Update on Digital Hardware Developments at DESY

Michael Fenner, DESY Hamburg

12th MicroTCA Workshop for Industry and Research

6th of December 2023

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Agenda

Short Board Presentation (based on modern MPSoCs)

- Digital AMC portfolio
- **Highlights 2023: DAMC-UNIZUP and DRTM-8SFP+**

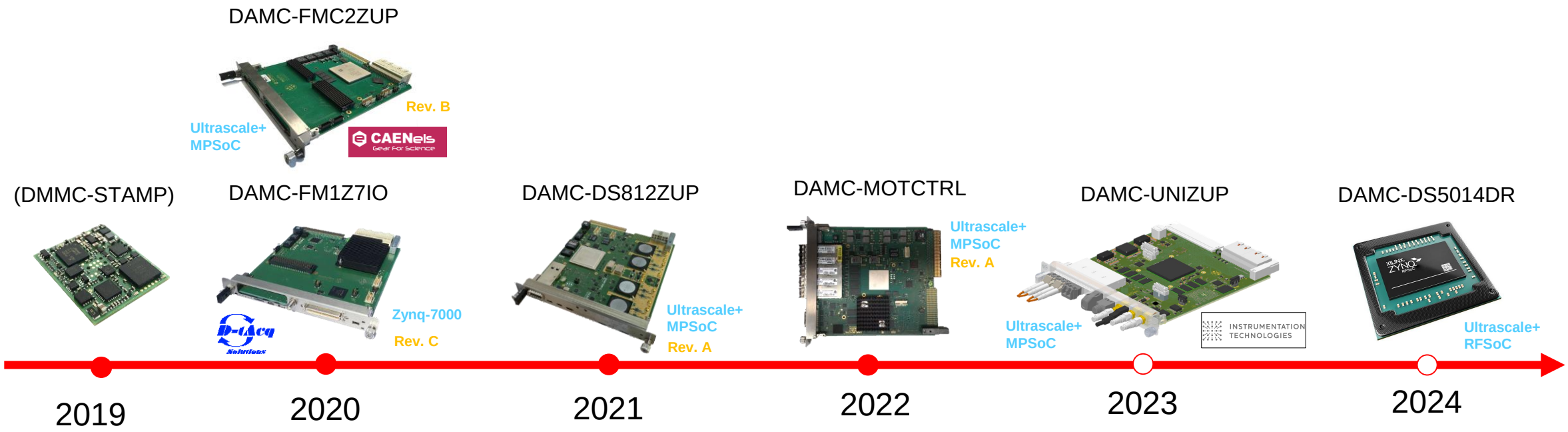
Yamaichi AMC Connector validation

Presentation of Lab Development Tools

- New MTCA Bring-up Adapter
- AMC and RTM Templates

Recent Board Portfolio

Timeline of SoC-Based Boards



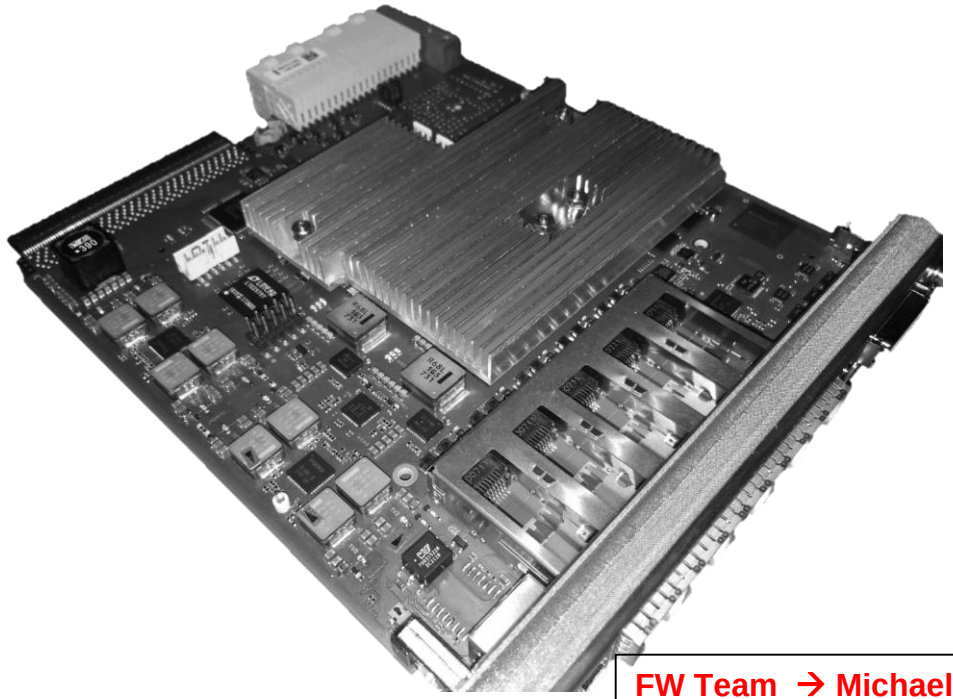
All new boards follow our development strategy:

- Shared and common components
- 4- or 6-eye reviews
- Pool of proven design blocks: DMMC-STAMP, White Rabbit, Power Section, FPGA, (DDRx) Memories and others…
- All these Boards have achieved
  - Full Performance in Rev. A → delivered to the partners (with 0, 1, 2 patch wires)
  - Series Production in Rev. B (we always had to address component obsolescence)
- Similar boards → fast development cycles → similar BSPs → Very low surprise ratio

DESY offers licenses for all MicroTCA developments, so that the boards get available to 3rd parties.

DAMC-MOTCTRL

MicroTCA.4 Motion controller

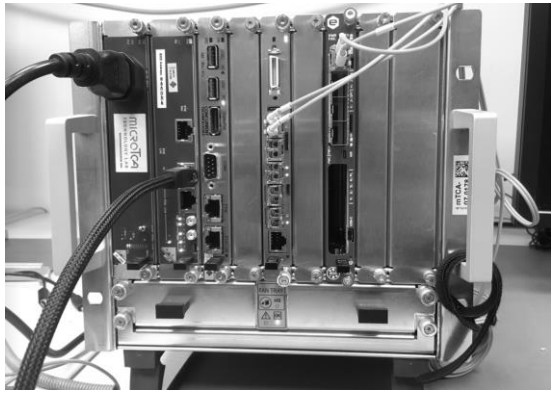


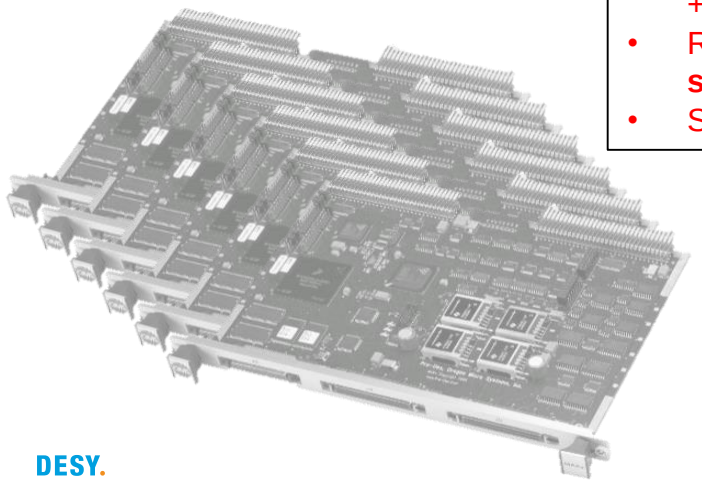
- Replacement for VME solution OMS MAXv: replacement for 6 cards (48 motors)
- Allows **distributed, synchronous motor movement**
- and **position-synchronous data acquisition** (via MicroTCA backplane triggers)
- Optical interface to Motor Drivers
- Heterogeneous approach
  - MPSoC (2GB DDR4)
  - Kintex-7 (4GB DDR3) real-time control
- MPSoC:
  - 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
- 26-pin connector: 3.3V /5V IO
- Monitor/Keyboard interface via USB-C

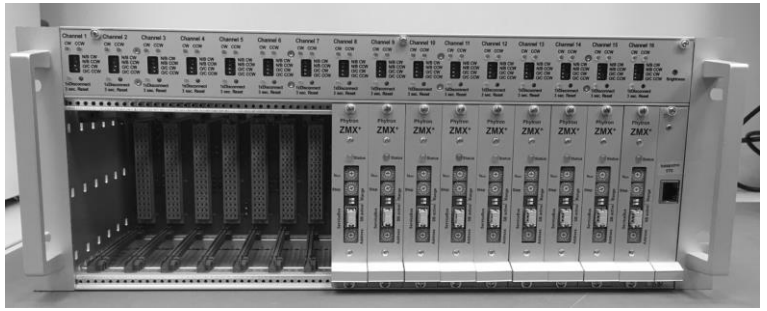
Power of this board lays in Firmware

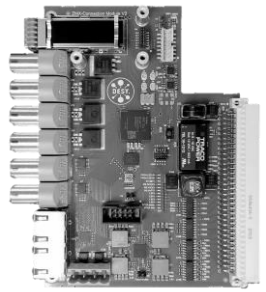
FW Team → Michael Randall et al. → Thursday 11:00 o'clock

- Developed a generic firmware module for **synchronous multi-axis motion** control + **encoder support** + limit-switch control.
- Released **OSS FWK-based FW 1.0.0** with CLI for high-level instrument **control software spec**
- Successfully **deployed and tested prototypes** at two different locations.









