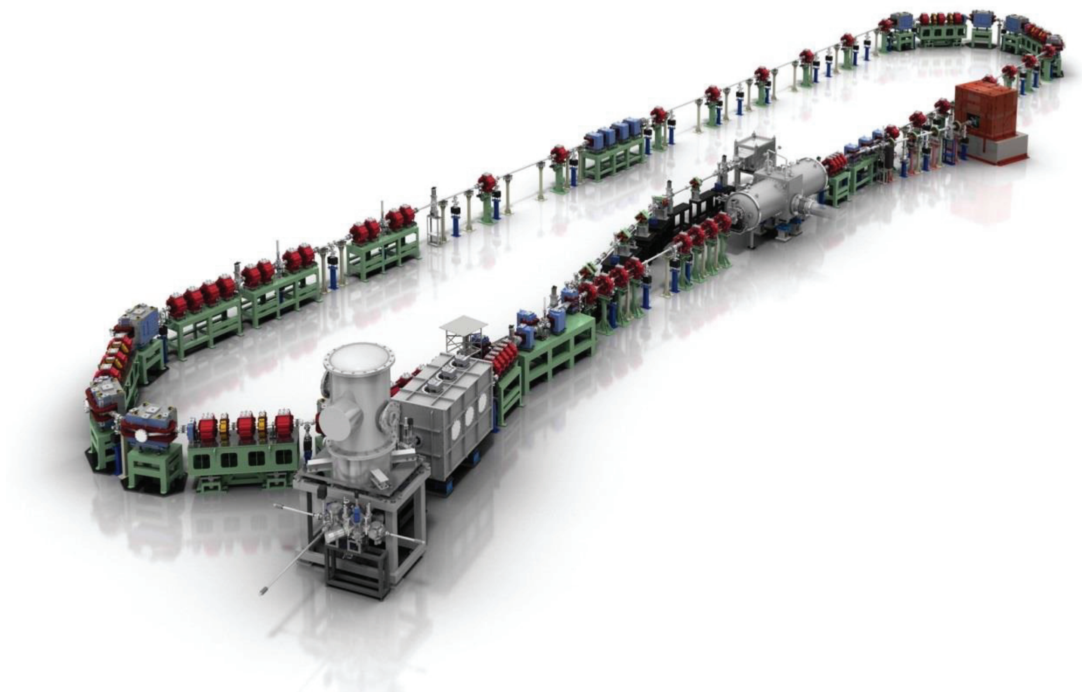
Characterization of microphonics in the compact ERL main linac cavities

Feng QIU (KEK), on behalf of the cERL LLRF group



ERL2019, Berlin (HZB) . Sep. 15 ~ Sep. 20, 2019

Main Content

- Introduction
- LLRF and Tuner control system
- RF stabilities of the ML cavities
- Microphonics measurement
- System identification of piezo tuner
- Summary

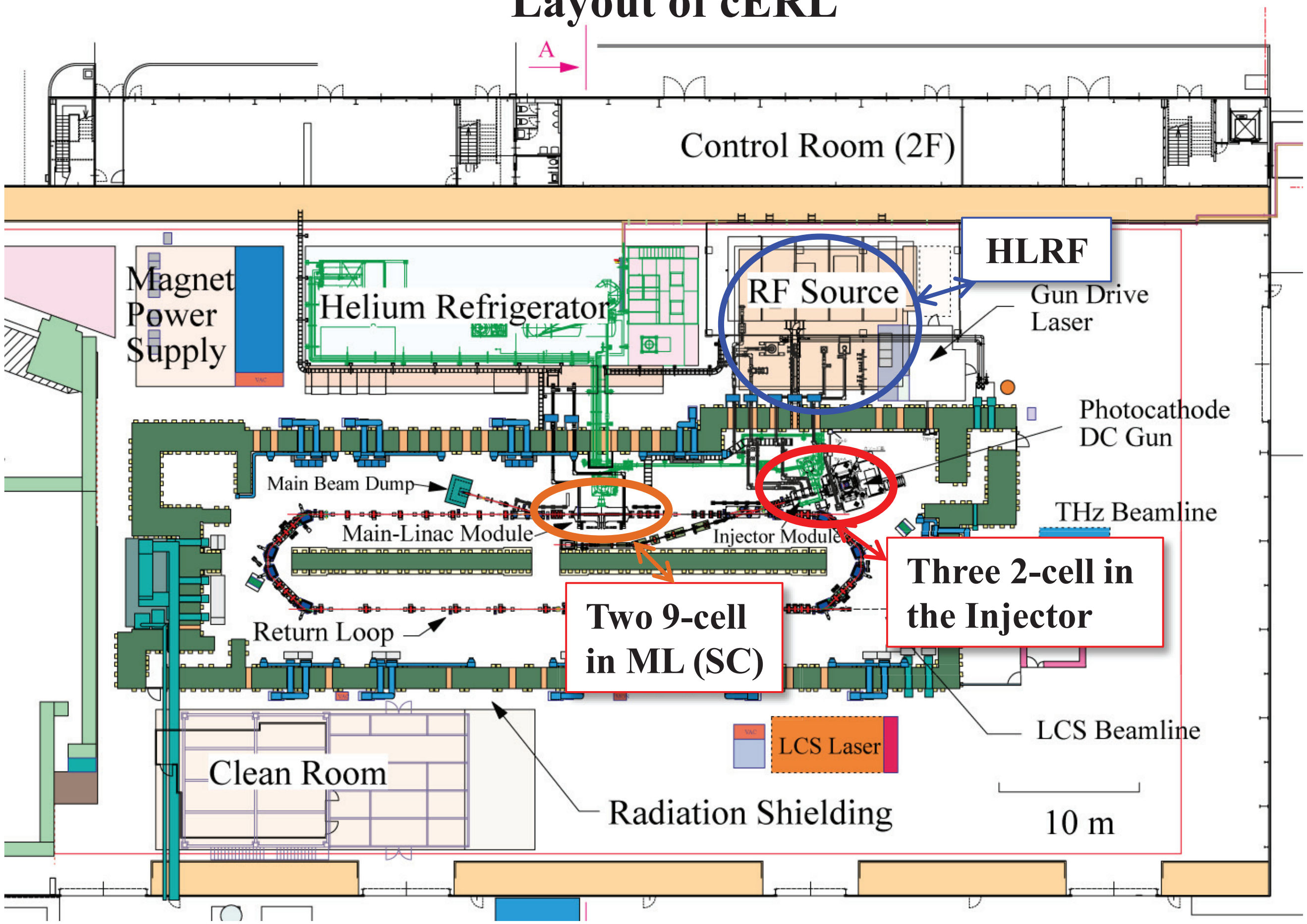
Introduction

- The Compact ERL (cERL) is a test facility to demonstrate ERL technology. It is a 1.3-GHz superconducting system and is operated in CW mode [1].

Layout of cERL

Injector consists of four cavities: Buncher (NC), Injector 1 (SC), Injector 2 (SC), Injector 3 (SC).

Main linac (ML) includes two nine-cell cavities (SC).



- April, 2013, injector commissioning. Oct. 2013, main linac commissioning.

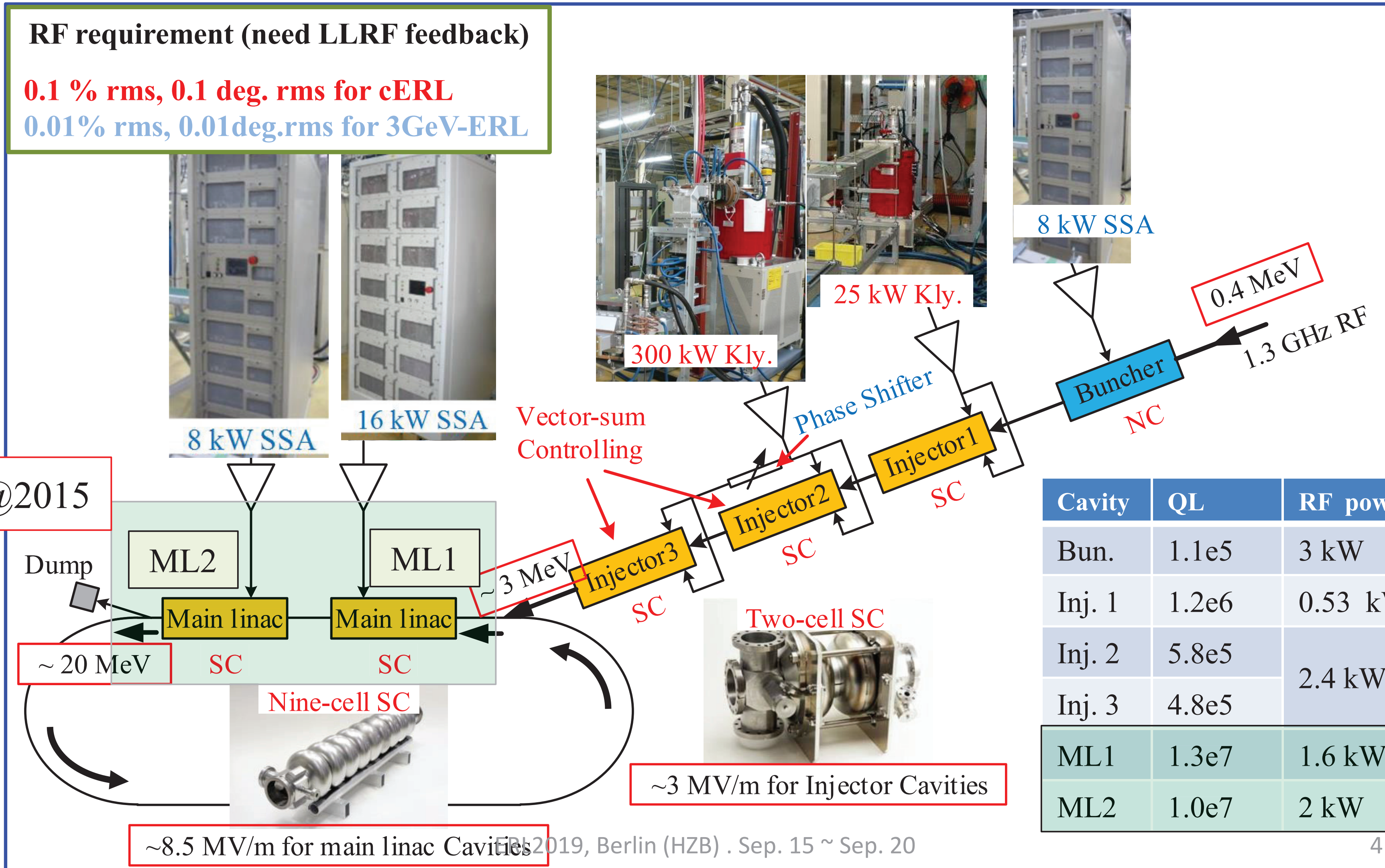
Cavity and RF system

- At present, total four kinds of power sources are applied in cERL : 8 kW SSA, 16 kW SSA, 25-kW klystron and 300 kW klystron.

