# RTM RF Backplane Extensions for MicroTCA.4 Crates – Concept and Performance Measurements

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HELMHOLTZ
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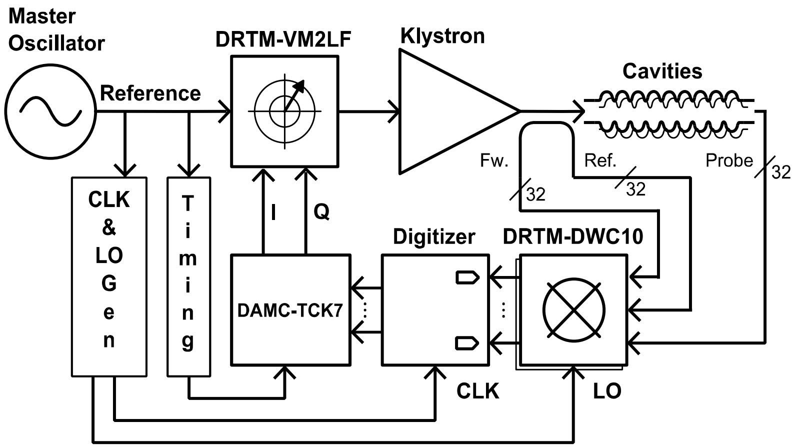
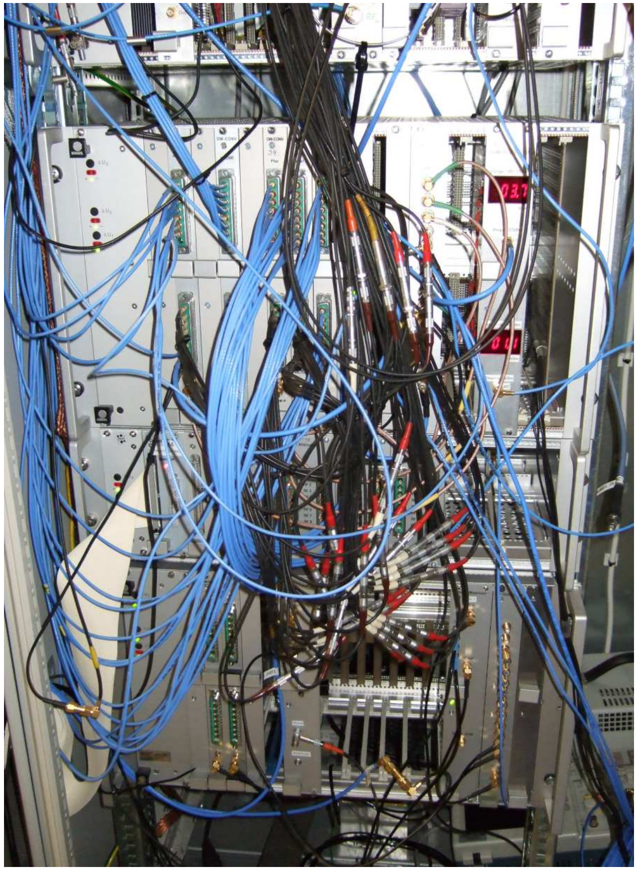
# RF Signal Distribution in Multichannel Control Systems

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

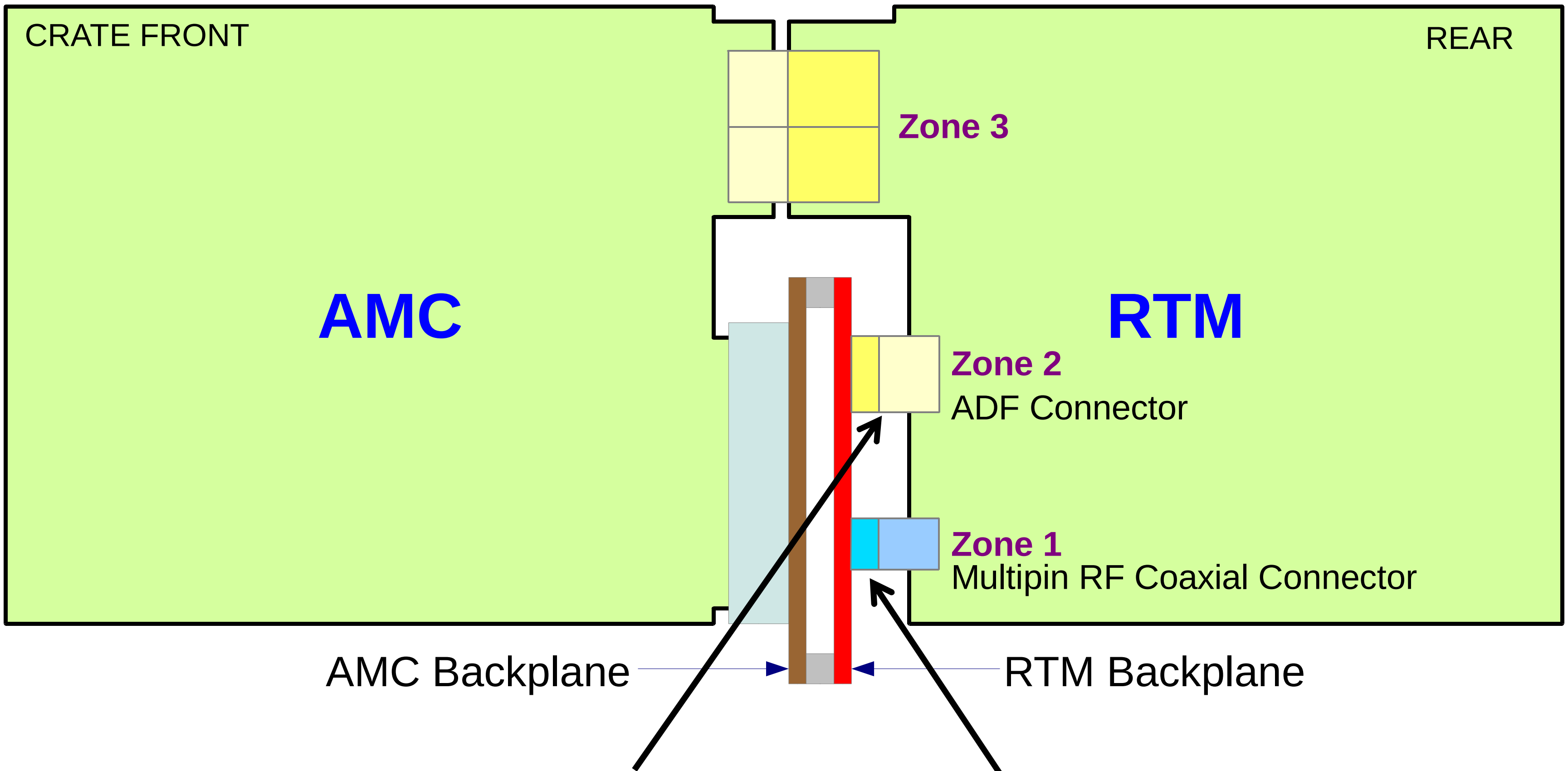
- Impedance controlled lines and coax connectors

