

RaToPUS: Radiation-Tolerant Switched-Mode AC/DC Power Supply

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<https://indico.cern.ch/event/971222/>



Controls
Electronics &
Mechatronics

Agenda

1. Context and Requirements

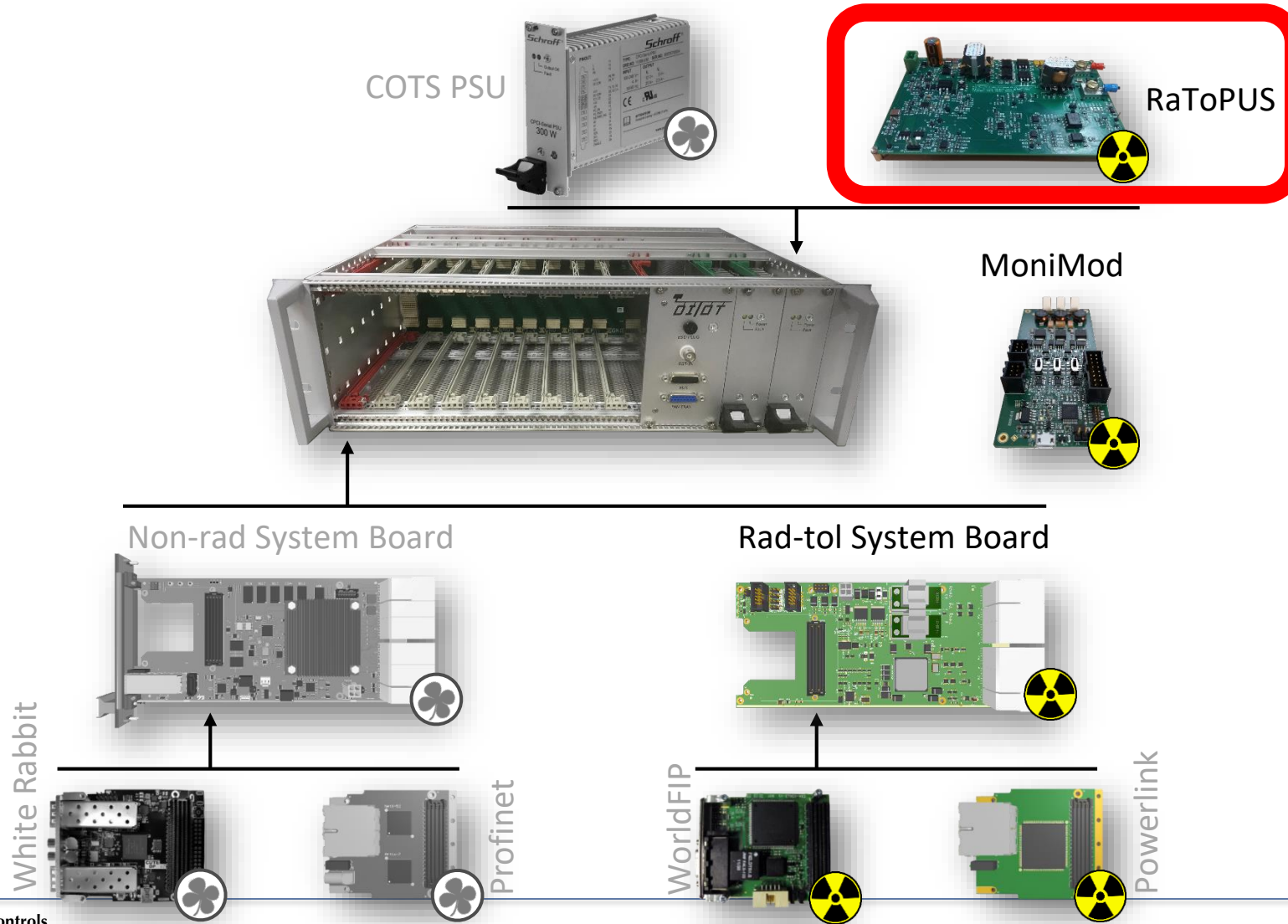
2. Power Architecture and Topologies

3. AC/DC Converter Status

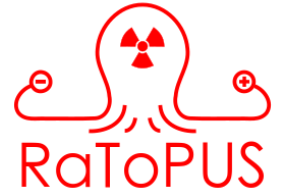
