DESY MicroTCA Solutions: FPGA- and SoC-Based Platforms for Science Community and Next-Generation Research Facilities

2025 MicroTCA/ATCA International Workshop for Large Scientific Facility Control

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Chongqing, China on Sep.15-Sep.17, 2025

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

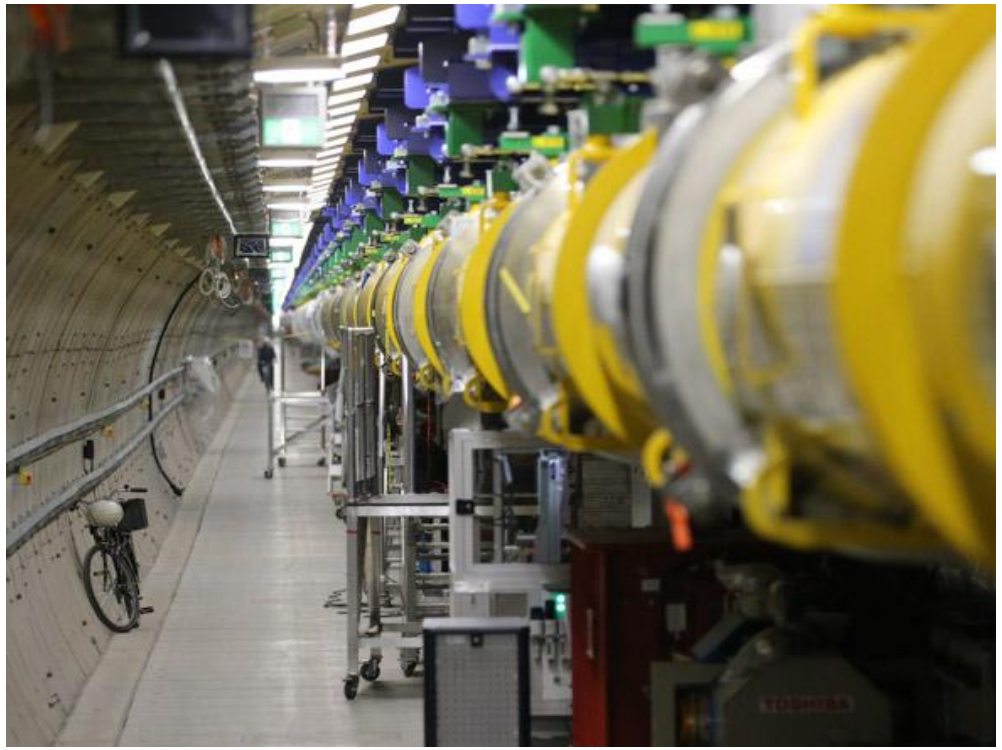
DESY.

Agenda

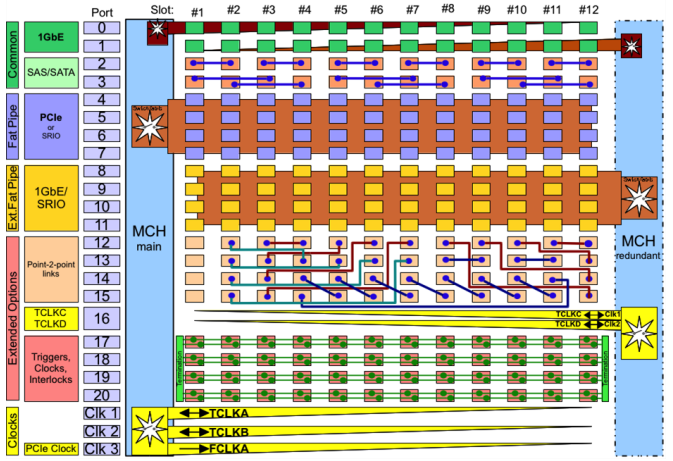
1. MicroTCA Eco System and Licensing Strategy
2. History and Highlight: New Developments
3. What we can offer: Community Tools

Background

- **DESY MSK = Accelerator Beam Controls**
- Responsible for LLRF electronics of large FLASH and XFEL (and other) accelerators:
  - As part of large DESY team: concept, design, installation, operation and maintenance
  - 100% end-to-end development in-house: hardware (schematics, board, test), firmware and software10 years+ of electronics life time (hostile environment), 24/7 operation, limited access to electronics



Powerful Backplane (PCIe, Triggers, P2P)



Analog/Digital Split

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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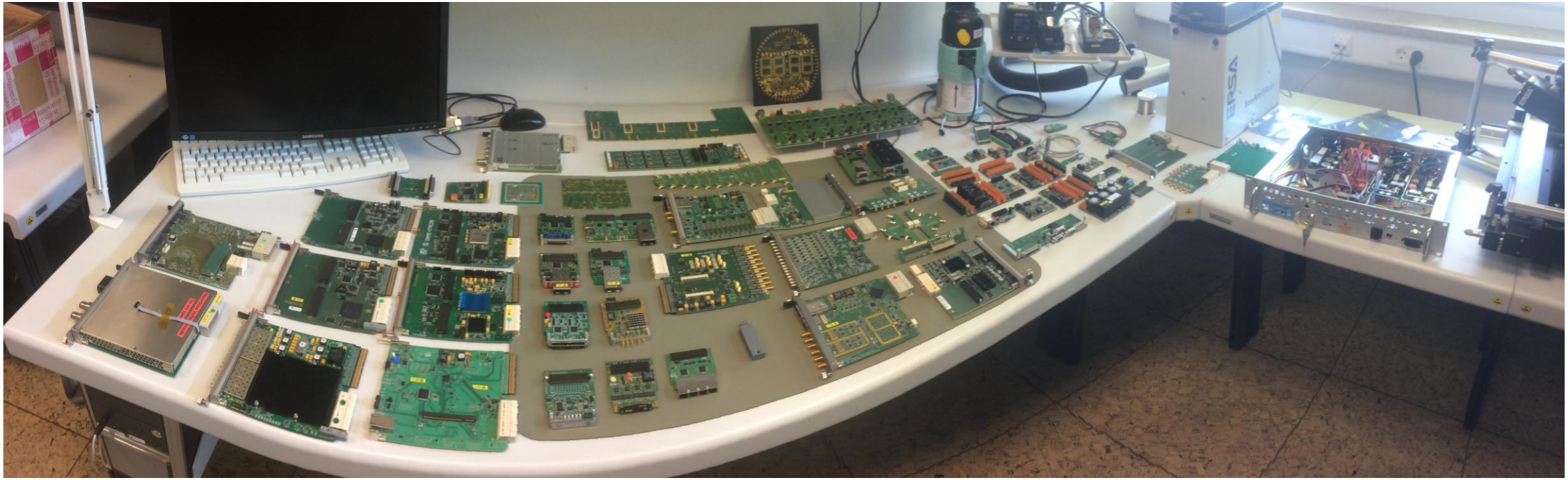
Main responsibility

We develop and maintain digital electronic boards



AMC
DAMC-FMC20
DAMC-FMC25
DAMC-FMC2ZUP
DAMC-FMC1Z7IO
DAMC-TCK7
DAMC-MOTCTRL
DAMC-DS812ZUP
DAMC-MMCBREAKOUT
DAMC-Template
DAMC-AMCTest
DAMC-StarterMMC
DAMC-MMCNEEDLETEST
DAMC-UNIZUP
DAMC-X3TIMER
DAMC-DS5014

FMC
DFMC-AD16
DFMC-DS800
DFMC-MD22
DFMC-SFP4
DFMC-SIO
DFMC-TC4
DFMC-TestAdp
DFMC-UNI-IO

LISA
~ 5 Boards

RTM
DRTM-PZT4
DRTM-MXC
DRTM-AD84
DRTM-PZT4
DRTM-DS812FT
DRTM-CLKFT
DRTM-Template
DRTM-VM2

eRTM
DRTM-HVPM

19-inch boxes
X2 Converter Box
LDD (Mezzanine, Carriers)

19-inch components
FRED, FredFan, FredFanPWM (MO)
H-Bridge Driver
Redundancy Controller 4P
Redundancy Controller 3P+1N
ZMX Connection Module
TMCB2
GPIOTest
PowerSeqPatch
REFMOPT patch
Patchpanel (Uni-IO)

Eval Boards
DS8XX DC/DC Eval. Loop Eval.
Motion Controller DCDC Eval.
Coaxipack2 Eval

Development Support
RTM Standalone Driver
AMC Bringup Adapter
DFMC-Extender
FMC Test Carrier
SE2DIFF Adapter
Breakout MD22
Breakout AD16

Stand-Alone
DMMC-STAMP
RadCon
ZMX Test Board
NoiseEater

Company Support
Struck (MMC)
CAENels
Piezotechnics, Eicsys (PZT4)
Techlab
Embeck, Hitachi, 7Solutions, D-TACQ, CEA

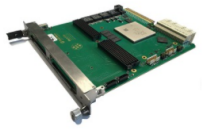
- Photo is 6 years old: Underlined Boards are not shown on picture
- *Italic* Boards are not developed by us, but maintained by us

Licensing Strategy

- We promote an ecosystem
- DESY has licensed almost all developments: components are available for us **and** for third parties
- Strategy: Concentrate on the application; purchase all “unexciting” infrastructure

AMC

DAMC-FMC2ZUP
Zynq Ultrascale+ MPSoC based Dual FMC/FMC+ Carrier Board with D1.1 RTM support



DAMC-FMC1Z7IO
Cost-Optimized IO Controller Board with one FMC socket

DAMC-TCK7
AMC Data Processing and Telecommunication Module

ADVANCED MEZZANINE CARDS

AMC boards (Advanced Mezzanine Card) are the key components of a MicroTCA system. Within the MicroTCA.4 crate, AMCs are placed in the front of the crate. They are connected by a high-speed backplane that carriers serial links, power and management data. Every AMC card is monitored and managed. This allows hot-plug, hot-swap, health monitoring and thermal management of the modules.

There are six standard sizes of AMCs: single and double width as well as compact, mid-size and full-size height. Every combination of width and height is valid. The power consumption of an AMC is divided into 3.3V management power plus 12V payload power.
AMC boards are used for digital processing. On every AMC board there is a controlling unit called MMC (Module Management Controller).
Plugging in the AMC board to the MTCA crate connects the board to the backplane of the crate. The backplane ensures the connection of the AMC boards with every other AMC board in the crate.
Plus, every AMC board is connected to the MCH (MicroTCA Carrier Hub), which is the overall management card of the MTCA system. The MCH gives management power to the AMCs first. This power is used to check if everything is ok with the AMC. If the MMC, the managing unit on the AMC detects no problems on the board, the MCH gives payload power to the AMC.

Clustering of AMCs in the system is possible.

DAMC-FMC25
AMC Dual HPC-FMC Carrier

DAMC-FMC20
AMC Dual FMC Carrier Board

X2TIMER
AMC Fast Timing System

DAMC-UNIZUP

...

RTM

DRTM-MXC
Mobile GPU Carrier

REAR-TRANSITION-MODULES

RTMs, the rear-transition-modules, are extension boards that are placed in the back of the MTCA.4 crate. They directly connect to the front AMCs via the Zone 3 connector.
The possibility to separate analogue and digital functions by moving sensitive analogue electronics to the RTM is one of the key strengths of MicroTCA.4.

