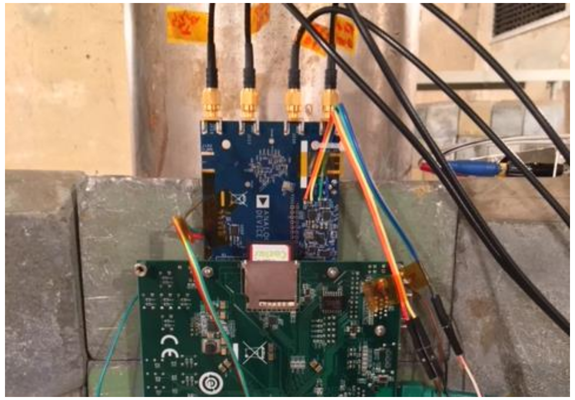
Total ionizing dose effects testing

- Automatic test procedure that allows detailed investigation:
    - Current condition
    - State machine control
    - RX/TX Amplifiers
    - Mixer
    - Synthesizer/ADC/DAC
    - Filter response
    - …
- AD9361 is installed on daughterboard (blue) and is not surrounded by other sensitive devices (good DUT isolation)
- Carrier-board interfaces DUT and allows data access and controlling (shielded by lead bricks)



PhD thesis, source: Budroweit

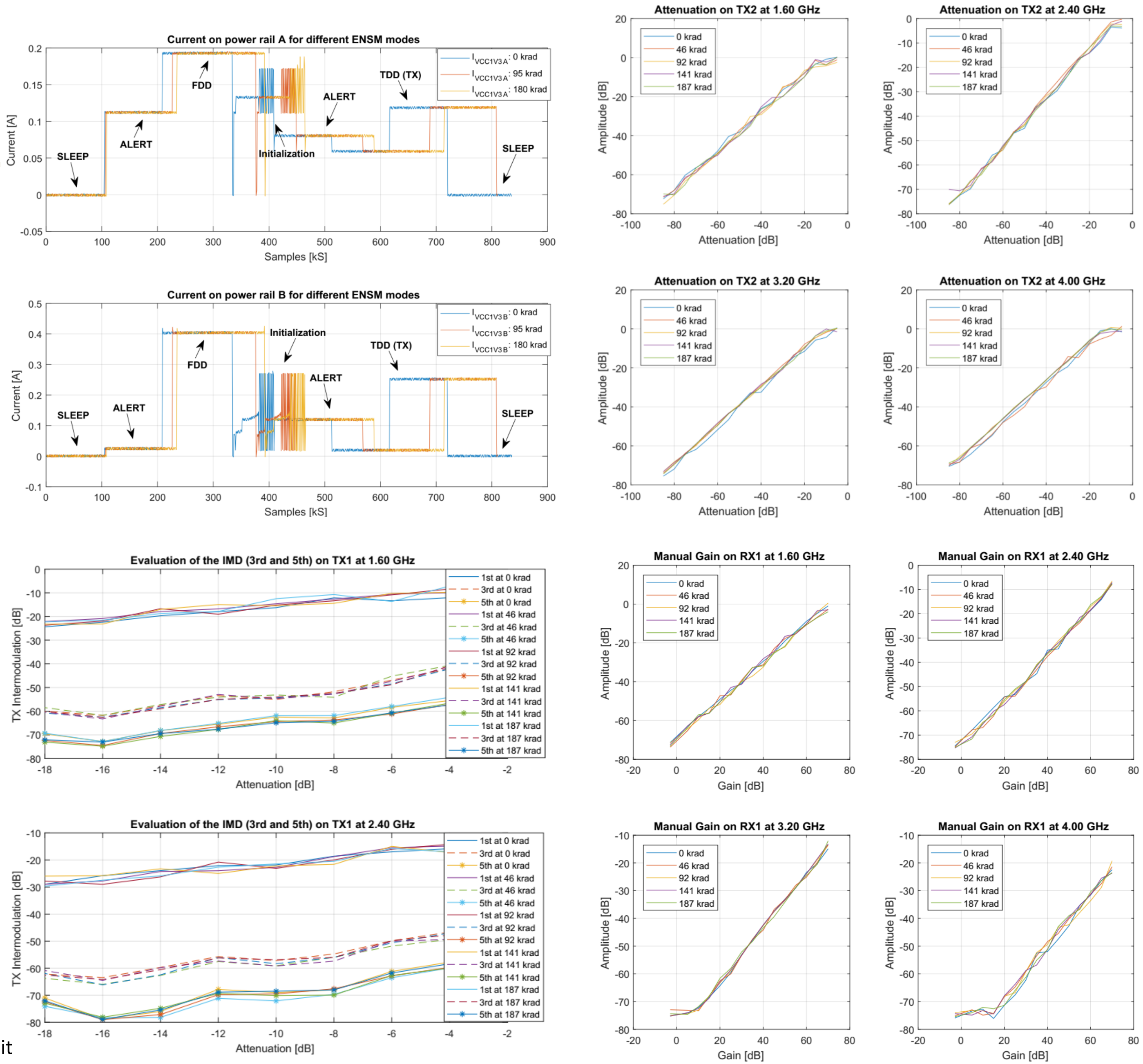




Radiation Testing on RFICs

Total ionizing dose effects testing

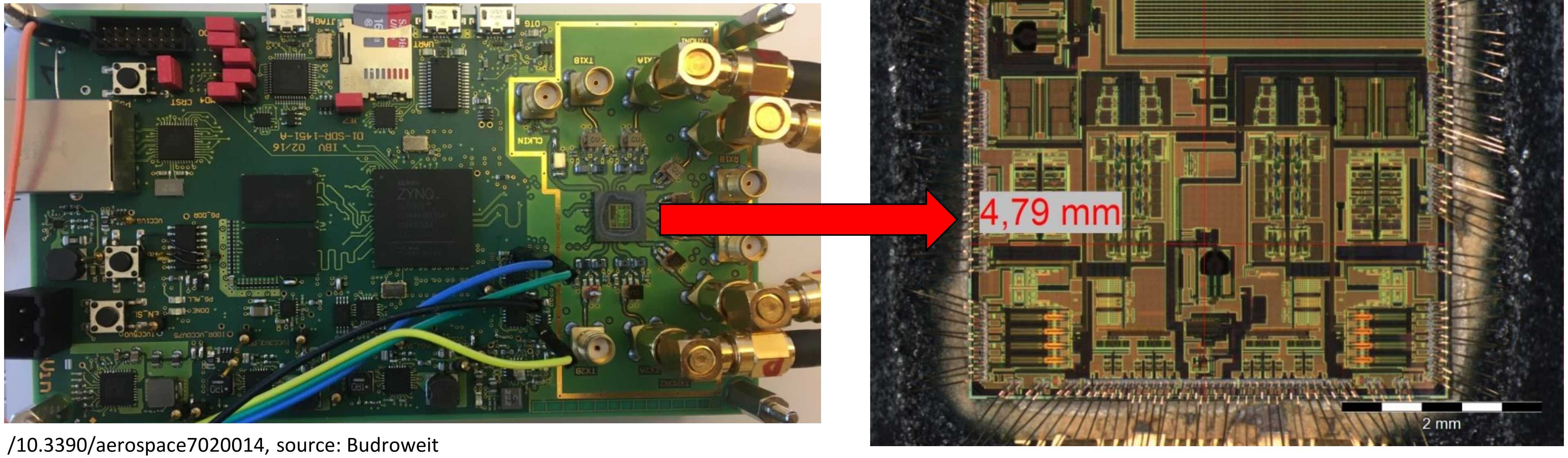
- Co-60 Source of HZB (Potsdam) and X-Ray machine from CERN
