Piezo Control Device
Preliminary Design Review

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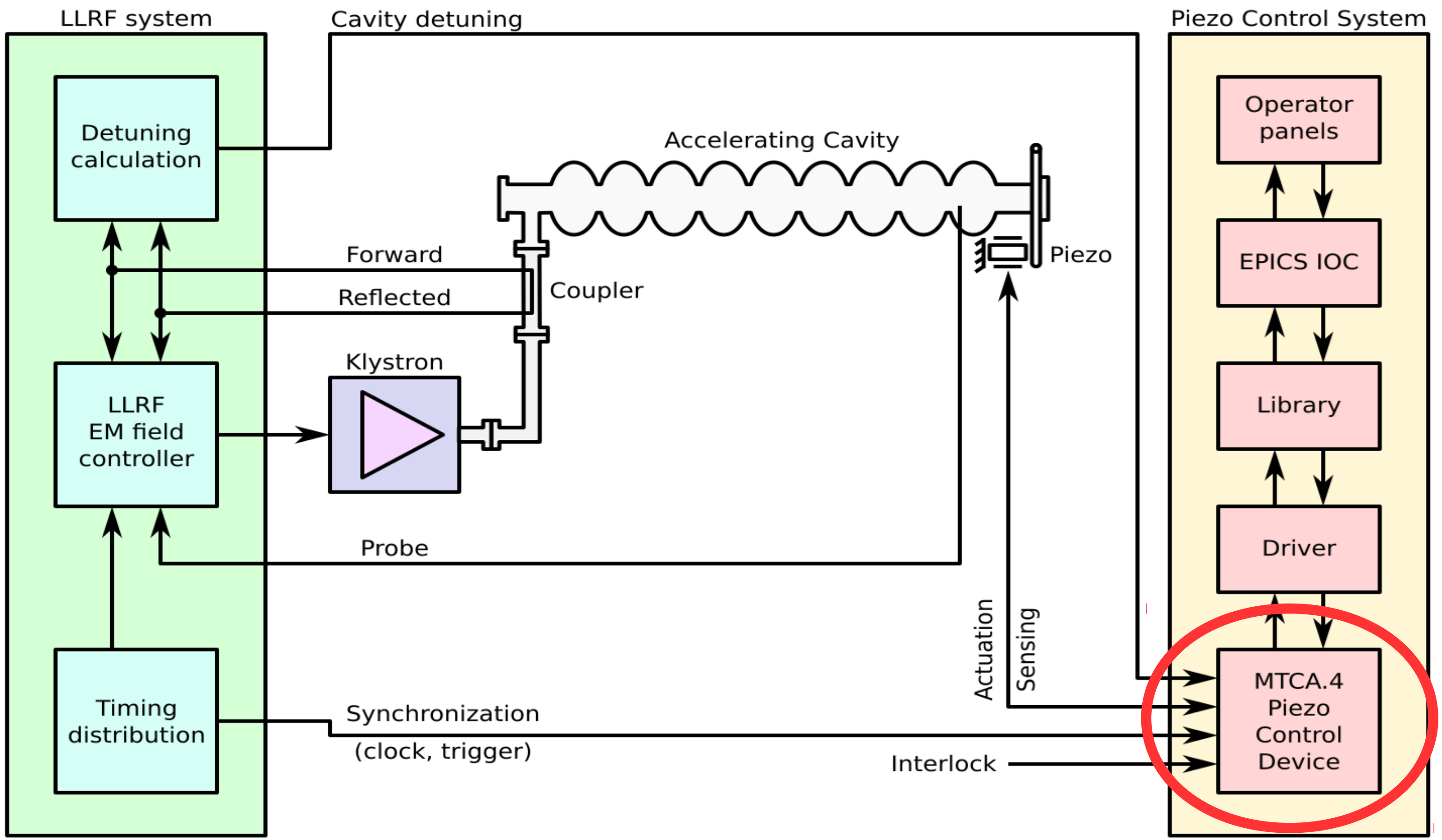
Agenda

- Specification for Piezo Compensation System
- Laboratory Tests
- Tests at Freia
- Final Design
- QA – Resources, Risk Analysis

Piezo Compensation System



Specification for PCS

Description:	This document describes the requirements for the Piezo Control System (PCS) of ESS Linac
Title:	Piezo Control Device In Kind Contribution of PEG Consortium

Functional Specification for Piezo Control System

- Provide a control signal for piezo actuators of medium- and high-beta accelerator cavities operating in cryogenic temperatures
- Measure cavity deformation using piezo device as sensor element
- Support two independent channels with configurable mode of operation: piezo actuator or sensor
- Provide a digital control and diagnostic interface of piezo driver via Zone 3 connector
- Should be compatible with MicroTCA.4 standard
- Provide health monitoring and diagnostics
- Assure safe operation of piezo actuator

Piezo Actuators

Cavity type	Piezo actuator type
Medium Beta cavities	Noliac NAC 2022 H30
High Beta cavities	Noliac NAC 2022 H30
Spoke cavities	Piezo #1: Noliac NAC2022-H90-A01 Piezo #2: PI PICMA P-888.91

Piezo type	**Noliac NAC 2022 H30**
Dimensions	10 x 10 x 30 mm
Cell material	NCE51F
Number of cells	15
Total capacitance (room temp.)	6.6 μF
Total capacitance (cryo, 20 K)	**~2.2 μF**
Max. free stroke	**49.5 μm**
Blocking force	4200 N
Max. operating voltage	200 V (±100 V)
Max. operating temperature	200°C

