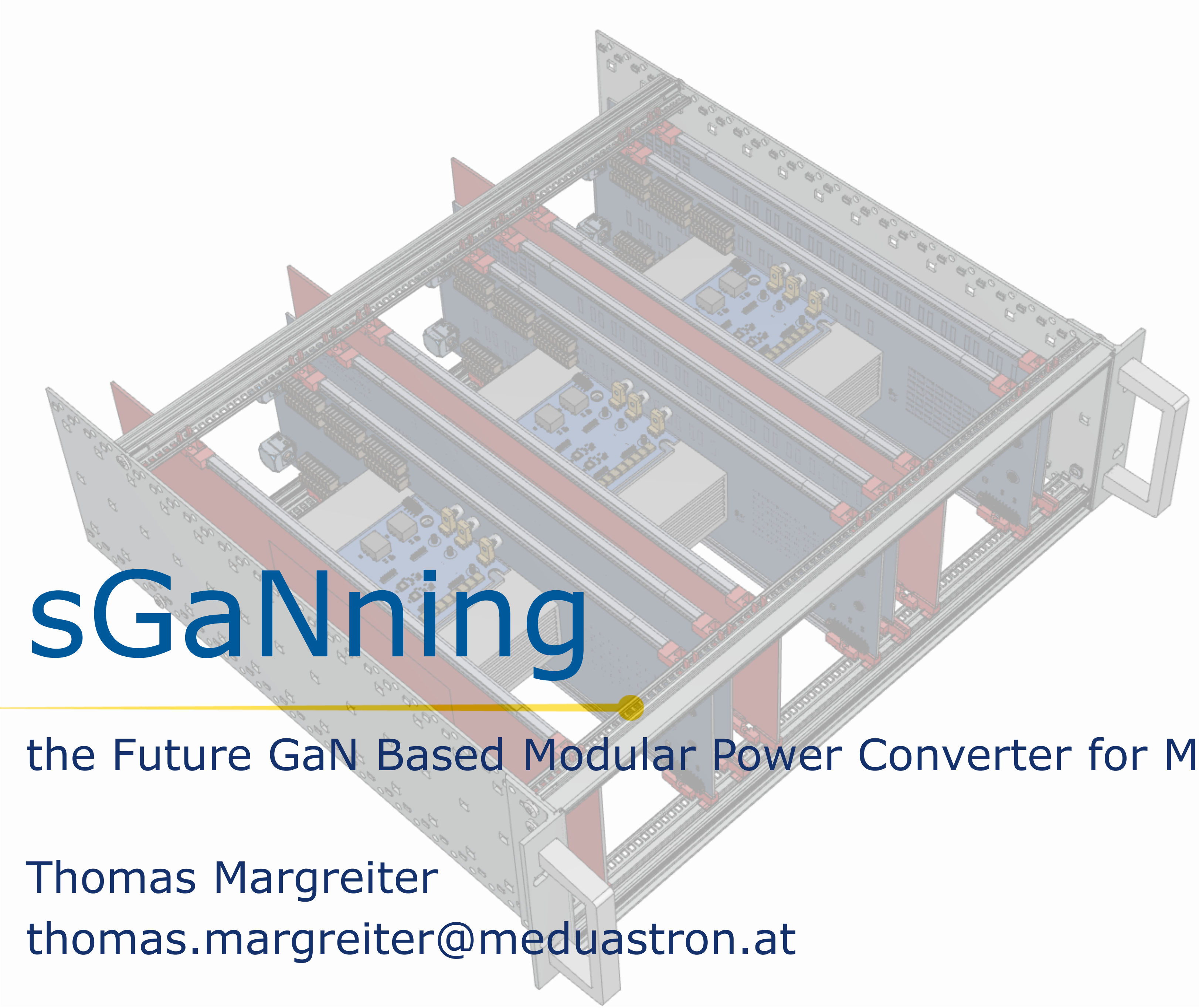


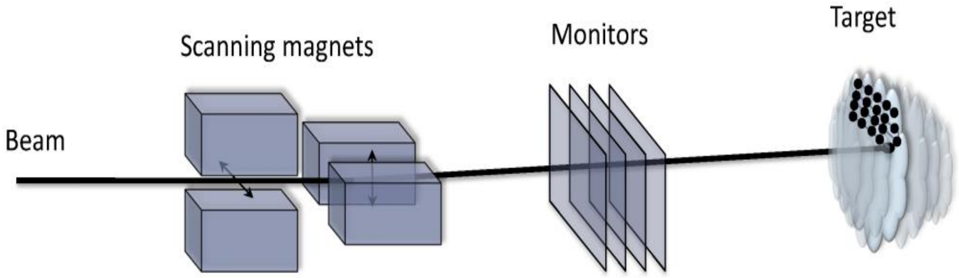
sGaNning

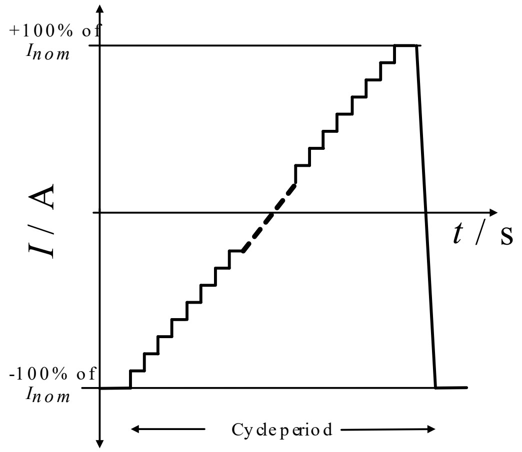
the Future GaN Based Modular Power Converter for MedAustron

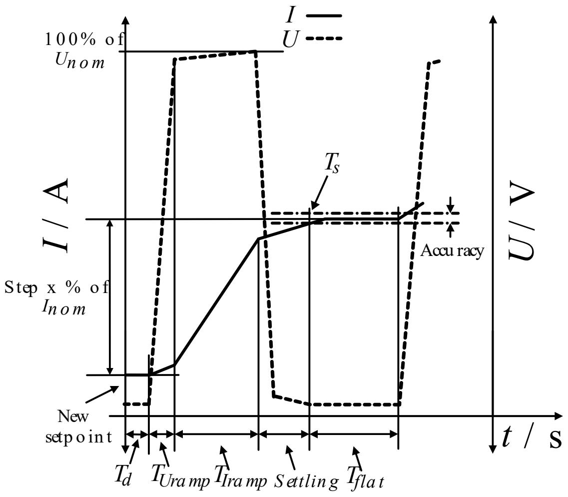
Thomas Margreiter
thomas.margreiter@meduastron.at

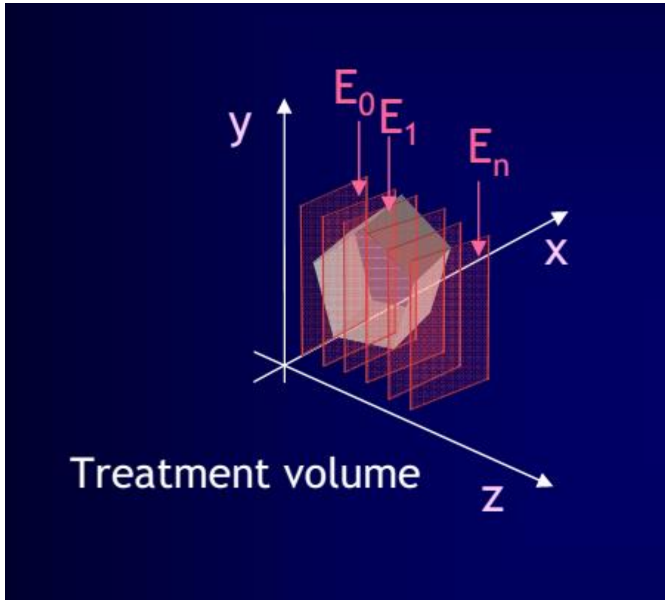
THE SCANNING MAGNET SYSTEM

„Scanning“









„Iso-Energy Slices“

EXISTING SCANNING POWER CONVERTERS (POD)

- Speed: Very high ramp rate = 220kA/s
- Current Precision Class = 200ppm
- Nothing comparable in the power electronics market