DRTM-AD84
RTM 8Ch ADC, 4Ch DAC

DRTM-DWC8VM1
RTM 8 Channel Down-Converter 1 Channel Up-Converter

DRTM-DWC10
RTM 10 Channel Down-Converter

DRTM-PZT4
RTM 4 Channel Piezo Driver

DRTM-LOG1300
eRTM Local Oscillator Generation

DRTM-DS8VM1
RTM 8-Channel Direct Sampling 1-Channel Vector Modulator

DRTM-VM2LF
RTM 2 Channel Vector Modulator Low Frequency

DRTM-VM2HF
RTM 2 Channel Vector Modulator High Frequency

DESY MMC Stamp

FMC

DFMC-DS800
FMC Direct-Sampling A-D Converter

FPGA MEZZANINE CARDS

FPGA Mezzanine Card (FMC) is a standard defining I/O mezzanine cards and corresponding carrier boards. Huge ecosystem of carrier boards, both in MicroTCA format and standalone boards, provides a good prototyping platform, suitable for experimental physics and industrial applications. The FMC mezzanine format provides additional degree of modularity for a lot of I/O applications, such as ADC and DAC boards, or communications boards.

DFMC-AD16
FMC 16-channel A-D Converter

DFMC-MD22
FMC 2 channel stepper motor driver

DFMC-UNI-IO
FMC Multi-Purpose I/O Board

DFMC-TESTADP
FMC Loopback Adapter

DFMC-SFP4
FMC 4-Channel SFP+ Adapter

All SoC developments of the last few years

Similarity 1: Boards are all based on DMMC-STAMP

DAMC-FMC2ZUP (Supercarrier)

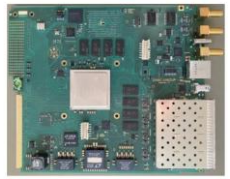
(DMMC-STAMP)

DAMC-FMC1Z7IO

DAMC-DS812ZUP

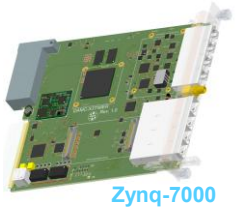
DAMC-MOTCTRL

DAMC-UNIZUP

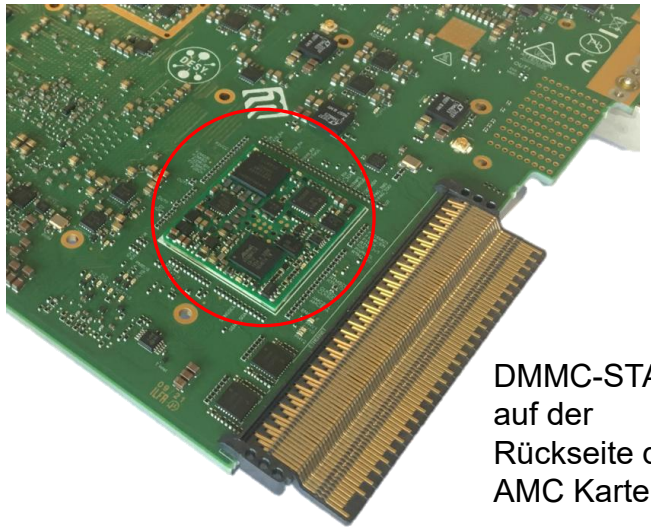


DAMC-DS5014DR
(RFSoC-based)

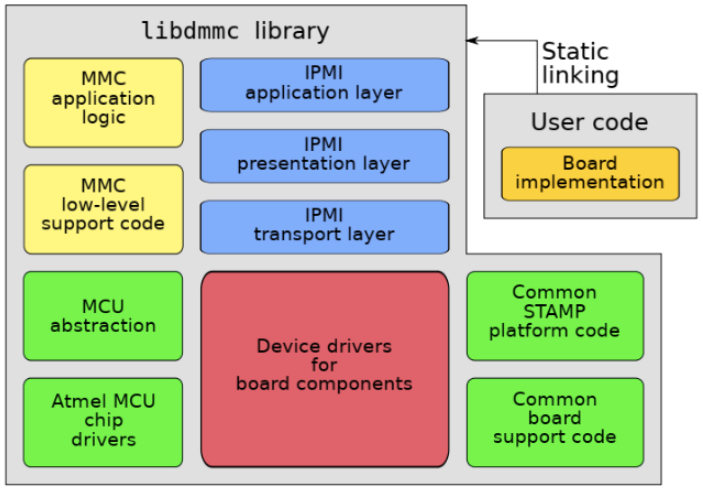
DAMC-X3Timer



2019 2020 2021 2022 2023 2024 2025



DMMC-STAMP auf der Rückseite der AMC Karte



- DMMC-Stamp handles MicroTCA Management
- Complete software framework
- 95% re-use
- Compatibility with all MCHs we know of

- In-system update (from MMC and FPGA)
- Serial-over-IPMI (remote access to the FPGA and MMC UART)

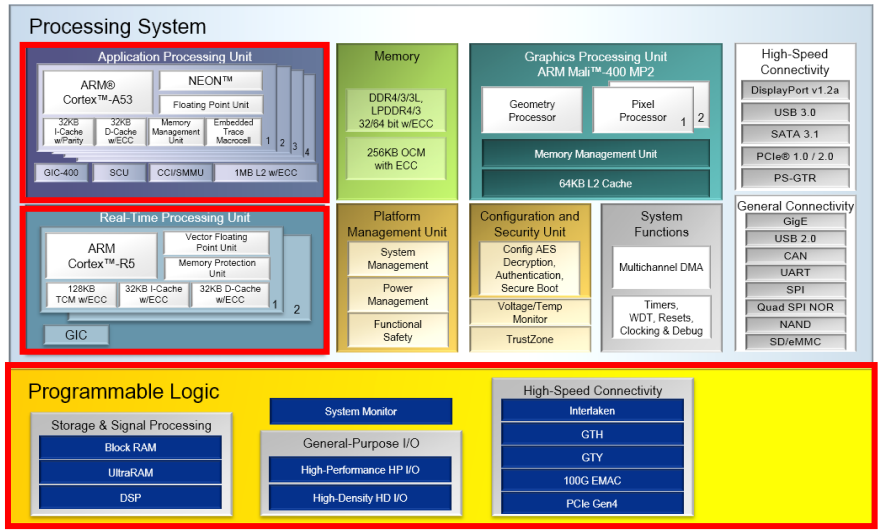
- 2024: over 1000 pieces produced
- used by 30 partners
- 100% test in the needle test adapter

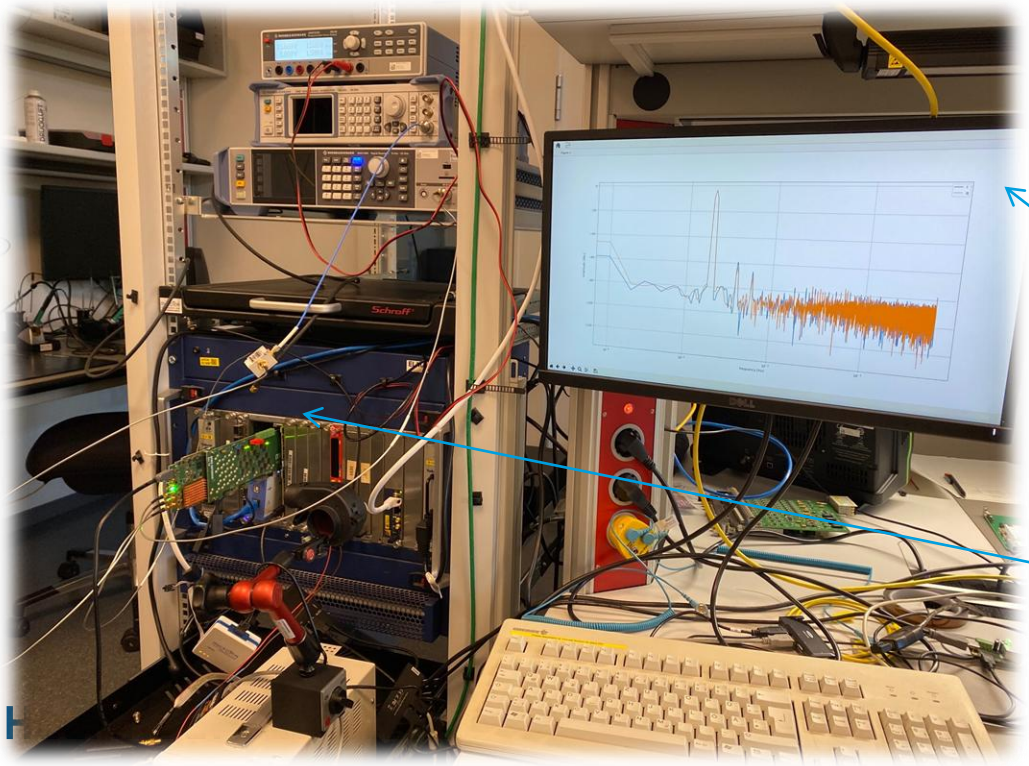
Why MPSoC?

Similarity 2: Processor inside FPGA

- Everything is SoC-based
- Processor-centric approach (“Raspberry Pi in FPGA”)
- Changed development method towards: “on-the-fly”, “re-use”, “modular” and “low-code”
- Keywords: IP modules, Linux, Python

DESY DAMC-FMC2ZUP Board



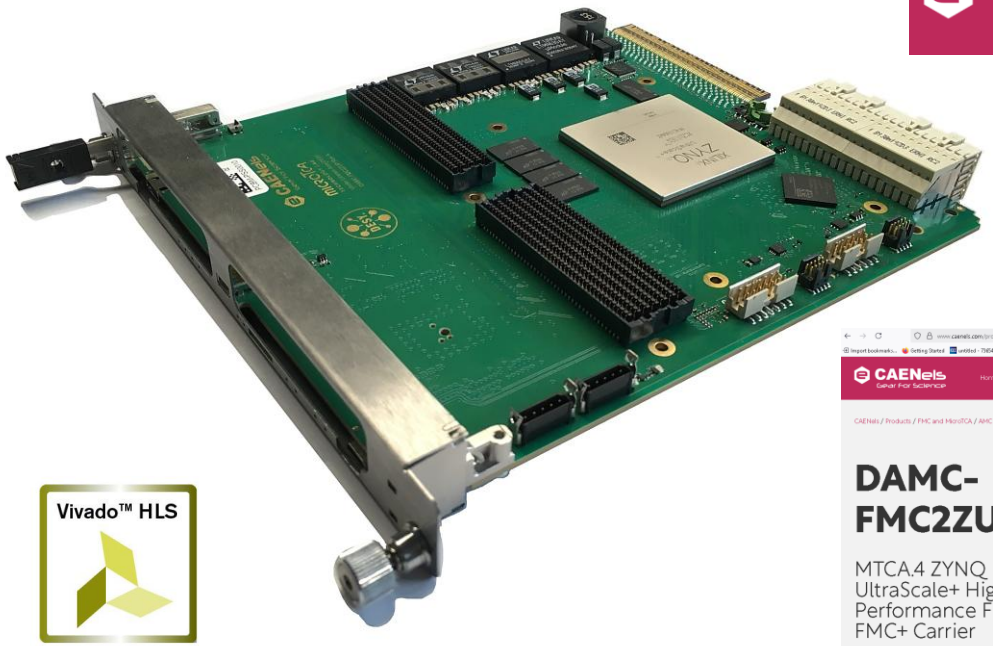


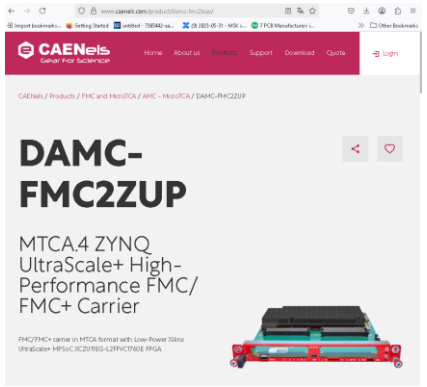
Courtesy of J. Marjanovic and S. Farina

- DAMC-FMC2ZUP board runs graphical **Linux desktop** (Displayport)
- Additionally: **Web server** with Jupyter
- DAMC-FMC2ZUP collects data from FMC-DS500; Output via **Python** Mathplotlib

High performance processing MPSoC-based FMC carrier

DAMC-FMC2ZUP



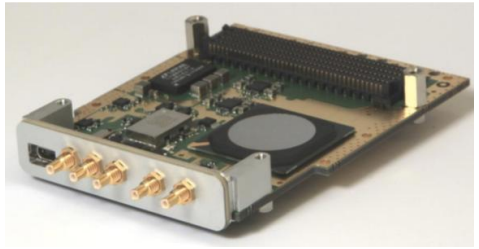


"Working horse", very powerful, very flexible FMC carrier - is part of a family of boards.