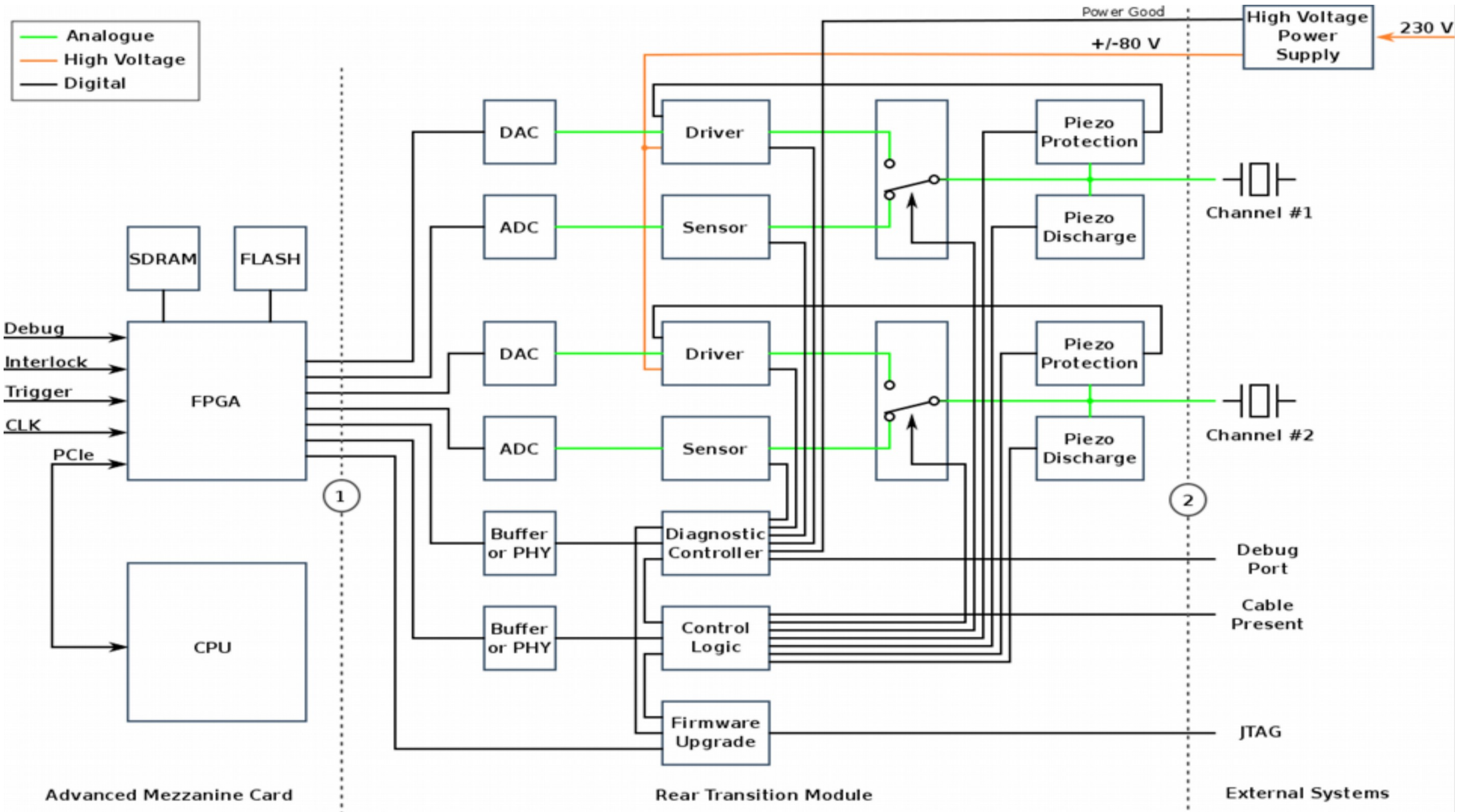
Main requirements of PCD

Parameter	Value	Comments
Supported standards	MTCA.0, MTCA.4, AMC.0, AMC.2, IPMI 2.0	
Number of channels	2 bipolar channels with actuator/sensor mode	
Repetition Rate	14 Hz	pulse duration: max. 3.5 ms
Piezo capacitance	6.6 – 9.5 µF (room temperature)	high and medium beta cavities
Piezo supply voltage	±80 V (160 Vpp)	
Maximum actuator power	35 W per channel	
Controller Bandwidth	DC – 1 kHz	
Actuator excitation signal	Arbitrary waveform generation Sampling frequency: min. 1 MHz Number of samples: min. 30000 Resolution: 16-bits Output voltage range: ±80 V	
Piezo sensor	Sampling frequency: min. 1 MHz Number of samples: min. 30000 Resolution: 16-bits Input voltage range: ±1 V Input impedance: 10 kΩ	
Protection	Overcurrent,Overvoltage Thermal protection of the driver Maximal control power of piezo	
Cable length	min. 30 m long, max. 45 m long	

Piezo Actuators for Spoke Cavities

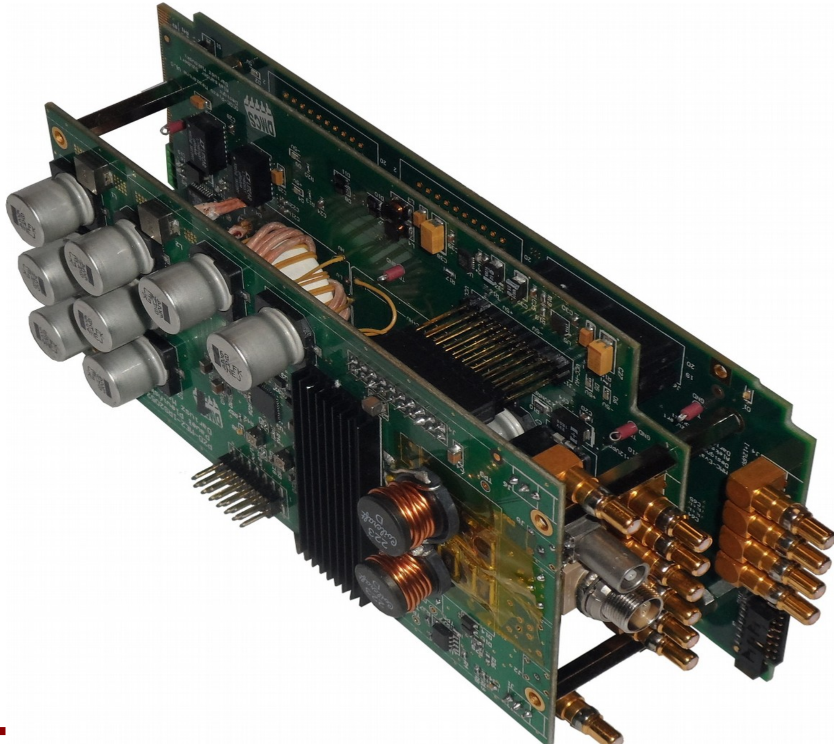
Piezo type	Noliac NAC2022-H90-A01	PI PICMA 2x P-888.90 and 1x P-888.50
Dimensions	10 x 10 x 90 mm	10 x 10 x 90 mm
Cell material	NCE51F	PIC252
Number of cells	45	
Capacitance (room temperature)	17.4 µF ±15%	32 µF ±20% (2x 13 µF + 1x 6 µF)
Capacitance (cryo temperature, 20 K)	~5.8 µF	~10 µF
Max. free stroke	145.2 µm	79 µm (2x32 µm + 15 µm)
Blocking stroke in cryo temp.	9 µm	TBD
Blocking force max.	4200 N	~3600 N
Max. operating voltage	200 V	-20 to 120 V
Max. operating temperature	150°C	150°C
Unloaded resonance frequency	248 kHz – 11 kHz	40/70 kHz
Comment	Suggested by INPO	Hybrid solution, suggested by INPO

