LLRF and timing system based on MicroTCA.4 at SPring-8

10/10/2022, Low Level RF Workshop 2022 #58

Eito Iwai (JASRI/RIKEN) for SPring-8

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SPring-8

JASRI

RIKEN

Recent LLRF/timing related activities at SPring-8

- LLRF for SPring-8 SR: 10.18429/JACoW-IPAC2017-THPAB117
  - NIM+VME based → MicroTCA.4(MTCA.4) based, replaced in 2018-2019
- Beam injection from SACLA to SPring-8 SR (2020-): 10.18429/JACoW-IPAC2019-THPRB034, 10.18429/JACoW-IPAC2019-THYYPLS1
  - Sync. between two accelerators w/ two different base-clocks that are NOT in rational-relationship by using timing-sync RTM

- New Linac for New SUBARU (NS)
  - Another SR facility for EUV light source, owned by Univ. of Hyogo
  - 1GeV Top-up operation + 1.5GeV Decay mode
  - Injector Linac
    - had shared 1GeV Linac with SPring-8 SR
    - the 1GeV Linac (+ 8GeV Sy) were terminated

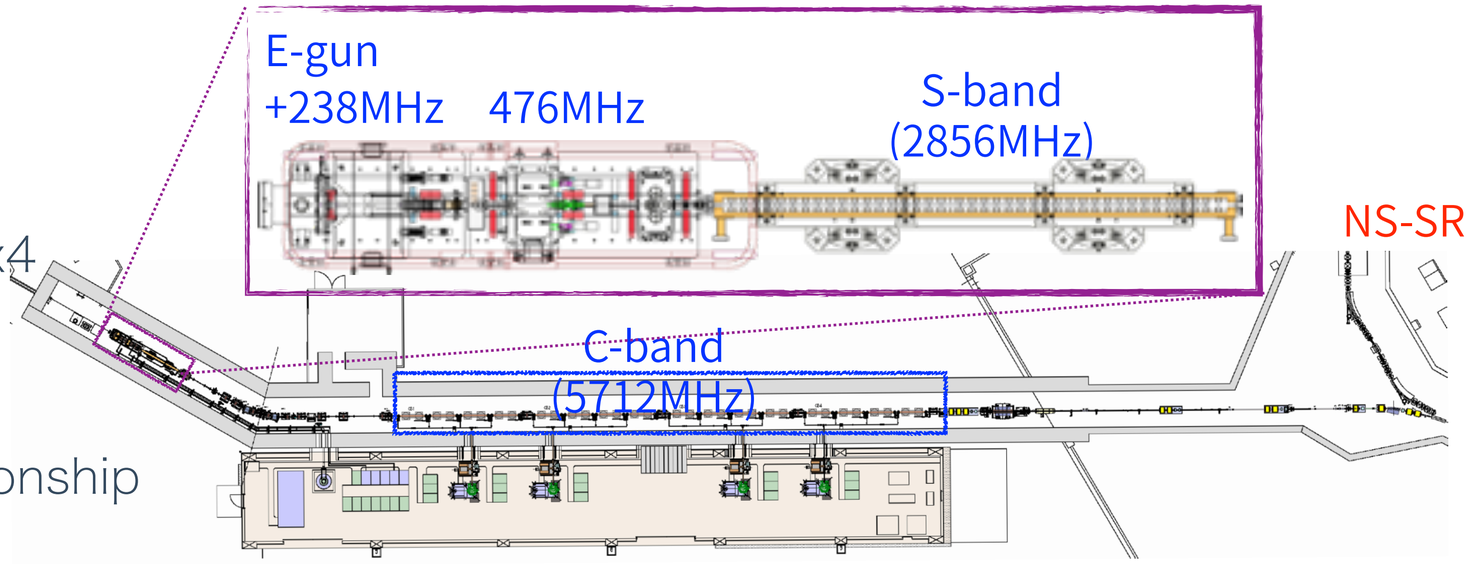
  ➡ A new dedicated injector linac for NS (prototype of a new linac for “NanoTeras

- NanoTerasu: A new 3GeV light source in north-east Japan
  - Acc part is managed by QST, SPring-8 (RIKEN+JASRI) is fully contributing
  - Hardware installation is on-going
  - Beam commissioning will be started by the middle of 2023

  ➡ Similar LLRF/timing system is being installed

New NS Linac and LLRF/timing system

- NS new Linac
  - 1GeV, 100pC, 1pps
    (up to 60pps for conditioning)
  - RF: 238MHz, 476MHz, S-band, C-band x4



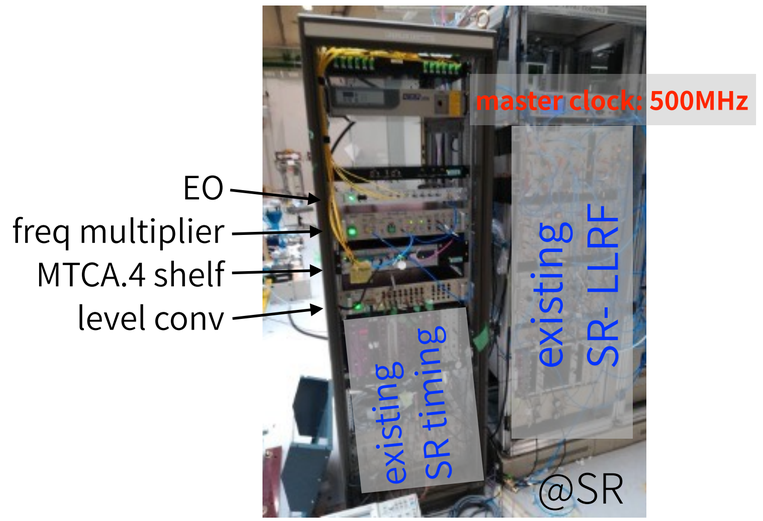
- Timing-sync with SR
  - base frequencies: rational number relationship