DAMC-UNIZUP: Universal MPSoC Processing Board

DAMC-UNIZUP

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)

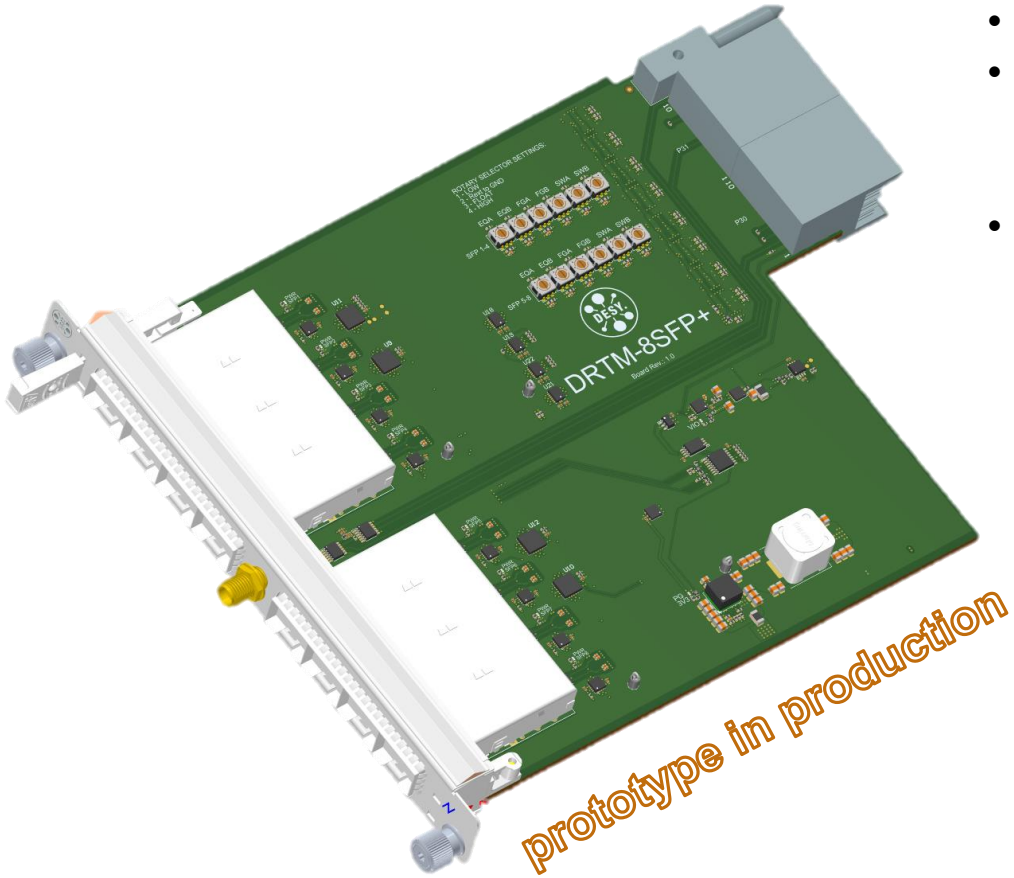
"Step-sister" of DAMC-FMC2ZUP

Main Features:

- Inherits the technology of DAMC-FMC2ZUP
- Universal MPSoC Board with more **powerful RTM connectivity**
- High-Performance FPGA: Zynq Ultrascale+ **ZU7CG…ZU11EG** (in lower pin-count package)

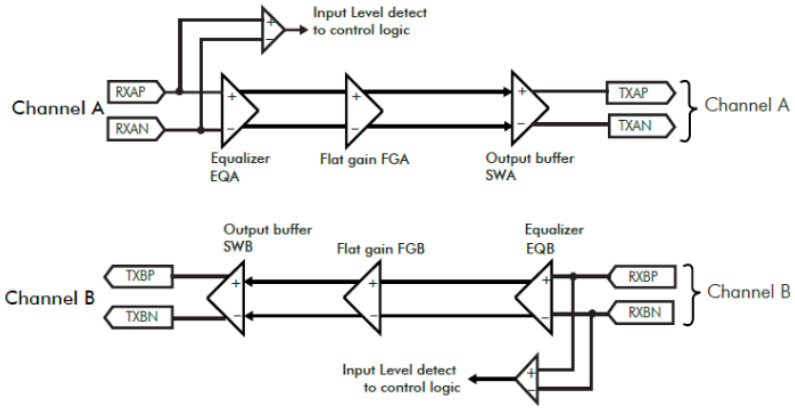
- **New features**
  - **2 x 64bit** wide DDR4 interfaces (total of 8GB RAM)
  - RTM D1.2 or D1.3 connectivity **to MPSoC** (assembly option)
    - D1.2: 38 LVDS pairs and 4 MGTs → e.g. parallel ADCs on RTM
    - D1.3: 28 LVDS pairs and 8 MGTs → e.g. JESD204B ADCs on RTM
  - **4 SFP+** ports integrated
  - GTH Transceivers operate at 16.375 Gbps (no 28Gbps GTY)
  - Connectors for **slow and fast trigger inputs/outputs** on front panel
  - 2 front panel clock inputs via SMA, 1 output

DRTM-8SFP+ RTM Optical Interface Board:



Main Features:

- Follows MicroTCA4.1 class definition (+voltage adjustment)
- Compatible to all our boards (and many partner's boards)
  - Compatible to 1.8V FPGAs (required for modern FPGA HP banks)
  - Compatible to 2.5V and 3.3V Zone 3 voltage (backwards compatibility)
- Allows data transmission of up to 12.5 Gbps
  - Provides sockets for 8 SFP+ transceiver modules
  - contains re-drivers for each channel with linear equalizer
  - allows to tweak eye opening for optimal signal integrity



- RTM Class D1.1 to D1.3 compatibility → up to 8 SFP+ Modules
  - Fits behind DAMC-UNIZUP with all 8 transceivers (Class D1.3)
  - Fits behind DAMC-FMC2UP with 2 transceivers (Class D1.1)

- Clock Input from RTM (replaces DESY clock feed-trough RTM)

DAMC-DS5014DR: RFSoC

Main Features:

- 8x 14bits **ADC, 5 Gsps, 6 GHz** analog bandwidth
- 8x 14bits **DAC, 10 Gsps, 6 GHz** full-power BW
- DACs and ADCs to RTM **or**
- DACs and ADCs to front panel
- Coaxial analog Zone 3 RF Class RF1.1
- Flexible to-RTM or to-front-panel RF harness option