RF requirement (need LLRF feedback)

0.1 % rms, 0.1 deg. rms for cERL

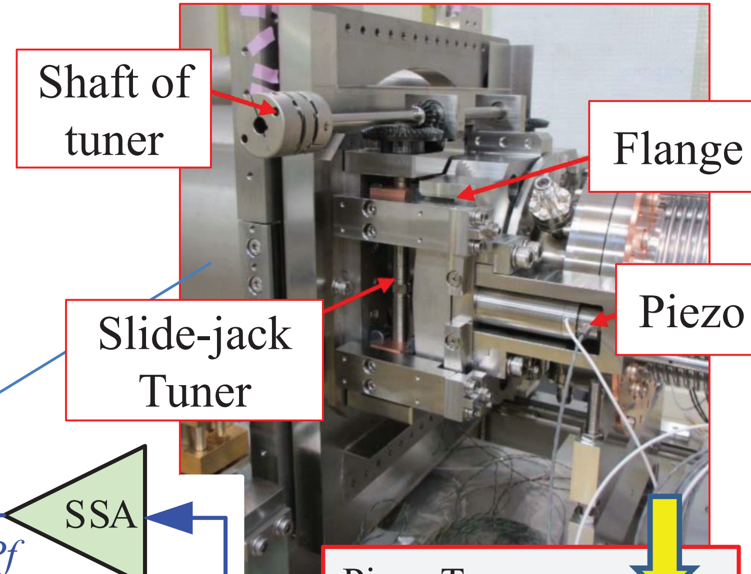
0.01% rms, 0.01deg.rms for 3GeV-ERL



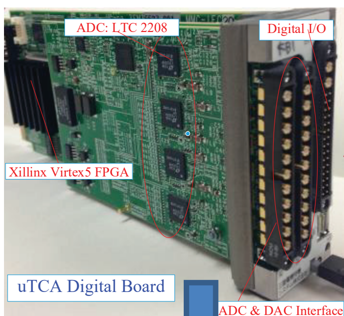
Cavity	QL	RF power
Bun.	1.1e5	3 kW
Inj. 1	1.2e6	0.53 kW
Inj. 2	5.8e5	2.4 kW
Inj. 3	4.8e5	
ML1	1.3e7	1.6 kW
ML2	1.0e7	2 kW

LLRF & Tuner (Hardware)

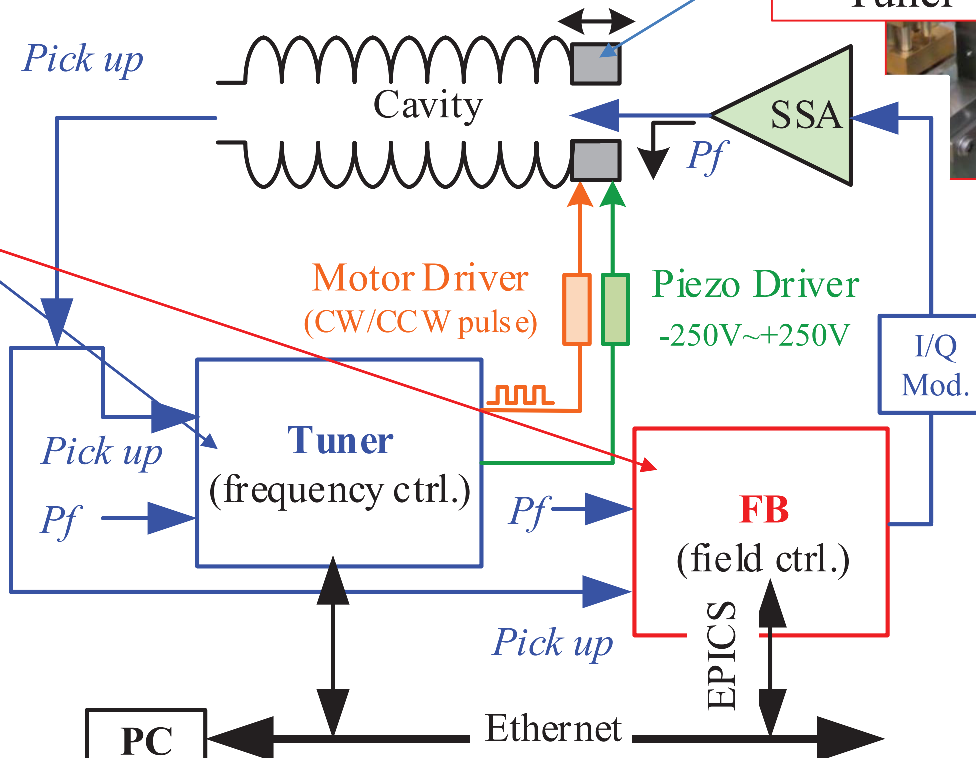
- MicroTCA-based digital low level radio frequency (LLRF) system and tuner resonance control system are applied in cERL.



Piezo Tuner
0 V~500 V
Stroke = 4 μm @ 2 K
1 μm→300 Hz
Cavity BW: 130 Hz
(QL~1e7)

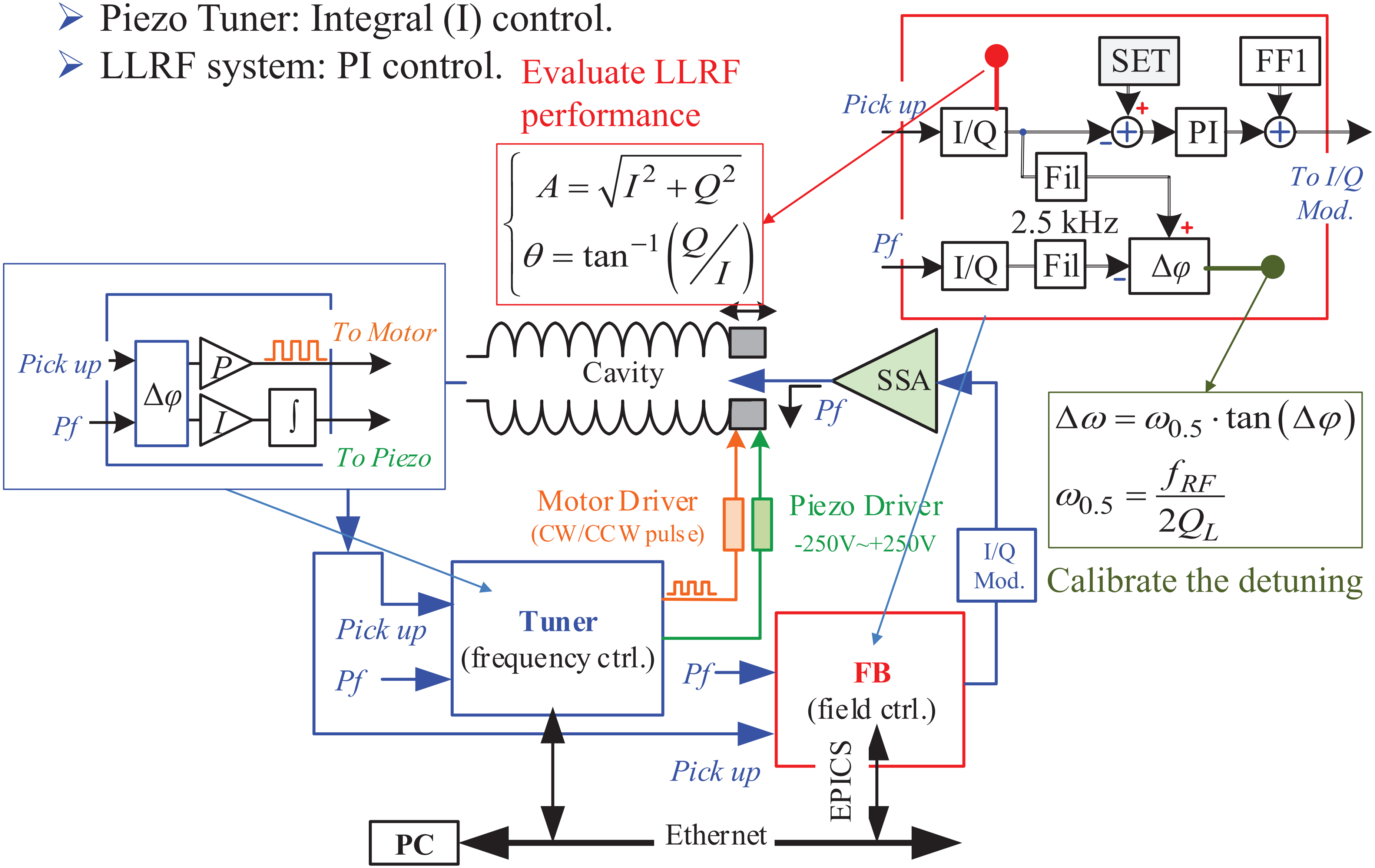


Micro TCA.0 board
- FPGA vertix5-FX
- 16-bit DAC × 4 ch
- 16-bit ADC × 4 ch
- Dig. I/O × 12 ch
- Epics in Power PC



LLRF & Tuner (Algorithm)

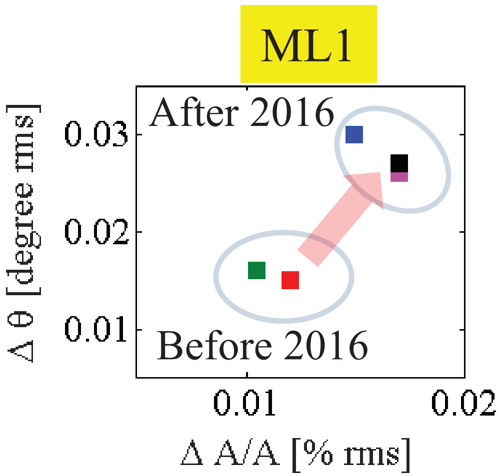
- Piezo Tuner: Integral (I) control.
- LLRF system: PI control.