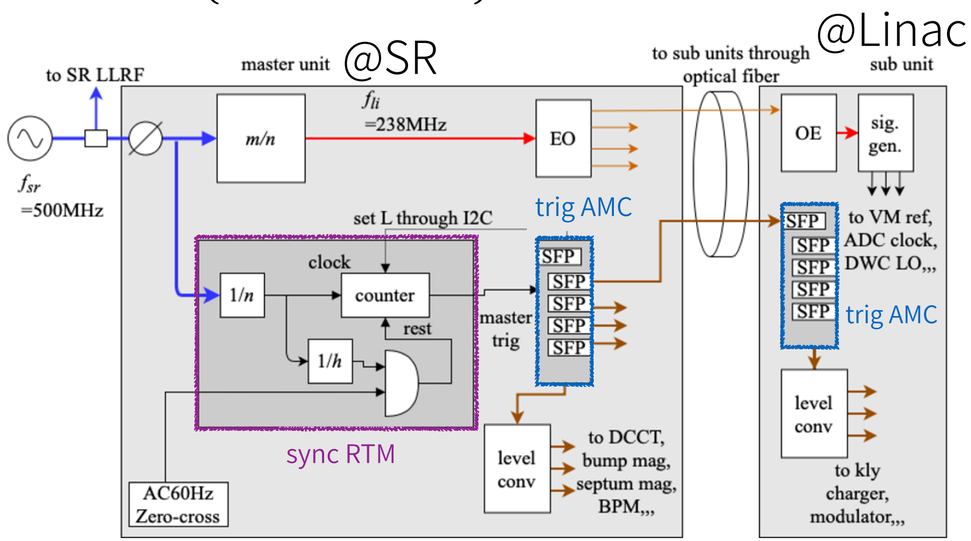
- Requirements
  - stable to keep >90% injection efficiency almost without daily machine-tunings
  - high reliability
  - low cost
- MTCA.4 based system
  - High-integration, High-throughput, Less-wiring, module-management
  - COTS: digitizer AMC, RF-frontend RTM, MCH, CPU, PS, shelf …
  - developing items: digitizer firmware, trigger AMC, timing-sync RTM …

Timing sync with SR

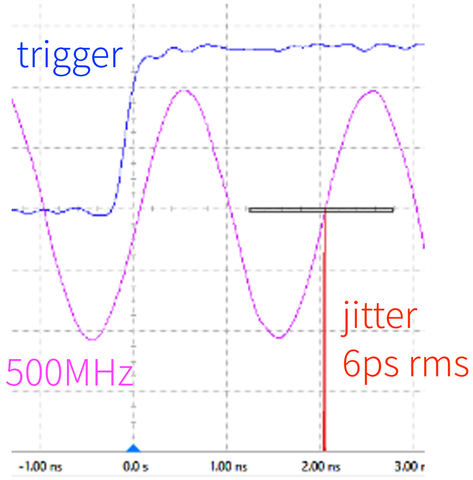
- Base clock of Linac: 238MHz, generated from base clock of SR, 500MHz

$$f_{li} = \frac{m}{n} \times f_{sr} = \frac{308}{647} \times 499.9555\ \mathrm{MHz} \cong 238\ \mathrm{MHz} \times (1 + 1.2 \times 10^{-6})$$

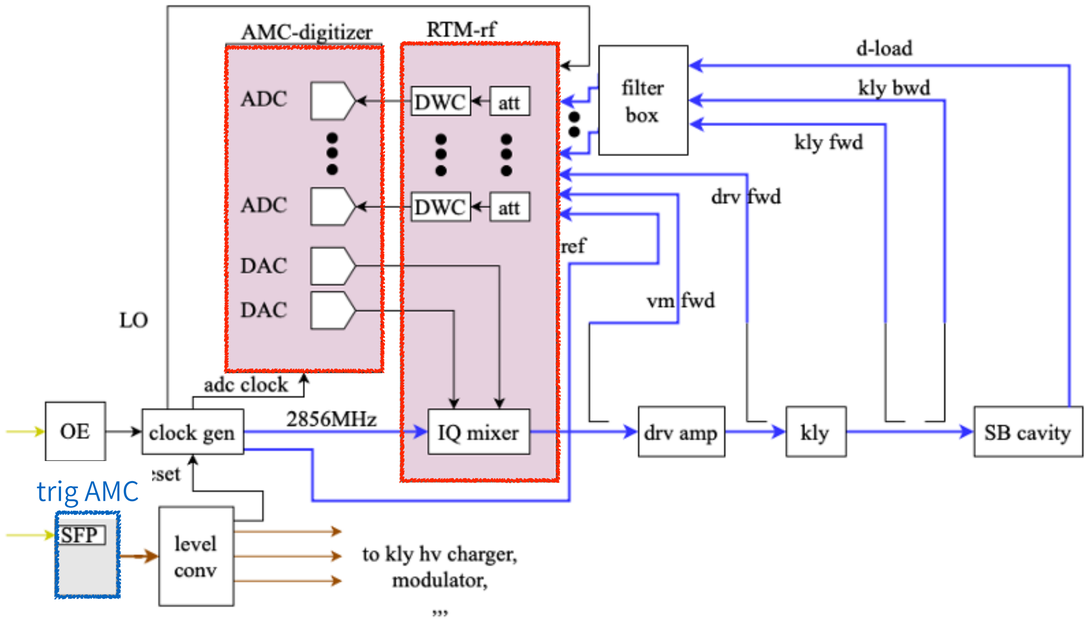




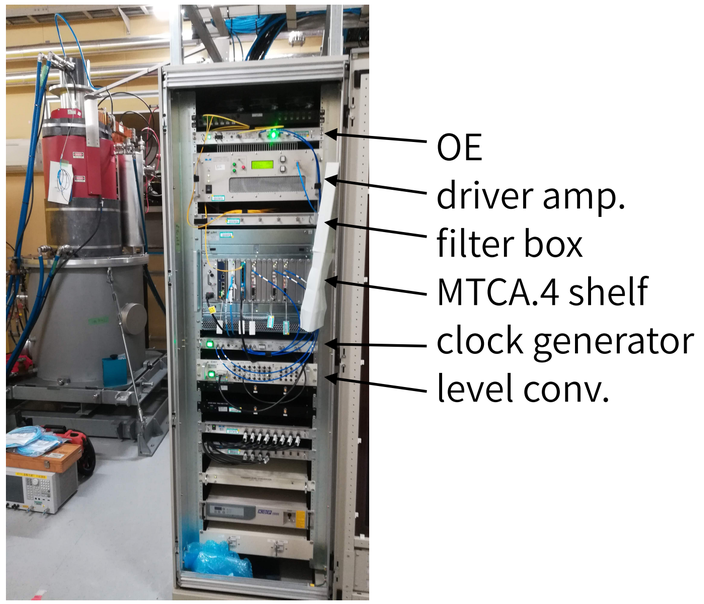
- Triggers:
  - wait for followings to sync
    - AC 60Hz
    - target bucket in SR
    - 238MHz
  - coincidence between the two base-freqs: every ~1.3μs
    → wait certain times to the target bucket