Main Features:

- High-performance FPGA: Zynq Ultrascale+ **ZU11EG or ZU19EG**
- Full Backplane and RTM D1.1 connectivity
- **FMC/FMC+** mezzanine support (**28 Gbps**)
- Quad-Core ARM Cortex-A53 @1.5 GHz, Dual-Core ARM-R5 RT @600 MHz and Mali-400 MP2 graphics
- PCIe x4 (**x8** option on supported systems); Gen.3 supported
- **USB type-C Alternate Mode Display Port** for standalone operation (no need for additional AMC CPU Module)
- Flexible clocking scheme and front panel connector for external clock input and **White Rabbit support**
- Supported by all Xilinx development tools (e.g. Vivado HLx)

DFMC-DS800



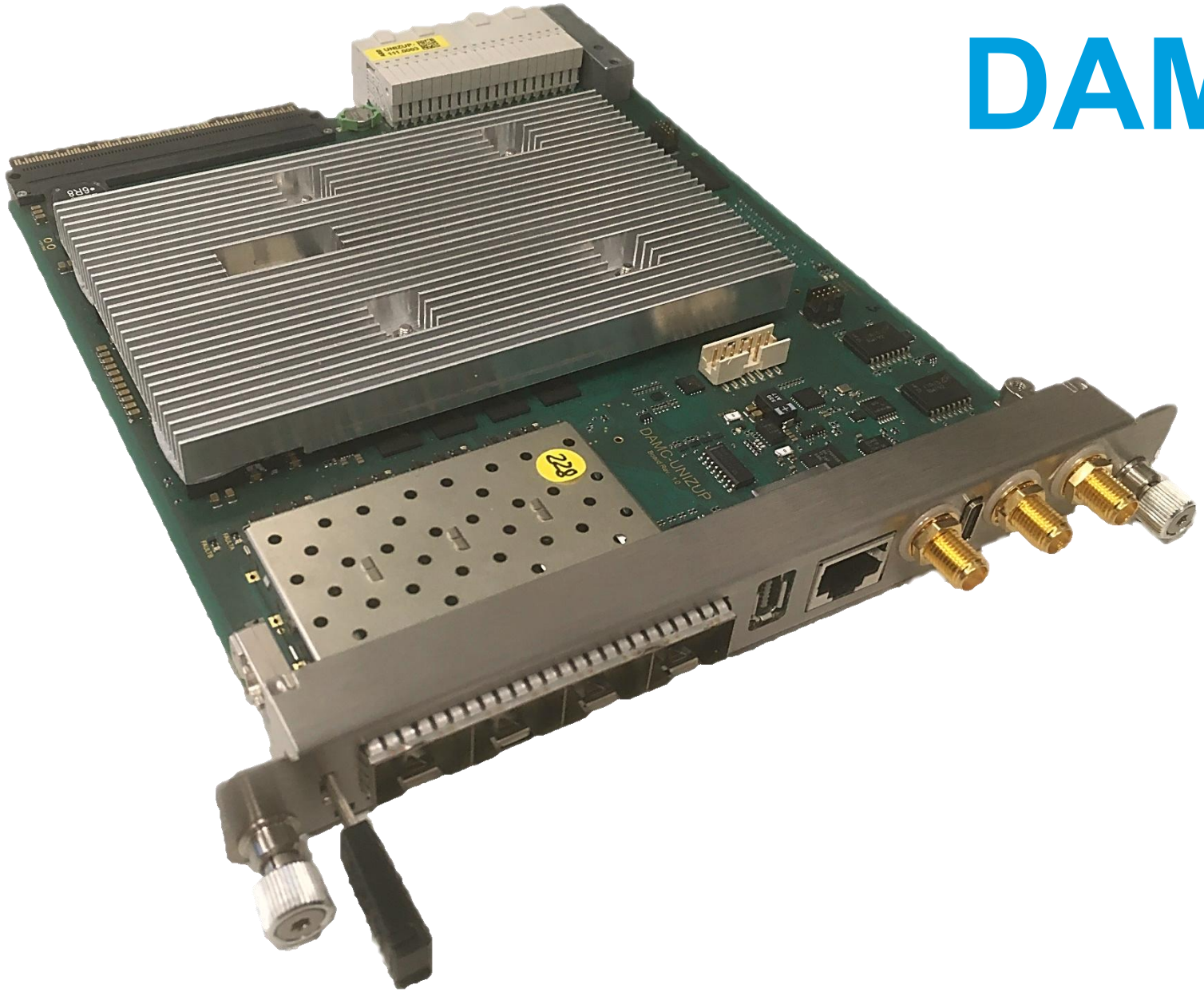
DFMC-MD22

FMC 2 channel stepper motor driver

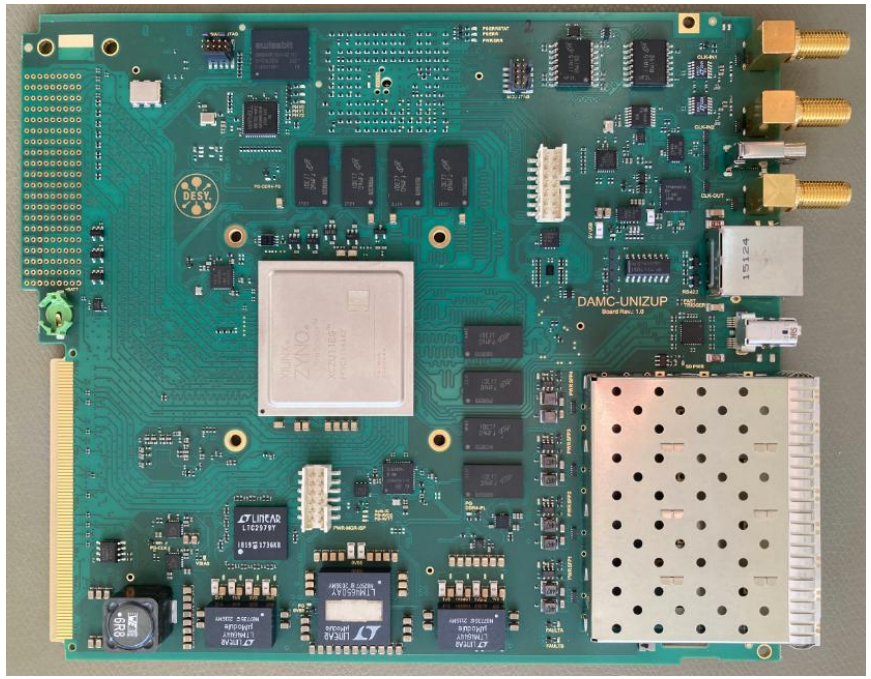
DFMC-AD16

FMC 16-channel A-D Converter

DAMC-UNIZUP



DAMC-UNIZUP



“Little Sister” of DAMC-FMC2ZUP

- Lower-cost-board with smaller FPGA: hundreds of units will be needed at Petra IV
- 14 instead of 16 layers, 0402 components, (only 0201 capacitors)

Facts

- Board inherits the **technology of DAMC-FMC2ZUP**
- Universal MPSoC board with high-performance **RTM connectivity**
- Large FPGA (in smaller package):
  Zynq Ultrascale+ **ZU7CG…ZU11EG**

New:

- **2 x 64bit wide** DDR4 interfaces (in total 8GiB RAM)
- **4 integrated SFP+** slots with 16.375 Gbps (not 28 Gbps GTY)
- Connectors for “**slow trigger”** (RS485 for machine protection) and **“fast trigger”** on Front Panel
- 2 Front panel clock inputs via SMA, 1 Output

Vivado™ HLS

INSTRUMENTATION TECHNOLOGIES

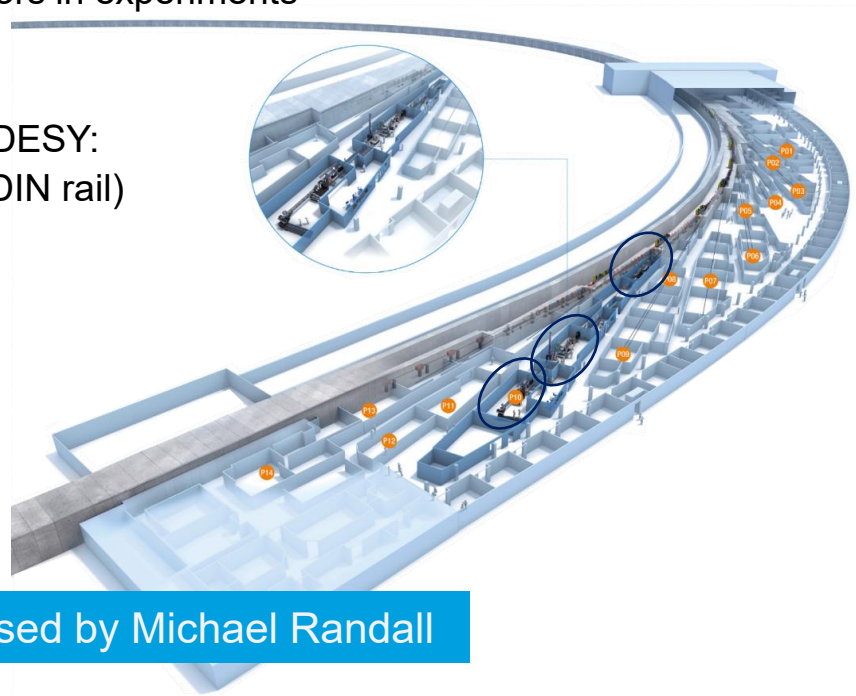
Inherited features:

- Quad-Core ARM Cortex-A53 @1.5 GHz, Dual-Core ARM-R5 RT @600 MHz and Mali-400 MP2 graphics
- PCIe x4 (**x8** option on supported systems); Gen.3 supported
- **USB type-C Alternate Mode Display Port** for standalone operation (no need for additional AMC CPU Module)
- Flexible clocking scheme and front panel connector for external clock input and **White Rabbit support**
- Supported by all Xilinx development tools (e.g. Vivado HLx)

DESY.

