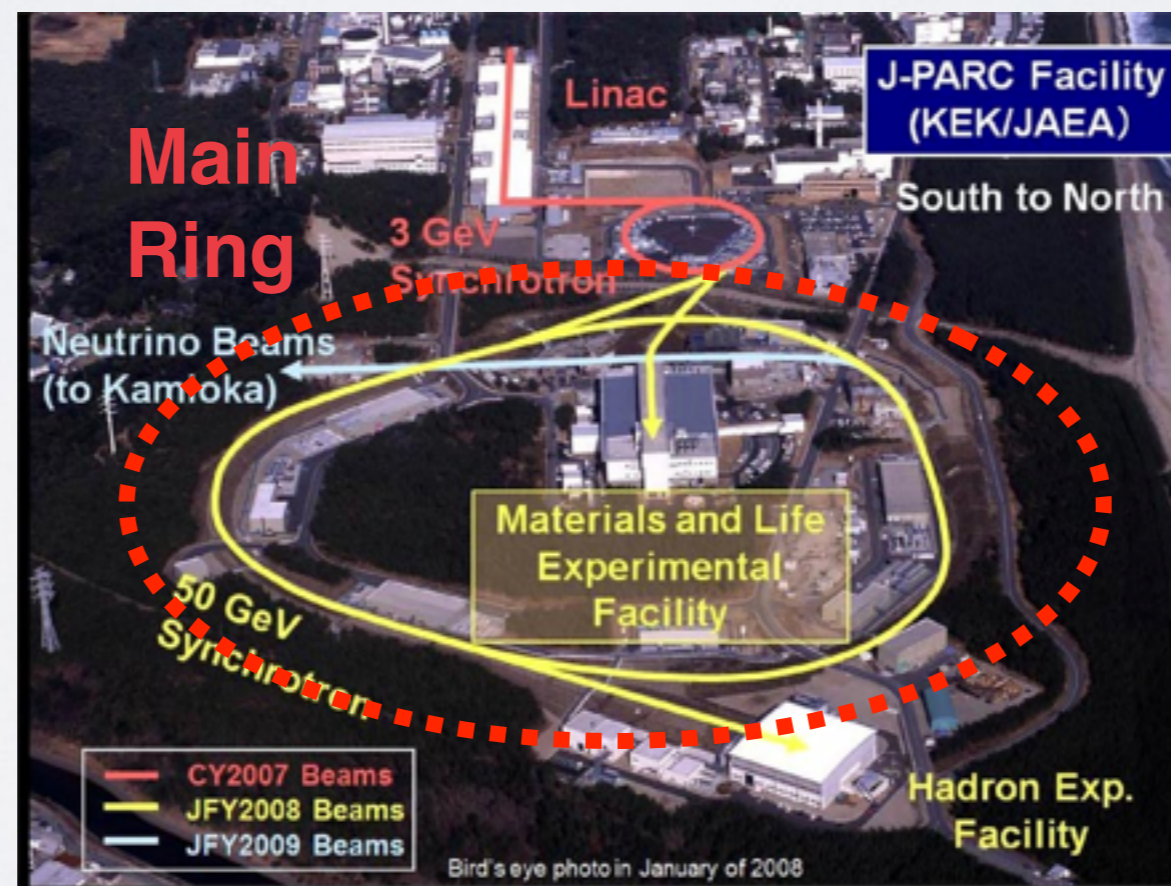


# Longitudinal Mode-by-Mode Feedback System for The J-PARC Main Ring

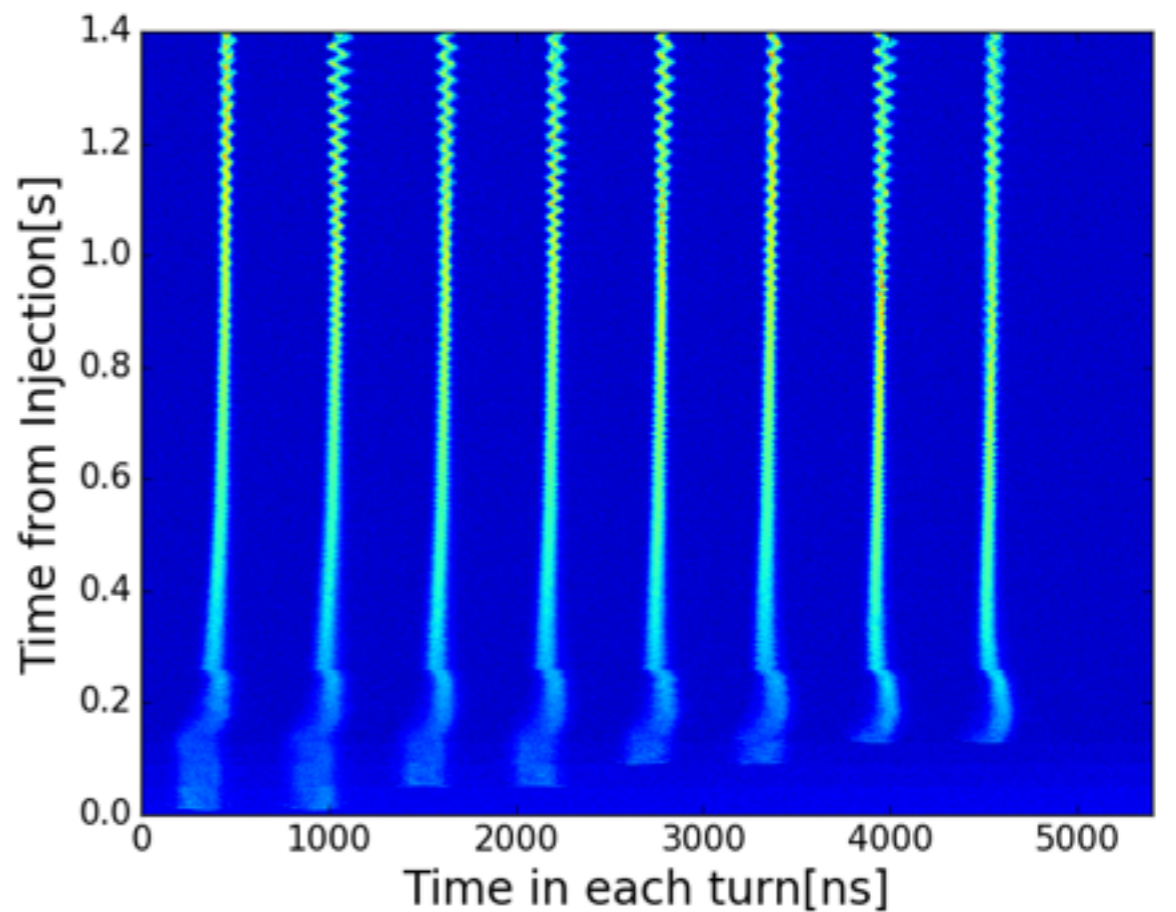
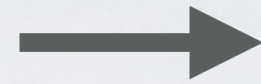
Yasuyuki Sugiyama, Masahito Yoshii, KEK/J-PARC  
Fumihiko Tamura, JAEA/J-PARC



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# Coupled Bunch Instability in J-PARC MR

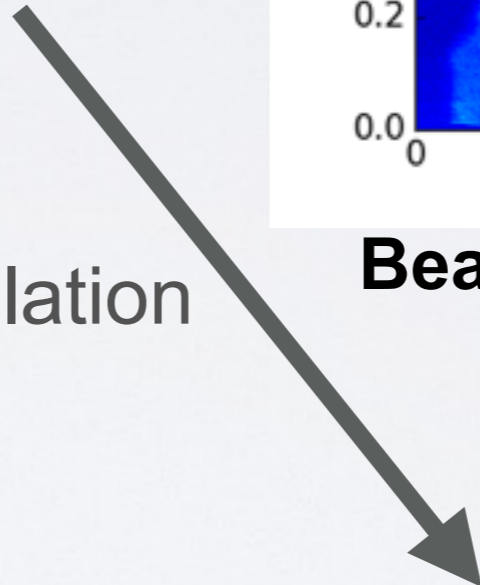
- Longitudinal Oscillation becomes serious in the J-PARC Main Ring (MR)



