Applications of MTCA at J-PARC

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J-PARC Center

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Contents

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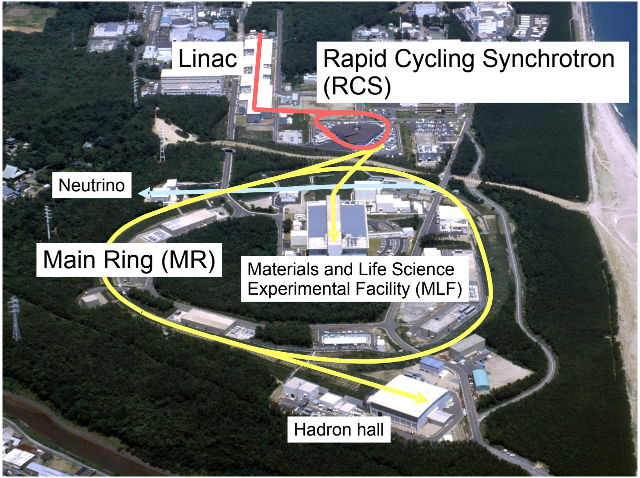
Japan Proton Accelerator Research Complex (J-PARC)



J-PARC Consists of 400 MeV linac, 3 GeV RCS, 30 GeV Main Ring, and experimental facilities (MLF, Hadron, Neutrino).

- Very high intensity proton beam
- Secondary particles used for material/life science and nuclear/particle physics

Beam operation started in 2006.

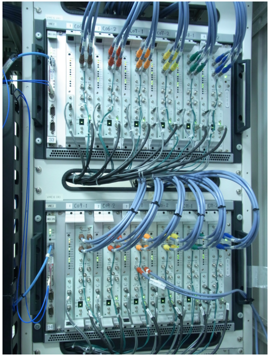
Platforms originally used in J-PARC accelerators

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

Timing system

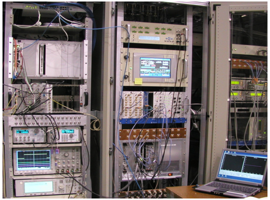
VME+NIM

RCS BPM controller



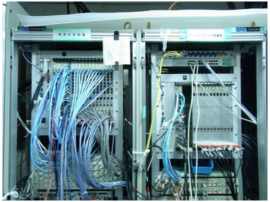
VME

Linac LLRF:



NIM (analog) + cPCI (digital)

RCS, MR:



Specialized 9U VME

Renovation necessary

Our MTCA developments started in 2016.

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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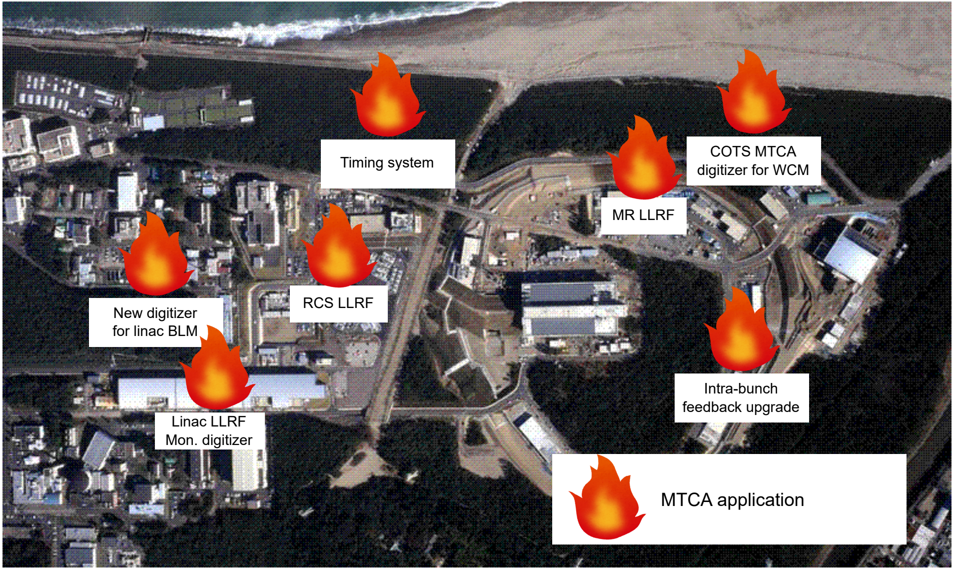
MTCA applications in J-PARC