4. DC/DC Converter Status

5. Next Steps and Conclusion

Modular DI/OT Platform



Context and Requirements

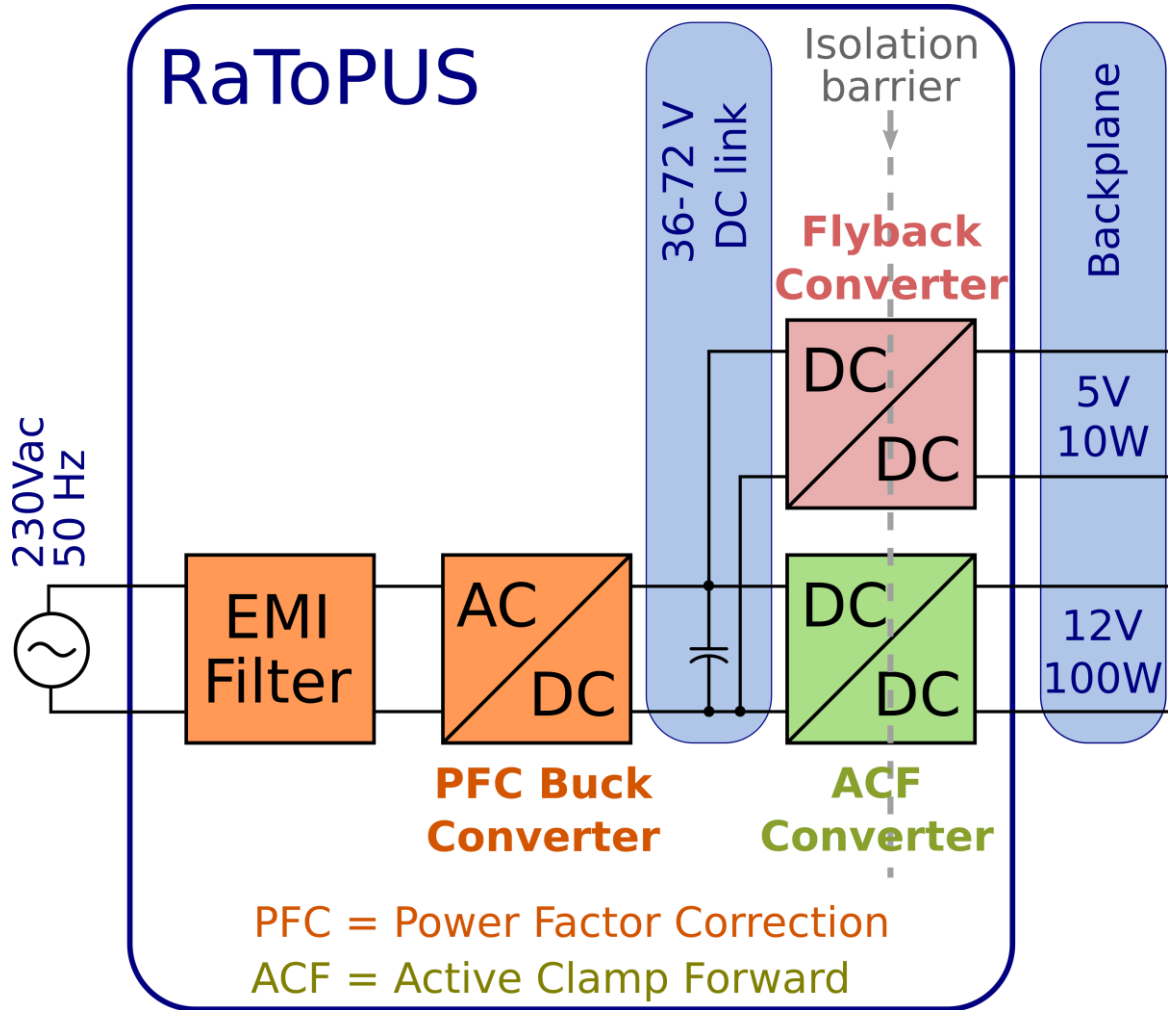


Power Supply Requirements

- 3U form-factor (similar to CPCIs PSUs)
- Dual redundancy; Power sharing
- Input: 230Vac; Outputs: 12Vdc (100W), 5Vdc (10W)
- Target TID: 500 Gy
- Full technical specifications:

