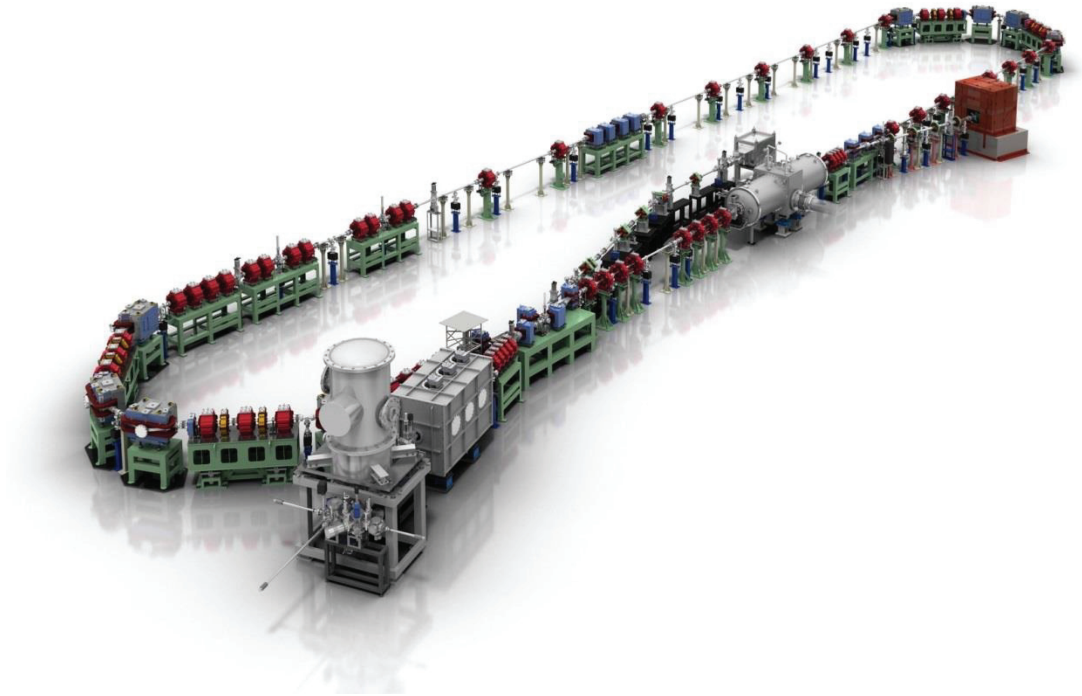
Characterization of microphonics in the compact ERL main linac cavities

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

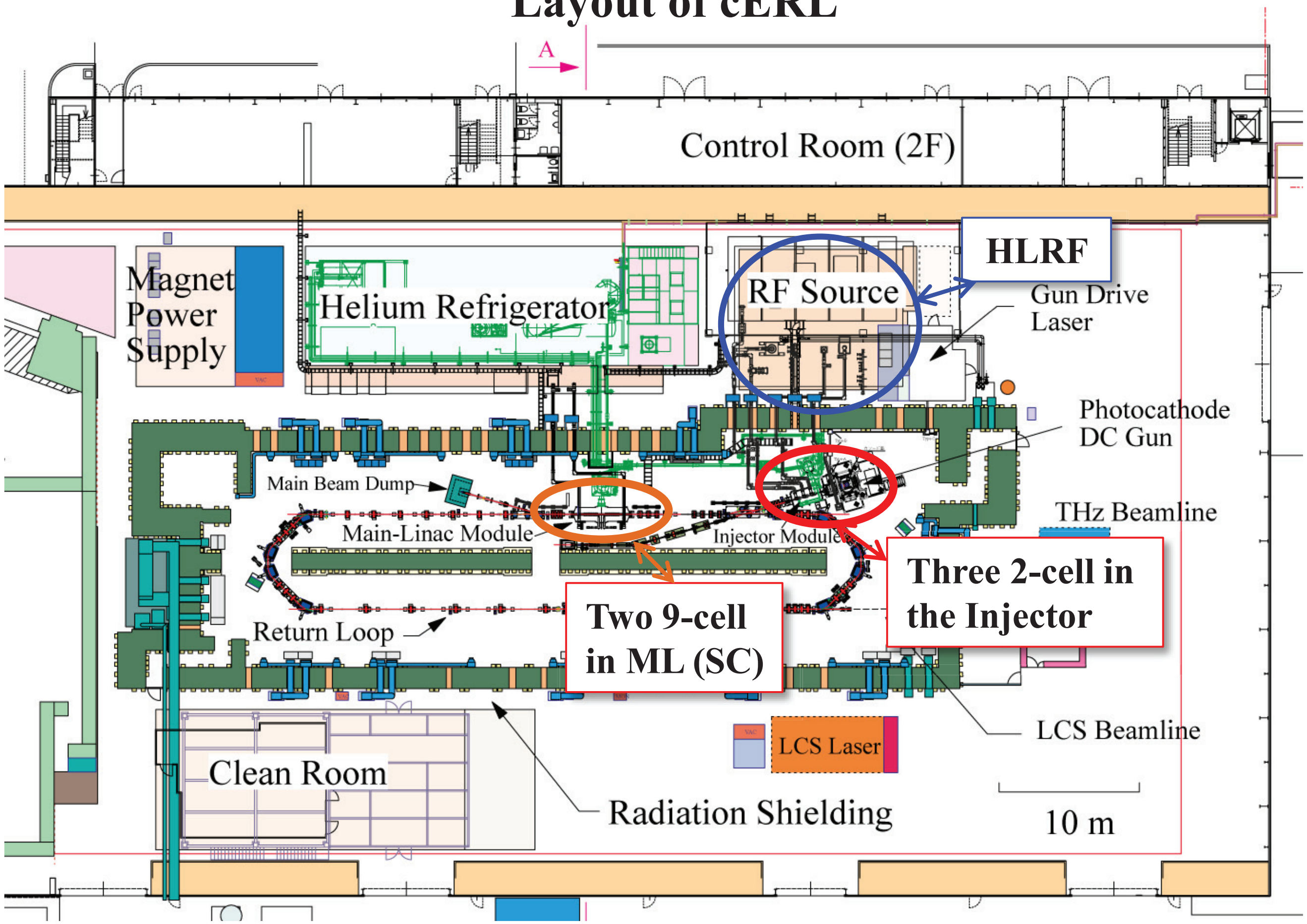
Introduction

- 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].

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).

Layout of cERL



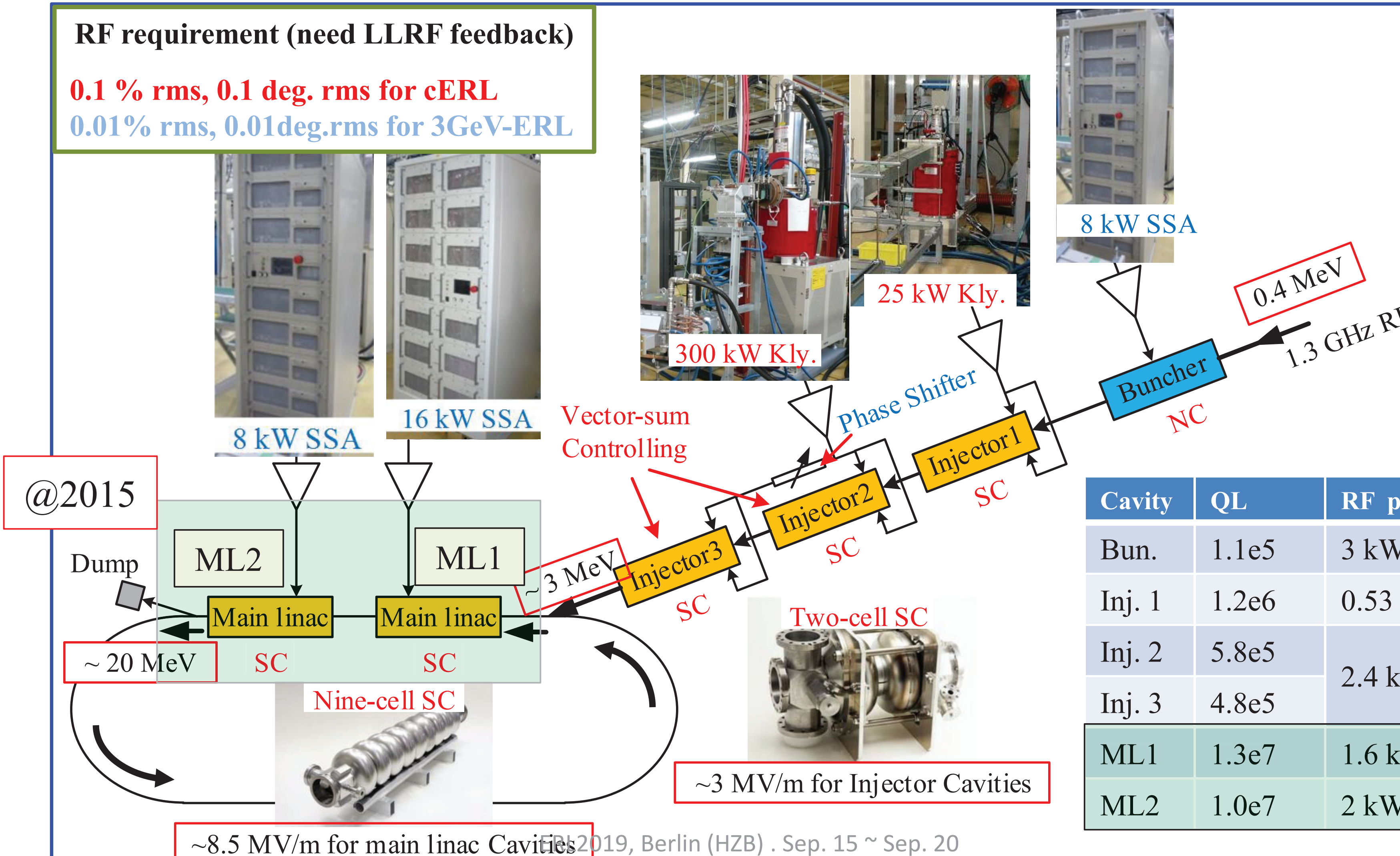
- April, 2013, injector commissioning. Oct. 2013, main linac commissioning.

