RTM Backplane Extension for the MTCA.4 Standard

From Simple Idea to PICMG Specification

Effort on RF Performance and Documentation

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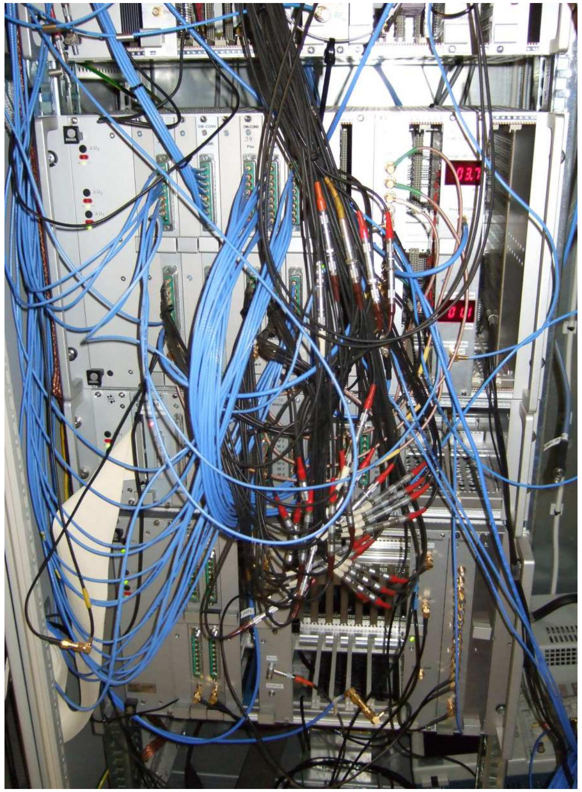
RF Signal Distribution in Multichannel Control Systems

- RF front end require distribution of tens precise LO / CLK / REF signals to RTM and/or AMC cards

- Impedance controlled lines and coax connectors

- Tens of cables hanging in front of the crate very difficult cable management!



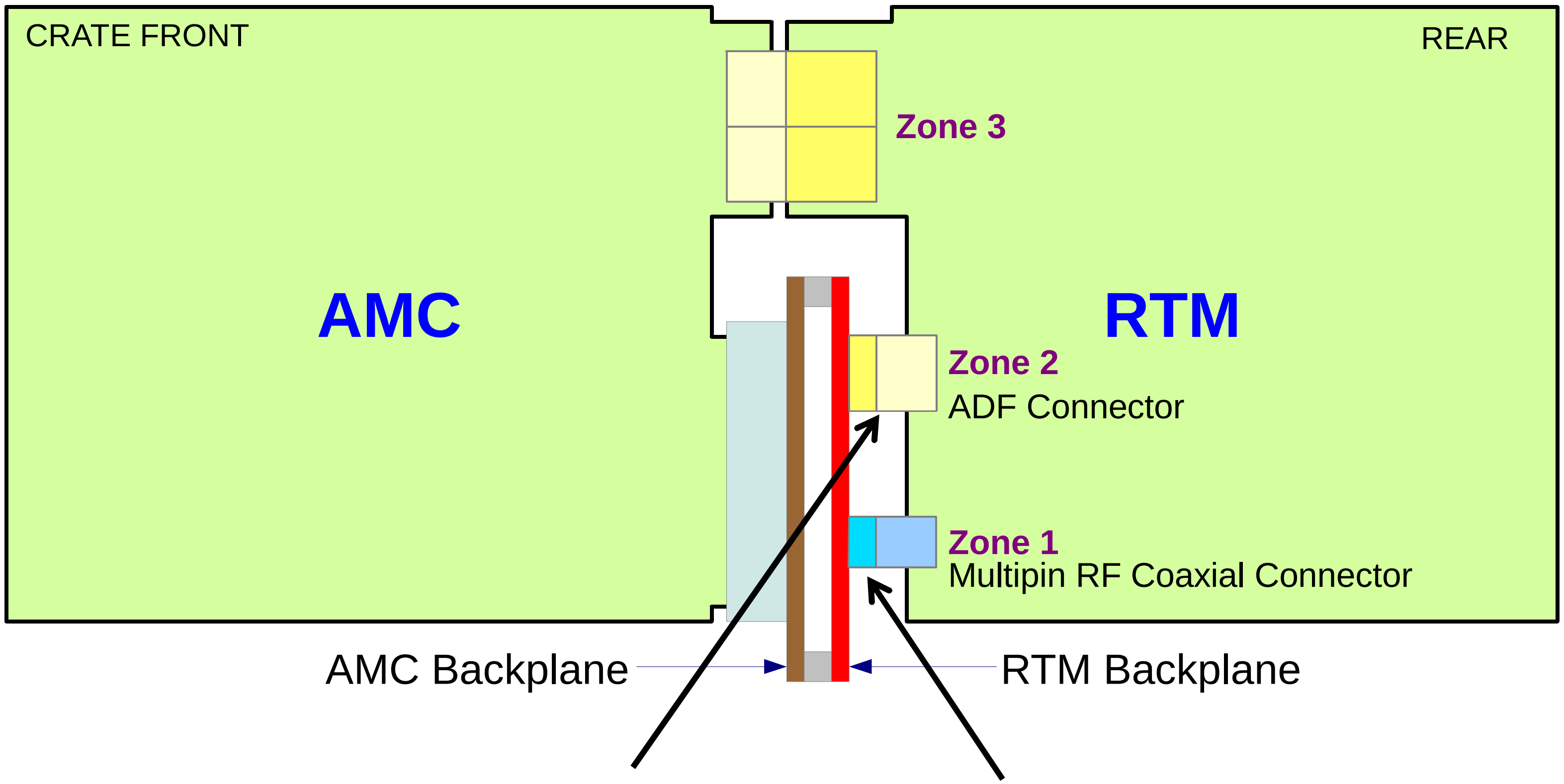
The First Idea: RF Backplane

- Distribute LLRF signals to RTMs in XFEL LLRF Control System
  - LO to downconverters (1354 MHz or other)
  - MO Reference (1300 MHz)
  - Clock (81 MHz)
  - Clean „analog” bipolar power supply
  - Minimize „cable-salad” on the back of the crate
- Improve system reliability
- Easier maintenance: no need to disconnect multiple cables during service

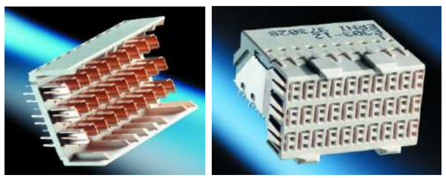
AMC-RTM Pair – RF Backplane Connectors

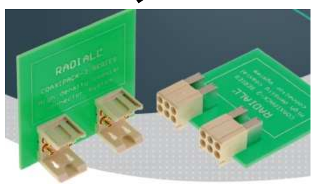
Abbreviation **uRFB** - **u**TCA **RF B**ackplane

