7th MicroTCA workshop, Hamburg

MicroTCA.4 based LLRF control system of the J-PARC RCS: design and status

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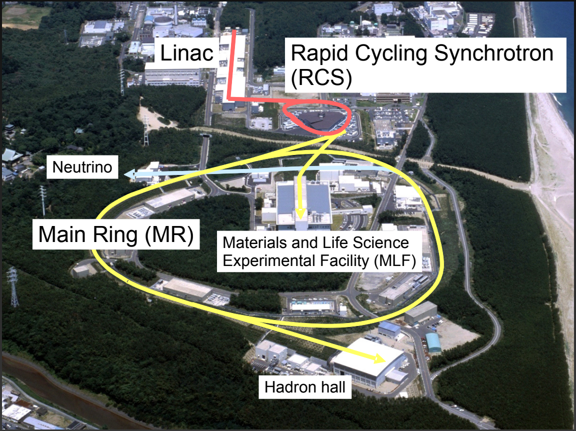
Contents

MicroTCA in Japan

MicroTCA is growing in Japanese accelerators:

- KEK
  - LLRF for SuperKEKB, STF, etc.
  - T. Matsumoto's presentation in the last MTCA workshop
    https://indico.desy.de/indico/event/18211/session/16/contribution/42/material/slides/0.pdf
- Spring8/SACLA
  - LLRF, beam monitors, camera, etc.
    http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7097434&isnumber=7097401
  - I heard that RIKEN bought 30-40 MTCA.4 shelves in this FY
- J-PARC
  - Following these successful applications above, just started to use MTCA
- Only a few Japanese companies making MTCA modules

Japan Proton Accelerator Research Complex (J-PARC)



- Consists of 400 MeV linac, 3 GeV RCS, 30 GeV Main Ring, and experimental facilities
- High intensity: 1 MW (RCS), 750 kW (MR)
- Beam operation started in 2006

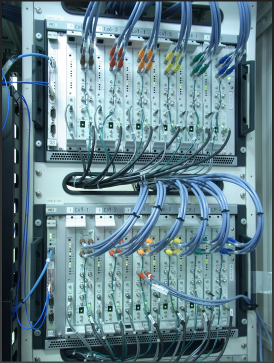
Platforms currently used in J-PARC accelerators

VME / cPCI systems used for high-end / complicated applications (timing, beam instrumentation, LLRF, etc.):

Timing system

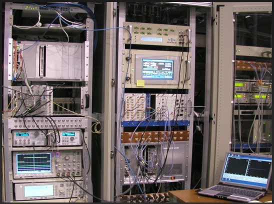
VME+NIM

RCS BPM controller



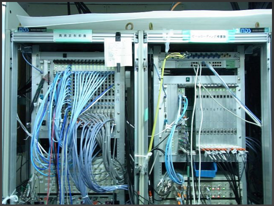
VME

Linac LLRF:



NIM (analog) + cPCI (digital)

RCS, MR:



Specialized 9U VME

Now is the time of renovation

J-PARC beam operation started in 2006:

- So far, the existing systems running nicely
  - Control, instrumentation, LLRF
- Many systems over 10 years old
  - “Very long time” for digital parts
- Obsolete FPGAs, DSPs, opt components, etc.
  - It will be soon difficult to maintain the existing digital systems

Renovation programs of some of the instrumentation / LLRF systems are ongoing.