- Three tests in total:
    - Co60: 2015 + 2018
        - Target dose: >190 krad(SiO2)
        - Dose rate: 11.5 krad(SiO2)/h
        - Samples: 2
    - X-Ray: 2019
        - Target dose: 80Mrad(SiO2)
        - Dose rate: 4.1 Mrad(SiO2)/h
        - Samples: 2



PhD thesis, source: Budroweit

Single event effects testing

- Single Event Effects testing performed under Proton and Heavy Ion
  - Proton: up to 190MeV (@KVI, Groningen, NL)
  - Heavy Ion: up to $LET_{(eff)}$ = 125 MeV.cm²/mg (@ UCL, Louvain la euve, BL)
- Test board has been developed for this propose
- Decapping required
- Two samples tested

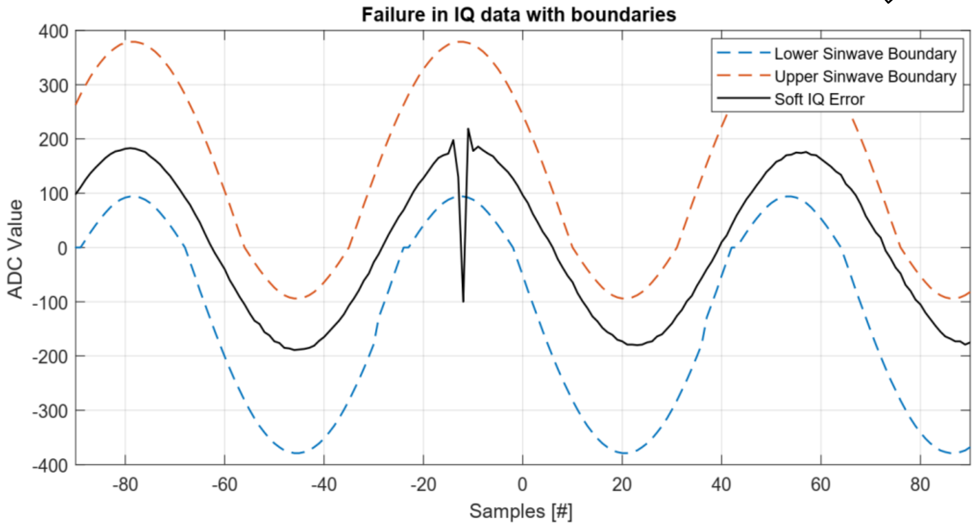


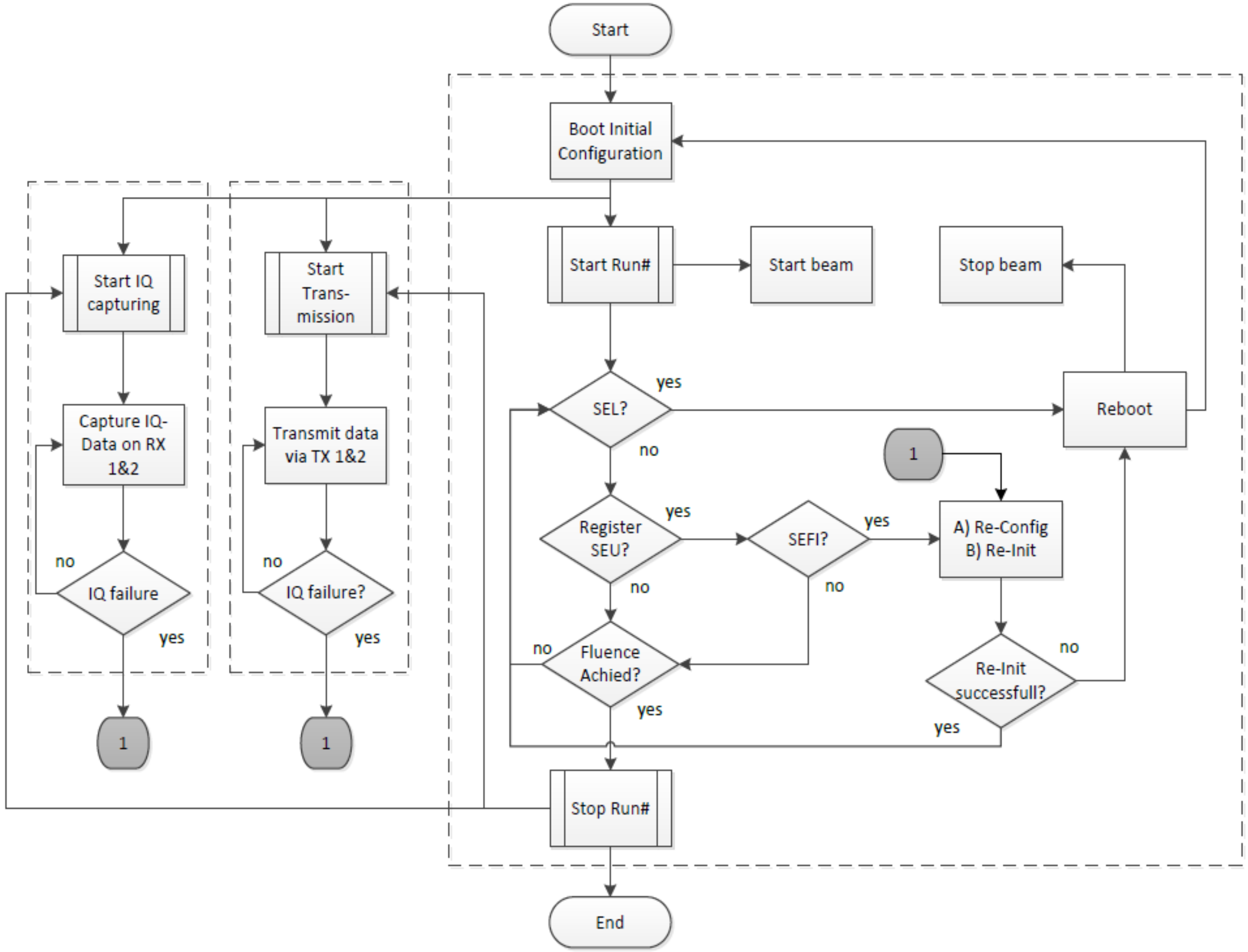
/10.3390/aerospace7020014, source: Budroweit