In general: RTM Backplane



ERMET ZD,
3x10 diff. pairs

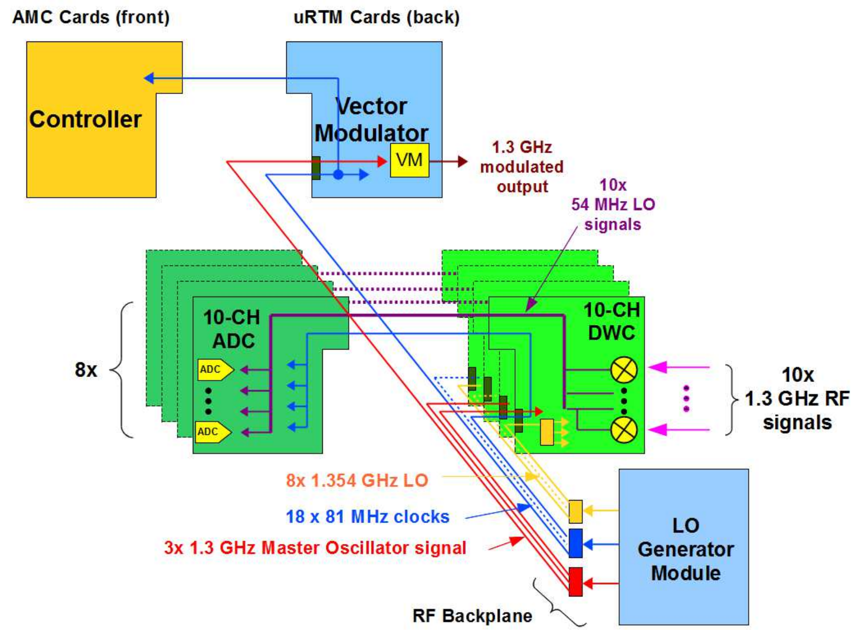


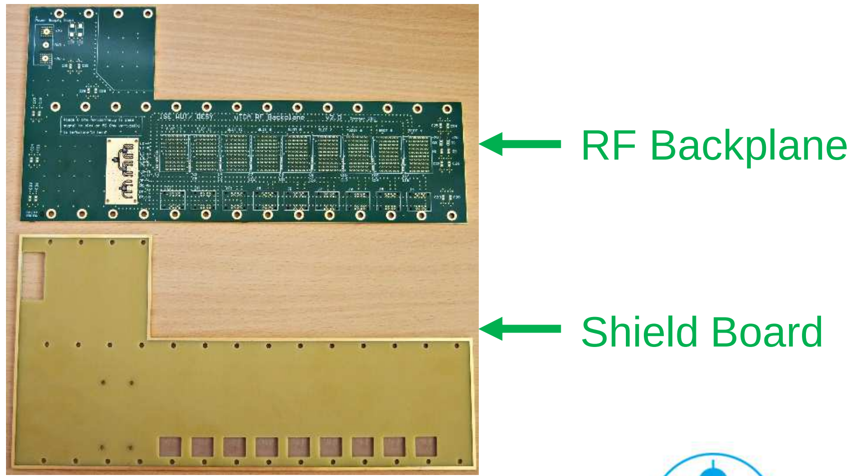


Radiall Coaxipack 2
6-pin, 6GHz RF connectors

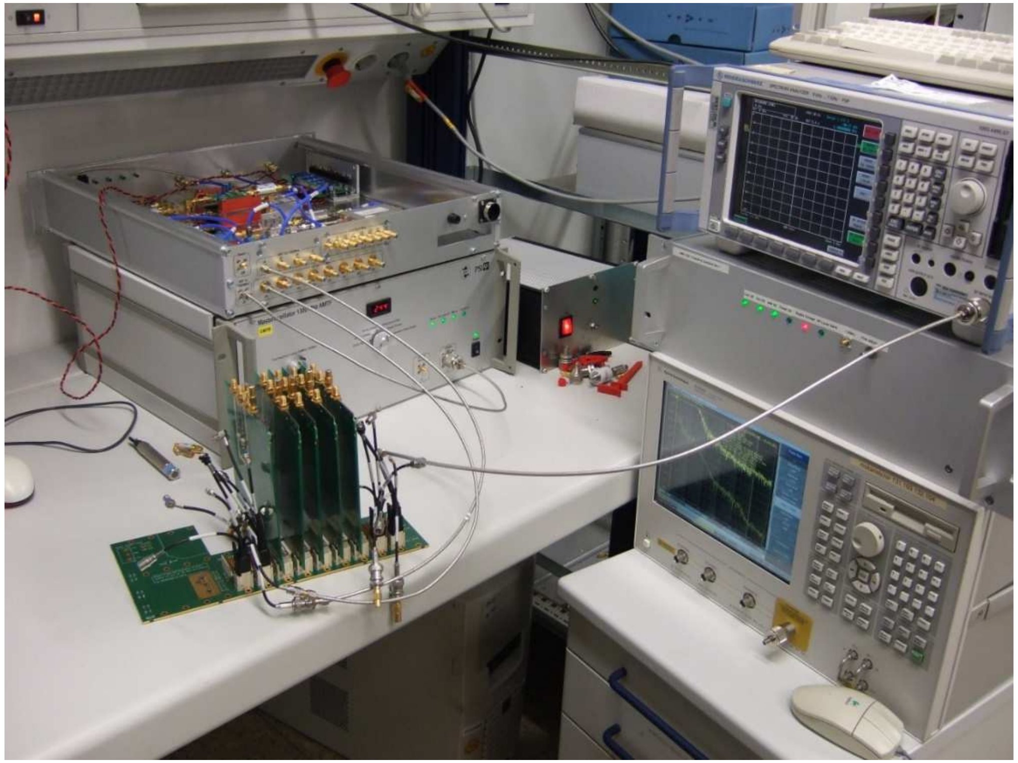
First RF Backplane Version –Assumptions and Problems

- Custom design for XFEL LLRF
- Single input with adapter board
- RF signals distributed to 8 slots
- LO and MO signal power splitting on board (careful RF design)
- 50Ω matching of not used RF signals:
  - manually by putting loads on connectors (dummy load boards)
- EMI protection from the „digital world” (AMC Backplane)





Performance Measurements



Measured

- RF Loss
- Crosstalk
- Phase noise and jitter outside and inside of the crate

- Designed adapter boards for tests
- No detectable signal degradation was observed in the crate (spectrum, jitter)