MTCA seems to be good for next generation systems

- Modular configuration
- High speed backplane

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MTCA.4 in J-PARC accelerators

Custom module w/o shelf:

(reported by Y. Sugiyama in last workshop,
https://indico.desy.de/indico/event/18211/session/9/contribution/39/material/slides/0.pdf)

- Linac: digitizer, LLRF
- RCS: vector voltage control test module
- MR: Longitudinal damper

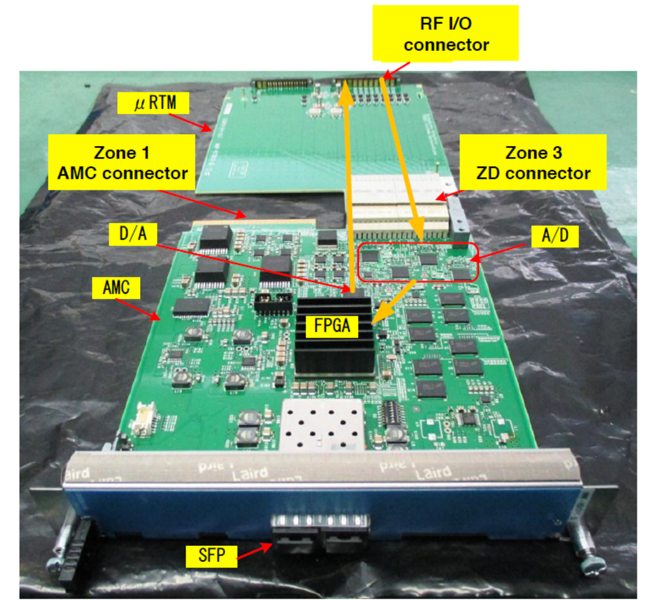
With full-featured shelf:

- RCS LLRF control system

All custom systems made by Mitsubishi Electric TOKKI systems company.

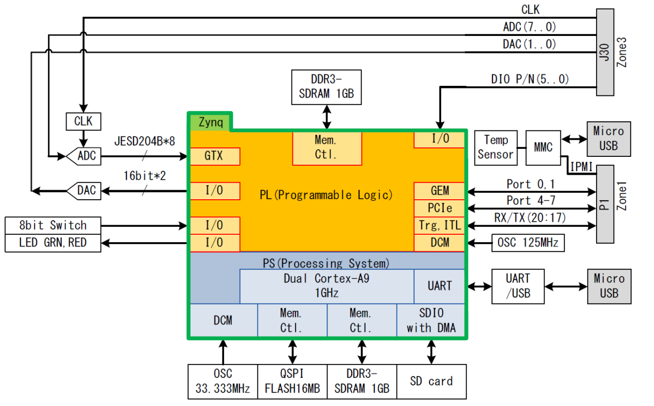
- We order a system including hardware and logic

Mitsubishi TOKKI AMC + (Dummy) RTM



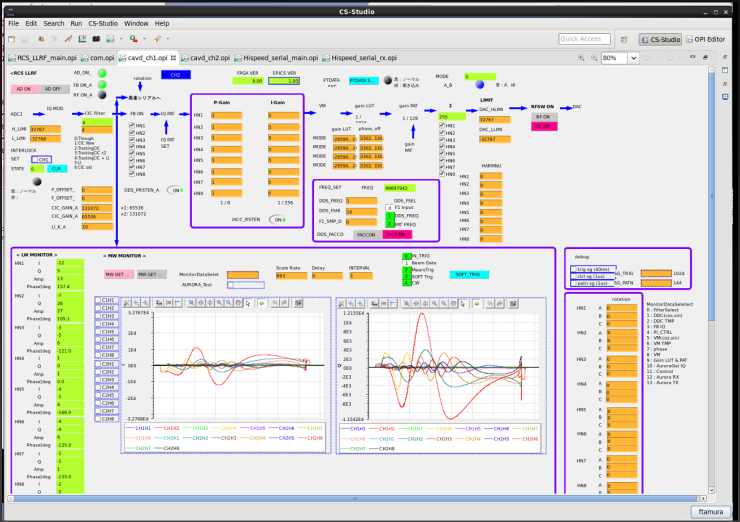
Mitsubishi TOKKI AMC

Xilinx Zynq FPGA is employed:



- FPGA Zynq XC7Z045
- 8x ADC, 2x DAC
- 1 GB SDRAM
- Linux / EPICS IOC embedded on Zynq SoC

Delivered with CSS OPI



The AMC / FPGA logic delivered with CSS OPI.

