RaToPUS: A Generic Radiation Tolerant Power Supply for Distributed I/O Tier Project

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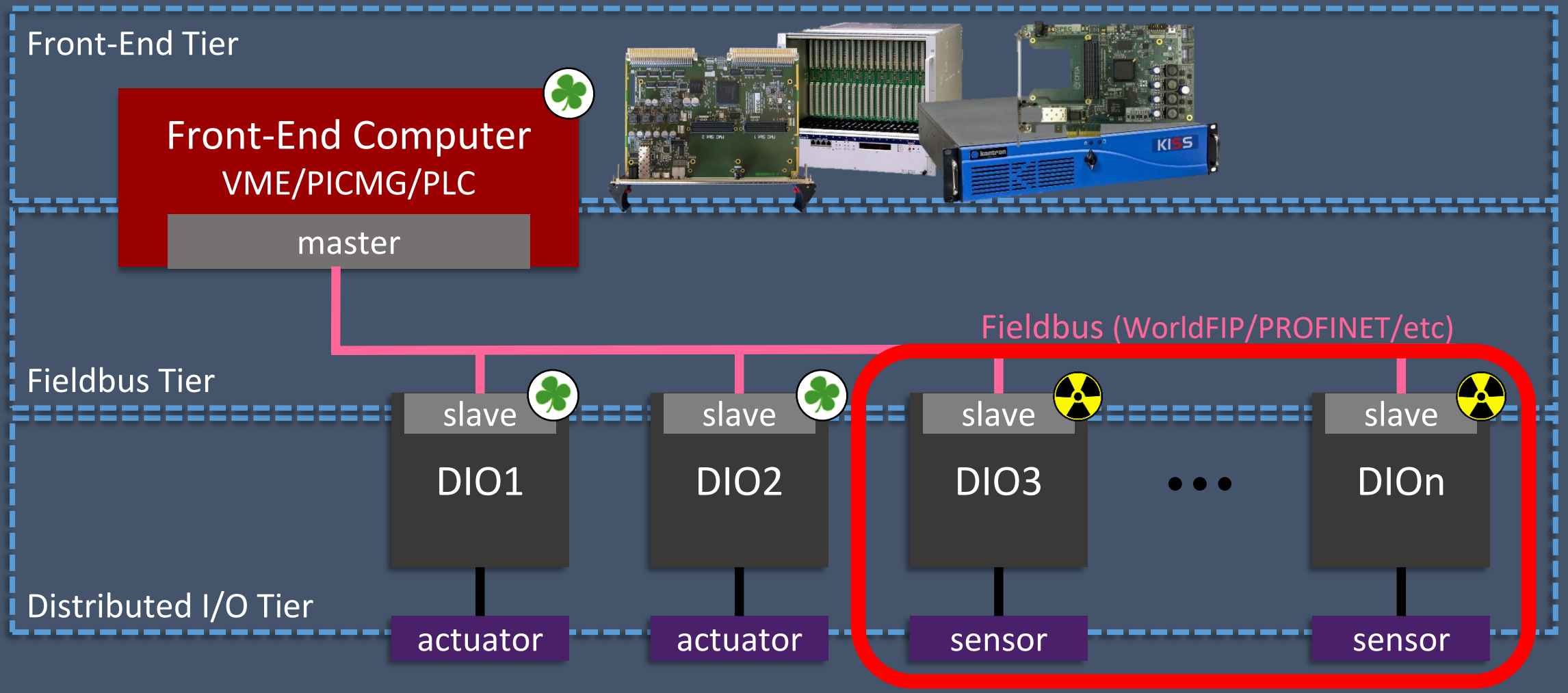
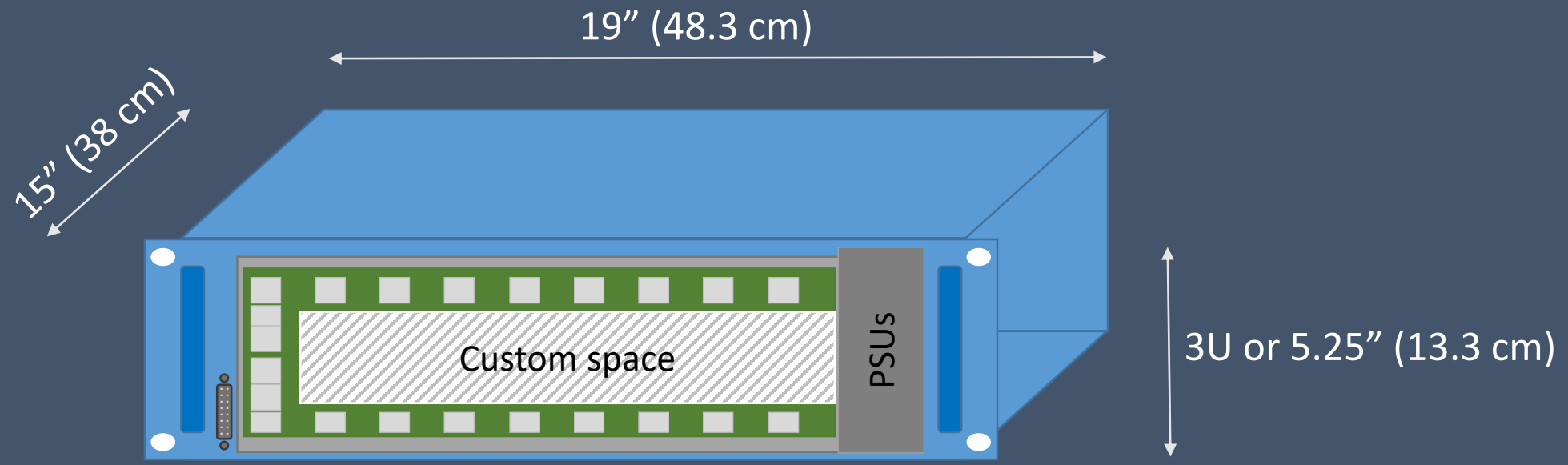
R2E ANNUAL MEETING | 12 DEC 2018

Objective

Design and test a generic PSU for Distributed I/O Tier (DIOT) crates
to be used under radiation environment by various CERN user groups.