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)

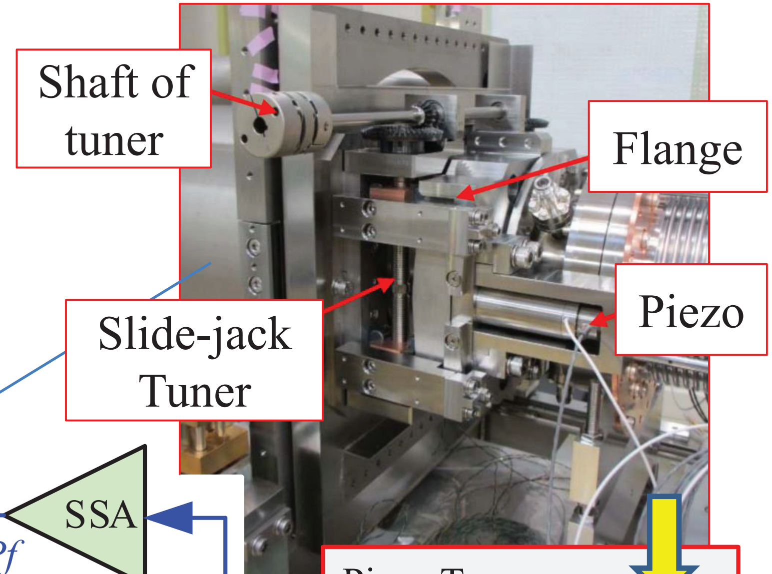
0.1 % rms, 0.1 deg. rms for cERL
0.01% rms, 0.01deg.rms for 3GeV-ERL



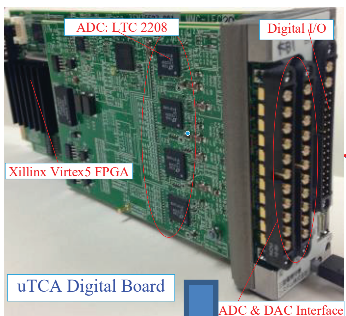
Cavity	QL	RF power
Bun.	1.1e5	3 kW
Inj. 1	1.2e6	0.53 kW
Inj. 2	5.8e5	2.4 kW
Inj. 3	4.8e5	
ML1	1.3e7	1.6 kW
ML2	1.0e7	2 kW

LLRF & Tuner (Hardware)

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

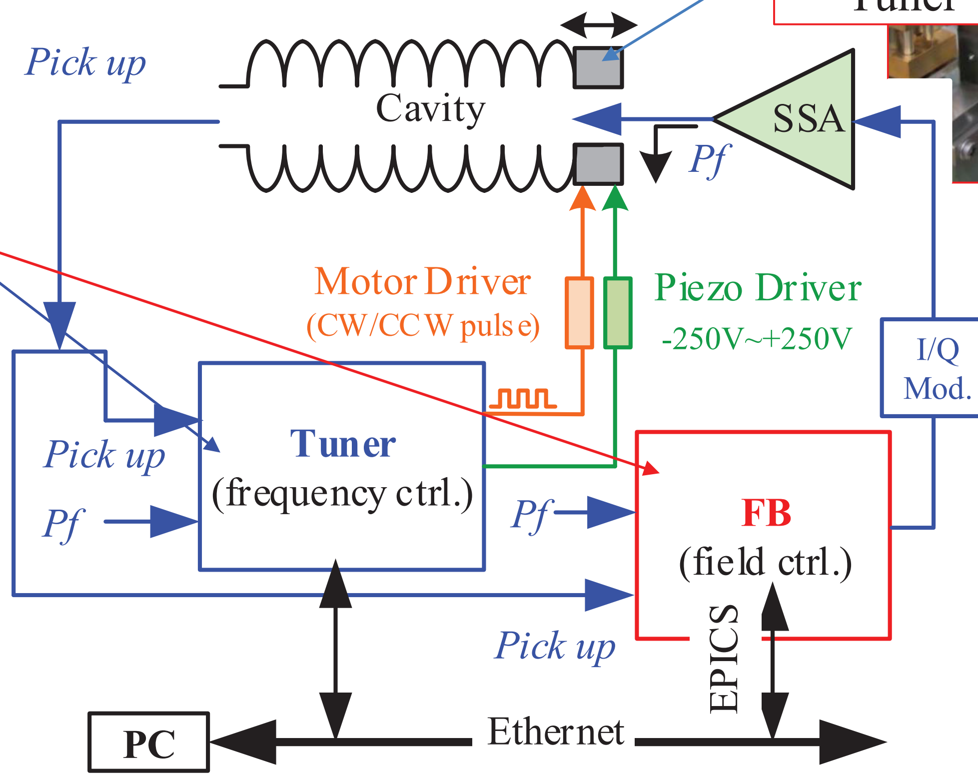


Piezo Tuner
0 V~500 V
Stroke = 4 μm @ 2 K
1 μm→300 Hz
Cavity BW: 130 Hz
(QL~1e7)



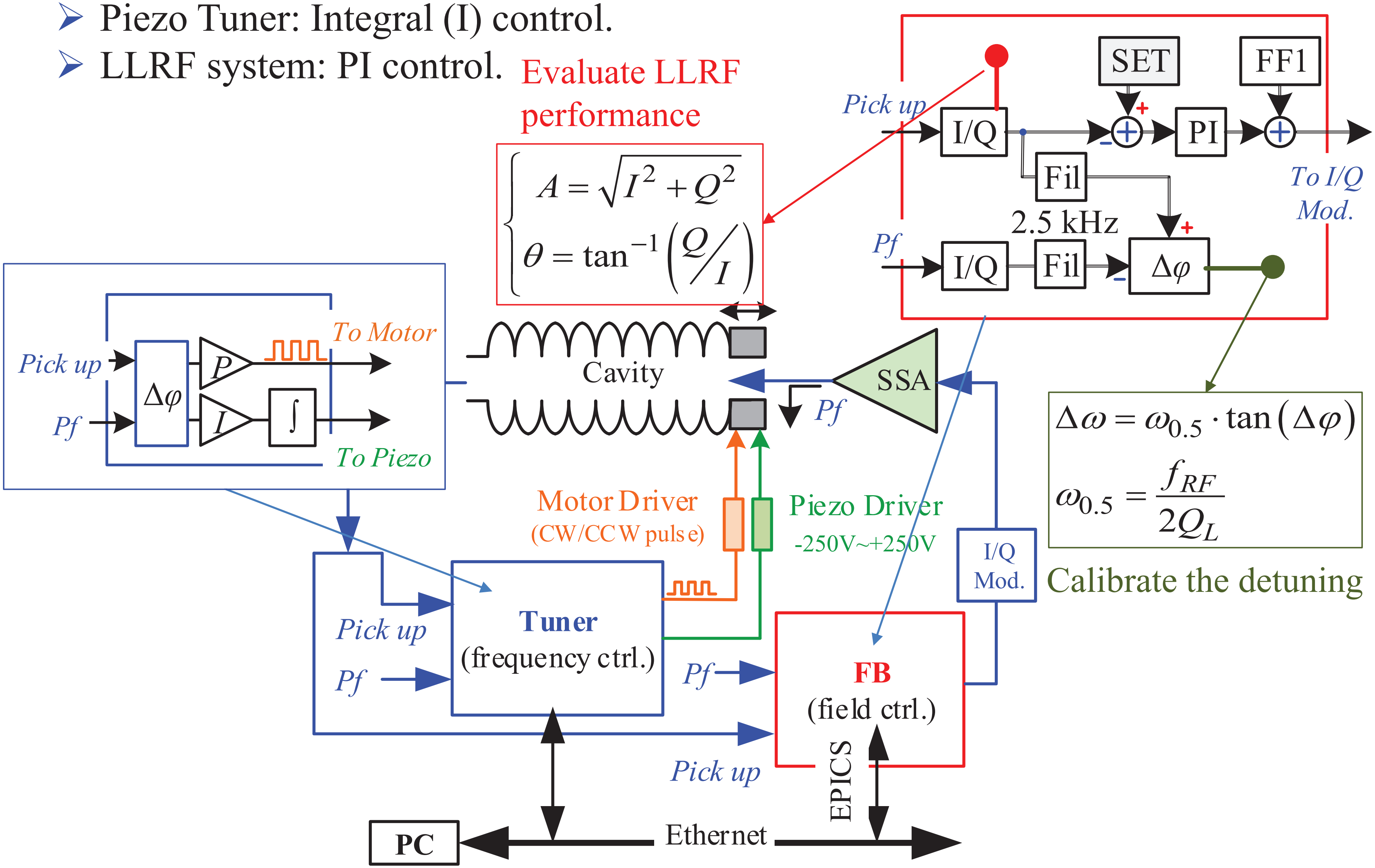
Micro TCA.0 board

- 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.