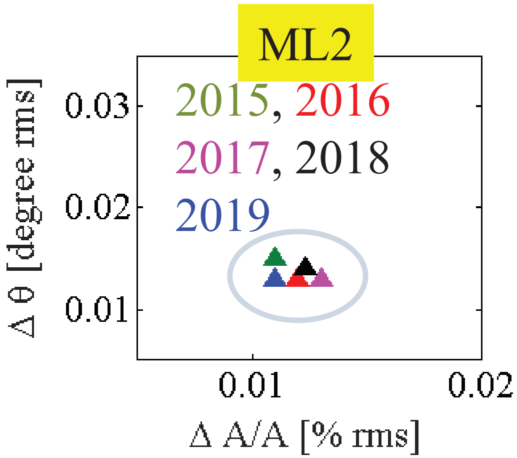


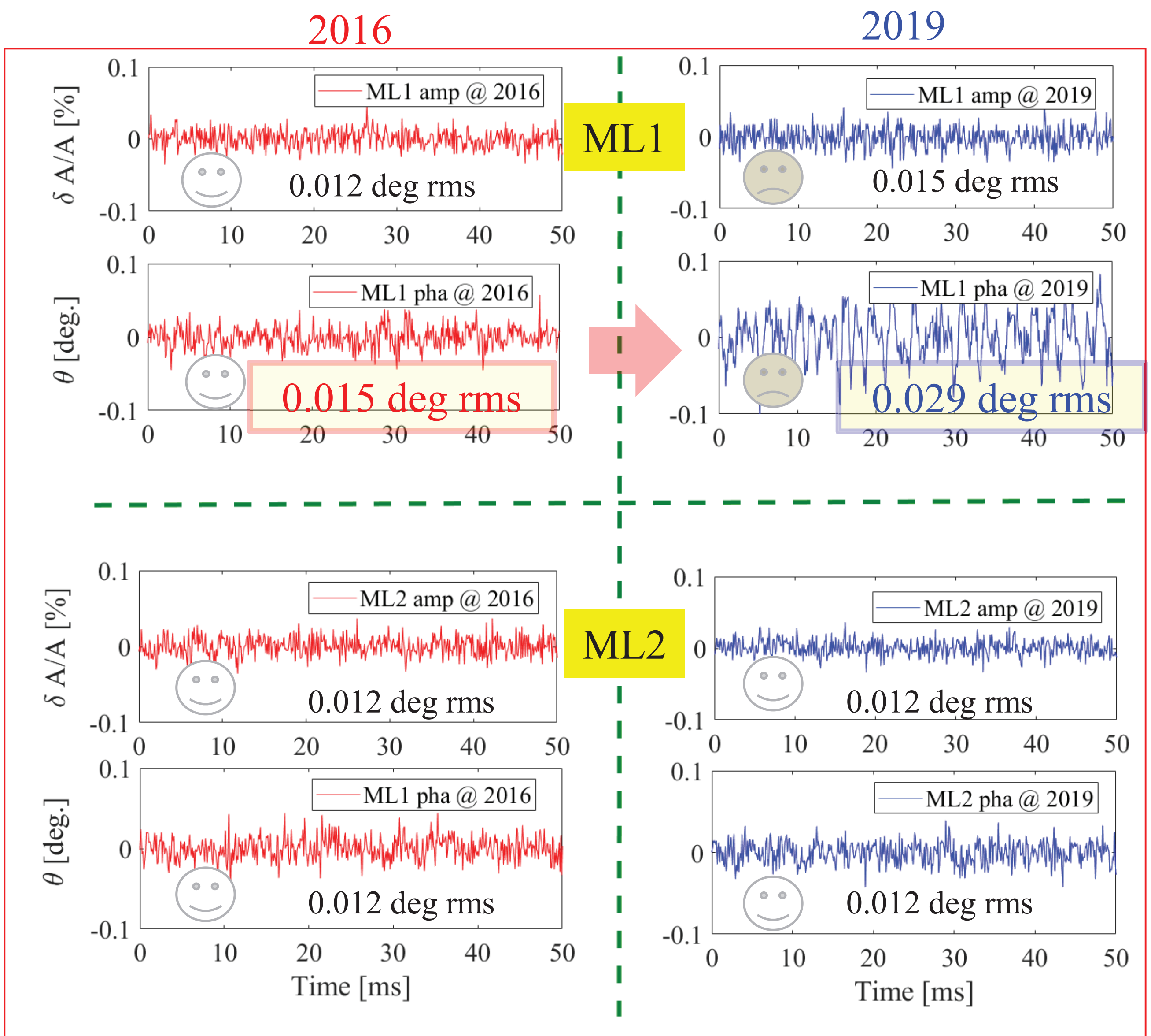
Main Content

- Introduction
- LLRF and Tuner control system
- RF stabilities of ML cavities
- Microphonics measurement
- System identification of piezo tuner
- Summary

RF stabilities (under FB)



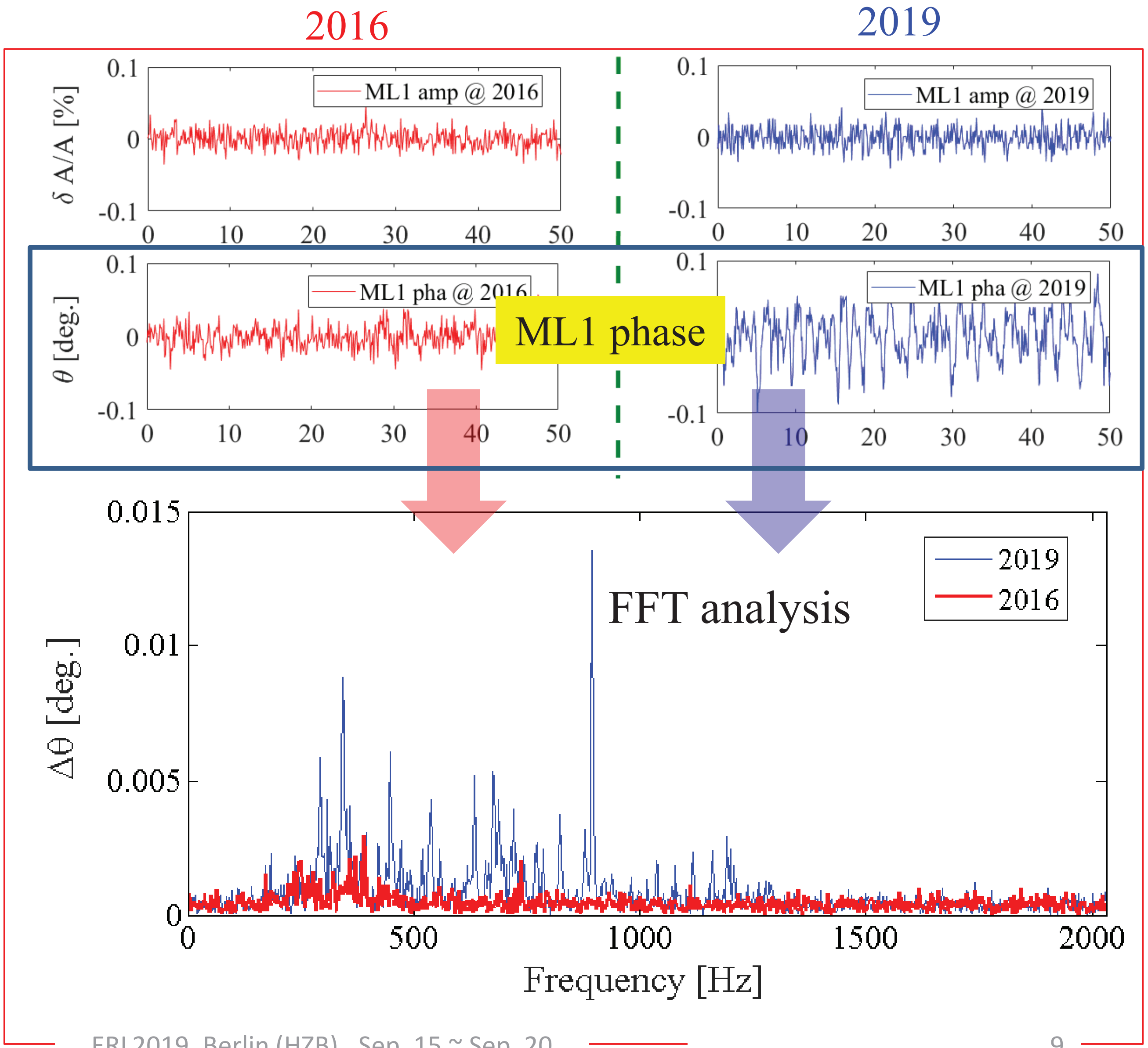




- Performance of ML1 becomes worse in the past 5 years, ML2 performs well.