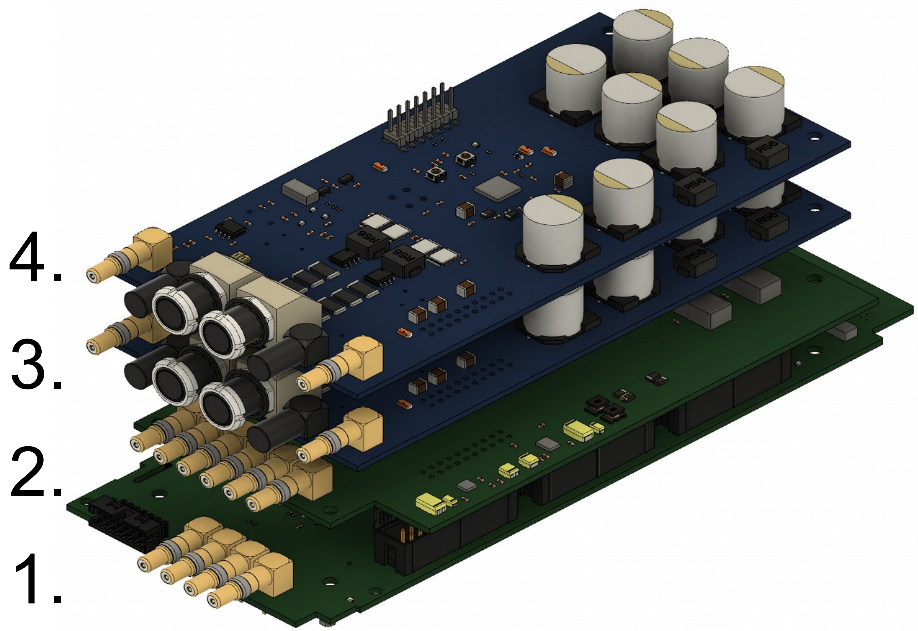
Block Diagram of Piezo Control System



PCS – First Prototype

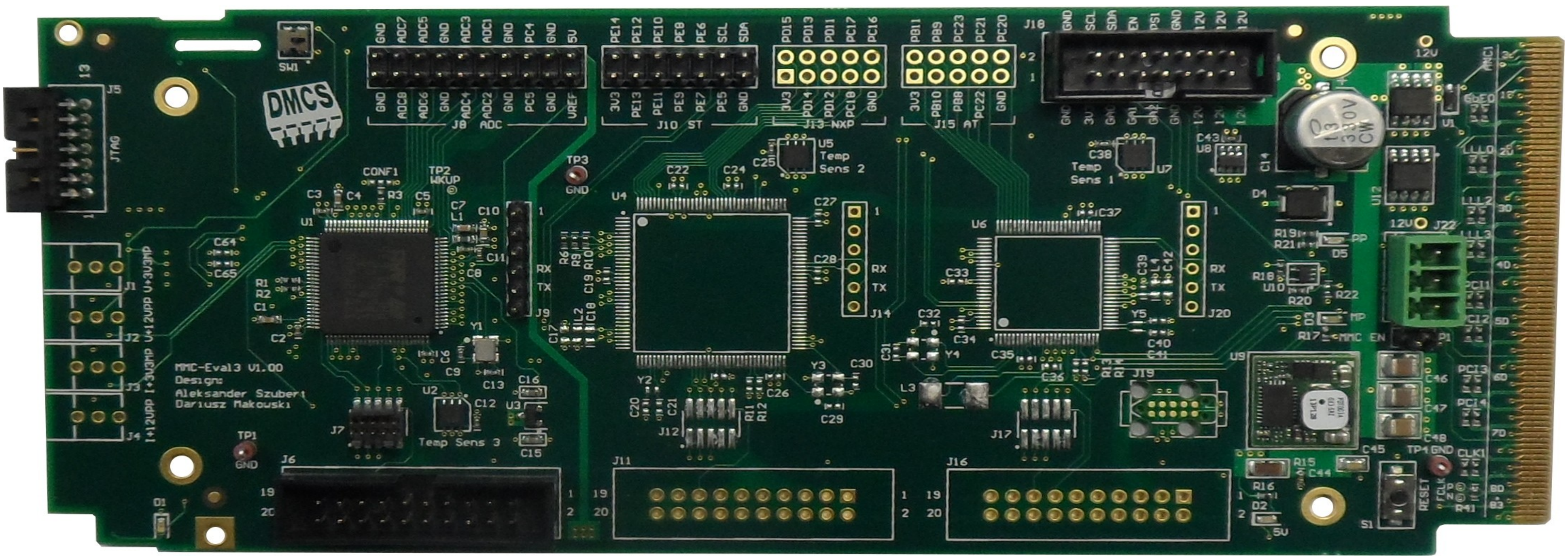
4. Piezo Driver module #1
3. Piezo Driver module #2
2. DC/DC Boost converter
1. AMC carrier module with MMC





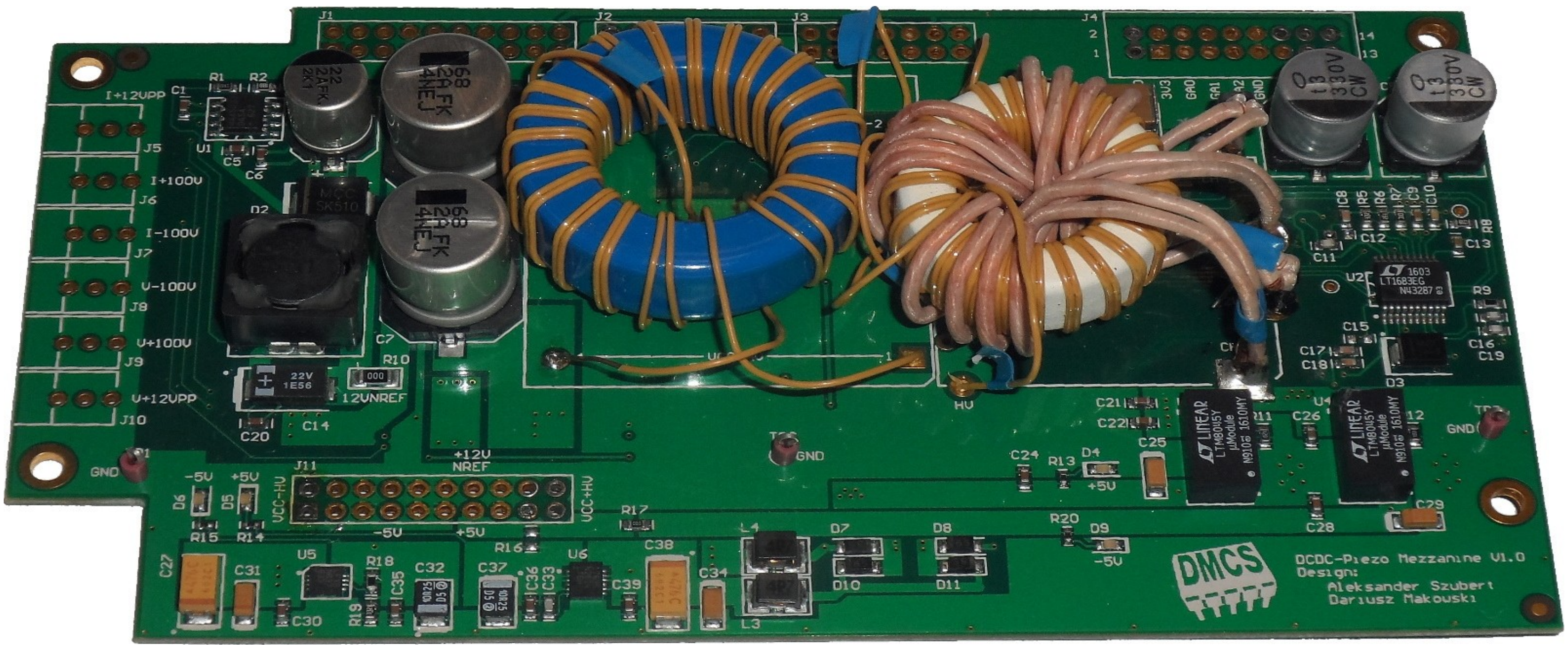
Module Management Controller – PCD Carrier Module

- Equipped with ARM STM microcontroller
- Power and current monitoring (via scope and MMC)
- Provides power supply from MicroTCA chassis
- Provide diagnostics and monitoring: IPMI sensors, ID signature, FRU, etc.