[1] <https://ohwr.org/project/psu-rad-acdc-230v-12v5v-110w/wikis/home>

Power Architecture and Topology Selection



Main development stages:

1. **AC/DC**: 230Vac to 48Vdc

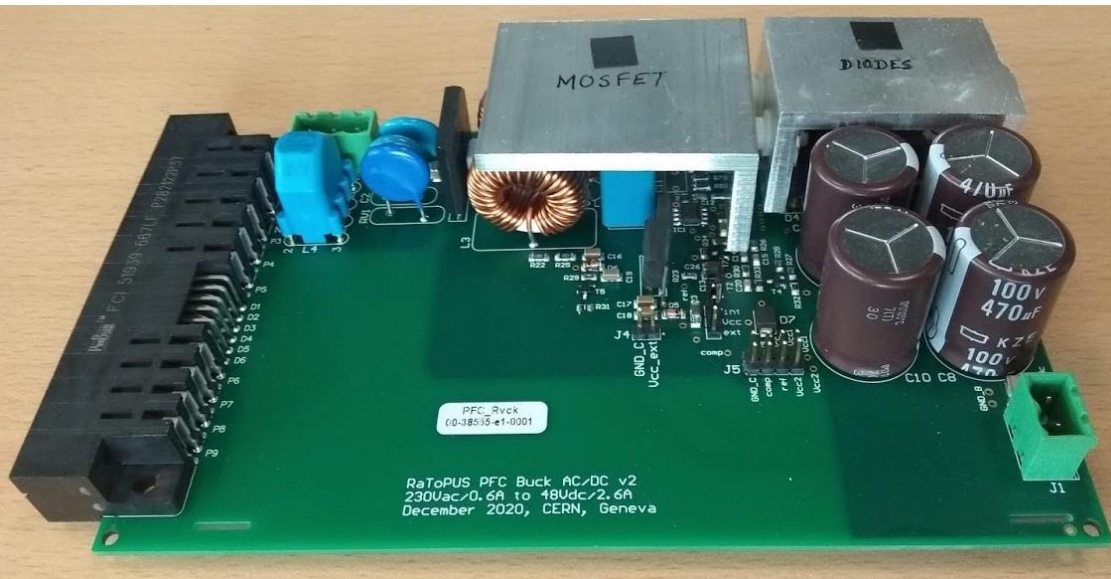
2. **12V DC/DC**: 48Vdc to 12Vdc

3. **5V DC/DC**: 48Vdc to 5Vdc

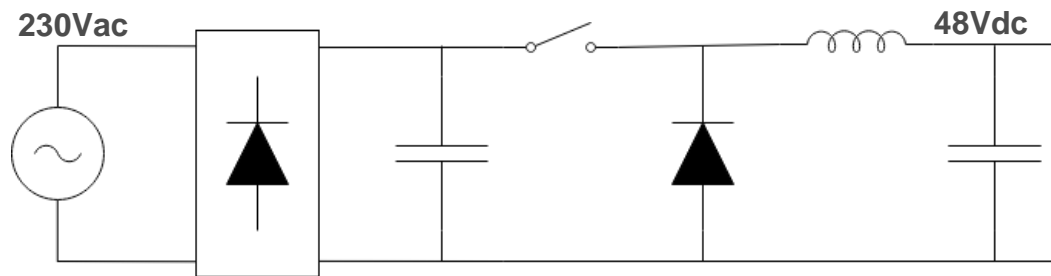
4. **RaToPUS**: System Integration

= 1 + 2 + 3 + MoniMod + Mechanical

AC/DC Converter: Design Highlights



- ❑ Topology: **Power Factor Correction (PFC) Buck**
- ❑ Input: **230Vac**; Output: **48Vdc, 125W**
- ❑ Enables low V_{DS} for power MOSFETs in DC/DC
- ❑ Inherent inrush current limiting
- ❑ Custom magnetics for efficiency improvement
- ❑ All device temperatures **< 75°C** for $P_o=125W$
- ❑ Efficiency **> 90%** for load **> 60%**
- ❑ Power factor **> 0.9** for load **> 60%**
- ❑ V_o ripple **< 10%**
- ❑ Detailed and accurate simulation model