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

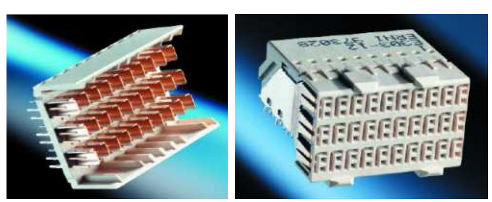


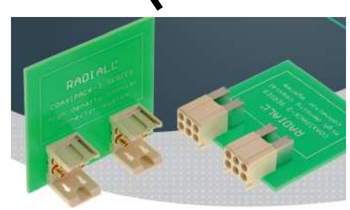



# The First Idea – RTM RF Backplane in the MTCA.4 Crate




ERMET ZD,
3x10 diff. pairs

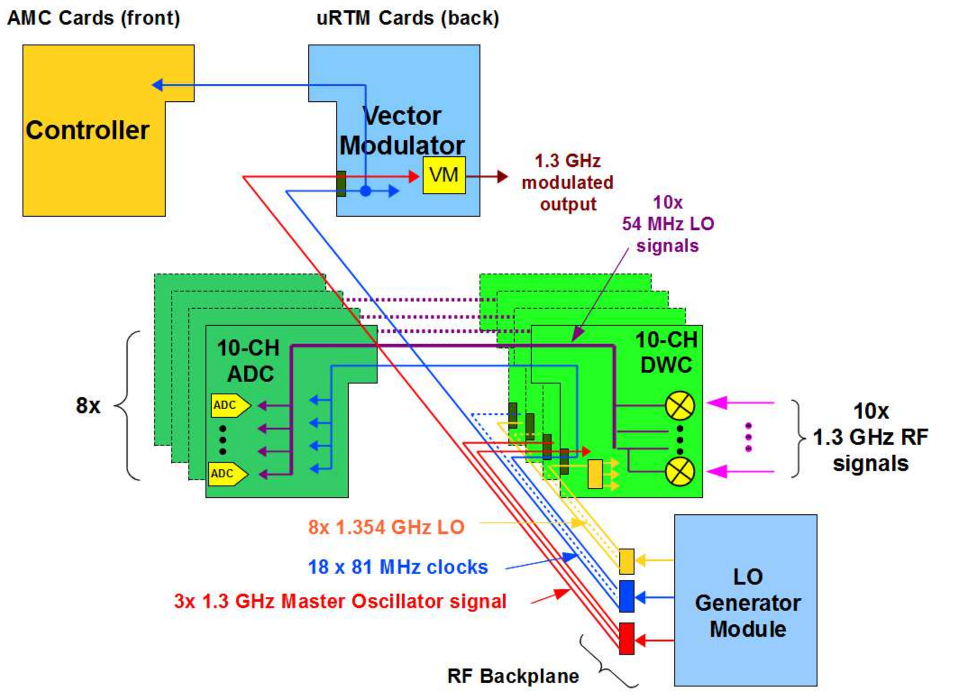


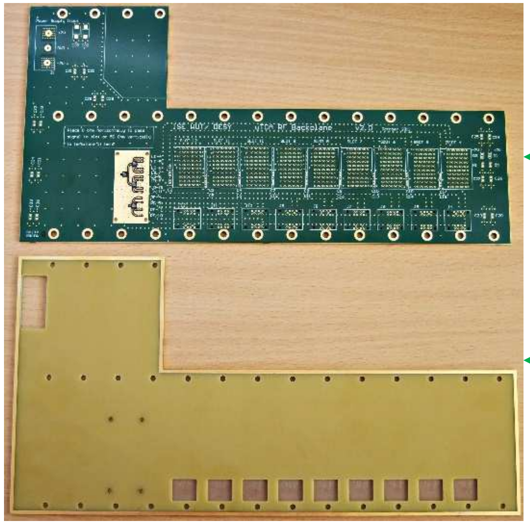


Radiall Coaxipack 2
6-pin, 6GHz RF connectors

# First RF Backplane Version – Assumptions and Problems

- Custom design for E-XFEL LLRF
- Single input with adapter board
- RF signals distributed to 8 slots
- LO and MO signal power splitting on board (careful RF design) (no flexibility)
- 50Ω matching of not used RF signals:
