DAMC-UNIZUP: Universal MPSoC-based Controller Board

Libera Workshop 2024, Dobrovo v Birdih

Michael Fenner
April 17th 2024

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

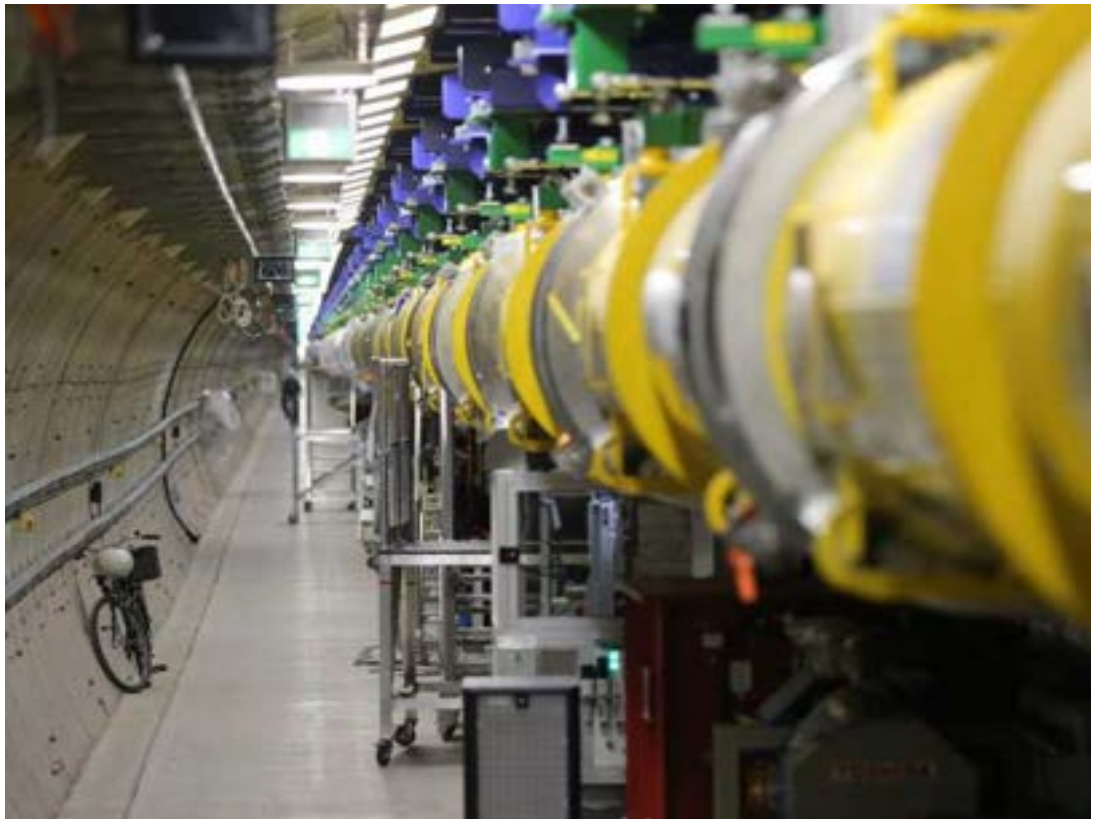
DESY.

Agenda

1. Our Background
2. DAMC-UNIZUP
3. „Tool Boxes“ for the Community

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
- Compl. development “in-house”: hardware (schematics, board, test), firmware and software design
- 10 years+ of electronics life time (hostile environment), 24/7 operation, limited access to electronics



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

...

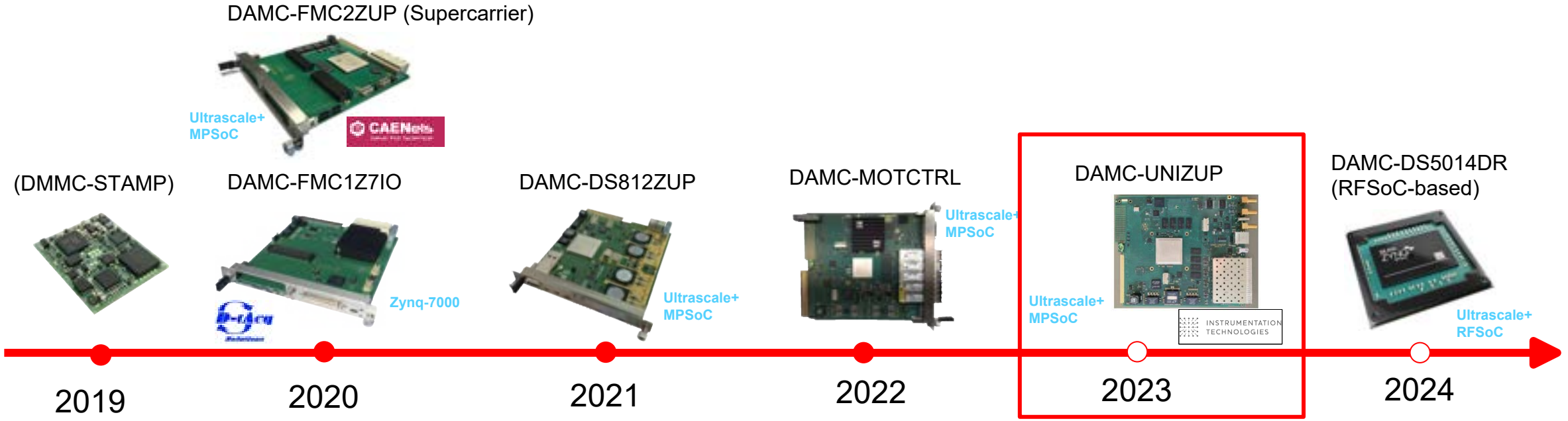
RTM

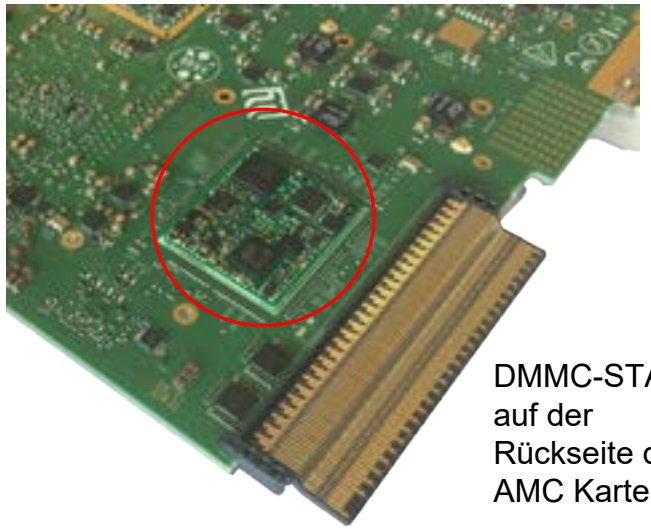
DESY MMC Stamp

FMC

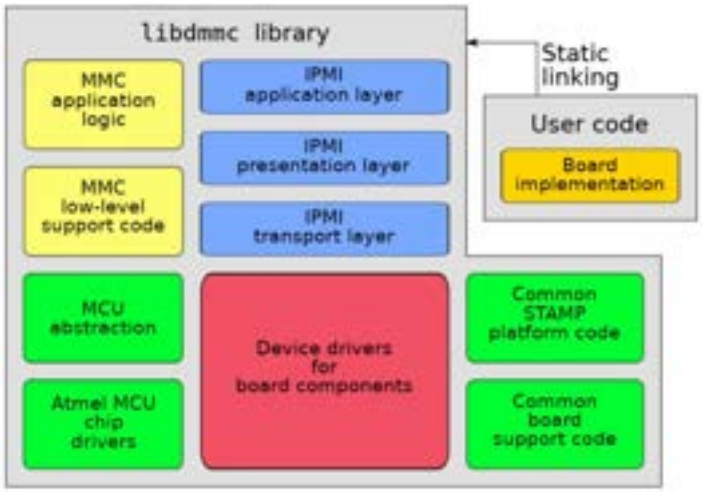
All SoC developments of the last few years

Similarity 1: Boards are all based on DMMC-STAMP





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)

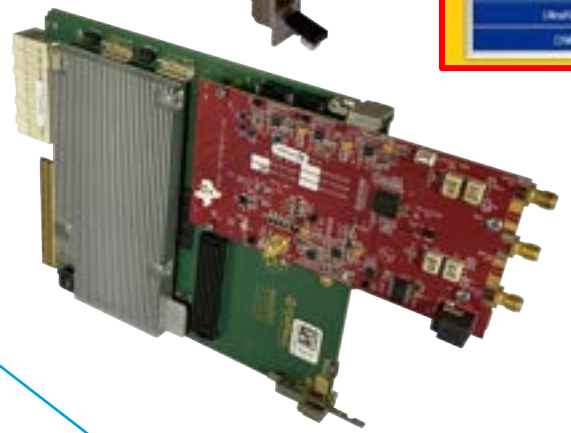
- 2024: over 1000 pieces produced
- used by 30 partners
- 100% test in the needle test adapter

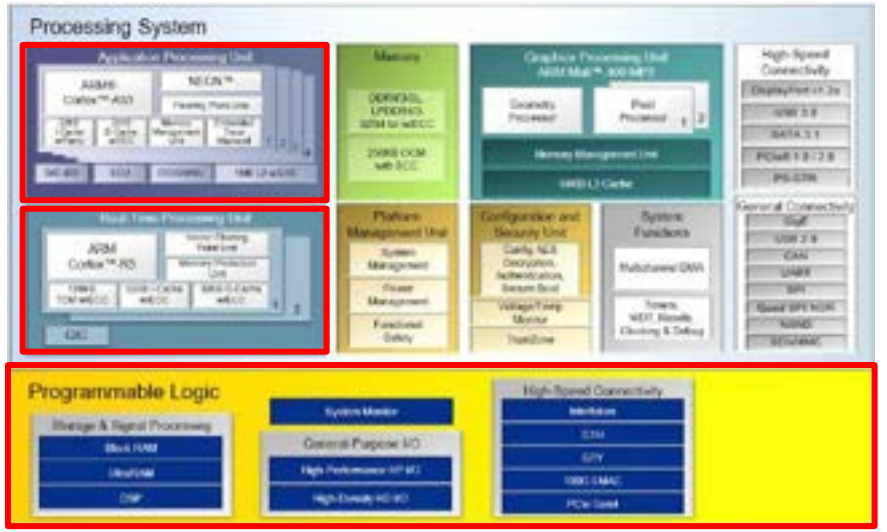
Why MPSoC?