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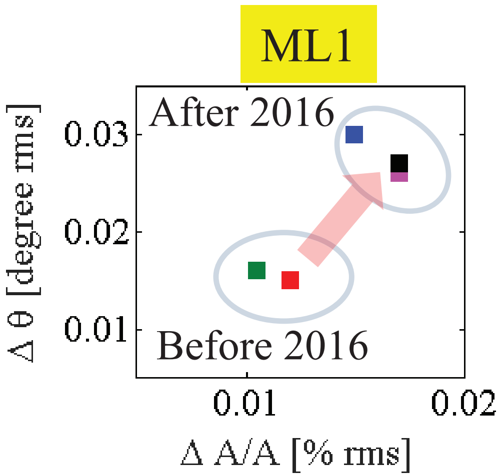
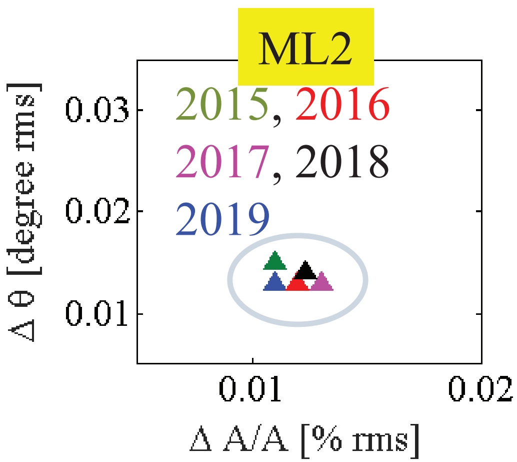
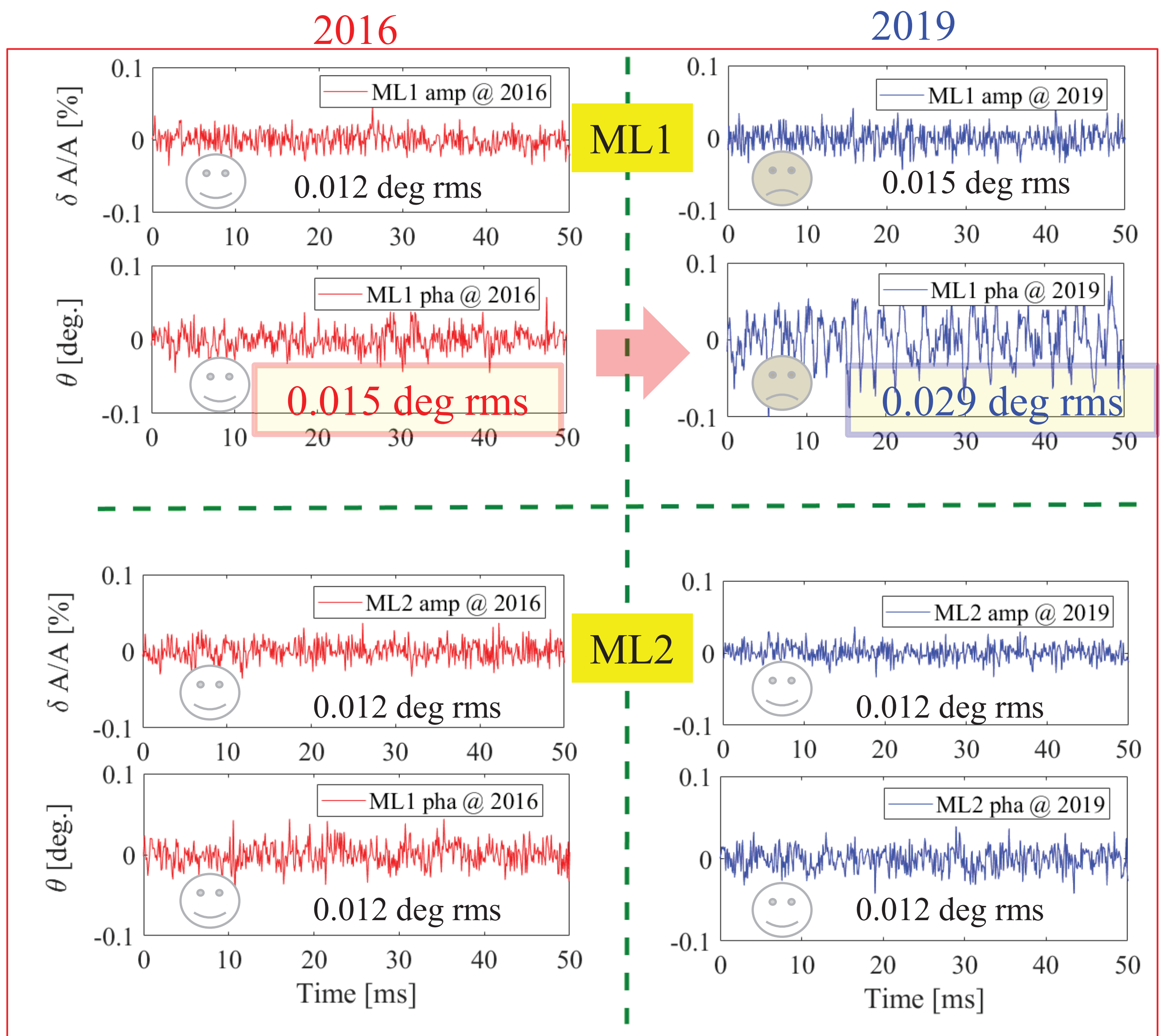
RF stabilities (under FB)