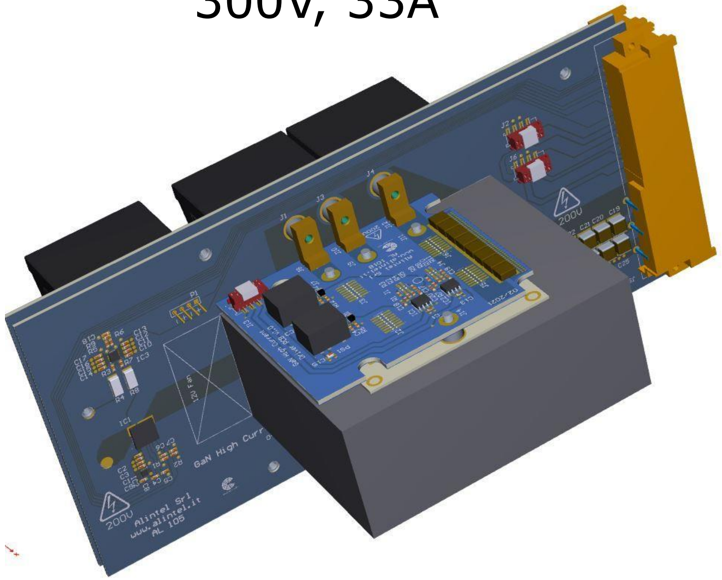
DESIGN OBJECTIVES FOR THE SGANNING'S

Parameter	MA Scanning PCO [1]	sGaNning PCO
Max Current Ramp Rate	220kA/s	**≥ 450kA/s**
Current step time + Settling time	300µs	**150µs**
Minimum time between steps	300µs	**from 200µs to 10µs**
Current precision after transient	±100 ppm	**±100 ppm**
Residual peak-to-peak I ripple	<100ppm	**<100ppm**
Current over/under shoot	<100ppm	**<100ppm**
Mean time to recovery (MTTR)	< 4 hrs	**≤ 2 hrs**
Mechanical footprint (WxHxD)	1800x2200x900 mm	**≤ 1800x2200x900 mm**

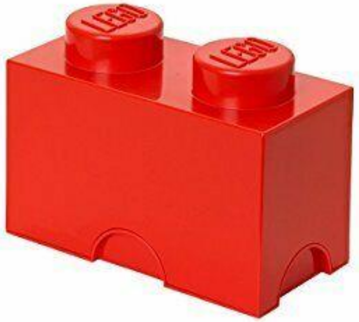
IDEA: MODULAR “BRICK” APPROACH

Goal for sGaNning specs: 1200V, 600A

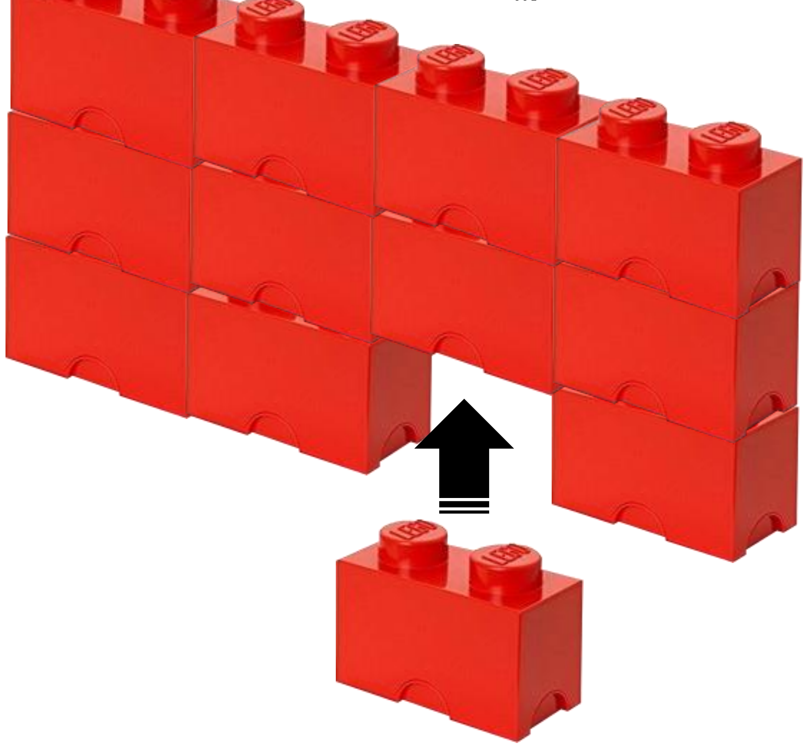
“Submodule”
300V, 33A



PCO BRICK
“Submodule”
300V, 33A



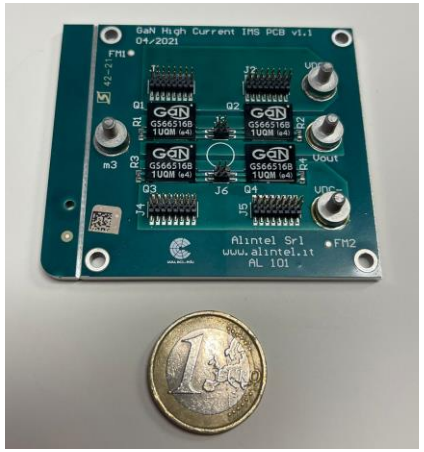
L_m = 3mH

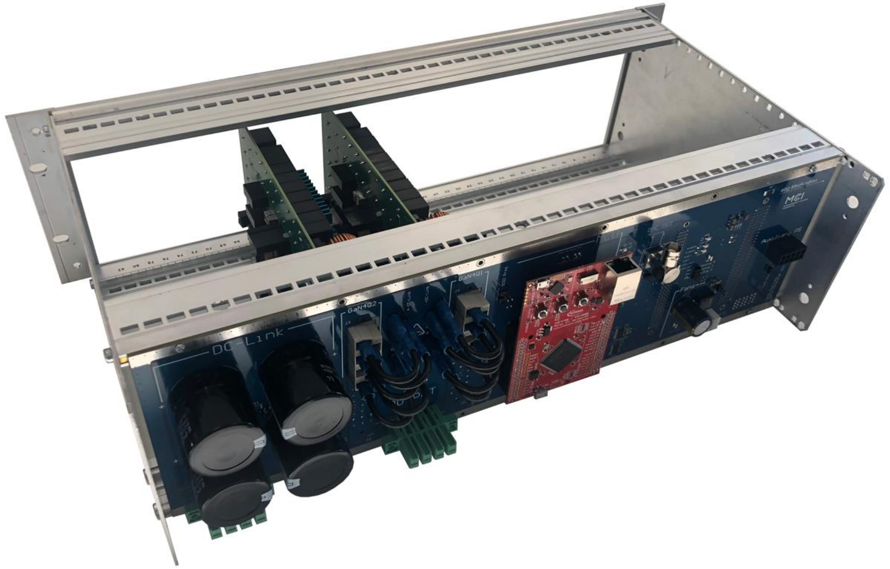


Just another BRICK in the wall!