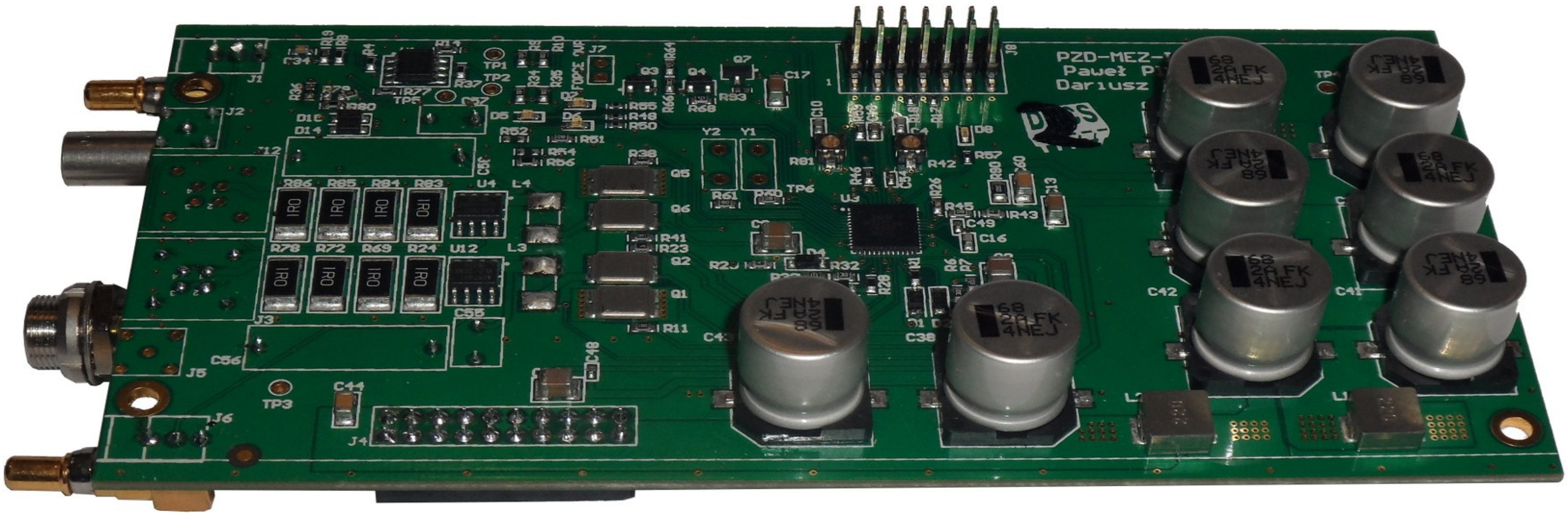
Power Supply Module

- Output Power: 100 W (2 channels), efficiency: 80 – 90%
  - +/- 50 V, 1 A (+/- 85 V, 0.6 A)
  - +/- 5 V, 500 mA (+/-15 V, 500 mA)
- Over-current protection, built-in diagnostics and monitoring
- **Testing of power consumption, MicroTCA.4 cooling and protection circuits.**



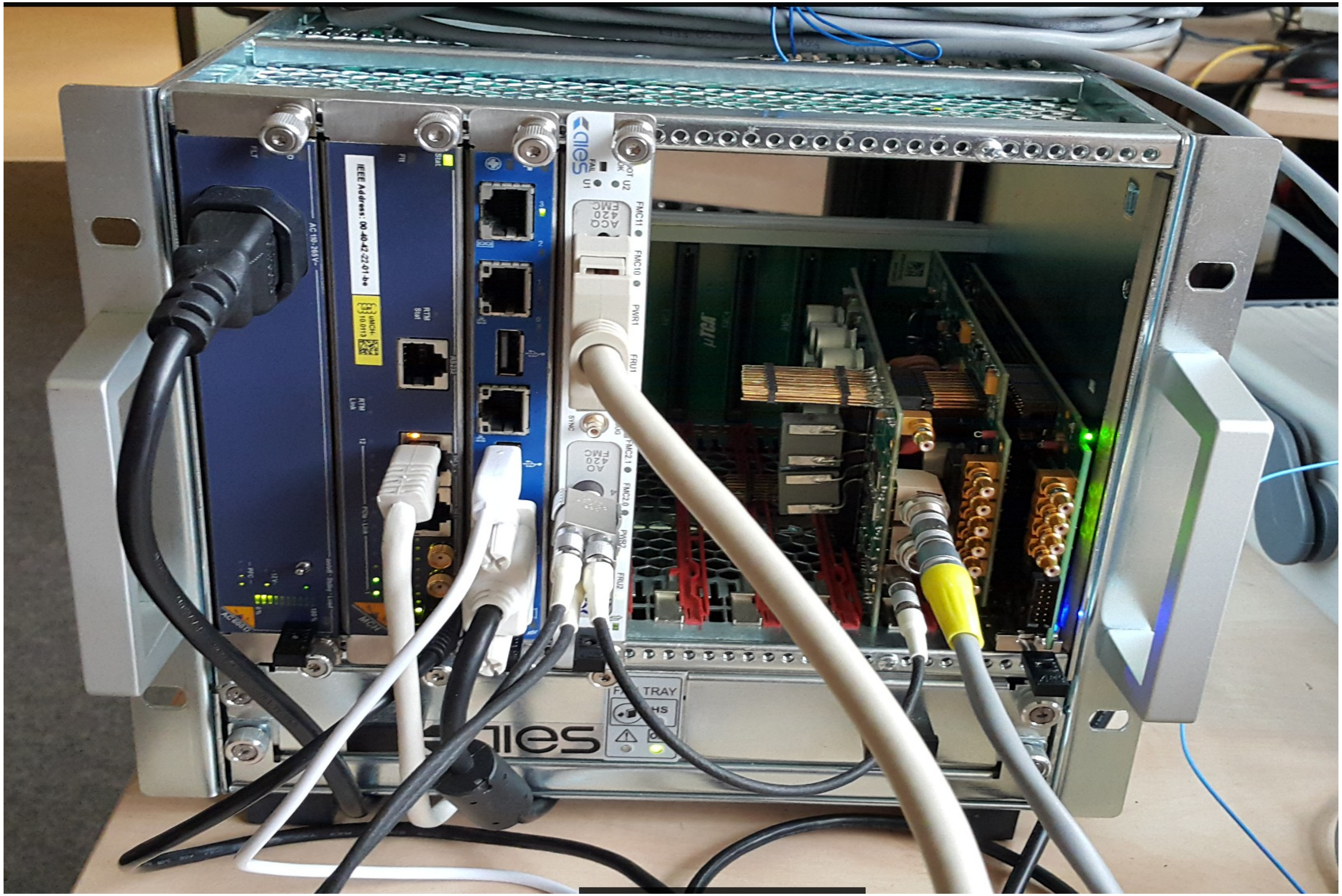
Testing of Piezo Driver Module

- Output Power: 50 W, efficiency: 80 – 90% Class D stage
- Single channel, ca. +/- 95 V, max. 10-20 uF
- Built-in diagnostics, monitoring and protection circuits
- **Testing of:**
  - **Piezo actuator control (single vs dual channel),**
  - **Hardware design (output voltage, driving capacity, heat dissipation, power consumption, etc.)**
  - **Piezo monitoring**