DIOT crate mockup



- Each PSU: 3U x 170 mm x 8HP
- Two PSUs in redundant/load-sharing mode
- Accessible from front side

Target user groups in CERN

- Beam instrumentation (BE-BI)
- Magnet positioning (EN-SMM)
- Machine protection (TE-MPE)
- Electrical power converters (TE-EPC)
- More …?

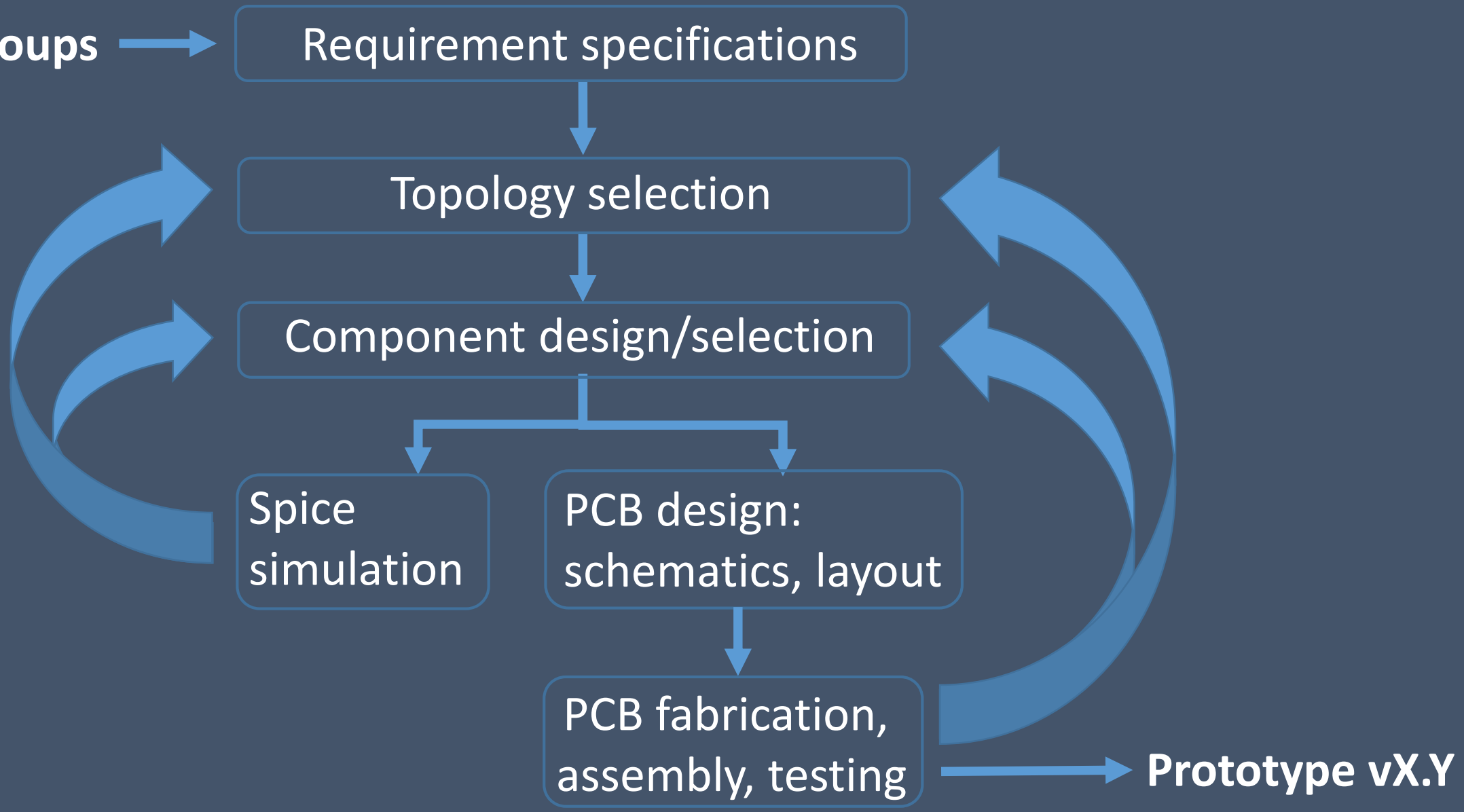
Assumptions

1. All PCBs in the crate (system and peripheral) have POL regulators for low voltage digital circuits (1-3.3V)
2. Power for high performance analog circuits (<10mV ripple + noise) is provided by dedicated linear regulators external to RaToPUS.