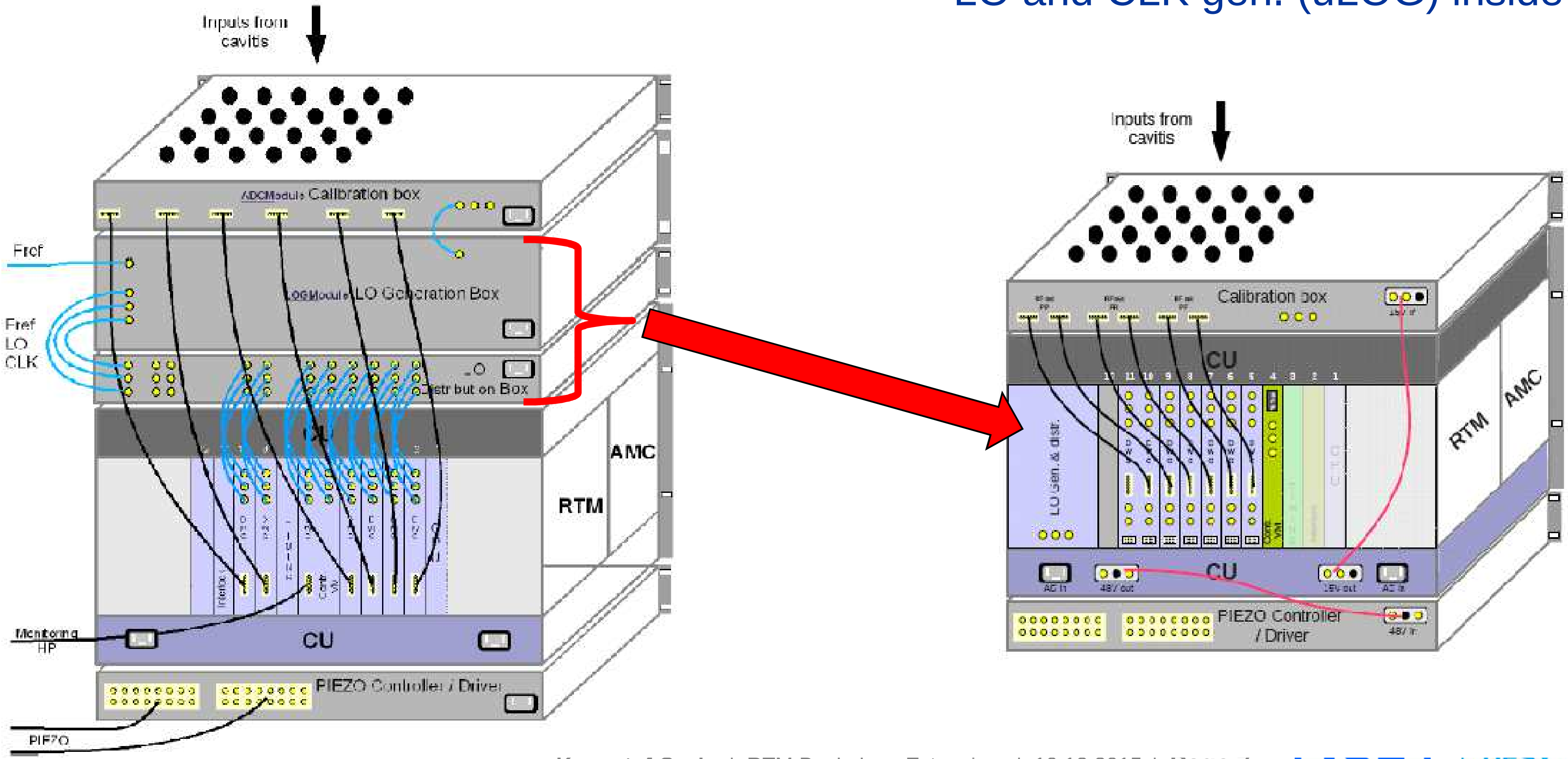
LLRF System Size Reduction

Idea to fit the LO and CLK generation and distribution inside of the MTCA.4 crate

System with signals distributed outside the crate

System with RF Backplane

- Space reduction
- LO and CLK gen. (uLOG) inside



Further Development of RF Backplane Concept

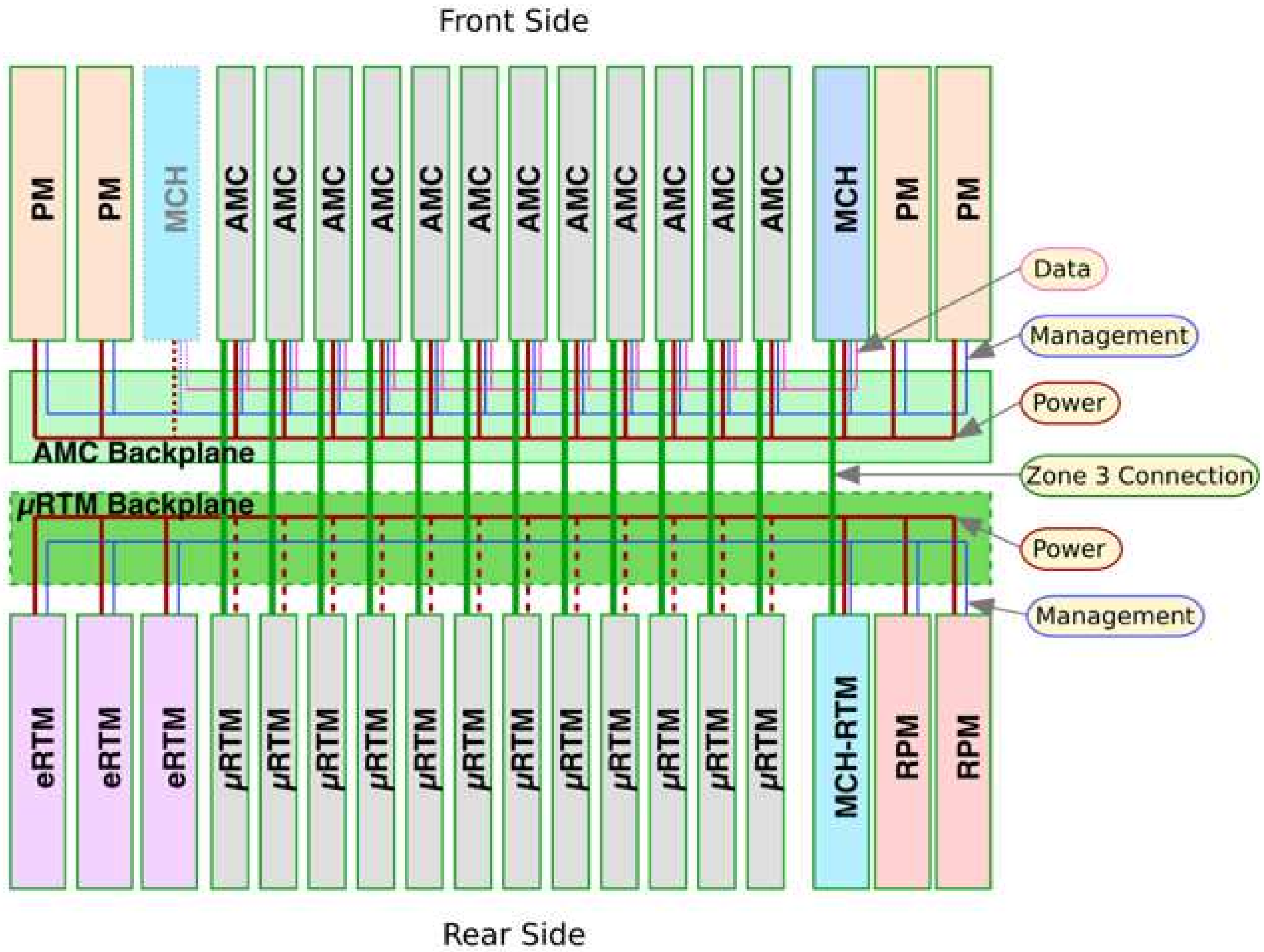
- Slot 15 dedicated for signal entry
- RF signal distribution to all µRTM slots
- Automatic matching of unused RF signals
  - RF hot-plug (probably world's first)
- Empty areas behind front Power Module and MCH used for further extensions of MTCA.4 standard
  - eRTM concept
  - Rear Power Modules for eRTMs and µRTMs
- Necessary to introduce management over the Backplane
- Decided to change the „RF Backplane" to more general „RTM Backplane" name