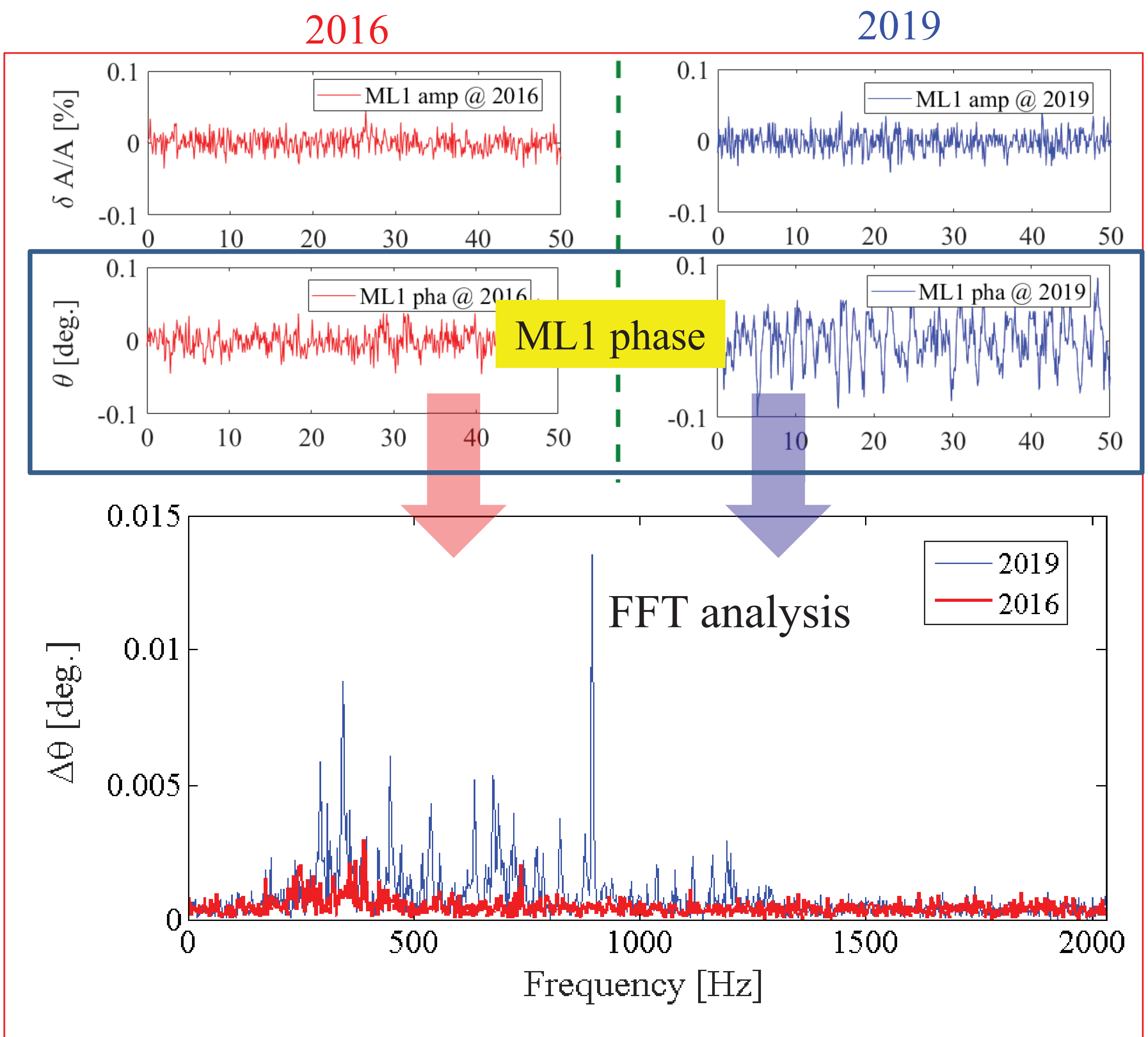




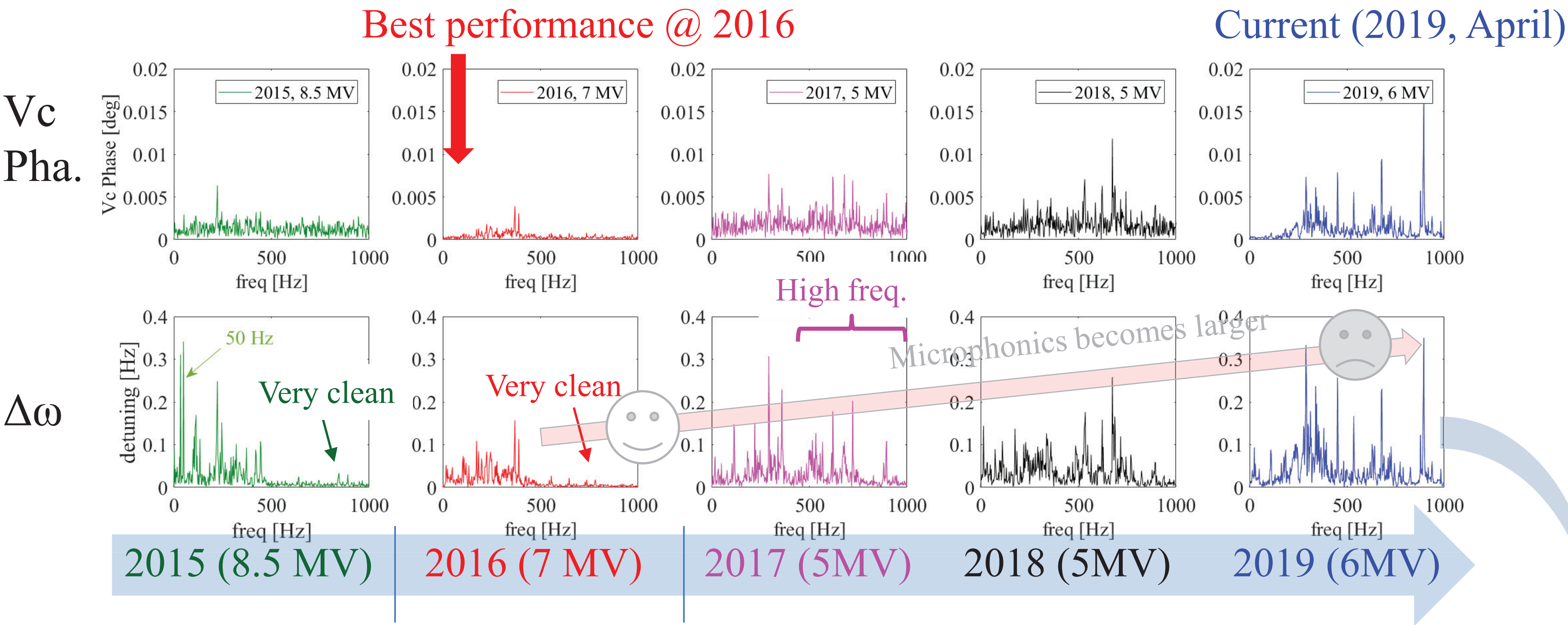
- Performance of ML1 becomes worse in the past 5 years, ML2 performs well.

RF stabilities of ML1

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

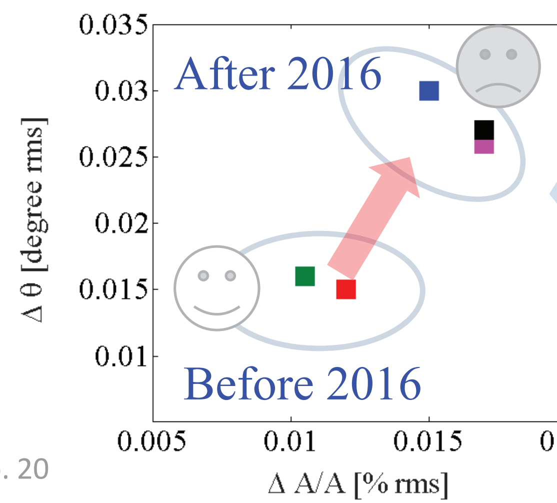


RF stabilities of ML1



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].

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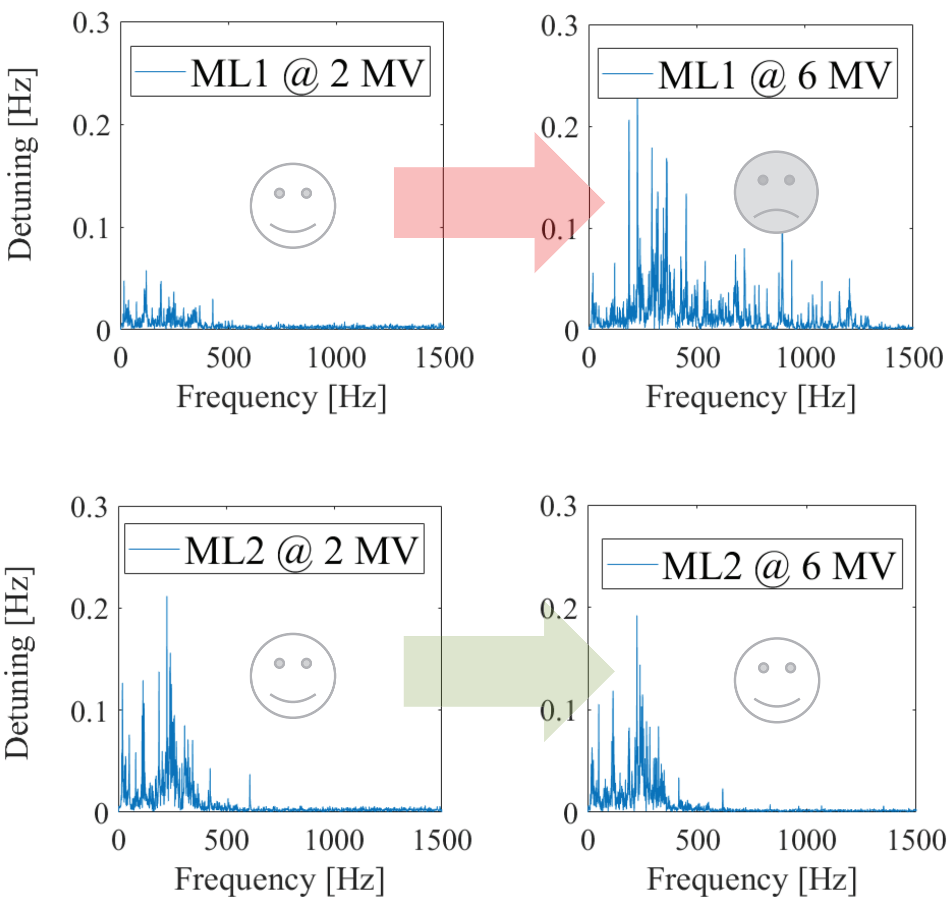
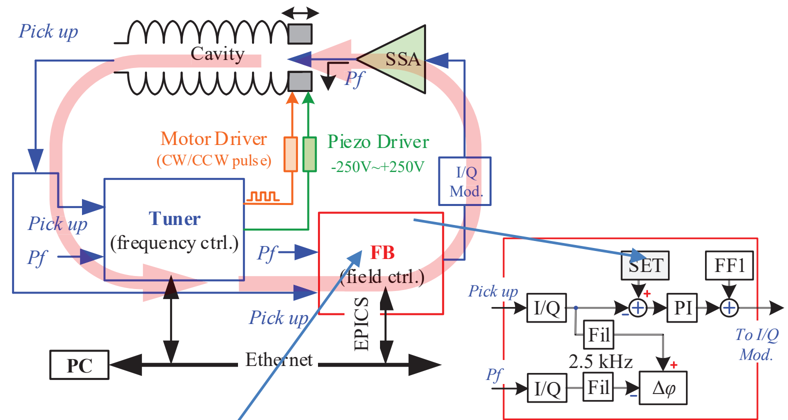
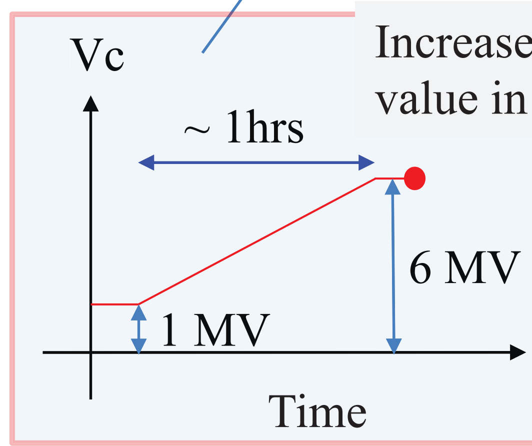
Field Scanning (cont'd)