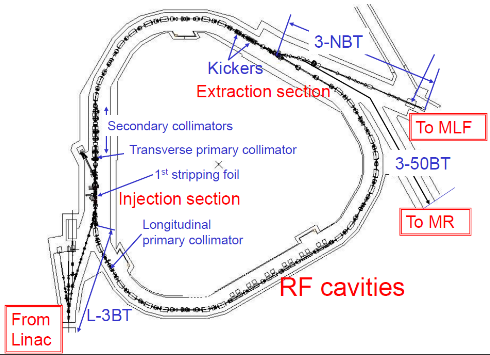
- Mitsubishi uses OPI for their debugging of logic
- Of course, we have to write “final” OPI by ourselves

1. Introduction

2. New LLRF control system based on MTCA.4

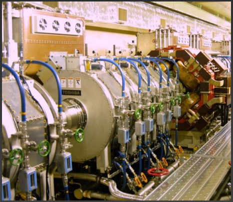
3. Conclusion, discussion, and question

J-PARC rapid cycling synchrotron (RCS)



parameter	
circumference	348.333 m
energy	0.400–3 GeV
beam intensity	8.3×10^{13} ppp
beam power	1 MW
repetition rate	25 Hz
accelerating freq	1.22–1.67 MHz
harmonic number	2
max rf voltage	440 kV
No. of cavities	12
Q of rf cavity	2

MA cavity and tube amplifier:

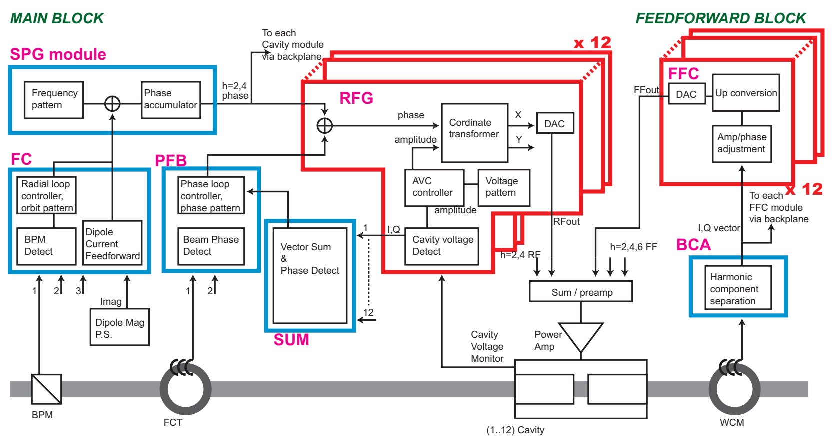


- Magnetic alloy (MA) cavities employed
  - high rf voltage, 440 kV by 12 cavities
  - driven by high power tetrode tube amp
  - Wideband, Q = 2

RCS LLRF is a complicated system:

- Frequency sweep
- Voltage patterns / regulations
- Beam feedback loops

This slide shows the complexity of RCS LLRF



(Blue) common functions for whole system / (Red) for each of 12 cavities

- Frequency sweep / pattern
- Dual harmonic (multiharmonic) voltage control of 12 cavities
- Beam feedback loops
- Vector sum of 12 cavity voltages
- Beam loading compensation