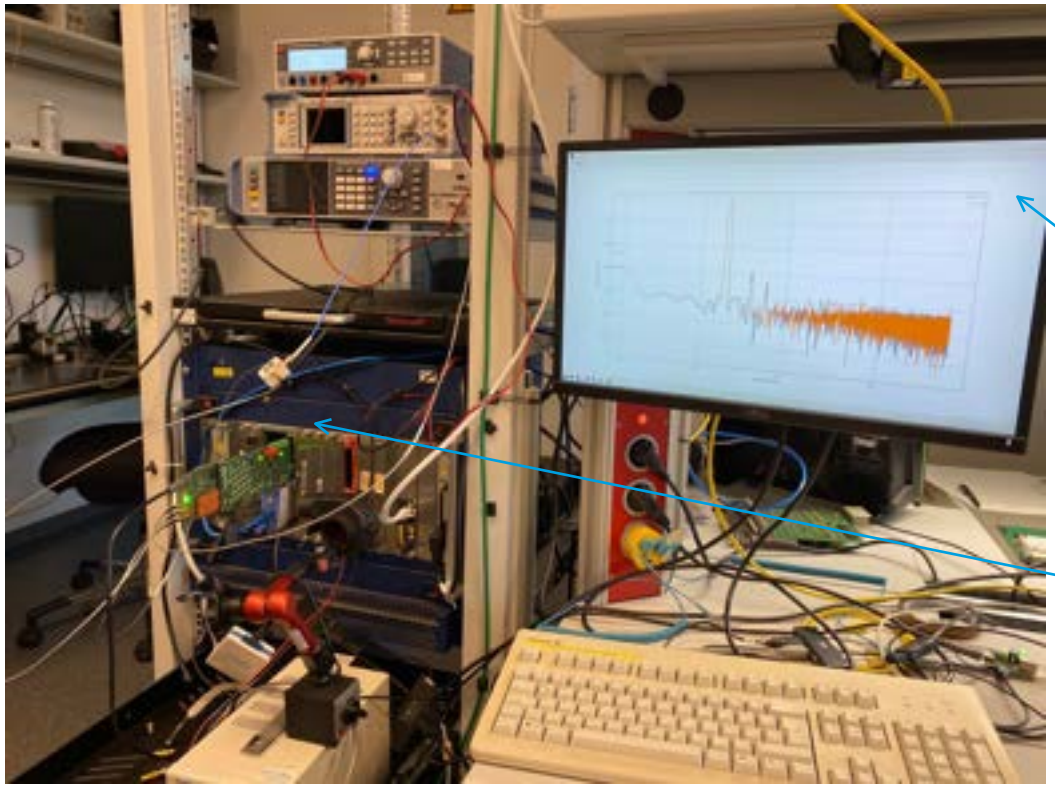
Similarity 2: Processor inside FPGA

- 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



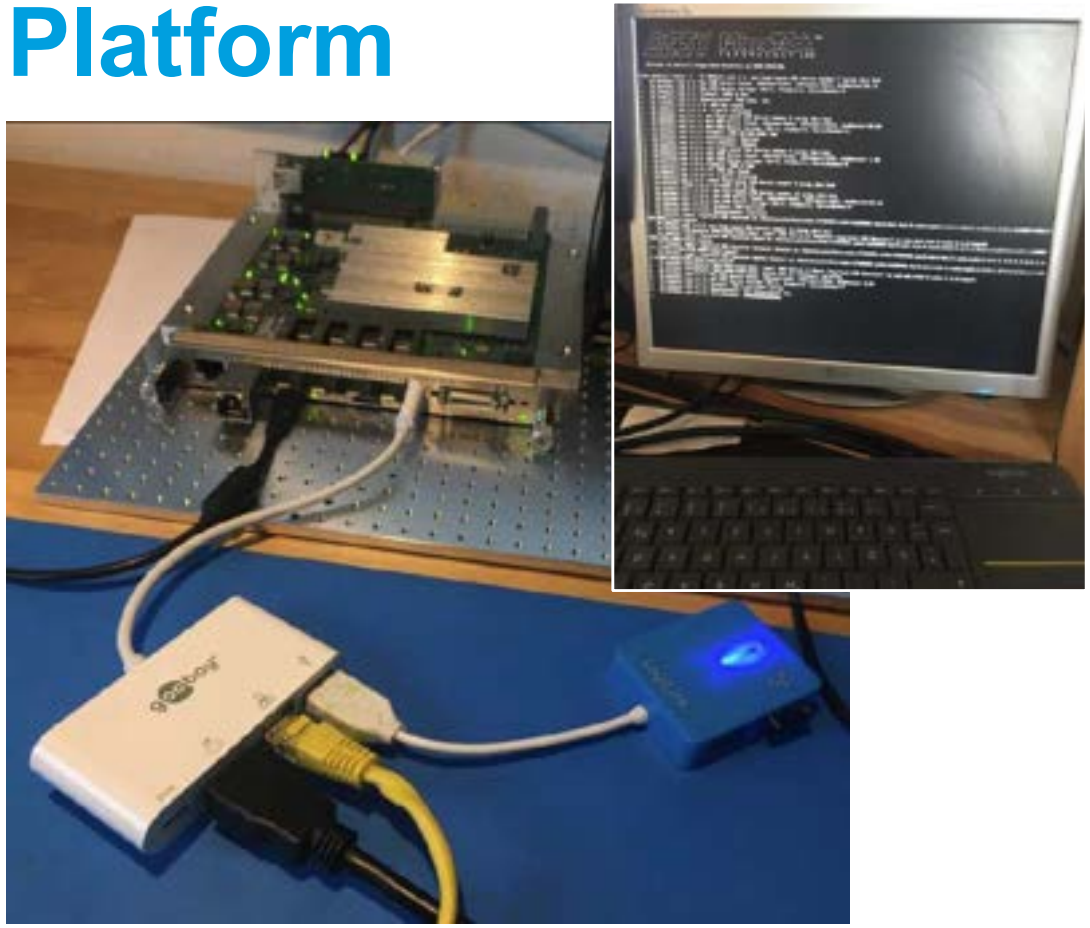




Courtesy of J. Marjanovic and S. Farina

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

Processor-centric Platform



https://www.delock.de/produkt/87297/merkmale.html?g=1107

- In the future there will be no more high-end FPGAs without a processor
- Magic is invisible at first glance
- From the outside: Micro-SD slot, USB-C port

- From the inside:
  - “Big” ARM Cortex-A53 processor
  - Dual or quad core CPU up to 1.5GHz per core
  - Board runs Yocto Linux
  - USB-C connection enables complete PC functionality
  - Display via HDMI
  - USB for keyboard, mouse and USB sticks
  - Ethernet connection
  - FPGA can be fully managed processor

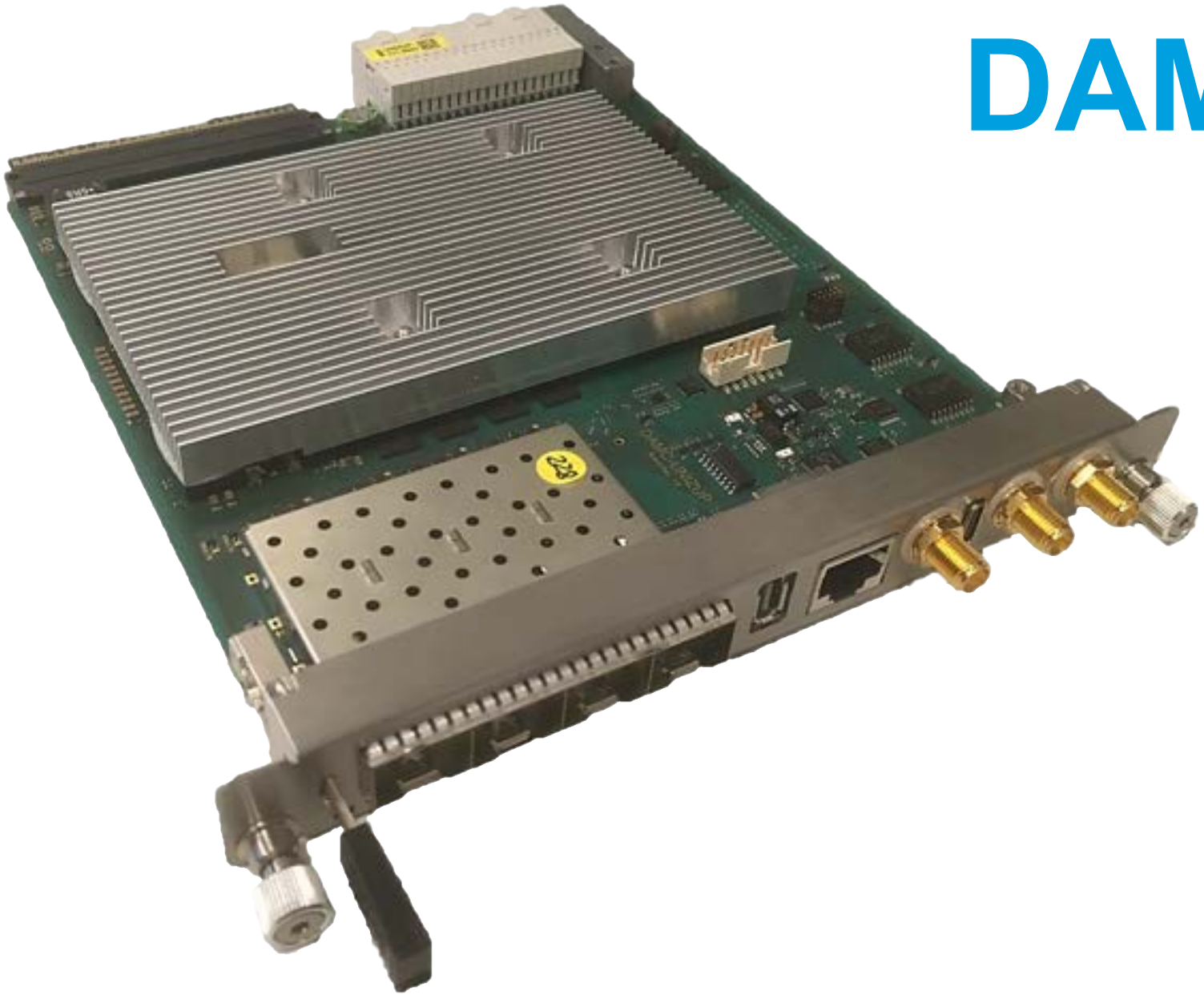
- PCIe Root complex: Board can replace entire CPU module (depending on computing power requirements)