Under Development

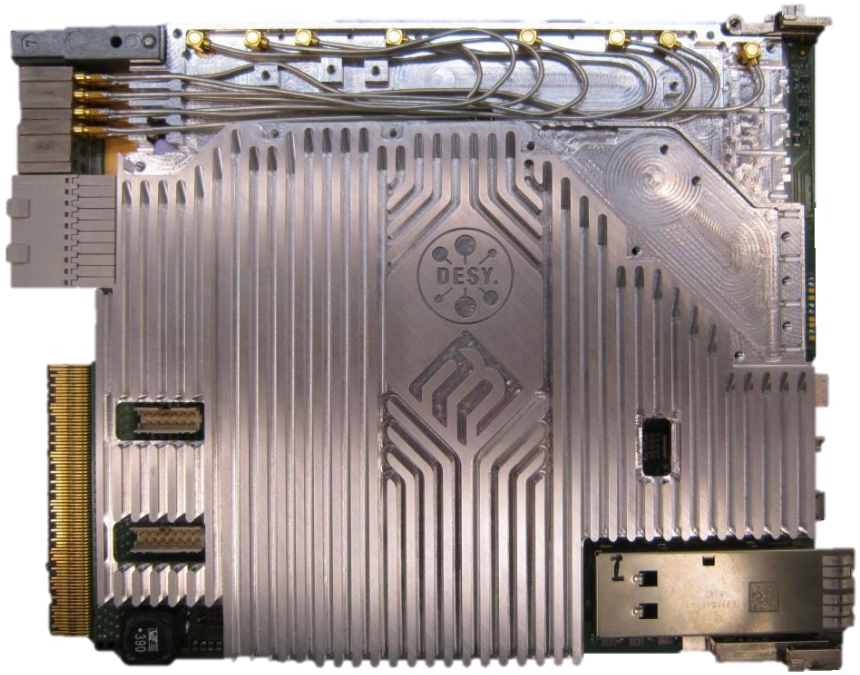
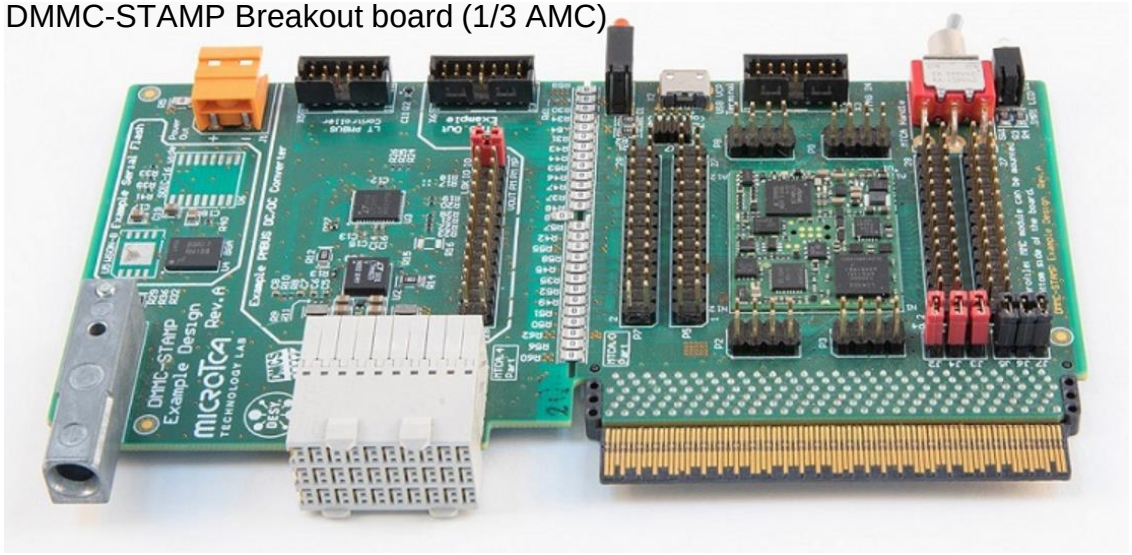


Photo:
https://www.avnet.com/wps/portal/silica/products/product-highlights/xilinx-rfsoc/

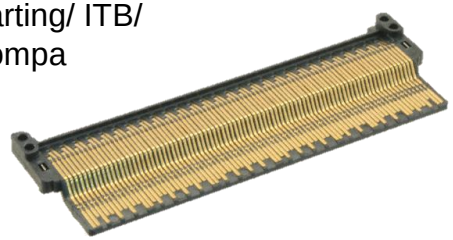
Yamaichi AMC Connector

AMC Connector Alternate Solution

DMMC-STAMP Breakout board (1/3 AMC)

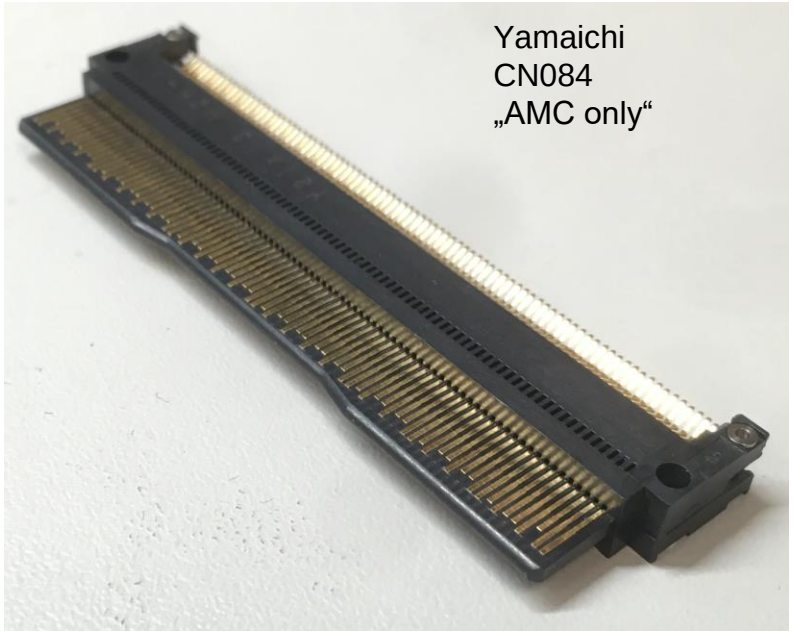


Harting/ ITB/ Rompa



Yamaichi CN084 „MCH“

Yamaichi CN084 „AMC only“



- All our AMCs have a plastic connector
- Rompa/ ITB end-of-life notice affected all boards

Product End of Life Notice, Last Time Buy

Notification date: 18 November 2022

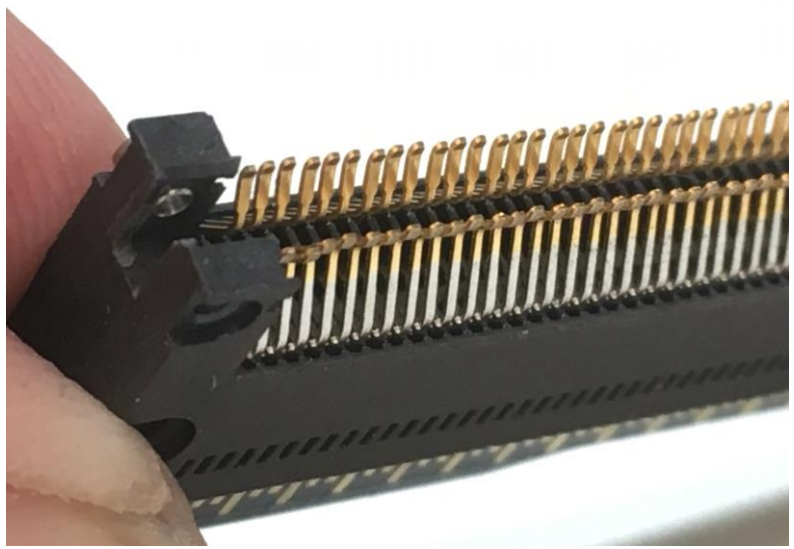
taken back… - state 2023: „in production“

- We started to look for alternatives
- Yamaichi offers an MCH connector, but no separate AMC connector
- 1st piece of stack should fit → we gave it a try…
- Would like to share the results

Why separate ANC Connector?

- Provides “smooth” mechanical interface
- Rounded plastic vs. chamfered glass fibers
- Flexibility in PCB thickness (up to 2.0mm)
- Easier to manufacture PCBs
- We see up to ~1000 mating cycles (5x more)
- Beyond that: backplane fails → catastrophic damage