- Development in cooperation with MCI INNSBRUCK | AUSTRIA

SGANNING DEVELOPMENT HISTORY





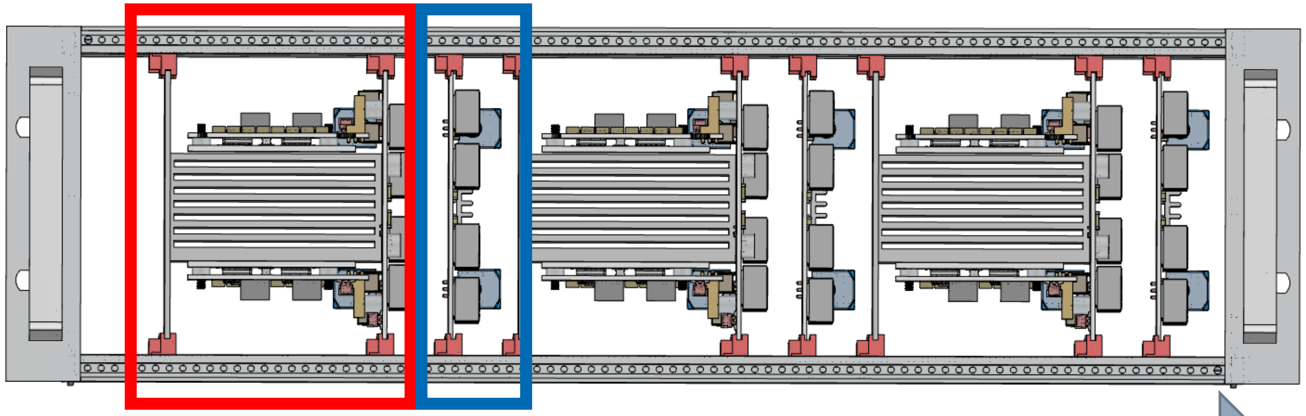
2019:
200V, 20A
Thomas Riedler, et. Al., [2]

2020-2021:
200V, 40A
Lukas Wild, et. Al., [3]

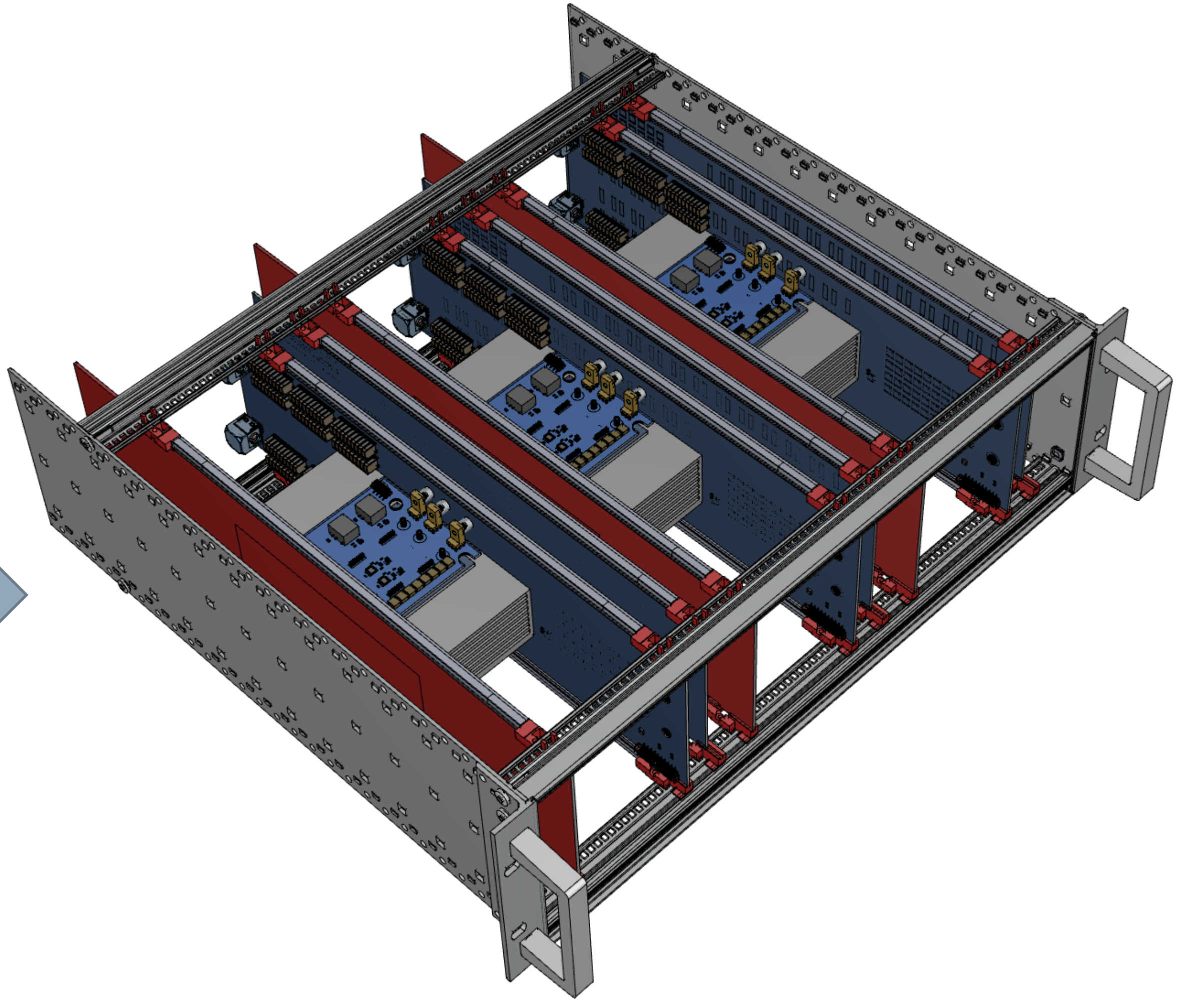
2021:
200V, 40A
Thomas Margreiter, et. Al., [4]

SGANNING PROTOTYPE

- 3 Submodules in one 19” Subrack front view:



2023:
300V, 100A



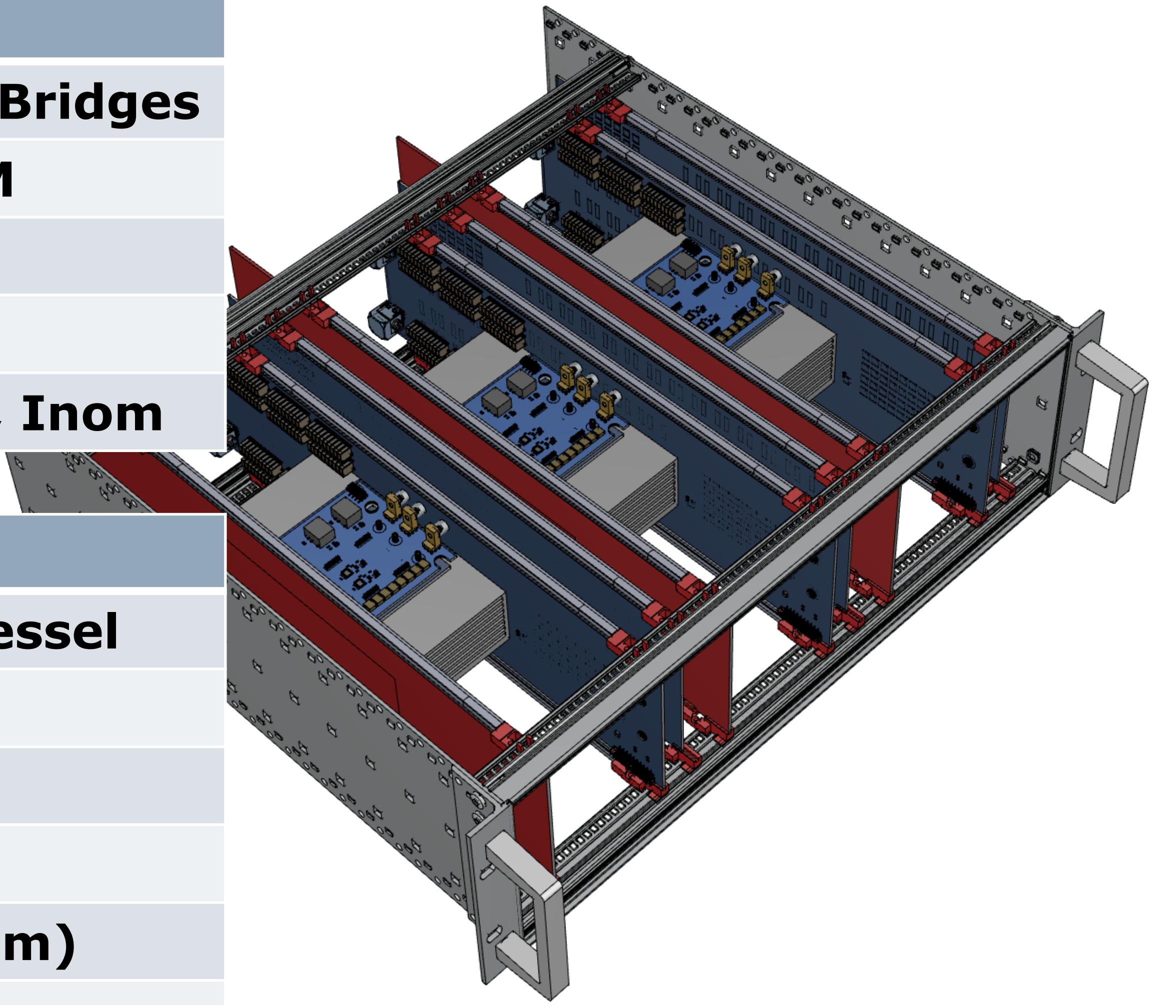
➔ Mainboards with H-Bridge
➔ Corresponding Filterboards