talk by Vollrath Dirksen

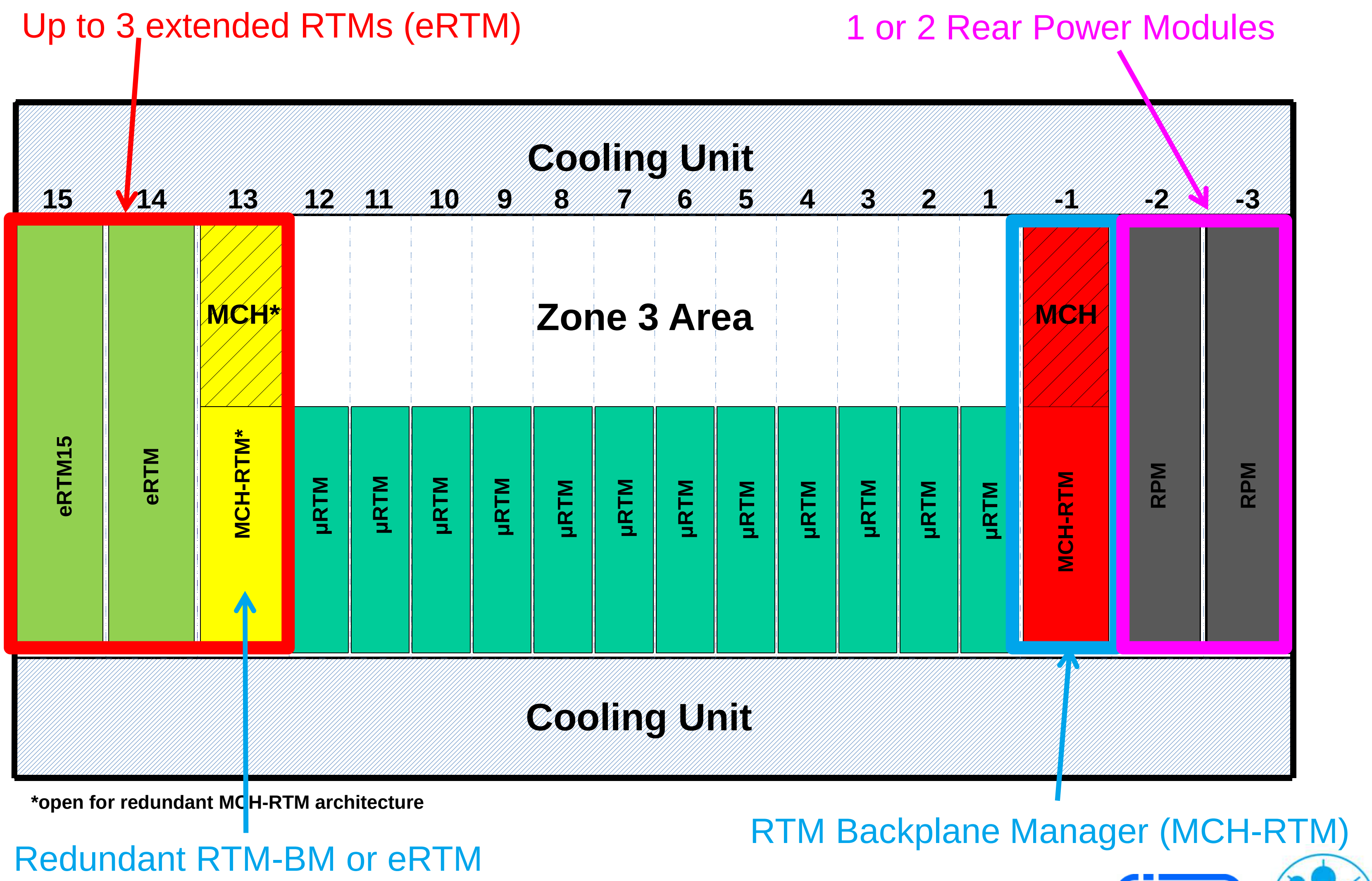
uRFB – Final Concept Highlights

- **Fully compatible to the standard**. No mechanical collision with standard RTM boards. Supported by crate manufacturers
- **Hot swap functionality for RF signals.** IPMI extension for RTM Backplane worked out with N.A.T.
- RTM Backplane is passive. All intelligence in modules -> great flexibility for users
- Developed a concept of extended RTM (eRTM) boards
- Redundant high performance rear power supply for analog applications and additional power for digital RTMs

Slots, eRTMs and Rear Power Supply Modules



Slots, eRTMs and Rear Power Supply Modules – Rear View

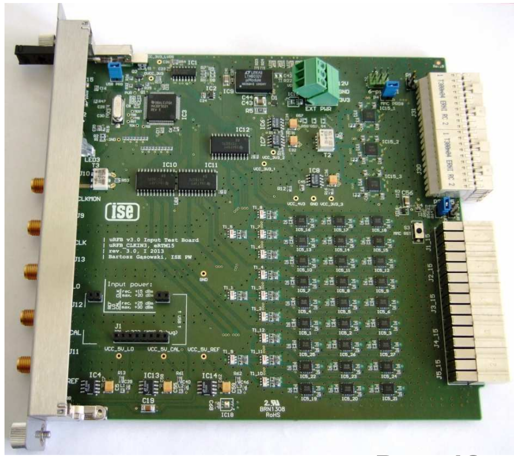


eRTMs

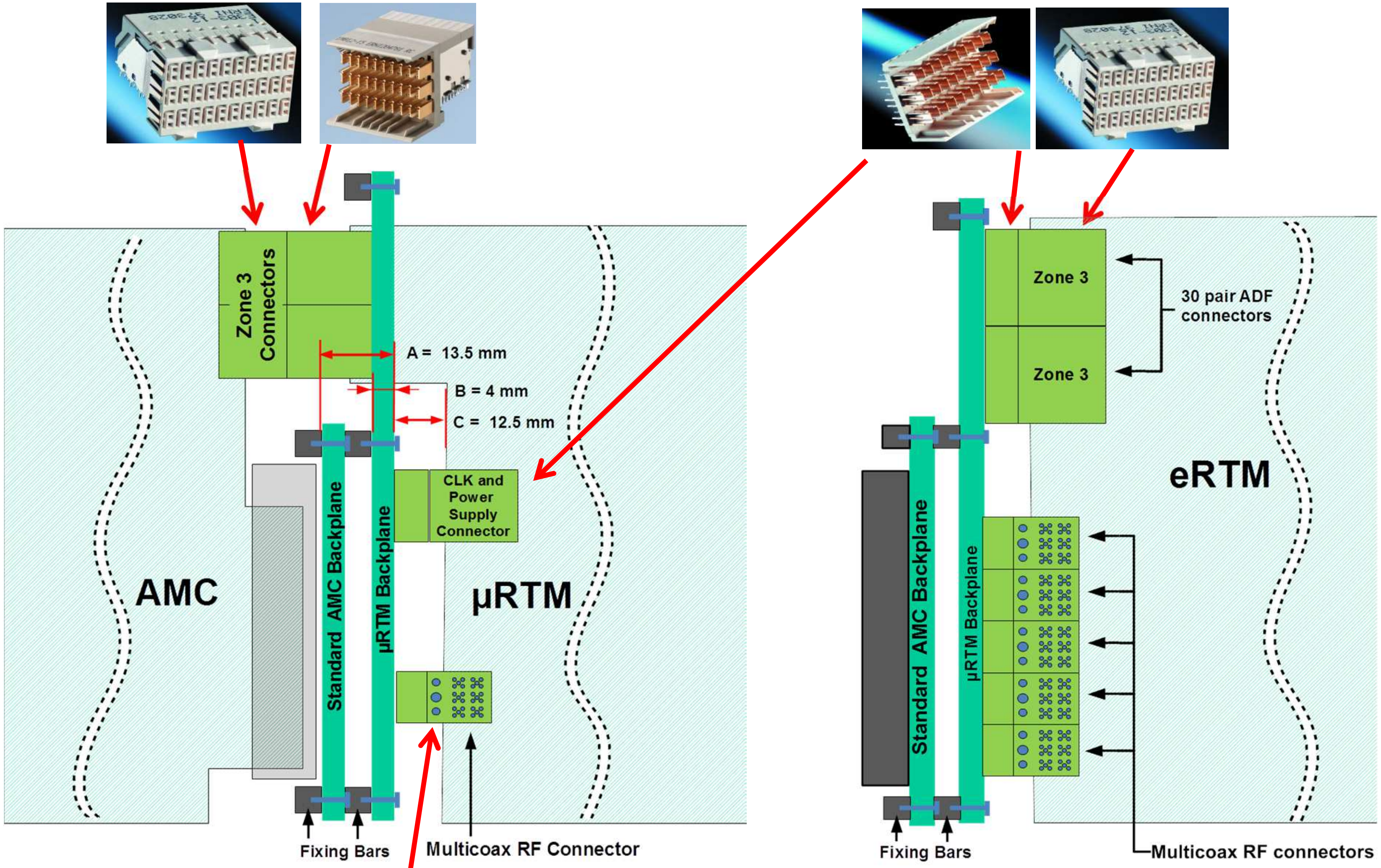
- Offer system designers additional space (note that eRTMs are wider (6HE) than uRTMs (4HE))
- Designers can use 2 or 3 slots for one module
  - eRTMs are intended for applications requiring significant space for components like filters or precise temperature stabilization
- Backplane provides management, power supply and data links for eRTMs
- Slot 15 was designated for RF signal entry