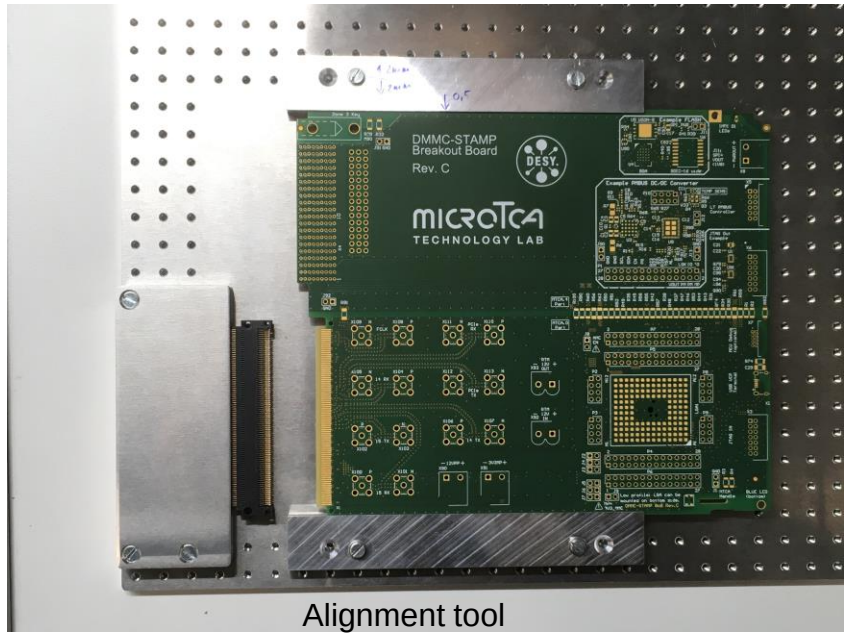
Yamaichi CN084



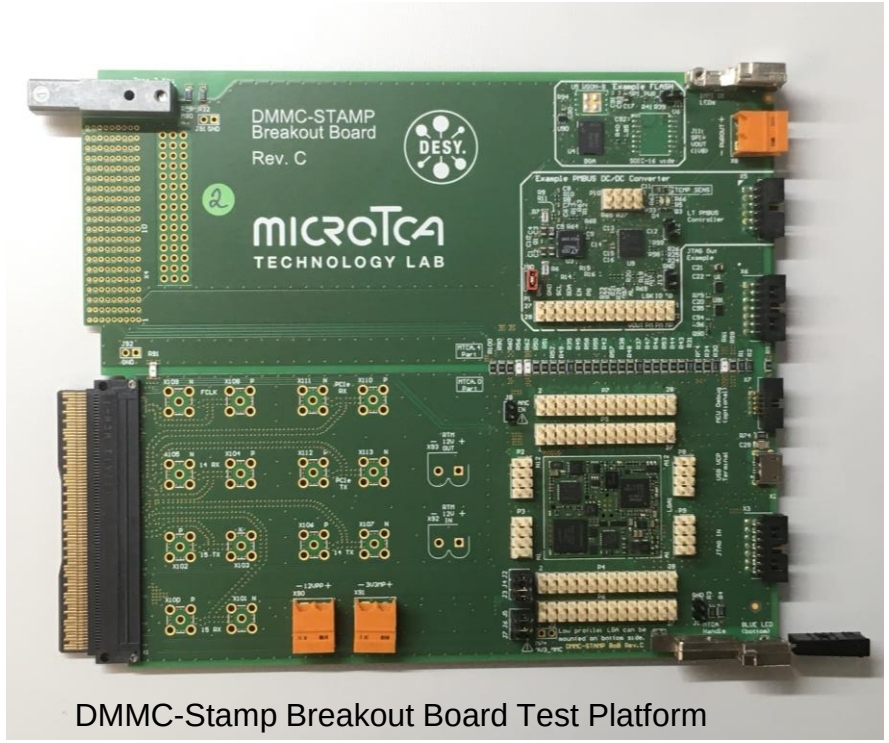
Yamaichi CN084 without pin cover

Gold finger stubs

- Our focus: signal integrity
- 10Gbps data rate (or more)
- Good: No through-hole pins anymore
- Concern: Stubs created by gold fingers
- Question: How will the connector perform?
- We re-designed our DMMC STAMP breakout board and added some test connectors
- First lesson learned: We needed to design an alignment tool…



Alignment tool

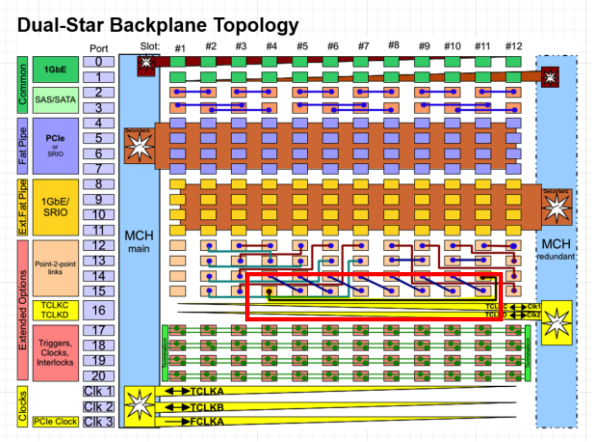


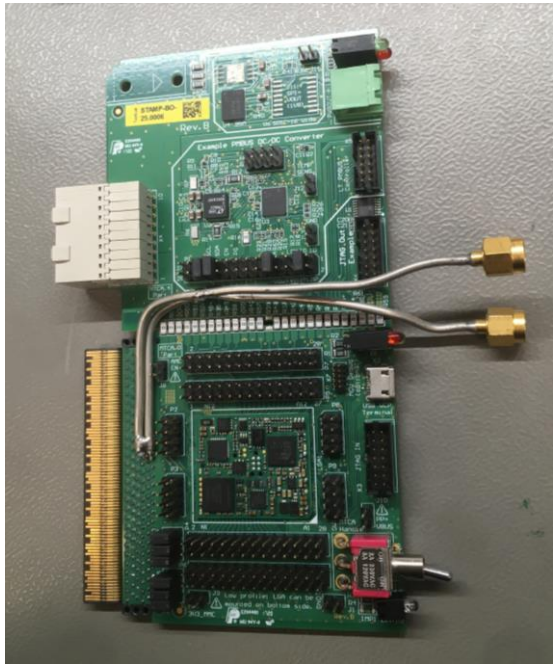
DMMC-Stamp Breakout Board Test Platform

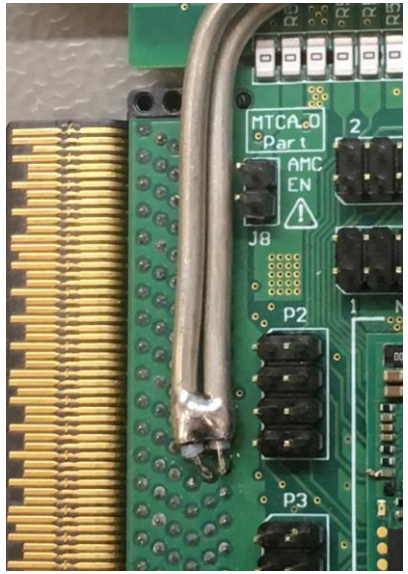
10G Eye Test Setup

DMMC-Stamp Breakout Board In Create

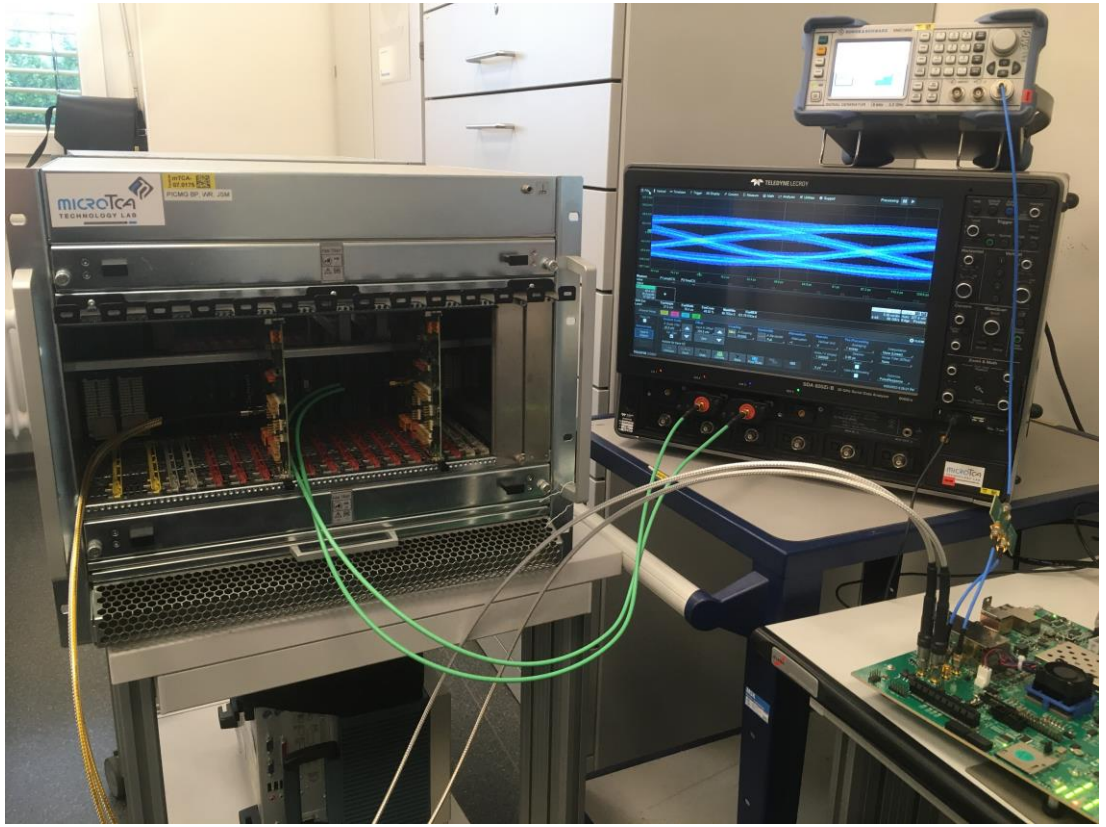
- We installed two boards and tested the longest P2P path
- We generated signals with ZCU102 evaluation board
- Measured eye at 10Gbps





