11th MicroTCA Workshop for Industry and Research

Status of MTCA at J-PARC in 2022

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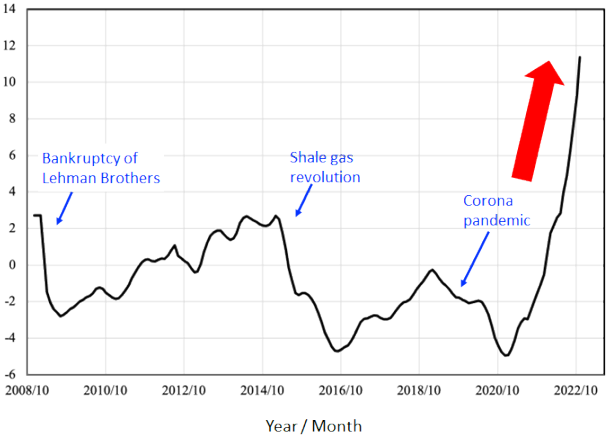
Contents

1. Introduction

2. Selected topics
   Replacement cPCI LLRF with MTCA at linac rf stations (Kenta Futatsukawa)
   Deployment of new LLRF for MR (Yasuyuki Sugiyama)
   Development of muon linac LLRF using COTS modules (Ersin Cicek)

3. Discussion

Introduction

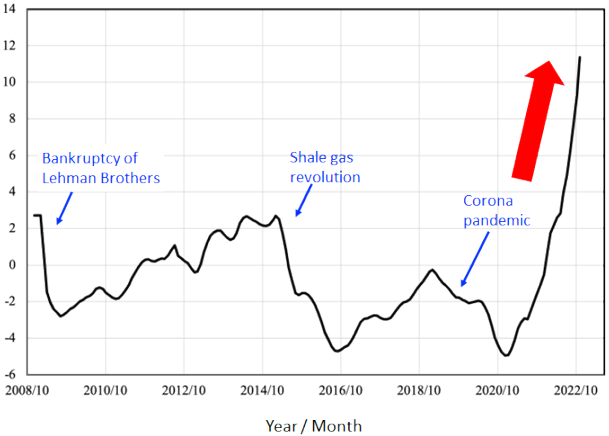


Electricity price is steeply going high...

- Budget crisis
- Beam operating time reduced
- R&D activities (new custom modules etc.) are decelerated

But, MTCA never dies at J-PARC!

Introduction



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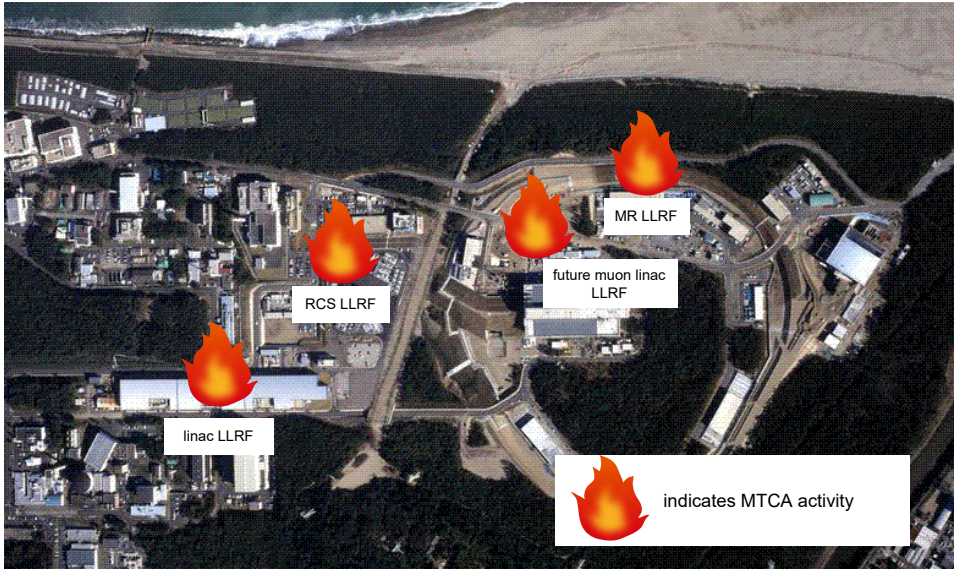
Overview