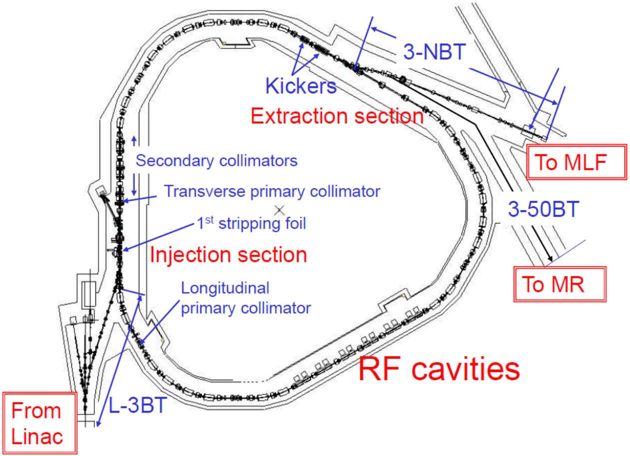


1. Introduction

2. Applications at J-PARC
   RCS LLRF
   Other major applications
   Ongoing development: new digitizer for Linac BLM

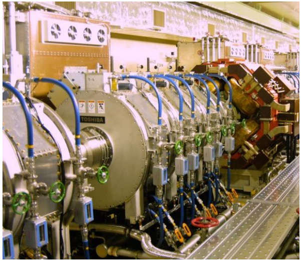
3. Summary and outlook

J-PARC rapid cycling synchrotron (RCS)



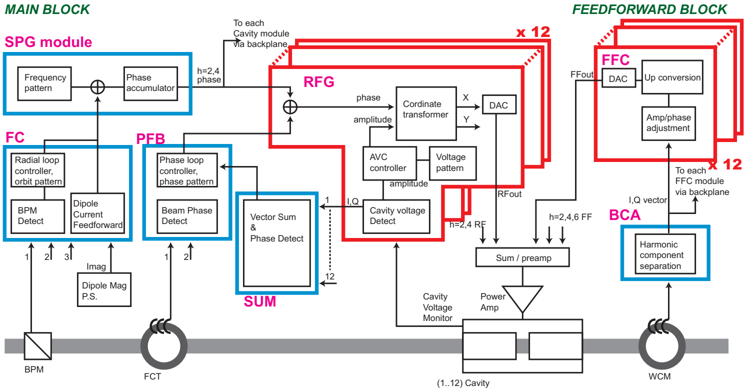
parameter	
circumference	348.333 m
energy	0.400–3 GeV
beam intensity	8.3×10^{13} ppp
beam power	1 MW
repetition rate	25 Hz
accelerating freq	1.22–1.67 MHz
harmonic number	2
max rf voltage	440 kV
No. of cavities	12
Q of rf cavity	2

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, $Q = 2$, dual harmonic operation

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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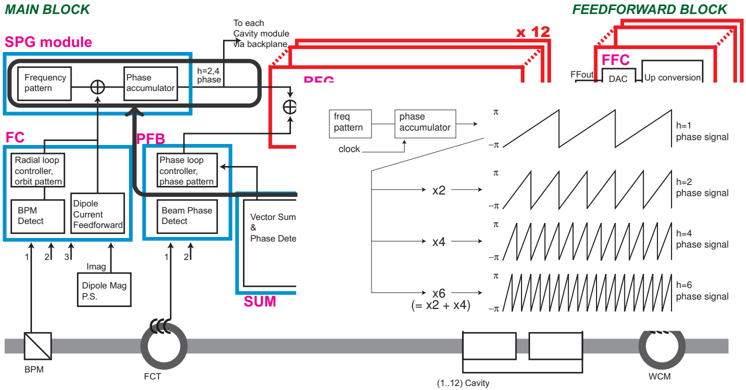