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



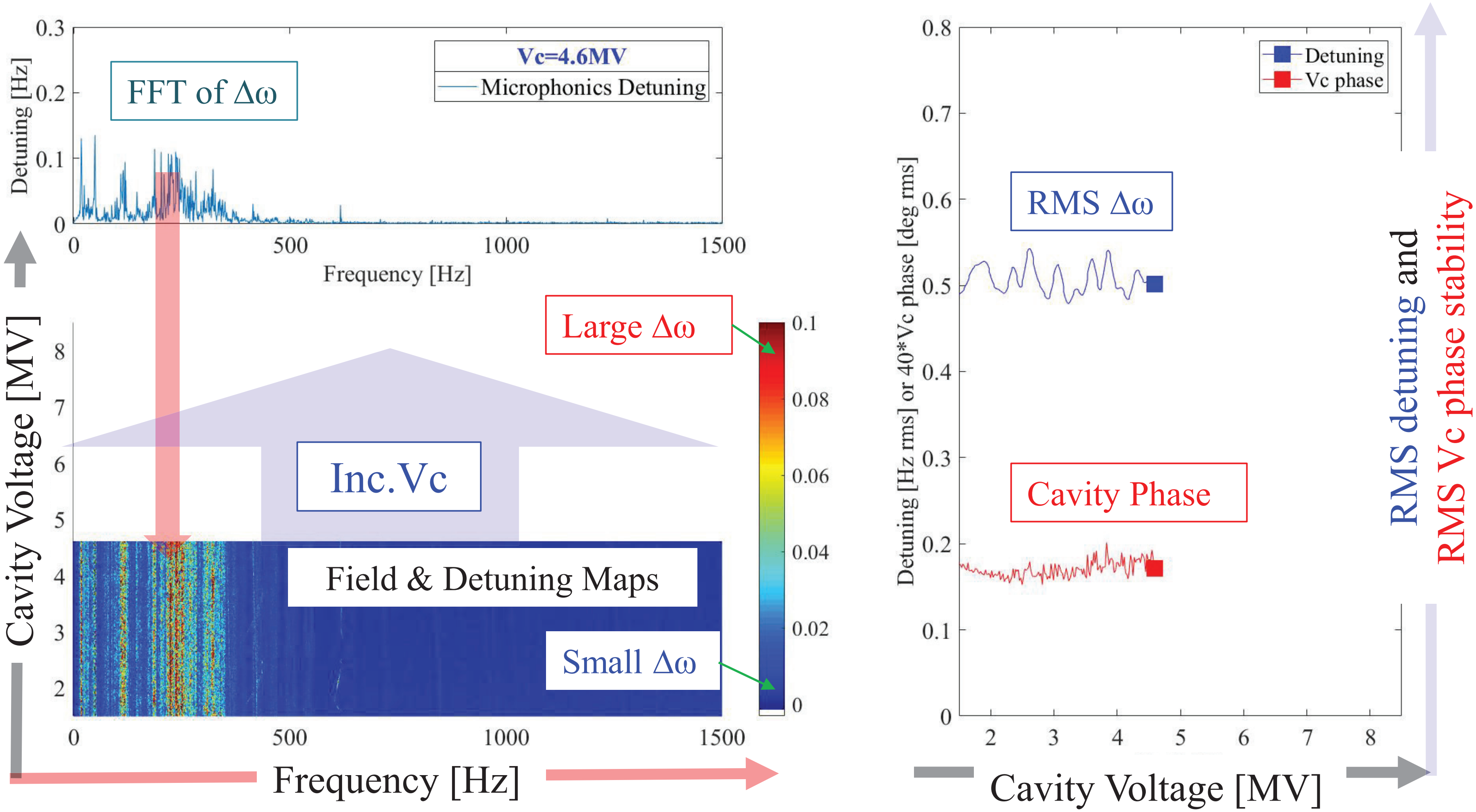




Increase the set value in the FB loop.