openembedded

yocto PROJECT

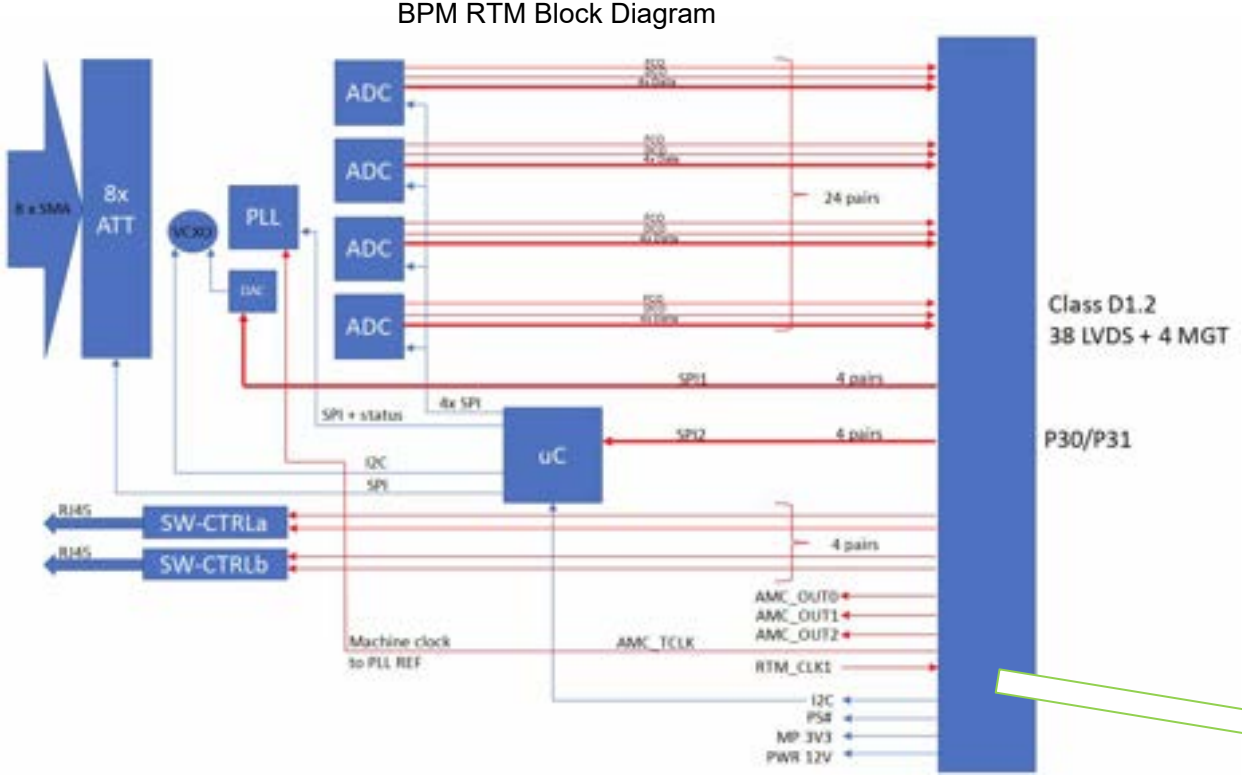
DESY.

DAMC-UNIZUP



Motivation

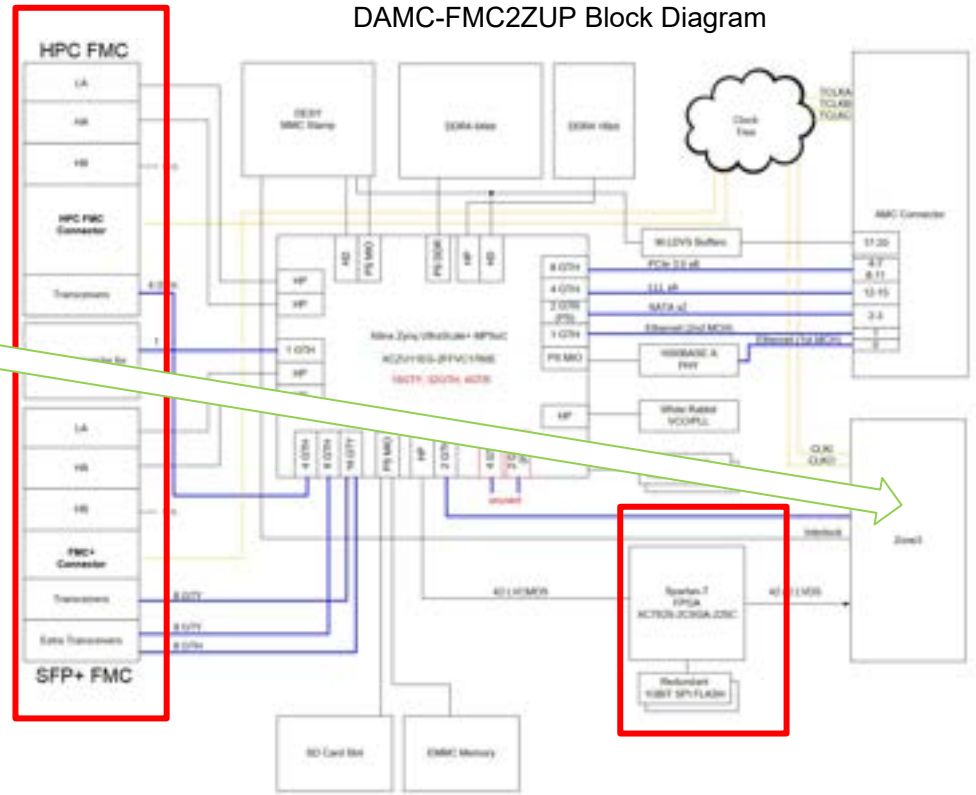
BPM RTM Block Diagram



Courtesy of I-Tech

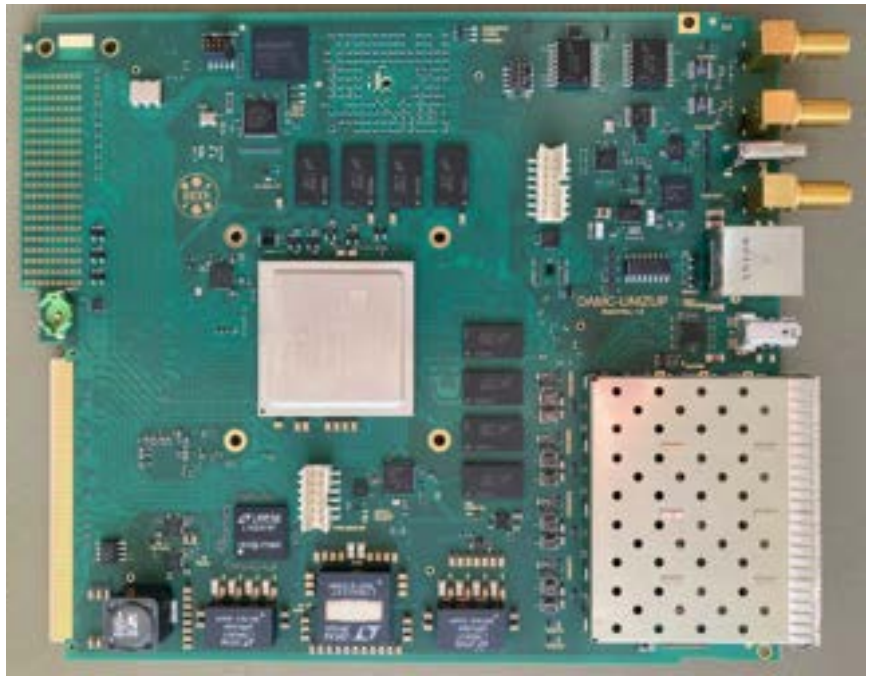
- Upcoming „Petra IV“ light source will need BPM System
- Will be developed by I-TECH, shall be in MicroTCA Modular approach: RTM from I-TECH RTM plus universal digital front board → which AMC to choose?
- DAMC-FMC2ZUP was used for prototyping, but...

DAMC-FMC2ZUP Block Diagram



- Dual-FPGA with Spartan-7 based interface is a little over-powered
- FMCs provide flexibility → but application needs fixed SFP+ modules instead
- Central FPGA has no direct access to RTM

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)

“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:

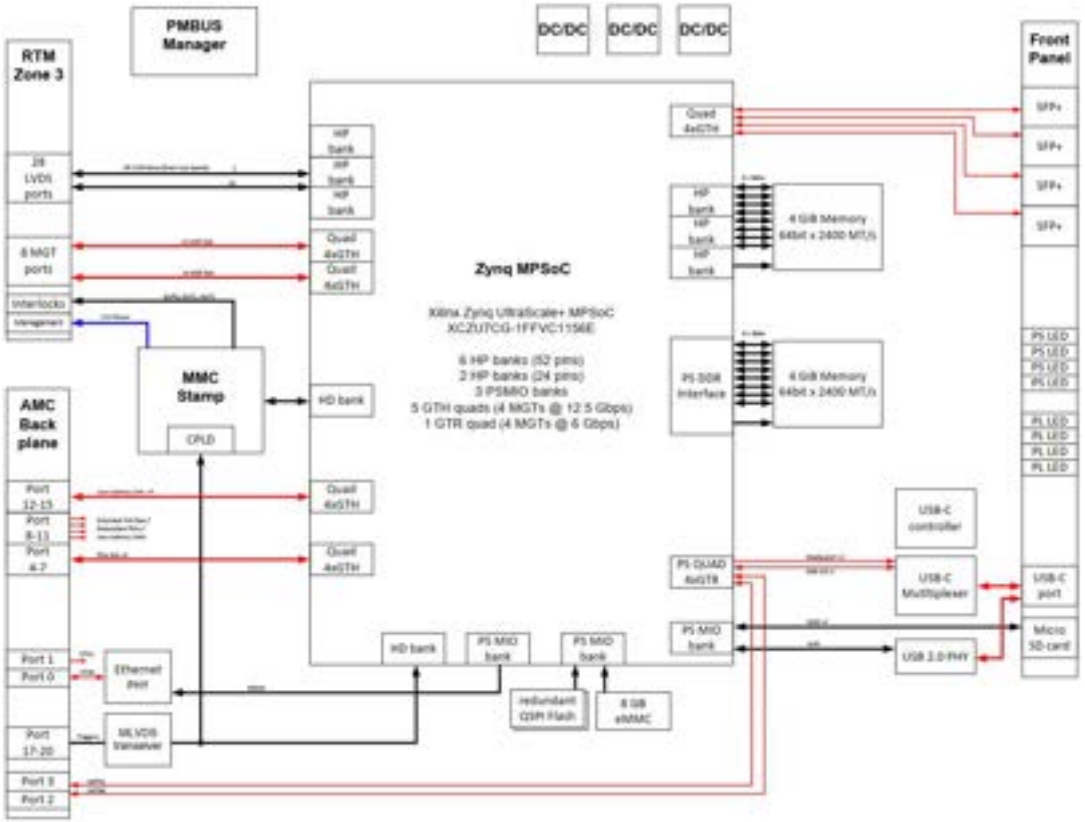
- **2 x 64bit wide** DDR4 interfaces (in total 8GiB RAM)
- **4 integrated SFP+** slots with 16.375 Gbps (not 28 Gbps GTY)
- Connectors for “**slow trigger”** (RS485 for machine protection) and **“fast trigger”** on Front Panel
- 2 Front panel clock inputs via SMA, 1 Output

DESY.