RF stabilities of ML1

- Some components (> 500 Hz) were excited in the cavity phase of ML1 in 2019.



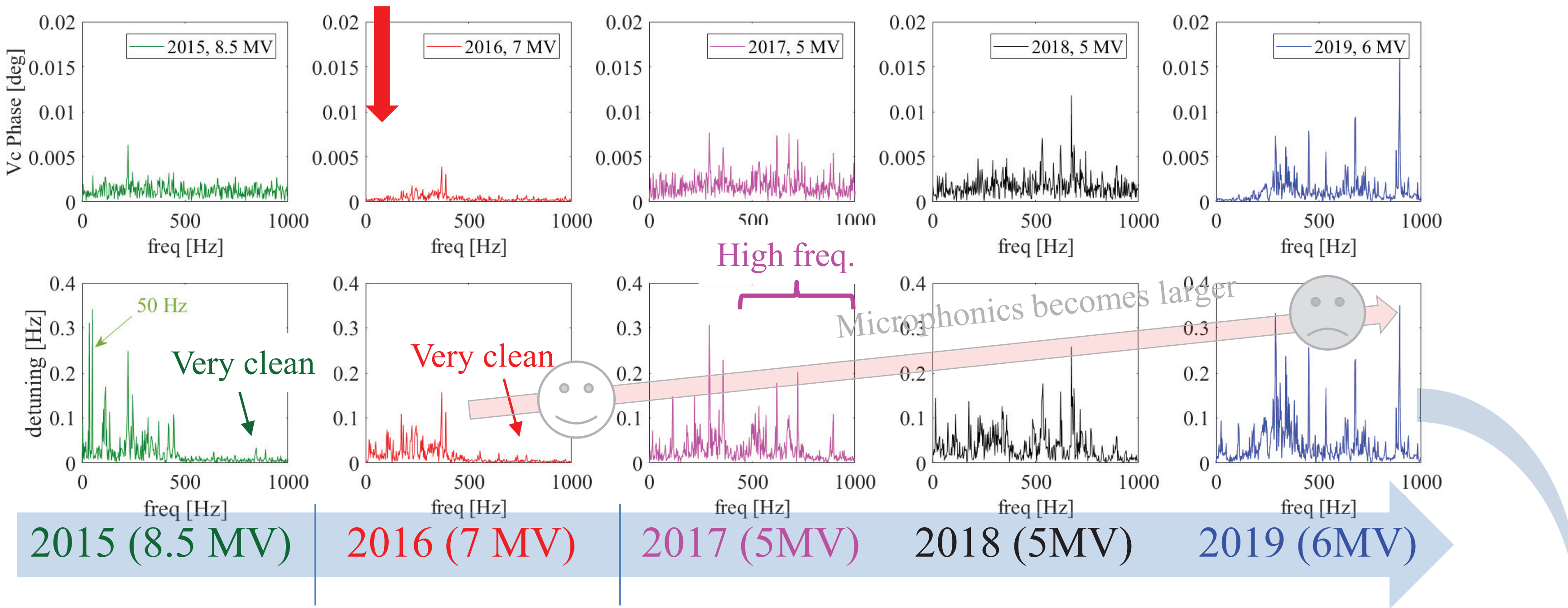
RF stabilities of ML1

Best performance @ 2016

Current (2019, April)

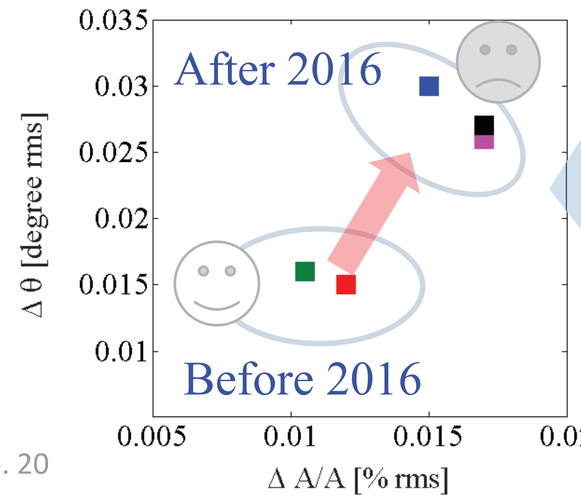
Vc Pha.

Δω



Add rubber sheet under the scroll pump to remove the 50 Hz.

Cavity degrade due to field emission and thermal breakdown [2]



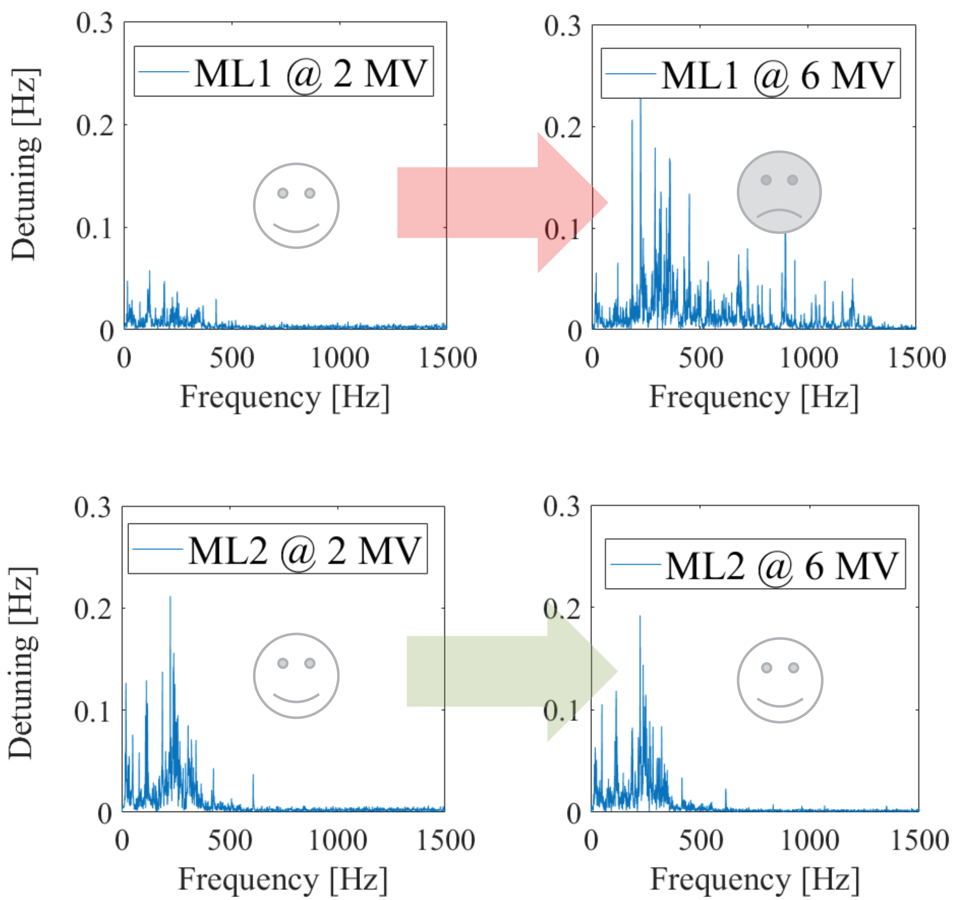
- RF stabilities becomes worse due to the deteriorated microphonics conditions [3].

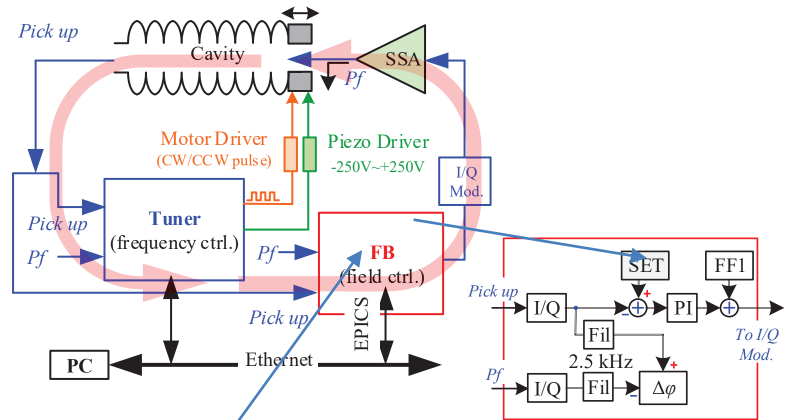
Main Content

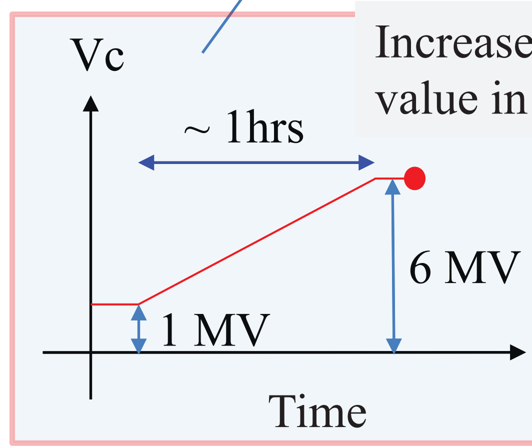
- Introduction
- LLRF and Tuner control system
- RF stabilities of the ML cavities
- Microphonics measurement
- System identification of piezo tuner
- Summary

Field Scanning (cont'd)

- In 2019, accidentally, we found that the back-ground mircophpnics in ML1 depends on its cavity field.
- Field-scanning (under feedback operation).