LLRF for new NS Linac



@SB



(※ including non-LLRF stuff)

unit	type	ADC/DAC clock [MHz]	Pulse width [μs]	LO clock [MHz]	requirement	
					δA/A [%]	δφ [deg]
238	under sampling	238 x 4/5	100	—	0.08	0.5
476	down conversion	238	40	476 - 238/4	0.15	0.2
SB			1	2856 - 238/4	0.3	0.5
CB-N			3 (PSK)	5712 - 238/4	0.3	2.5

- AMC/RTM
  - 238MHz: MME-ADC01B (Mitsubishi Elec. Tokki System) + 72DSR238A (Candox Systems)
  - else: SIS8325 + DWC8VM1 (Struck innovative systeme) w/ custom firmware (Mitsui E&S Systems Research)

Check & Calibration Items

- Amplitude dependence (~linearity)
- Phase dependence (phase-slipping measurement)
  → To guarantee the VM calibration above
- Output characteristics of DAC/VM
  → use ADC for (self-)calibration
- Crosstalk
- Step attenuator equipped in RTM
- LLRF trigger timing

Amp/Phase dependence of ADC

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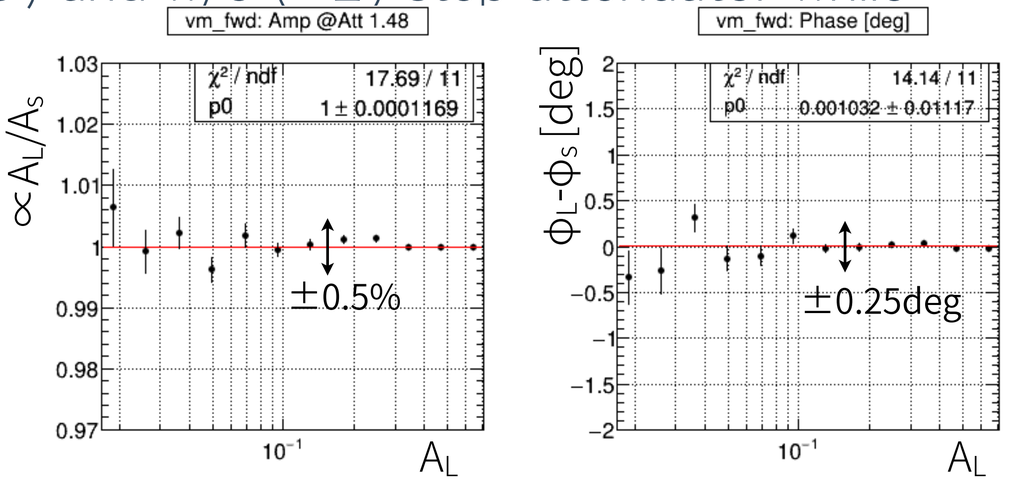
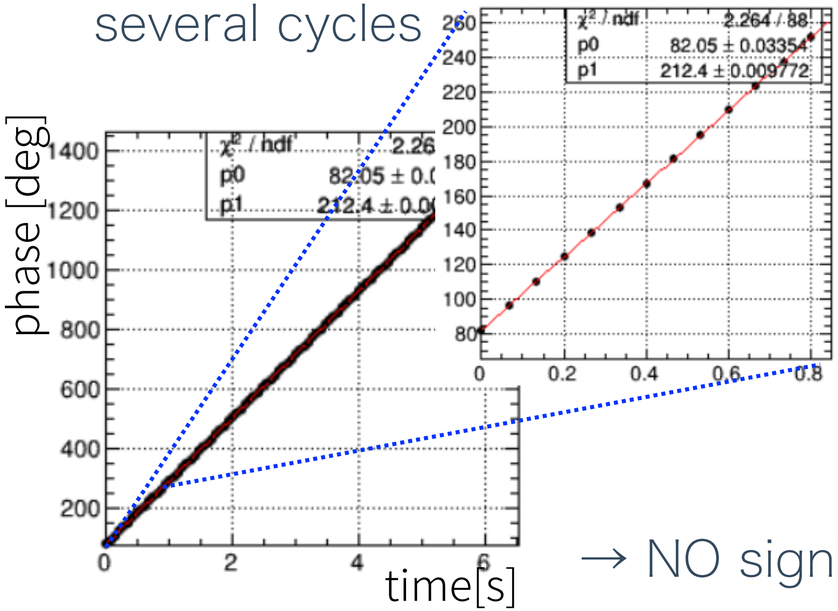
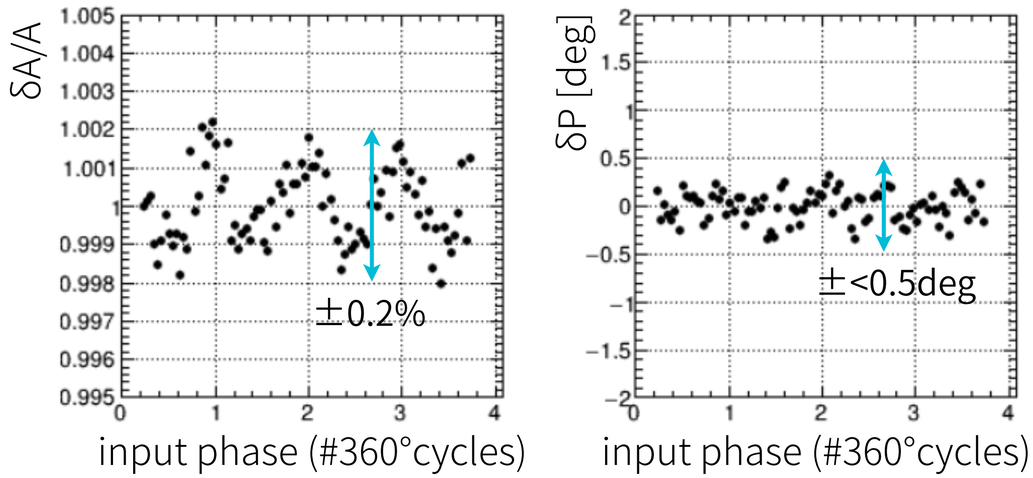
- Amplitude dep (~linearity) : compare outputs w/ (='S') and w/o (='L') step attenuator while changing the input amplitude