eRTM #15 example. LO and CLK generator
Courtesy: T. Rohlev, U. Mavric

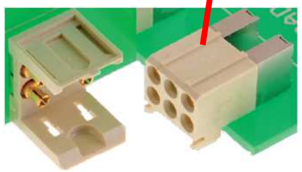
Universal slot #15 test adaptor



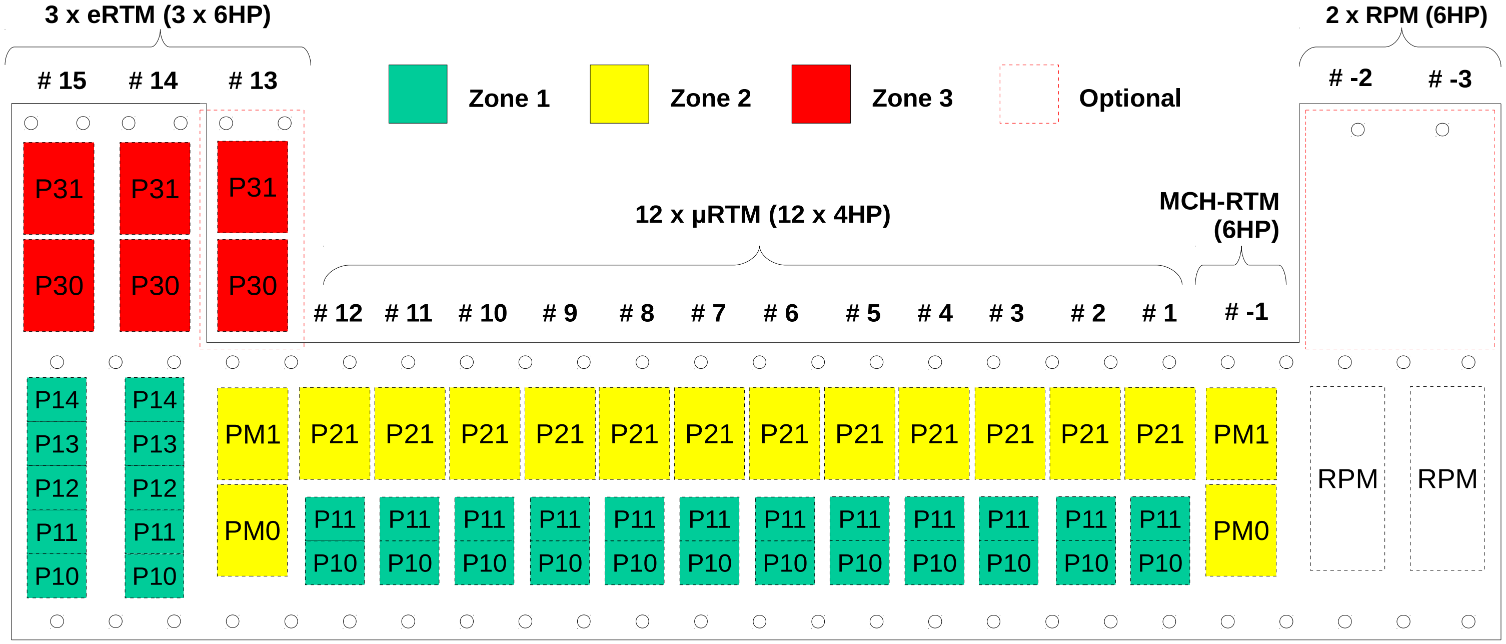
RTM Backplane Connectors for µRTM and eRTM



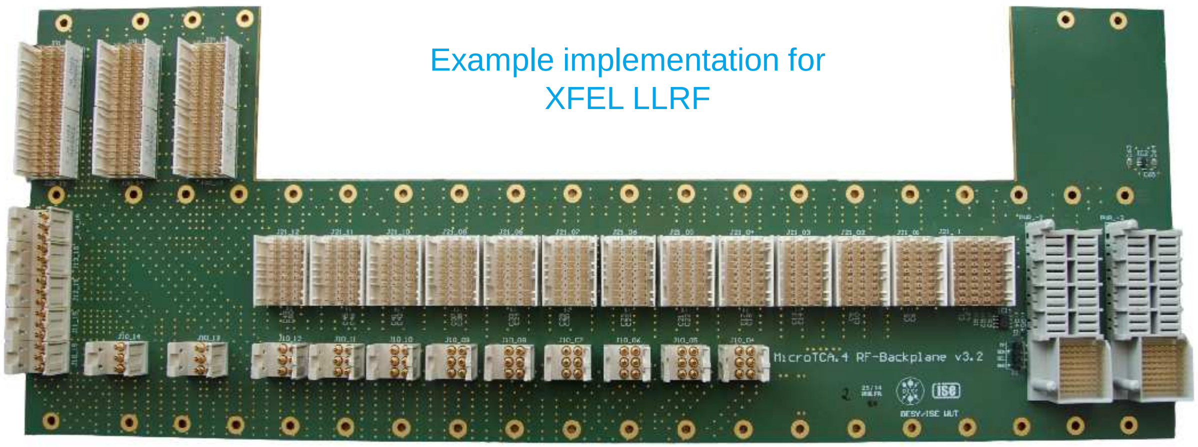
Up to 6 coax lines
50Ω, DC-6GHz



Connector Zones on the RTM Backplane

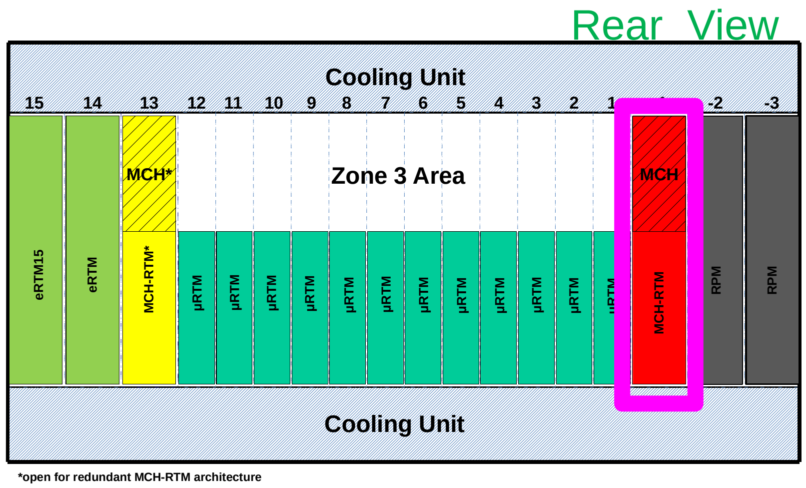


Example implementation for
XFEL LLRF



uRFB Management and Rear Power Supply

- Management by MCH-RTM in slot #-1 and (option) #13
- MCH to MCH-RTM interface via Zone 3
- Standard (AMC) management extended to the RTM side: reduced development cost and time