Radiation Testing on RFICs

Single event effects testing

- Complex test setup and procedure
- Scrubbing of registers
- Functional validation
- Independent RF Data evaluation (IQ Data)
- Automatic recovery

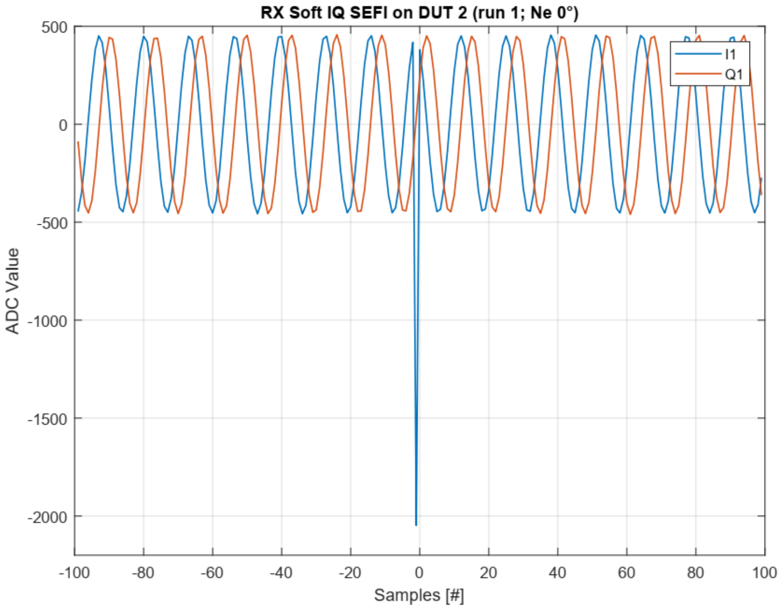



Start
Boot Initial Configuration
Start IQ capturing
Capture IQ-Data on RX 1&2
no
IQ failure
yes
1
Start Trans-mission
Transmit data via TX 1&2
no
IQ failure?
yes
1
Start Run#
Start beam
Stop beam
SEL?
yes
no
Reboot
1
Register SEU?
yes
SEFI?
yes
A) Re-Config B) Re-Init
no
no
no
Fluence Achied?
yes
no
Re-Init successfull?
yes
Stop Run#
End

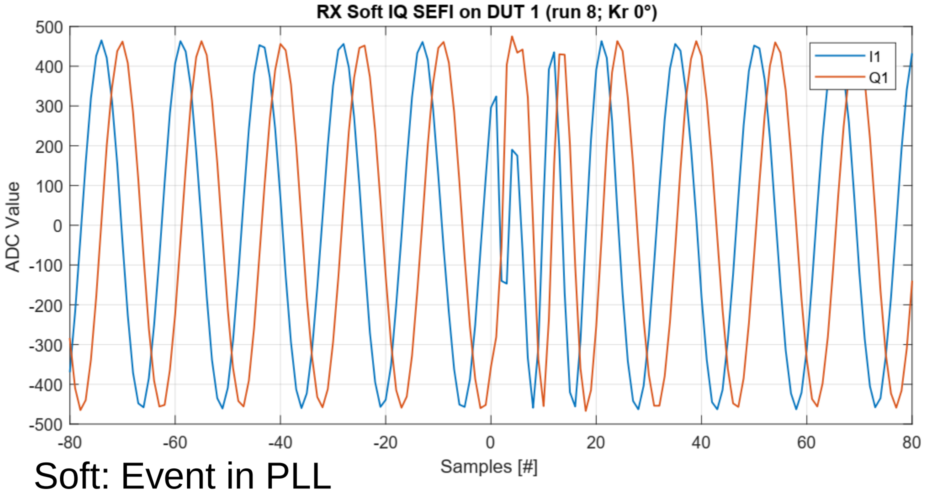
/10.3390/aerospace7020014, source: Budroweit