- Phase dep: Giving inputs w/ slightly different frequency and measure phase slipping over several cycles





→ NO significant Amp/Phase dep observed, VM correction should be OK

DAC/VM

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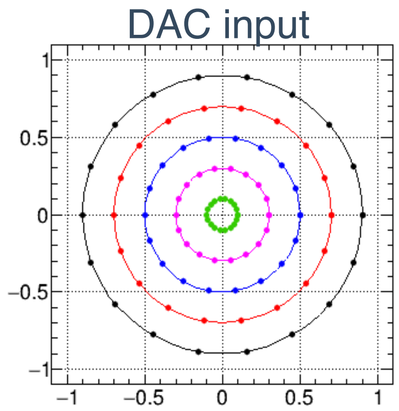
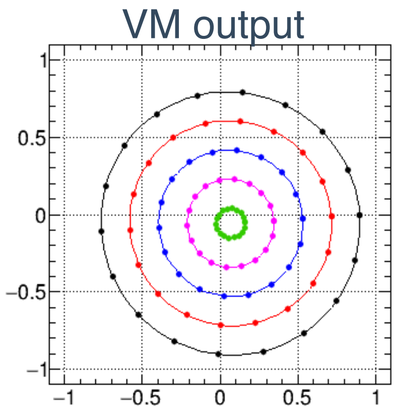
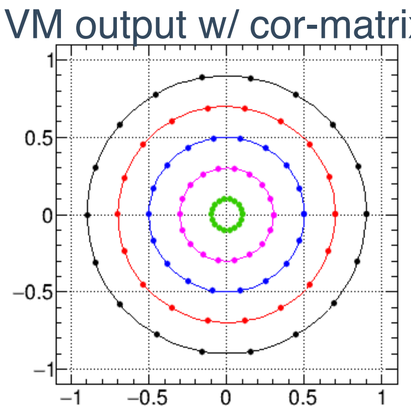
- Using ADC for (self-)calibration for Struck modules

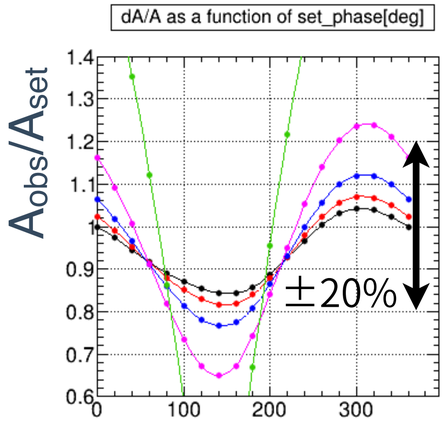


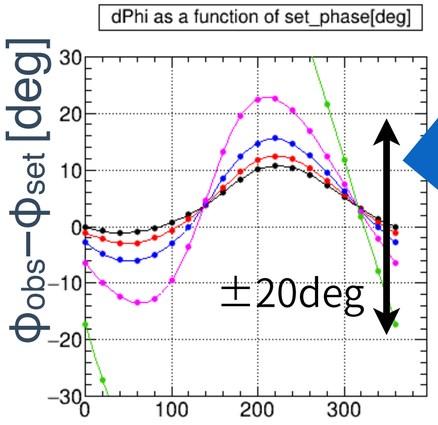


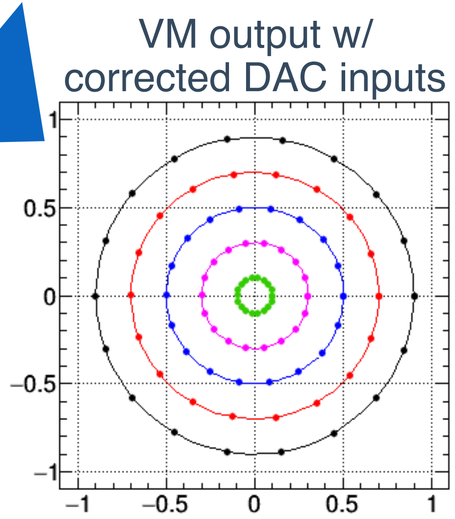


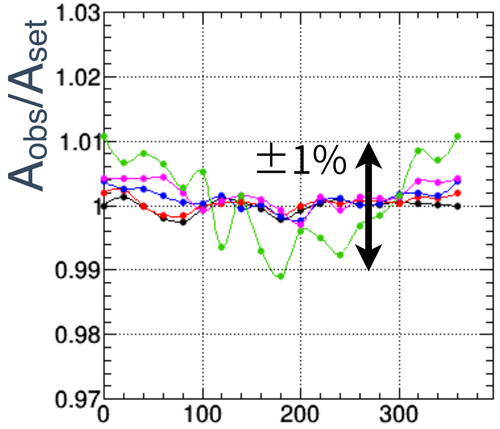
← Parameterize correction matrix
- DAC offset
- distortion (I/Q scale, angle)
- rotation