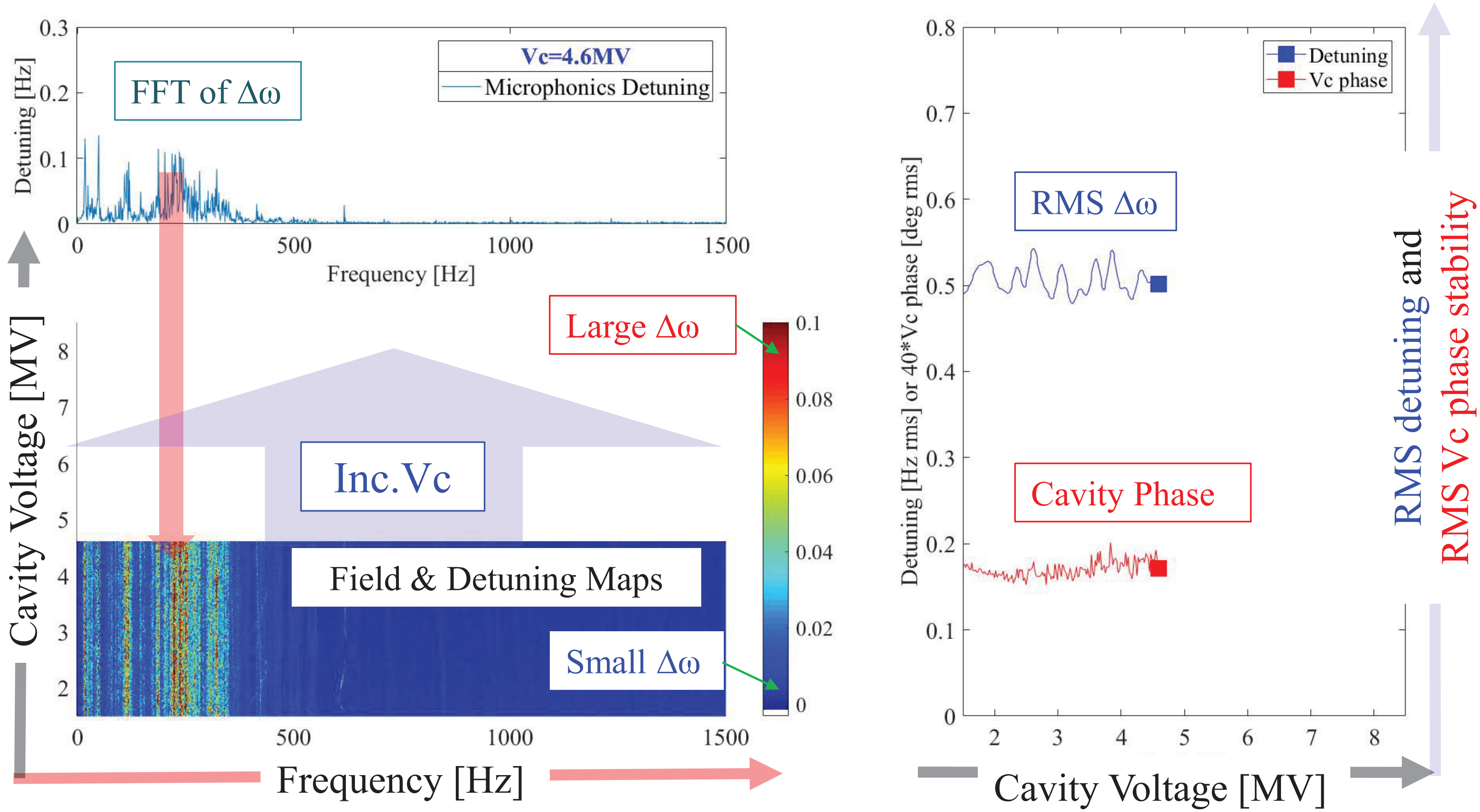




Increase the set value in the FB loop.

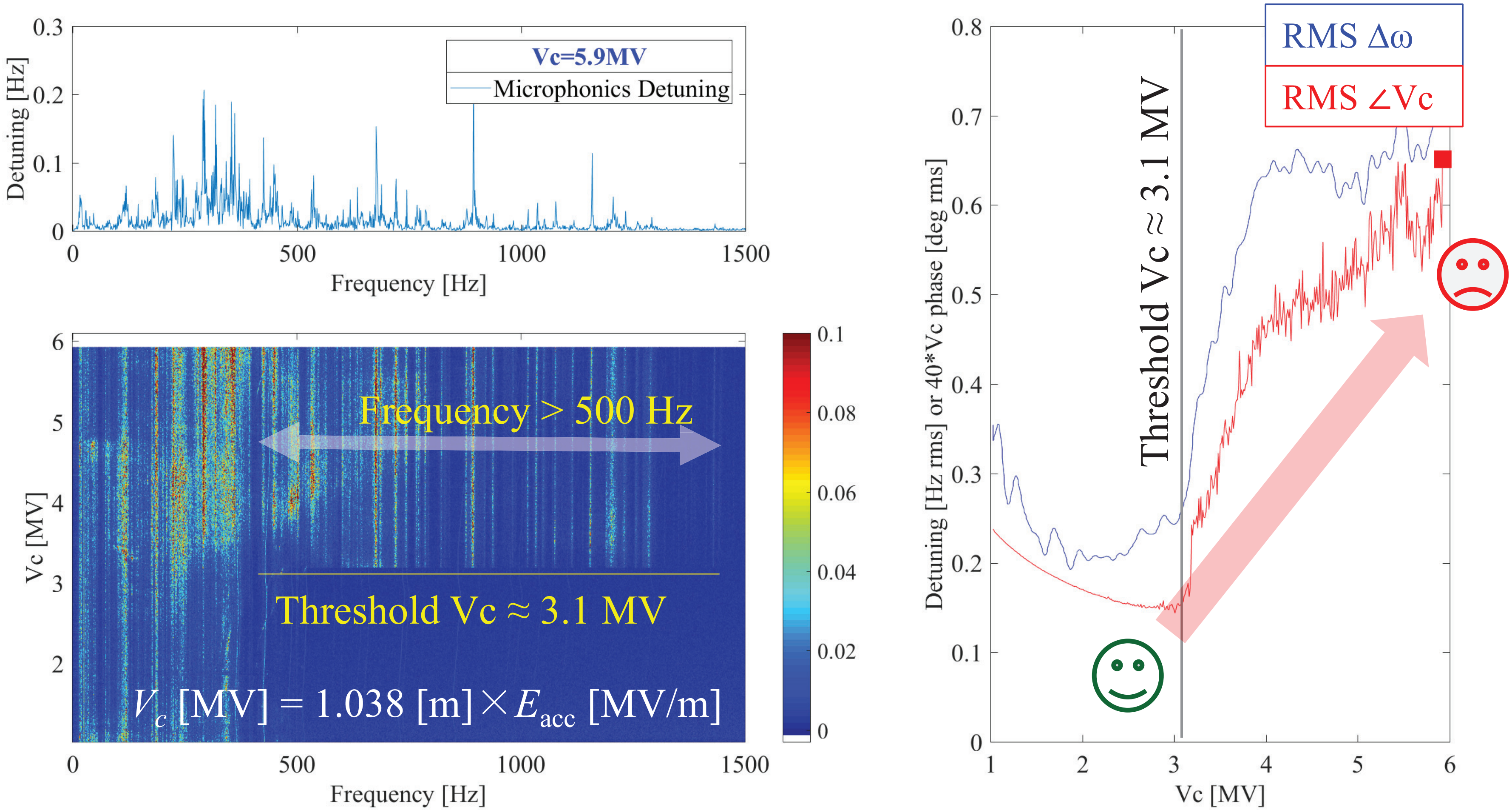
Field Scanning

- Perform the FFT analysis of the detuning under different field, then plot the Map.