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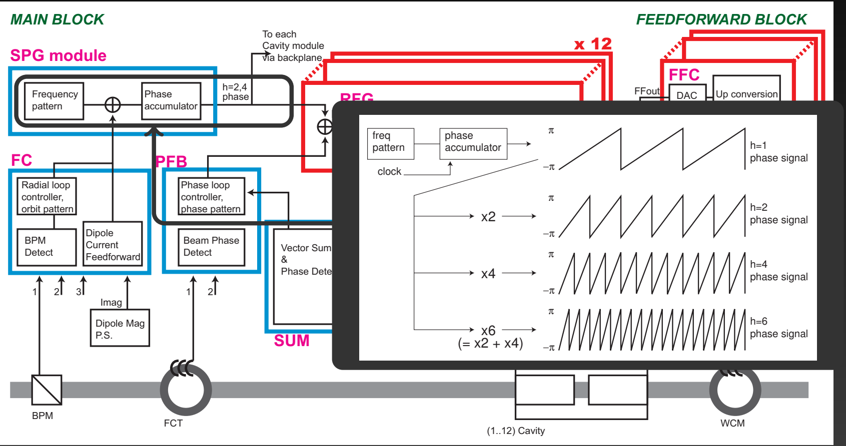

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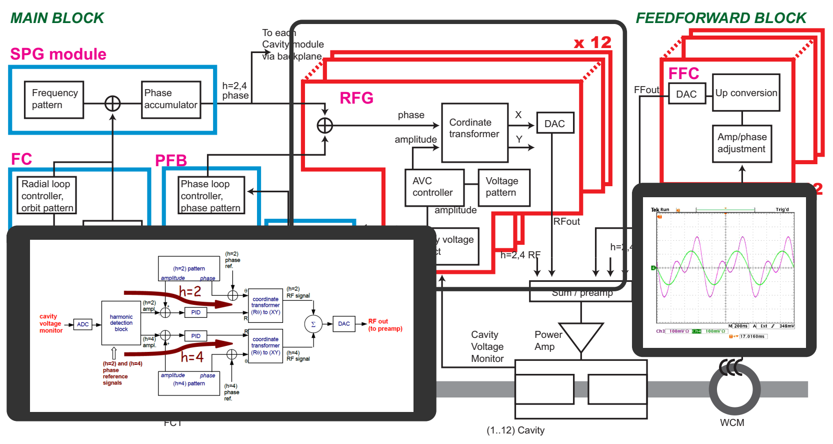

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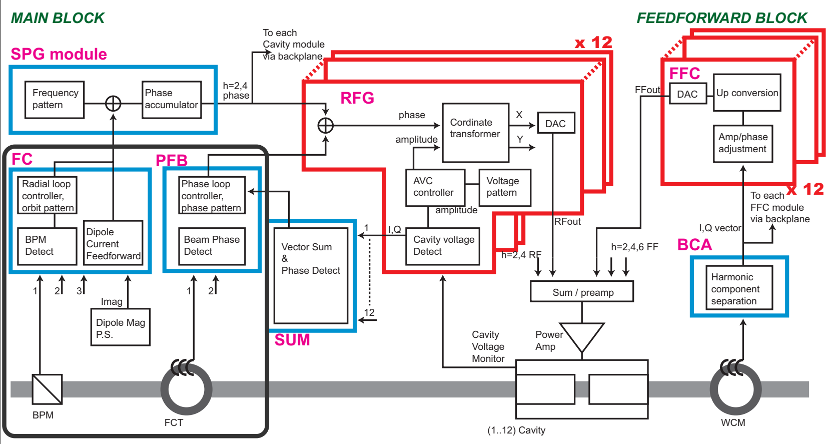

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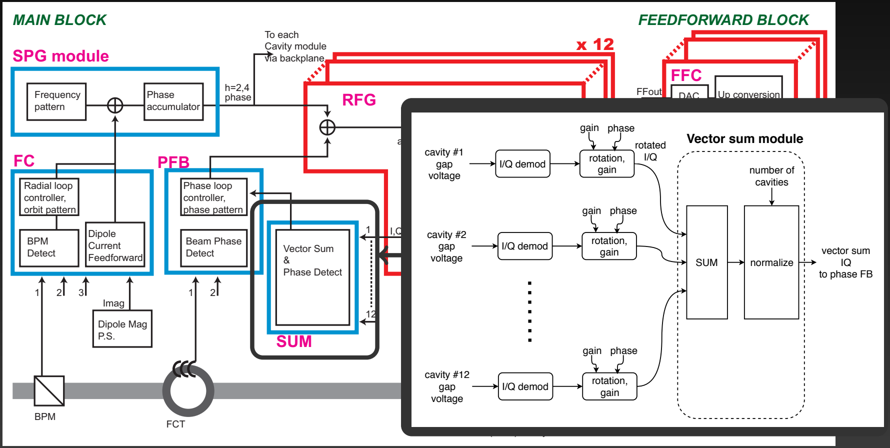