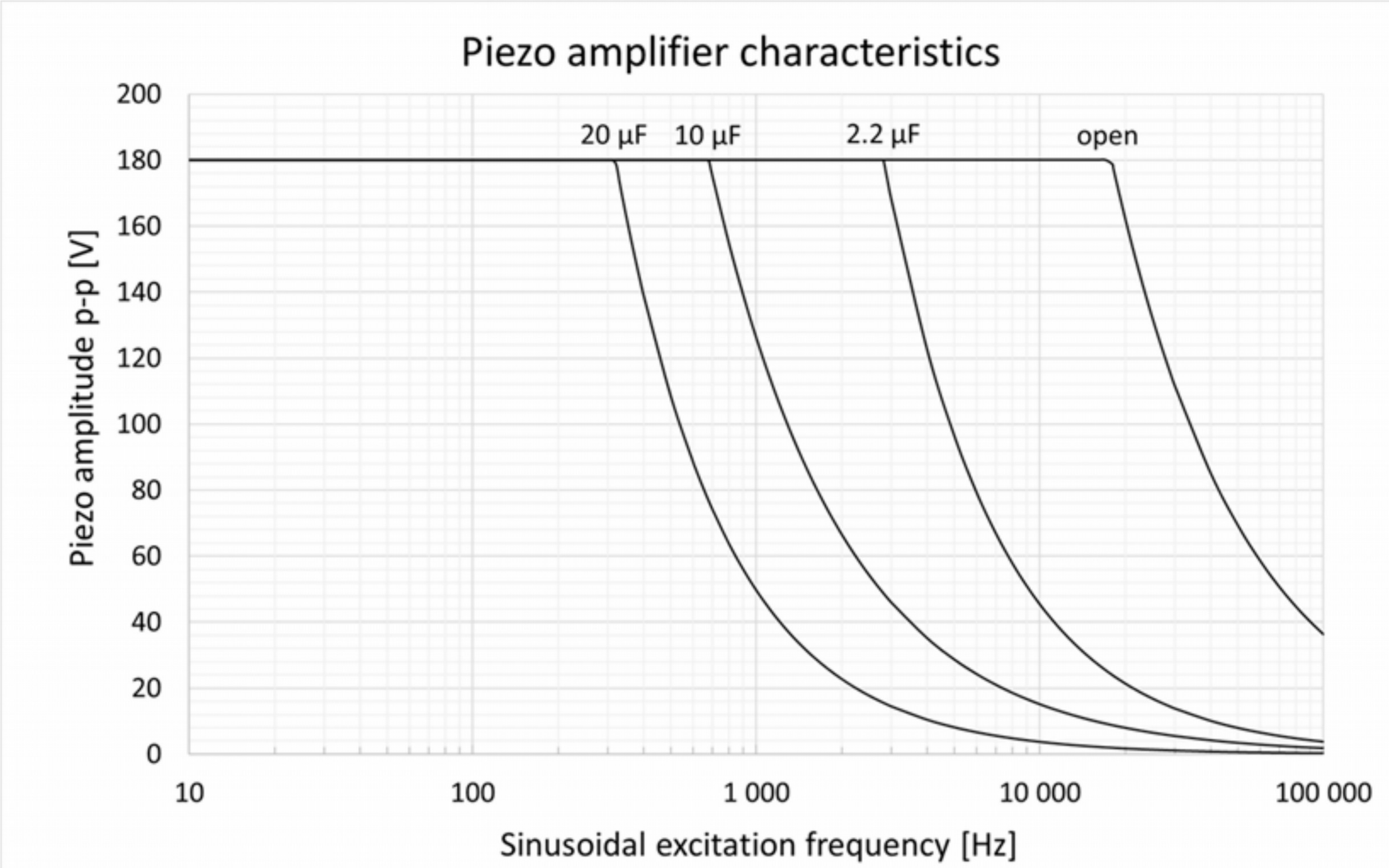
Piezo Controller and Piezo Monitor

PCS Development and Testing at DMCS

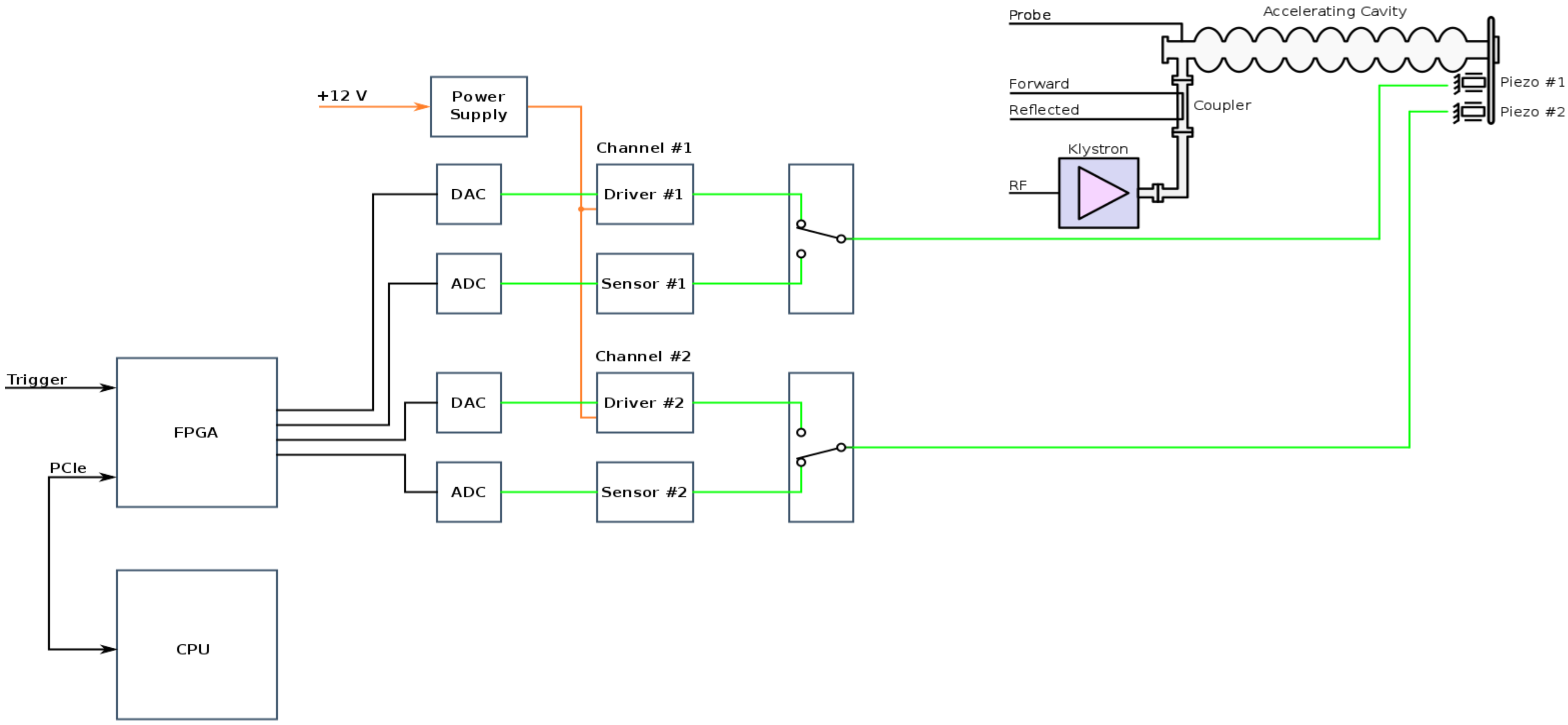


Piezo Actuator, Sensor, and Tensometer installed in Machine Vince

Piezo Control Device – SOA Characteristics in CW Mode



Tests at Freia Facility - Evaluation of Piezo Driver in open loop



Summary of Laboratory Tests

- The built prototype seems to be able to drive M- and H-beta cavities piezoactuators (Noliac NAC 2022 H30, C=2.2 μF) with 180 Vpp amplitude and 3 kHz frequency in CW mode
- Performance in pulsed mode is even much better