- Interleaved operation
- High power density
- Lower cooling requirements

DESIGN CONSIDERATIONS

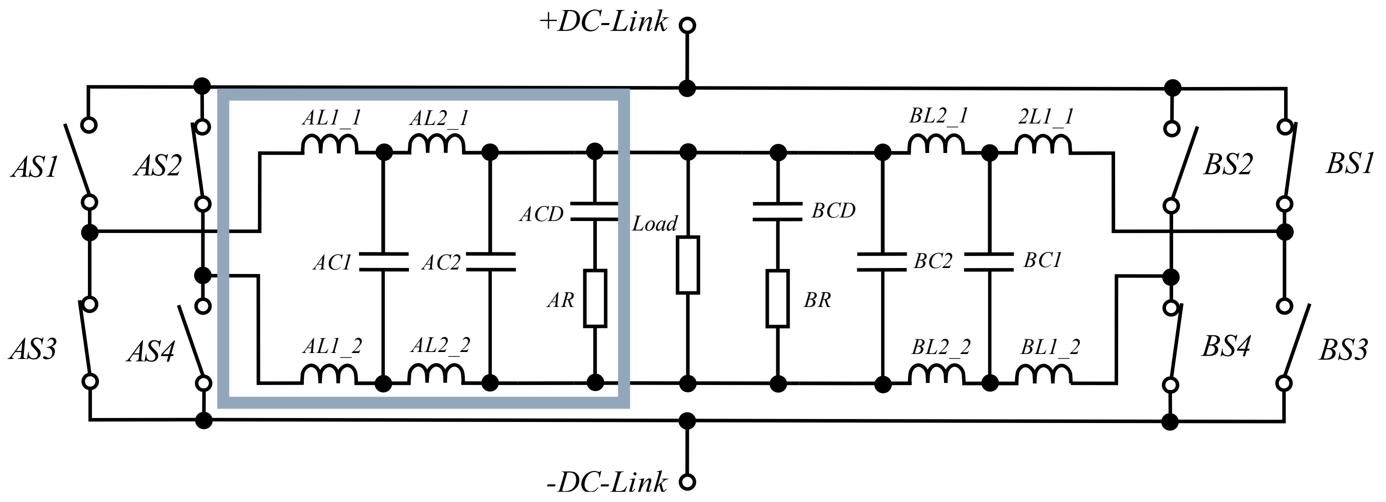
Mainboard Params.	Value
Switching stage topology	**2 Hard paralleled H-Bridges**
Switching technique	**Unipolar PWM**
f_{sw}	**150kHz**
f_{ctrl}	**≥ 75kHz**
P_{loss}	**120W @ TJ = 90°C, Inom**

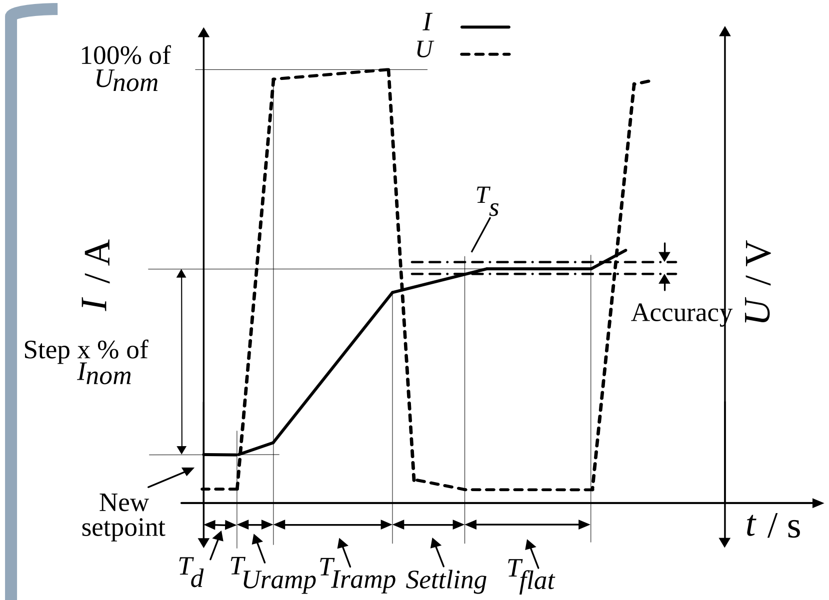
Filterboard Params.	Value
Filter topology	**Split 4th order Bessel**
f_o	**25kHz**
f_{-3dB}	**50kHz**
P_{RD}	**50W**
ΔI_{pp}	**2*(10% of Inom)**
G_B	**0.0013 @ f_{sw}**



FILTER DESIGN: CONSIDERATIONS PT.II

- Filter structure shown for 2 H-Bridges interleaved:





- Two degrees of freedom design approach
- Components chosen by means of genetic algorithm
- Crucial design considerations regarding R_D

$$\Delta I_{max} = \frac{V_{out_{max}}}{L_{m_{max}}} \Delta T_{max}$$

$$T_{cycle} = 4 \frac{I_{nom}}{\Delta I_{max}} (T_s + T_{flat})$$

Power dissipation in the damping path.
Fast and frequent transients: 150µs
Worst case considerations are important!