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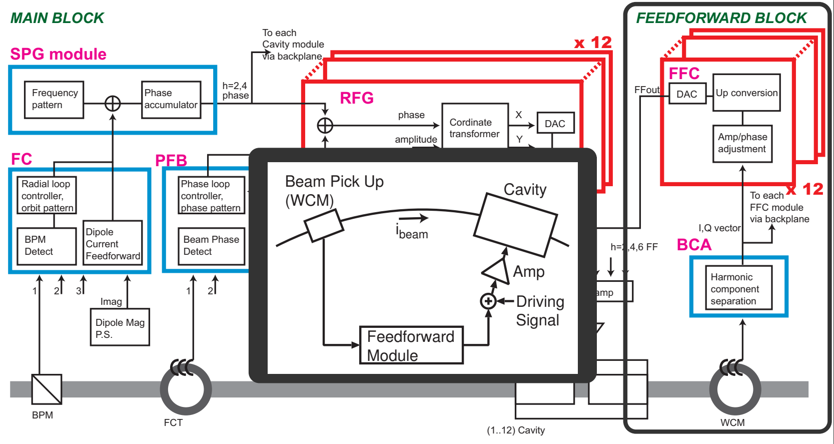

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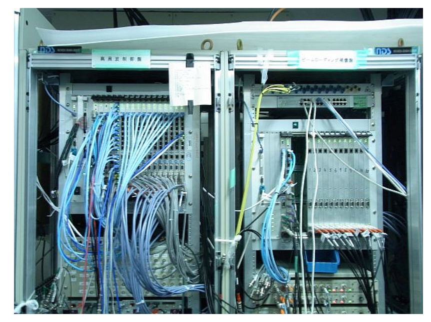
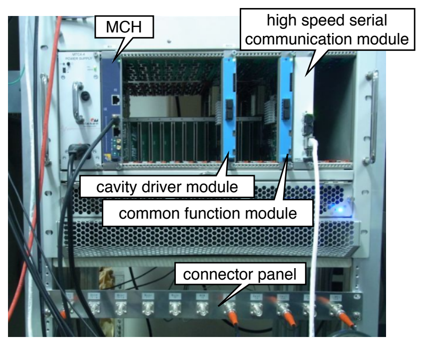
Next generation LLRF for RCS under development

Existing VME system:



- Specialized 9U VME
- Modules are different for functions
- Serial cables between modules

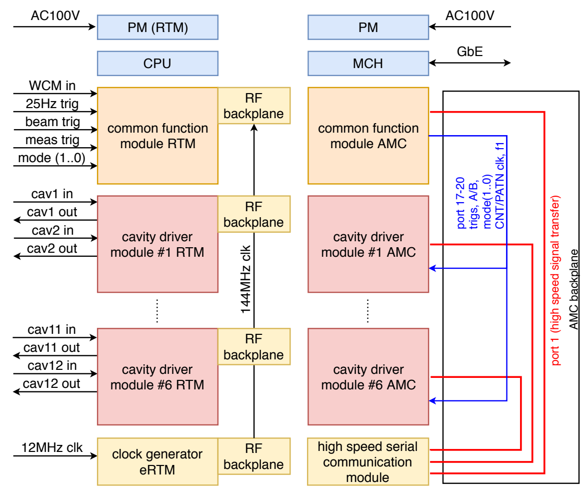
New MTCA.4 system:



- Infrastructures (shelf, PM, CPU, MCH)
- 1x common function module
- 1x cavity driver module (5 more necessary for 12 cavities)
- 1x high speed serial communication module

Configuration and signal flow

Full-featured MTCA.4 shelf with rf backplane employed.