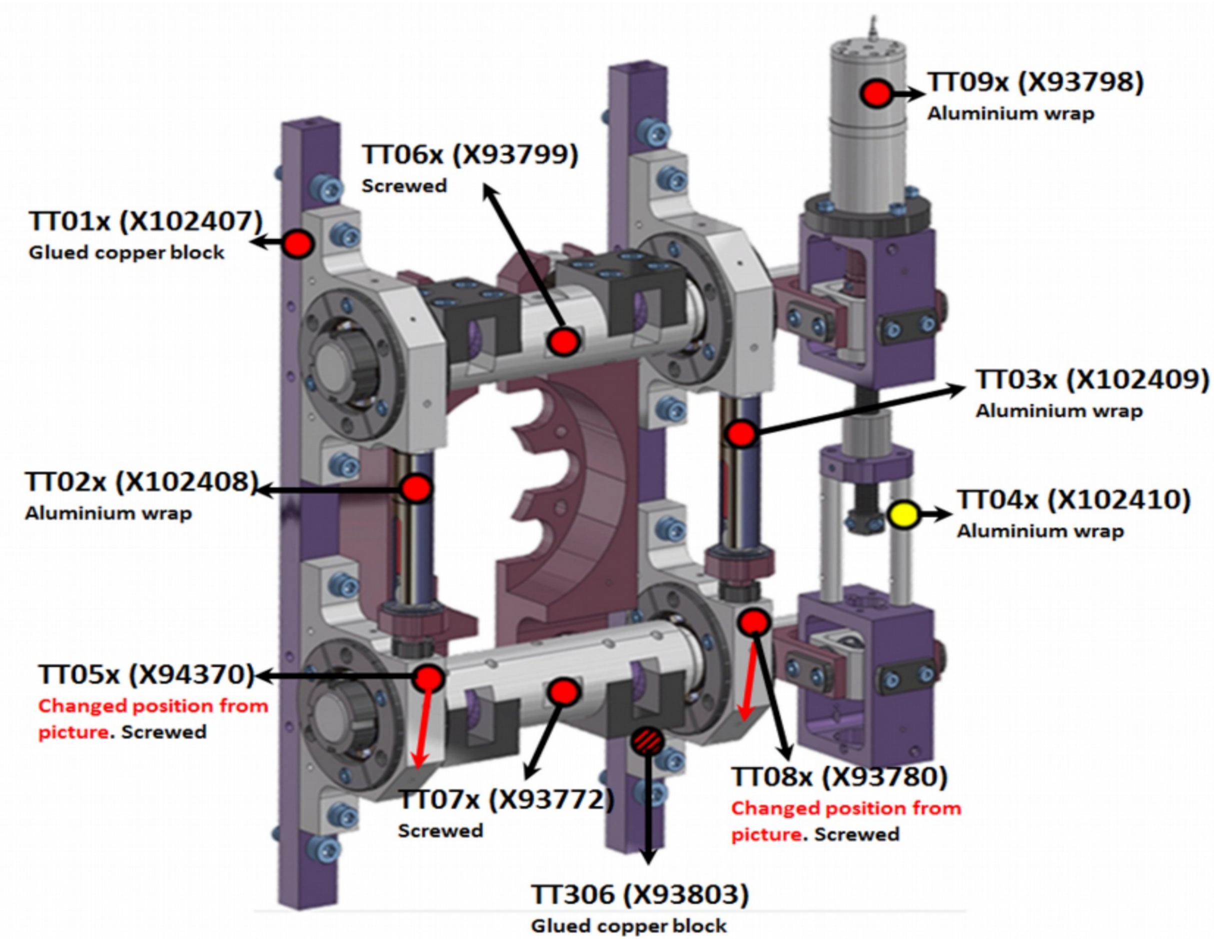
Estimation:

- In CW mode, piezo driver should be able to drive piezo actuators of spoke cavities (ca. 5.8 and 10 μF):
  - Noliac piezo up to 180 Vpp amplitude for 1 kHz signal
  - PI piezo up to 120 Vpp amplitude for 1 kHz signal
- In pulsed mode we should reach 180 Vpp amplitude for both piezos

Tests at Freia Facility

- Testing of Piezo Control Device at Freia (19-21 April)
- Available spoke cavity with two piezo actuators Noliac and PI
- Cooled down to 2 K (piezo temperature ~20 K before driving)
- Measured piezo capacitance in real conditions
  - Noliac NAC 2022 H50 (T=19.34 K, C=3.14 uF)
  - PI PICMA P-888.91 (T=26.47 K, C=5.18 uF)
- Cable resistance R=4.7 Ohm (both directions), cable length 35 m (estimated)
- Piezo coupling: 1 : 333 (Actuator U=20 Vpp, Sensor U=0.06 V)
- Tested various configurations:
  - Driver – Sensor, 2x Driver
- Various excitations:
  - Sinusoidal, frequency sweep
  - Measured power/current consumption, driver temperature