Project schedule

	YEAR #1				YEAR #2			
Task	**2018 Q4**	**2019 Q1**	**2019 Q2**	**2019 Q3**	**2019 Q4**	**2020 Q1**	**2020 Q2**	**2020 Q3**
Define specifications; Survey existing solutions	■	■						
Design and simulation	■	■	■	■				
Radiation effects training	■	■	■	■				
Laboratory prototyping	■	■	■	■	■			
Define test specifications and test plan			■	■	■	■		
Non-radiation testing and improvements				■	■	■	■	
Radiation testing and improvements					■	■	■	■

Project workflow



Requirement specifications (tentative)

Parameter	Value
Input: V_{in}, f, I_{in}	230 Vac, 50 Hz
Outputs: V_{o1},I_{o1} (P_{o1}) V_{o2}, I_{o2} (P_{o2})	12 V, 8.33 A (100 W) 5 V, 2 A (10 W)
Output voltage ripple + noise, ΔV_{o1} ΔV_{o2}	100 mVpp for 12 V 20 mVpp for 5 V
TID	>500 Gy (1000 Gy?)
PCB dimensions	100 mm x 160 mm x 37 mm
PSU dimensions (including packaging)	3U x 170 mm x 8HP i.e. 133 mm x 170 mm x 40 mm
Switching frequency, f_s	250 kHz - 1 MHz
External monitoring/control	PMBus and PS_ON (for remote switching ON/OFF)
EMI specifications	EN55022 Class B
Thermal environment: - Ambient temperature - Fan tray available	 40^{o}C Yes

Existing Rad-Tol PSU solutions at CERN

50 Hz Transformer (7-15Vac) ⟶ Bridge Rectifier (10-20Vdc) ⟶ LDO

50 Hz Transformer (7-15Vac) ⟶ Bridge Rectifier (10-20Vdc) ⟶ DC/DC

- BE-BI-BL (25W)
- TE-MPE-EP (40W)
- TE-CRG-CI (100W)

Advantages

- Simple and robust design
- No higher voltage switching

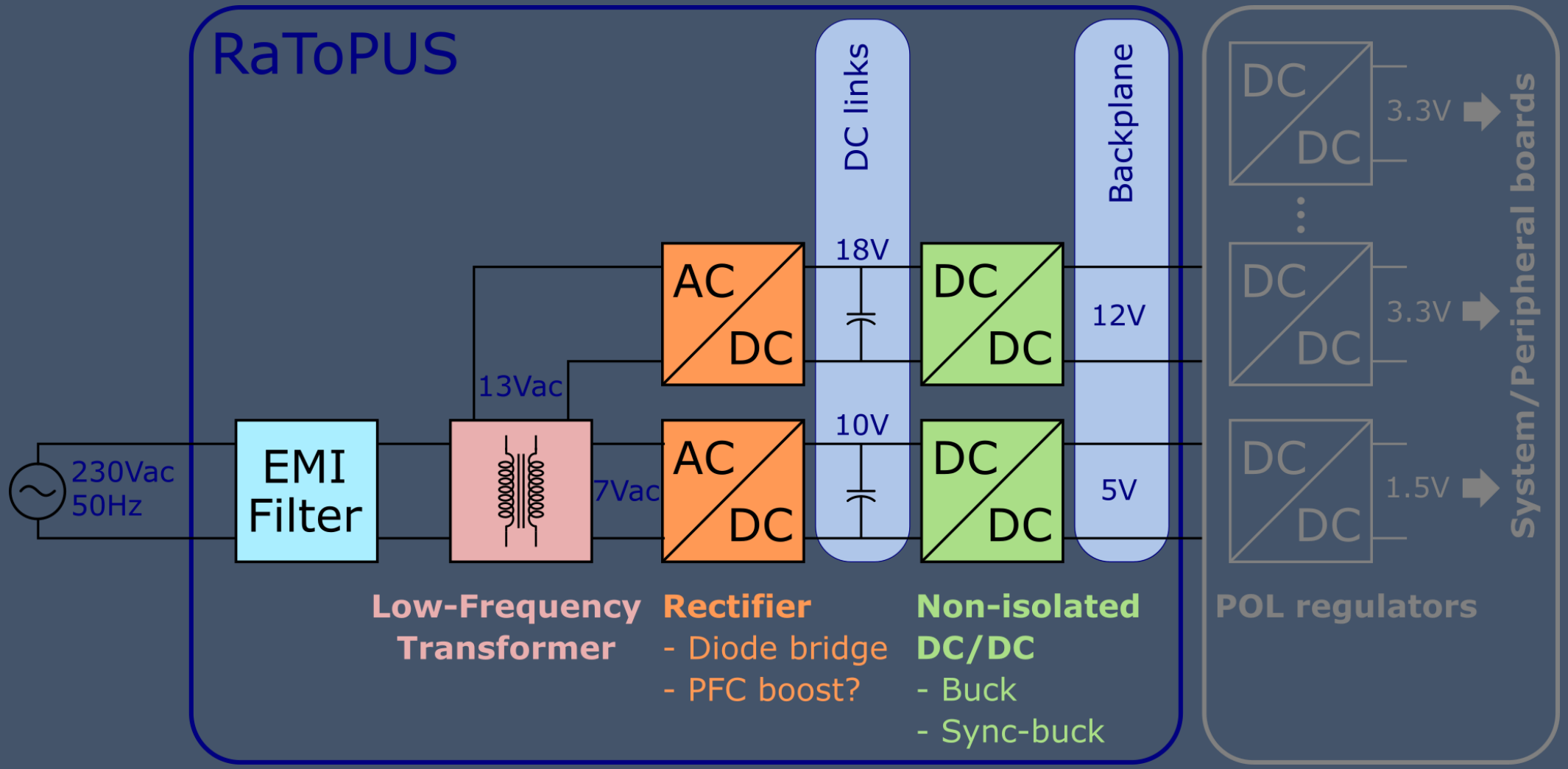
Disadvantages

- Large and costly transformer
- Large heat dissipation in crate
- No PFC ⟹ Large EMI filter