MR LLRF
future muon linac
LLRF
RCS LLRF
linac LLRF
indicates MTCA activity

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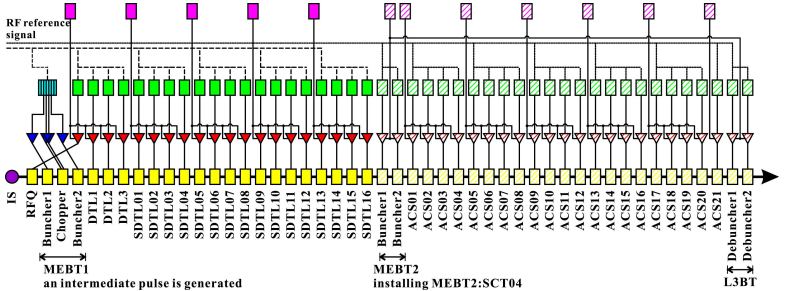
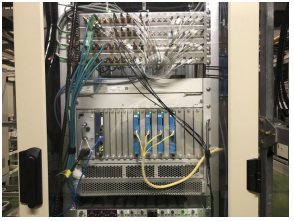
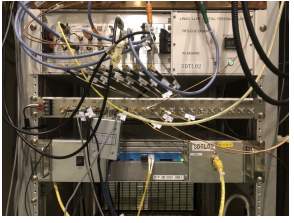
Replacement cPCI LLRF with MTCA at linac rf stations



Full MTCA.4 shelf:



Digitizer box:



All 324 MHz stations (up to SDTL, 24) are now with MTCA.

- MTCA.4 shelf: MEBT1 B1, B2, C1, C2 (4 boards) @ constant temperature and humidity racks
- Digitizer box: RFQ, DTL1-3, SDTL01-16 (20 sets)

Digitizer boxes are to be replaced with MTCA.4 shelf.

972 MHz stations (ACS) are still with original cPCI LLRF.

- Lower latency AMC is required

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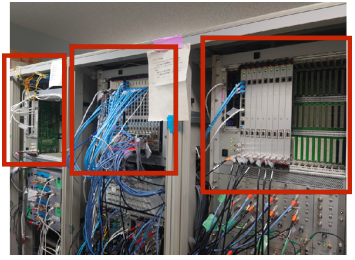
Deployment of new LLRF for MR

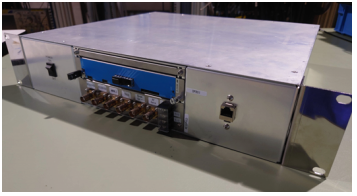
Replacement of original MR LLRF (from 2008) successfully replaced with new MTCA one in 2022.

Original VME LLRF:



New MTCA LLRF (main):

New MTCA LLRF (sub):
(located in different building)

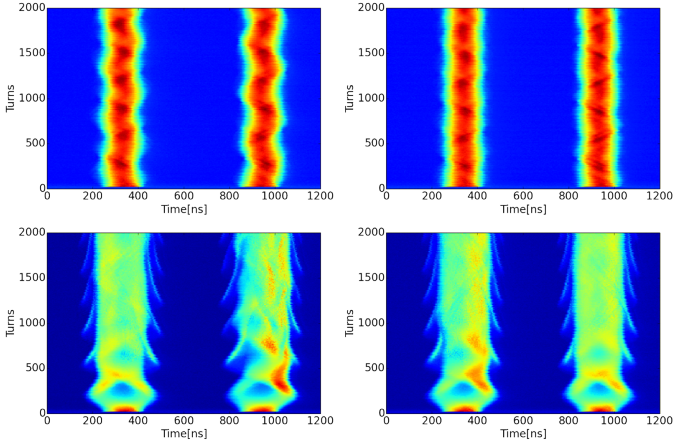


- Cavity upgrade: 9 in Ins-C straight section $\rightarrow$ 9 (Ins-C) + 2 (Ins-A), more accelerating voltage to shorten repetition period from 2.48 s to 1.36 s
- Main LLRF: full MTCA.4 shelf
- Sub LLRF (different building): implemented in a box similar to linac
- Main and sub are connected via optical cable

Deployment of new LLRF for MR

Performance is good.