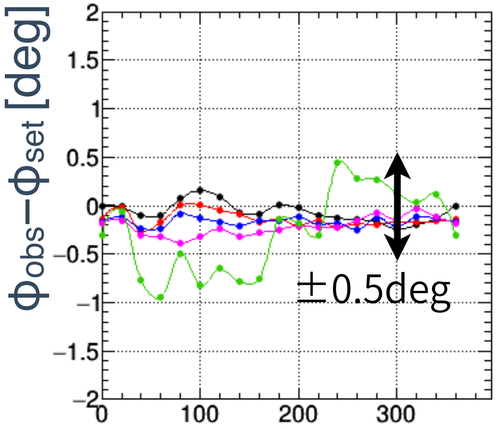
0.9
0.7
0.5
0.3
0.1







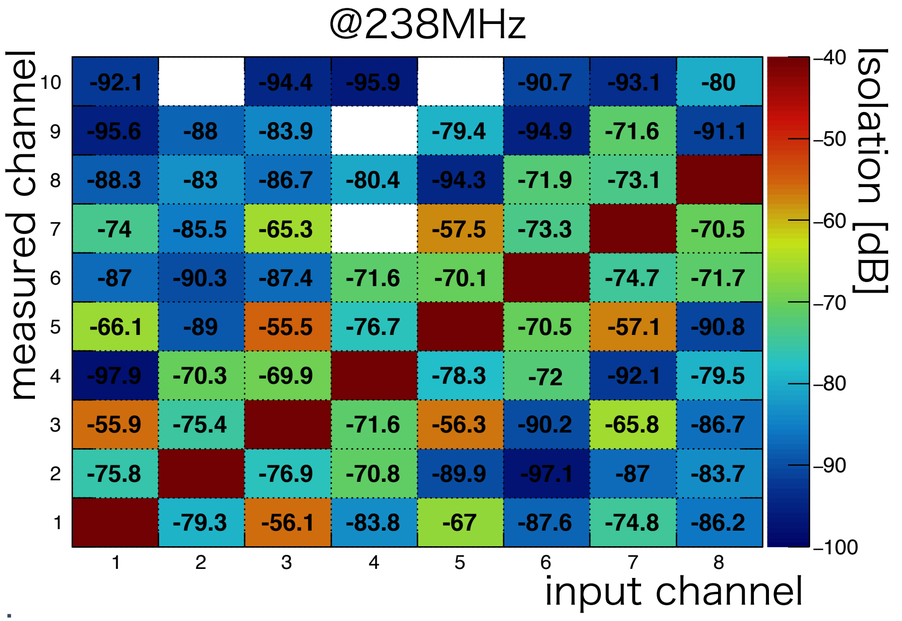


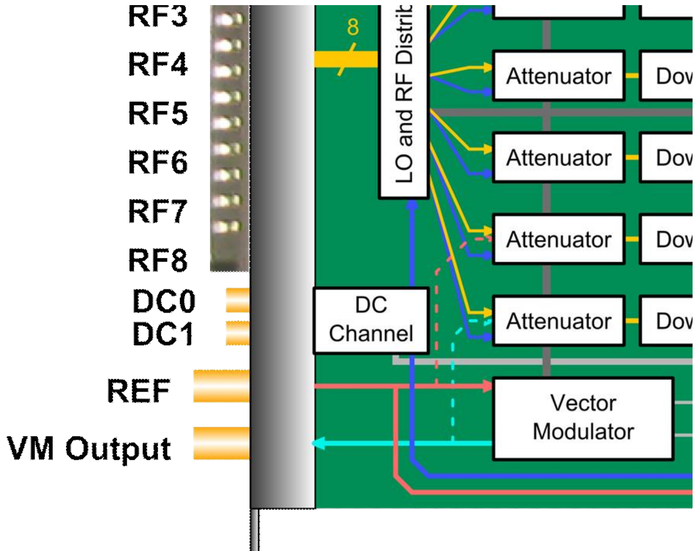


Crosstalk

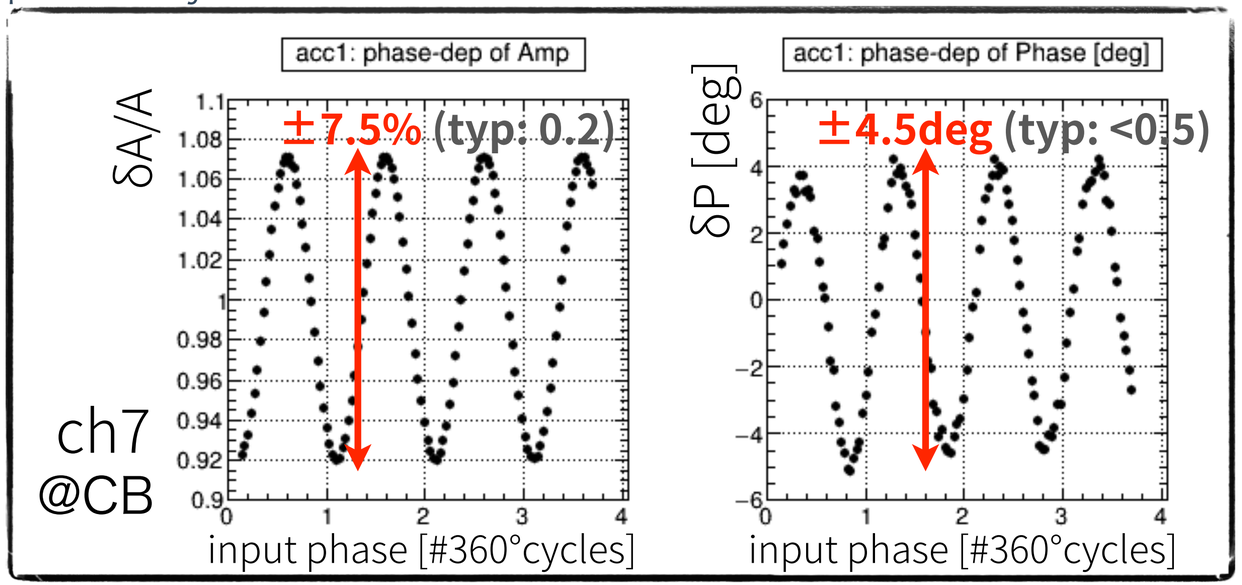
- Under sampling: MME-ADC01B + 72DSR238A
  - Limitation from Zone3 Class A1
  - < -70dB by not using ch3 & ch5

- Down conversion: SIS8325 + DWC8VM1
  - ch-assign options for ch7&8: external or REF/VMout
  - isolation seems to be not good even selecting “external” option
  - If not wiring REF&VMout (ex: monitor), isolation is good enough
  - <-70dB by assigning ch7, 8 to REF, VMout respectively