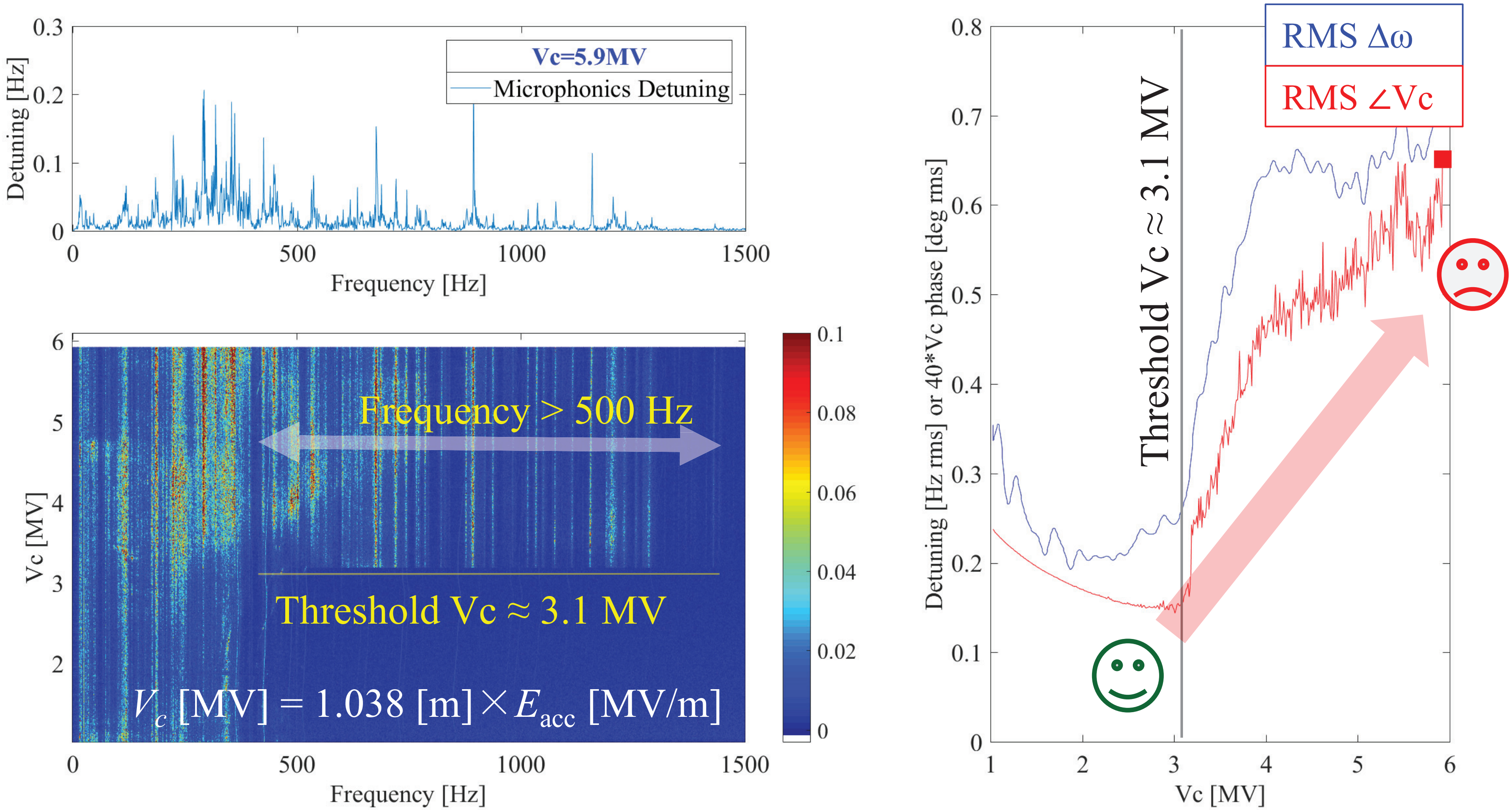
Field Scanning

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



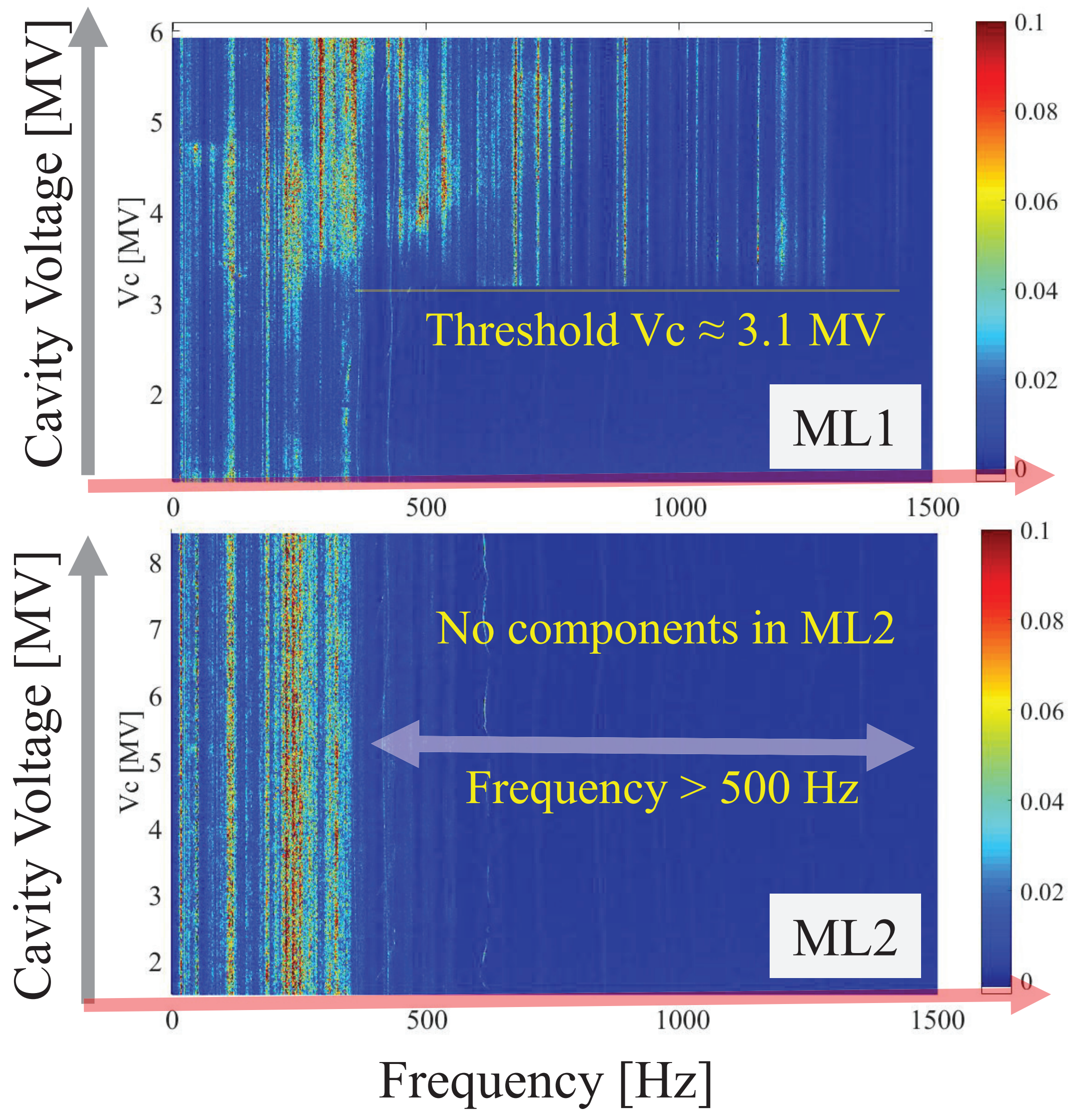
ML1 Field Scanning (result)

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

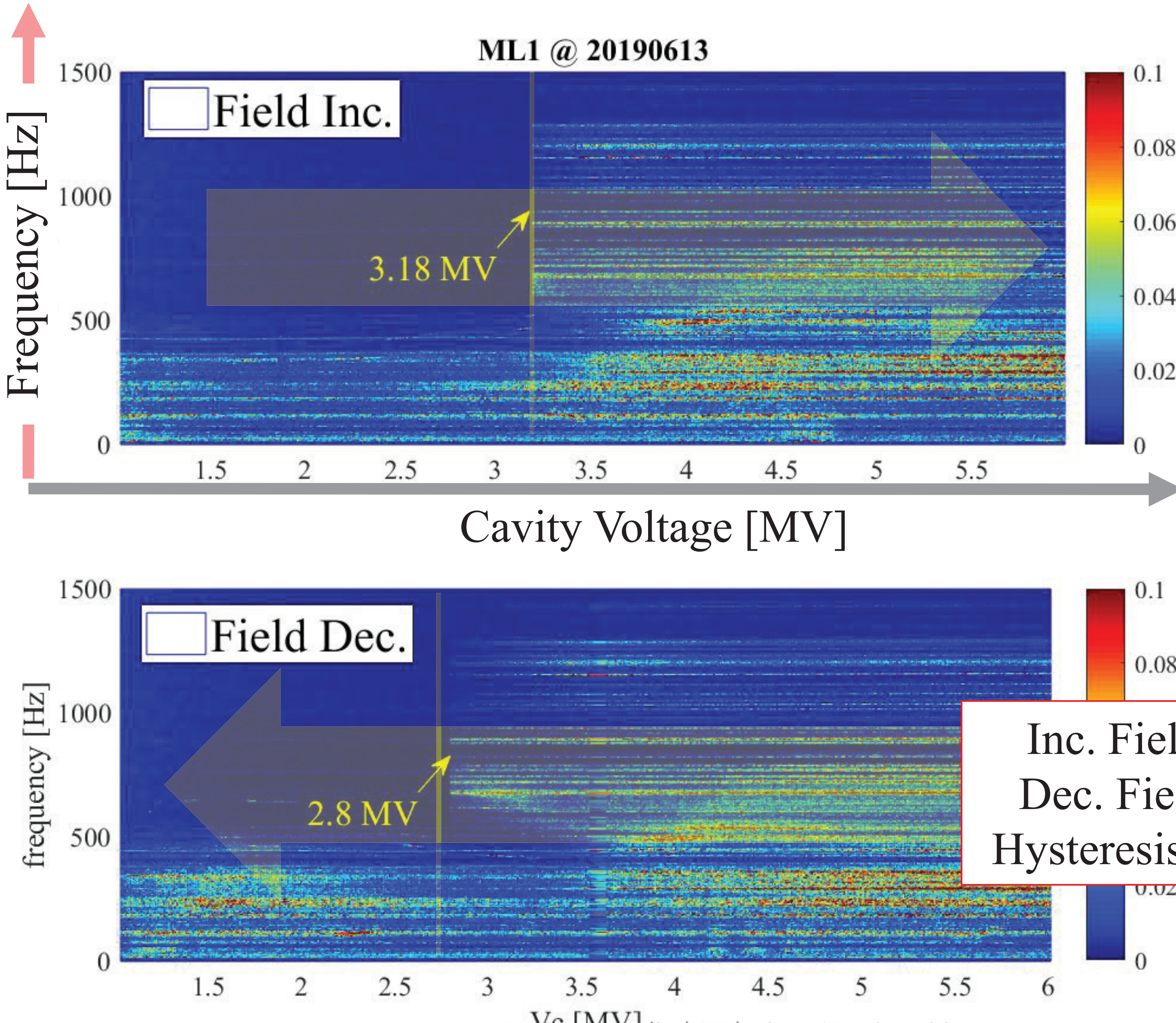


Field-detuning Map (ML1 vs. ML2)