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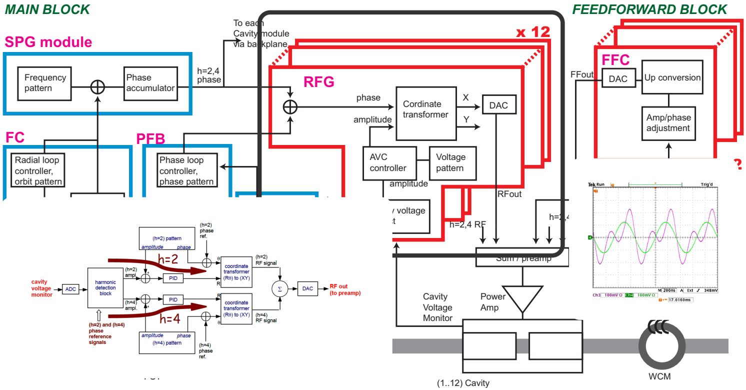

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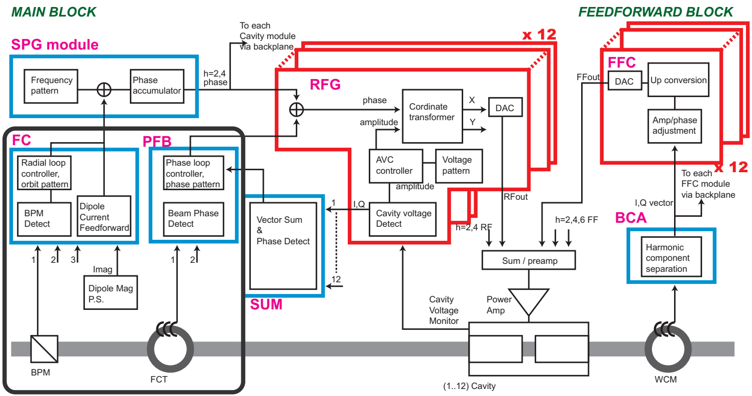

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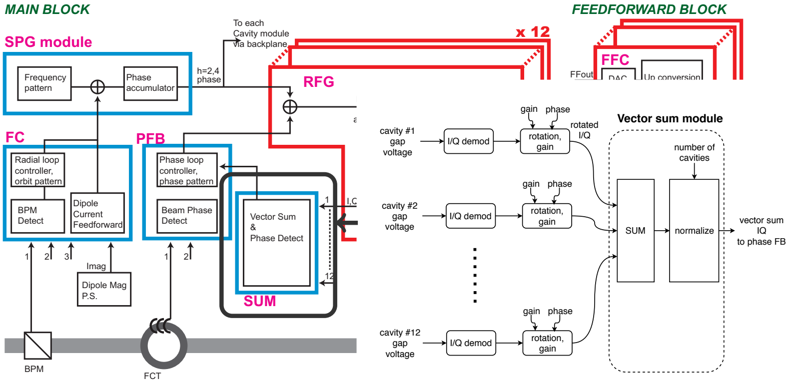

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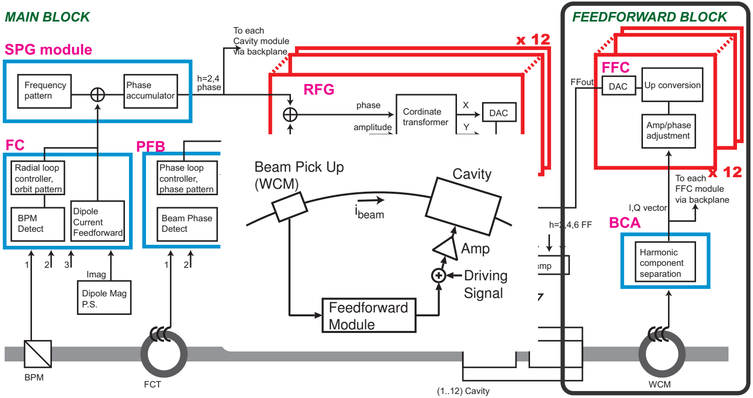