DAMC-UNIZUP

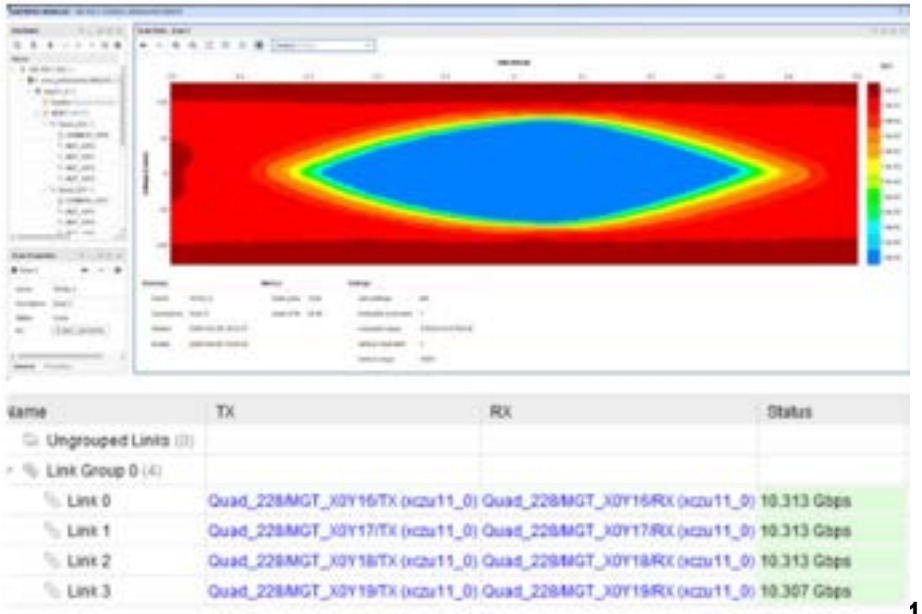
Board was designed specifically for high-bandwidth RTM-Applications

- First 3 prototypes built
- Perfect results in Rev. 1.0, all tests 100% positive, 100% specified performance
- RTM Class D1.2 or D1.3 connectivity to MPSoC (assembly option)
  - D1.2: **38 LVDS** pairs and **4 MGTs** → e.g.. parallel ADCs on RTM (I-TECH)
  - D1.3: **28 LVDS** pairs and **8 MGTs** → e.g. serial JESD204B ADCs on RTM



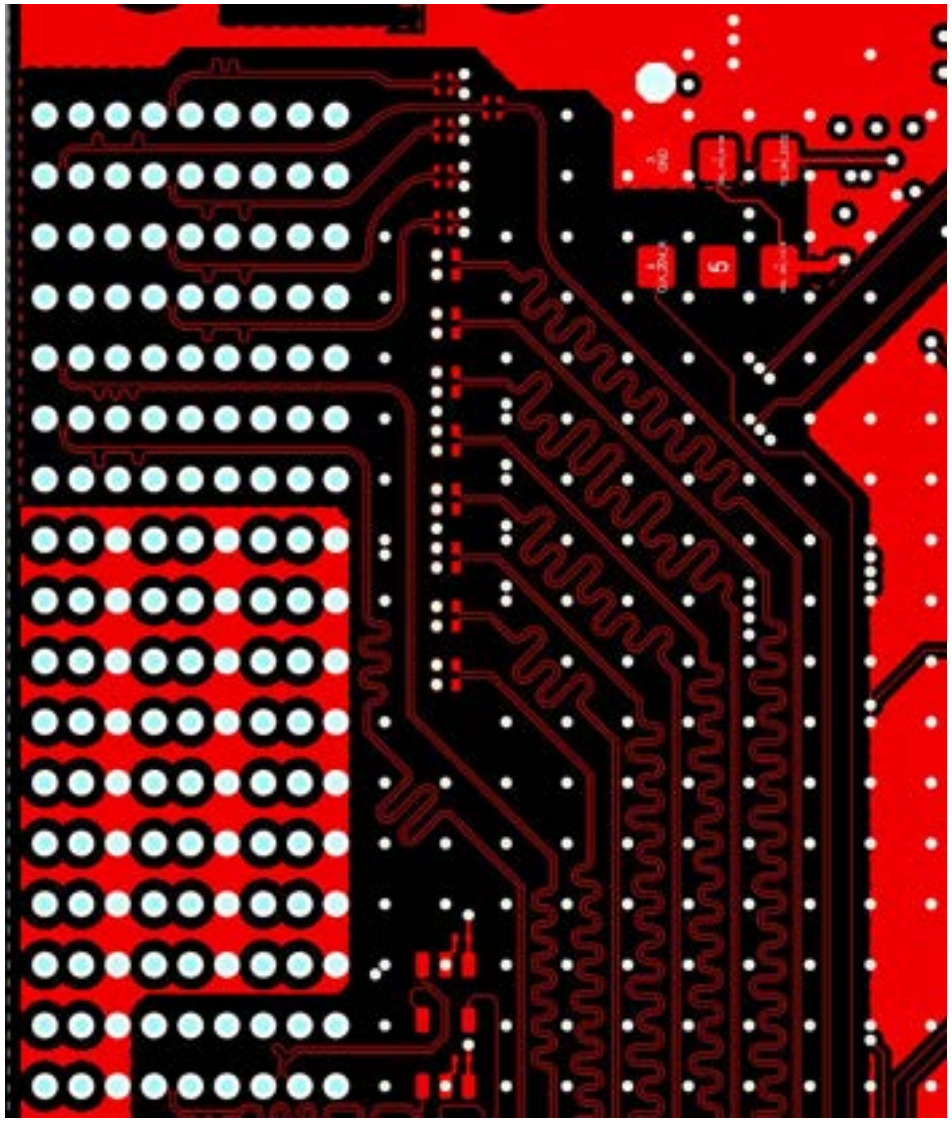
DAMC-UNIZUP Block Diagram

Perfect SFP+ eye diagram:

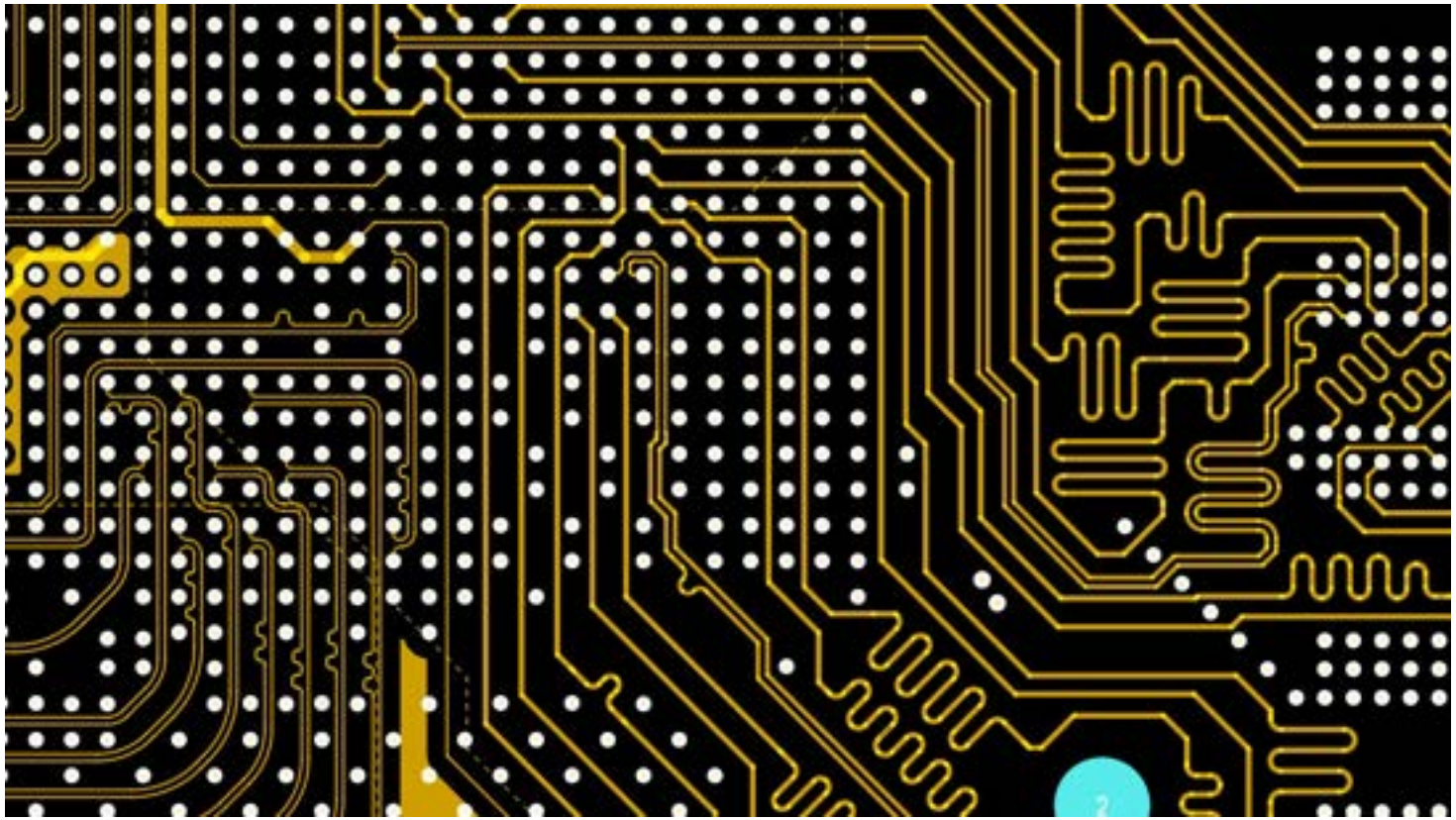


Layout-Details

Nothing is trivial, everything is fast



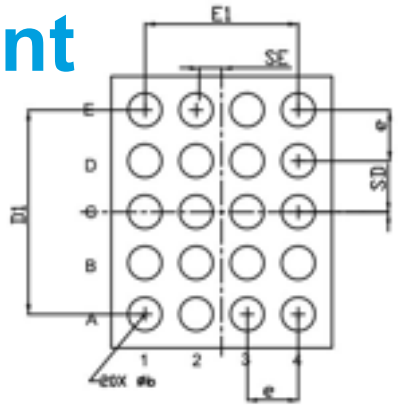
- 14 layers, 2729 components, 10030 pads, 6217 vias, 76216 tracks
- Challenge: “wide” 100µm technology, no HDI (only complete “through” vias)
- LVDS: 1250 Mbps (625 MHz): DDR4: 2666 MT/s (1.3 GHz), Serial Transceivers (MGTs): 16.375 Gbps
- Almost everything in the layout is designed “rounded off”
- 100% length compensation (usually better 1ps / 0.15mm)
- Via in Pads, “GSS-Vias”, taking into account the stub length per layer
- Sandwich structure: SIG-GND-SIG-GND ... Power, Power, ... GND, SIG