  - manually by putting loads on connectors (dummy load boards)
- EMI protection from the „digital world" (AMC Backplane)
- Improve system reliability
- Easier maintenance: no need to disconnect multiple cables during service



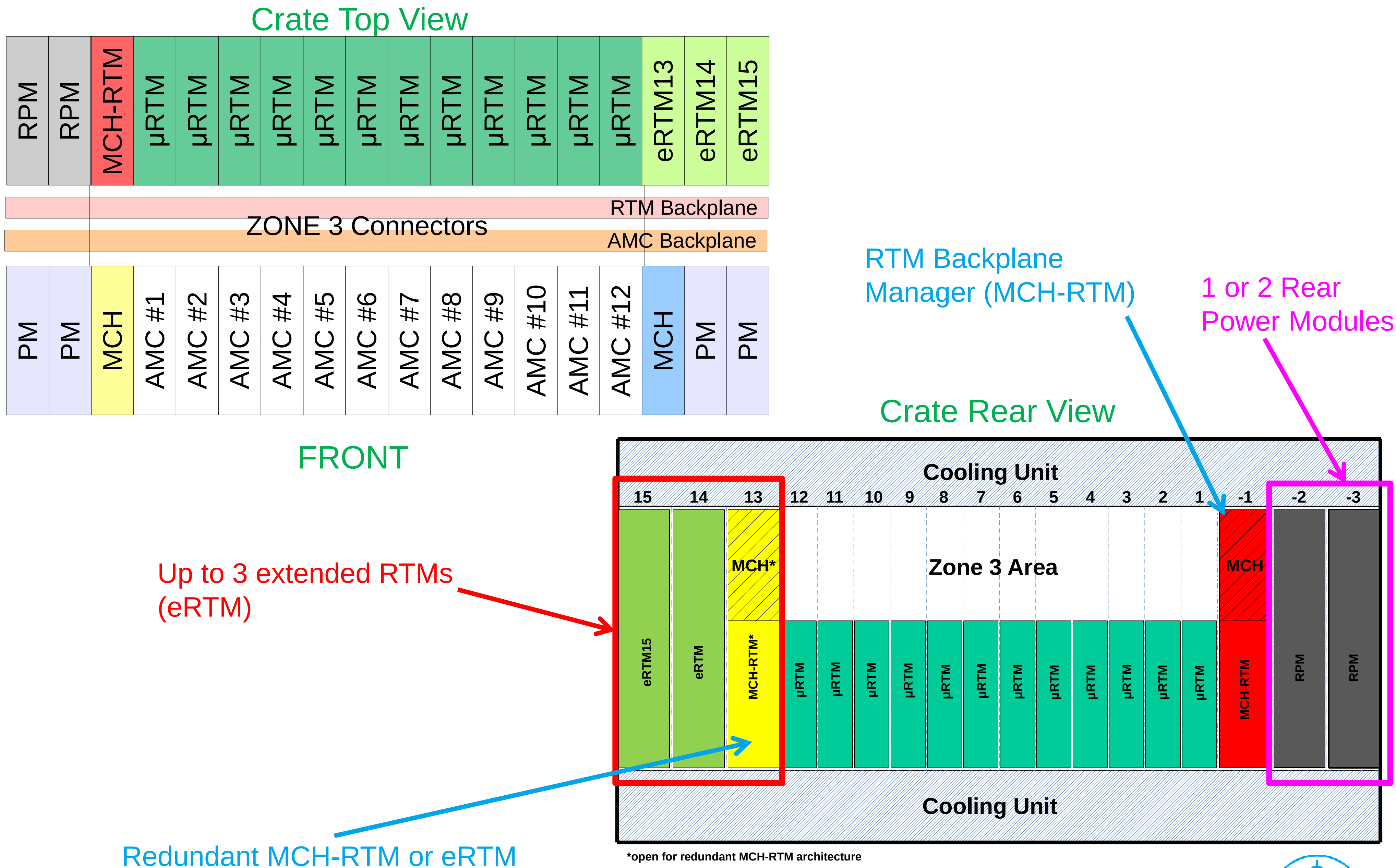
# Further Development of RF Backplane Concept

- 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
  - **Allows for significant reduction of control system size (removal of external LO and CLK signal sources)**
- RF signal distribution from slot #15 to all µRTM slots
- Automatic matching of unused RF signals
  - RF hot-plug (probably world's first)
- Necessary to introduce management over the Backplane