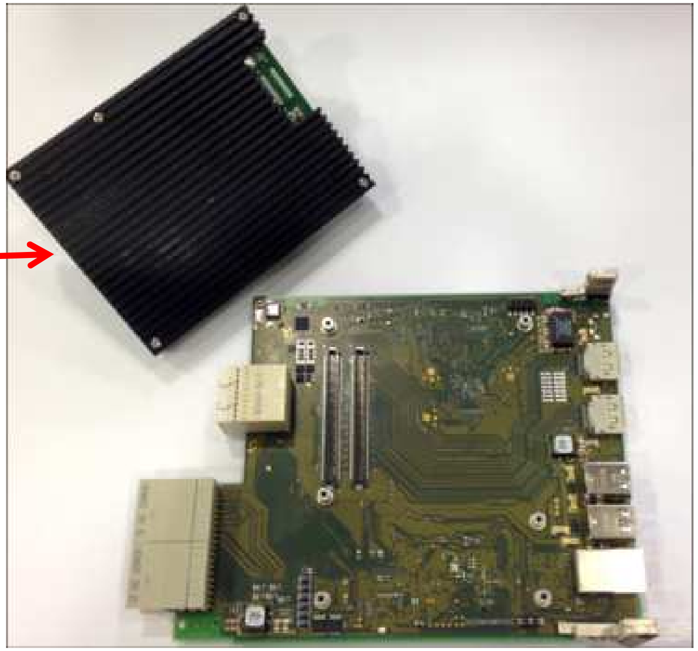
- eRTM and uRTM FRUs with information about connectivity and power supply
- Rear PM can supply **4 x +12V to eRTMs** and **12x +/- VV to µRTMs**
- µRTM can use +/-VV from RTM Backplane **or** standard +12V from AMC
- Economic use case: power supply for eRTM in slot #15 from MCH-RTM (no Rear PM) but limited to max 25W

MCH-RTM

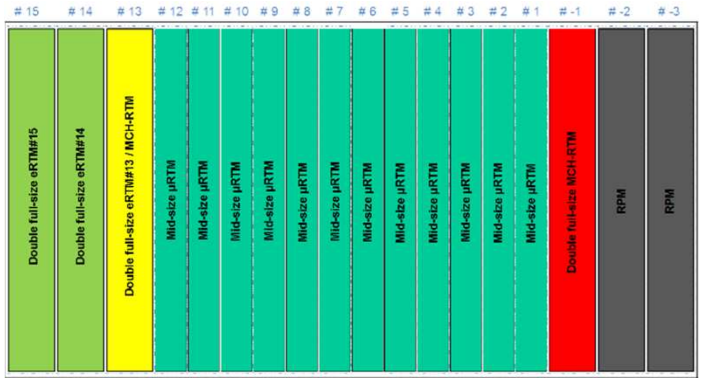
- All operational use cases covered by the MCH-RTM (see talk by Vollrath Dirksen)

- MCH-RTM can also provide fast CPU with direct links to AMC backplane

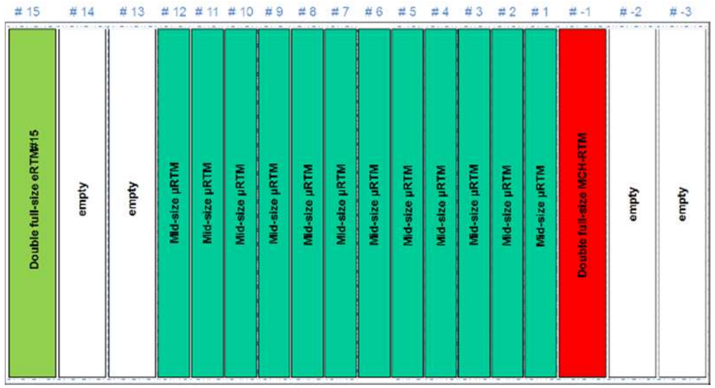
MCH-RTM. Courtesy N.A.T.



Fully equipped rear side ot the crate



Economic scenario



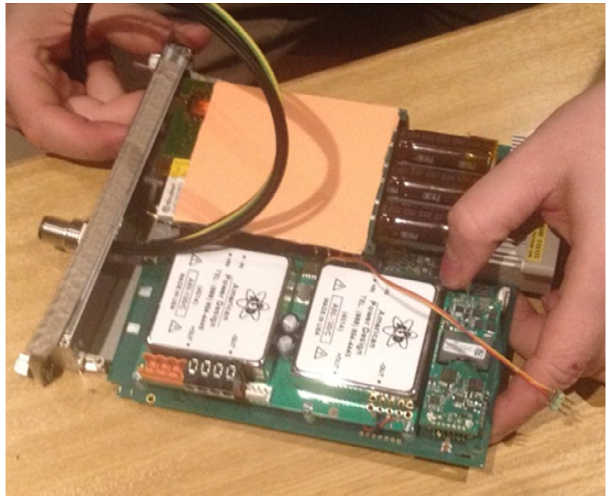
Rear Power Modules

- Rear PMs provide variable bipolar voltage 0 to +/- 15V for µRTMs
- Standard PMs can be used to supply eRTMs and MCH-RTM (4 x 12V PP only)
- Custom Rear PMs for +/-12V and +/- VV
- Option to install high voltage (~100 V, not distributed via RTM Backplane for safety reasons!) Rear PM for e.g. piezo driver application

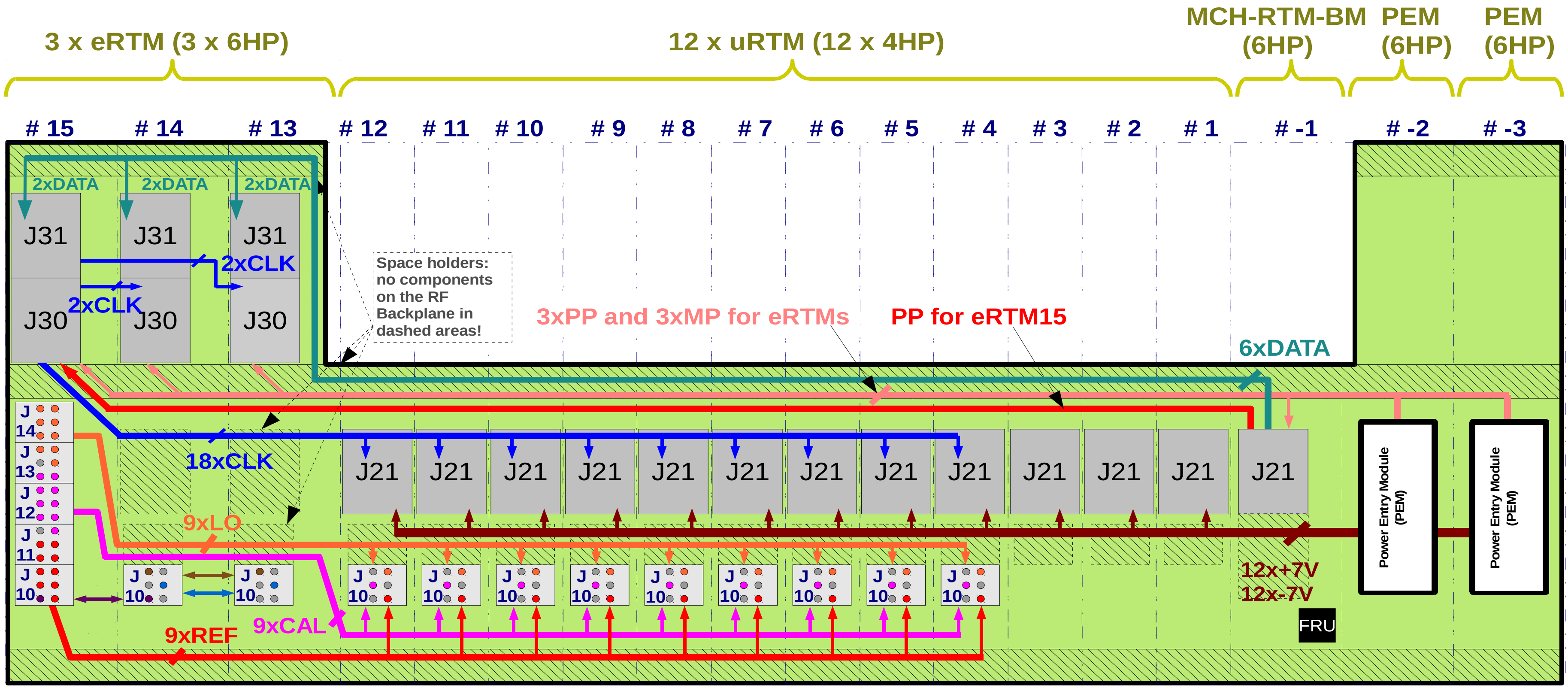
Crate with standard MTCA.4 PM

Rear PM Carrier (by N.A.T.)