Motion Controller

- DESY needs to move motors in experiments

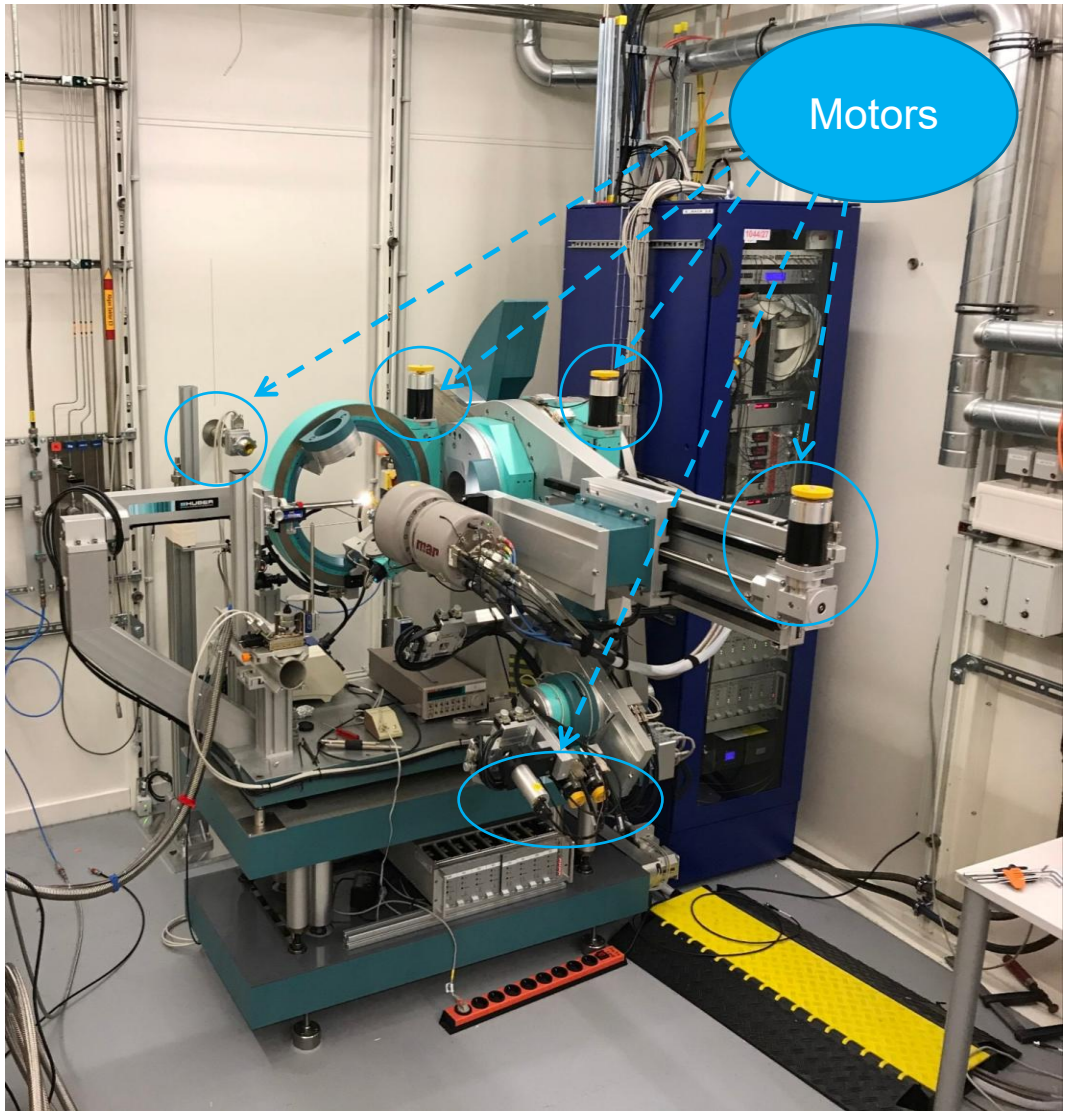


- Popular motion control at DESY:
  - Beckhoff EtherCAT (DIN rail)
  - OMS MAXv (VME)

Already discussed by Michael Randall

- MicroTCA infrastructure is planned for upcoming Petra IV
- A replacement for VME systems is required
  - to overcome limitation of 8 motors per card,
  - to provide (long-desired) card-to-card communication

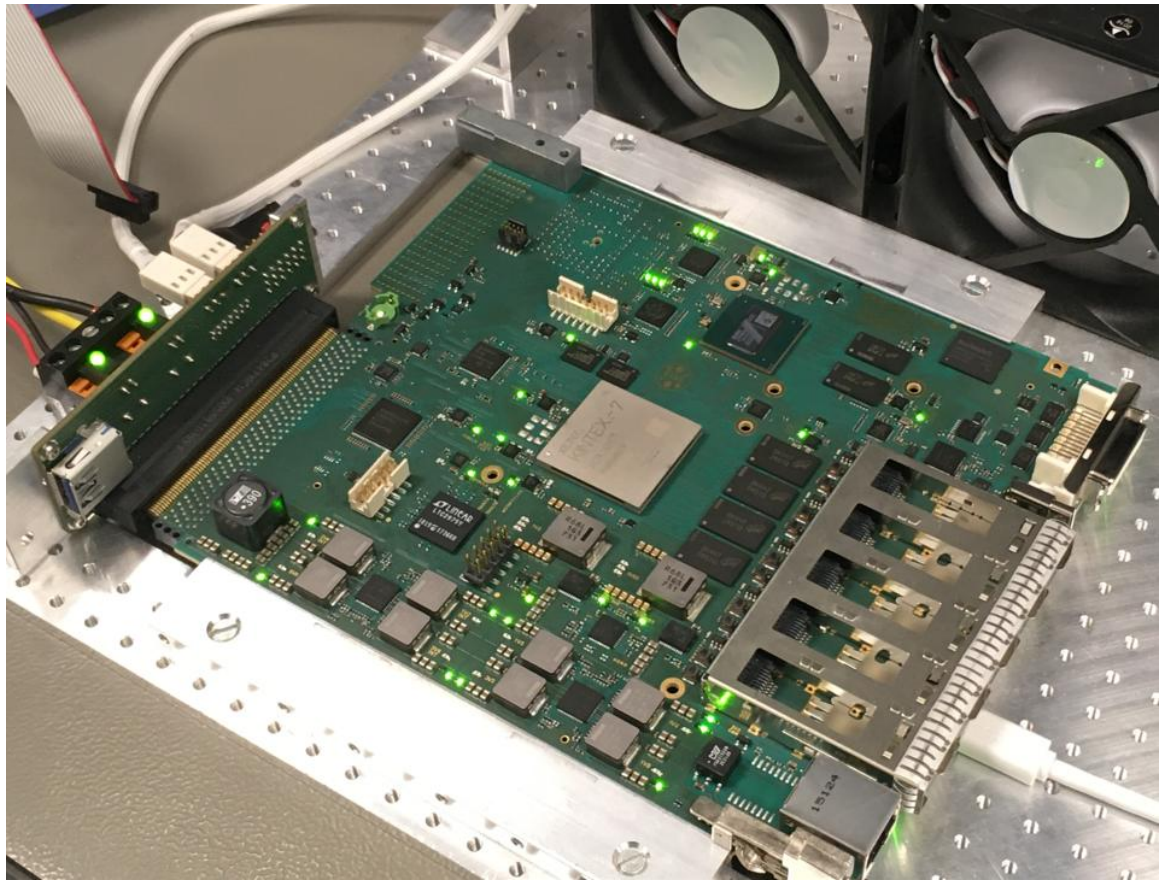
- DAMC-MOTCTRL:
  - Controls (min.) 48 motors/axis per card (FW depended)
  - Scalable interconnection of several cards in the crate and campus-wide
  - Position-triggered data acquisition with other MicroTCA cards
  - Focus on competitive cost factor (licensing planned)



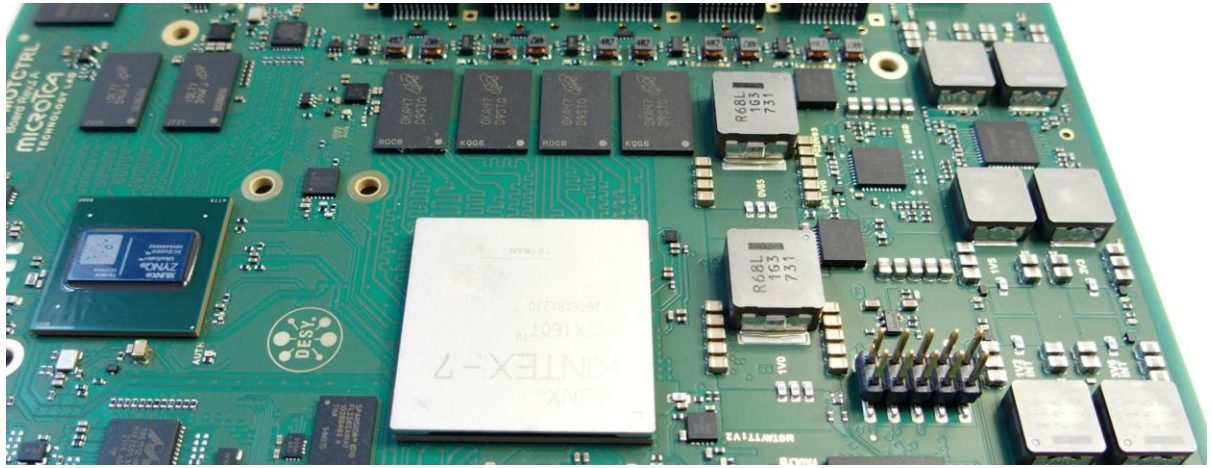
Diffractometer at Beamline
(Martin Tolkiehn)

Hardware Plattform

Hardware Plattform



- Board is fully running in Rev. A
- No single patch wire.



- **Heterogeneous Approach**
  - MPSoC (2GB DDR4) and FPGA (4GB DDR3)
  - Kintex-7: real-time control
- **MPSoC:**
  - „Raspberry Pi“ inside the FPGA (runs Yocto Linux)
  - responsible for non-realtime tasks
  - communication to other cards
- 5 SFP+ ports (1Gbps to 10Gbps)
  - e.g. 3x Motor interfaces, 2x Ring topology
- HW Support: CAN EtherCAT, SERCOS
- Backplane Ethernet
- 26-pin connector: 3.3V /5V IO
- Monitor/Keyboard interface via USB-C

DAMC-DS812ZUP

8-Channel Giga-sample Digitizer

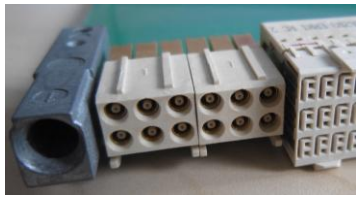
Vivado™ HLS

jupyter

python™

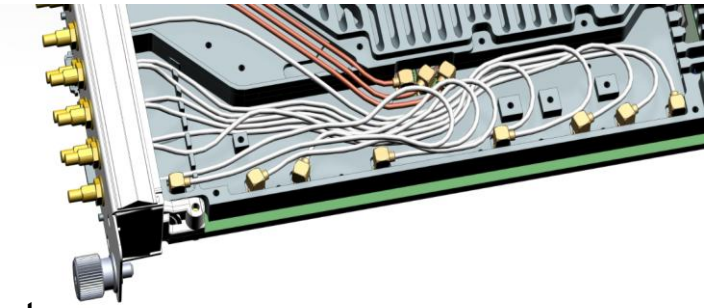
Modes of operation:

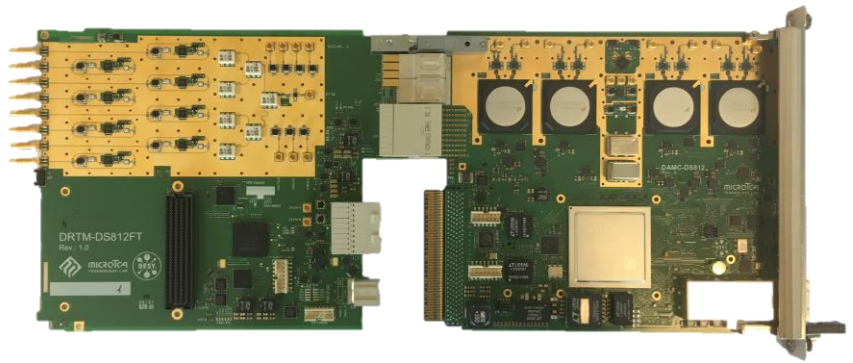
- **8-Channel 800 MSPS digitizer** or **4-channel 1600 MSPS**

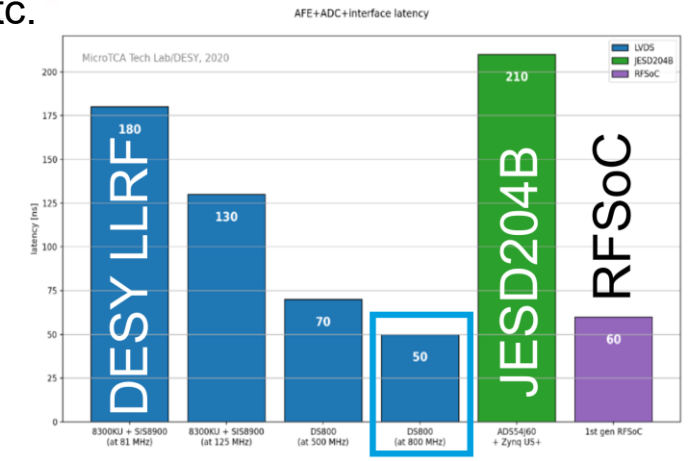


New:

- Coaxial Zone-3 connection “RF1.0”
- Front panel/ RTM swapping concept using semi-rigid coaxial RF cables
- Front Panel: oscilloscope-like application and board bring-up
- RTM: space for signal conditioning, filters, etc.