Single event effects testing

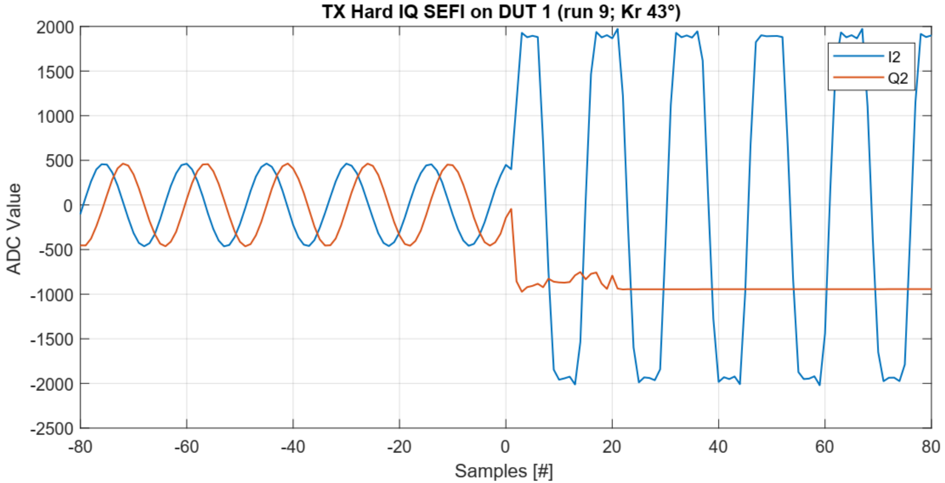
Examples of IQ Failures / Signatures



Soft: SEU in ADC



Soft: Event in PLL



Hard: Loss of IQ data

PhD thesis, source: Budroweit

Radiation Testing on RFICs

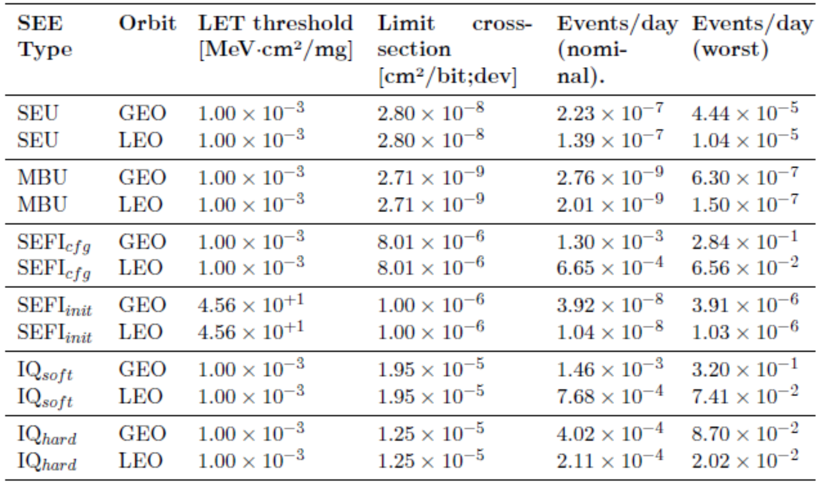
Single event effects testing

- No destructive events
- Very good SEE response
- Many SEUs, often not critical
- Mainly recovered by re-configuration
- IQ Failures: 50% hard; 50% soft
- Hard IQ Failure recovered by re-initialization

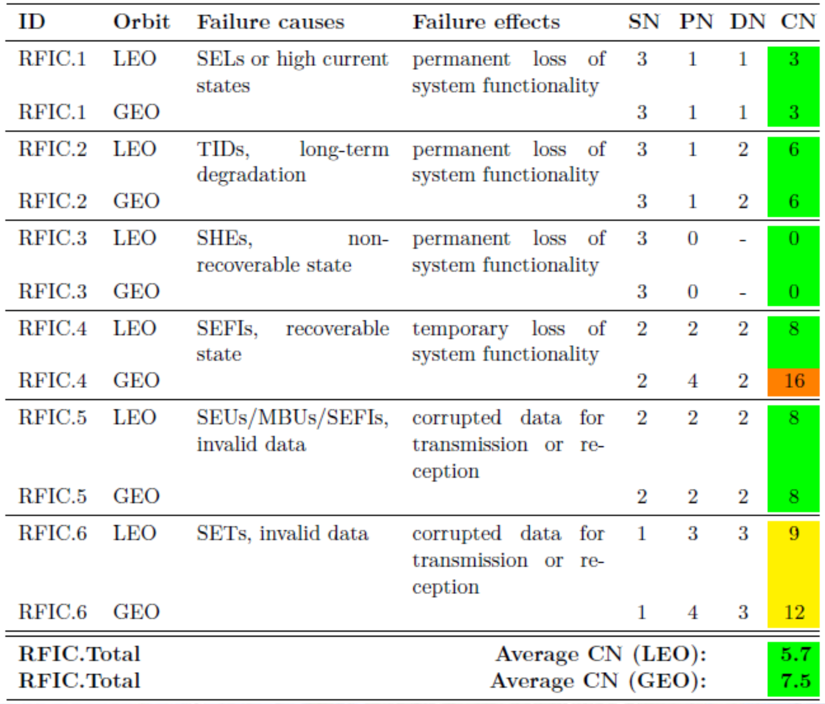
- Results presented for Heavy Ions
- Proton response much lower (in order of ~10 events)
- Performing the FMECA-based RHA results into a very low criticality:

GEO (15yr) and LEO (2yr, 800km, SSO) reference mission:

  - ➢ Nominal conditions: YEARS for failure
  - ➢ Worst conditions: DAYS for failure



SEE Type	Orbit	LET threshold [MeV·cm²/mg]	Limit cross-section [cm²/bit;dev]	Events/day (nominal).	Events/day (worst)
SEU	GEO	1.00×10^{-3}	2.80×10^{-8}	2.23×10^{-7}	4.44×10^{-5}
SEU	LEO	1.00×10^{-3}	2.80×10^{-8}	1.39×10^{-7}	1.04×10^{-5}
MBU	GEO	1.00×10^{-3}	2.71×10^{-9}	2.76×10^{-9}	6.30×10^{-7}
MBU	LEO	1.00×10^{-3}	2.71×10^{-9}	2.01×10^{-9}	1.50×10^{-7}
SEFI_{cfg}	GEO	1.00×10^{-3}	8.01×10^{-6}	1.30×10^{-3}	2.84×10^{-1}
SEFI_{cfg}	LEO	1.00×10^{-3}	8.01×10^{-6}	6.65×10^{-4}	6.56×10^{-2}
SEFI_{init}	GEO	$4.56 \times 10^{+1}$	1.00×10^{-6}	3.92×10^{-8}	3.91×10^{-6}
SEFI_{init}	LEO	$4.56 \times 10^{+1}$	1.00×10^{-6}	1.04×10^{-8}	1.03×10^{-6}
IQ_{soft}	GEO	1.00×10^{-3}	1.95×10^{-5}	1.46×10^{-3}	3.20×10^{-1}
IQ_{soft}	LEO	1.00×10^{-3}	1.95×10^{-5}	7.68×10^{-4}	7.41×10^{-2}
IQ_{hard}	GEO	1.00×10^{-3}	1.25×10^{-5}	4.02×10^{-4}	8.70×10^{-2}
IQ_{hard}	LEO	1.00×10^{-3}	1.25×10^{-5}	2.11×10^{-4}	2.02×10^{-2}