# RTM Backplane – 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

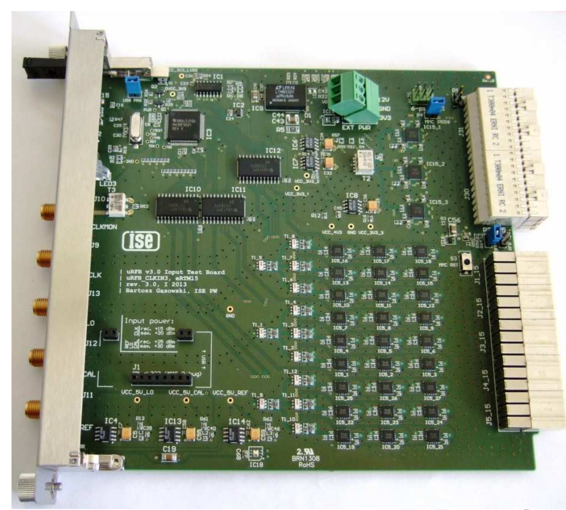


# eRTMs

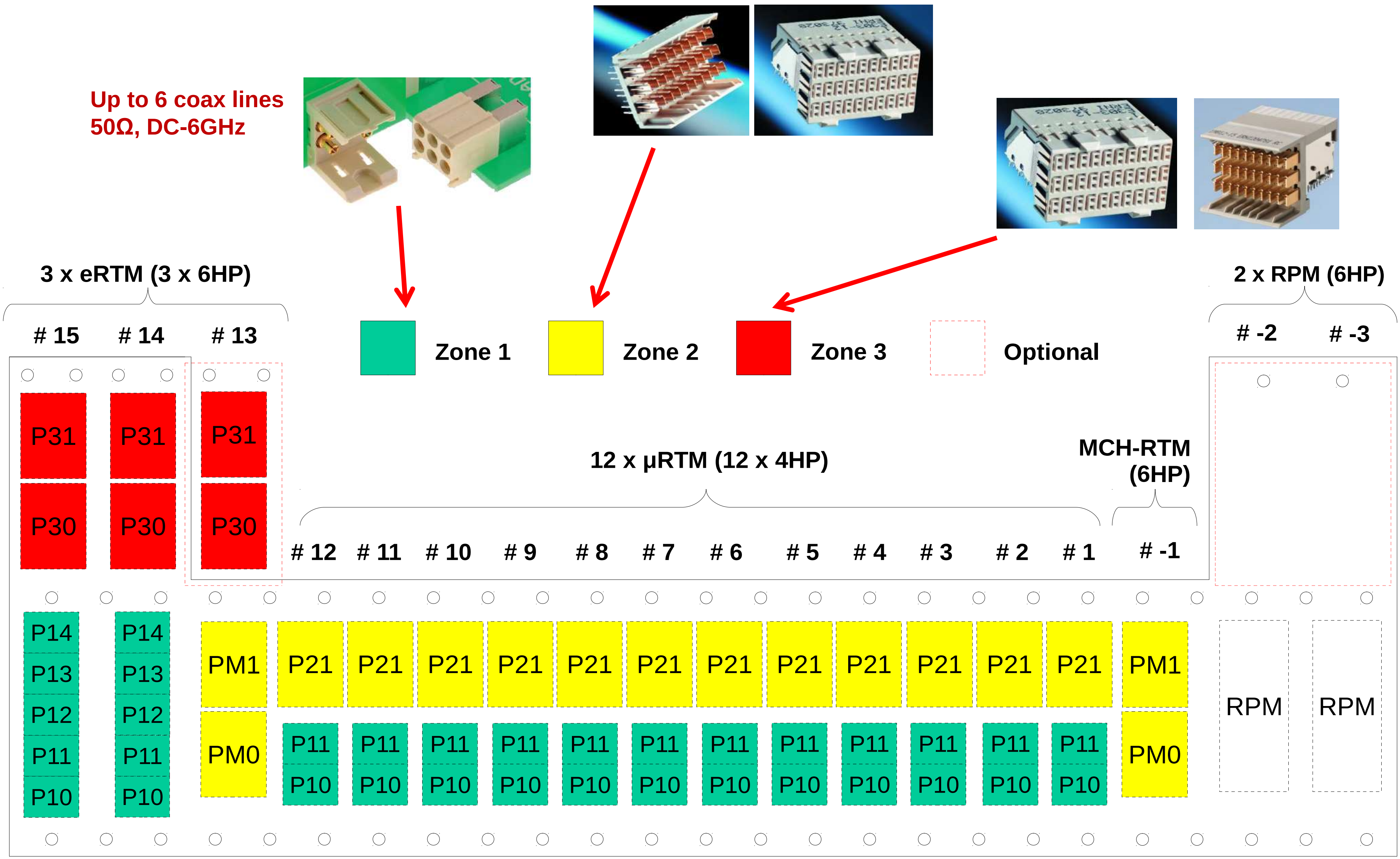
- Offer system designers additional space (note that eRTMs are wider (6HE) than uRTMs (4HE))
- Designers can use 2 or 3 slots for one module
  - eRTMs are intended for applications requiring significant space for components like filters or precise temperature stabilization
- Backplane provides management, 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. **See poster on Tuesday**