Rear PM with 100V module for piezo driver



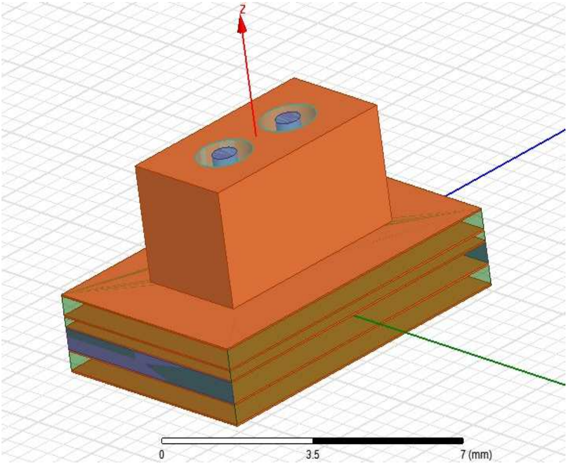
Simplified Block Diagram of RF Backplane Designed for XFEL LLRF

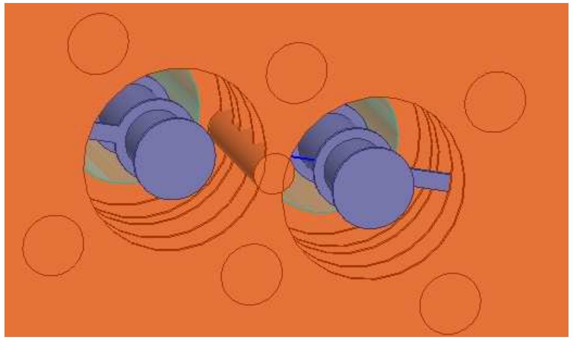


- 27 RF signals (optimized for 1.3 GHz but can work up to 6 GHz)
- 22 CLK signals
- „Analog” power supply: +/-7 V for RTMs and +12 V for eRTMs
- Management and communication

RF and CLK Performance Optimization

- Required:
  - min. 80 dB isolation of RF-to-RF and CLK-to-RF signals
  - „as low as reasonably achievable” RF loss and phase drifts
  - Reflections lower than -15 dB
- Careful RF PCB design performed
  - 16 layer PCB
  - Hybrid design: RF substrate for RF and CLK lines, standard substrate for power supply
  - Large effort put in grounding (to minimize reflections, crosstalk, loss)
  - Optimization of power supply network (4 x 12V, 7A; 12 x 2 x +/- VV 2A) including control of return currents
  - 3D EM simulations of coaxial connectors to PCB interface



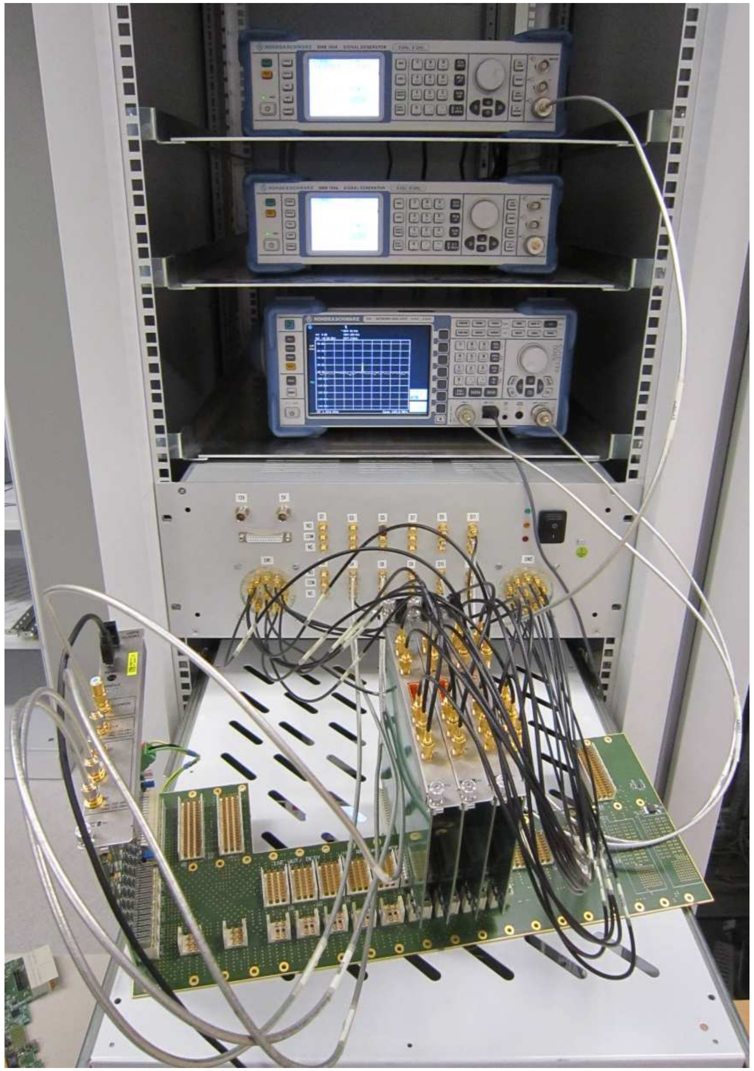


Automated Test Stand

- Time consuming RF measurements of RF and CLK performance

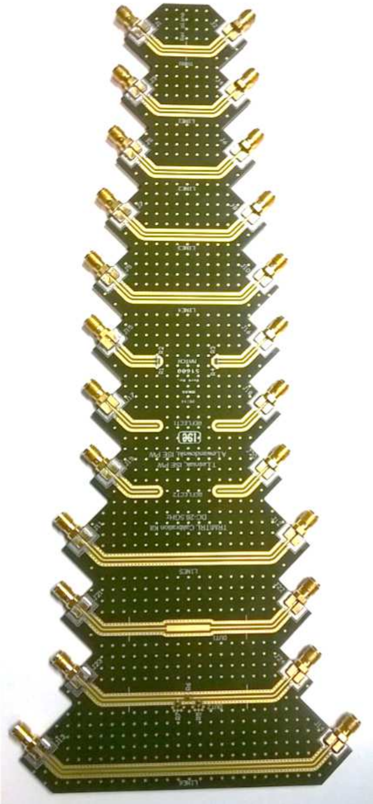
- Automated test stand and adapter boards were designed to allow fully automatic measurements and report generation

- ~400 VNA measurements needed for full test
    - manually 1-2 days + 1 day for report generation assuming no human mistake is done…
    - with test stand ~25 min. including report