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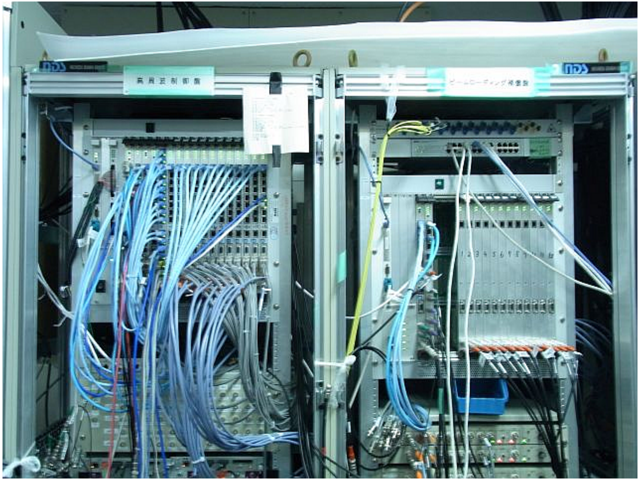
Original RCS LLRF



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

Next generation LLRF control system for RCS deployed in 2019

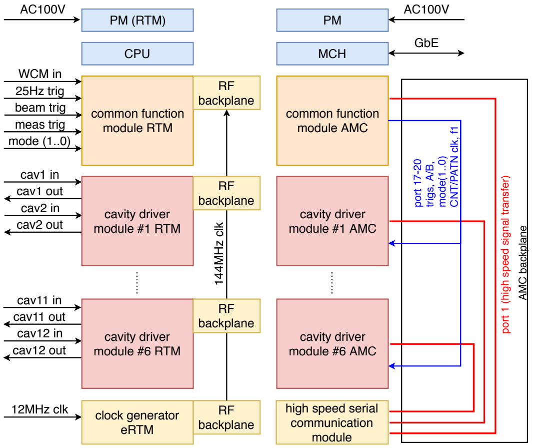
- Shelf with rf backplane
- 1x common function AMC/RTM
- 6x cavity driver AMC/RTM for 12 cavities
- Clock eRTM
- High speed serial communication module

- Signal transfer via backplane, no cables between modules
- Better maintainability

F. Tamura, et al., IEEE Transactions on Nuclear Science, vol. 66, no. 7, pp. 1242-1248 (2019)

Configuration and signal flow

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



System clk:

- 144 MHz
  (original LLRF: 36 MHz)
- generated by clock gen eRTM, distributed via 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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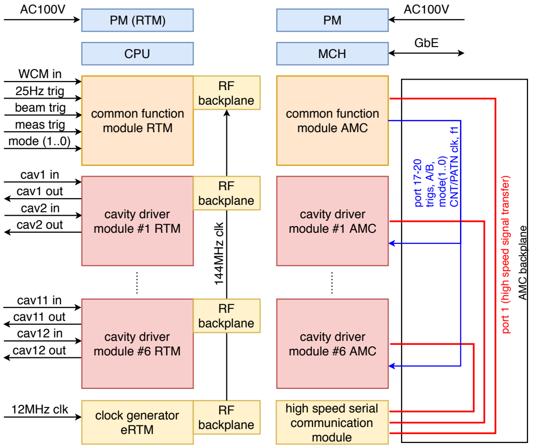

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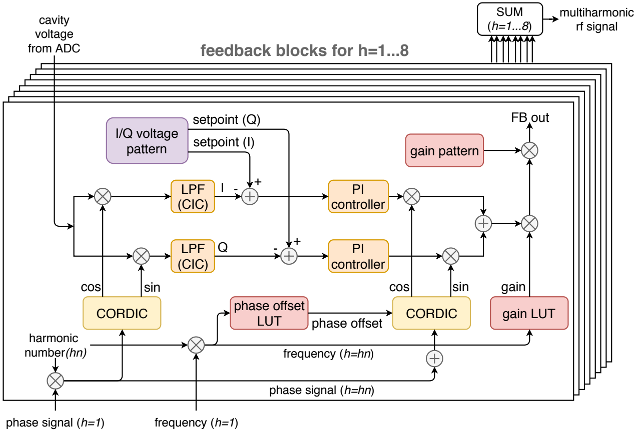
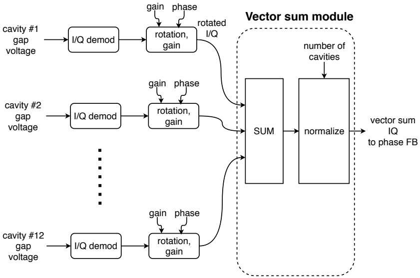
Multiharmonic vector voltage control FB for beam loading compensation