Universal slot #15 test adaptor

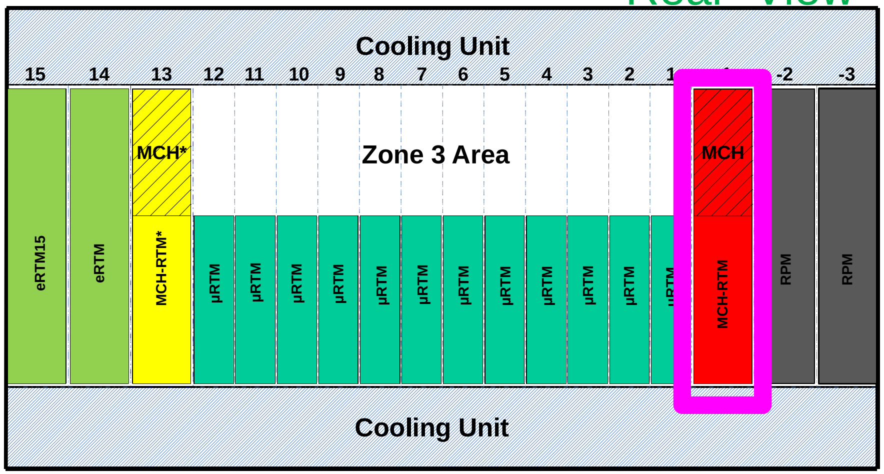


# Connector Zones on the RTM Backplane



# uRFB Management and Rear Power Supply

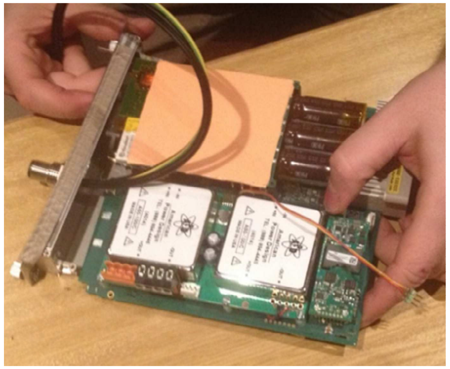
- Management by MCH-RTM in slot #-1 and (option) #13
- Standard (AMC) management extended to the RTM side
- MCH-RTM can also provide fast CPU with direct links to AMC backplane
- FRUs with information about connectivity and power
- Rear PM can supply **4 x +12V to eRTMs** and **12x +/- VV to µRTMs**
- 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
- Optional high voltage (~100 V, not on the RTM Backplane for safety reasons!) Rear PM for e.g. piezo driver application



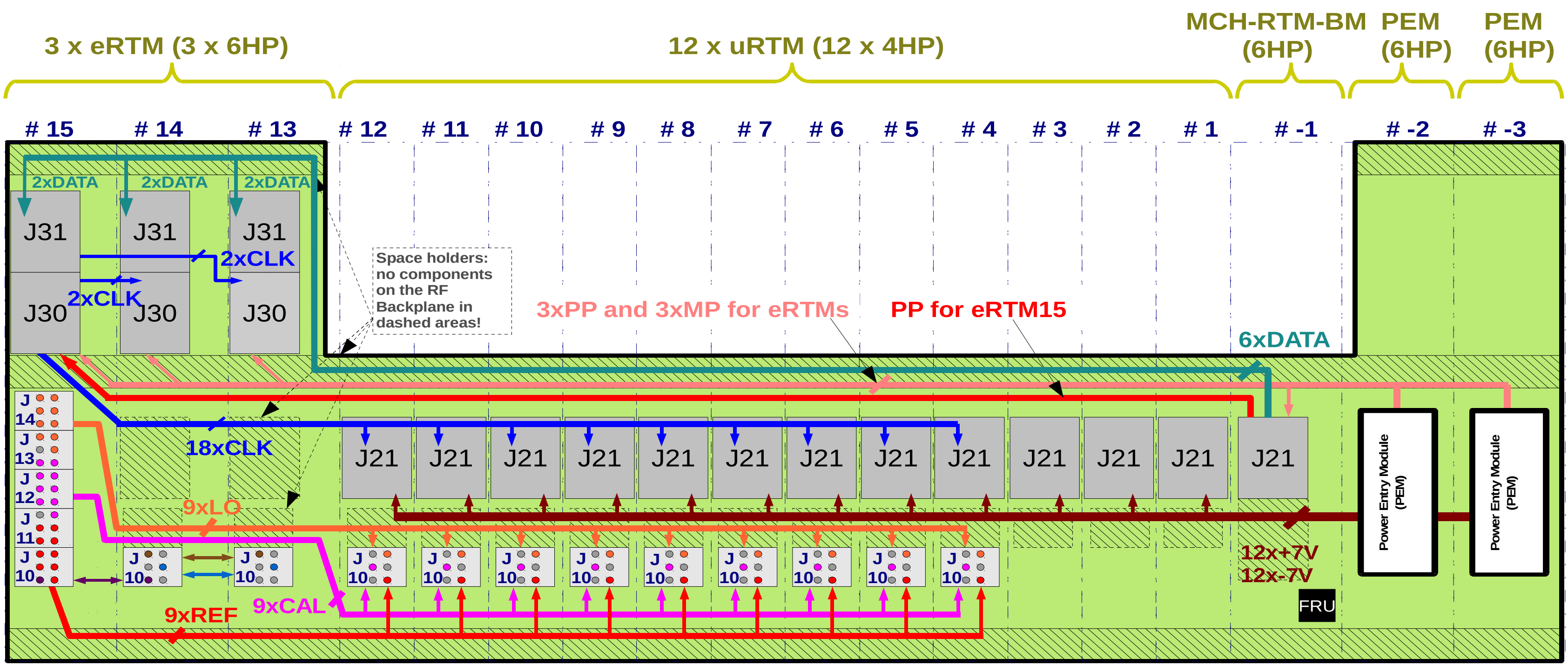
*open for redundant MCH-RTM architecture

MCH-RTM. Courtesy N.A.T.