50 Hz Transformer (35Vac) ⟶ Bridge/PFC Rectifier ⟶ DC/DC (48Vdc)

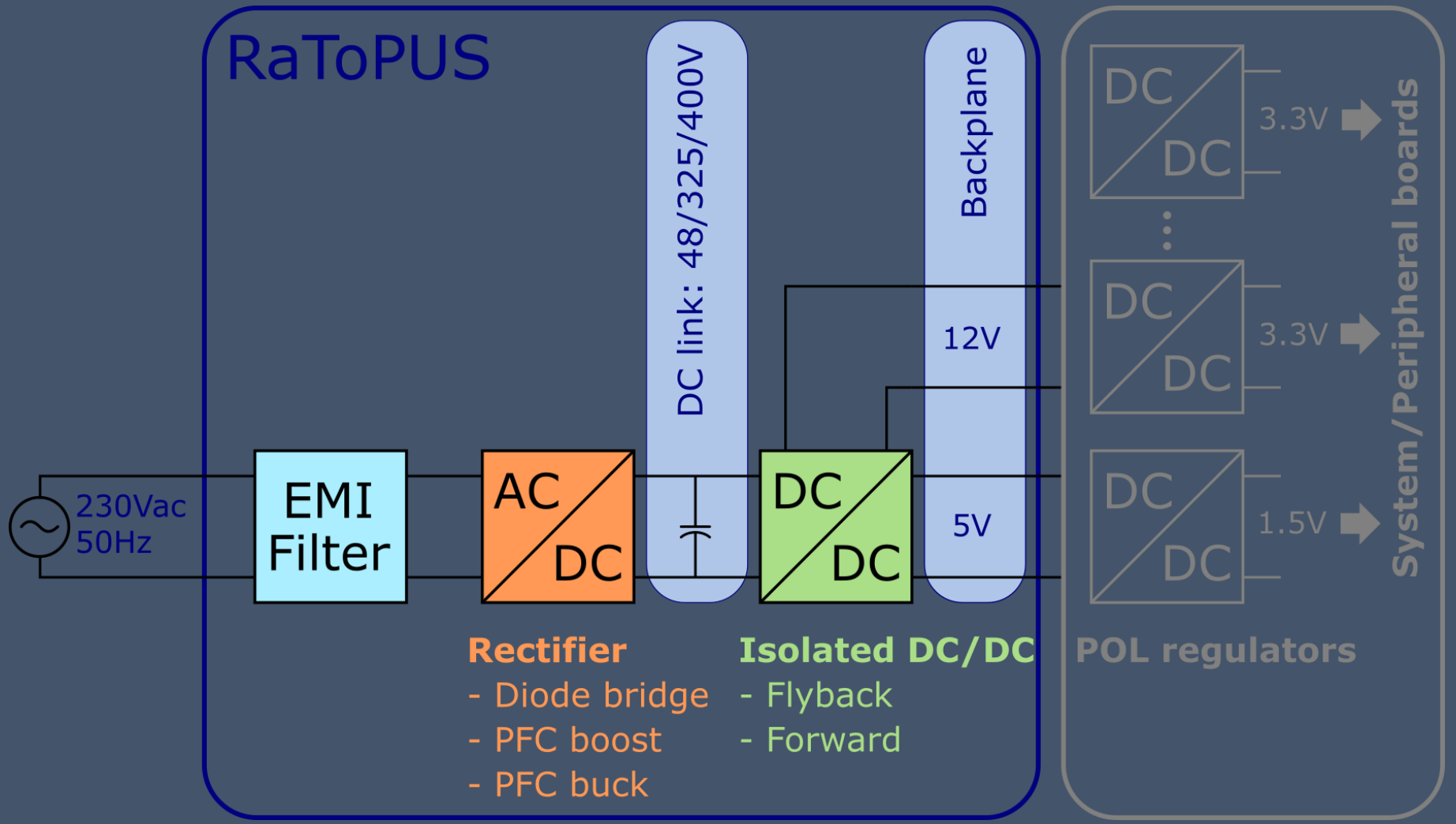
- TE-EPC-CCE (70W)

RaToPUS power architecture: Option-1



- Large low-frequency transformer
- MOSFETs switching at lower voltage
- Large EMI filter?

RaToPUS power architecture: Option-2



- Small high-frequency transformer (part of isolated DC/DC converter)
- MOSFETs switching at higher voltage
- Small EMI filter

Radiation hardness: Power stage components

Component	Options	Rad hardness (TID)
EMI Filter	Schurter FMLB-41	✓
Bridge rectifier diodes	Multicomp ABS8	TBD
Power MOSFETs	Infineon IRLI540N Infineon IRHNJ67C30 Infineon IRFB4310 Vishay IRFL110	TBD 1000 Gy† 300 Gy* 300 Gy*
Filter and DC link capacitors: Ceramic Aluminium electrolytic Tantalum electrolytic	TDK C Series -- --	✓
Filter inductor	Bourns SRP1038A Series	✓
HF transformer	Coilcraft	✓
LF transformer	Toroidal	✓

✓ Passive components are assumed to be rad hard by default *Tested by CERN †Tested by manufacturer