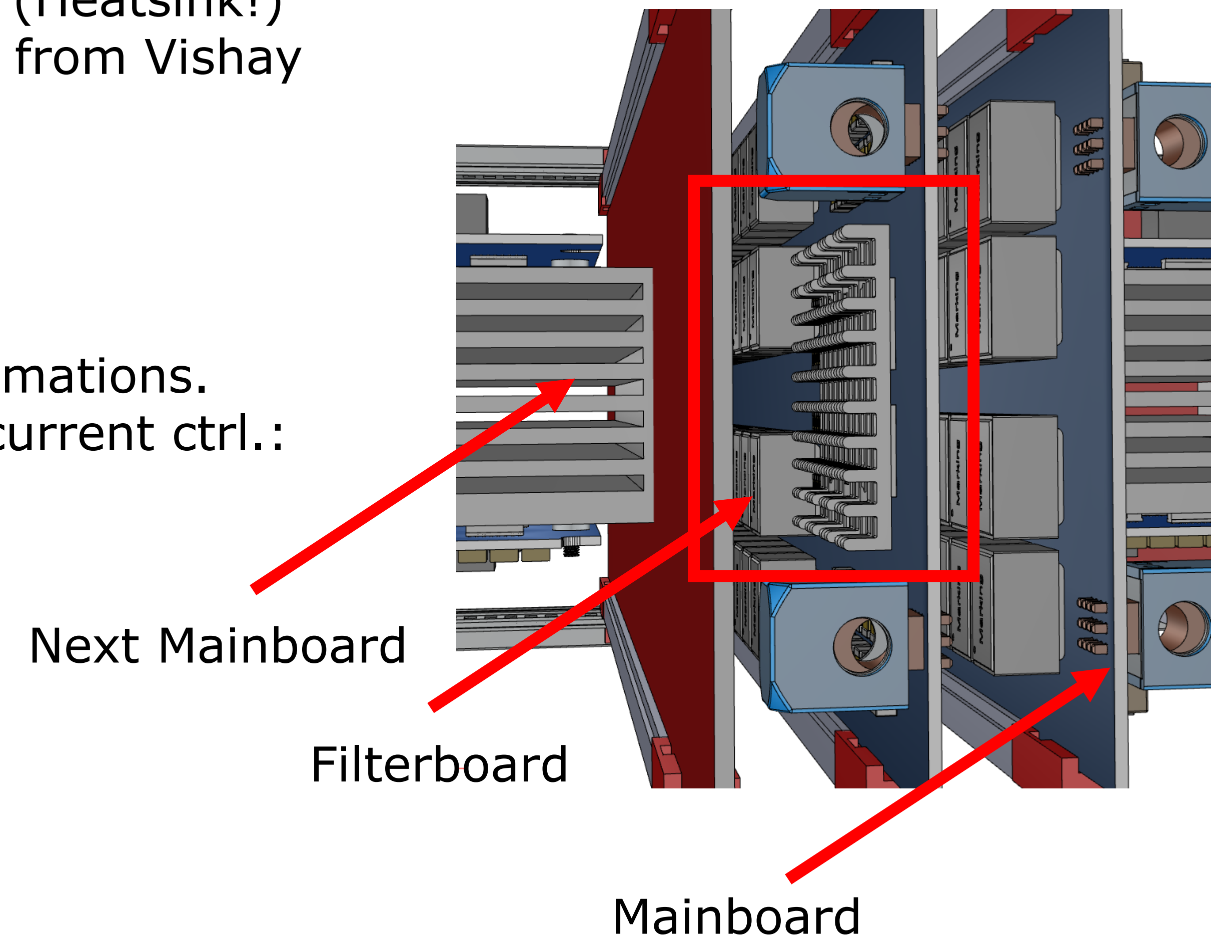
FILTER DESIGN: GOING DOWN THE DRAIN

- Space that can be occupied is very limited (Heatsink!)
- Power resistor with 120W & 25mmx30mm from Vishay

[5]

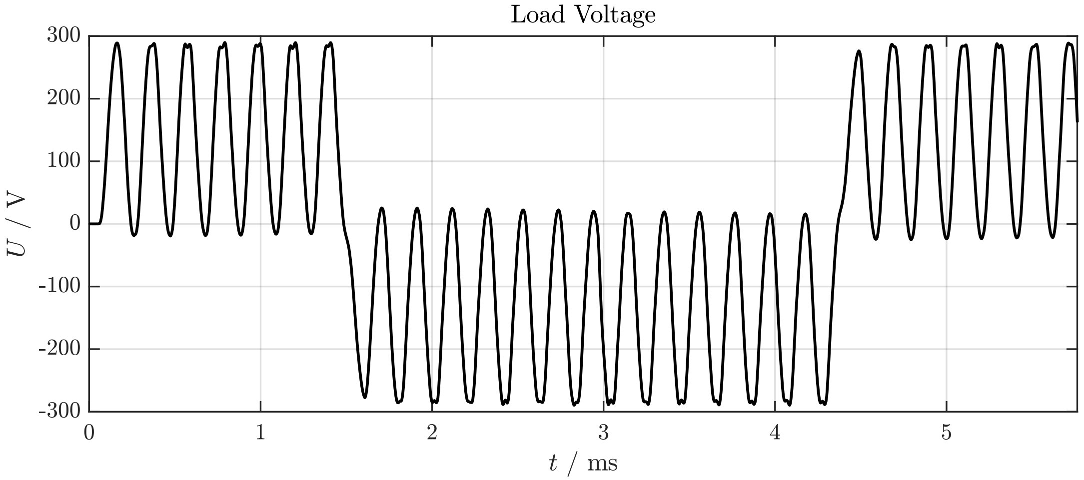
- Closed loop simulations for power loss estimations.
- PI as inner loop (voltage source), RST as current ctrl.:

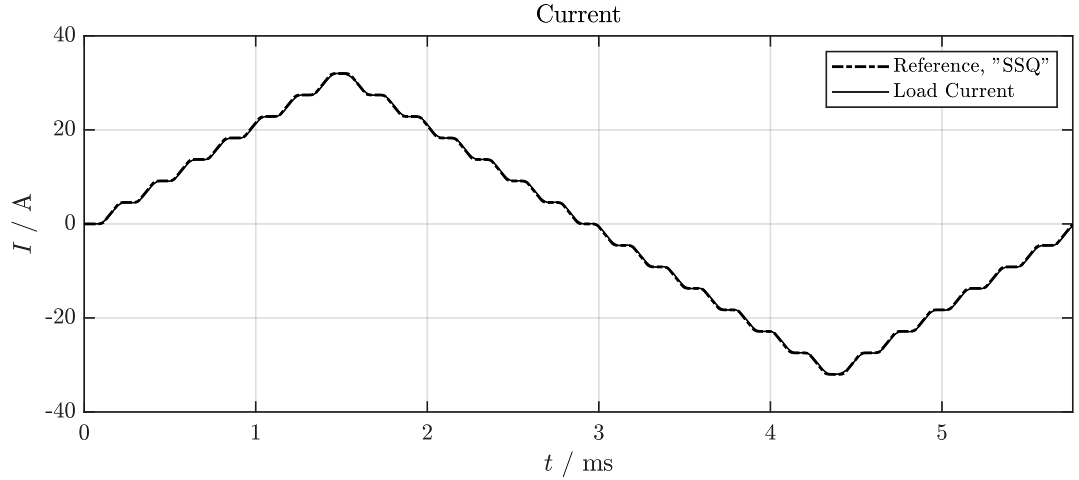
Parameter	Value (for Submodule!)
di/dt	**45kA/s**
I_{step}	**~ 4.5A**
T_s	**150µs**
f_{ctrl}	**75kHz**
ζ	**1**
f_{BW}	**7.5kHz**
L_m	**8.3mH**



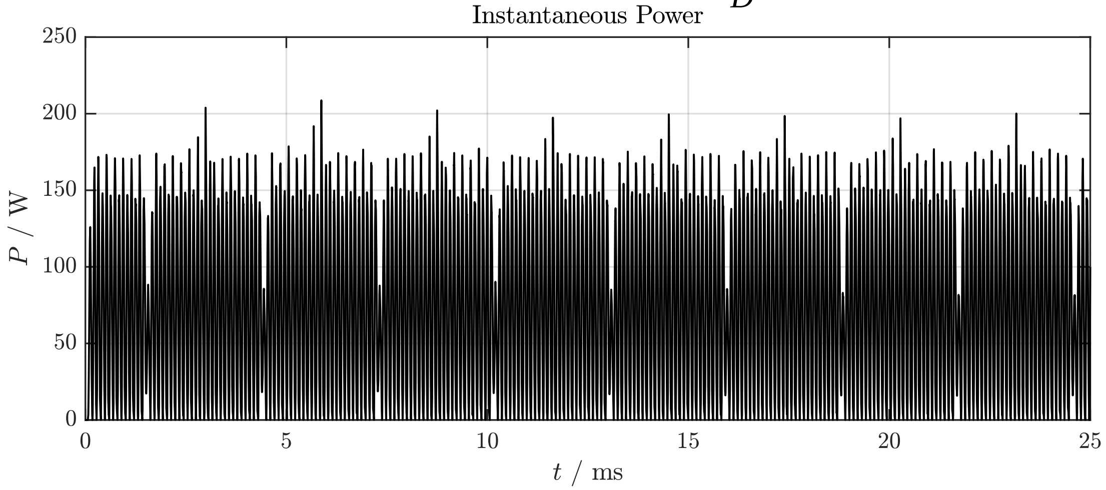
FILTER DESIGN: GOING DOWN THE DRAIN

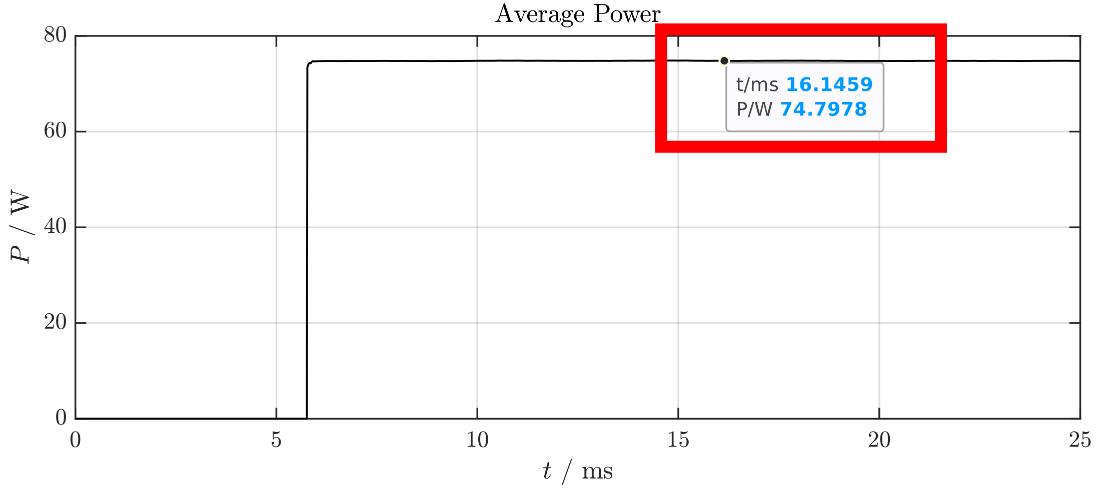
- Waveforms with closed loop simulations:





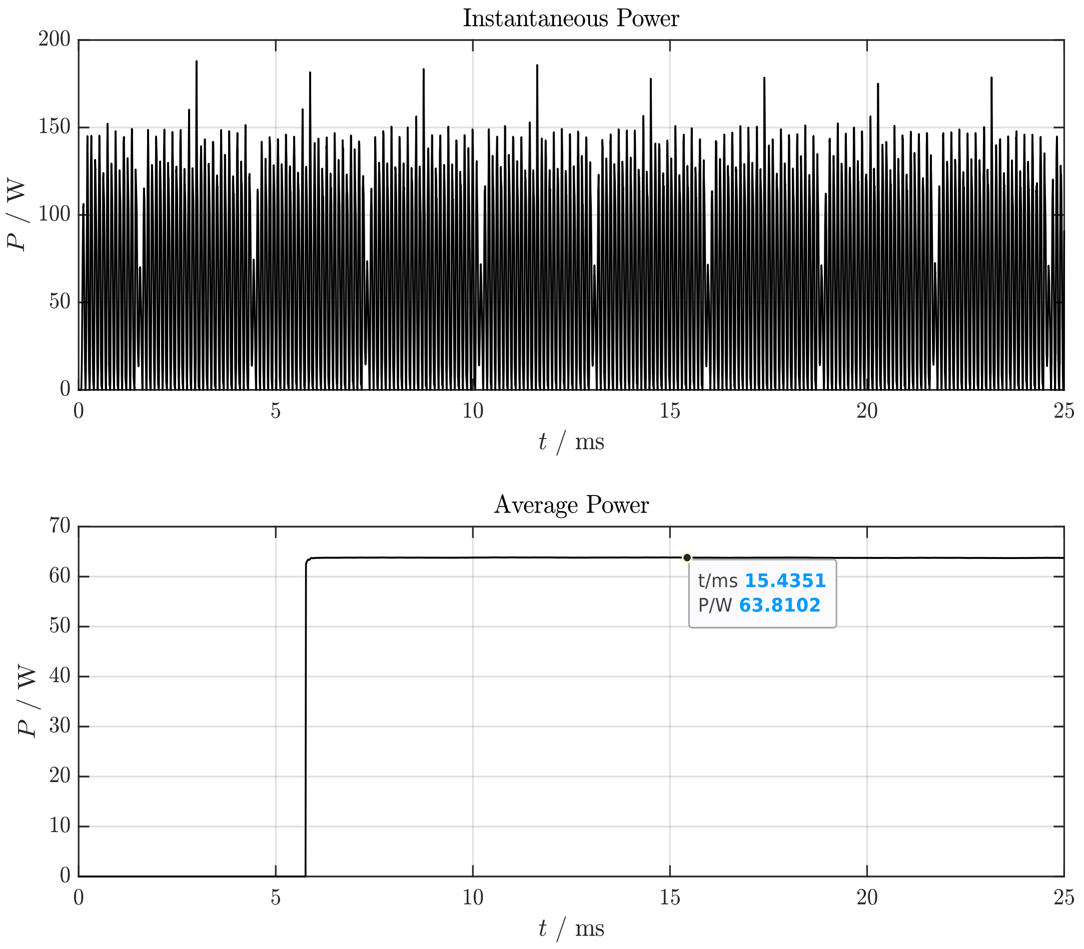
- Losses on R_D:



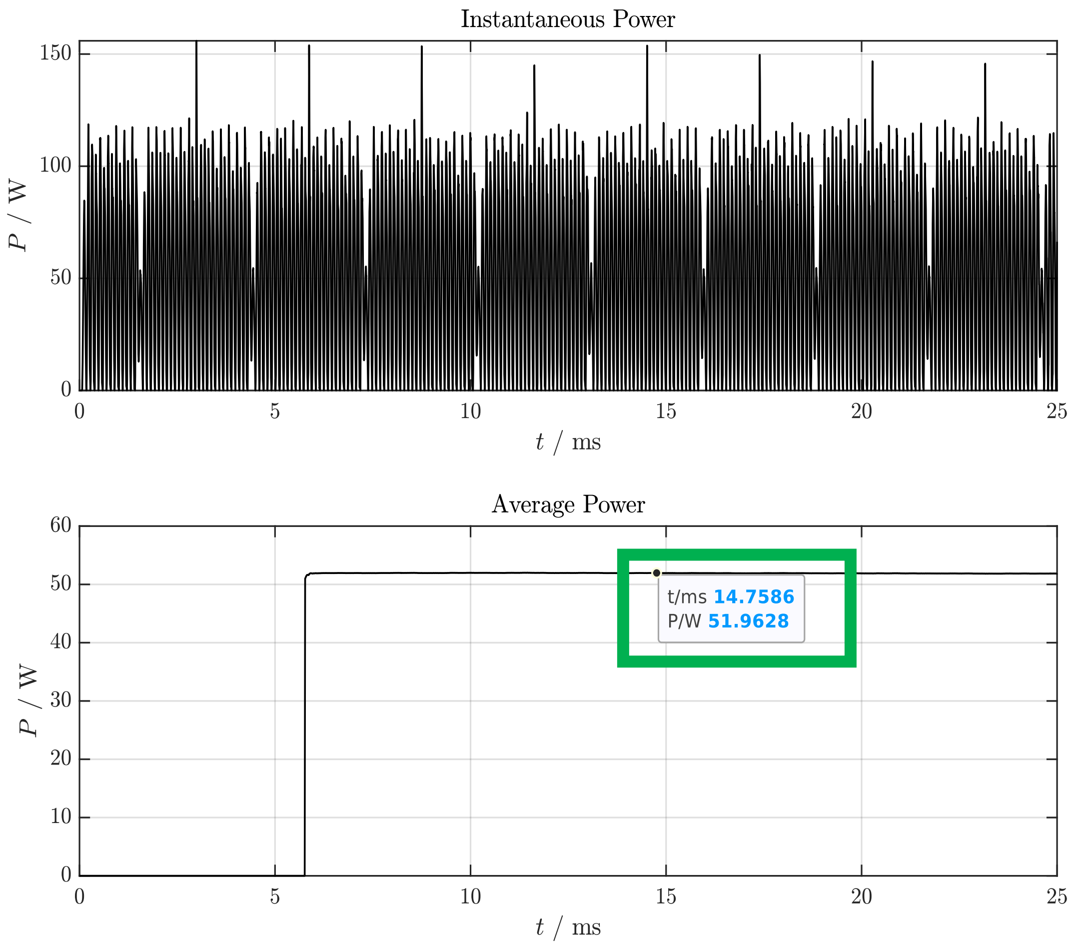


FILTER DESIGN: GOING DOWN THE DRAIN

- C_2 + 10% and C_D -10%:

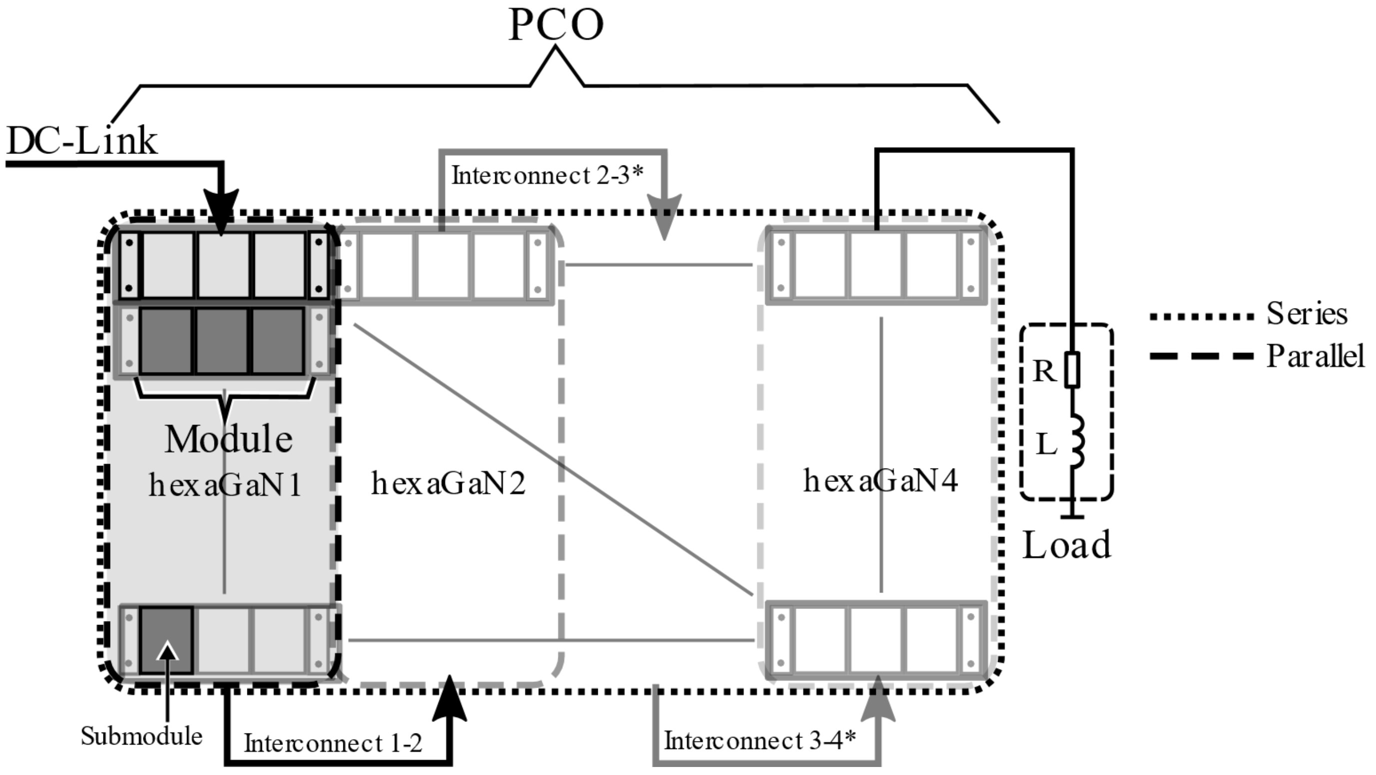


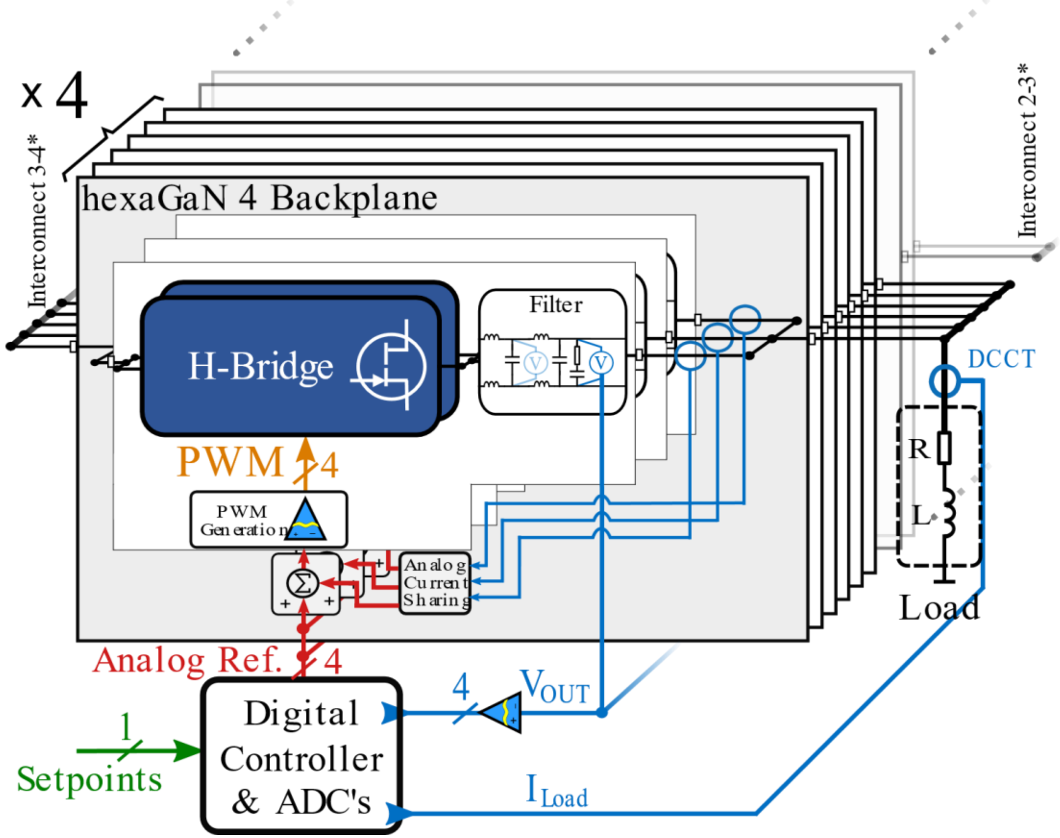
- C_2 + 20% and C_D -20%:



SGANNING PCO: STRUCTURE

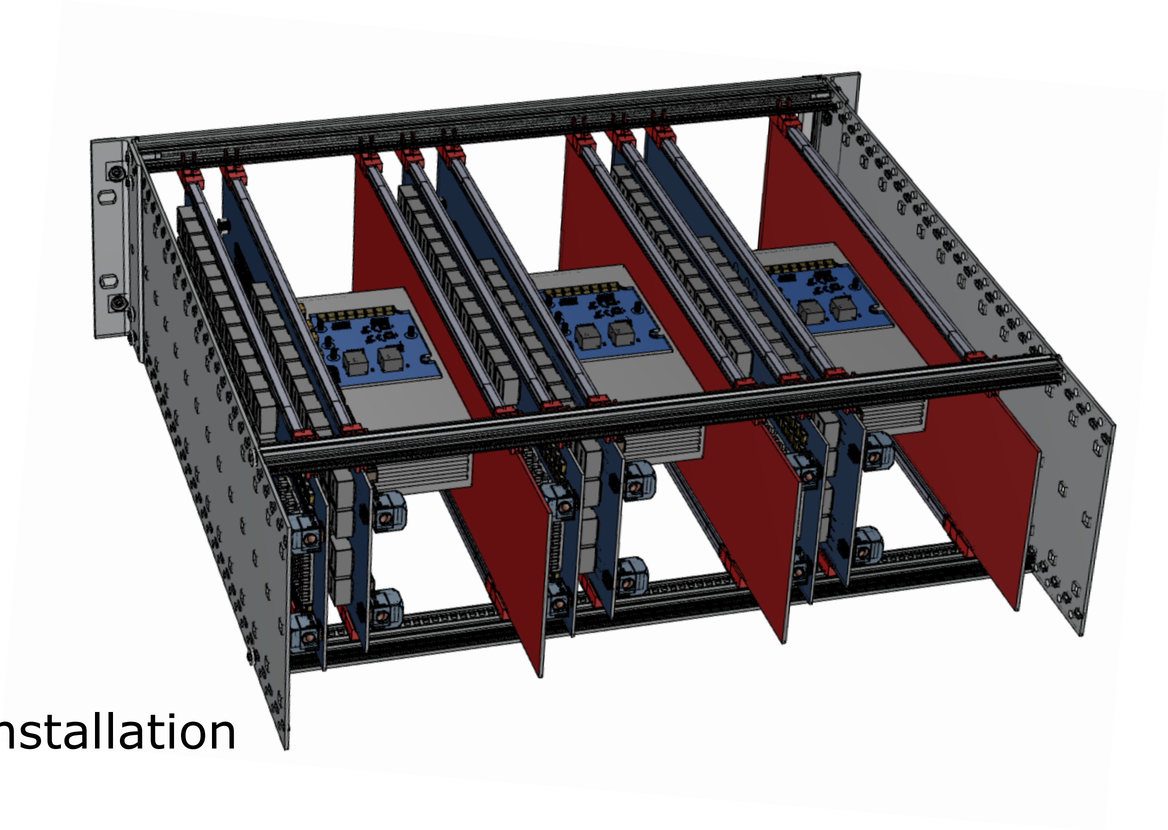
- One hexGaN are 6 subracks in parallel
- Distribution of PWM signals with local controller on submodule or subrack level
- Currents measured per submodule for analog or digital I balancing
- Voltages on submodule level for voltage control and “fine” current control





CONCLUSION & OUTLOOK

- Evaluated existing design
- Investigated filter requirements
- Development of a control structure
- Prototype right now in routing stage



➔ Prototype expected by 07.2023
➔ Submodule stress tests together with CERN
➔ 12.2023: End of submodule test, release of the design to a power electronic company (t.b.d.)
➔ End of 2024: Delivery of the 1st sGaNning
➔ Mid of 2025: End of commissioning, ready for installation

Thank you for your attention!