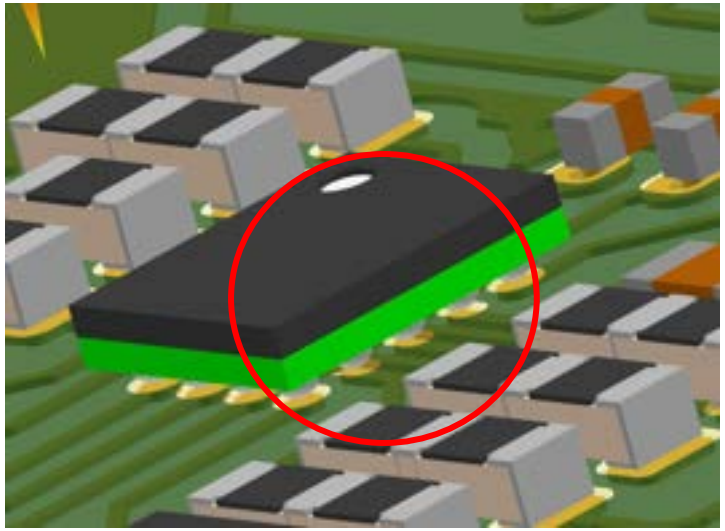


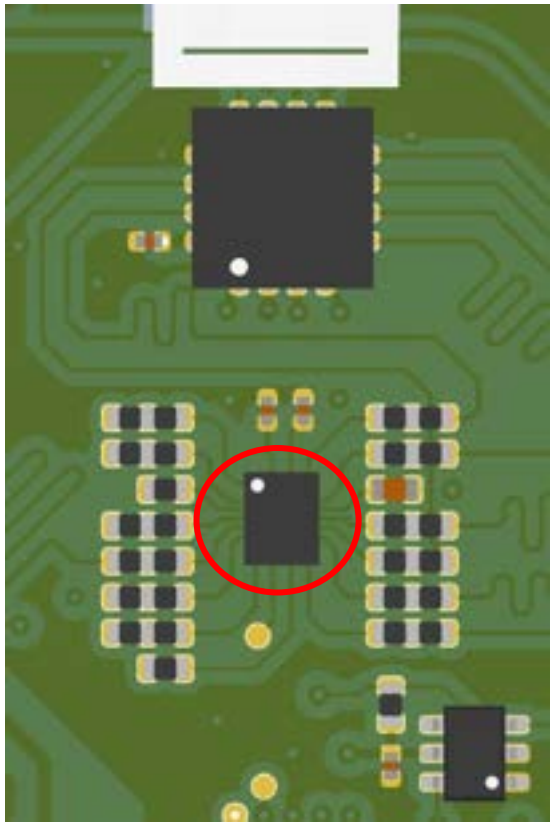
Board was testbed for new Component

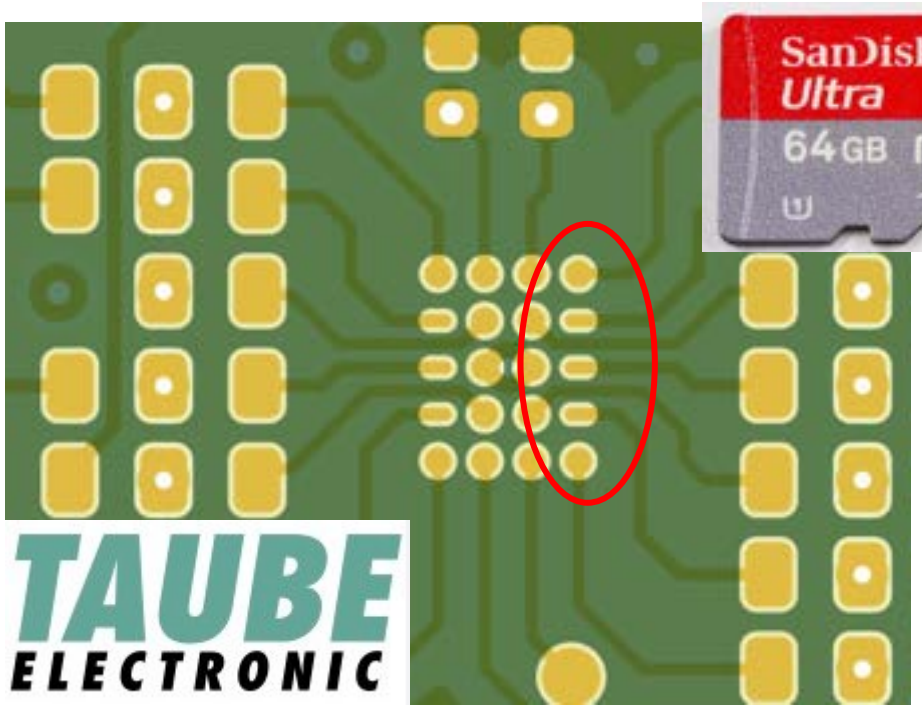
Challenge: PI4ULS3V4857GEAEX SD 3.0 Translator

- Bidirectional level converter with variable voltage required (SD3.0)
- BGA pitch: 0.4mm (only “cell phone components” on market)
- Impossible to route in 100um technology (0.8mm pitch required)
- Approach: “Shave the pads” and hope it works
- Reward: 100 Megabytes per second SD card transfer rate (depending on card)
- Common Components strategy:
  This block will be re-used for all other new boards







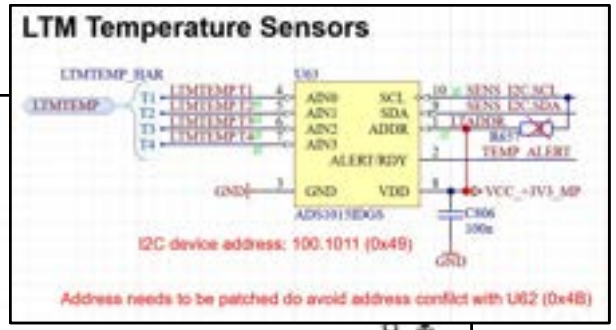



```
 root@UNIZUP-001  ~  dd if=/dev/zero of=./TestingFile bs=100M count=10 oflag=direct
10+0 records in
10+0 records out
1048576000 bytes (1.0 GB, 1000 MiB) copied, 17.2029 s, 61.0 MB/s
 root@UNIZUP-001  ~  dd if=./TestingFile of=/dev/null bs=100M count=10 oflag=dsync
10+0 records in
10+0 records out
1048576000 bytes (1.0 GB, 1000 MiB) copied, 11.2052 s, 93.6 MB/s
 root@UNIZUP-001  ~
```

Quality Strategy

What we have achieved...

- Very proud of our team achievements during last years
- All SoC prototype boards achieved 100% functionality and performance in first revision, mostly without any patch wire
- Shared component database (Altium Vault) with 4-eye-checks on each component
- „Common Building Blocks“ strategy (all boards share pages)
- „Design Input Review“, „Design Output Review“
- 100% Issue tracking in Redmine (we track „everything“)
- Complete patch documentation in schematics (only a few....)
- All design data storage with *git*
- DESY has it‘s own on-premise *gitlab* server



REDMINE
flexible project management

Estimated time: 0.00 Spent time: 0.00

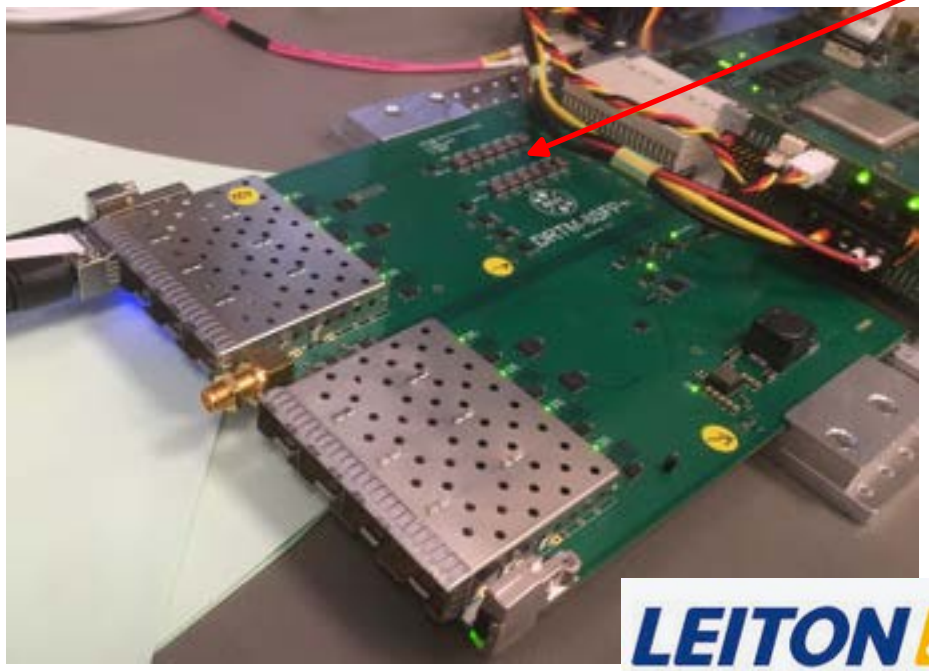
#	TRACKER	STATUS	PRIORITY	SUBJECT	ASSIGNEE	UPDATED	PROJECT
13007	Bug	New	Normal	Front Panel: Lightpipes do not fit into holes		2024-04-04 14:59	DAMC-UNIZUP
12978	Improvement	New	Normal	Fast trigger connector should be moved		2024-03-22 19:02	DAMC-UNIZUP
12977	Improvement	New	Normal	Front Panel: Fast Trigger hole is not shaped nicely		2024-04-04 15:00	DAMC-UNIZUP
12976	Bug	New	Normal	SMA connectors are mounted too colse to front...		2024-03-22 19:00	DAMC-UNIZUP
12975	Bug	New	Normal	Front Panel: SMA holes are too small		2024-04-04 15:00	DAMC-UNIZUP
12950	Bug	New	Normal	SELTCLKABRTM must not be push-pull driven		2024-03-14 18:54	DAMC-UNIZUP
12949	Improvement	New	Normal	Front Pannel can be improved		2024-03-14 18:48	DAMC-UNIZUP
12948	Bug	New	Normal	SMA connectors too close to front panel		2024-03-14 14:14	DAMC-UNIZUP
12915	Improvement	New	Normal	Increase eMMC from 8GB to 16GB		2024-03-08 17:01	DAMC-UNIZUP
12913	Improvement	New	Normal	Review USB capacitors		2024-03-08 11:09	DAMC-UNIZUP
12903	Bug	New	Normal	Board temperature sensors in wrong place		2024-03-06 17:04	DAMC-UNIZUP
12893	Improvement	New	Normal	Typo in Schematics on page 26		2024-03-05 17:11	DAMC-UNIZUP
12886	Implementation	New	Normal	SD2.0 Translator can be set to DNF in Rev. 2.0		2024-03-01 18:57	DAMC-UNIZUP
12877	Bug	New	Normal	Wrong net names on Zone 3 OUT buffer		2024-02-28 19:28	DAMC-UNIZUP
12875	Implementation	New	Normal	LTC6957IMS-2 is EOL		2024-02-28 16:32	DAMC-UNIZUP
12858	Improvement	New	Normal	5V Power increase request		2024-02-23 22:43	DAMC-UNIZUP
12857	Bug	New	Normal	Power switchoff with Certain USB-C docks		2024-02-23 22:22	DAMC-UNIZUP
12849	Improvement	New	Normal	Better P/N matching on DDR4 Datastrobe		2024-02-23 22:23	DAMC-UNIZUP
12846	Improvement	New	Normal	Better PMBUS connector location requested		2024-02-23 22:44	DAMC-UNIZUP
12845	Improvement	New	Normal	SD Buffer footprint improvement for mass-pro...		2024-02-23 22:23	DAMC-UNIZUP
12843	Improvement	New	Normal	DESY Logo is partially covered by heatsink		2024-02-21 10:37	DAMC-UNIZUP
12842	Improvement	New	Normal	10k PU on SD Card DAT3 line		2024-02-23 22:44	DAMC-UNIZUP
12799	Bug	New	Normal	Unwanted SD card power injection		2024-02-23 22:45	DAMC-UNIZUP
12798	Bug	New	Normal	SD2.0 boot mode is not supported		2024-02-16 23:05	DAMC-UNIZUP
12787	Improvement	New	Normal	SerDes Ethernet Lanes need P/N matching		2024-02-13 09:48	DAMC-UNIZUP

