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

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# 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

COTS PSU

RaToPUS

Non-rad System Board

MoniMod

Rad-tol System Board

White Rabbit

Profinet

WorldFIP

Powerlink

03/02/2021 Lalit Patnaik - RaToPUS: Radiation-Tolerant Switched-Mode AC/DC Power Supply
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
   \[1 + 2 + 3 + \text{MoniMod} + \text{Mechanical}\]
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

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[3] Talk describing PFC Buck AC/DC design: [https://www.youtube.com/watch?v=P5XJ3-uSUCa](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 $V_{DS} \approx 100V$ 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

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)

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

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

- **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!
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
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