- New system can compensate beam loading of up to eight harmonics (original system: three)
- Less oscillation with compensation of $h = 6 \cdots 12$ compared to three ($h = 8, 9, 10$)



New MTCA LLRF for MR has been successfully deployed.

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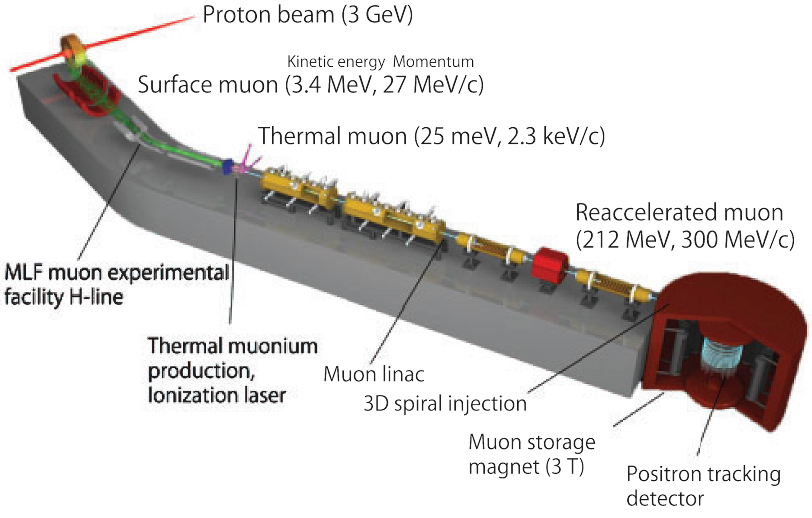
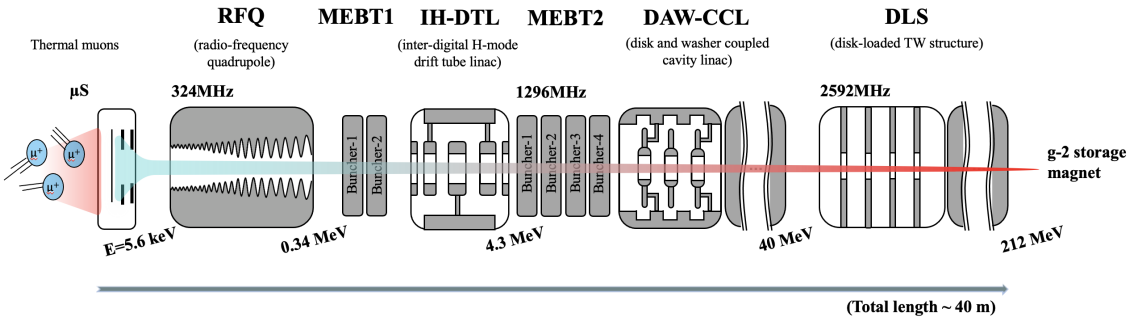
Muon linac for g−2/EDM experiments



Experiments at J-PARC MLF for measuring the muon anomalous magnetic moment and electric dipole moment.

Muon linac layout

muon linac accelerator



μS : muon source
RFQ : radio-frequency quadrupole linac
MEBT1 : medium-energy beam transport line 1
IH-DTL: inter-digital H-mode drift tube linac
MEBT2 : medium-energy beam transport line 2
DAW : disk and washer coupled cavity linac
DLS : disk-loaded TW structure

#frequencies (UHF/L-band/S-band): 3
#rf sources (klystron/SSA): 12
#cavity types (normal conducting): 5-6

RF parameters

	Muon Linac
Beam current	1×10^6 particles/s*
Kinetic energy	212 MeV
Pulse width	10 ns
Repetition rate	25 Hz
Required RF stability	±1%, ±1 deg (pp)+

*It is not necessary to consider a beam load compensation system (FF_BEAM) because the beam current is quite small.

In addition, desired amplitude and phase specifications for the RF system are achievable if a digital feedback (DFB) system is adopted.