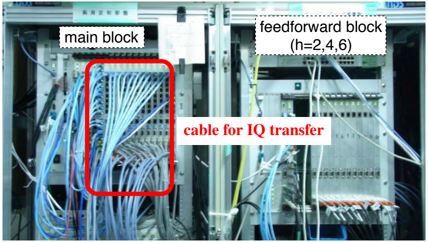


- Lots of resources necessary (narrow band LPF, CORDIC, multiharmonic)
- Thanks to Zynq capacity, a cavity driver handles two cavities / eight harmonics

high speed serial communication

Vector sum:





Star topology signal transfer is necessary.

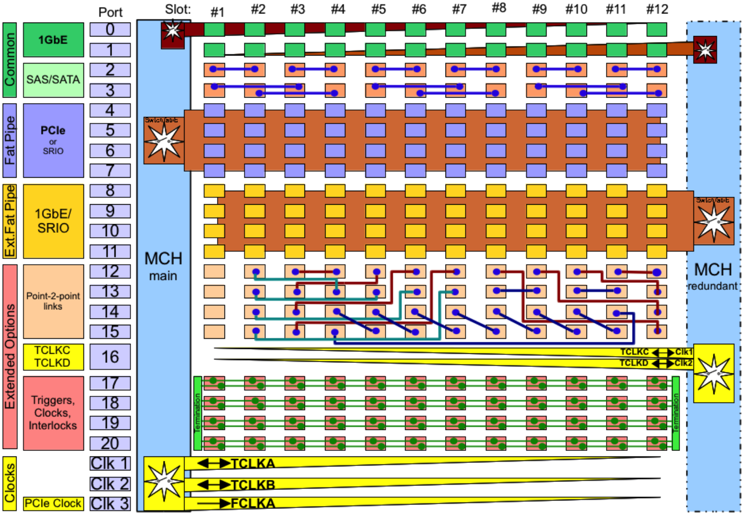
- Vector sum:
  Cavity IQs (drivers)
  → vector sum → phase FB
- Phase FB signal (common)
  → volt control (driver modules)

Existing system uses cables and parallel backplane.

- Not very sophisticated

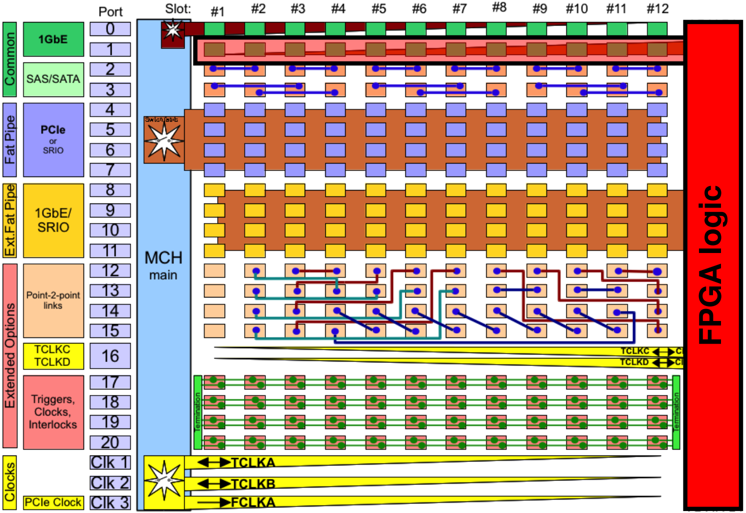
How can we realize star topology with MicroTCA.4?