[2] Lalit Patnaik, Grzegorz Daniluk, Salvatore Danzeca, “Design of a 100W Radiation-Tolerant Power-Factor-Correction Buck AC/DC Converter,” PCIM Europe 2020: <https://ieeexplore.ieee.org/document/9178215>

[3] Talk describing PFC Buck AC/DC design: <https://www.youtube.com/watch?v=P5XJ3-uSUcA>

AC/DC Converter: Radiation Tolerance

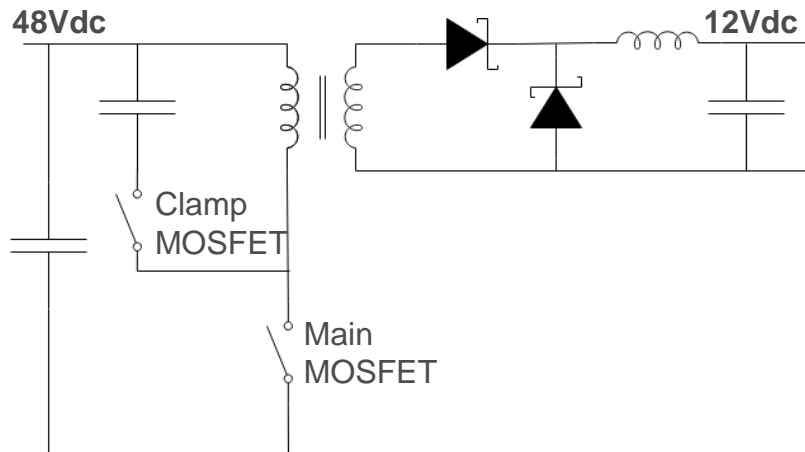
❑ Radiation tolerance measures:

- 800V power MOSFETs (IPA80R280P7, rad tested)
Maximum operating voltage 375V
- SOIC-8 PWM IC (TL2843BDR-8, rad tested)
Same chip as that used for DC/DC control

❑ Upcoming radiation campaigns:

- Co-60 in Feb 2021
- PSI (full RaToPUS) in July 2021

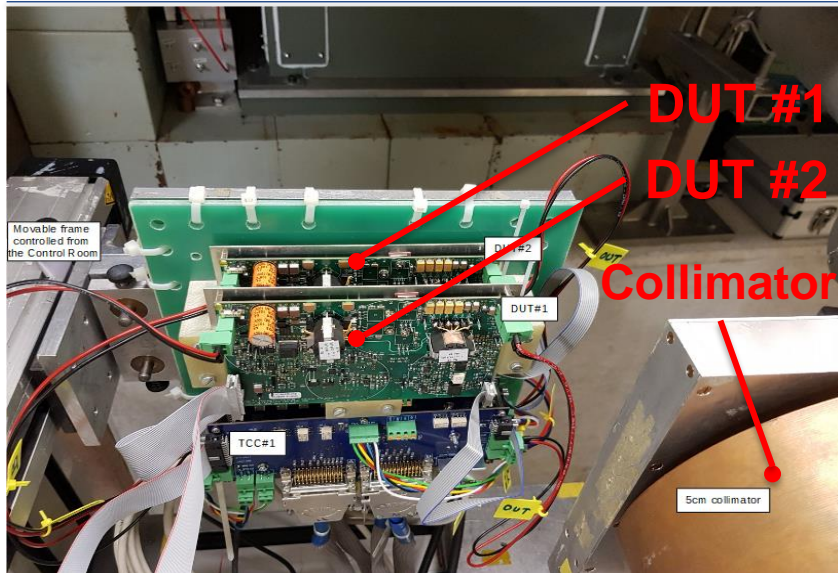
DC/DC Converter: Design Highlights



- ❑ BE/CEM – SY/EPC Collaboration
- ❑ Topology: **Active Clamp Forward (ACF)**
- ❑ Input: **48Vdc**; Output: **12Vdc, 100W**
- ❑ Enables low operating V_{DS} ($\sim 100V$) for MOSFET
- ❑ Zero-Voltage Switching (ZVS):
Low switching losses, Low EMI
- ❑ Efficiency > **89%** for load > 30%
- ❑ V_o ripple < 60mV
- ❑ Detailed and accurate simulation model
- ❑ Thermal runaway issue resolved

[4] Design Report: https://ohwr.org/project/psu-rad-acdc-230v-12v5v-110w/blob/master/stages/dc_dc_12v/Documentation/R2E-Active-Clamp-Forward-DC-DC-Design-Report.pdf