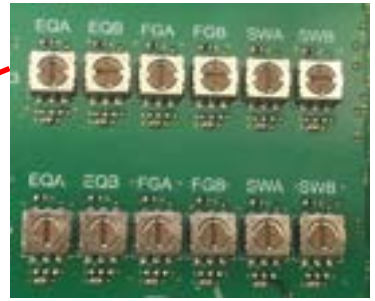
DRTM-8SFP+

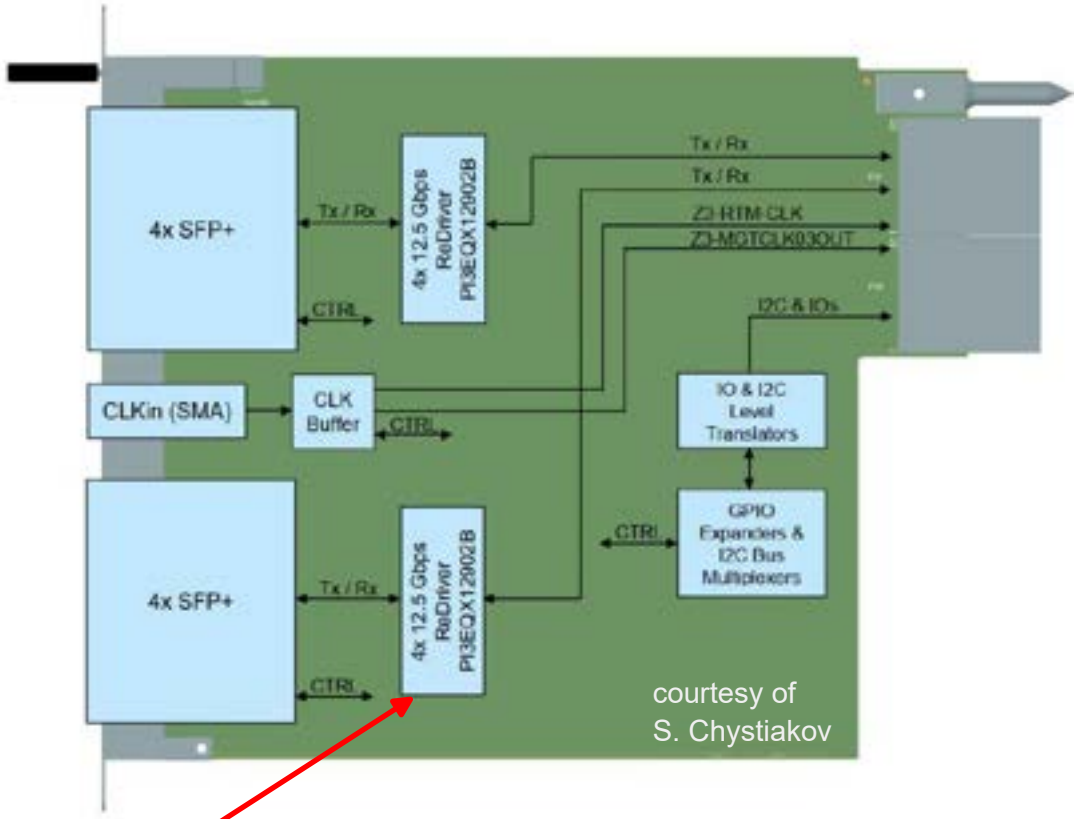
DAMC-8SFP+

Fan-out of MGT Channels from DAMC-UNIZUP

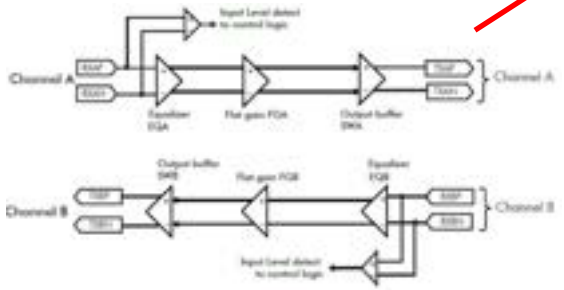
- We needed to verify UNIZUPs 8 MGTs to RTM
- We designed a 8-SFP+ RTM
- Board works on all other Digital Class AMCs
- Brings 1 to 8 MGTs to RTM **12.5 Gbps**: not trivial
- First use of “analog” equalizer
- Development time: 3 months
- Low-cost circuit board and components
- Manufactured in the “**PCB pool**” from Leiton (Berlin)
- Material: Panasonic R-1566W (Dk=0.010 !!!)

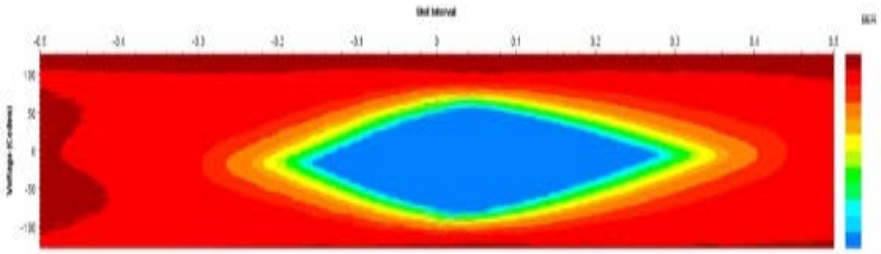


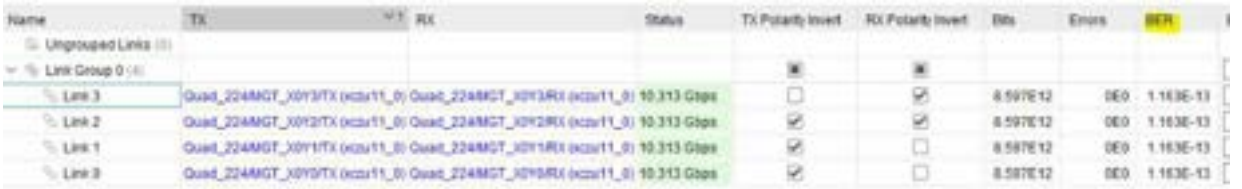




courtesy of
S. Chystiakov







LEITON

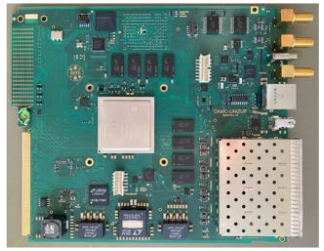
Improving of signal integrity by using a Re-Driver

First use of an analog equalizer

- Super critical RTM MGT routing on DAMC-UNIZUP
- 10.315 Gbps (up to 12.5 Gbps)
- Bad channel:
  - two 0-ohm bridges
  - Erni connector
- “Warning: it doesn’t work” – but it does, *if you do it right*…

PI3EQX12902B: 4 Configurations possible

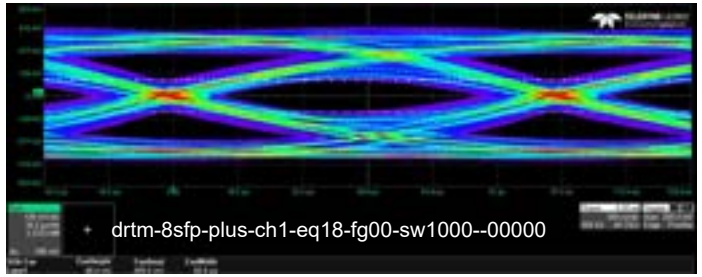
	Equalizer setting (dB)				
	@2.5GHz	@3GHz	@4GHz	@5GHz	@6GHz
1	1.8	2.6	4.5	6.6	8.9
2	3.7	4.7	6.7	9.4	11.7 (Default)
3	5.1	6.3	8.7	11.2	13.5
4	6.8	8.2	10.8	13.2	15.3



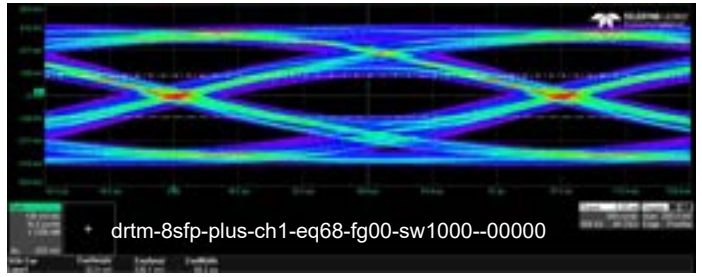
https://www.erni.com/de/produkte-und-loesungen/steckverbinder/ermet-zd-steckverbinder

DAMC-UNIZUP RTM Class D1.3 verification successful!