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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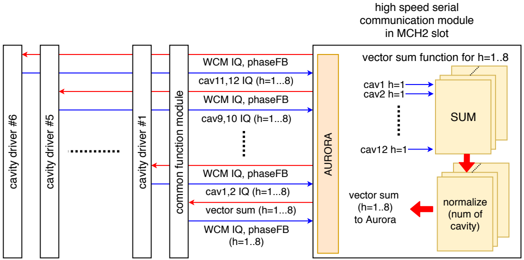
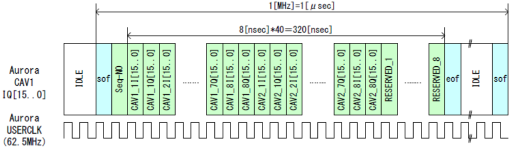
High speed serial communication

Signal flow using Port1:



Aurora data format:



High speed serial communication module:

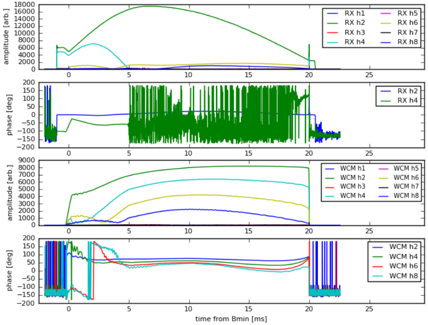
- Virtex-5 used
- Gathers and delivers signals from/to cavity driver modules and common function module
- Vector sum function implemented

Xilinx Aurora used:

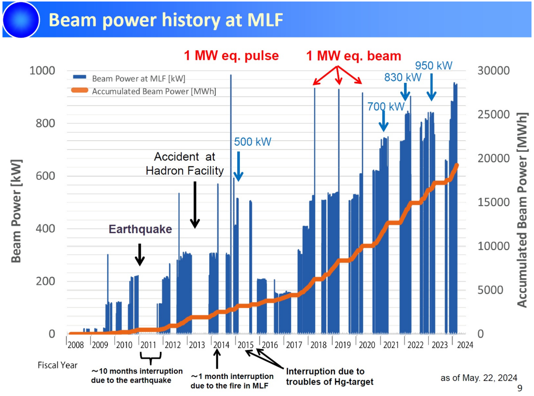
- 1 data frame contains 40 data blocks of 16-bits
- Enough for sending 2x cavities' I/Q signals of 8x harmonics
- Sent every control clock (1 MHz)

New MTCA LLRF contributed to stable operation

Improved beam loading compensation:



F.Tamura, et al., Phys. Rev. Accel. Beams 22, 092001



Since 2019, the output beam power has been increased steadily.

- Design beam power of 1 MW achieved

RCS LLRF summary

The replacement of the original system with MTCA-based system was very successful:

- Messy cabling removed thanks to high speed backplane
- Three VME chasis $\rightarrow$ a single MLCA shelf for full function
- Stable operation
- Hot-swap

Other major applications

Linac LLRF:

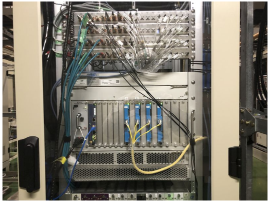
- “Present Status of J-PARC LINAC LLRF”, Kenta Futatsukawa, on Friday

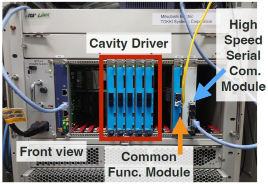
MR LLRF

- “Operation status of MTCA.4 based LLRF control system for the J-PARC MR “, Yasuyuki Sugiyama, on Friday

WCM digitizer for MR

- “A high-speed MTCA.4-based digitizer for the J-PARC MR”, Yasuyuki Sugiyama, today





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2. Applications at J-PARC

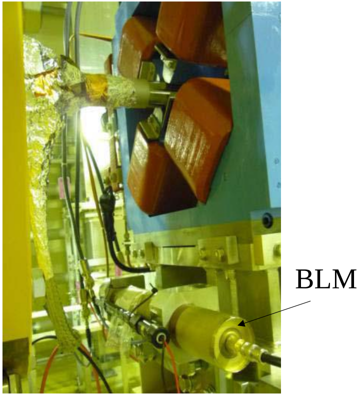
RCS LLRF

Other major applications

Ongoing development: new digitizer for Linac BLM

3. Summary and outlook

BLM: Beam Loss Monitor



Gas Proportional BLM, E6876-600
Canon Electron Tubes & Devices Co., Ltd.