**Beam Oscillation In J-PARC MR**

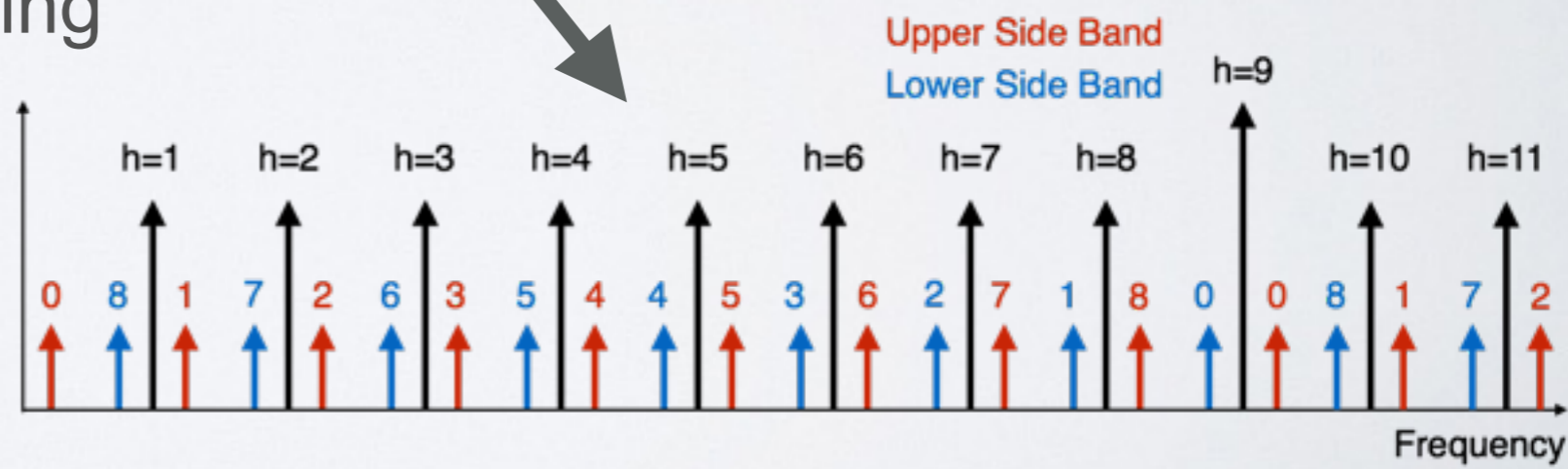
- ➔ Coupled Bunch (CB) Instability

- Oscillation appears as sidebands in the spectrum of the beam signal.



- ➔ Control these sidebands with Feedback to suppress the oscillation

- ➔ Requires Sideband filtering




**The CB modes spectrum for the J-PARC MR. (h=1: revolution frequency)**




# Poster

- Overview of J-PARC MR and CB instability
- Detail of Feedback system and its processor.
- Result of the preliminary beam measurement



## Longitudinal Mode-by-Mode Feedback System for The J-PARC Main Ring

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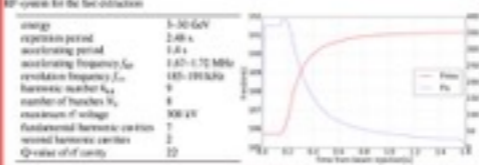


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### J-PARC MR and Longitudinal Coupled Bunch Oscillation

- Main Ring (MR) accelerates protons from 3 GeV to 30 GeV.
- MR delivers  $2.6 \times 10^{14}$  ppp (500 kW) as of May2018.
- **Synchrotron Freq.  $F_s$  is changing during the acceleration.**

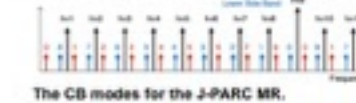
energy	1-30 GeV
extraction period	2.40 $\mu$ s
accelerating period	1.8 $\mu$ s
accelerating frequency $f_{ac}$	2.67-1.75 MHz
revolution frequency $f_{rev}$	165-100 kHz
harmonic number $h$	9
number of bunches $N_b$	6
maximum of voltage	300 kV
fundamental harmonic current	1
second harmonic current	2
Q-value of cavity	22



The mountain plot at 480 kW.

### Coupled Bunch (CB) Oscillation


- For M bunches, there are M coupled bunch oscillation modes with the mode number  $n = 0 \dots M - 1$ .
- Appears as the sidebands of the harmonic components in the beam spectrum. USB  $f_{cb}^+ = n f_{rev} + f_s$
- From the analysis, the LSB  $f_{cb}^- = (M-n) f_{rev} - f_s$  is significant in mode  $n=8$  in  $h=8$  and  $10$  component.



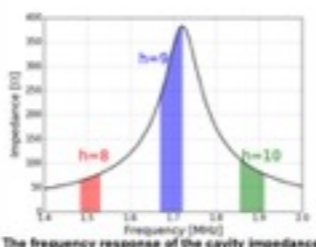
The CB modes for the J-PARC MR.

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### Longitudinal Mode-By-Mode Feedback System



- Detect the oscillation component of the beam signal (synchrotron sideband).
- Control the oscillation component by feedback.
- Share High Level RF with existing LLRF system
- RF cavity for the acceleration has the impedance large enough to generate the kick voltage in  $h=8$  and  $h=10$  to be controlled.
- RF cavity can be used as a longitudinal kicker for the feedback control.