System clk:

- 144 MHz (existing: 36 MHz)
- generated by clock gen eRTM, distributed via DESY-type rf backplane

Modules classified into two categories:

- Common function module: frequency pattern, phase FB, . . .
- Cavity driver: rf gen for cavities, feedforward driver

A special module in MCH2 slot:

- High speed serial communication module, described later

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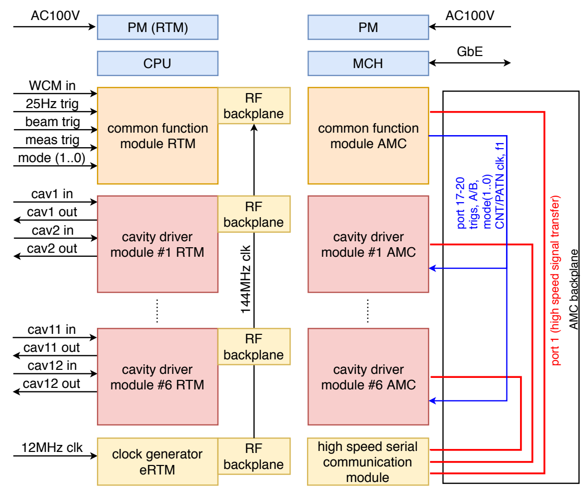

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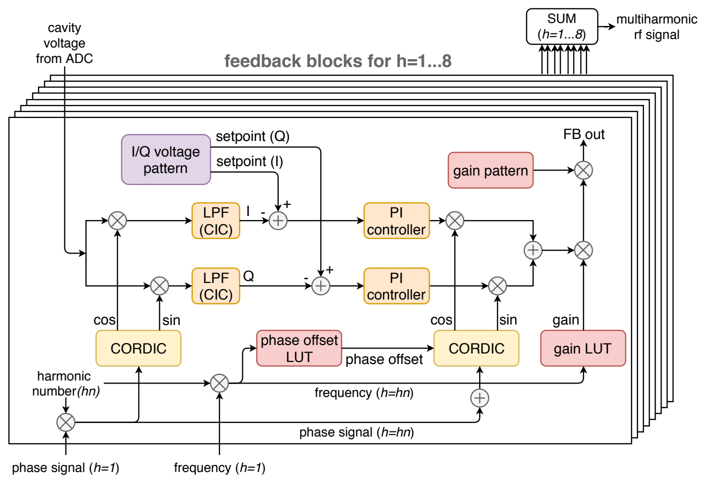
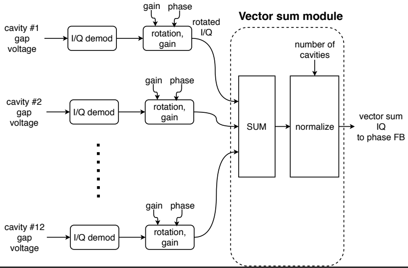
Multiharmonic vector voltage control for beam loading compensation

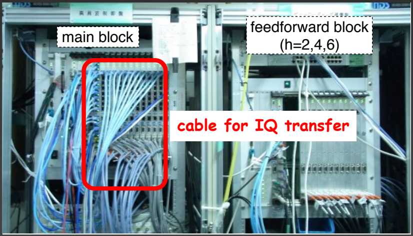


- Lots of resources necessary (narrow band LPF, CORDIC, multiharmonic)
- Thanks to Zynq capacity, a cavity driver handles two cavities / eight harmonics

high speed serial communication

Vector sum:





Star topology signal transfer is necessary.