+RF system stability requirements: ±1% in amplitude, ±1 deg in phase.
→ Our goals:
- RF & clock generation: ±0.3 deg (~1/3)
- feedback (short term): ±0.3% , ±0.3 deg (~1/3)
- long term stability: ±0.3% , ±0.3 deg (~1/3)

	RFQ	IH-DTL	DAW-CCL	DLS
Frequency	324 MHz	324 MHz	1296 MHz	2592 MHz
# of RF sources	1	1	3	1
Max. RF power (SSA/klystron)	5 kW	600 kW	2.5-3.0 MW	40-60 MW
RF power source	SSA	Klystron	Klystron	Klystron(※)
RF pulse width	40 μs	40 μs	40 μs	4 μs

(※) SLED method employment for S-band is being considered.

Feedback: Hardware

- Considering the R&D, **a Vadatech COTS RFSoC AMC (AMC574)** has been purchased as the first step.
- Essential µTCA.4 components (an MCH, CPU, power supply, and chassis) have been rented.
  - Later, the number of AMC574 boards will be increased (a **total of 5~6 modules** are considered in the LLRF system).
  - We plan a control system with **an AMC574 board for 2~4 RF sources (klystron/SSA).**
  - Employment of the **direct sampling method** for UHF and L-band is considered.

AD/DA: AMC574

MCH: UTC004

CPU: AMC756

Panel: AMC999

Chassis: VT811

- ***AMC574:*** 112-123-100; Xilinx Zynq® UltraScale + **RFSoC** XCZU29DR FPGA;
  - 16x ADCs & 16x DACs
  - "External I/Os" and "REFCLK at 324 MHz (500 MHz max.)"
- ***MCH:*** UTC004-100-010-000-000
- ***CPU*:** AMC756-112-000-000, Processor AMC Intel® Xeon® Processor E3-1505M v6 (**only 1x module for both test&operation)**
- ***Chassis:*** VT811-300-000-000 (**only 1x module for both test&operation):** a total of 12x AMCs can be mounted.
  - A power module (single 1000W AC) to be used in the chassis.

- ADC CLK: 1944MHz (=1296MHz+324 × 2MHz),
- FPGA CLK: 96MHz (=12MHz × 8)
  or 108MHz (=324MHz/3)

- For the digital feedback control and interlock (ILK) systems, an in-house FPGA firmware development is aimed.
  - As the first step, we designed and built **a new in-house DFB system with a Red Pitaya board**.
  - Implementation a similar FPGA design on the AMC574 board is planned.

"Compact and Efficient Radio Frequency Digital Feedback Control System for Accelerator Applications", *Nucl. Instrum. Methods Phys. Res. A. 1046 (2022), Article 167700.*

Schedule

		2021	2022	2023	2024	2025	2026
Digital feedback system (DFB)	Test (without using the actual board) • FPGA (red-pitaya): Firmware • MTCA system (owned by LI): Board communication (DESY Struck boards)						
	• Purchase one actual board and MCH / shelf, etc. • Purchase four actual additional boards						
	Test (using an actual board) • RF performance evaluation of the actual board • Built-in interlock function						
	Embedding in the system						
RF reference signal	Evaluation board selection, modification, evaluation						
	Fabrication of reference signal generator						
Constant temperature and humidity & Drift correction	Testing: • Validation of cable drift measurement method • Performance evaluation of constant temperature and humidity system for the LLRF rack						
	Purchasing a temperature&humidity control system rack Pickup signal constant temperature						
LLRF system	Test & assembly • Test & assembly of 1x LLRF system • Test & assembly of other LLRF systems						
	• Purchase 1x LLRF system (Frequency difference requires purchase for that amount) • Purchasing other LLRF systems • In addition, cables and their installation costs, etc.						

Discussion

Immigration of LLRF systems to MTCA at J-PARC is successful.

- Linac: half
- RCS and MR: completed

I am going to encourage my colleagues to employ MTCA.

- Beam monitors, timing systems...

Ersin's work with COTS AMC for muon linac is important for us.

- First application of COTS AMC at J-PARC, in-house FPGA programming (I know that it is normal in other countries)
- FPGA programming is outsourced in other MTCA projects at J-PARC. A reason of high cost