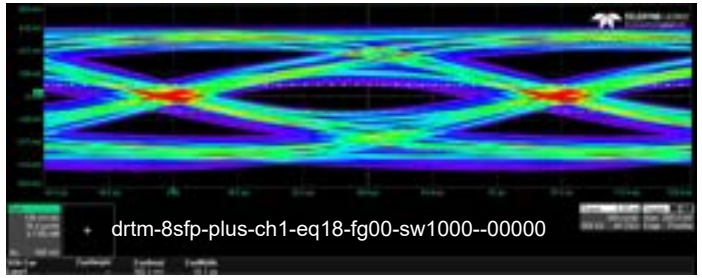
Good channel: 5 GHz: +6.6dB



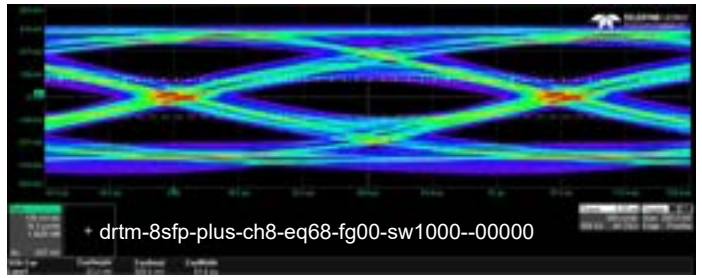
Good channel: 5 GHz: +13.2dB



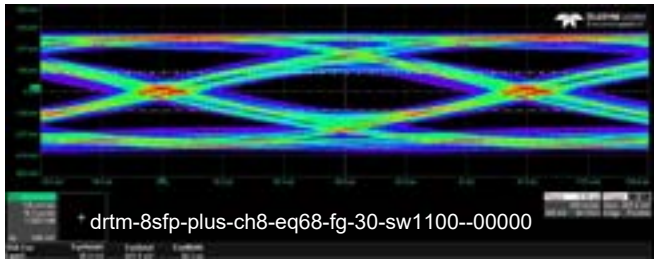
Bad channel: 5 GHz: +6.6dB



Bad channel: 5 GHz: +13.2dB



Bad channel,
13.2dB, 1100mV Level, -3.0dB “flat gain”



We invite everybody to be part of the MicroTCA ecosystem

What we can offer...

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

MicroTCA.4 Template

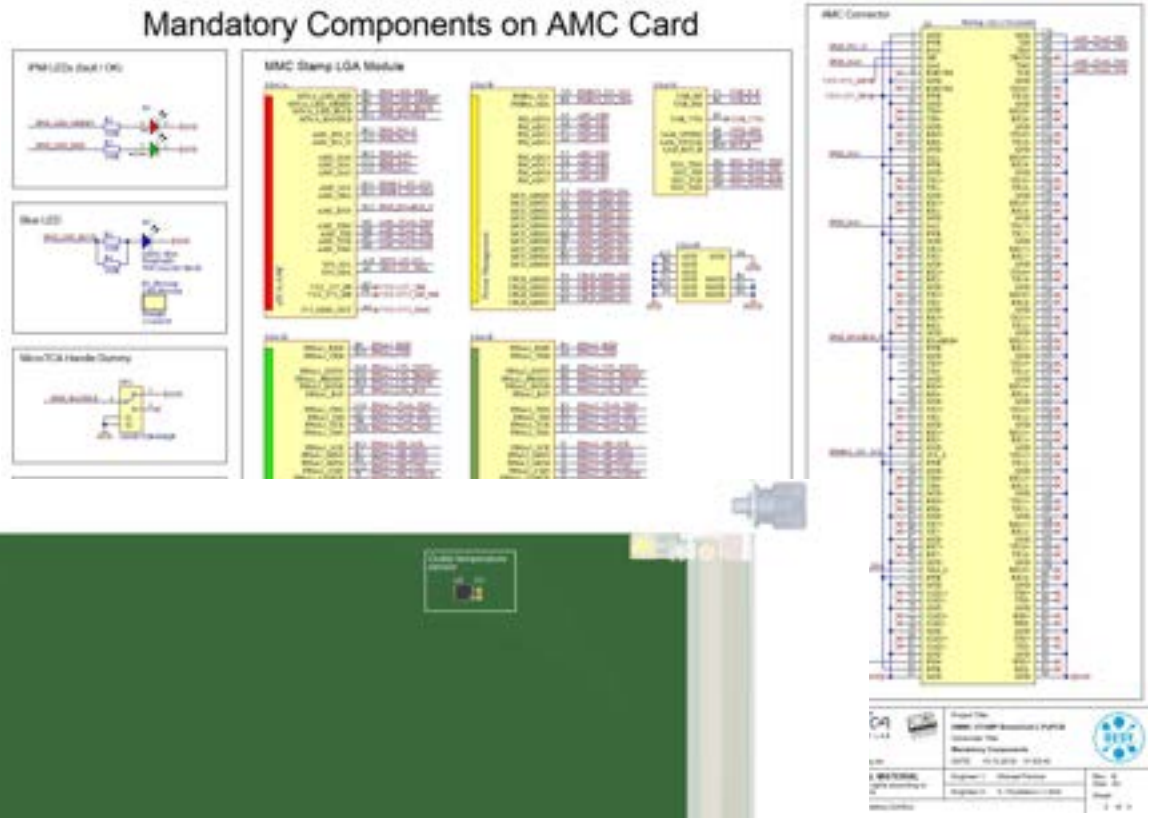
Community Support

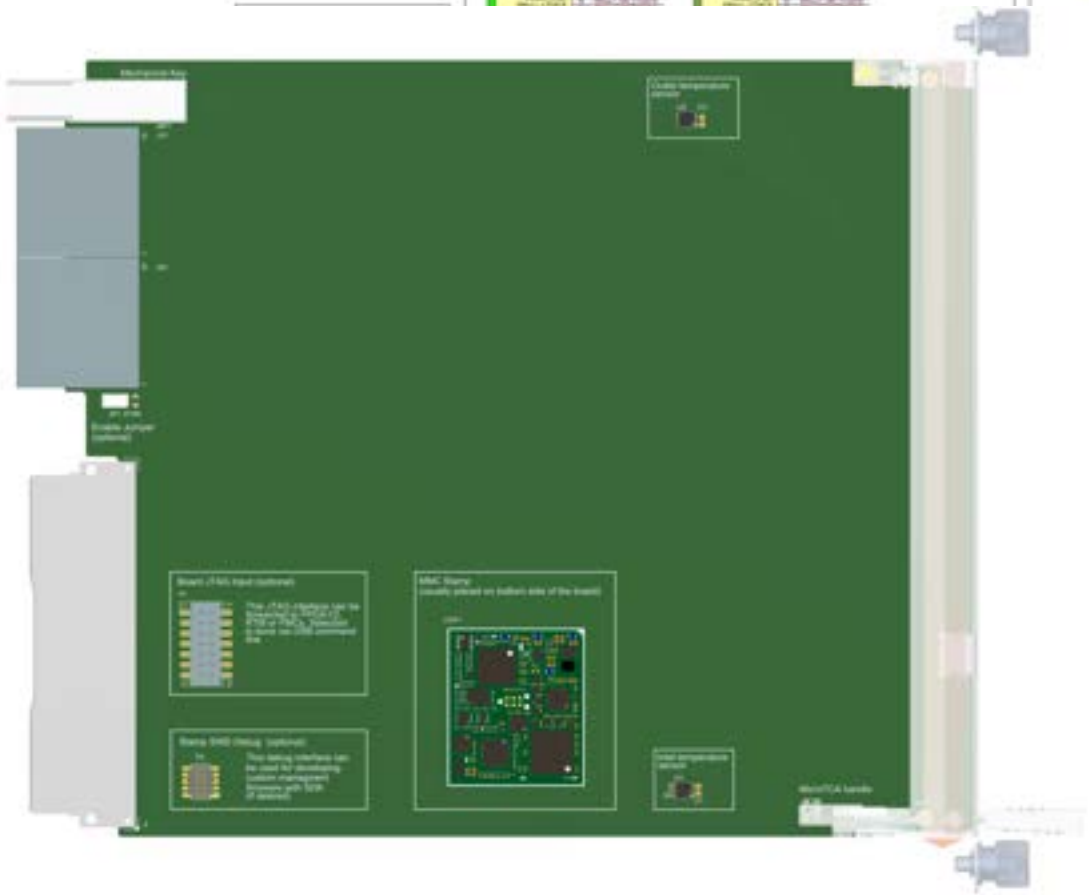
Idea: Jump-Start with MicroTCA as you would with any other board