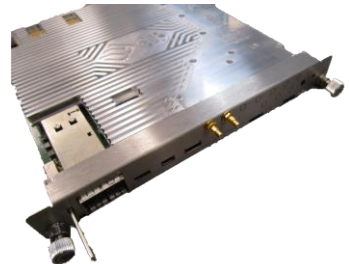




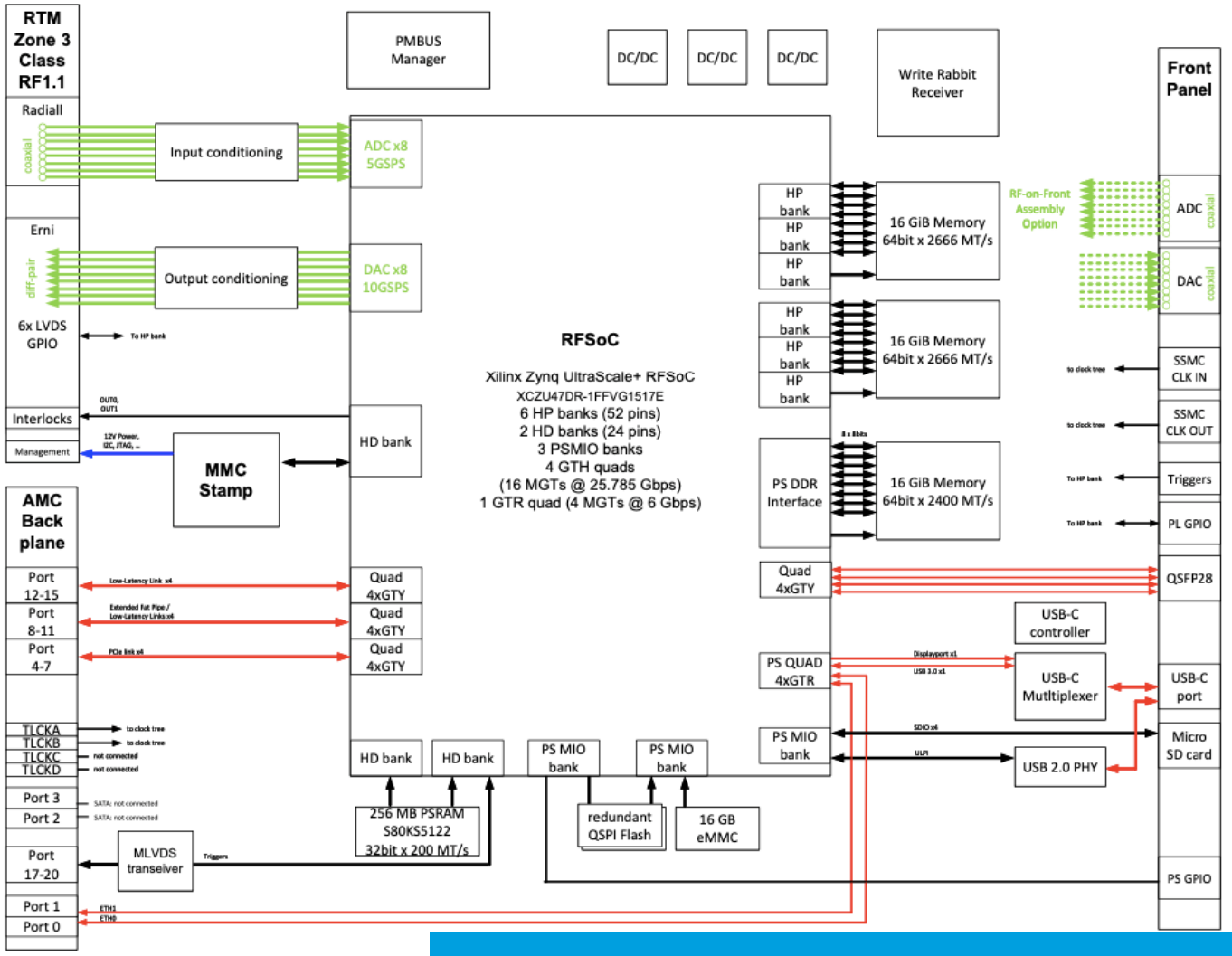


Main Features:

- 2.7GHz input BW, 12bits, 8-channels (Amplifier Bandwidth: 4.8 GHz)
- 50ns end-to-end latency
- **Coaxial analog Zone 3 RF1.0 Class**
- RF input from front panel or RTM: 800 MSPS / 1600 MSPS
- On-board PLL: 14fs jitter

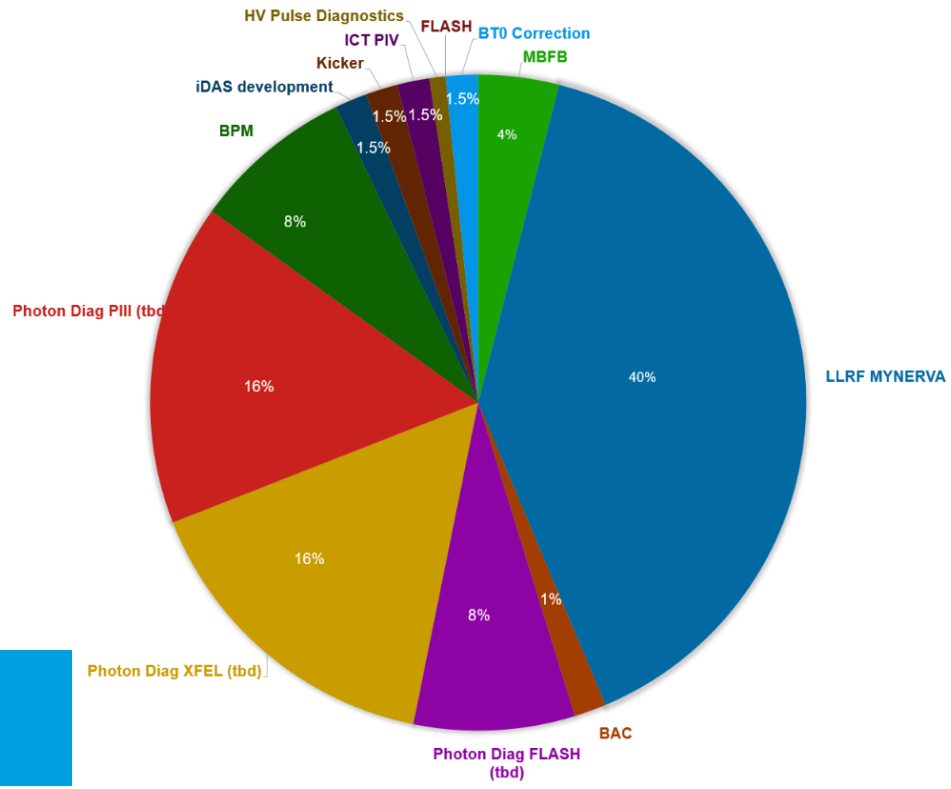


DAMC-DS5014DR: RFSoC



Features

- 8x 14 bits **ADC, 5 GSPS, 6GHz** analog bandwidth
- 8x 14 bits **DAC, 10 GSPS, 4GHz** analog bandwidth
- DC- and AC operation (assembly option)



HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Under Development

We invite everybody to be part of the MicroTCA ecosystem

What we can offer...

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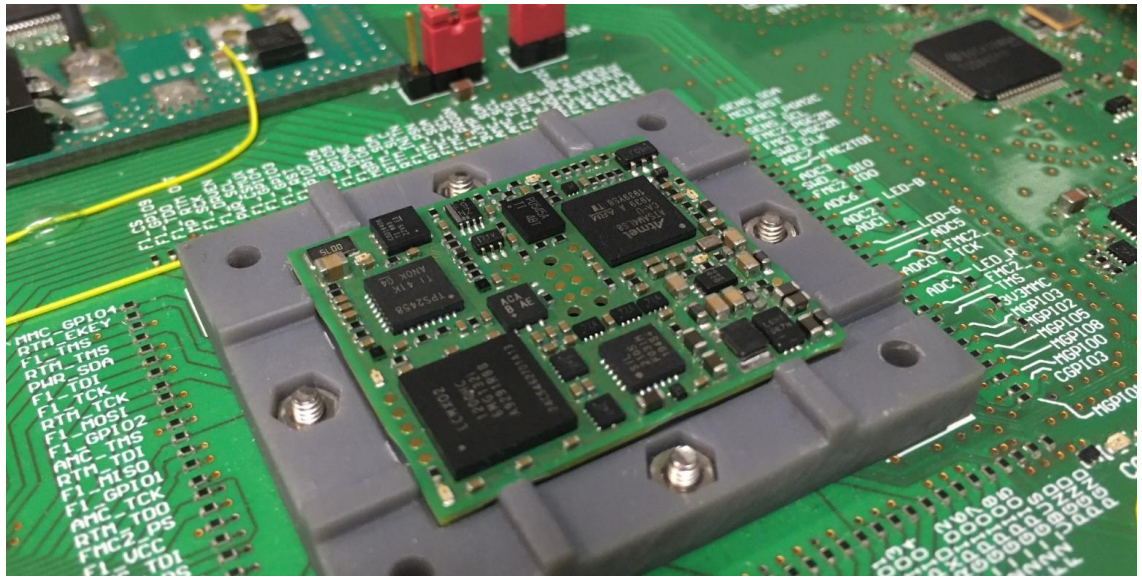
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