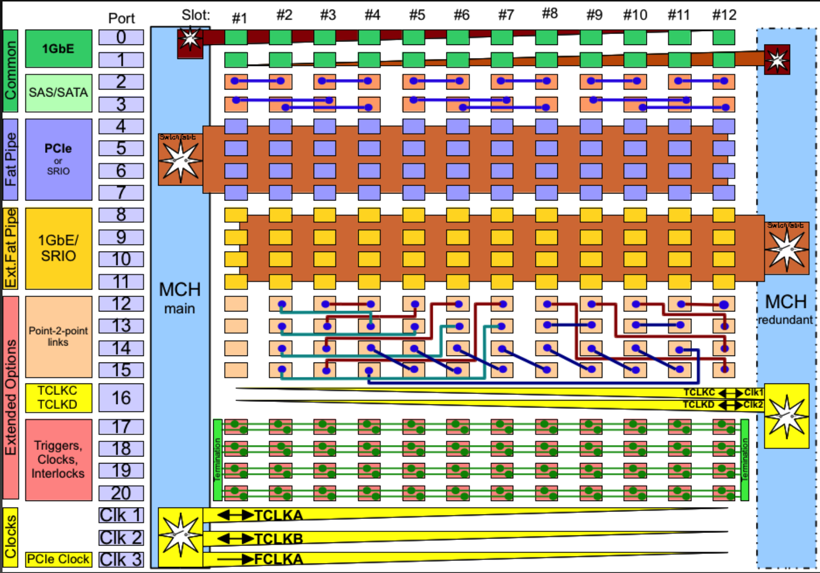
- Vector sum:
  Cavity IQs (drivers)
  → vector sum → phase FB
- Phase FB signal (common)
  → volt control (driver modules)

Existing system uses cables and parallel backplane.

- Not very sophisticated

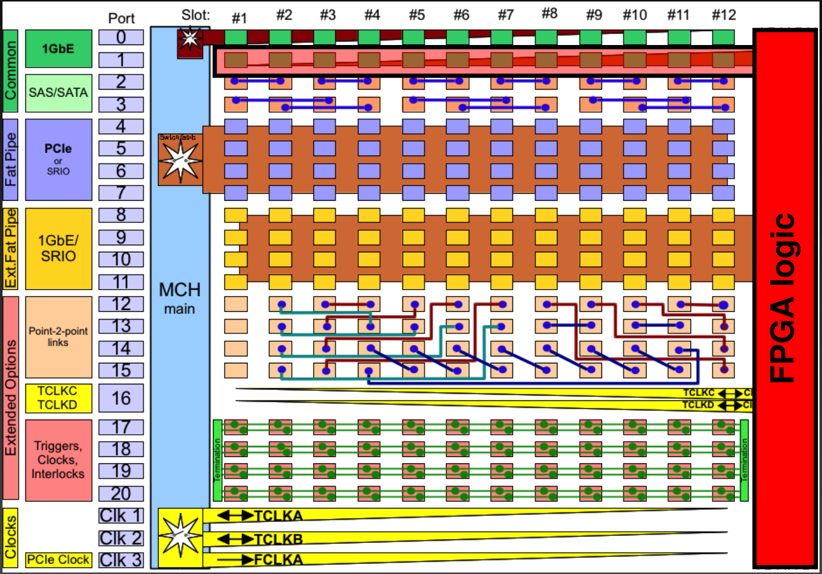
How can we realize star topology with MicroTCA.4?