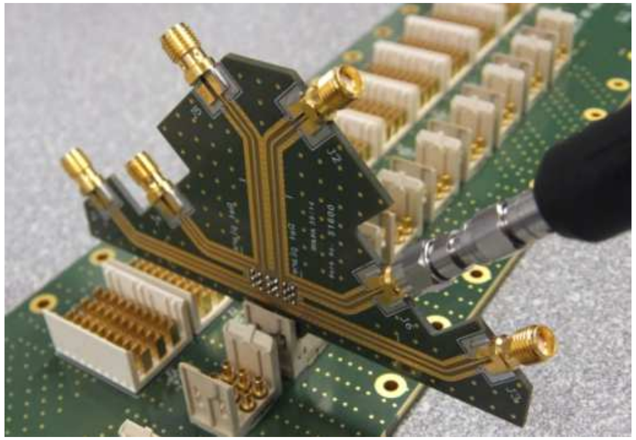


Test Boards

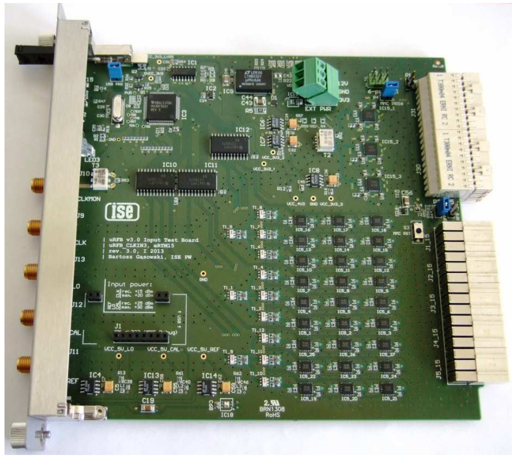
VNA calibration board



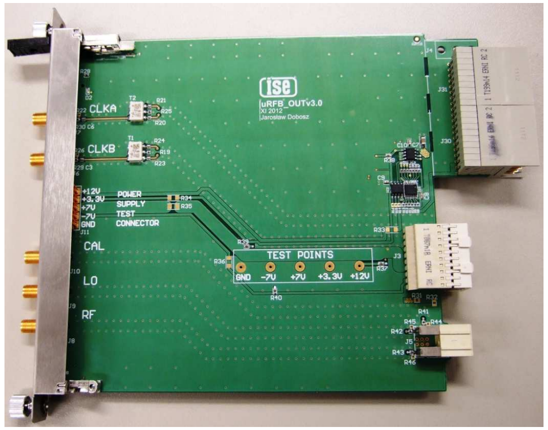
Adapter board for precise S-parameter measurements



eRTM15 test board



uRTM test board



Performance Measurement Results (Example)

Reflections (red) and RF loss (blue) for the most distant slot

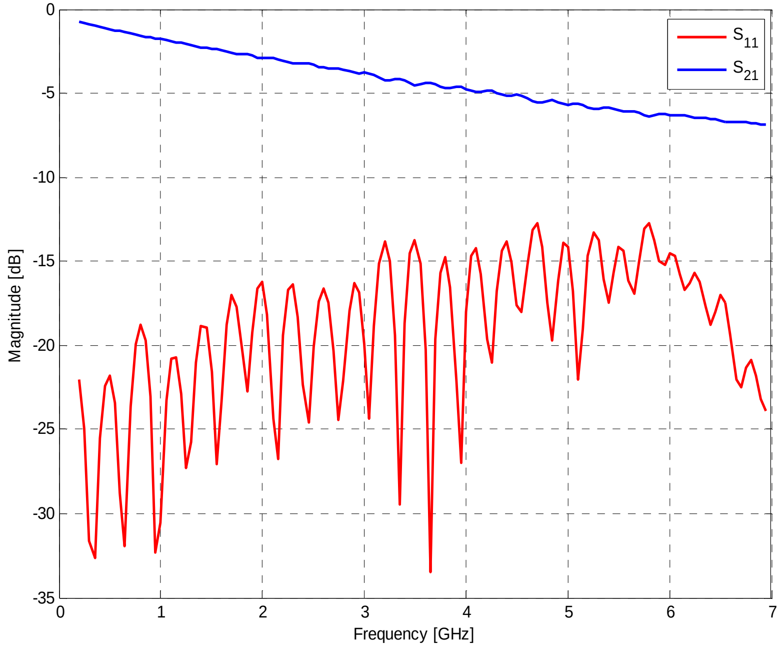


Table I: Measured Attenuation and Reflections of the Backplane **@1.3GHz** for LO, REF and CAL Lines

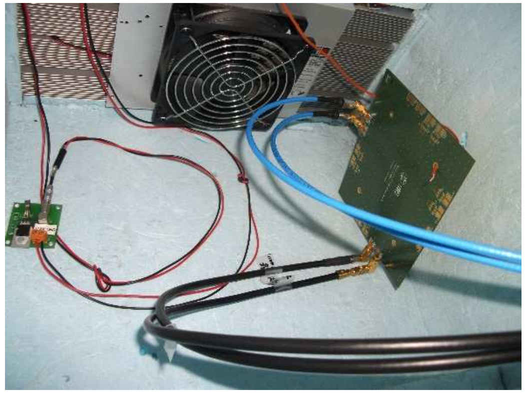
Slot	A_{REF} [dB]	$\|\Gamma_{REF}\|$ [dB]	A_{LO} [dB]	$\|\Gamma_{LO}\|$ [dB]	A_{CAL} [dB]	$\|\Gamma_{CAL}\|$ [dB]
4	2.4	-24.3	2.9	-40.0	2.5	-26.1
5	2.1	-23.4	2.7	-20.5	2.4	-17.9
6	2	-20.4	2.3	-25.7	2.3	-22.4
7	2	-15.9	2.2	-18.7	2.1	-22.3
8	1.6	-22.5	2.2	-21.0	2.0	-19.0
9	1.6	-24.5	2.0	-23.0	1.7	-26.8
10	1.5	-16.0	1.9	-18.6	1.6	-18.8
11	1.4	-19.4	1.5	-22.4	1.5	-19.6
12	1.1	-16.2	1.4	-19.1	1.4	-30.0

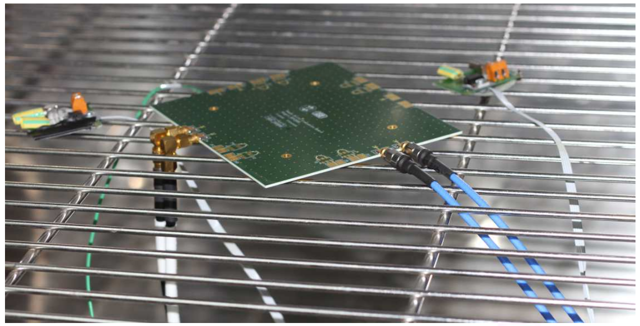
Table I: Measured crosstalk between REF and LO lines @ **1.3 GHz**, [dB]

		Aggressors								
		REF4	REF5	REF6	REF7	REF8	REF9	REF10	REF11	REF12
Victims	LO4	93	109	95	97	115	105	105	112	113
	LO5	103	102	106	93	114	101	109	109	112
	LO6	102	95	93	113	119	112	106	111	117
	LO7	100	102	104	97	113	104	111	109	113
	LO8	95	102	109	103	97	106	106	113	114
	LO9	95	97	111	111	115	93	107	108	109
	LO10	97	100	114	112	118	111	103	109	105
	LO11	95	111	112	114	113	102	107	95	109
	LO12	103	105	108	106	109	101	107	109	93

Phase Drifs

- Critical for LLRF applications
- PCB traces are sensitive to temperature and humidity variations on level important for LLRF
- Test board was designed and a method developed to calibrate out test cable drifts
- Measured phase drifts
  - by temperature are in range of 40 – 70 fs/^{o}C p-p (~0.035 $^o/^o$C) for the longest line
  - by humidity $\sim 2\,\frac{fs}{\%RH}$
  - usually humidity changes by few tens $^{\%}/_{day}$)
  - Expected drifts 10 – 20 $\frac{fs}{\%RH}$ p-p during day





PICMG Standardization Process

- All ideas and developments were base for PICMG standardization
- PICMG Hardware Group did a great job to collect it all, improve and significantly extend before putting into PICMG document (talk by Ray Larsen)
- PICMG document covers general RTM Backplane with MCH-RTM, eRTMs and Rear PMs, mechanics, protective covers and more
- Very impressive document: ~140 pages, 45 figures, 55 tables
- Close to release

Summary

- Compact solution integrated with the crate
- No collision with standard MTCA cards
- Reduces number of cable connections and improves reliability and maintainability
- Hot-swap for high-performance RF signals up to 6 GHz
- High-performance +/-V managed power supplies for RTMs
- eRTMs to increase number and size of modules
- Developed and tested successfully
- Still plan to do extensive performance tests with Rear PMs
- PICMG standard to be available soon

Thank you for attention!