ID	Orbit	Failure causes	Failure effects	SN	PN	DN	CN
RFIC.1	LEO	SELs or high current states	permanent loss of system functionality	3	1	1	3
RFIC.1	GEO			3	1	1	3
RFIC.2	LEO	TIDs, long-term degradation	permanent loss of system functionality	3	1	2	6
RFIC.2	GEO			3	1	2	6
RFIC.3	LEO	SHEs, non-recoverable state	permanent loss of system functionality	3	0	-	0
RFIC.3	GEO			3	0	-	0
RFIC.4	LEO	SEFIs, recoverable state	temporary loss of system functionality	2	2	2	8
RFIC.4	GEO			2	4	2	16
RFIC.5	LEO	SEUs/MBUs/SEFIs, invalid data	corrupted data for transmission or reception	2	2	2	8
RFIC.5	GEO			2	2	2	8
RFIC.6	LEO	SETs, invalid data	corrupted data for transmission or reception	1	3	3	9
RFIC.6	GEO			1	4	3	12
RFIC.Total			**Average CN (LEO):**				**5.7**
RFIC.Total			**Average CN (GEO):**				**7.5**

PhD thesis, source: Budroweit

System-Level Verification

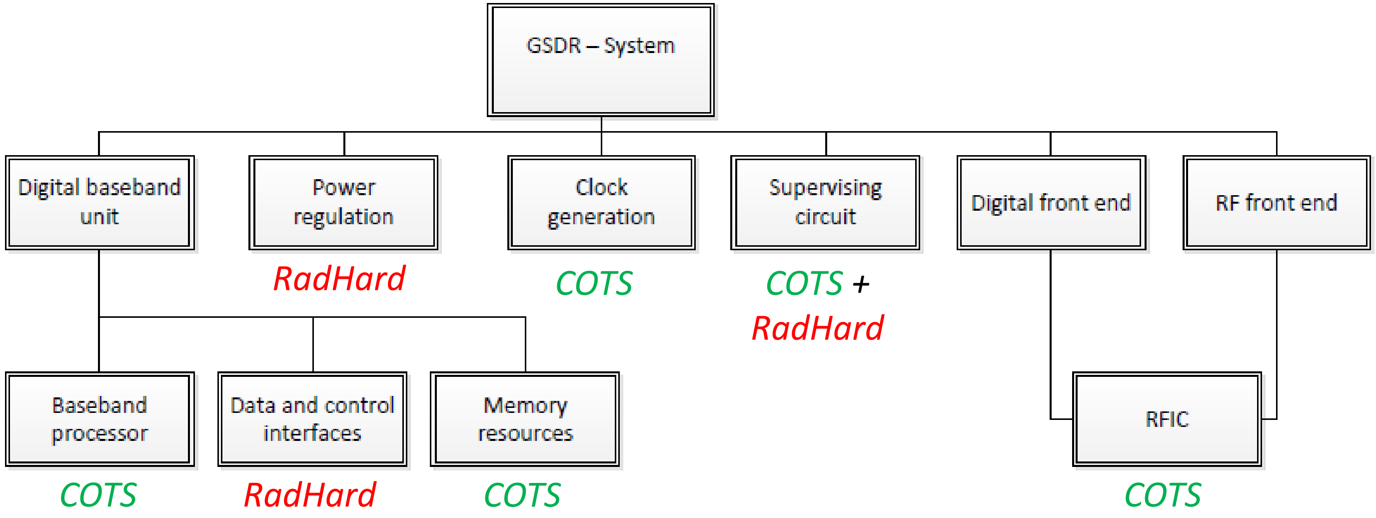

Knowledge for Tomorrow

DLR

RADSAGA

System-Level Verification

GSDR: Final system design


GSDR – System

Digital baseband unit

Power regulation

RadHard

Clock generation

COTS

Supervising circuit

COTS + *RadHard*

Digital front end

RF front end

Baseband processor

COTS

Data and control interfaces

RadHard

Memory resources

COTS

RFIC

COTS

- Hybrid system design of *COTS* and *RadHard* devices
- Verified and selected by the FMECA-based RHA approach
- An essential part of the system functionality is the software and operating system:
  - General functionality
  - Control of system
  - Detection of failures and recovery mechanism

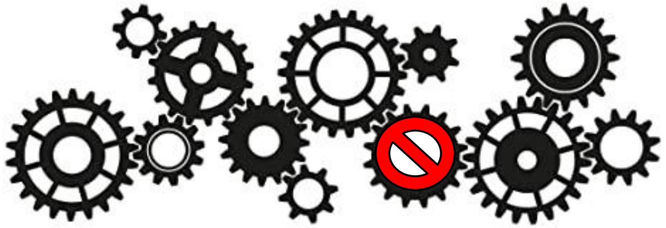
PhD thesis, source: Budroweit

GSDR: System-level verification

Purpose of system-level verification:

- Different task forms the overall system functionality
- Single failures can cause functional losses
- Verification of failure detection and potentially recovery

System



For TID:

✓ Co60-Source can be used (no limitation in space)

For SEE:

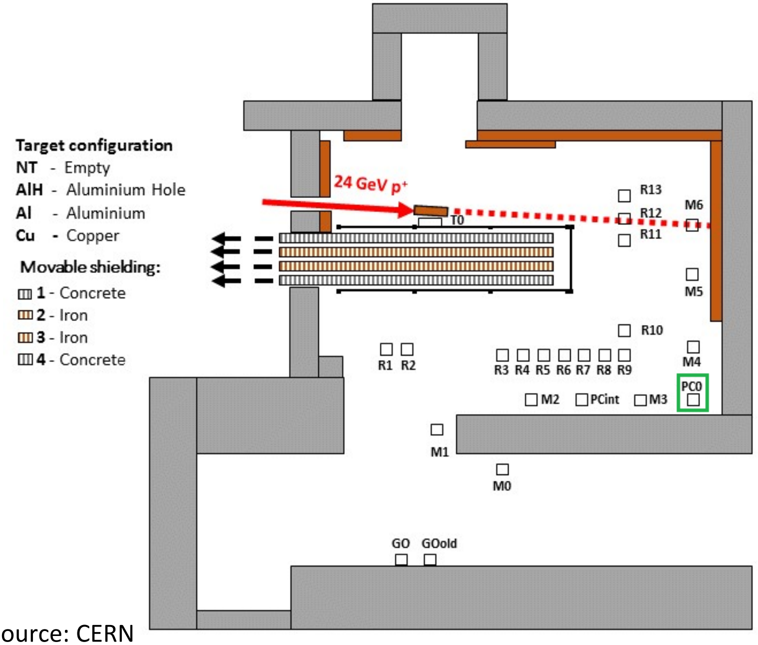
- Particle accelerators have only a narrow beam (<100mm diameter)
- Local irradiation (single devices or groups of the system)
- Failure propagation unclear