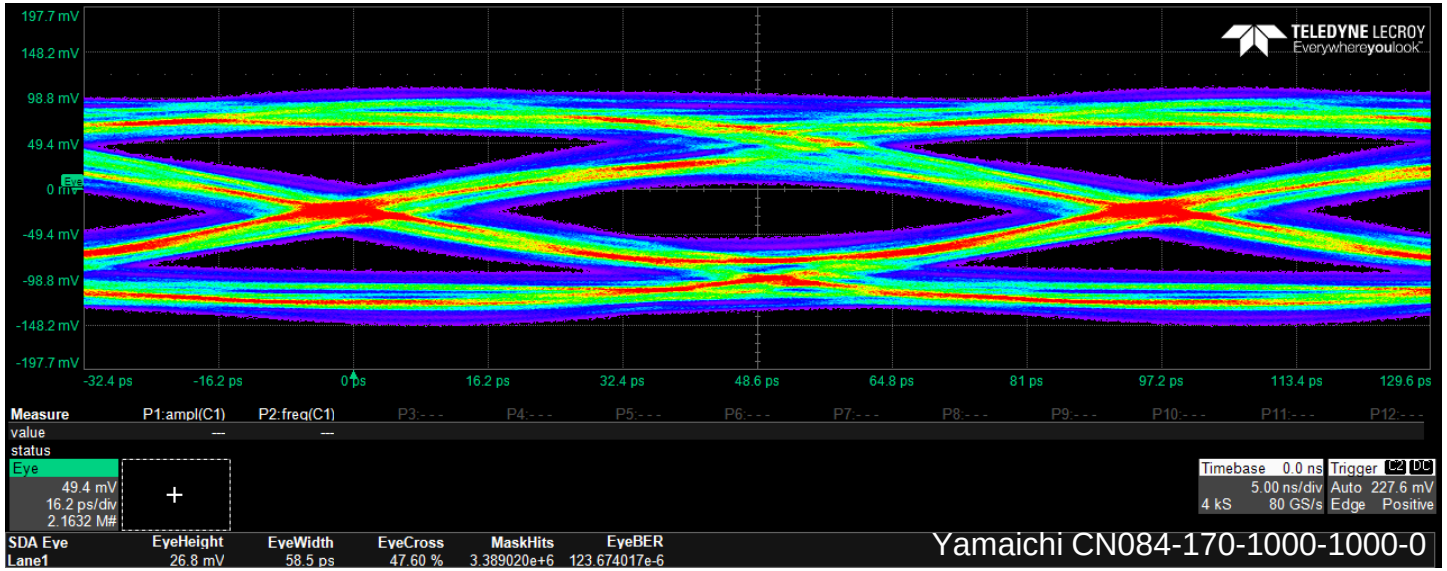


Soldered-in semi-rigid cables for reference measurement (Harting/ITB/Rompa)

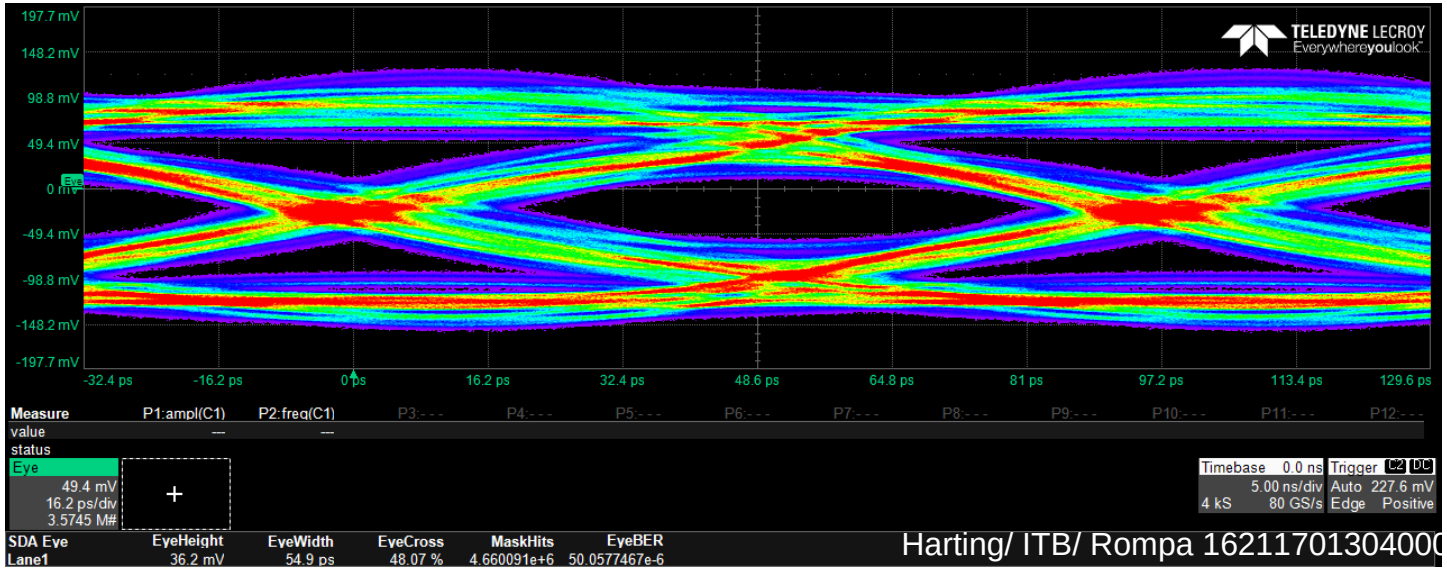


Test Setup: 10Gbps Signal Generation with IBERT on ZCU102

10G Eye Test Results



Yamaichi CN084-170-1000-1000-0



Harting/ ITB/ Rompa 16211701304000

Yamaichi results:

- 26.8mV eye height
- 58.5ps eye width

Harting/ ITB/ Rompa results:

- 36.2mV eye height
- 54.9ps eye width

Similar results (Longer FR4 traces on test board)
However, TX pre-emphasis settings needed (identical settings on both connectors)

Fully approved for new DESY designs.