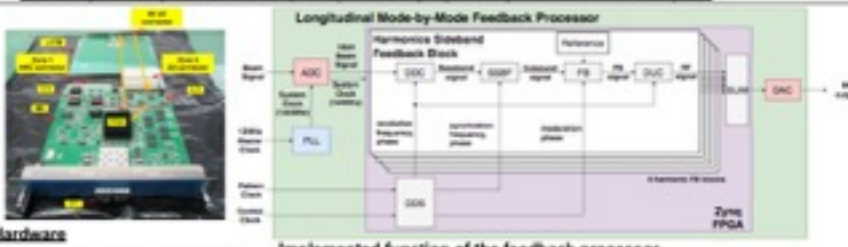


The frequency response of the cavity impedance.

### Longitudinal Mode-by-Mode Feedback Processor

**Requirement for the FB processor**

- Detect and control the synchrotron sideband of each harmonic component
- **Challenge: the synchrotron frequency is changing during the acceleration cycle.**



**Hardware**

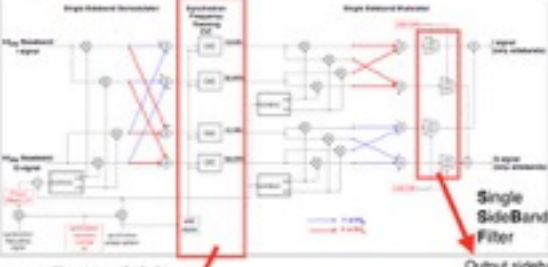
- MicroTCA 4 platform (AMC+RTM)
- AMC with 8ch. ADC, 2ch DAC and Zynq FPGA.
- EPICS-IOC running on the embedded LINUX in Zynq CPU
- Remote control via Channel Access

**Implemented function of the feedback processor**

- Demodulate and Modulate the baseband I/Q signal of the selected harmonic component by DDC and DUC.
- Detect and control only the sideband component.
- Filtering by Single SideBand Filter (SSBF).
- DDS generates sin/cos signals for DDC and DUC and SSBF.

**Single SideBand Filter (SSBF)**

- Demodulate the baseband signal to synchrotron frequency.
- Move synchrotron sideband to  $f=0$
- Suppress the unwanted sidebands
- Modulate the signal to the harmonics.



**Frequency Tracking CIC filter**

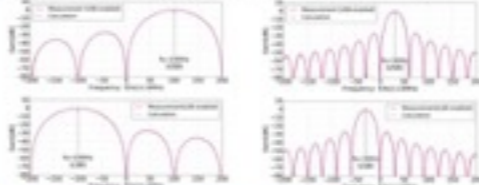
- Running CIC at  $32 f_s$  with the differential delay of 32 clock.
- Notches always at the harmonics of  $f_s$ , while  $f_s$  is changing!

Output sideband can be selected - Individual CB mode control!

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### Frequency response of the system

- The frequency response of the system was measured with the network analyzer.
- FB loop was closed with only P-control enabled to check the frequency response of the filter.
- Amplitude frequency response matched well with the calculation
- Rejection of the DC component and the change of the bandwidth and the peak of the passband along with  $f_s$  were confirmed.




### Beam Excitation Measurement

- Excited the beam by the system and monitor the beam oscillation
- 12 kW low intensity beam was chosen to have the beam without the oscillation.
- Excitation Amplitude: 2.5kV applied from 1.0 s after the beam injection.
- Excitation by modulating the reference pattern to excite the USB of  $h=8$  (CB mode  $n=8$ )

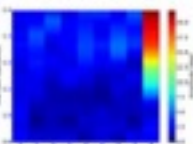
**Beam Oscillation**

- Beam was successfully excited.
- Prove the capability to generate the kick voltage large enough to control the oscillation.



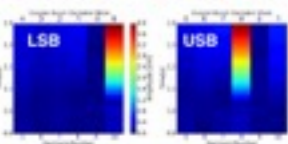
**CB mode analysis**

- Based on the bunch motion analysis of the oscilloscope data
- Confirmed that only the mode  $n=8$  was excited.



**Sidebands Detected by the system**

- Only LSB of  $h=10$  and USB of the  $h=8$  (CB mode  $n=8$ ) had growth
- Growth similar to the oscilloscope analysis based on the different method.
- Detection part worked as designed.



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### Summary and outlook

- We developed longitudinal mode-by-mode feedback system to control the CB oscillation.
- The sideband detection performance was measured with the beam excitation measurement.
- We will perform the beam test to suppress the beam oscillation by closing the FB loop.

12 June 2018, RT2018, Colonial Williamsburg, VA, USA
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