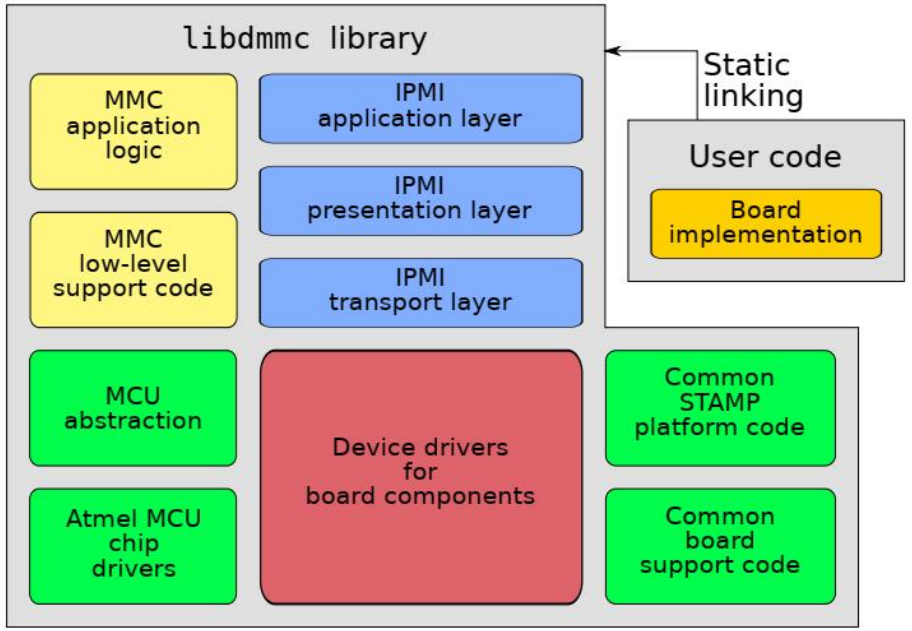
DMMC-STAMP: A complete Management solution for MicroTCA

- System on Module (SoM)
  - 25.5 x 29.5 x 2.3 mm
  - Pre-programmed firmware
  - Evaluation board available (BoB)
- Software Development Kit (SDK)
  - MMC firmware customization
  - DESY MMC Software Library (libdmmc)
  - Example implementations (BoB, DAMC-FMC2ZUP)
- Open Source Tools and Templates
  - AMC and RTM Altium Designer Templates
  - `mmcterm`: serial over IPMB
  - `bin2hpm`: create HPM files for IPMI upgrade
  - `frugy`: read and write FRUs
  - `cpld-img-tools`: bitstream conversion for Lattice CPLDs

Next talk by Patrick Huesmann



Post-Production test of DMMC-STAMP



MicroTCA.4 Template

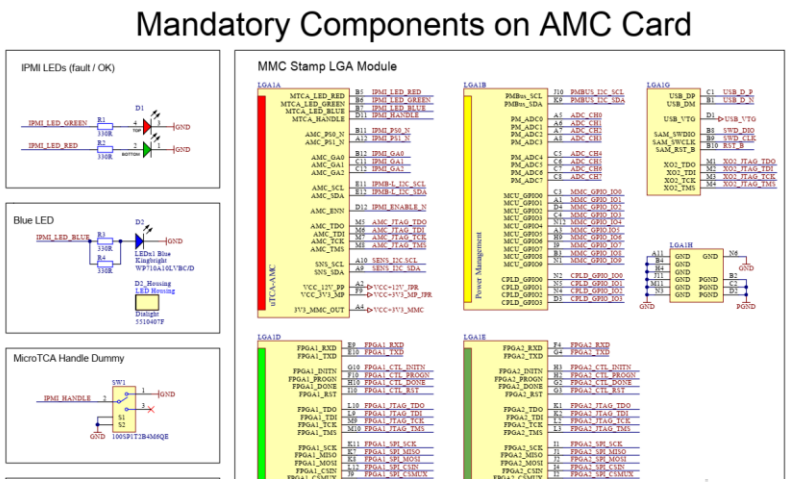
Community Support

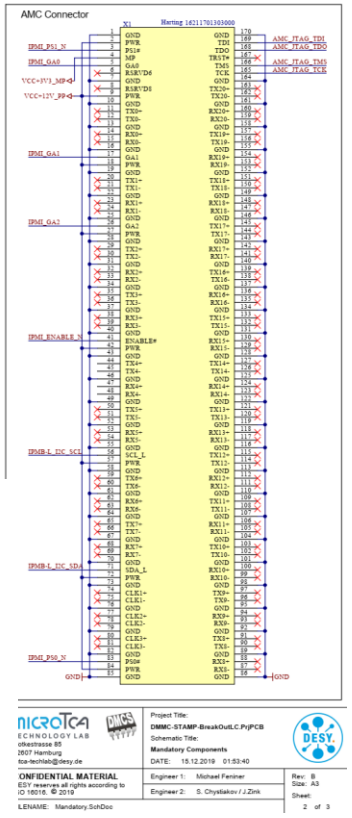
Idea: Jump-Start with MicroTCA as you would with any other board

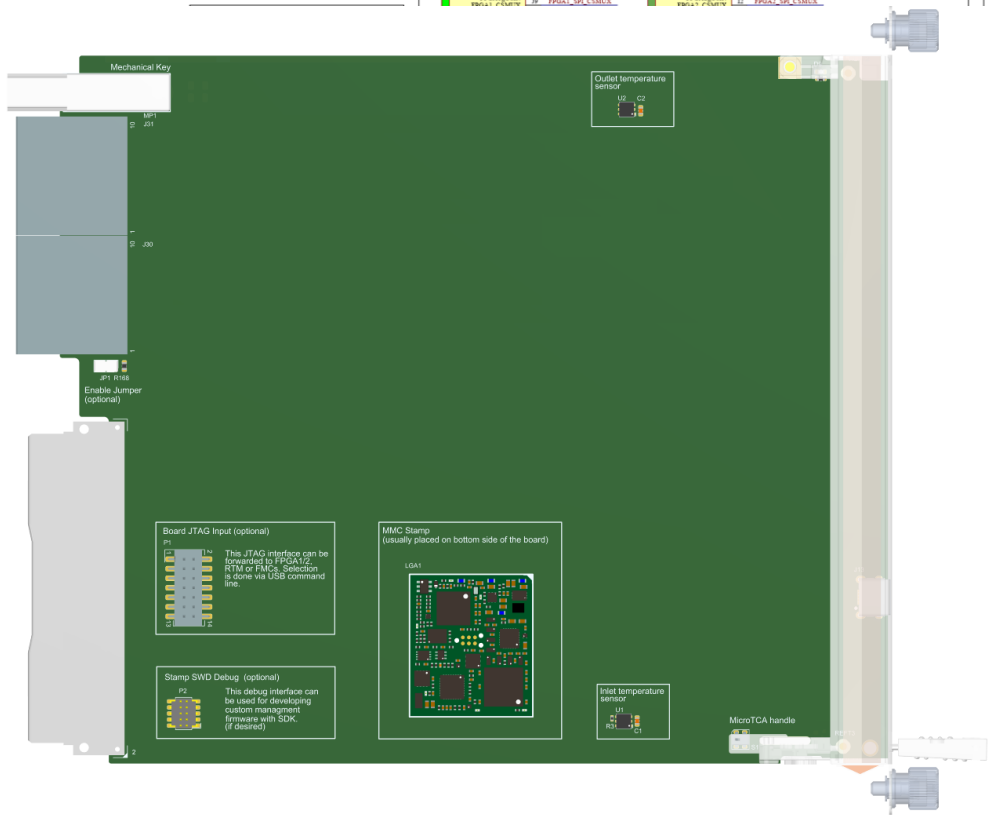
Fully MicroTCA compliant “empty” board
- Already “fully functional”
- Start with correct mechanical shape
- AMC and RTM “only” get power
- All the management is done on DMMC-STAMP

Purpose: facilitate development
- Allows design migration (e.g. from VME)
- Source design files (Altium Designer) are provided
  - Schematics
  - PCB

Components:
- MMC SoM, LEDs, Connectors, Temperature Sensors
- USB Interface for management and status





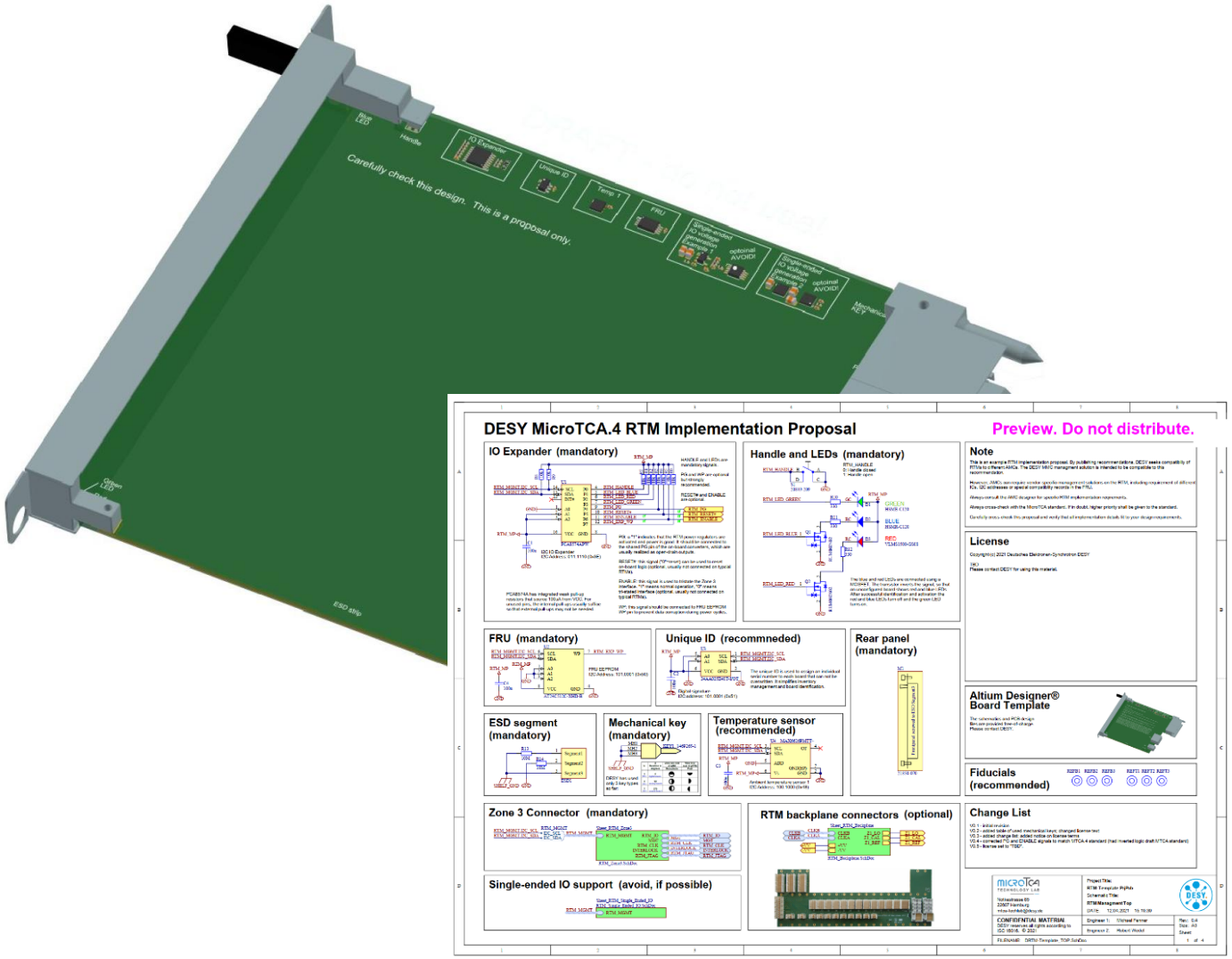


HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

RTM Template

Community Support



- We also provide a RTM Template
- Complete guide and “empty board” for own MTCA RTM designs Altium Designer Template
- MTCA Standard leaves freedom for RTM interface implementation (vendor-specific) risk of non-interchangeable AMC-RTM pairs
- DESY has a “class concept” Interchangeable boards
- DESY collected and documented best design practices beyond the standard