➢ *How to test on system-level that exceed the narrow beam?*

➢ *What about multi-point of failures?*

Possible solution for (soft) SEE:

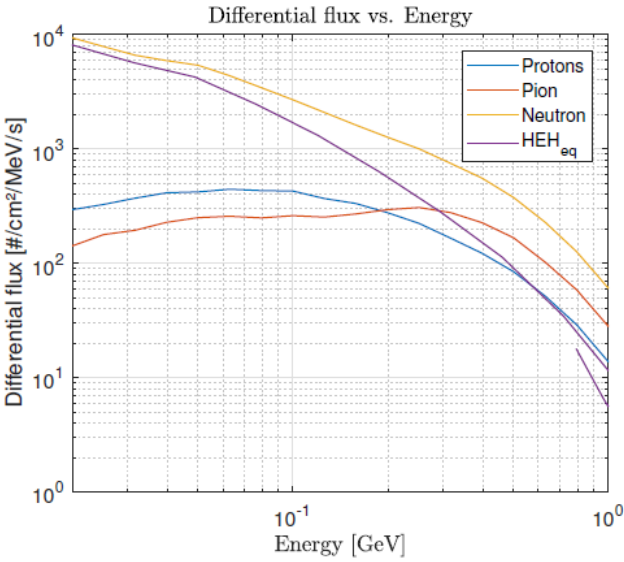
✓ CHARM - Mixed-Field Radiation Facility (Neutron, Protons, Electrons)

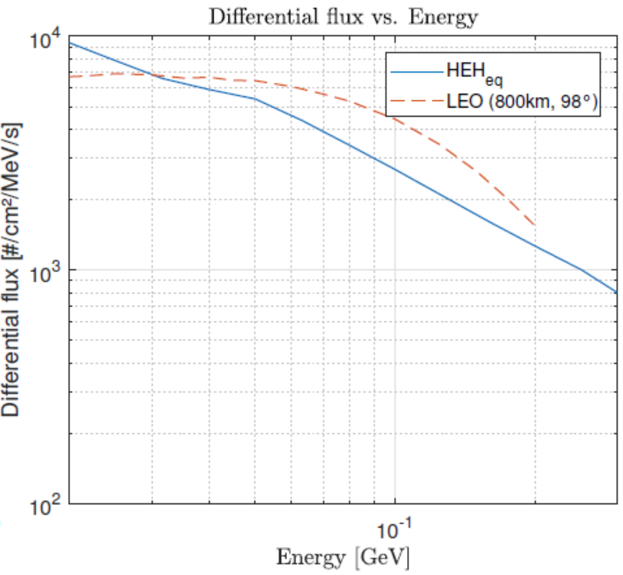


CHARM, source: CERN

GSDR: System-level verification at CHARM

- Similar differential flux compared to LEO mission (800km, SSA)

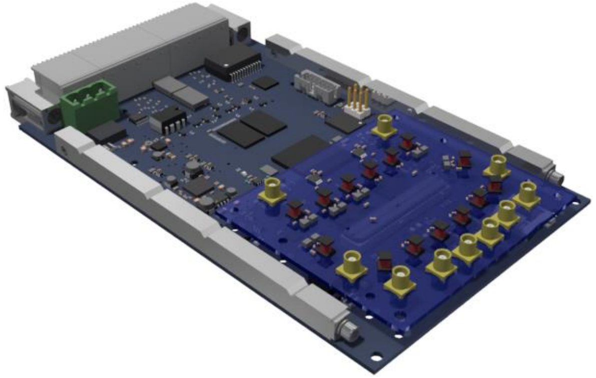


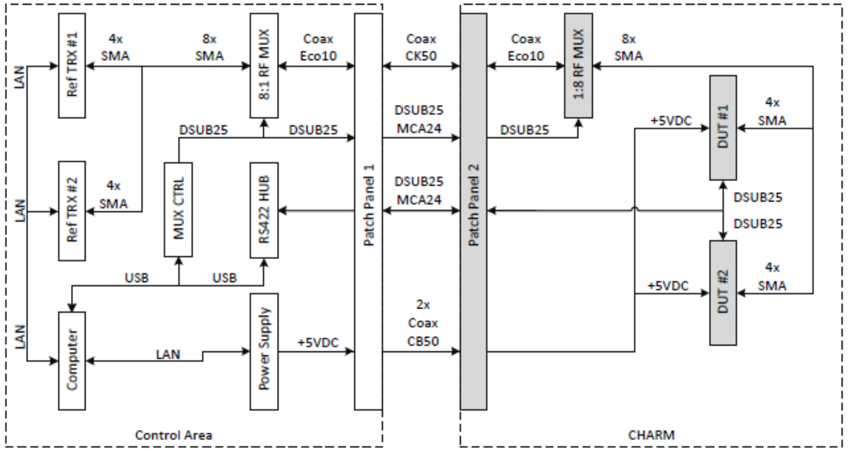


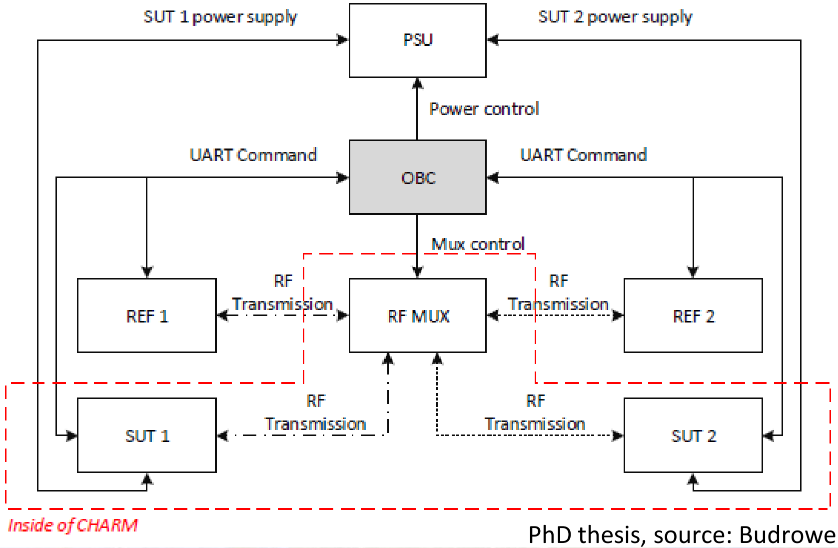
PhD thesis, source: Budroweit, CERN

GSDR: System-level verification at CHARM

- Similar differential flux compared to LEO mission (800km, SSA)
- 2x GSDR prototypes (Rev B.)
- Complete autonomous setup
    - Exchange of RF and digital data
    - On-board data processing (e.g. for RF data)
    - Overvoltage and current detection and protection
    - System-Watchdog executes reset if heart-beat disappears
    - Time-Out of command response (power-cycle)
    - Soft-Watchdog (on program/application level)
    - Memory scrubbing (NAND boot device)
    - RFIC verification
    - …