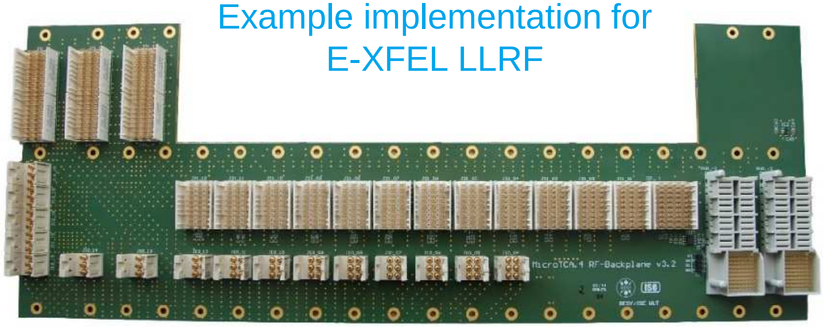
Rear PM with 100V Piezo power supply



# Simplified Block Diagram of RF Backplane Designed for XFEL LLRF



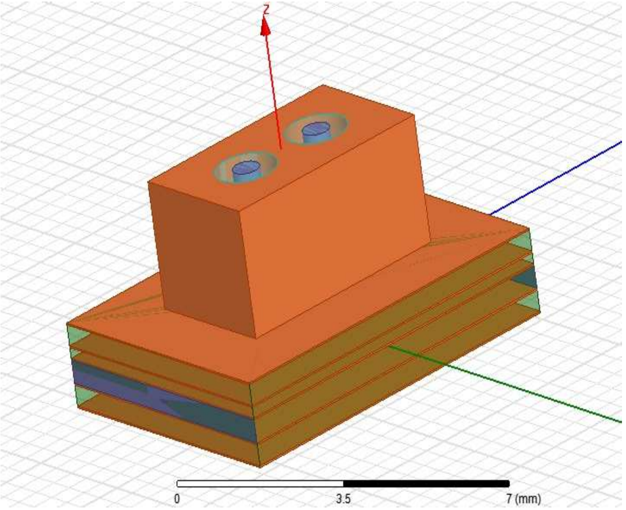

- 27 RF signals (optimized for 1.3 GHz but can work up to 6 GHz)
- 22 CLK signals
- „Analog” power supply: +/-7 V for RTMs and +12 V for eRTMs
- Management and communication