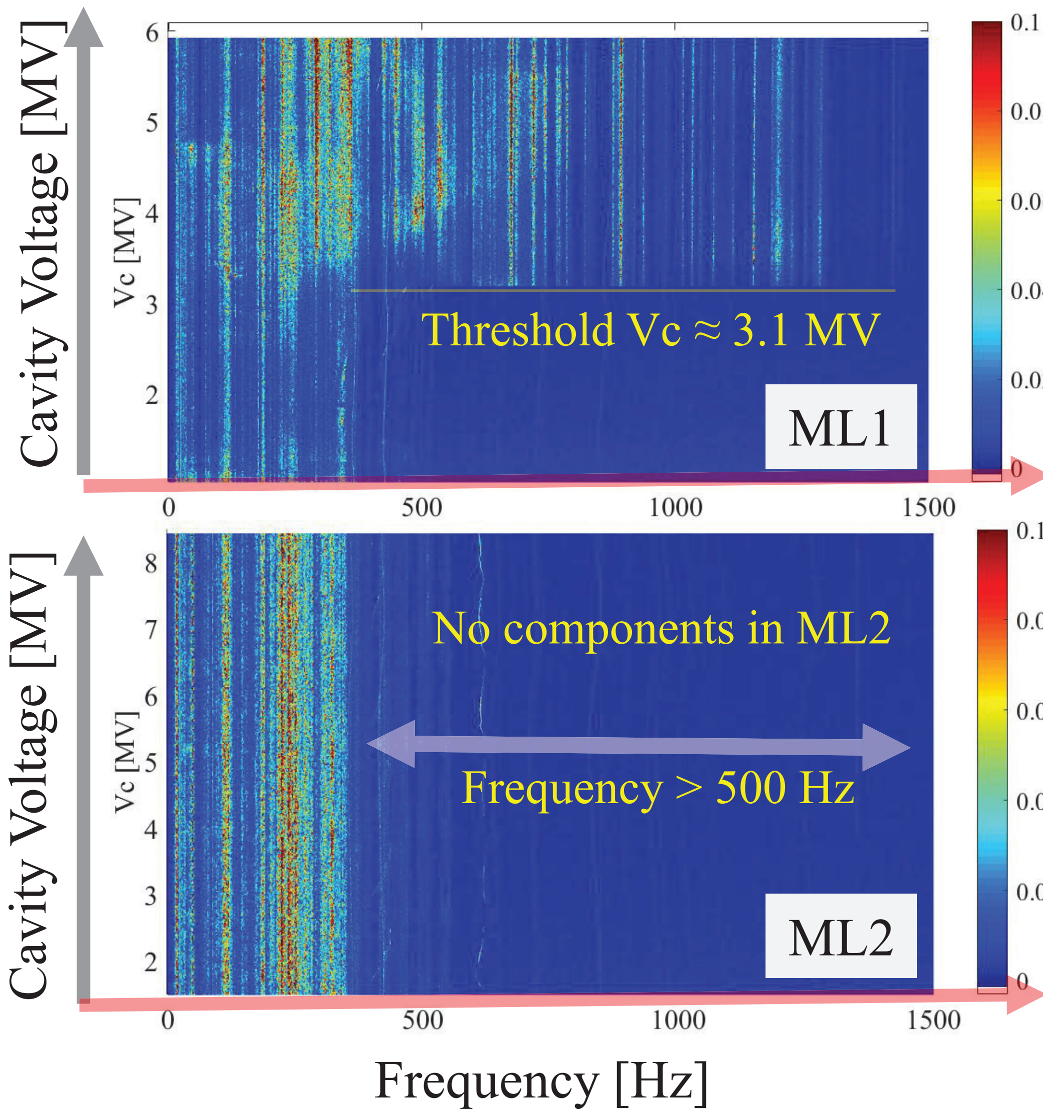
ML1 Field Scanning (result)

- High frequency component's suddenly appears @ ~3.1 MV (Threshold Vc).
- Detuning and RF phase stabilities becomes worse under higher Vc.

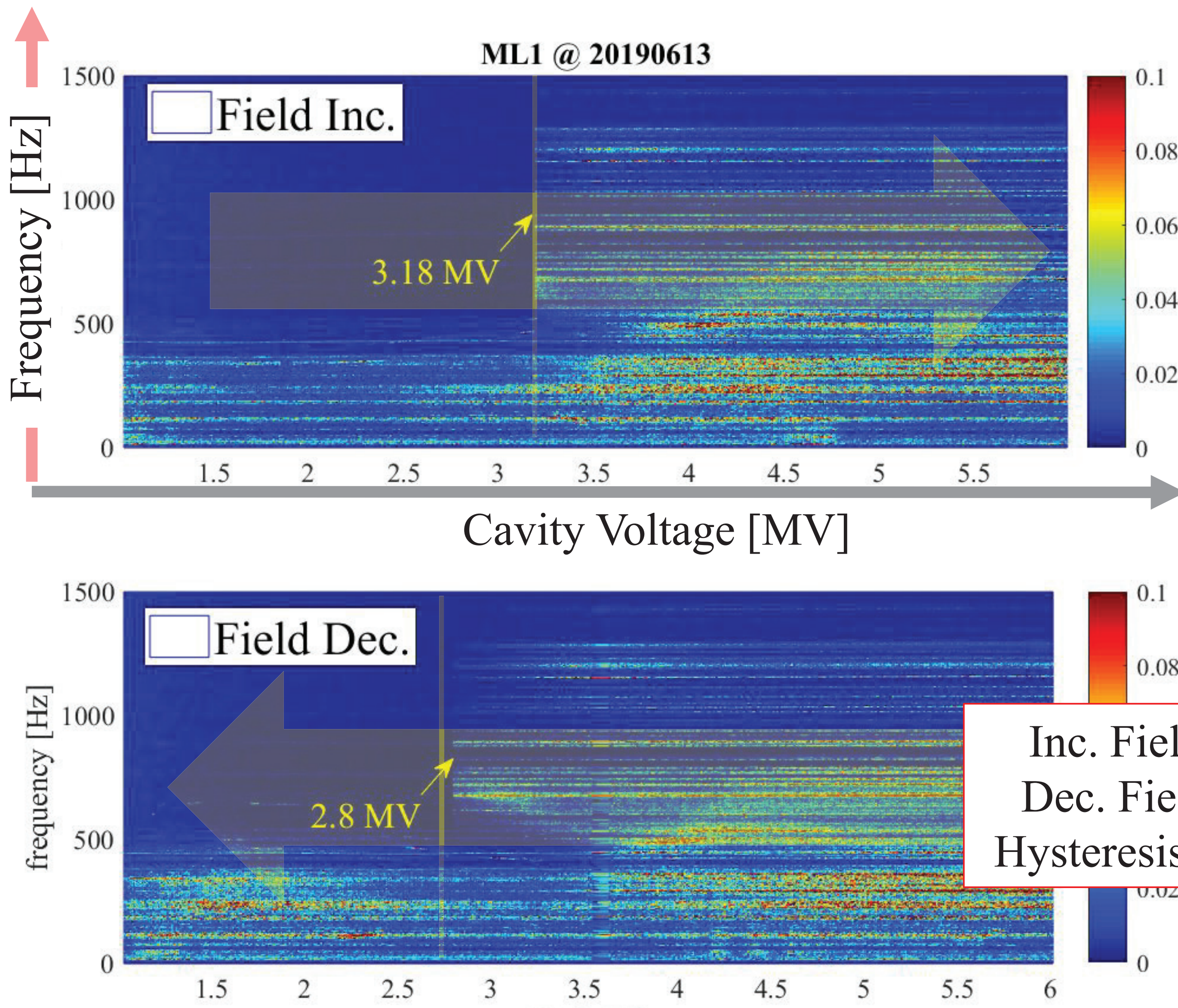


Field-detuning Map (ML1 vs. ML2)

- The boundary appeared only in the ML1.
- Why "field dependency microphonics"? The mechanism remains unclear.



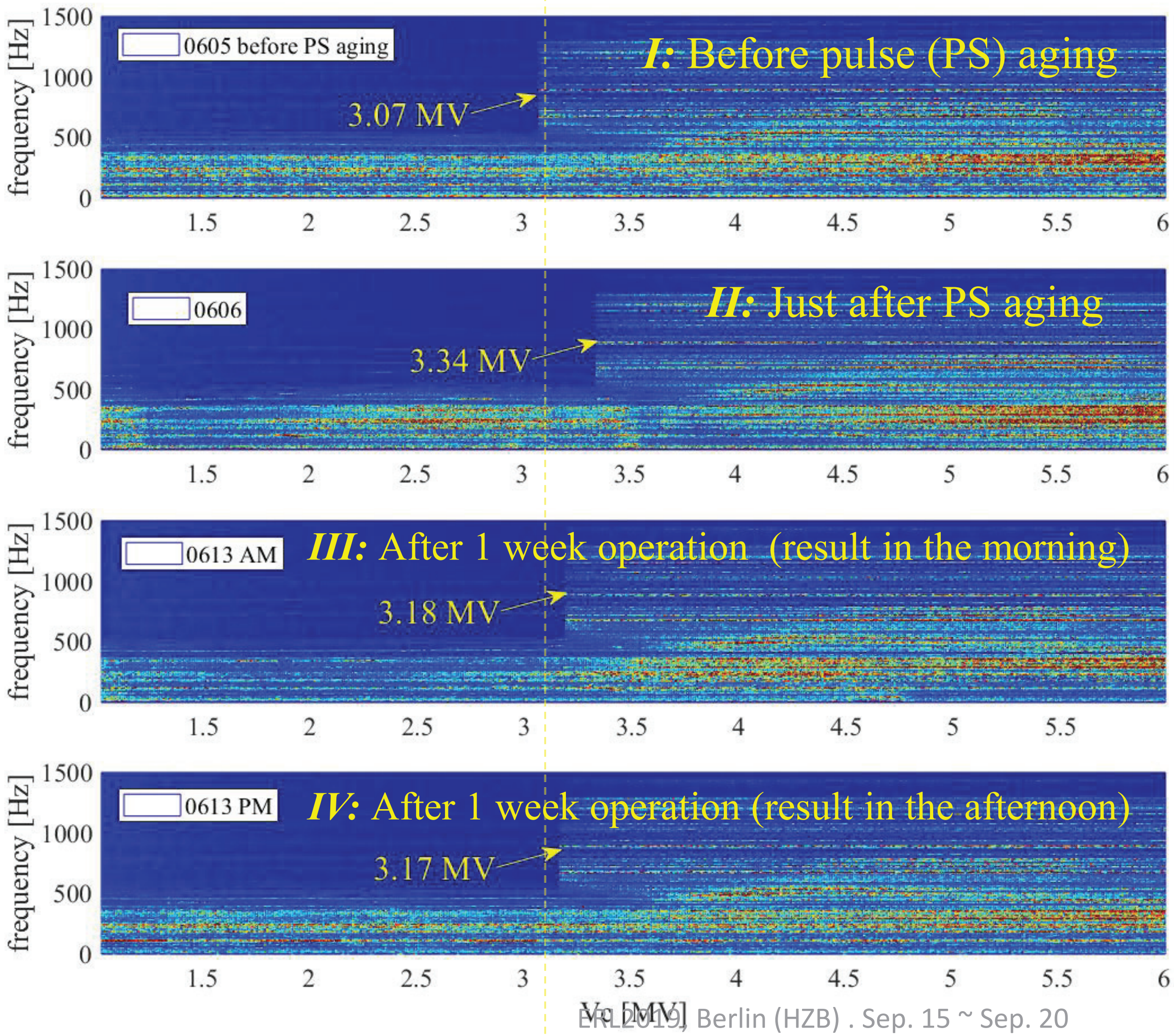
Hysteresis Phenomena



Inc. Field: 3.18 MV
Dec. Field: 2.80 MV
Hysteresis phenomena?