Piezo Actuators and Temperature Sensors Mount – Cold Tuning System

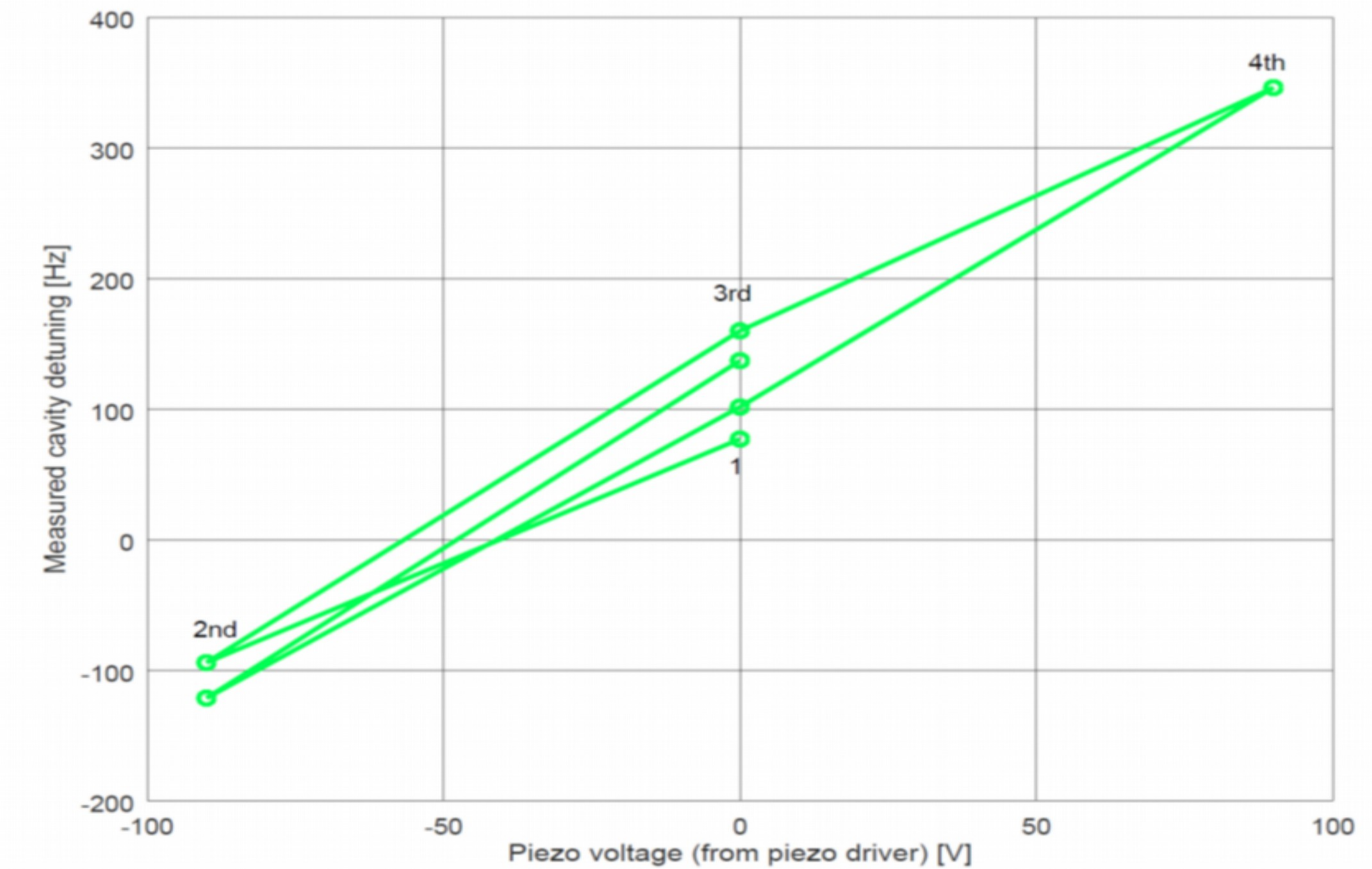


Piezo Actuators used During the Freia Tests

Piezo type	Noliac NAC 2022 H30-C01	Noliac NAC 2022 H50-C01	PI PICMA P-888.91
Dimensions	10 x 10 x 30 mm	10 x 10 x 50 mm	10 x 10 x 36 mm
Cell material	NCE51F	NCE51F	PIC252
Number of cells	15	25	
Capacitance (room temperature)	6.6 µF ±15%	9.5 µF ±15%	13 µF ±20%
Capacitance (cryo temperature, 20 K)	TBD	3.14 µF	5.18 µF
Max. free stroke	49.5 µm	79.2 µm	32 µm
Blocking stroke in cryo temp.	3 µm	5 µm	TBD
Blocking force max.	4200 N	4200 N	3800 N
Max. operating voltage	200 V	200 V	-20 to 120 V
Unloaded resonance frequency	248 kHz – 11 kHz	248 kHz – 11 kHz	40 kHz

Cavity Detuning vs Excitation Voltage of Piezo Driver

- Achieved cavity frequency change at the level of 460 Hz for maximum voltage change from -90 V to +90 V



Summary of Freia Tests

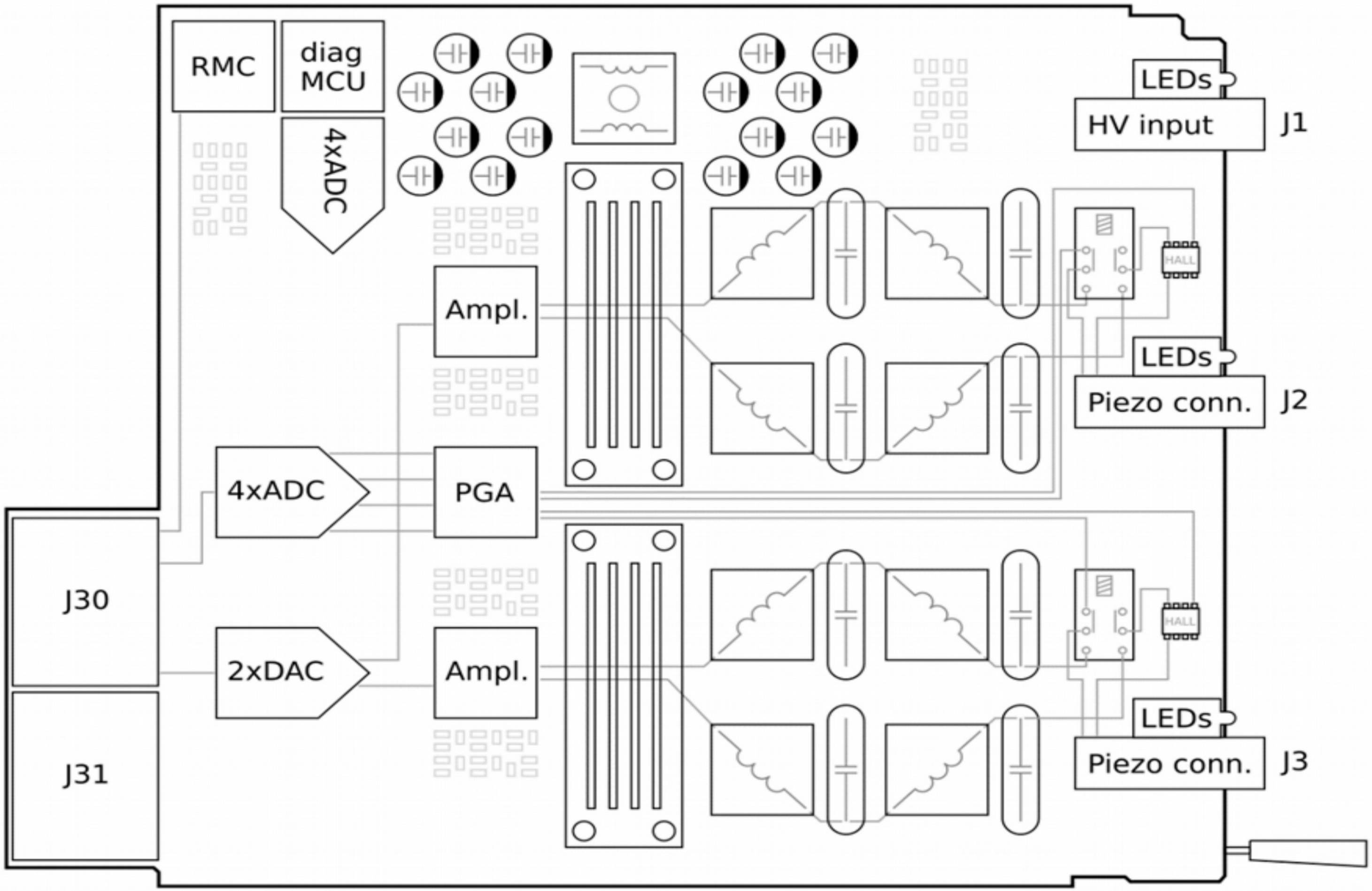
Continuous wave operation (1 kHz sine wave)

- Both piezos connected in parallel to a single driver
  - output voltage amplitude 132 Vpp before reaching the protection limit
- Two drivers driving separate piezos
  - output voltage amplitude of 128 Vpp before reaching the current limit in case of Noliac NAC 2022 H50-C01
  - output voltage amplitude of 120 Vpp before reaching the current limit in case of PI PICMA P-888.91.