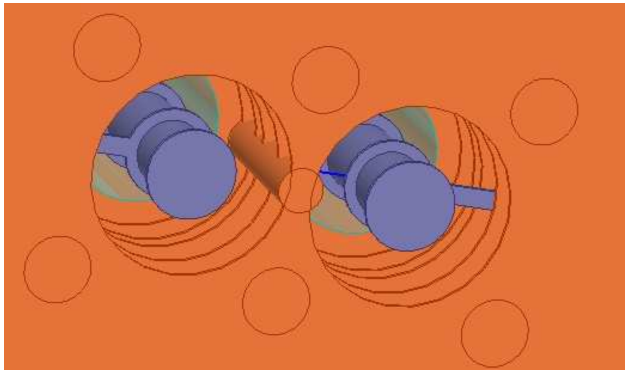


Example implementation for E-XFEL LLRF

# 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



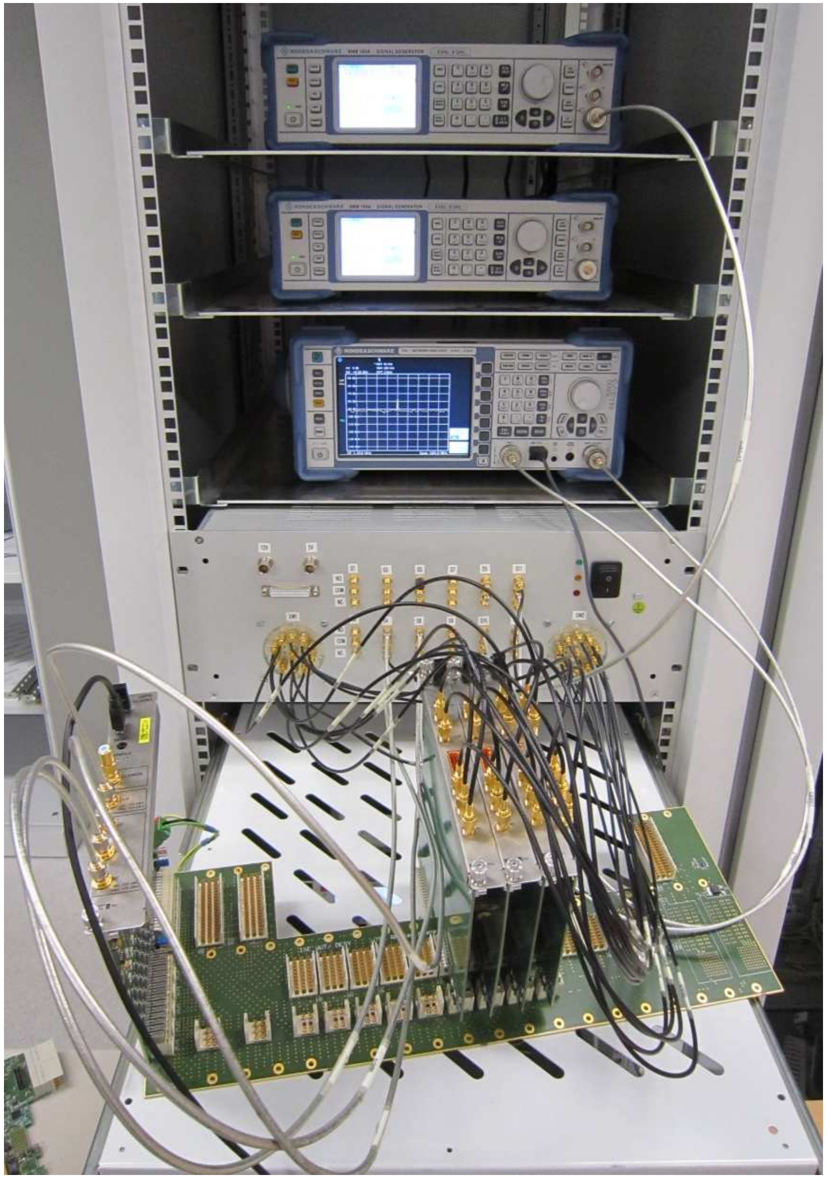



# Automated Test Stand

- Time consuming RF measurements of RF and CLK performance

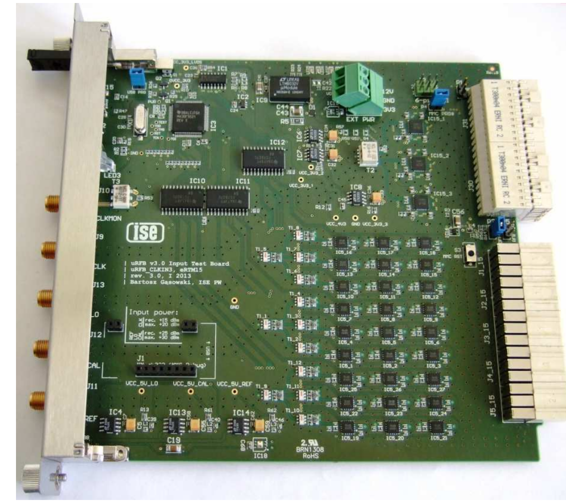
- Automated test stand and adapter boards were designed to allow fully automatic measurements and report generation