Observed crosstalk in phase-slipping measurement w/ REF-input



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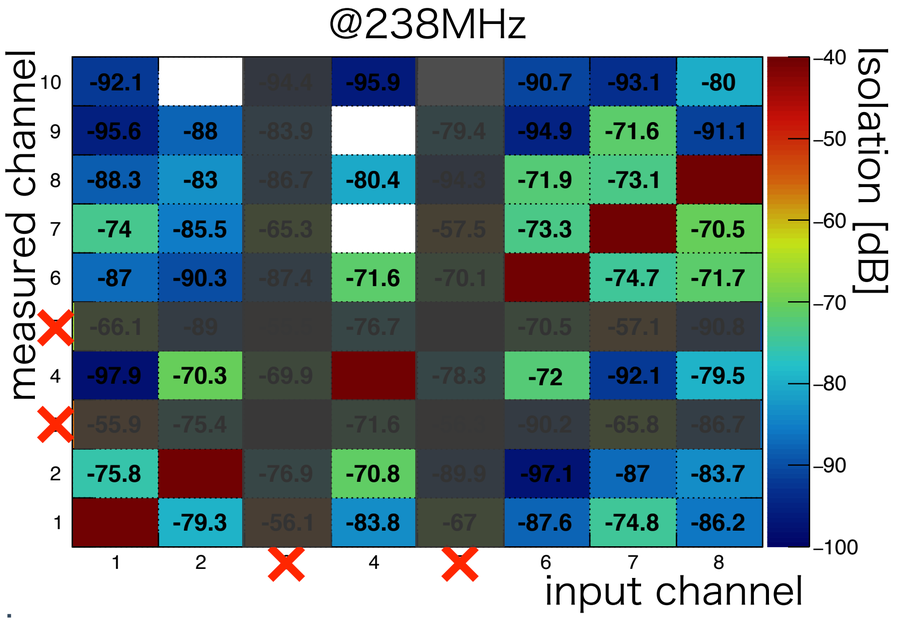

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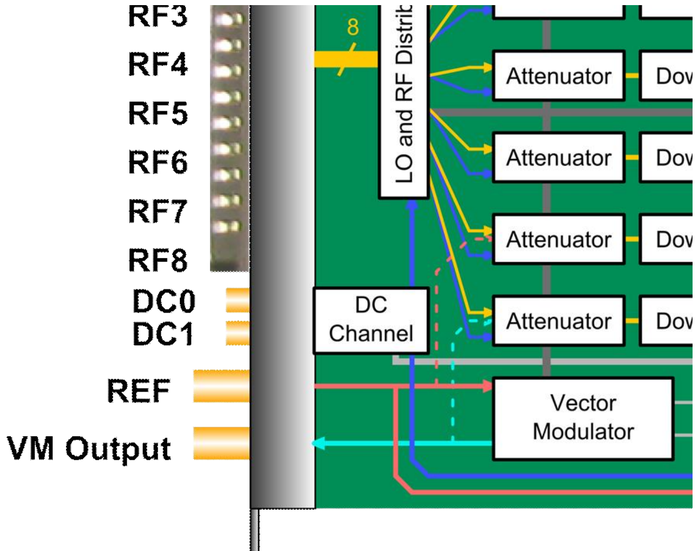

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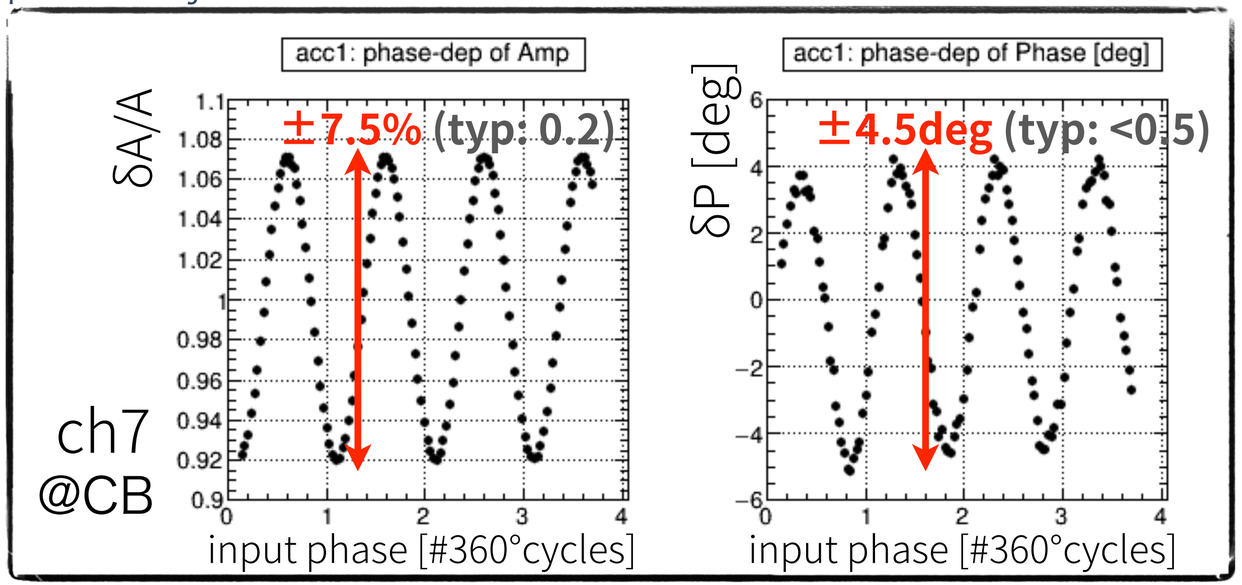