Threshold Vc vs. Quench limits

- The value of threshold Vc is probably related with quench limits (remains unclear)?



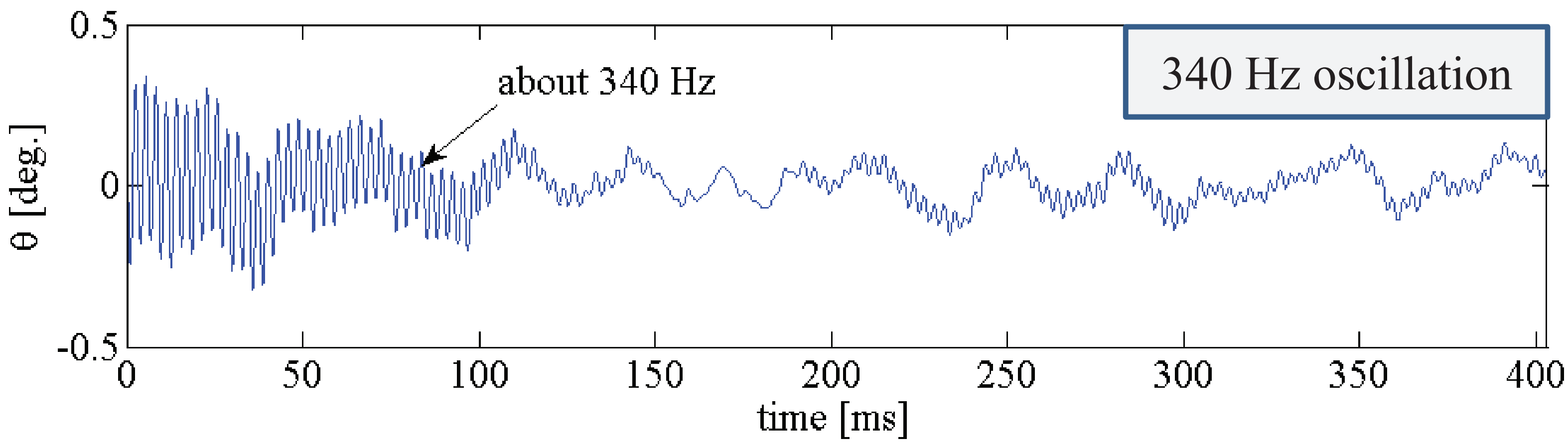
Case	Threshold Vc [MV]	Quench Limits [MV]
I	3.07	6.16
II	3.34	6.51
III	3.18	6.30
IV	3.17	6.30

Main Content

- Introduction
- LLRF and Tuner control system
- RF stabilities of the ML cavities
- Microphonics measurement
- System identification of piezo tuner
- Summary

Requirement for system model

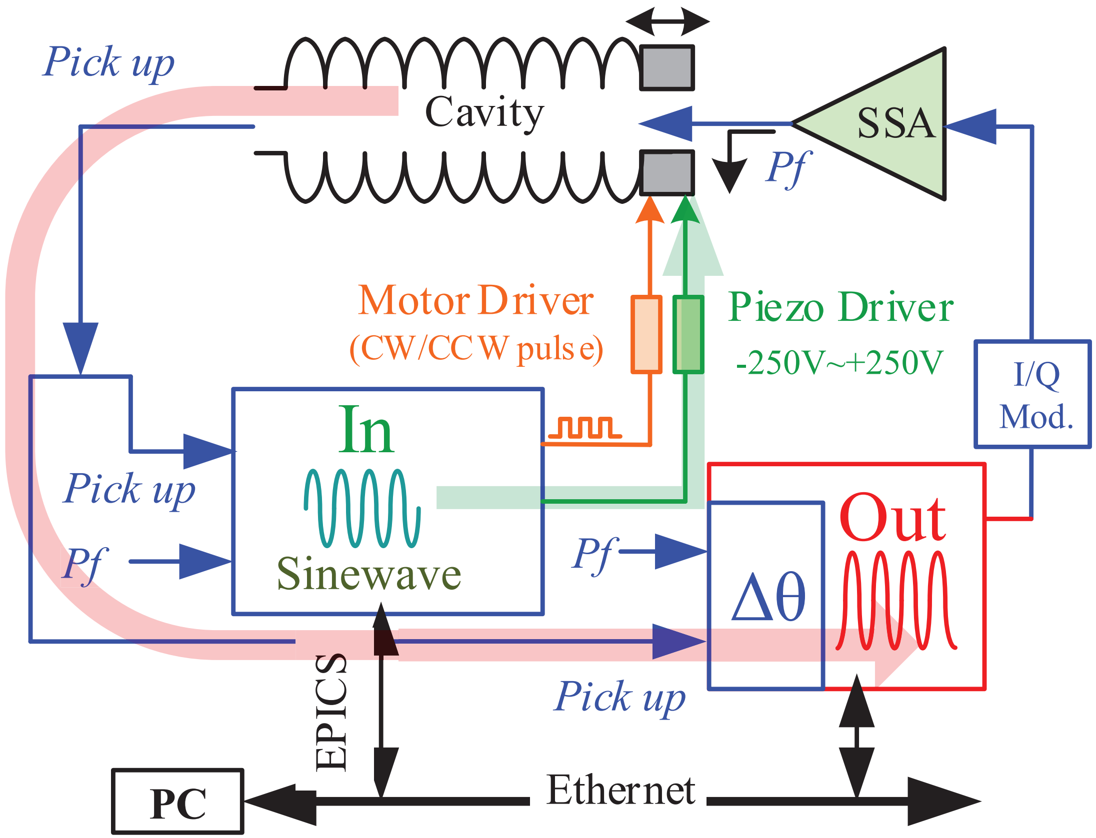
- Simply increasing the FB gain is **NOT** a good method, some mechanical modes would be excited and the system therefore oscillated [4].

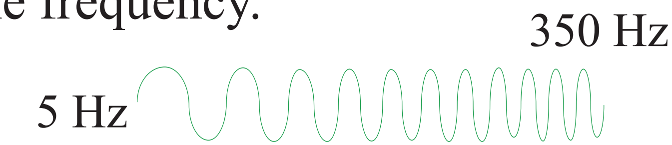


- Advanced control methods (e.g. active compensation method [5], or active noise control [6]) are better choice, for these cases, a system model is usually necessary (or helpful). We have to know the system better.

Identification of the TF Model

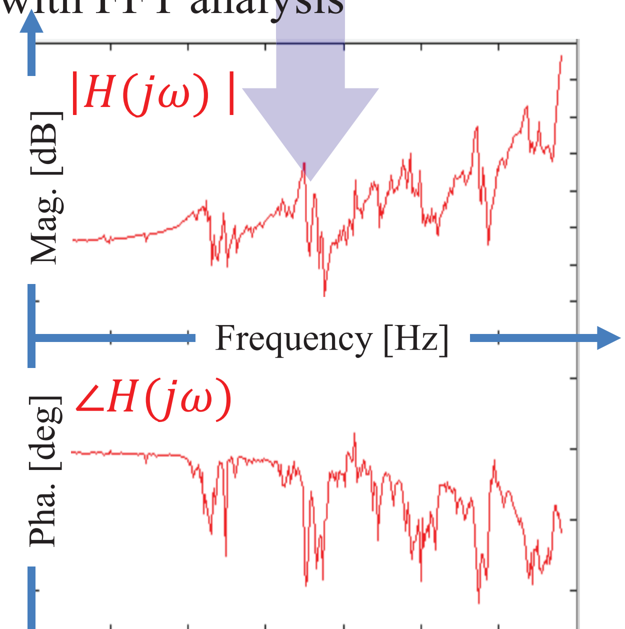
- Transfer function (TF): Piezo to RF.
- Excite piezo with sinusoidal signal and sweep the frequency.
- FFT analysis → TF model.





Frequency Range: 5 Hz to 350 Hz
Frequency Step: 1 Hz
For each frequency point: 5 sec.

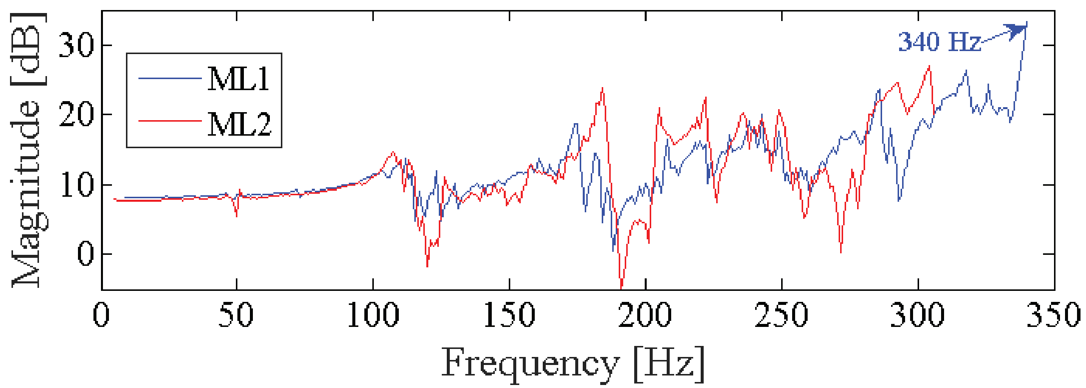
Obtain the frequency response with FFT analysis