[1] Technical Specification Family D Power Converters for the MedAustron Accelerator, I. De Cesaris, et. Al., unpublished, EBG MedAustron 2013, TD-121121-a-IDC v1.0, 2013

[2] HIGH PRECISION FOUR QUADRANT CONVERTER WITH GaN TECHNOLOGY, M. Incurvati, T. Margreiter, T. Riedler and R. Stärz, 12th International Particle Accelerator Conference (IPAC21), 2021, pp. 2431-2434, doi:10.18429/JACoWIPAC2021-TUPAB389.

[3] GaN High Current DC/DC converter for Physics Applications, M. Incurvati & L. Wild, MCI Department of Mechatronics, October 27, 2021

[4] Hardware and Control Design of a High Precision Modular Power Converter based on GaN Technology for Particle Accelerator Magnets, Th. Margreiter, I. De Cesaris, M. Incurvati, S. Pelletier, M. Schiestl & R. Stärz, European Power Electronics Conference, 2022

[5] Thick Film Power Resistor With NTC (Optional), Vishay, 2022

[6] HIGH-POWER MODULAR GAN BASED POWER SUPPLY FOR MEDAUSTRON SCANNING MAGNETS, T. Margreiter, R. A. Teixeira, I. D. Cesaris, S. Pelletier, M. Incurvati, T. Gadner, 14th International Particle Accelerator Conference (IPAC23), 2023, WEPM075.

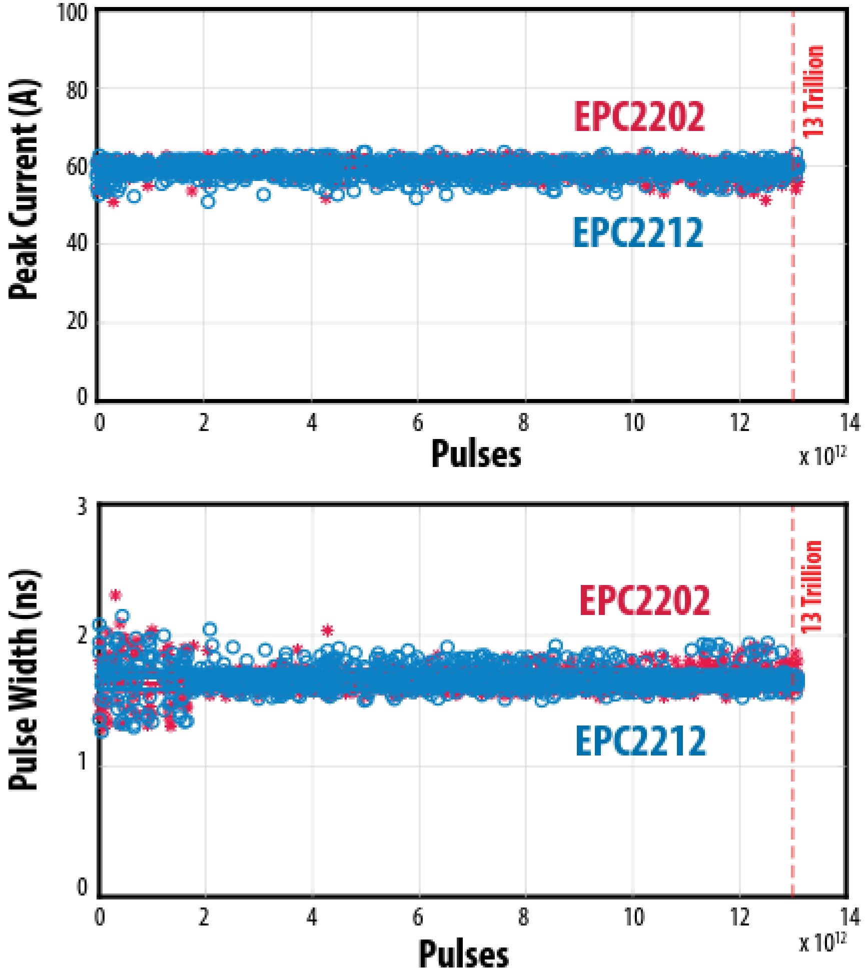


Figure 16: Long-term stability of pulse width (bottom and pulse height (middle) over 13-trillion lidar pulses. Data for four EPC2202 (red) devices and four EPC2212 (blue) devices are overlaid in the plots.

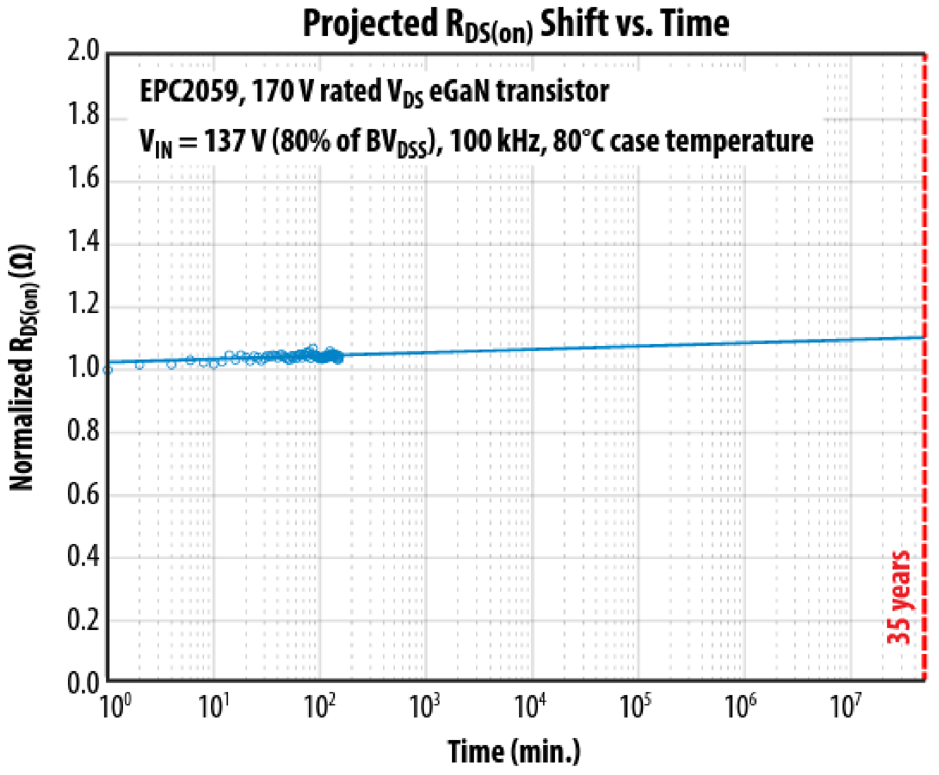


Figure 29: Projected $R_{DS(on)}$ shift of EPC2059, a 170 V rated device in 35 years of continuous hard-switching operation is expected to be approximately 10%.

EPC: Reliability Report - Phase 15

„GaN devices have been in volume production since 2010 and have demonstrated very high reliability in both laboratory testing and customer applications…