RX Pattern	TX Pre-Cursor	TX Post-Cursor	TX Diff Swing
PRBS 7-bit	1.67 dB (00111)	6.94 dB (10110)	1000 mV (11110)
PRBS 7-bit	1.67 dB (00111)	6.94 dB (10110)	1000 mV (11110)
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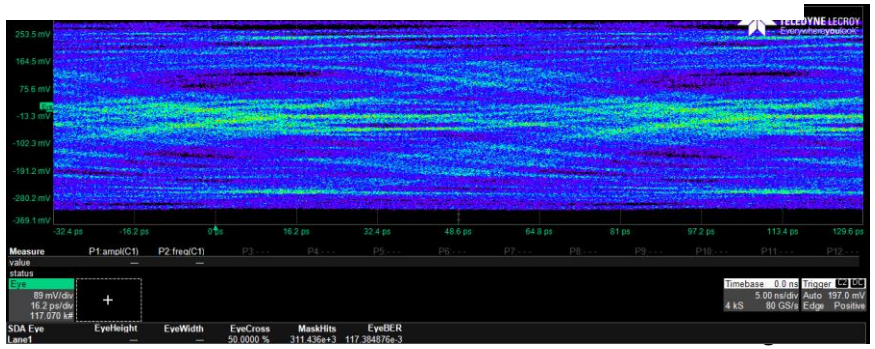
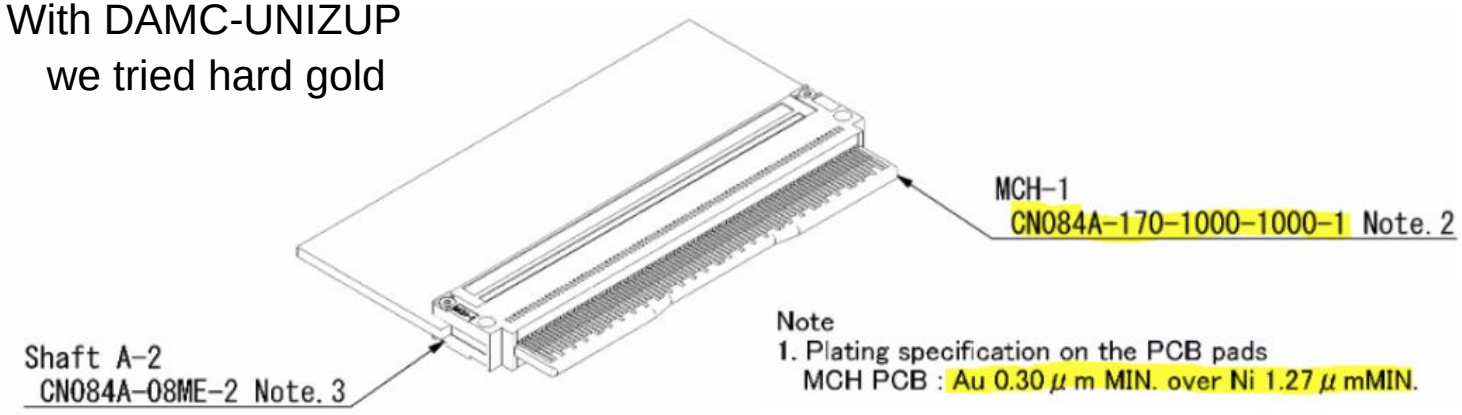
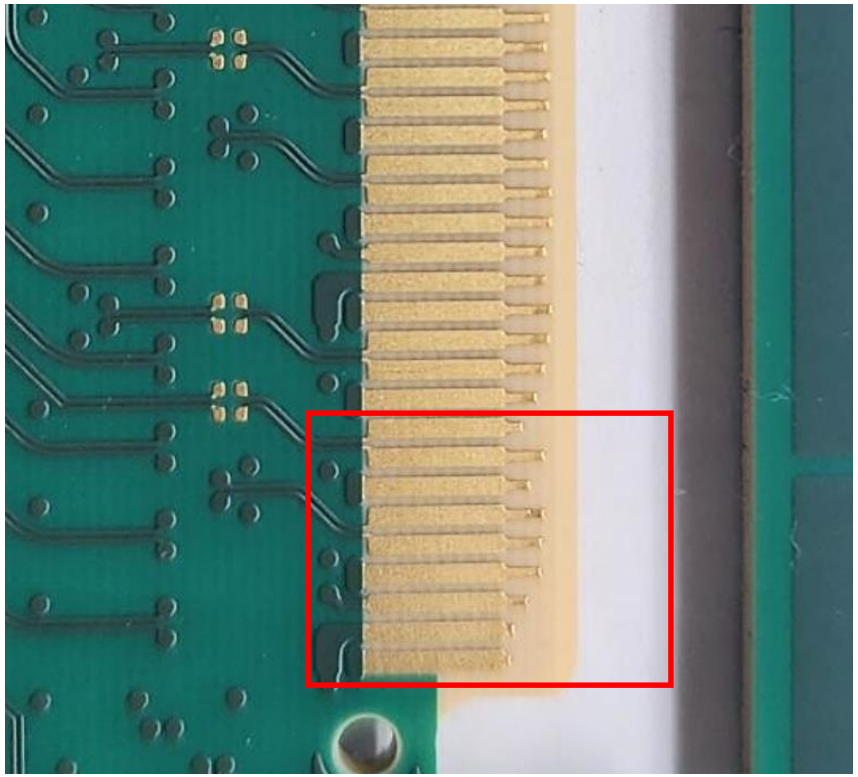


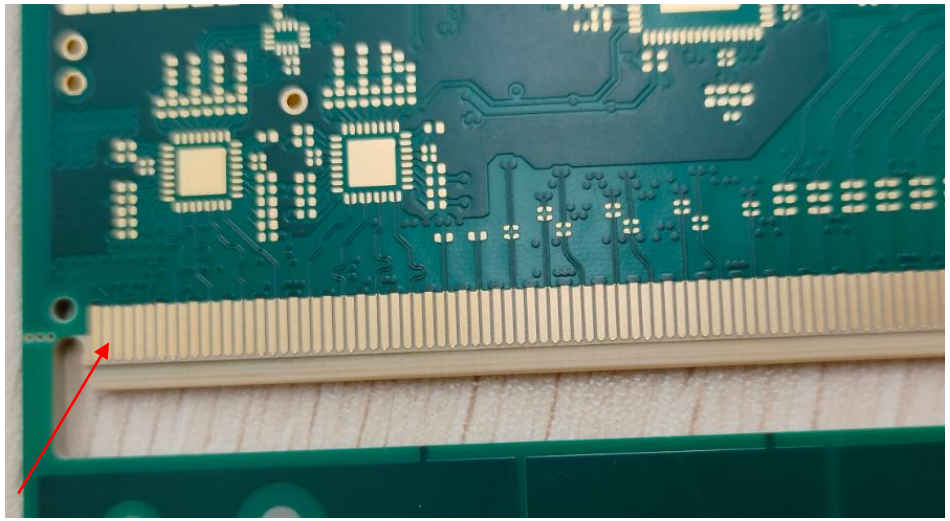
Manufacturing Challenge

- Yamaichi requests 0.3µm gold Surface
- DMMC-STAMP-Breakout: ENIG (4-7µm Ni / 0.05 - **0.1µm Au**)
- “Soft Gold” does not fulfill requirement
- With DAMC-UNIZUP
  we tried hard gold



First Try: left-over Tie-bards have been partially ripped off.



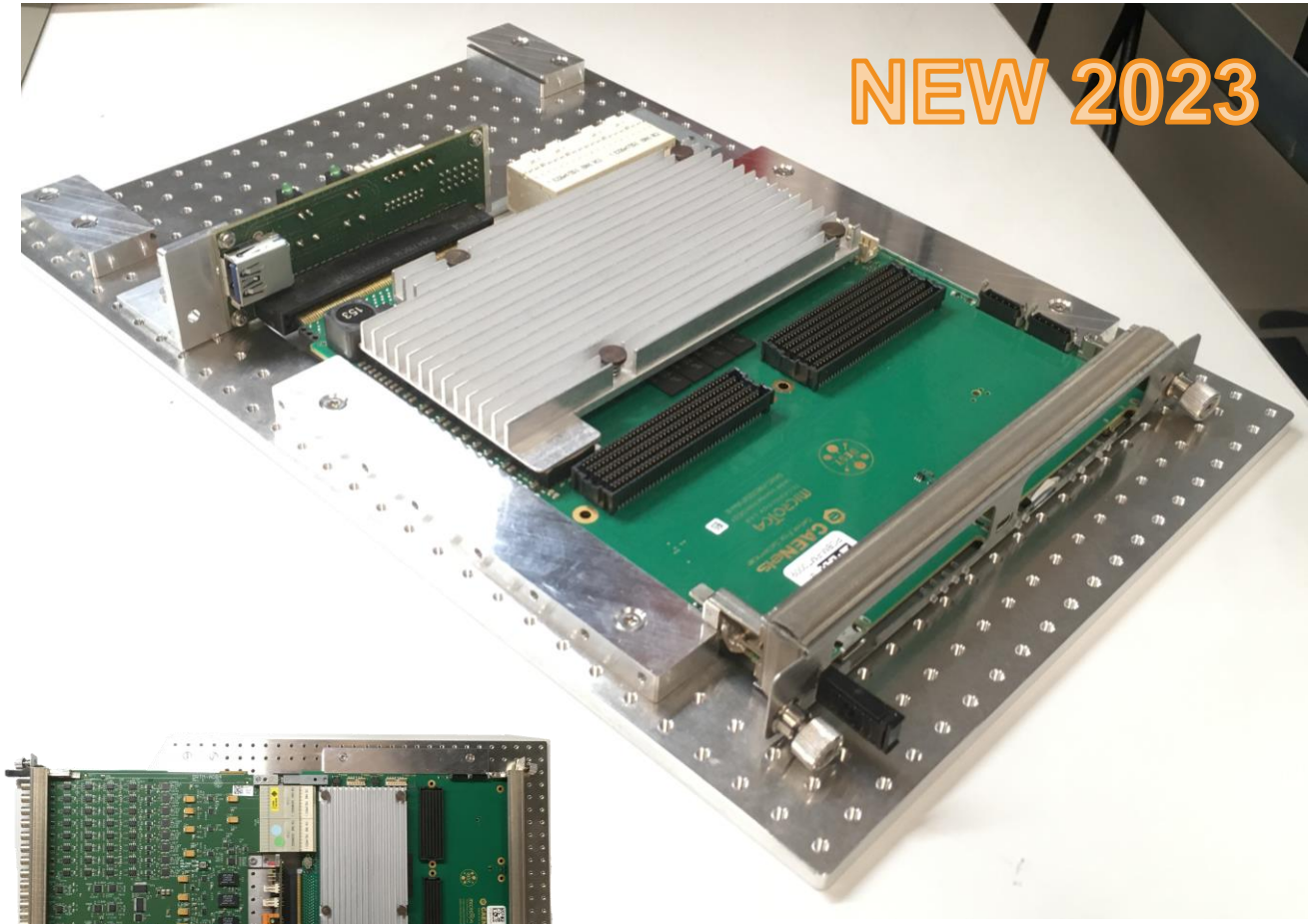


Second Try: Tie-bars have been milled off (but: step remains)