Step attenuator, Trigger-timing

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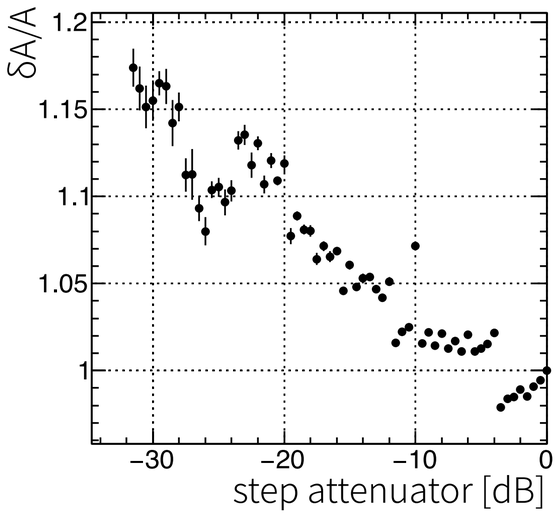
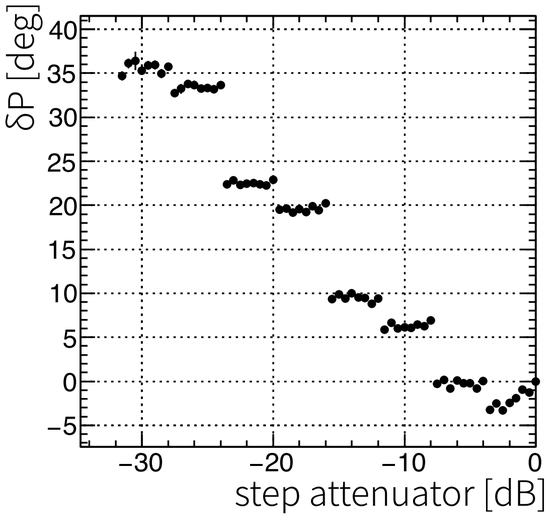
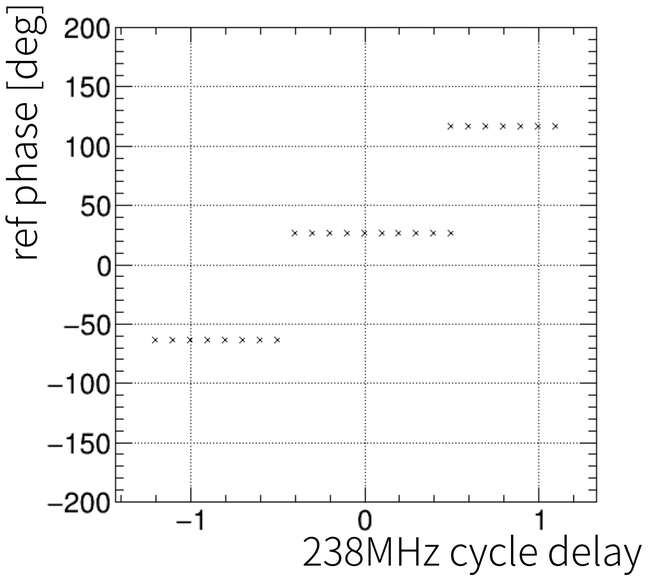
- Step attenuator calibration
  - difference from the specified attenuation
  - observed amp&phase are corrected with these result depending on the step attenuator setting
  - important especially to observe beam induced signal



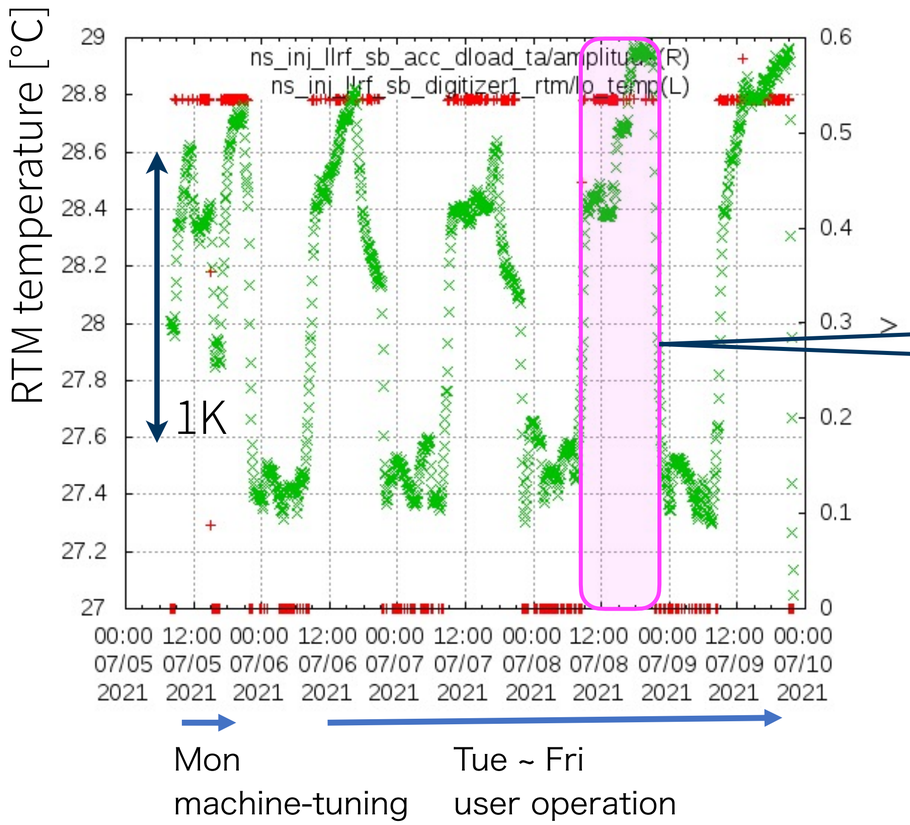


- Trigger timing:
  - IQ sampling w/ neighboring 4 sampling points
  - If triggers jitter against 238MHz-clk of NCO for DDC, phase jumps of 90 degrees should occur
  - Observed phase jump of 90 degrees every 238MHz-cycle, as expected
  - Trigger timing should be set to the middle of flattop