PhD thesis, source: Budroweit

System-Level Verification

GSDR: System-level verification at CHARM

- System(s) run with multiple tasks on request
  - ➢ HK-Data, RF-Data aq., Spectrogram, …

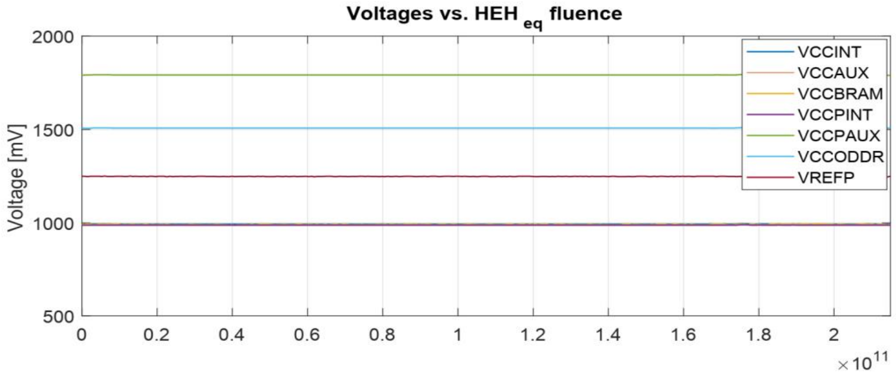
✓ No degradation of voltage and current due to TID
✓ No SELs or destructive failures (not expected)
✓ Ability to perform self-recovery verified

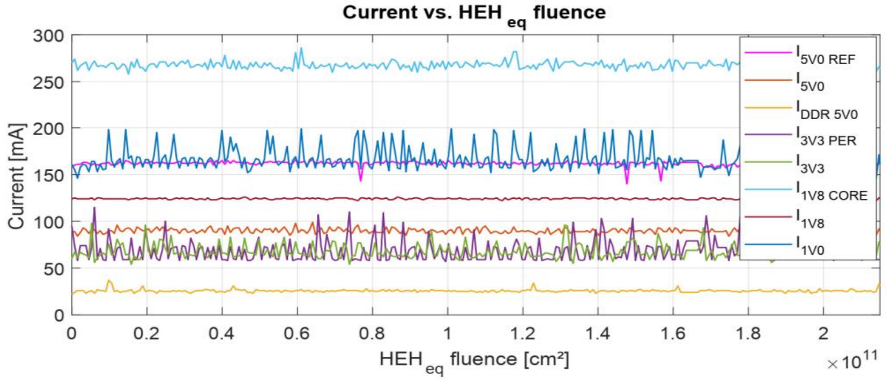
✓ 100% recovery from failure to valid system operation
  - ➢ 95% of all failures were system crashes (Zynq + DDR3)

✓ No interrupted boot-processes observed (process takes ~15sec)
✓ No invalid data on boot devices (NAND flash)
✓ Minor errors observed on RFICs

But:

– Data fly-by storage on SD-Card critical (SD-Card broken)
  - ➢ *SUT#2 (partially) not able to response on requested tasks*

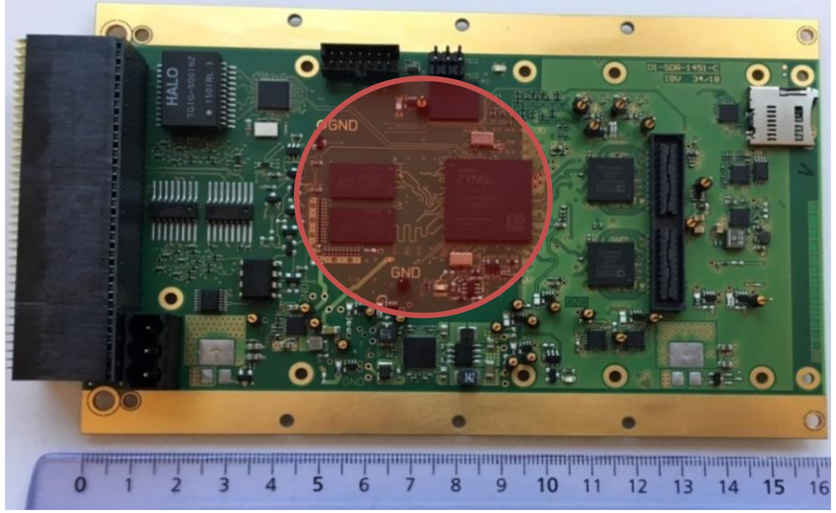




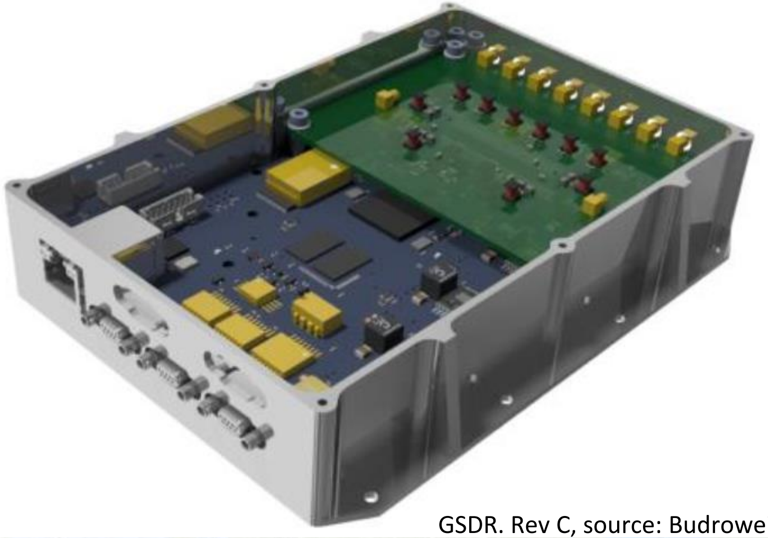
PhD thesis, source: Budroweit

GSDR: System-Level verification at KVI

- GSDR system has been irradiated to Proton (max. 190MeV)
  - Two test campaigns
  - Focusing on sensitive parts (Zynq, DDR3 SDRAM, NAND and RFIC)
  - Same configuration and software were used as in CHARM (only exception: SD-Card removed)
  - Fluence:
    - GSDR Rev B.: 5.0×10^8 #/cm^2
    - GSDR Rev C.: 2.5×10^9 #/cm^2