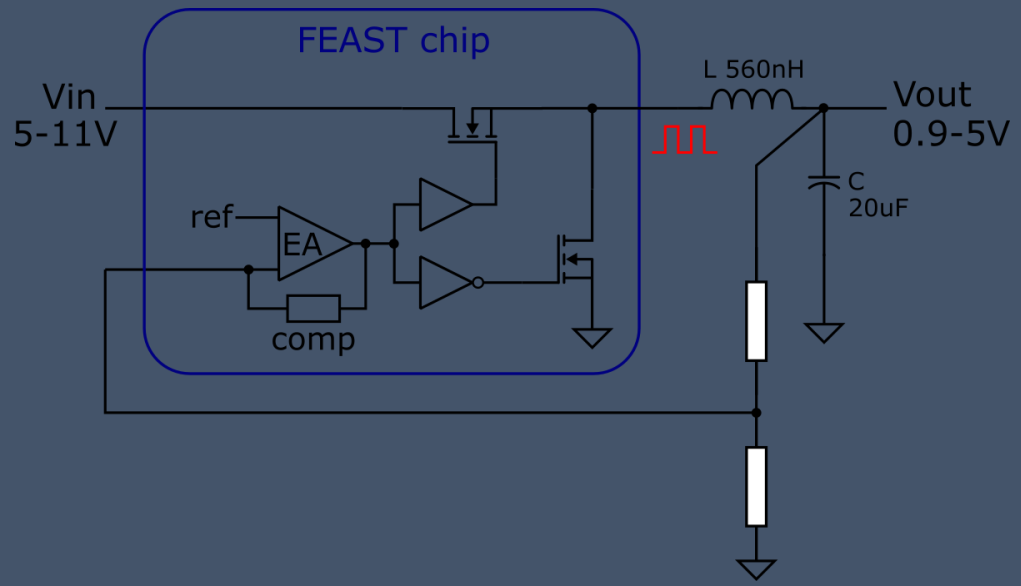
Radiation hardness: Other components

Component	Options	Rad hardness (TID)
Analog controllers for power stages: For DC-DC stage For PFC stage	FEAST ST1845 UCC28056	2 MGy* 1000 Gy† TBD
House-keeping bias (power supply for controllers): Extra flyback winding + diode on HF transformer	STPS10H100C Schottky	TBD
MOSFET gate drivers (+12V, -3V)	NCP5901 RHRPM4424	TBD 1000 Gy†
Isolated voltage sensing	HCNR200 ACPL-C87B	150 Gy* TBD
Isolated current sensing: Hall-effect sensors	ACS712	TBD
PWM pulse isolation: High-speed optocouplers	FOD8012A	TBD
Temperature sensing: Solid-state sensors Thermocouple/RTD	LM45 PT100	1000 Gy* ✓
MCU/DSP/FPGA for PMBus implementation	TBD	TBD

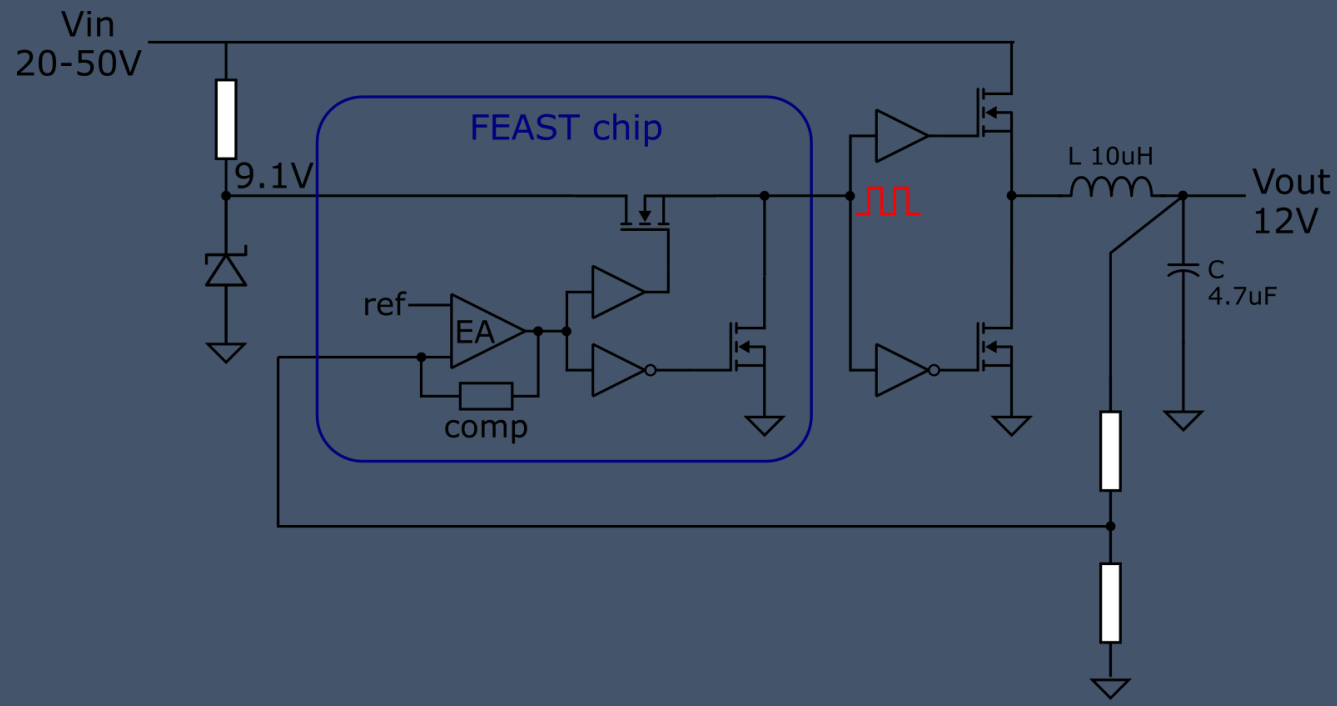
✓Passive components are assumed to be rad hard by default *Tested by CERN †Tested by manufacturer