Pulsed-mode operation (10 pulses, 1 kHz sine, 14 Hz repetition rate)

- Both piezos connected in parallel to a single driver
  - maximum of 180 Vpp amplitude; the driver was not disabled by protection circuit.
- Both piezos connected to two piezo driver modules
  - maximum of 180 Vpp amplitude on both piezo actuators; none of the drivers was disabled by protection circuit

Proposed Final Design of Piezo Control Device



Front-Panel Connectors

External power supply connector

Connector pin	Description	Electrical Specification	Direction
1	High voltage +	Max. 60 VDC, 1 A	In
2	GND	Ground, 2 A	
3	High voltage -	Max. 60 VDC, 1 A	In
4	SMBus - SDA	LVTTL 3.3 V	In-Out, Open Drain
5	SMBus - SCL	LVTTL 3.3 V	Out, Open Drain
6	SMBus - Alert	LVTTL 3.3 V	In
7	SMBus - GND	Ground	

Piezo sensor/actuator connector

Connector pin	Description	Electrical Specification	Direction
1	Driver output +	Max. 200 VDC, 1 A	Out
2	Driver output -	Max. 200 VDC, 1 A	Out
3	Plug ID	LVTTL 3.3 V	In
4	Gnd	Ground	

Zone 3 Connectivity

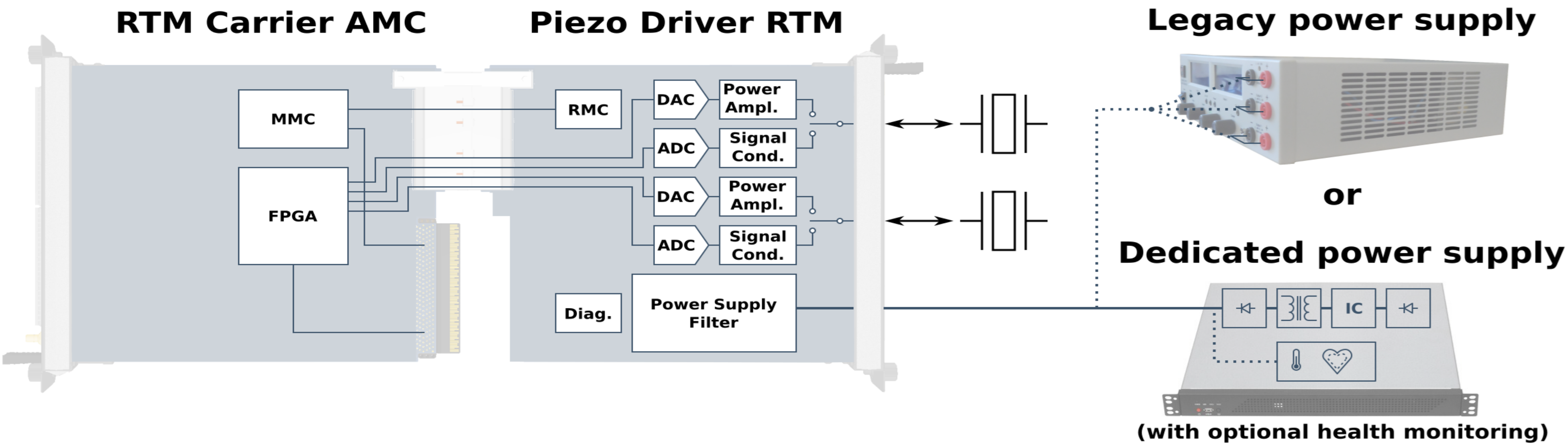
- The Zone 3 connectivity will follow DESY/TUL recommendation based on D1.2 Class (the high-speed lines will be not connected)
- All signals will use 2.5 V LVDS or LVCMOS voltage levels
- Signals will be used starting from J30 connector, A5 row

ID	Signal Name	Description	Electrical Specification	Directio n
		Piezo driver (DAC) channel 1		
1	**Piezo1_DAC_CSn**	Serial Interface Chip Select of DAC 1	LVCMOS 2.5 V	In
2	**Piezo1_DAC_SCLK**	Serial Interface Clock Input of DAC 1	LVCMOS 2.5 V	In
3	**Piezo1_DAC_DIN**	Serial Interface Data Input of DAC 1	LVCMOS 2.5 V	In
4	**Piezo1_DAC_CLRn**	Asynchronous Clear Input of DAC 1	LVCMOS 2.5 V	In
5	**Piezo1_Enable**	Enable channel 1 of power driver	LVCMOS 2.5 V	In
6	**Piezo1_Good**	Piezo driver 1 good signal	LVCMOS 2.5 V	Out
		Piezo driver (DAC) channel 2		
7	**Piezo2_DAC_CSn**	Serial Interface Chip Select of DAC 2	LVCMOS 2.5 V	In
8	**Piezo2_DAC_SCLK**	Serial Interface Clock Input of DAC 2	LVCMOS 2.5 V	In

External Power Supply Module

Three solutions are proposed:

1. Commercially available laboratory power supply
2. Custom solution based on industrial 19” power supply
3. Custom solution based on 19” power supply with additional health monitoring (temperatures and voltages, etc.)



PDC Development-Manufacture Schedule

Development or production phase	No of PCD mod	Schedule (2016 Q4 – 2021 Q2)	Est. Delivery Date
First prot. design			
First prot. production	2		
First prot. testing			Jul'17
Second prot. design Rev. A			
Second prot. production Rev. A	5		
Second prot. testing Rev. A			Mar'18
Preproduction			
Preproduction testing	10		
Proc. and production for M-beta			
Testing of medium-beta			
Delivery of medium-beta	36		Oct'18
Second prot. design Rev. B			
Second prot. production Rev. B	5		
Second prot. testing Rev. B			Mar'20
Proc. and production for H-beta			
Testing of high-beta			
Delivery of high-beta	42		Oct'20
Proc. and prod. of spare modules			
Testing of spare modules			
Delivery of spare modules	40		Jan'21
Milestone		M8, M15, M24, M29, M34, M35	

QA - Team Qualifications Matrix

Mapping of columns to the experience is as follows:

- Q1 Experience in design and development of complex control and diagnostic systems and related software technologies
- Q2 Experience in industrial control
- Q3 Exp. in participating to a large and distributed software project involving industry and res. Labs
- Q4 Experience in PXI/PXIe, MTCA.4 and ATCA based systems
- Q5 Experience in industrial computer form factors derived from the PCI-Express specification
- Q6 Experience in electronics, signal conditioning and EMC

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22
Andrzej Napieralski	✔	✔	✔	✔	✔	✔				✔				✔	✔		✔		✔	✔	✔	✔
Dariusz Makowski	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Grzegorz Jabłoński	✔	✔	✔	✔	✔	✔		✔		✔			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Aleksander Mielczarek	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Piotr Perek	✔	✔	✔	✔	✔				✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Paweł Plewiński		✔	✔	✔	✔				✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Aleksander Szubert		✔	✔	✔	✔	✔	✔		✔	✔			✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

QA - Risk Analysis

- Three main risks were identified
  - Undefined or imprecise requirements for piezo driver (piezo capacitance, operation conditions, i.e. piezo temperature, cable length)
    - Problem: Difficult to estimate driver power
    - Countermeasure: Collect and clarify precise requirements, overestimate driver parameters, test with in real conditions in cryostat
  - Unknown excitation signal and piezo control algorithm (signal shape, frequency, energy)
    - Problem: Difficult to estimate driver power
    - Countermeasure: Overestimate driver parameters, test with various excitation signals, use higher number of pulses for the signal
  - Lack of cooling in rear side of MicroTCA.4 chassis (RTM device)
    - Problem: max. power dissipated on RTM in MicroTCA.4 limited to 30 W
    - Countermeasure: Change PCS architecture (external power supply), high efficiency design, high quality component

Summary

- The designed driver prototype is able to drive piezo actuators of elliptical cavities
- The driver should be also able to drive spoke cavities with piezo stacks up to 10 uF in cryogenic temperature
- More tests with real cavities are required:
  - Noliac piezo and elliptical cavities
  - Evaluate and verify cavity detuning versus piezo amplitude
  - Lorentz force detuning: excitation signal, detuning algorithms, etc.
  - Spoke cavities and 90 mm long piezo actuators
- Second version of PCD is under development
  - Schematics done in 40%, 90% of components selected, PCB design not started
  - Production should start in August
  - Prototype should be available for debugging/testing in September
- Decision for external power supply required

Thank you for your attention

SOA Characteristics for Commercial Driver LE200/070 EBW