high speed serial communication



- There are no trivial star-like connections among AMCs
- Idea: putting FPGA logic in MCH2 slot and using Port1, although it sacrifices redundancy of MCH

high speed serial communication



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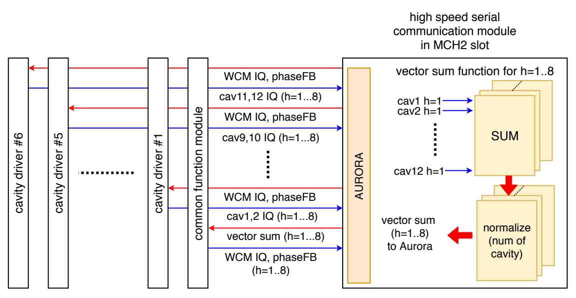
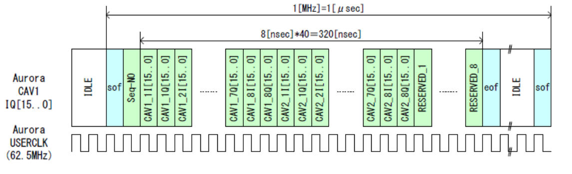
high speed serial communication

Signal flow using Port1:



Aurora data format:



High speed serial communication module:

- Virtex-5 used
- Gathers and delivers signals from/to cavity driver modules and common function module
- Vector sum function implemented

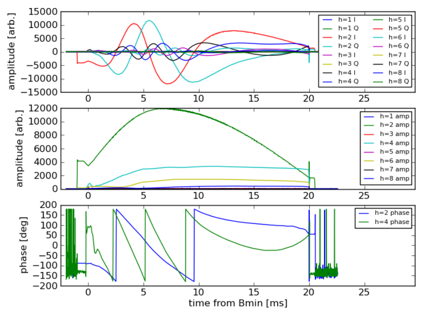
Xilinx Aurora used:

- 1 data frame contains 40 data blocks of 16-bits
- Enough for sending 2x cavities' I/Q signals of 8x harmonics
- Sent every control clock (1 MHz)

Current status

High intensity beam tests of multiharmonic voltage control with a cavity ongoing.

h4, h6, h8 FB off:



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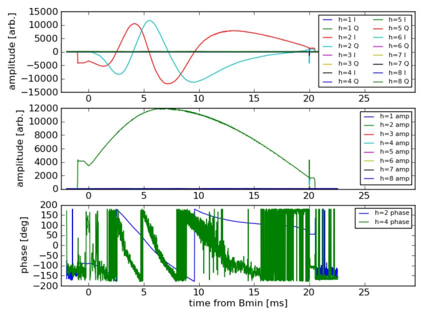

- Significant wake voltages (h4, h6) excited
- Clearly h4, h6, h8 components are suppressed

The remaining modules and functions are built and implemented in FY2018.

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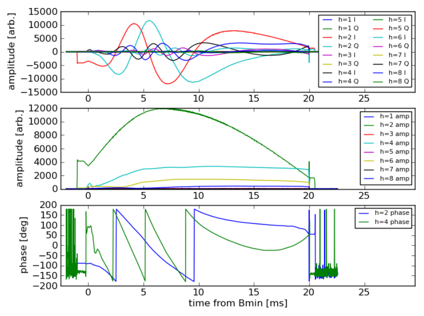

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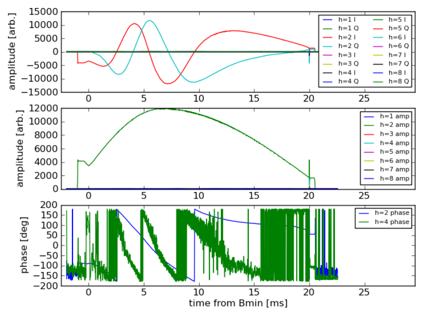

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Conclusion, discussion, and question

Next generation RCS LLRF under development:

- Will be completed in FY2018 and installed during next Summar
- Beam test results are promising

Discussion:

- It is not very good that only Mitsubishi TOKKI company is making MTCA modules in Japan
  - We should continue to appeal other companies

Question:

- Our usage of Port1 seems to be outside of standard
  - Is there any other solution to realize star configuration?
- Inserting / removing the modules is very hard
  - Sometimes front panel is bent
  - How do you survive?