Feasibility study: FEAST as controller for DC/DC stage

Typical configuration: Up to 10W



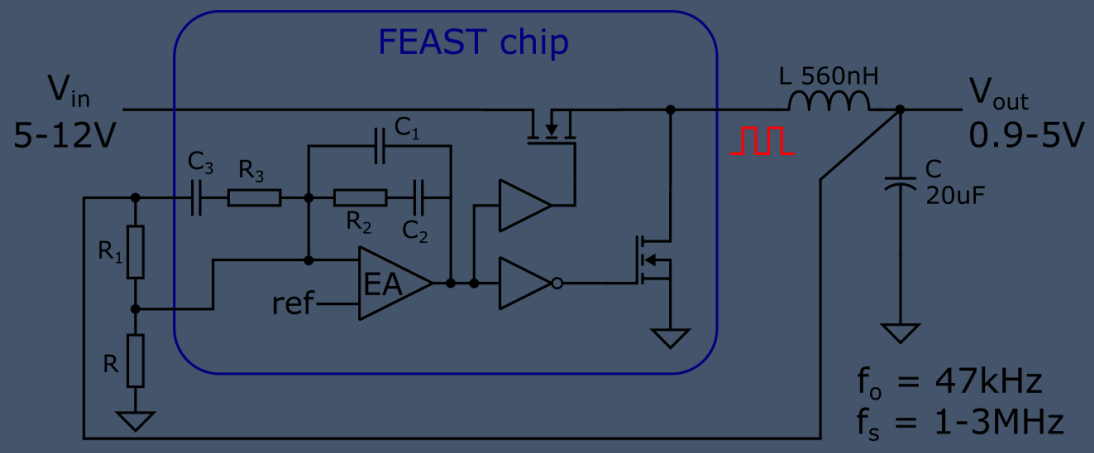
Modified configuration: Up to 100W



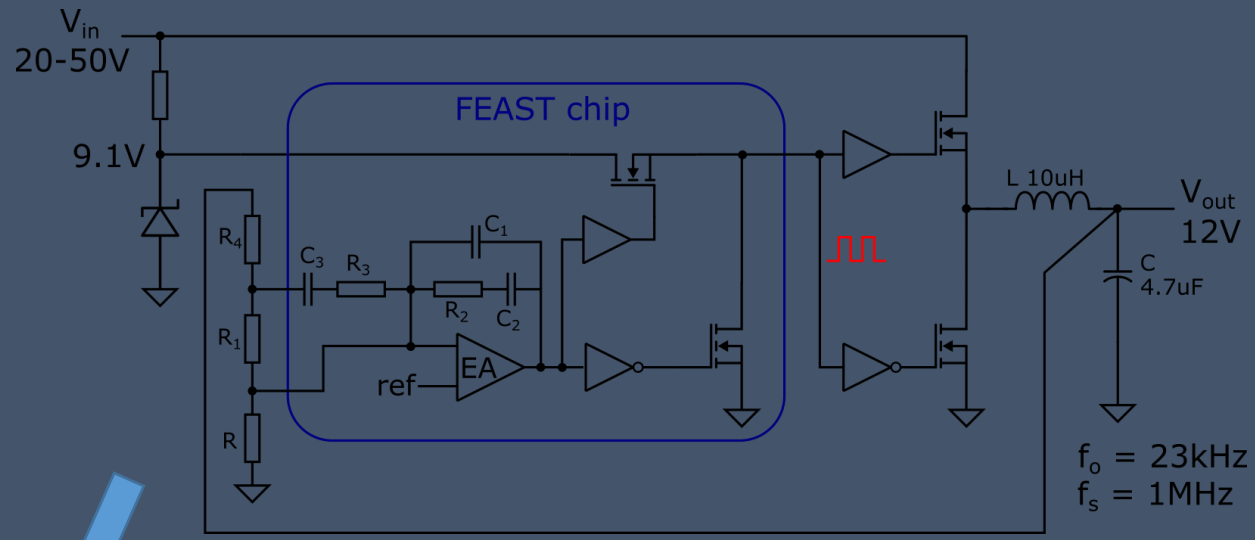
- External MOSFETs of higher V and I rating
- Larger LC filter on output side
- 9-12V HKB (house-keeping bias)
- Delayed EN for bootstrap capacitor charging

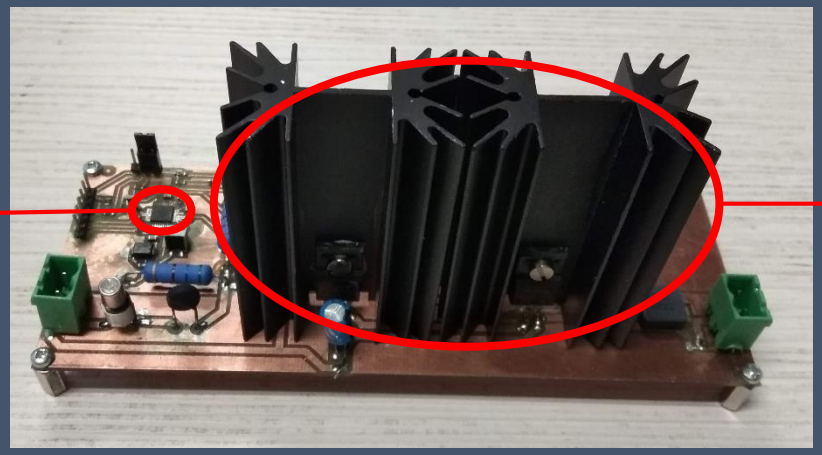
Feasibility study: FEAST as controller for DC/DC stage