DC/DC Converter: Radiation Tolerance



❑ Radiation tolerance measures:

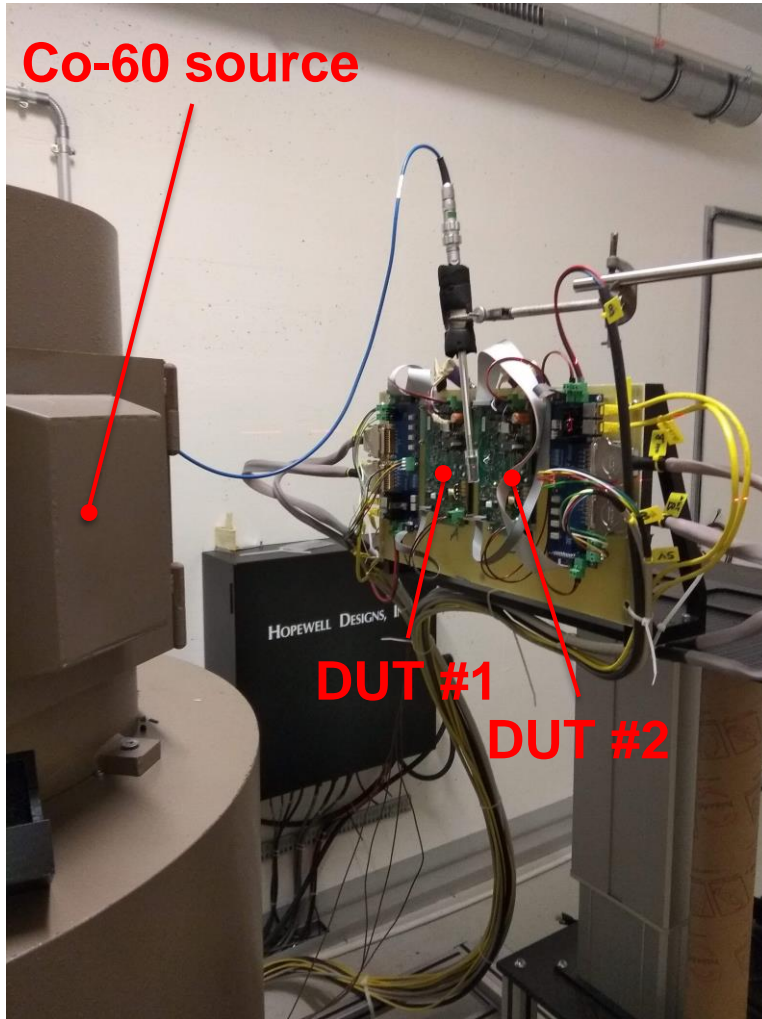
- 200V/250V power MOSFETs (IPB320N20N3, IPD600N25N3, rad tested)
Maximum operating voltage 125V
- SOIC-8 PWM IC (TL2843BDR-8, rad tested)
Same chip as that used for DC/DC control
- Isolated voltage sensing (ACPL-C87B, rad tested)
Instead of conventional approach of optocouplers

❑ PSI radiation campaign in Sept 2020

- No destructive SEE observed for normal operation
- Spurious over-current protection (OCP) triggering at 10-20Gy
- Main MOSFET failure in short circuit at 295-345Gy
- No failures of clamp MOSFET
- Compensation loop failure at 485Gy

[5] Radiation Test Report for PSI campaign: <https://edms.cern.ch/document/2429297/1>

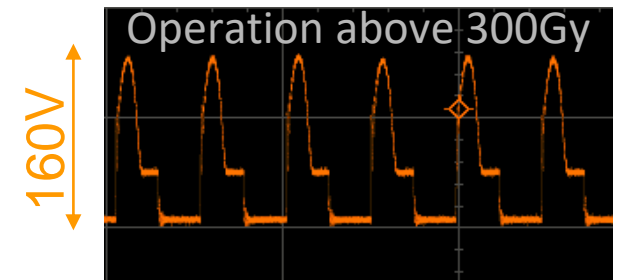
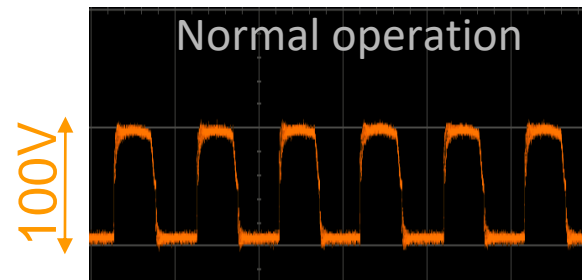
DC/DC Converter: Radiation Tolerance