- ~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

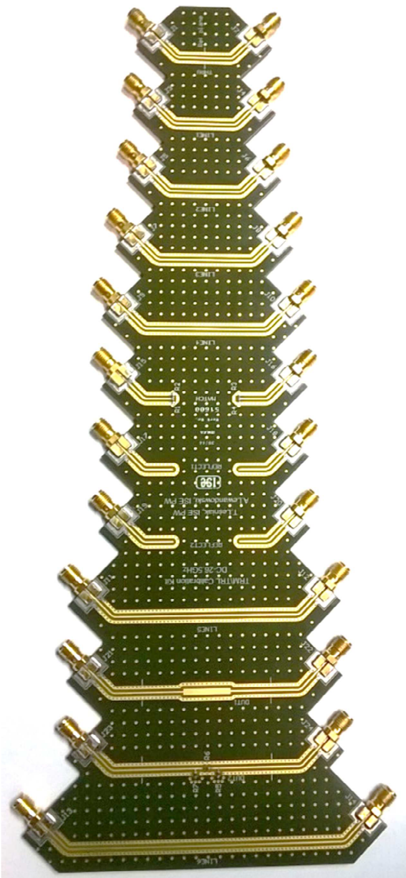


# Test Boards

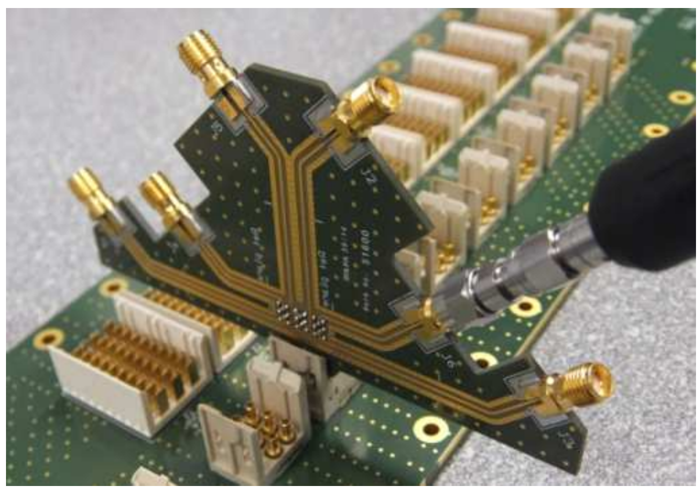
eRTM15 test board



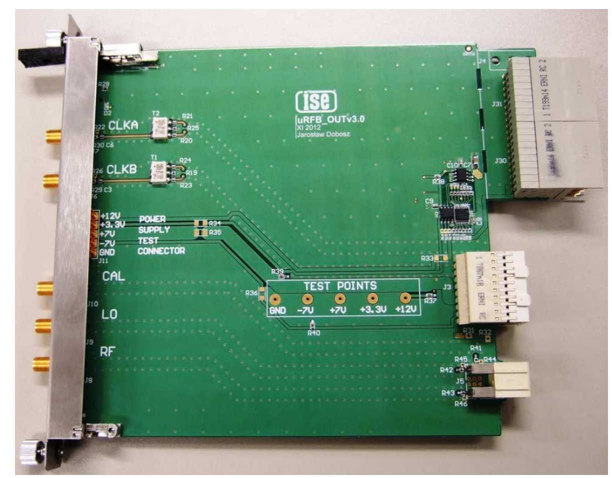
VNA calibration board



Adapter board for precise S-parameter measurements



uRTM test board



# Performance Measurement Results (Example)

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

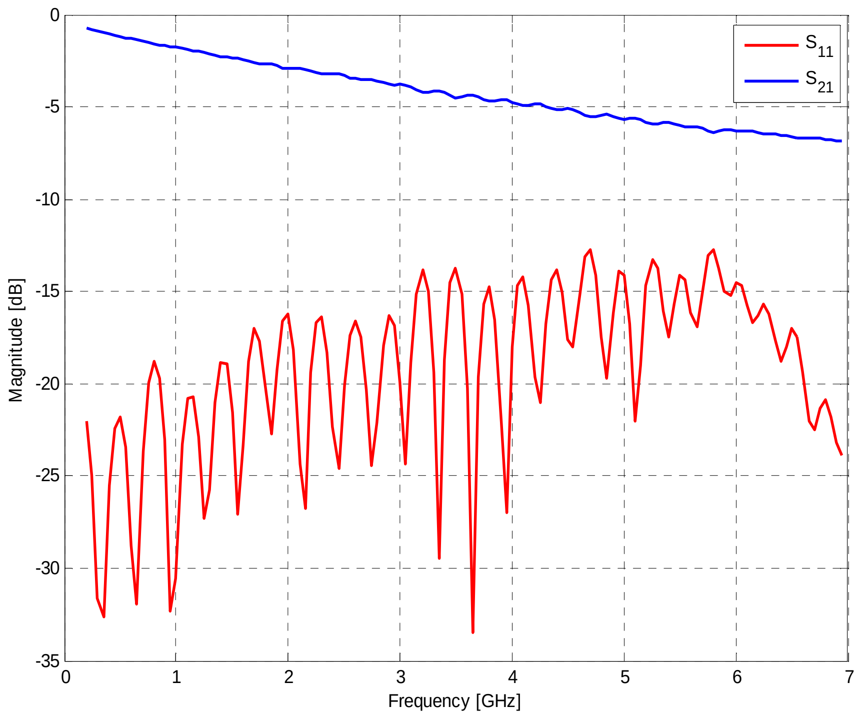



Table I: Measured Attenuation and Reflections of the Backplane **@1.3GHz** for LO, REF and CAL Lines

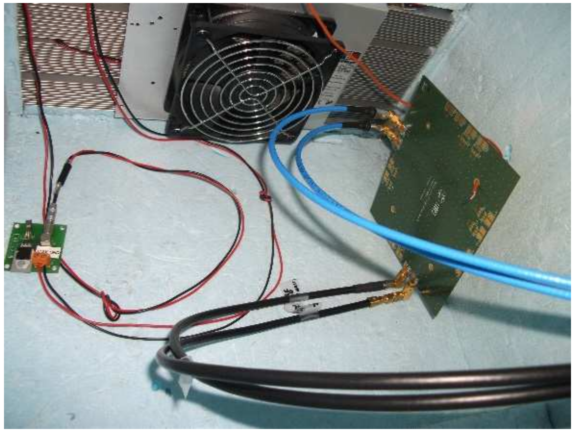
| Slot | $A_{REF}$ [dB] | $\|\Gamma_{REF}\|$ [dB] | $A_{LO}$ [dB] | $\|\Gamma_{LO}\|$ [dB] | $A_{CAL}$ [dB] | $\|\Gamma_{CAL}\|$ [dB] |
|---|---|---|---|---|---|---|
| 4 | 2.4 | -24.3 | 2.9 | -40.0 | 2.5 | -26.1 |
| 5 | 2.1 | -23.4 | 2.7 | -20.5 | 2.4 | -17.9 |
| 6 | 2 | -20.4 | 2.3 | -25.7 | 2.3 | -22.4 |
| 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 |

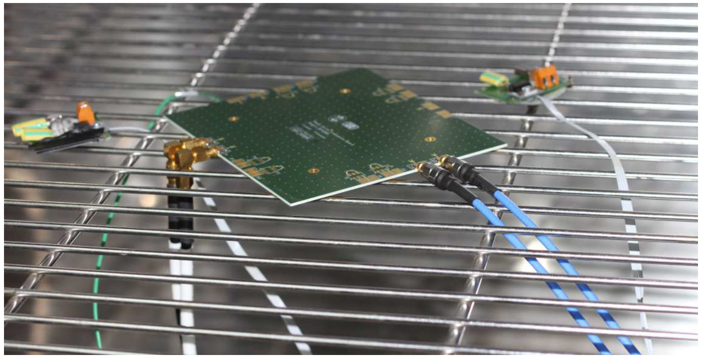
Table I: Measured crosstalk between REF and LO lines @ **1.3 GHz**, [dB]

| | | 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/°C p-p (~0.035 °/°C @1.3 GHz) for the longest line
  - by humidity ~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
- PICMG document covers general RTM Backplane with MCH-RTM, eRTMs and Rear PMs, mechanics, protective covers and more
- Very impressive document: ~170 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!