Typical configuration: Up to 10W



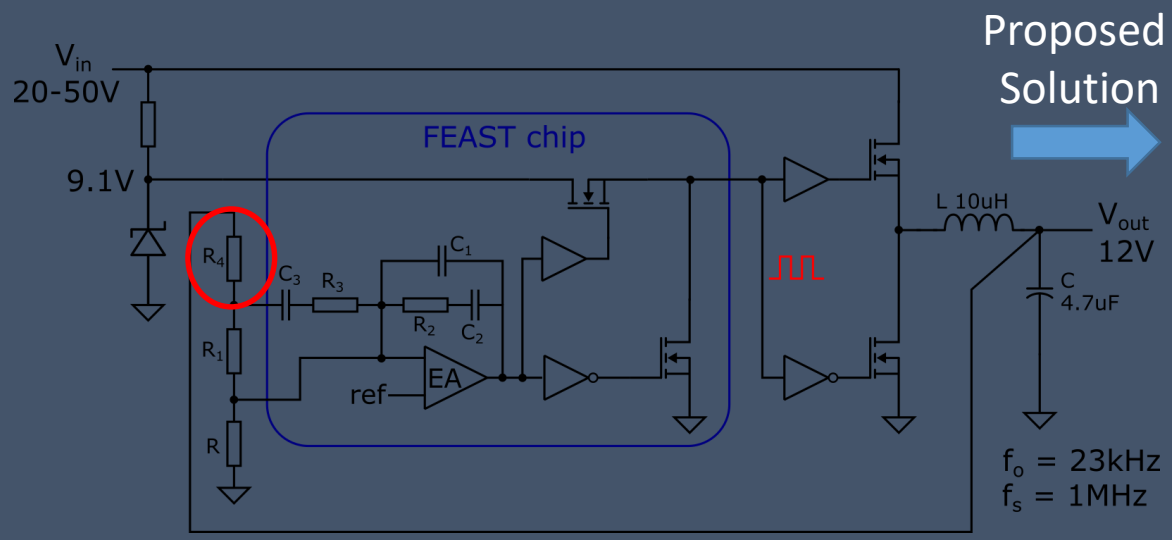
Modified configuration: Up to 100W



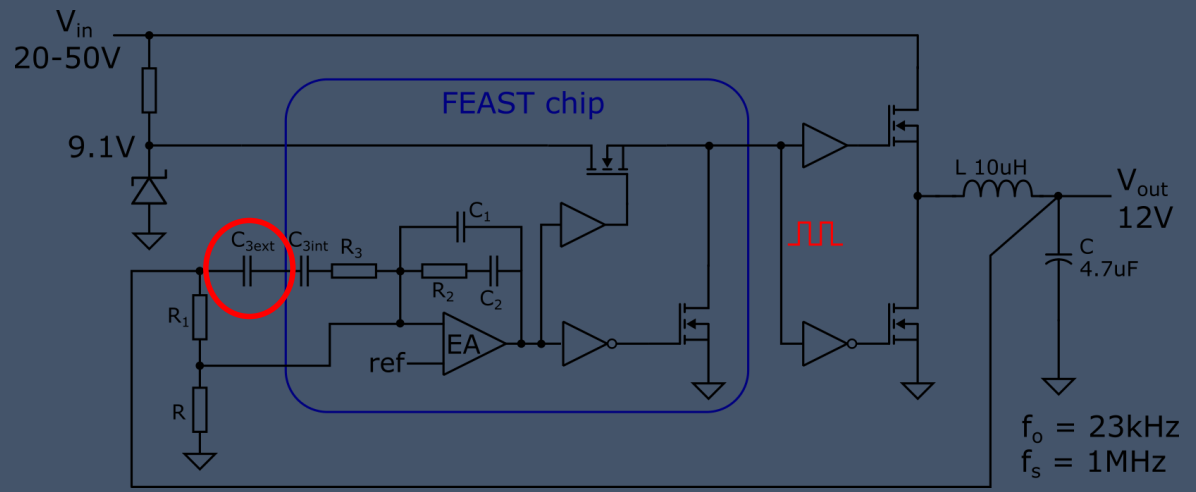


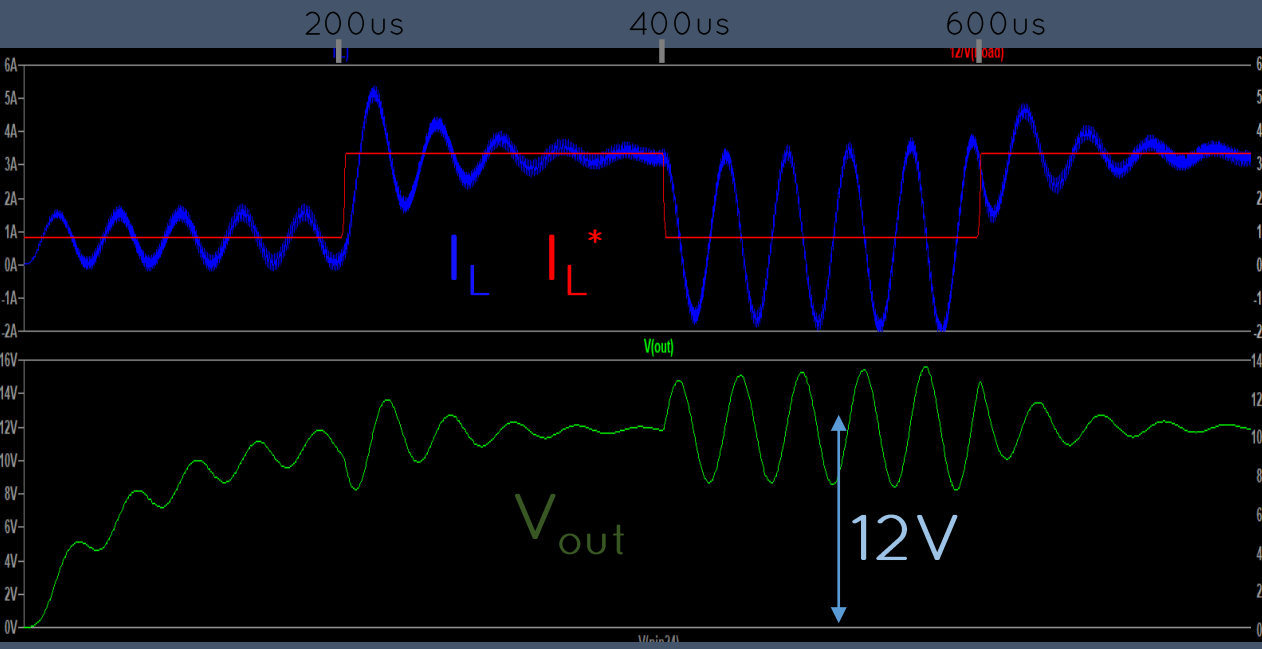
- Lab prototype
- Loop stability issues

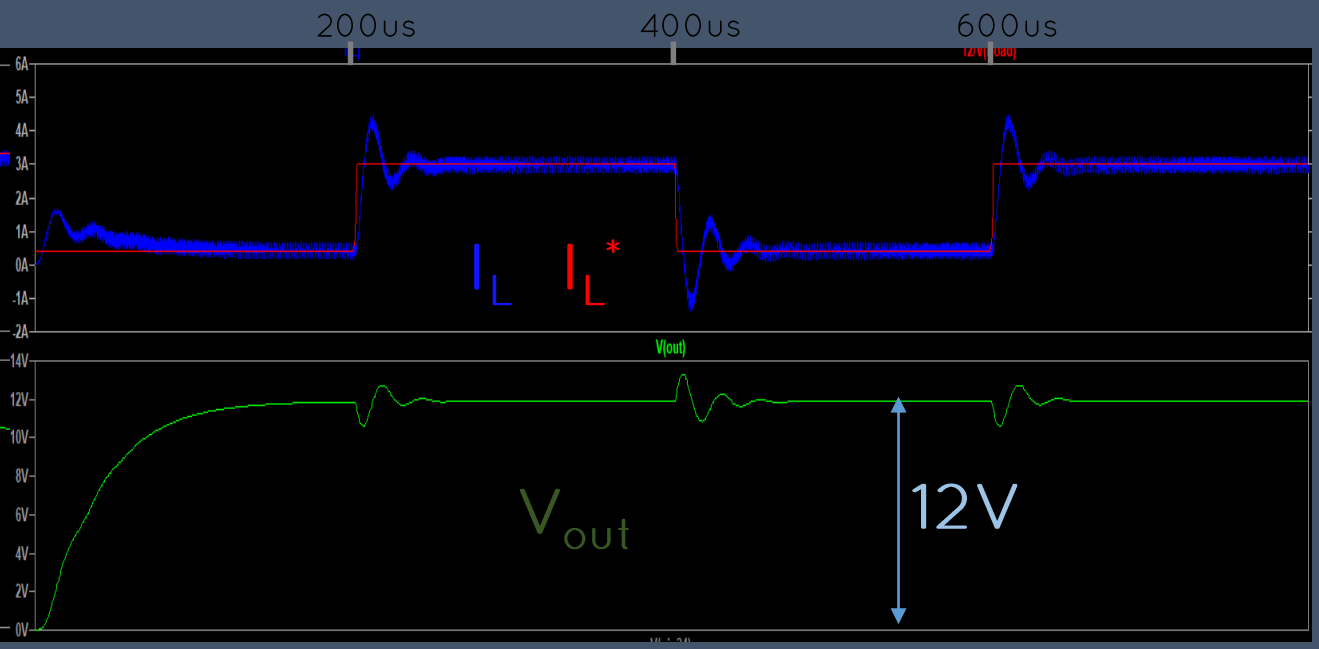
Feasibility study: FEAST as controller for DC/DC stage



Proposed Solution







Spice simulation results: With R_4 With C_{3ext}

Future work and open questions

- Can compensation network of FEAST be externally modified for stable operation with up to 100W load? Provisional answer: Yes
- Can the switching frequency of FEAST be pushed under 1 MHz? (Typical 1-3 MHz)
- Rad-hard isolated DC/DC converter: Design and implementation
- Rad-hard PFC converter: Design and implementation
- Can GaN/SiC FETs be reliably used in radiation environment?
- Effect of switching high voltage MOSFETs (600/700V) under radiation?
  - Threshold voltage
  - Leakage current
  - Single Event Effects/Burnout

https://wikis.cern.ch/display/DIOT/Rad-tol+power+supply