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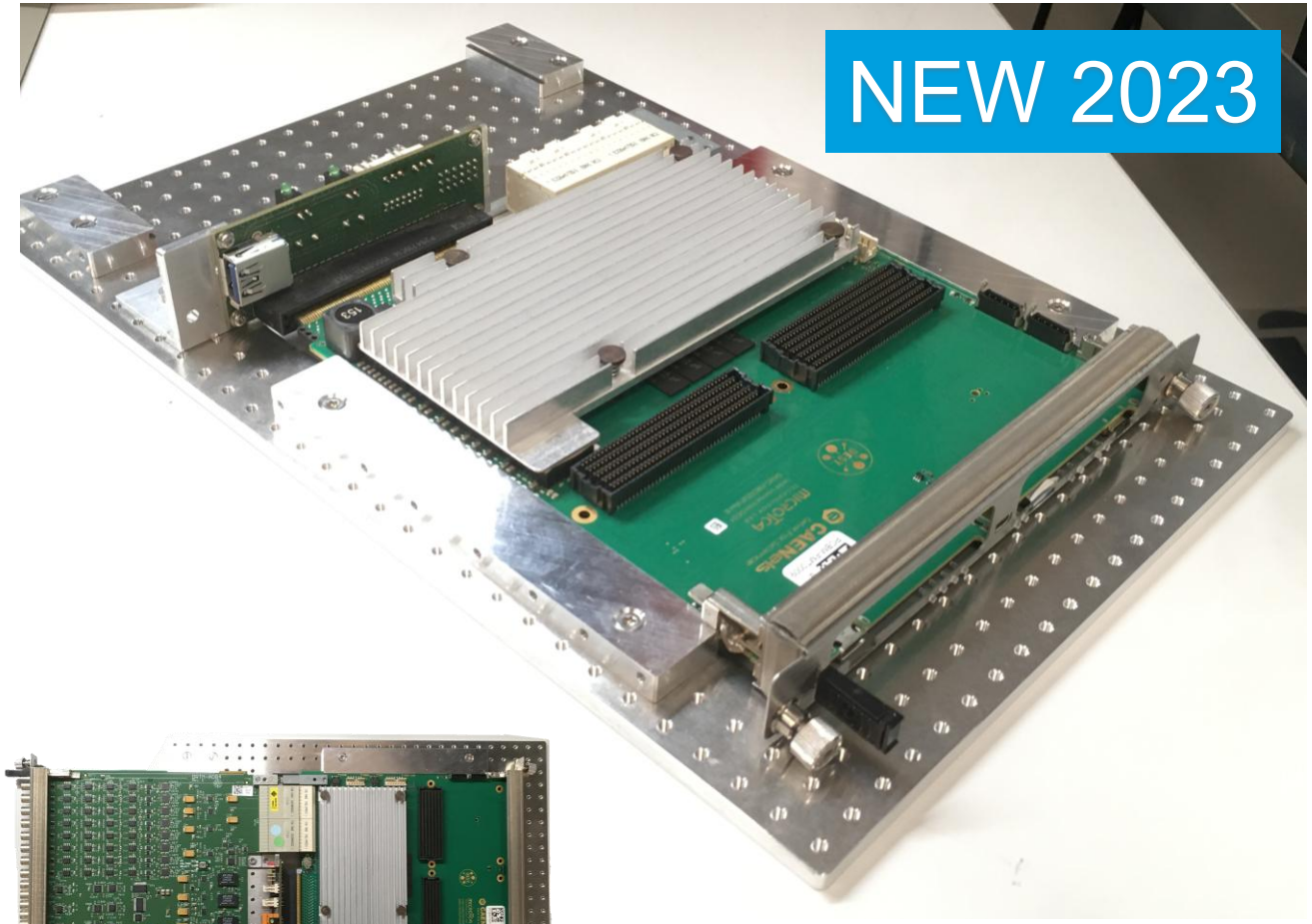
DESY.

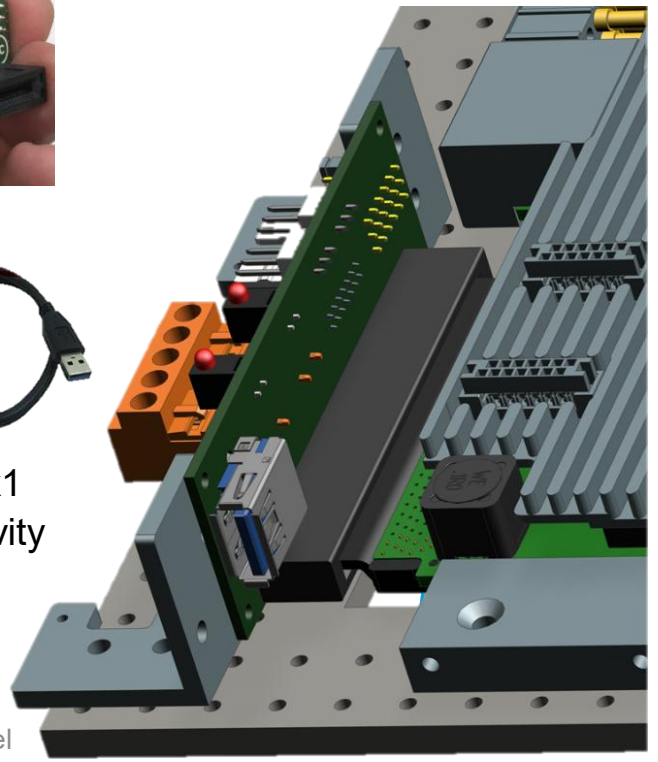
Benchtop Setup - Typical Bring-Up environment

- We have flexible lab development tools
- DESY provides them on request:
  - Aluminum frame production files
  - Bring-up PCB production files



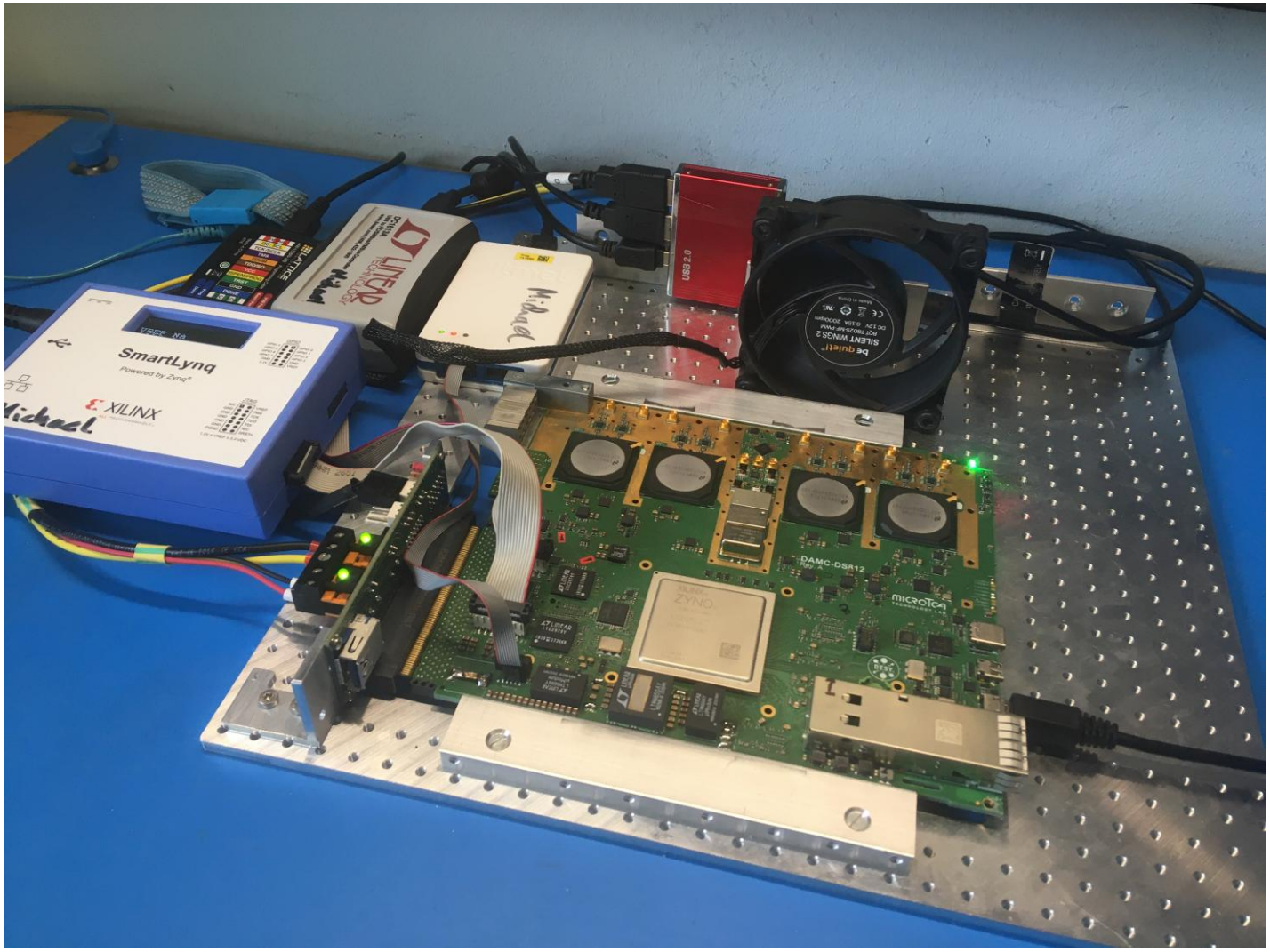
With RTM Support...

Adatper brings out PCIe x1 **Gen. 3 (8Gbps)** connectivity „on the lab desk“



courtesy of R. Wedel

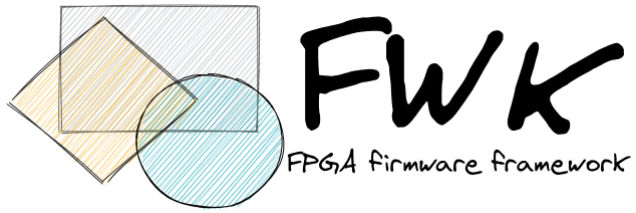
Typical Lab bring-up Setup



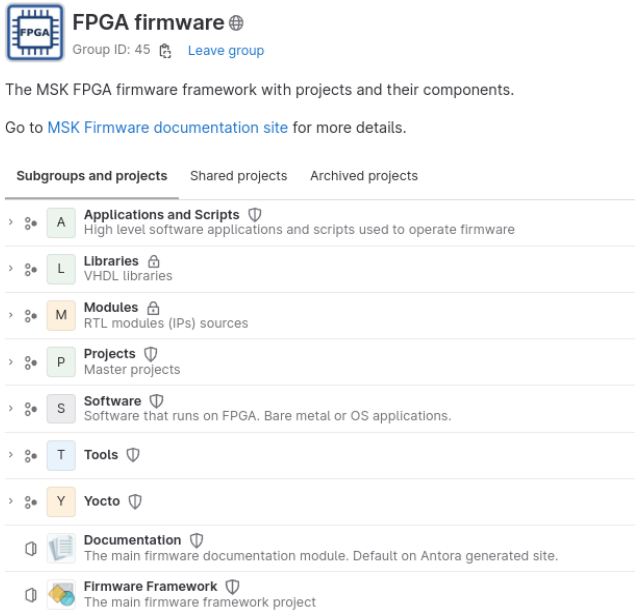
- Flexible and handy development tools
- DESY provides them (Creative Commons)
  - bring-up PCB production files
  - Aluminium frame production files

Write an email to me if you are interested in these designs.