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



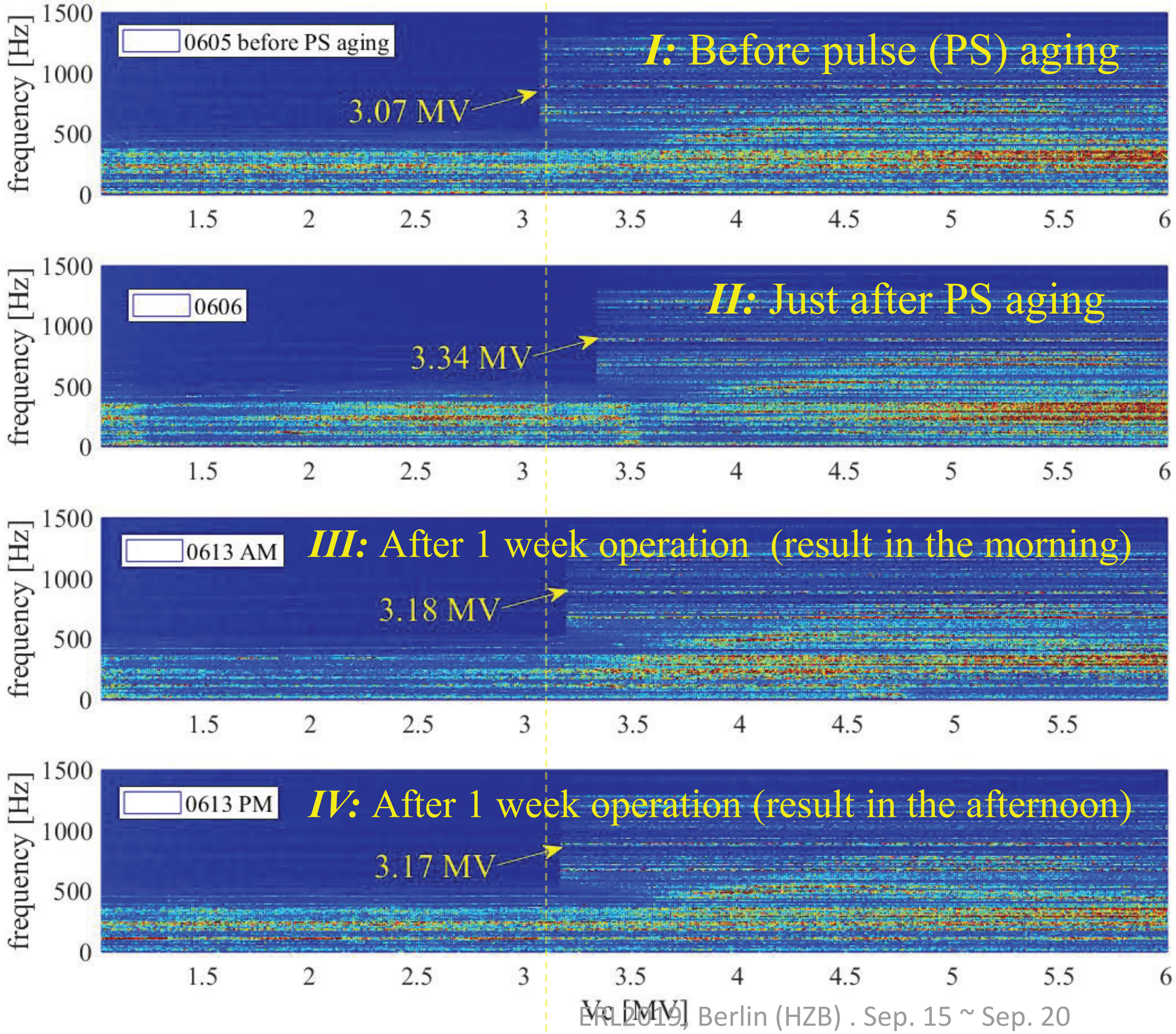
Hysteresis Phenomena



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

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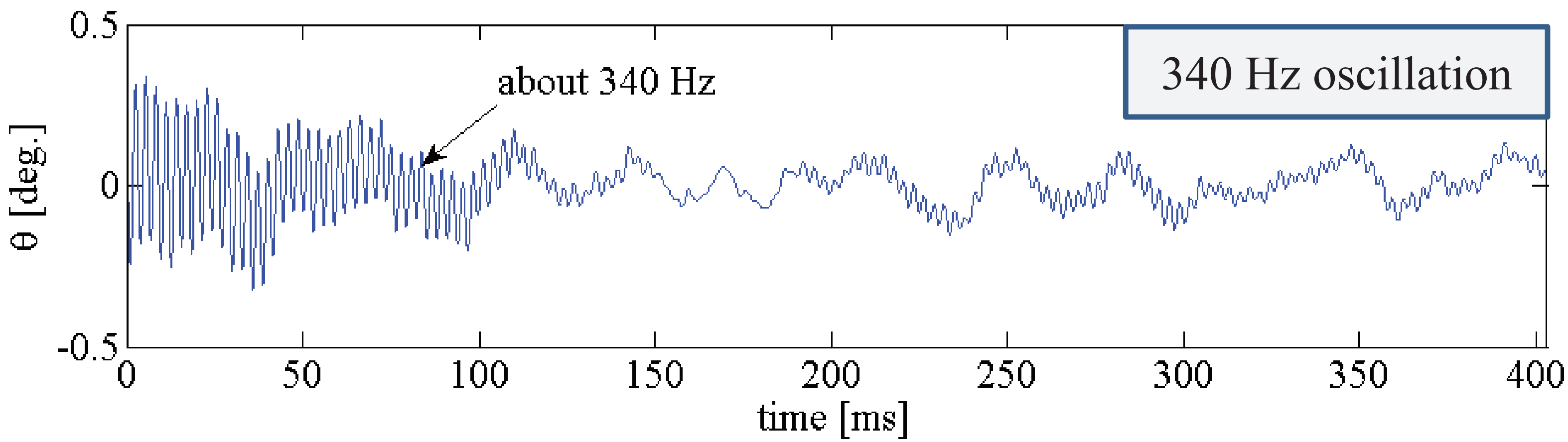
Requirement for system model

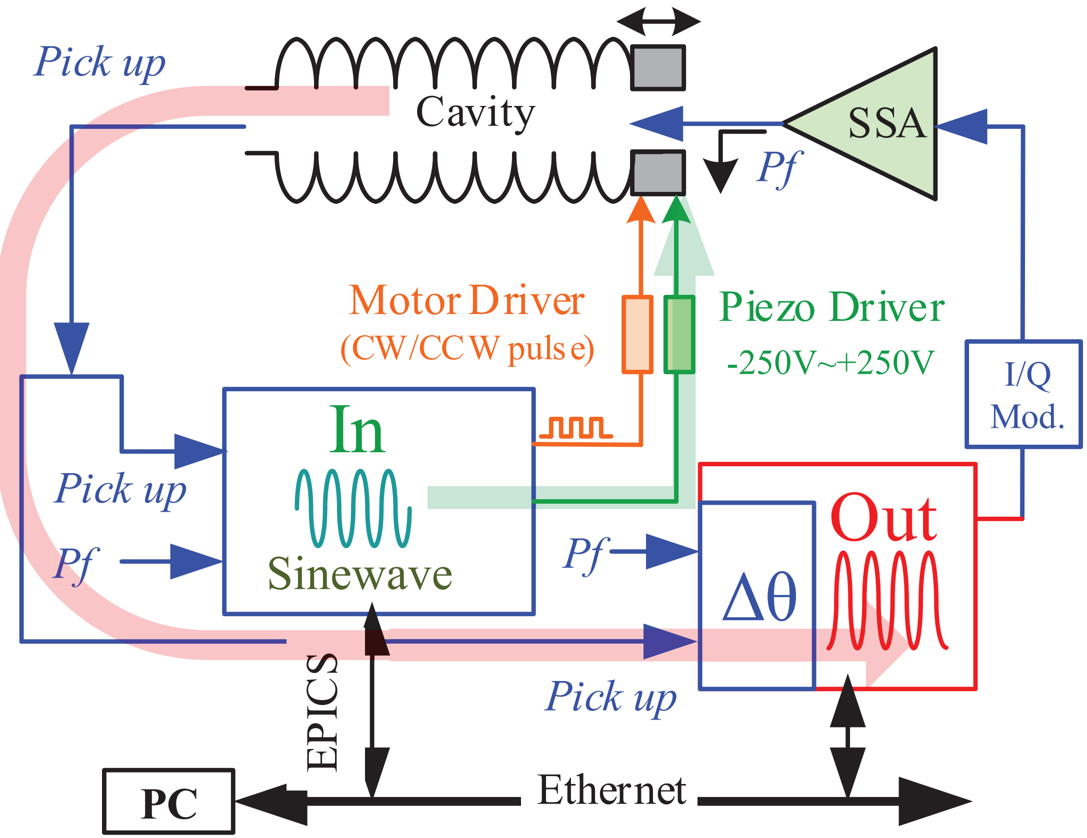
- Simply increasing the FB gain is **NOT** a good method, some mechanical modes would be excited and the system therefore oscillated [4].

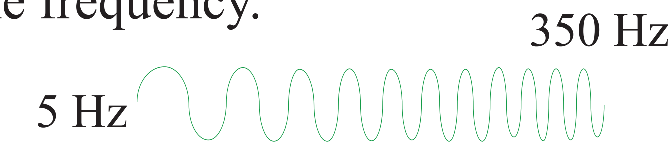


- Advanced control methods (e.g. active compensation method [5], or active noise control [6]) are better choice, for these cases, a system model is usually necessary (or helpful). We have to know the system better.

Identification of the TF Model

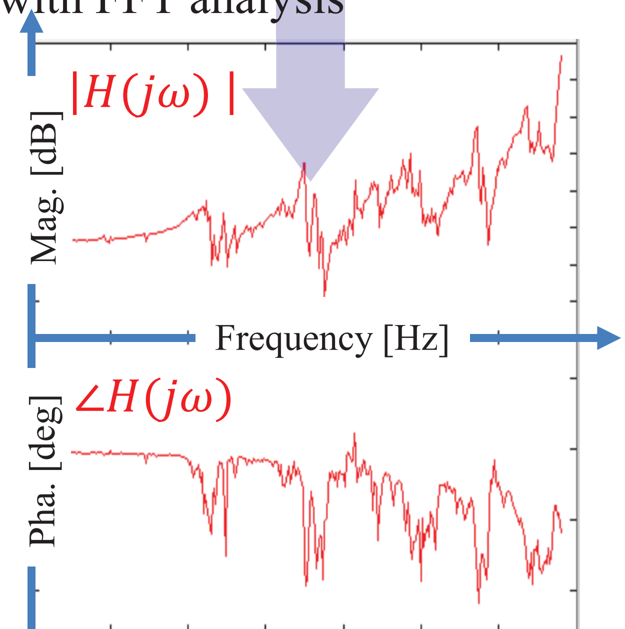
- Transfer function (TF): Piezo to RF.
- Excite piezo with sinusoidal signal and sweep the frequency.
- FFT analysis → TF model.