Length	600 mm
Diameter	50.8 mm
Enclosed Gas	Ar and additive gas
Gas Pressure	Approx. 1 atm

Realization of a microsecond response time makes it ideal for machine protection systems. (Taken from the website)

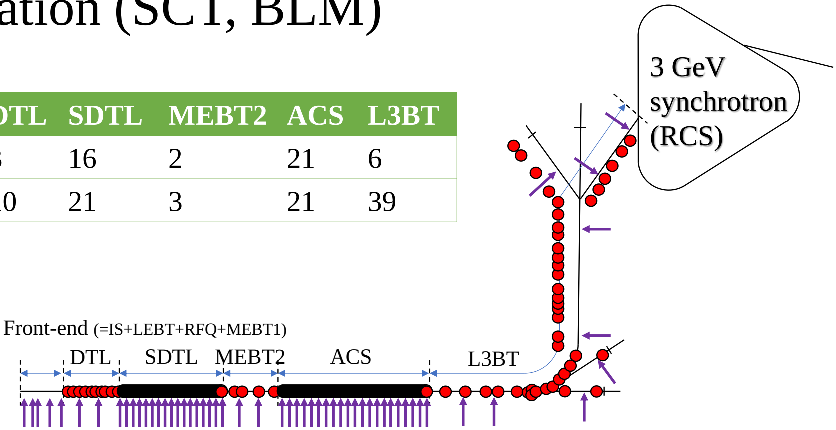
Abnormality detection is determined from signal peak value.
The integral value of the BLM signal is recorded as a trend.

Monitor Location (SCT, BLM)

Monitor	MEBT1	DTL	SDTL	MEBT2	ACS	L3BT
SCT ↑	5	3	16	2	21	6
BLM ●	0	10	21	3	21	39

SCT : Beam current

BLM : Beam loss



SCT and BLM are installed everywhere.

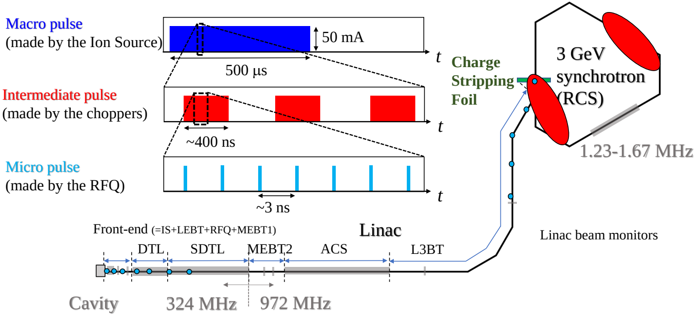
Usage of BLM

Machine Protection System (MPS) / Interlock

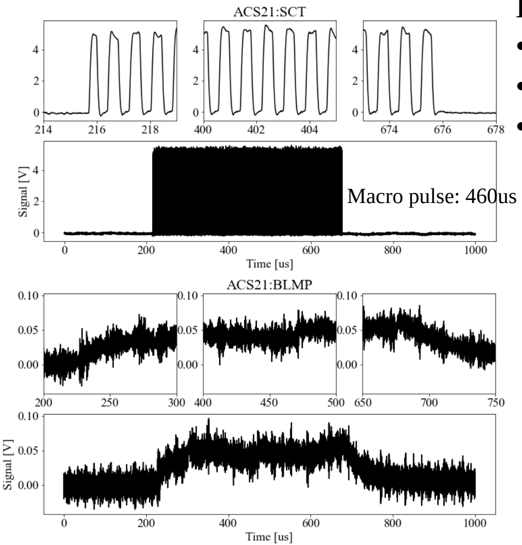
- Abnormal beam loss → beam stop

Beam diagnostics

- BLM is indirect but related to beam quality
- To characterize the beam in macro pulse

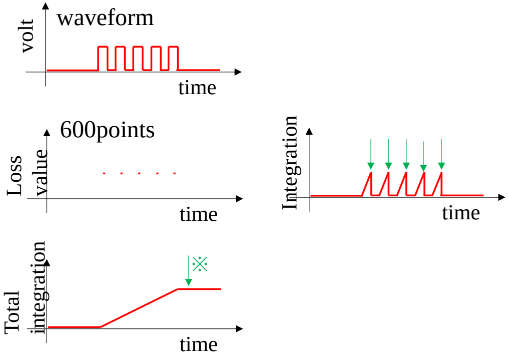


Waveforms and analysis



Digitizer acquires:

- Raw waveform
- Integration over an intermediate pulse
- Integration over macro pulse



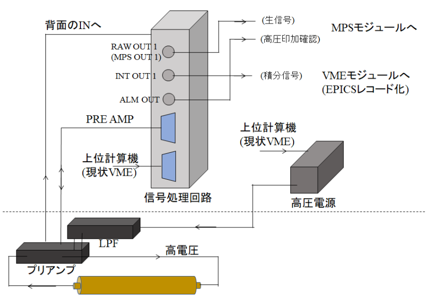
Original and new BLM data acquisition

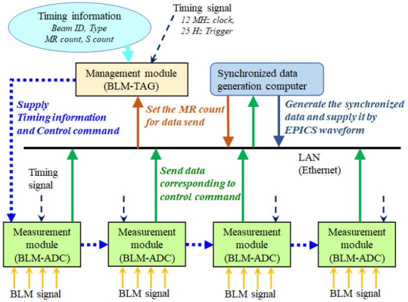
Original: BLM → pre-amp → analog signal processing module → VME (more than 15 yeas old)

New (planned): BLM → pre-amp → MicroTCA ADC/signal processing
Also, "synchronized data acquisition" is introduced, so that well-organized data storage according to beam destination (MLF/MR) is possible

- Sophisticated signal processing on FPGA
- High speed data transfer to storage server

MicroTCA is a good choice.





New digitizer for linac BLM: Summary

A new digitizer for linac BLM based on MTCA is considered.

- Sophisticated signal processing on FPGA
- High speed data transfer to storage server from MTCA CPU

The synchronized-data setup can be also used for SCT and BPM.

Summary and ourlook

Already deployed:

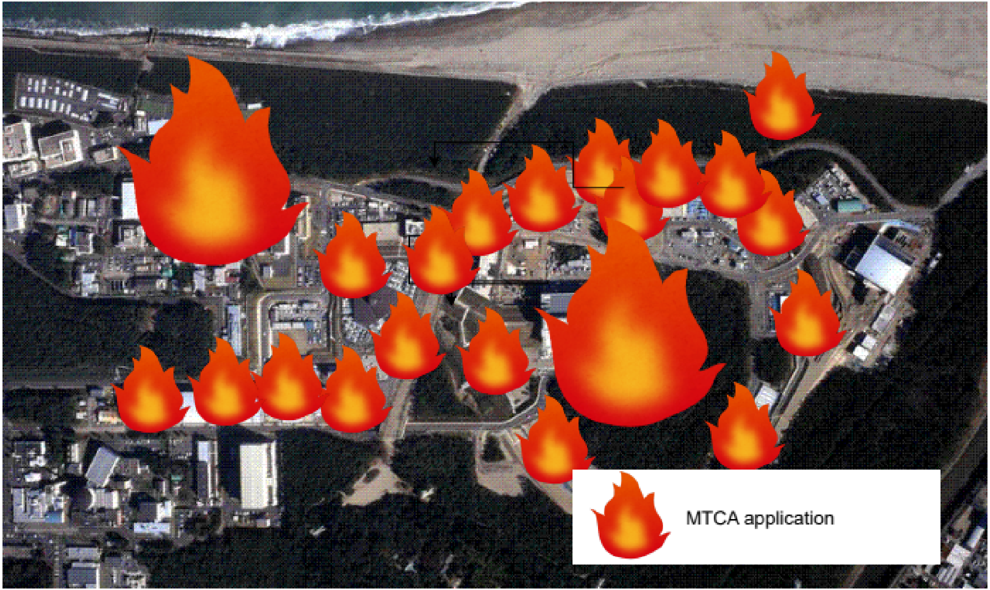
- LLRF (Linac, synchrotrons)
- WCM digitizer

They contribute to the stable operation of J-PARC accelerators.

Ongoing development:

- Digitizer for Linac BLM
- MR intra-bunch FB
- Timing system
- etc...

We continue to push the applications of MTCA at J-PARC.


MTCA application