- Hard gold needs contacts for electrode → tie bars are left over
- **First try:** Final milling did not work well and ripped off tie bars
  Long tie bars with different P/N length would be unacceptable for signal integrity
- **Second try:** Tie bars were milled away (step created…, ok for now)
- **Third try** (next board):
  Etch off tie bars: Can be done by manufacturer
  Try thicker soft gold: ENPIG? (Electroless Nickel Electroless Palladium Immersion Gold)

Development Tools

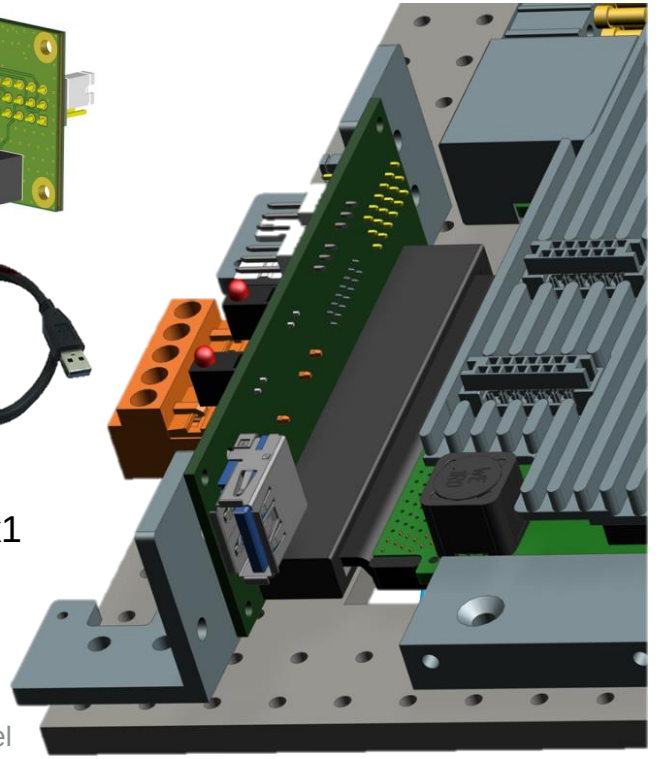
Typical Bring-Up Setup



With RTM Support...

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

Write an email to me if you are interested in the files!



Adatper brings out PCIe x1 Gen. 2 connectivity „on the lab desk“

courtesy of R. Wedel

MicroTCA template

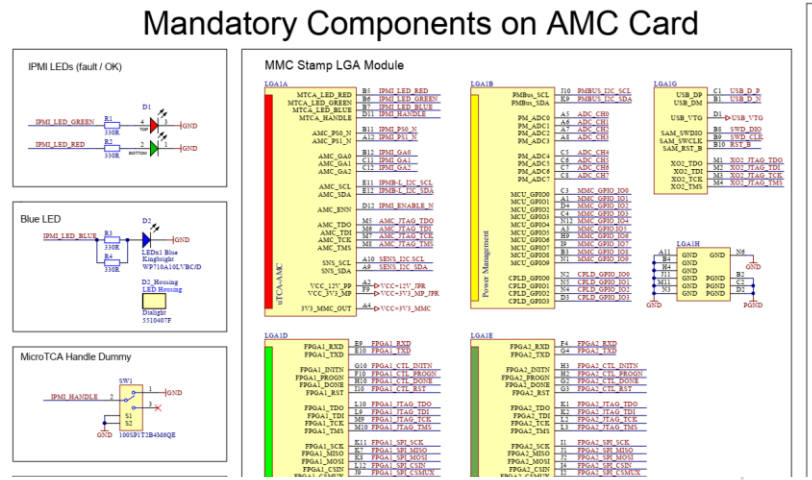
Idea: Jump-Start with MicroTCA as you would with any other board

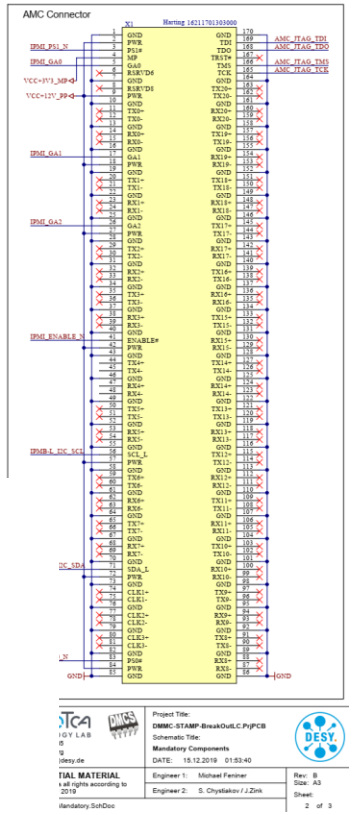
Fully MicroTCA compliant “empty” board
- Start with correct mechanical Shape
- AMC and RTM “only” get power
- All the management is done on DMMC-STAMP

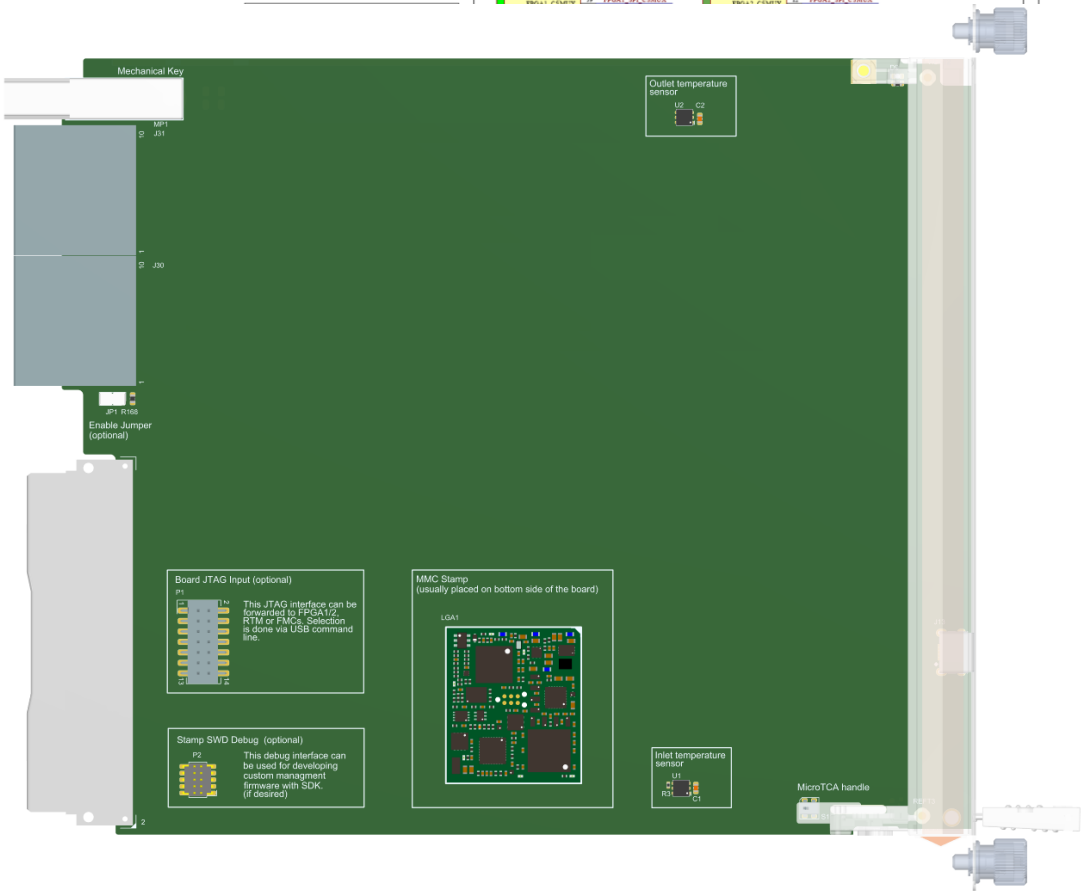
Purpose: facilitate development
- Allows design migration (e.g. from VME)
- Source design files (Altium Designer) are provided
  - Schematics
  - PCB

Components:
- MMC SoM, LEDs, Connectors, Temperature Sensors
- USB Interface for Management and Status