❑ Co-60 radiation campaign in Oct 2020

- Spurious OCP triggering at 250Gy
 - Clamp MOSFET stops switching at 300-320Gy
- Results in change of operation mode in DC/DC
Increased voltage stress on main MOSFET
 V_o continues to be in regulation
- Main MOSFET failure in short at 370Gy




Main
MOSFET
 V_{DS}



❑ Upcoming radiation campaigns:

- Co-60 in Feb 2021
- PSI (full RaToPUS) in July 2021

Next Steps

- 2021 Q1  AC/DC and DC/DC cards radiation tested at Co-60
AC/DC and DC/DC cards EMC tested
- 2021 Q2  RaToPUS integrated electrical design ready
AC/DC + 12V DC/DC + 5V DC/DC + MoniMod
RaToPUS mechanics ready
Enclosure + custom heatsinks
- 2021 Q3  6x RaToPUS prototypes (electrical + mechanical) ready
6x RaToPUS units radiation tested

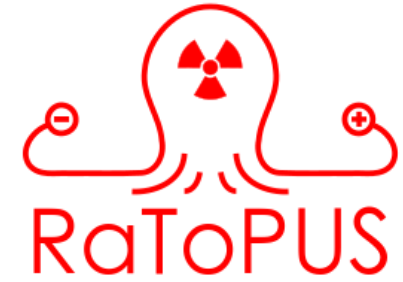
Conclusion

- ❑ RaToPUS is a radiation-tolerant switched-mode AC/DC power supply for DI/OT crates
 - Input: 230Vac; Outputs: 12V/100W, 5V/10W
 - Overall efficiency > 80%

- ❑ Modular design: 12V DC/DC can be used stand-alone for 48Vdc applications
 - Modified DC/DC to be used in new version of SY/EPC BiVolt and TriVolt modules

- ❑ Can serve as a reference design for other radiation-tolerant applications

- ❑ All design files and detailed simulation models available here:
 - <https://ohwr.org/project/psu-rad-acdc-230v-12v5v-110w/tree/master/>



Thank you for
your attention!