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

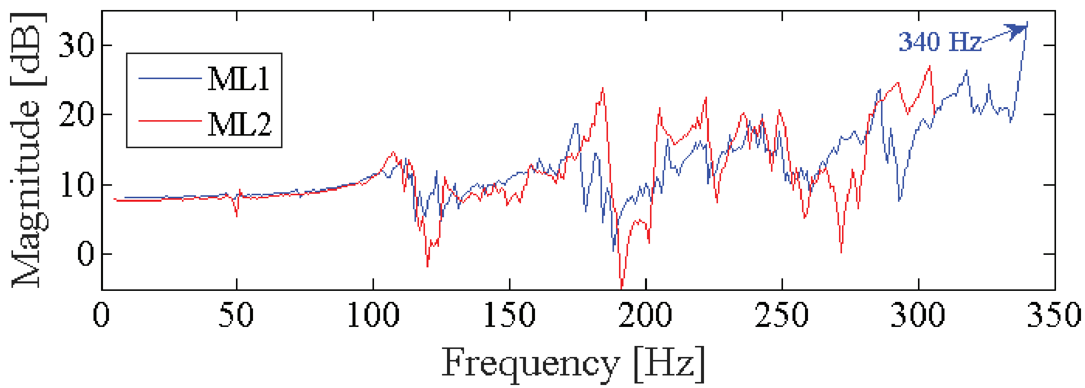
Obtain the frequency response with FFT analysis

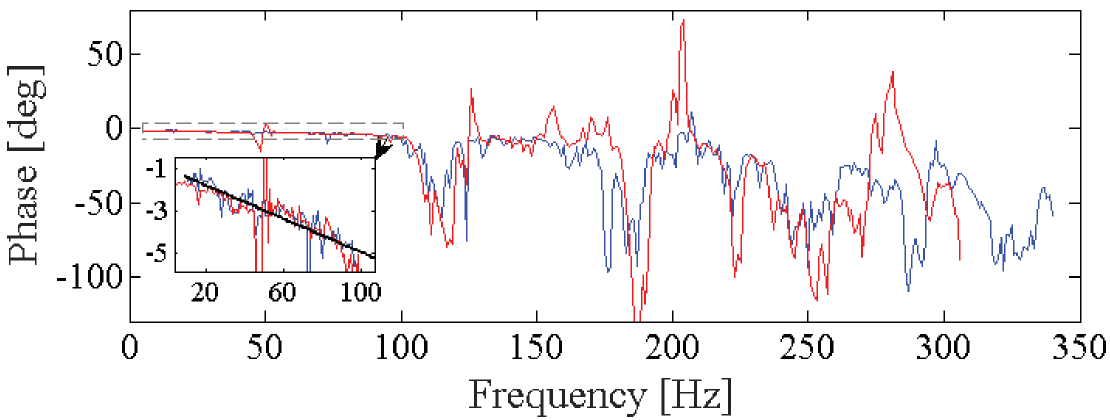


TF Model vs. Δω

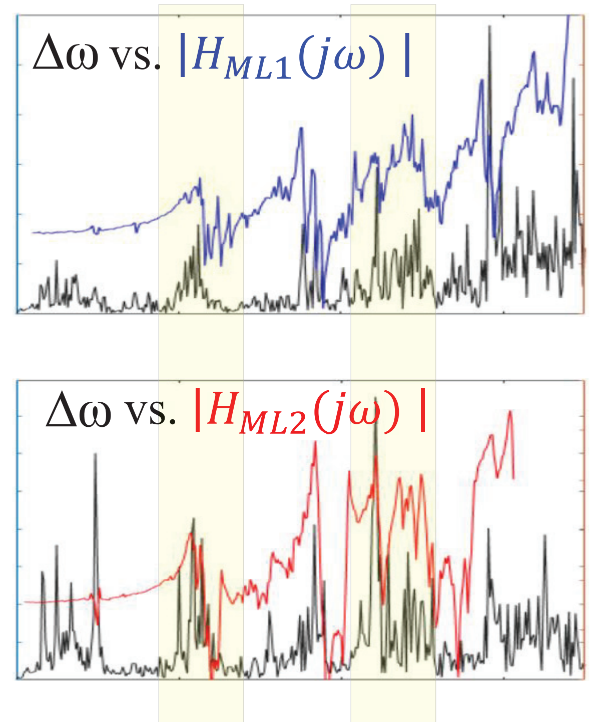
- Piezo Transfer function is probably related with Δω.

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





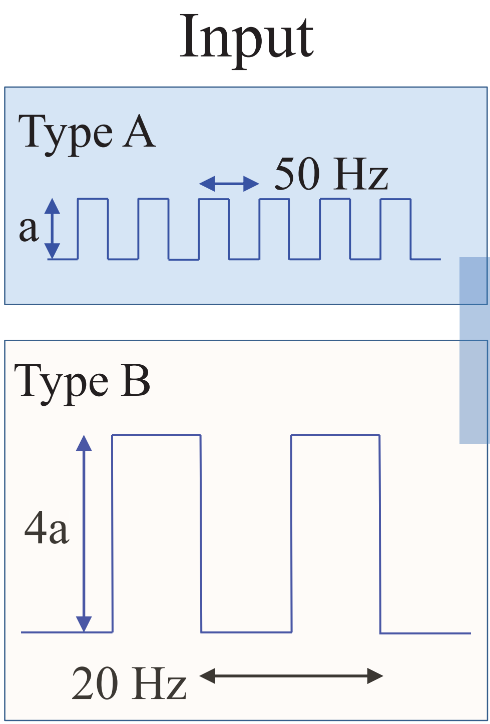
Microphonics and Tuner Model

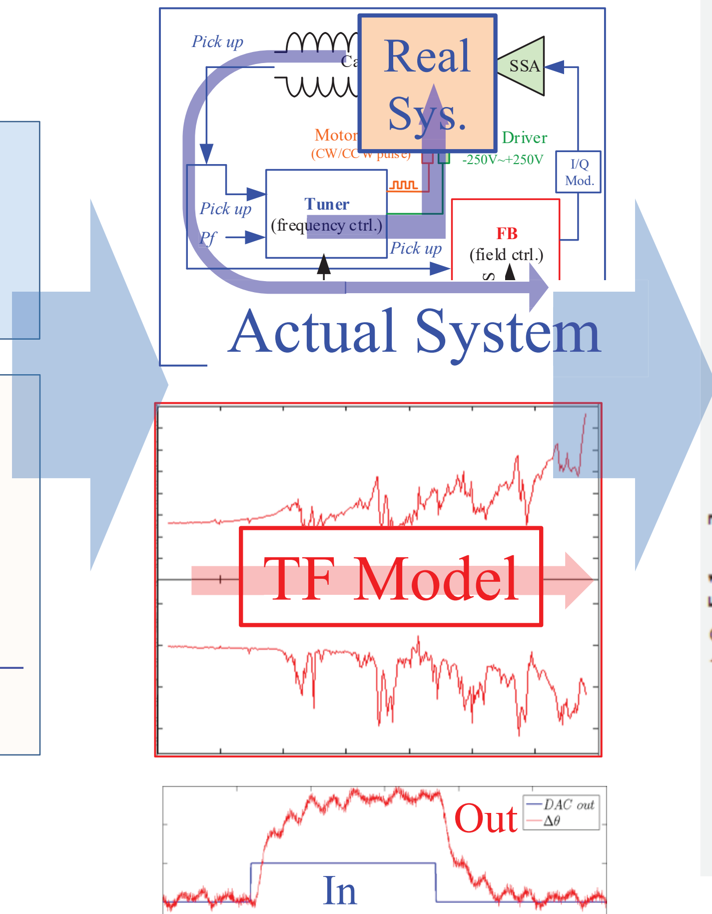


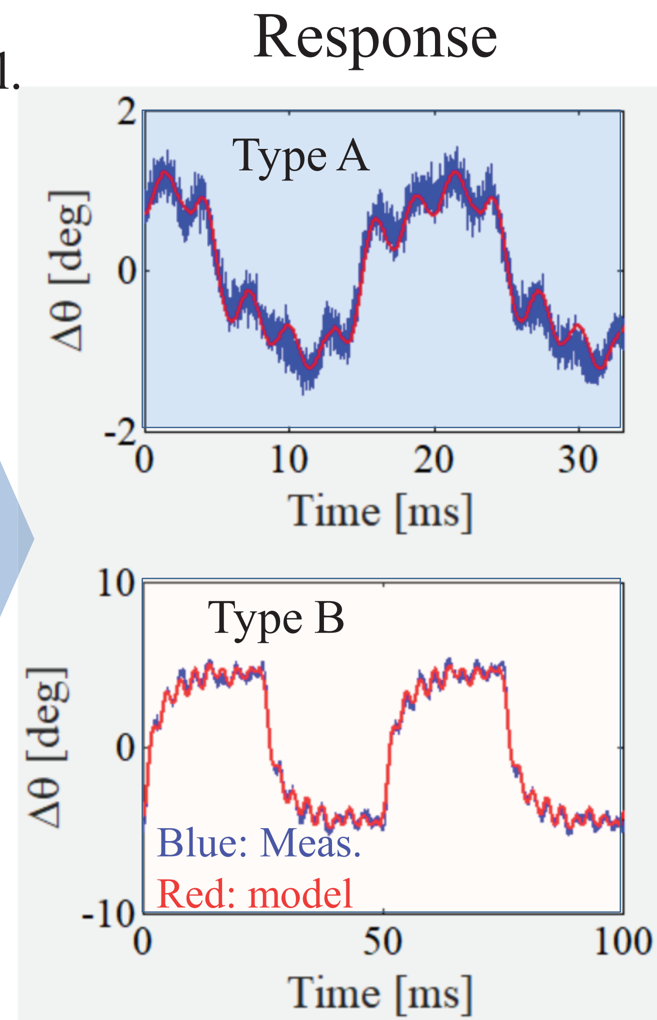
Overlap of Δω & $|H(j\omega)|$

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.







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.

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[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.