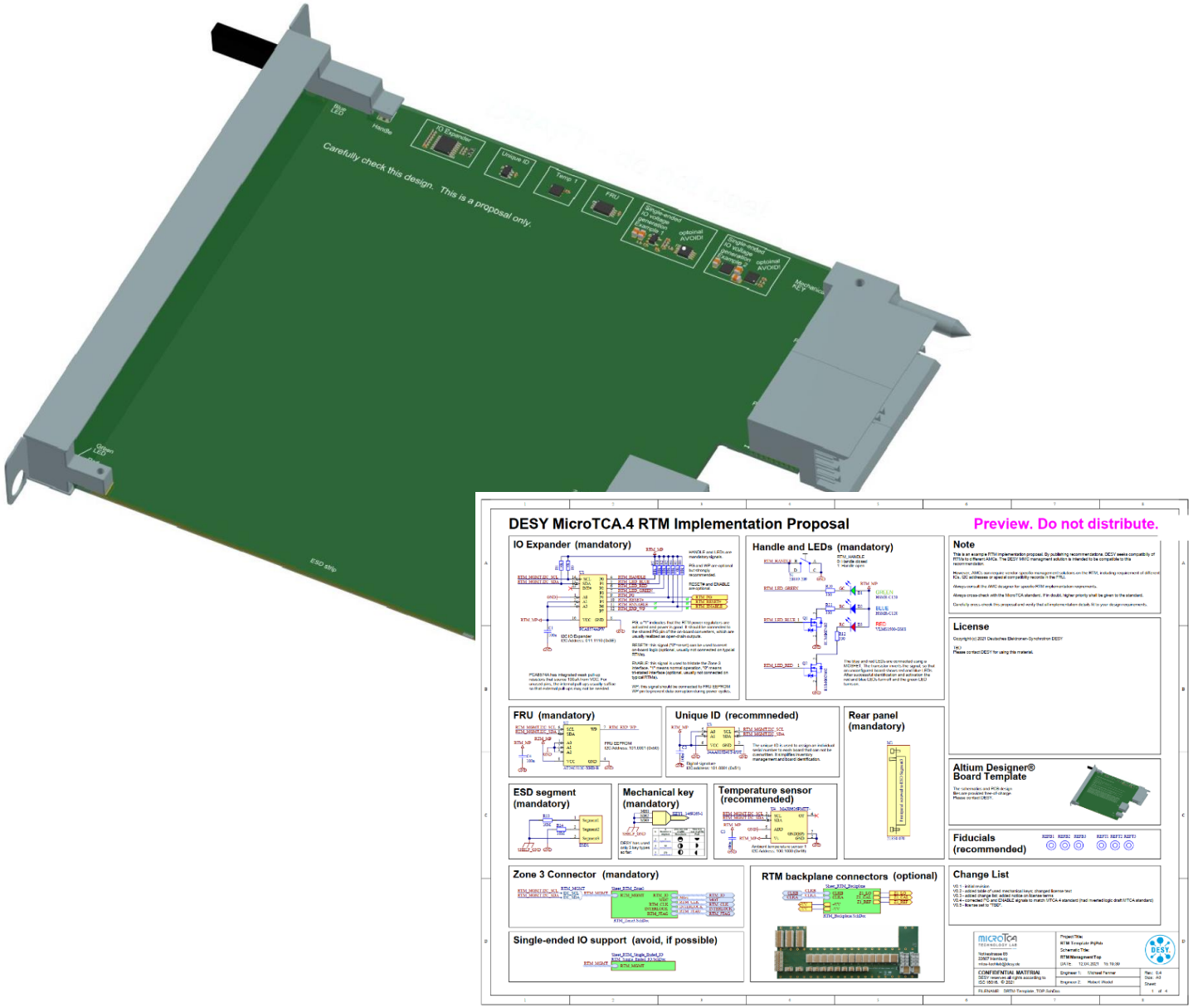
- MMC Stamp Breakout Board bases on the template





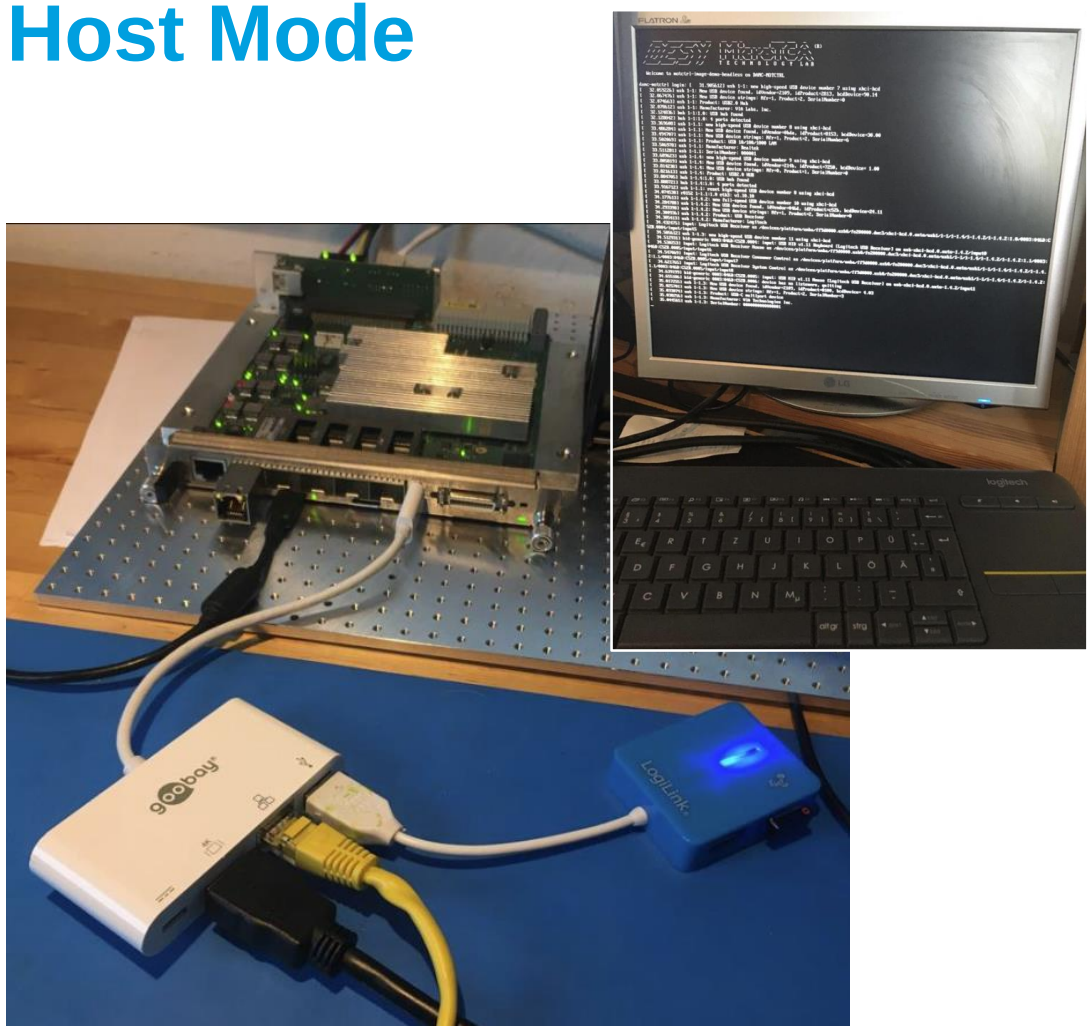


RTM Template



- We also provide a RTM Template
- Depicts MicroTCA4.1 Class recommendation (compatibility to ~70% of known AMCs)
- 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

Host Mode



Many modern FPGAs are SoMs

- From the outside: only SD Card, USB-C socket visible

But:

- ARM Processor is inside
- Boards run Yocto Linux
- USB-C dock brings out complete PC connectivity
  - HDMI
  - USB for Keyboard and Storage
  - Ethernet Network Interface

- PCIe Root Complex: Board can replace a complete CPU module inside MicroTCA (depends on processing needs)
- Board can work completely standalone like a PC

Thank you!

Acknowledgments: Stanislav Chystiakov, Robert Wedel, Martin Tolkiehn and the whole DESY MSK team

Contact

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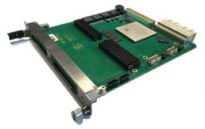
Overview of “commercial” products

- Complete ecosystem of MicroTCA products
- DESY has licensed nearly all boards so they are available for 3rd parties
- Strategy: Focus on your application, take standard products from others

AMC

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



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

DAMC-FMC25
AMC Dual HPC-FMC Carrier

DAMC-FMC20
AMC Dual FMC Carrier Board

DAMC-TCK7
AMC Data Processing and Telecommunication Module

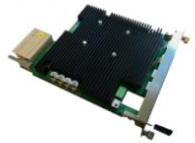
X2TIMER
AMC Fast Timing System

DAMC-UNIZUP

...

RTM

DRTM-MXC
Mobile GPU Carrier

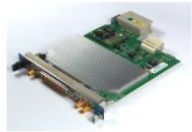


REAR-TRANSITION-MODULES

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