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



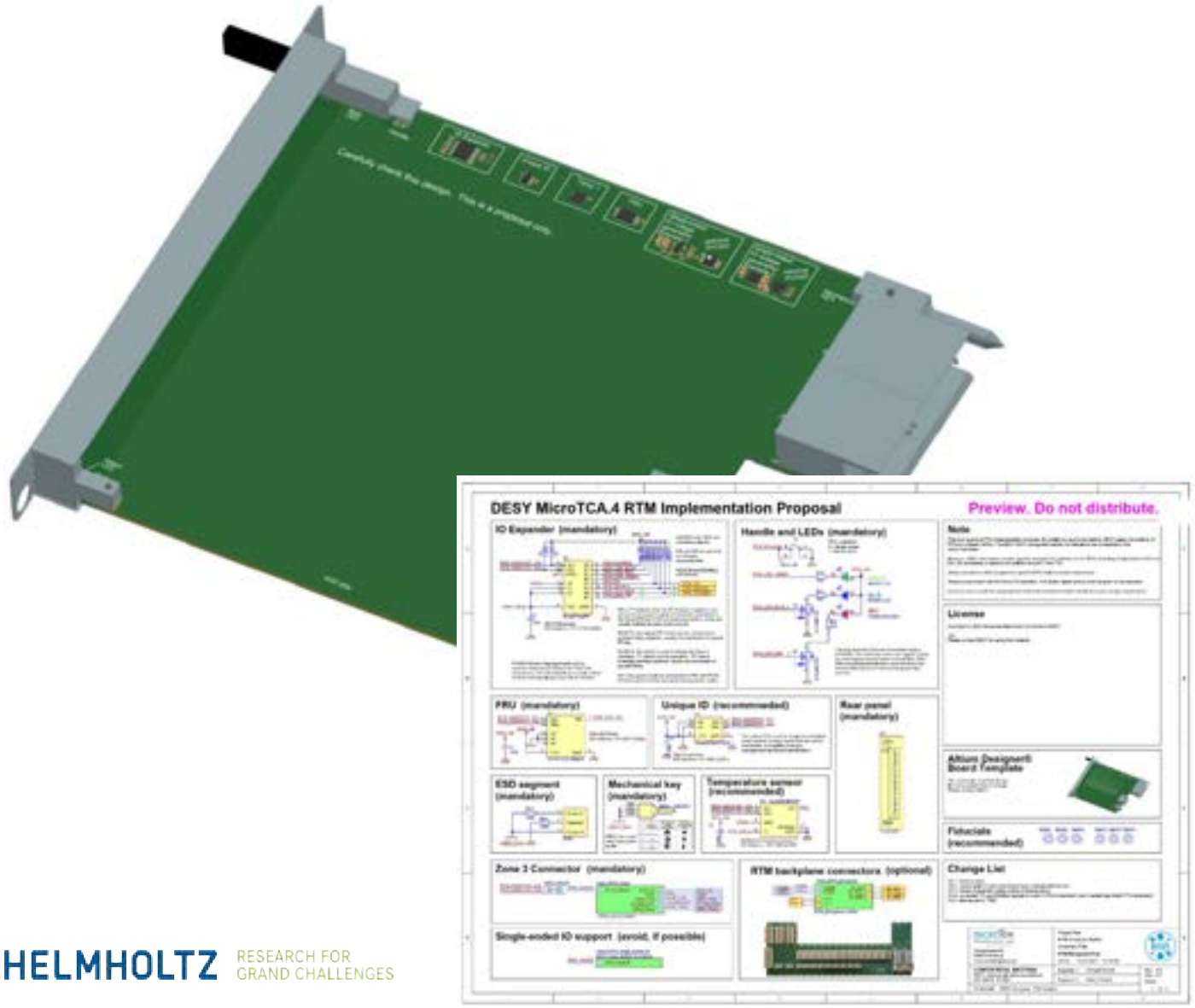


HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

RTM Template

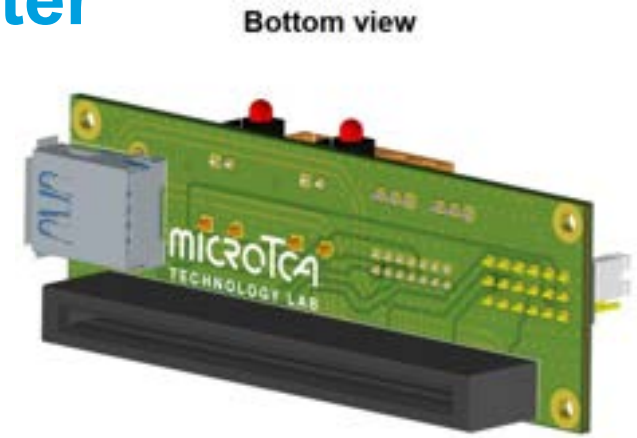
Community Support

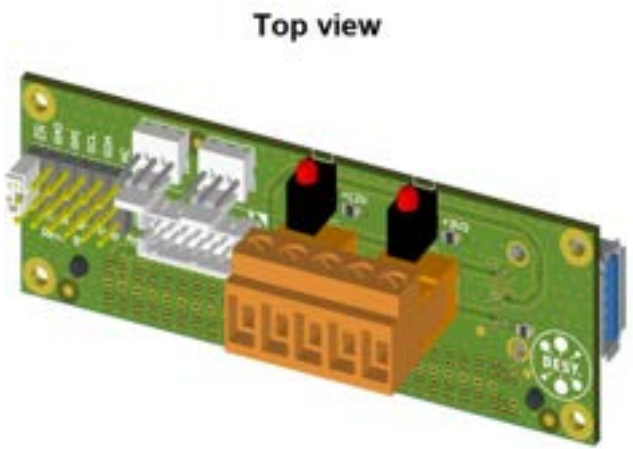


- We also provide a RTM Template
- Complete guide and “empty board” for own MTCA RTM designs → Altium Designer Template
- MTCA Standard leaves freedom for RTM interface implementation (vendor-specific) → risk of non-interchangeable AMC-RTM pairs
- DESY has a “class concept” → Interchangeable boards
-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

Tools: MicroTCA Bring-up Adapter

Community Support





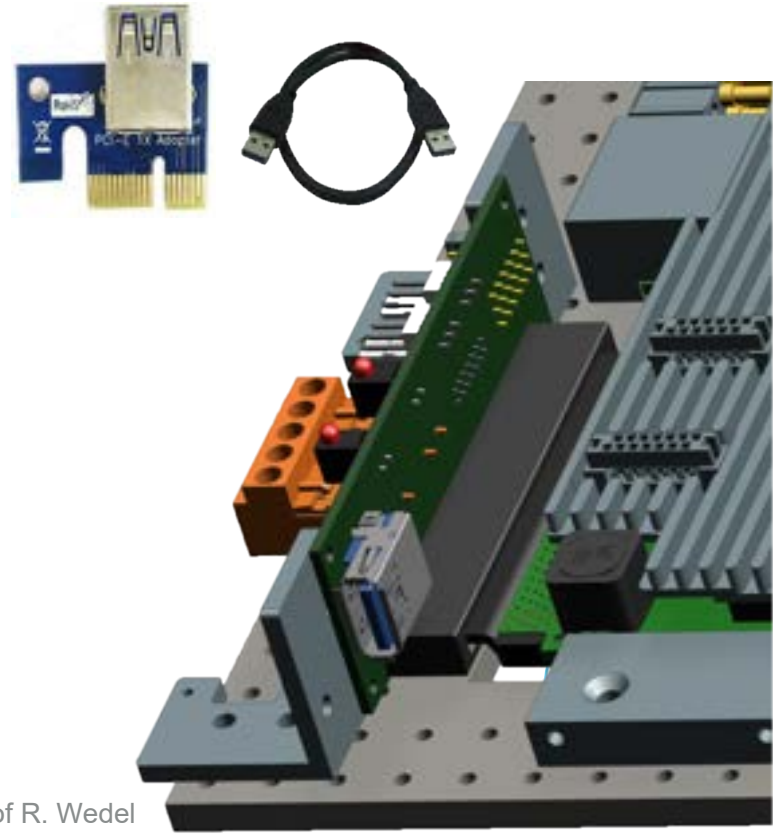
- Allows to connect power **and PCIe** to boards on the bench
- Mechanically compatible with RTMs
- PCIe option allows operate a MTCA board “inside a PC”

https://rk.edu.pl/en/risers-and-adapters-non-standard-gpu-connection/

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.



courtesy of R. Wedel

Thank you!

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

Contact

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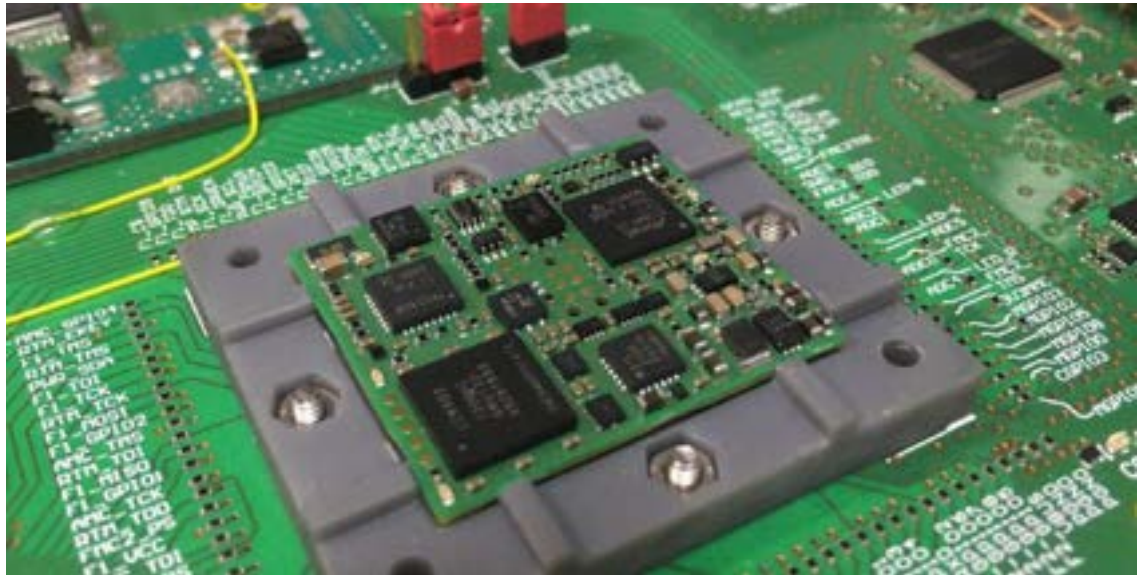
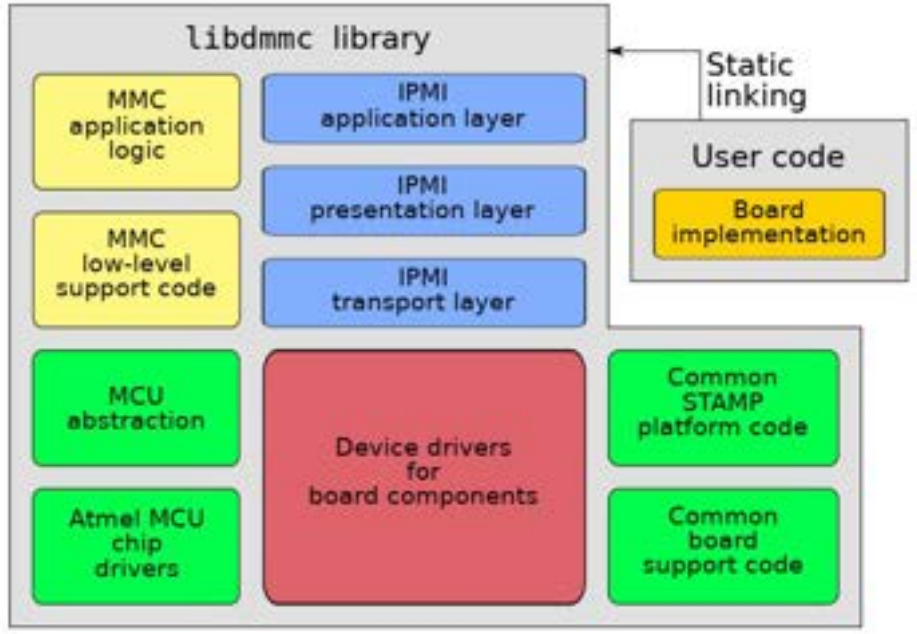
Backup

DMMC-STAMP

- 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



Post-Production test of DMMC-STAMP



Courtesy of Patrick Huesmann

DMMC-STAMP BoB (Break-out-Board)