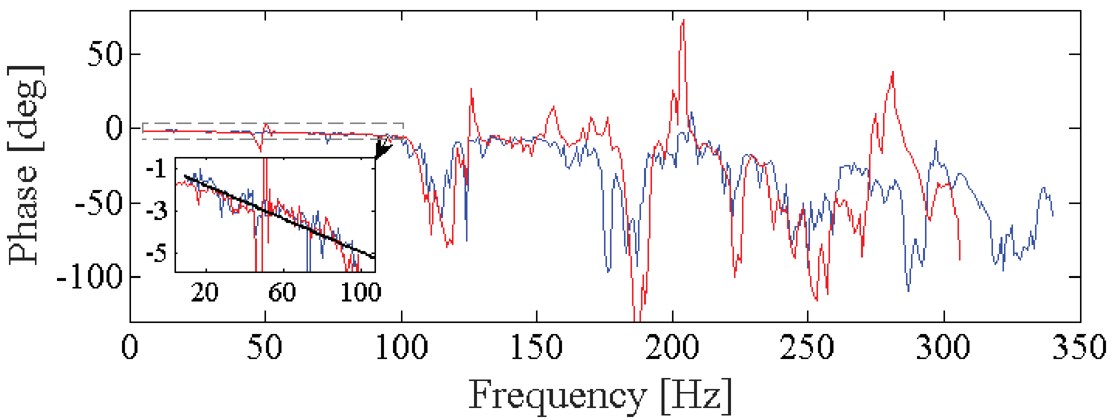


TF Model vs. Δω

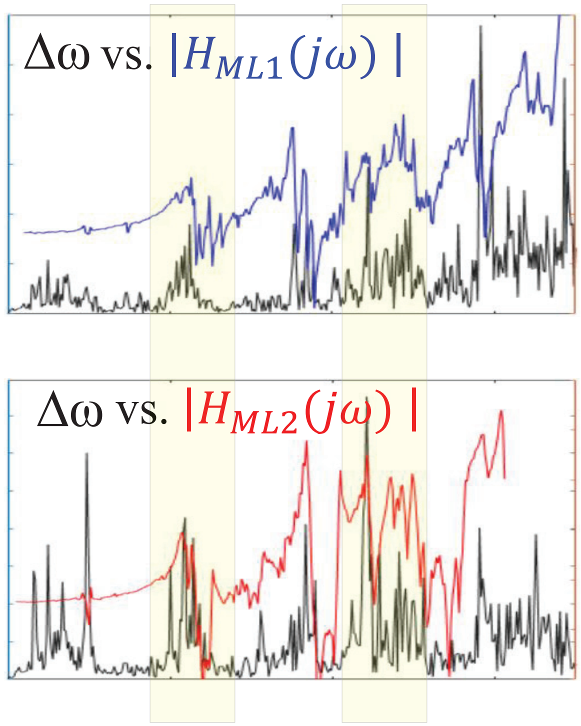
➢ Piezo Transfer function is probably related with Δω.

$$H(s)=\left(\frac{M_0}{\tau s+1}+\sum_{k=1}^{N}\frac{\omega_k^2 M_k}{s^2+2\xi_k\omega_k s+\omega_k^2}\right)e^{-T_d s}\ .$$





Microphonics and Tuner Model

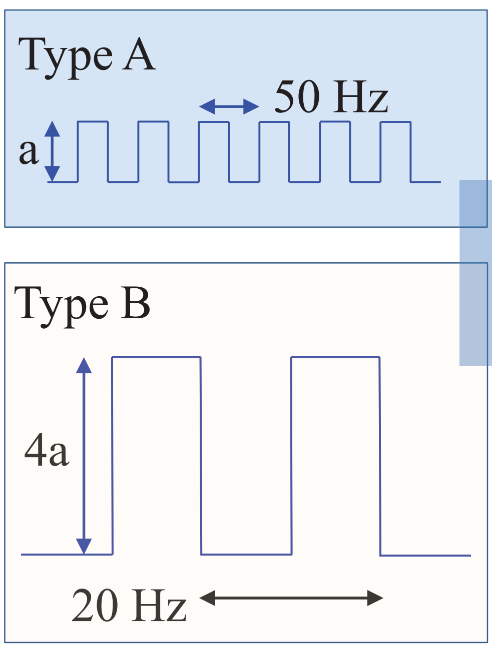


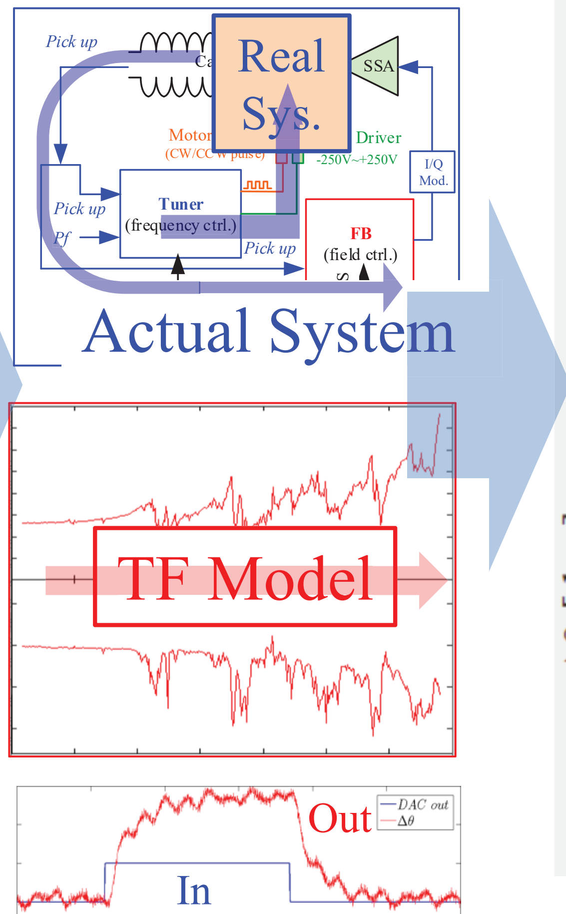
Overlap of Δω & $|H(j\omega)|$

Validation of the TF Model

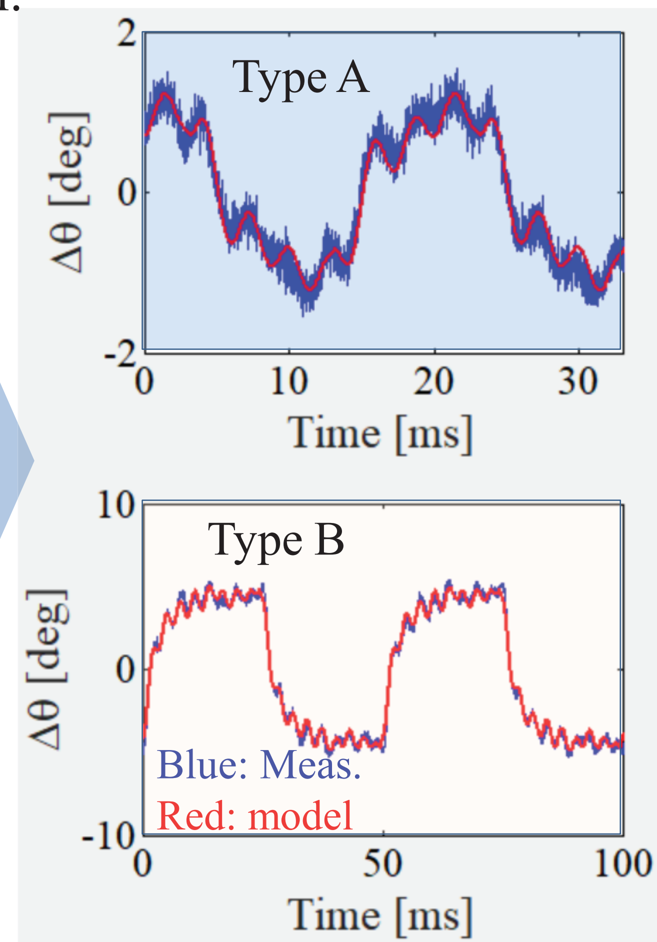
- Excite the system (and model) with square wave.
- TF Model vs. Actual System.
- We will optimize tuner control with TF model.

Input





Response



Summary

- RF stabilities of ML1 cavity were getting worse due to the deteriorated microphonics in the past 5 years.
- A "field level dependency microphonics" phenomenon was observed in ML1.
- The threshold Vc for the deteriorated microphonics is about 3.1 MV, and it is probably related with quench limits level.
- We have identified and validate the TF model of the piezo tuner system and we plan to optimize the tuner control with this TF model.

Thank you for your attention

Reference

[1] M. Akemoto *et al.*, “Construction and commissioning of compact energy-recovery linac at KEK”, *Nucl. Instr. Meth.*, vol. 877, pp. 197-219, 2018.

[2] H. Sakai *et al.*, “Long-term operation with Beam and Cavity Performance Degradation in Compact-ERL Main Linac at KEK”, in *Proc. LINAC’18*, Beijing, China, Sep. 2018, pp. 695-698.

[3] F. Qiu *et al.*, “Status of microphonics on cERL nine-cell cavities” in *Proc. PASJ2019*, Kyoto, Japan, July-Aug. 2019.

[4] F. Qiu *et al.*, “Progress in the work on the Tuner control system of the cERL at KEK”, in *Proc. IPAC’16*, Busan, Korea, May 2016. Pp.2742-2745.

[5] A. Neumann *et al.*, “Analysis and active compensation of microphonics in continuous wave narrow-bandwidth superconducting cavities”, *Phys. Rev. ST Accel. Beams*, vol. 13, p. 082001, Aug. 2010.

[6] N. Banerjee *et al.*, “Active compensation of microphonics detuning in high Q_L cavities”, *Phys. Rev. Accel. Beams*, vol. 22, p. 052002, May 2019.