FWK: The Swiss Army Knife of FPGA development



- MSK Firmware group maintains a large open-source repository for FPGA development. It contains:
  - BSPs, IPs,
  - FWK, Scripts, Tools, Example Designs in Vivado
  - Documentation
  - Is actively used in DESY's accelerators
- FWK: FPGA development toolkit written in Tcl for large FPGA projects
- Create and implement FPGA project using various vendor tools (including Vivado)
- Handle versioning
- Combine multiple IPs and create address mapping for each register
- Create documentation of the IPs
- Package an IP
- Create an IP using Higher-Level-Synthesis (eg. Xilinx HLS)
- Embedded Linux Creation with Yocto Flow



Visit now!
gitlab.desy.de/fpgafw

Documentation:
fpgafw.pages.desy.de/docs-pub/doc/

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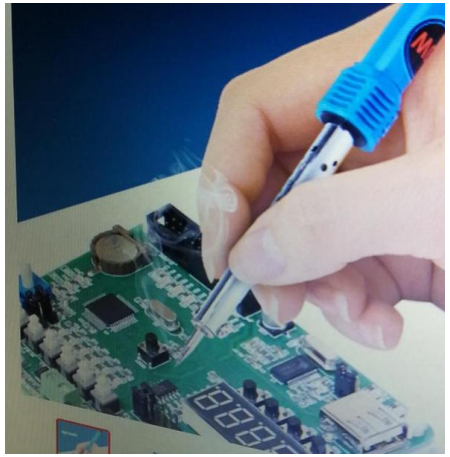
Courtesy of Çağıl Gümüş

DESY.

Summary

- **Overview:** DESY's MSK Digital Team develops and maintains FPGA- and SoC-based MicroTCA platforms for accelerator beam control, focusing on reliability, modularity, and full in-house hardware/firmware/software development.
- **Ecosystem & Licensing:** DESY has licensed nearly all of its developments, making the components accessible both internally and to external partners. The strategy is to focus on application-specific solutions while sourcing standard infrastructure from external suppliers.
- **Key Hardware:** The DMMC-STAMP ecosystem standardizes MicroTCA management, allowing for significant hardware/firmware reuse (95%), supporting in-system updates, and has been adopted by over 30 partners due to its open licensing strategy. Boards like DAMC-FMC2ZUP (high-performance MPSoC carrier), DAMC-UNIZUP (cost-optimized version), and DAMC-MOTCTRL (motor controller) enable scalable, processor-centric, "Raspberry Pi inside FPGA" solutions for data acquisition and control. High-speed digitizers: Includes 8-channel gigasample digitizers (DAMC-DS812ZUP), RFSoC-based converters (DAMC-DS5014DR).
- **Development Support:** DESY provides open-source FPGA tools (FWK), Altium design templates for AMC/RTM boards, and lab bring-up setups under Creative Commons to encourage community collaboration and rapid prototyping.
- **Future Outlook:** Next-generation MTCA efforts focus on PCIe Gen 5, 100 GbE, higher power per AMC (up to 220 W), and lower latency to meet the demands of future large research facilities.

Thank you!



:-) https://www.reddit.com/r/electronics/comments/d62qwi/karen_hold_it_like_you_were_soldering/

Contact

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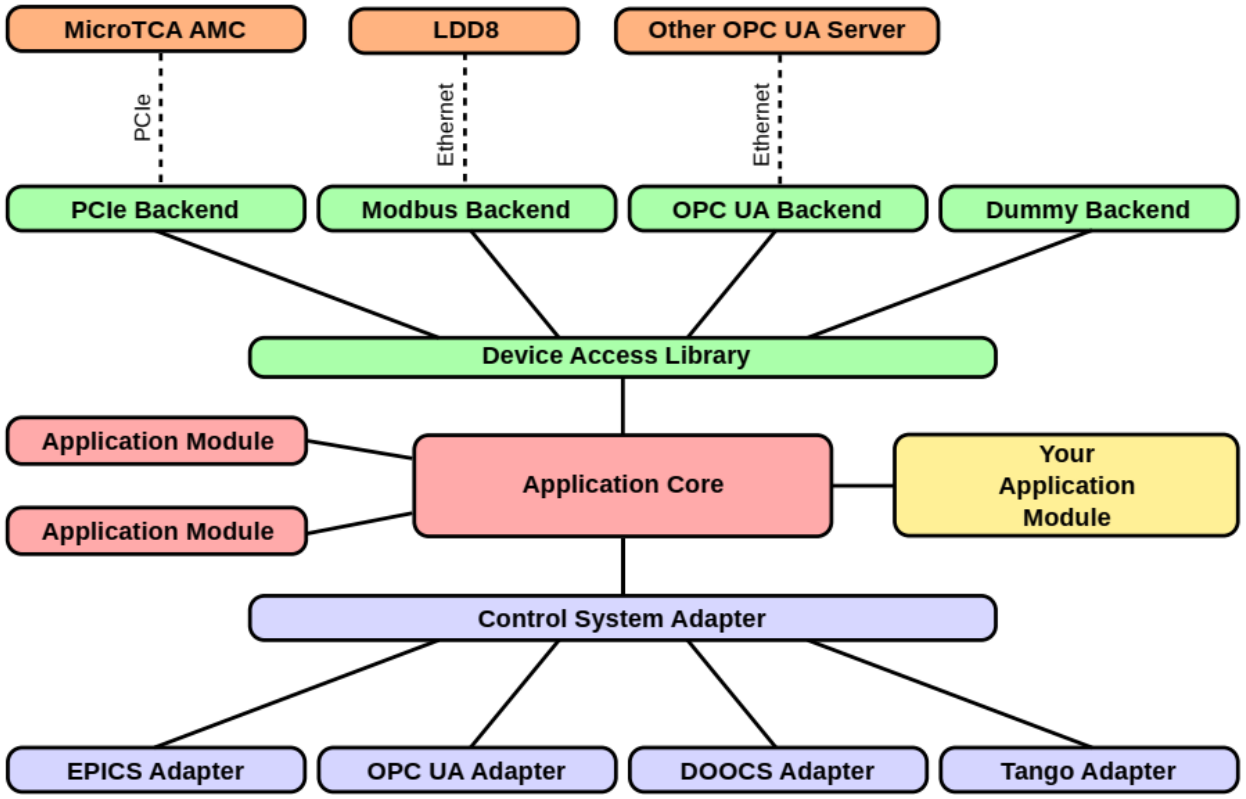
Thank you!

ChimeraTK – A software tool kit to facilitate control application development



DeviceAccess

- Common API for different backends
- Seamless integration with FWK
- Improved device abstraction
  - Named registers → process variables
- C++ (native)
  - Python bindings
  - Matlab bindings
  - Command line interface
  - Graphical user interface

ApplicationCore

- Model data flow with process variables
- Small self-contained modules
- Modern multi-threading

ControlSystemAdapter

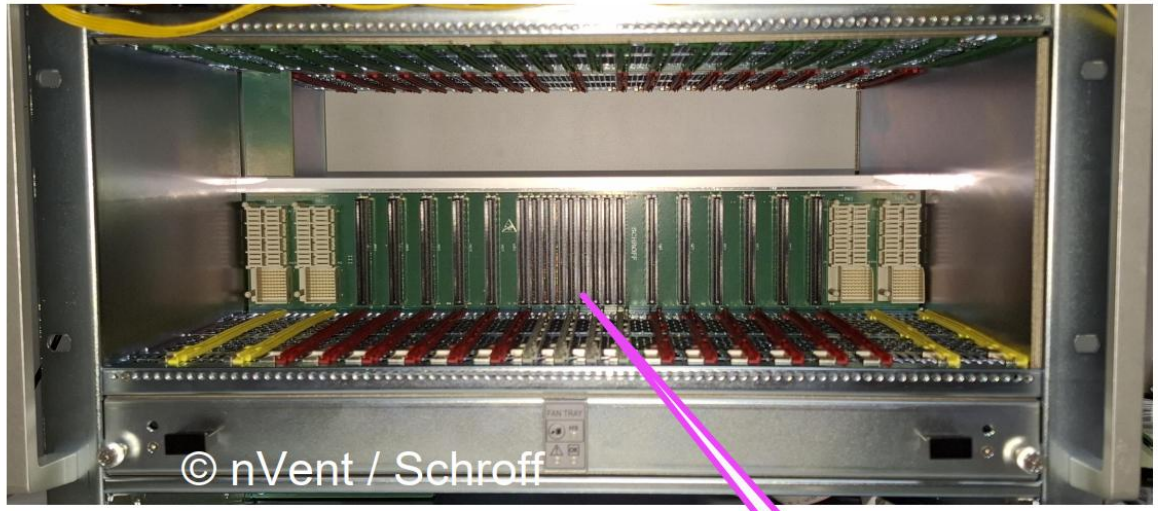
- Native integration into control systems
- Publish process variables

Courtesy of Martin Killenberg

Next Generation MTCA

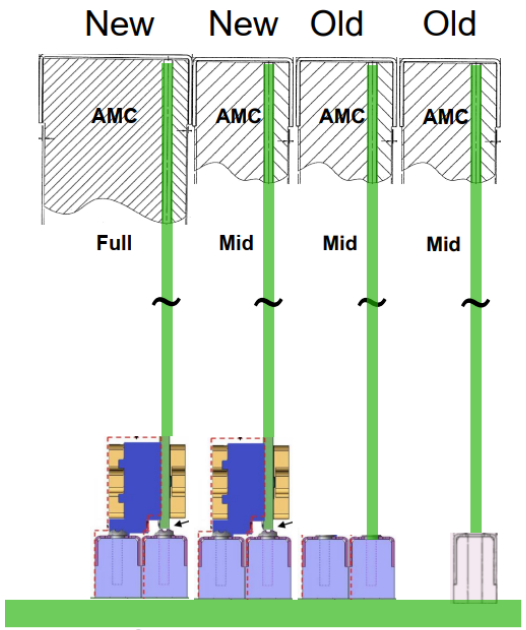
Community Support

- PCIe Gen. 5 and 100 GbE → 32 Gbps → lower latency
- Power: up to 220 W per AMC, more power on RTM
- Crate power ≥ 2 kW
- Split MCH

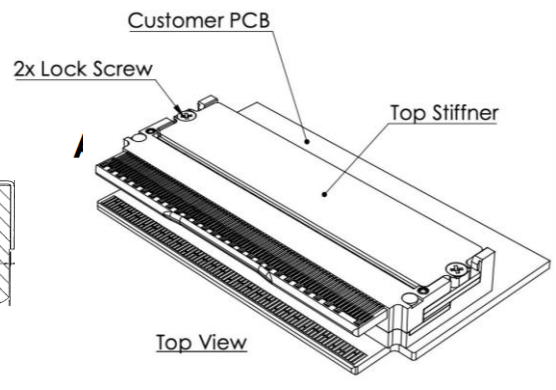


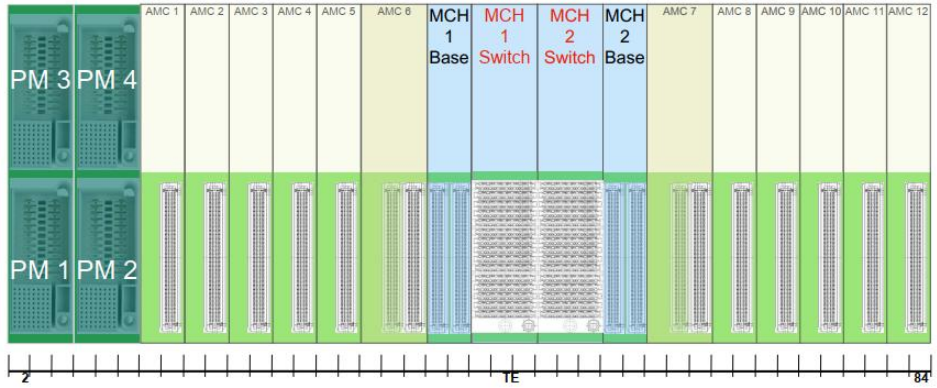
Redundant MCH in center of crate to achieve 32 Gbps in all slots

Courtesy of Kay Rehlich



Next Generation Backplane





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