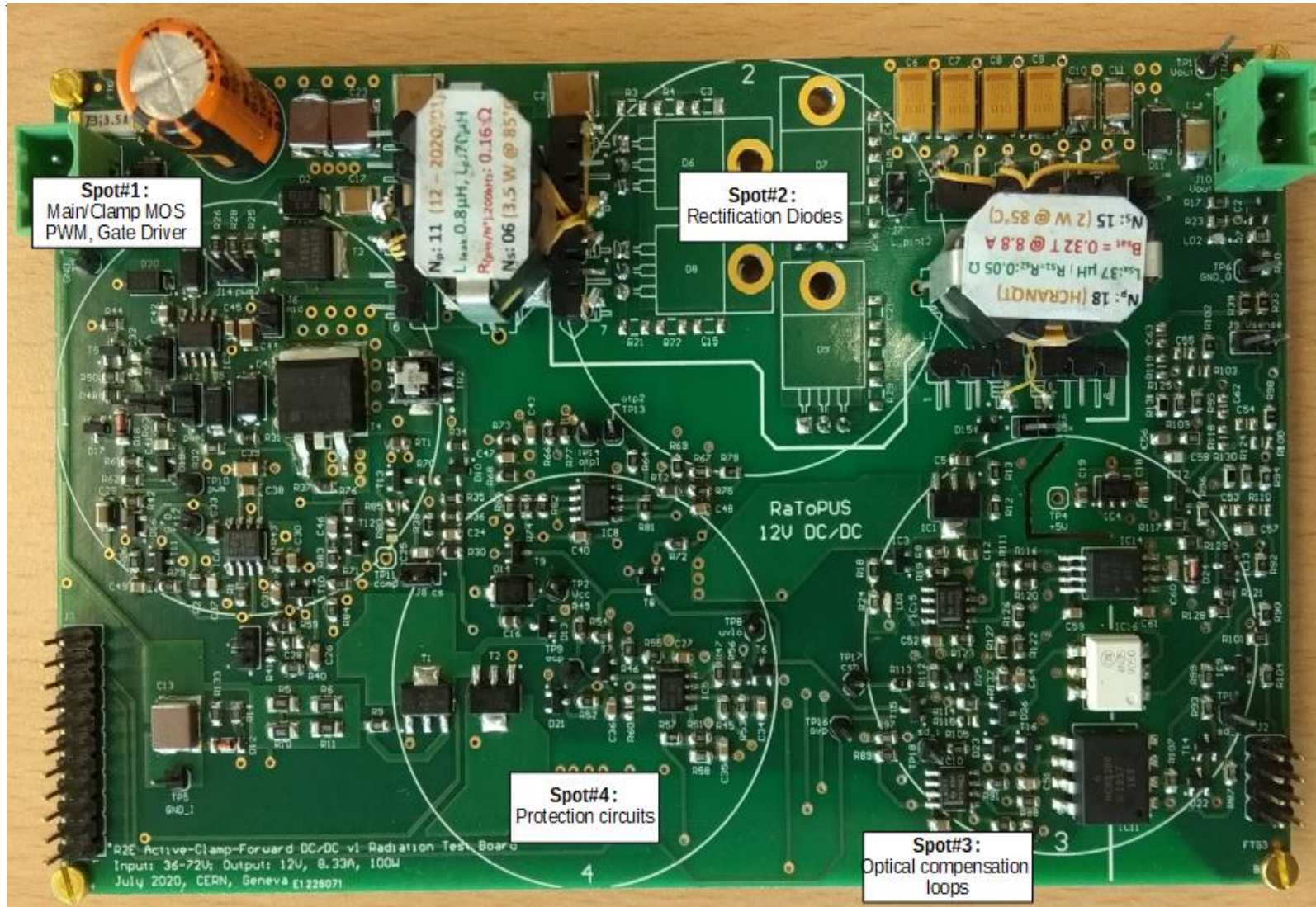


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Back-up Slides

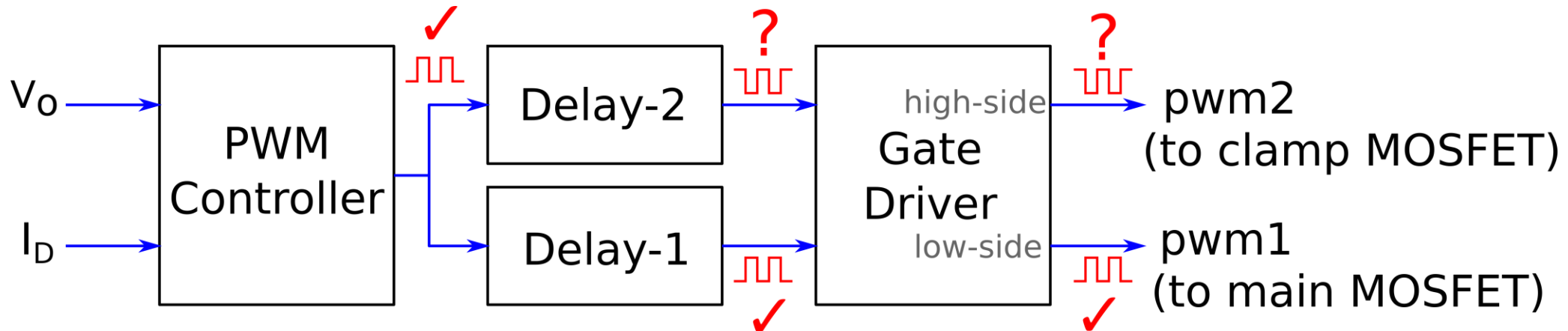


Irradiation Spots in DC/DC card for PSI Tests



- ❑ Each spot: Circle of 5cm diameter (p+ beam size)
- ❑ All active components covered by 4 spots
- ❑ Irradiation was done in steps where each spot absorbed 100Gy/run

Lost Pulses for Clamp MOSFET



- ❑ Among the signals in this figure, pwm1 is the only one observable
- ❑ During Co-60 test, pwm1 was nominal even when mode change happened (300-320Gy)
- ❑ Either Delay-2 or high-side of gate driver caused lost pulses