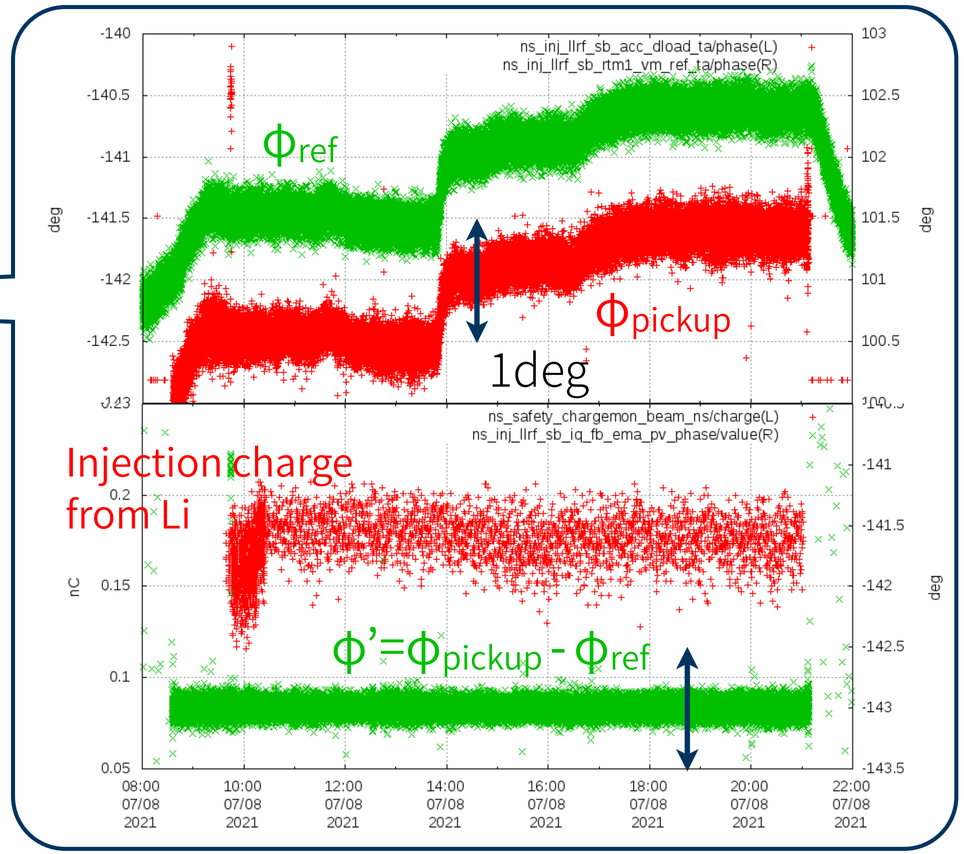


Stability

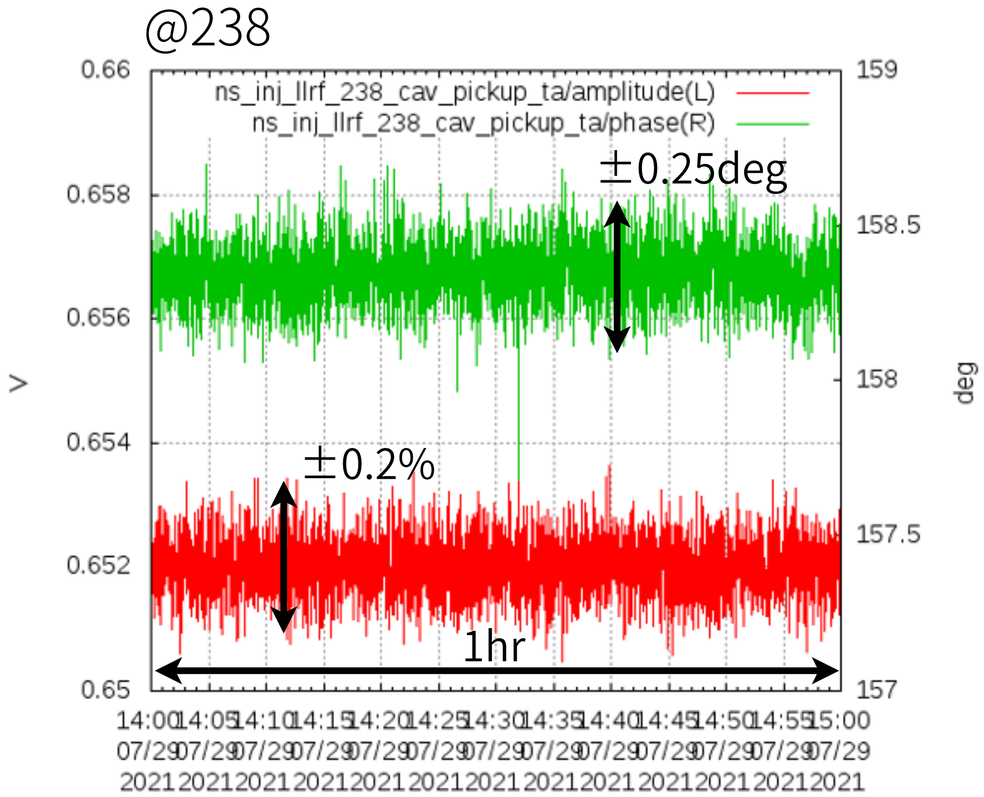
- Temperature dependence
  - History of RTM temp in 5 days
  - Ramp-up acc: ~1.5 K



- δϕ ~1deg both in ref/pickup signals
  - ϕ' = ϕ_{pickup} - ϕ_{ref}
  - Apply feedback for ϕ' to suppress effect due to temp drifts



Stability (cont'd)



(※ including non-LLRF stuff)

unit	δA/A [%]		δφ [deg]	
	required	achieved	required	achieved
238	0.08	0.07	0.5	0.10
476	0.15	0.03	0.2	0.17
SB	0.3	0.06	0.5	0.06
CB	0.3	0.07	2.5	0.08

- Stability within 1hr in rms
  → stable enough to satisfy requirements
- Almost NO daily tuning required

✓ Demonstrate good performance as a prototype of NanoTerasu

Summary

- Introduced LLRF/timing related activities at SPring-8; MTCA.4 based
- LLRF/timing system for a new Linac of NewSUBARU
  - based on MTCA.4 modules
    - digitizer AMC + RF-frontend RTM (238, 476MHz, SB, CB)
    - trigger AMC
    - timing-sync RTM
    - …
  - beam commissioning: 2021/02~, user operation: 2021/04~
    - ✓ NO serious troubles so far
    - ✓ Successfully fulfilled required performance
    - ✓ Achieved stable beam operation, almost NO daily tuning

➡ A similar system is being installed in NanoTerasu, the next generation 3GeV synchrotron radiation facility (HW installation under progress)