GSDR. Rev B, source: Budroweit



GSDR. Rev C, source: Budroweit

GSDR: System-Level verification at KVI

- GSDR system has been irradiated to Proton (max. 190MeV)
  - Two test campaigns
  - Focusing on sensitive parts (Zynq, DDR3 SDRAM, NAND and RFIC)
  - Same configuration and software were used as in CHARM (only exception: SD-Card removed)
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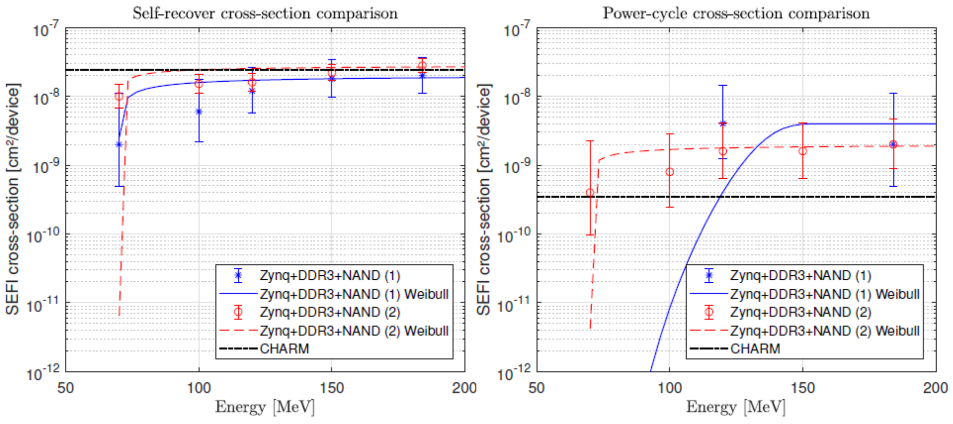

(a) Self-recovered (b) Power-cycled

- Comparable saturation of cross-section (for self-recovery)
    - ~1.9 × 10^{-8} cm^2/device (proton #1)
    - ~2.6 × 10^{-8} cm^2/device (proton #2)
    - 2.45 × 10^{-8} cm^2/device (CHARM)

SEE Type	Orbit	LET threshold	Limit cross-section	Events/day (nominal)	Events/day (worst)
SEFI_{Self}	GEO	$7.00 \times 10^{+1}$	2.18×10^{-8}	1.95×10^{-2}	$1.12 \times 10^{+0}$
SEFI_{PC}	GEO	$7.00 \times 10^{+1}$	1.57×10^{-9}	1.32×10^{-3}	6.97×10^{-2}
SEFI_{Self}	LEO	$7.00 \times 10^{+1}$	2.18×10^{-8}	8.62×10^{-2}	3.50×10^{-1}
SEFI_{PC}	LEO	$7.00 \times 10^{+1}$	1.57×10^{-9}	5.71×10^{-3}	2.22×10^{-2}

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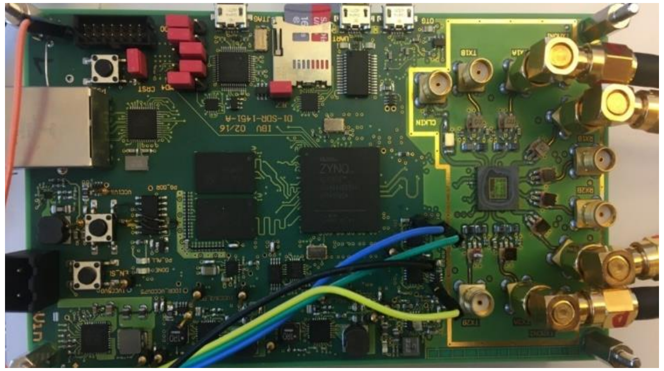
Conclusion

DLR RADSAGA

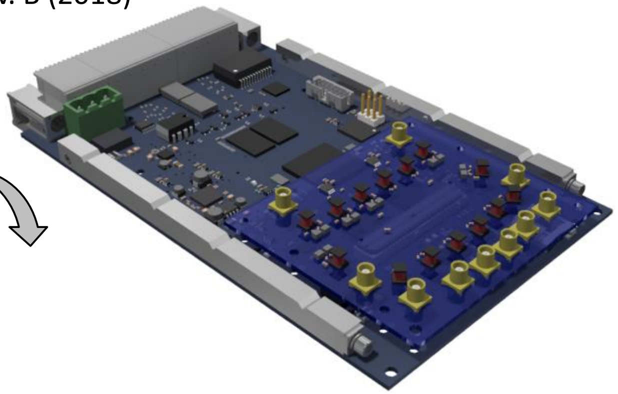
Conclusion

- A new generic SDR platform has been proposed
- Design of a FMECA-based risk assessment approach developed
- Novel radiation characterization on the AD9361 RFIC
- Hybrid design of using COTS and RadHard devices
- System validation at CHARM
- Satisfying cross-section results (no heavy-ion assumed):
  - ~1 self-recover event per day in GEO, ~8.5 days for LEO (worst case)
- Close cross-section saturation for self-recovery SEFIs for CHARM and KVI

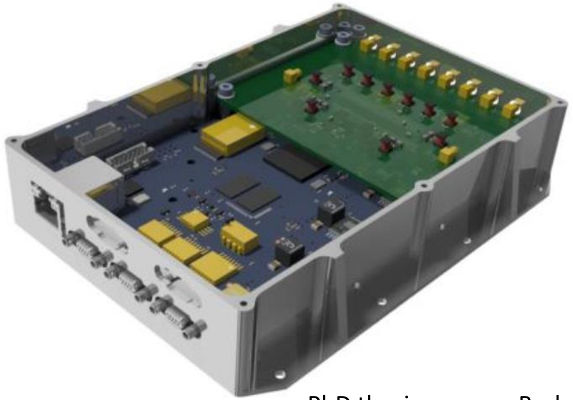
Rev. A (2015)



Rev. B (2018)



Rev. C (2019)



PhD thesis, source: Budroweit

Thank you
for your attention

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