Microphonic Characterization and Active Piezo Compensation of a 56 MHz Beam Driven SRF Cavity at RHIC

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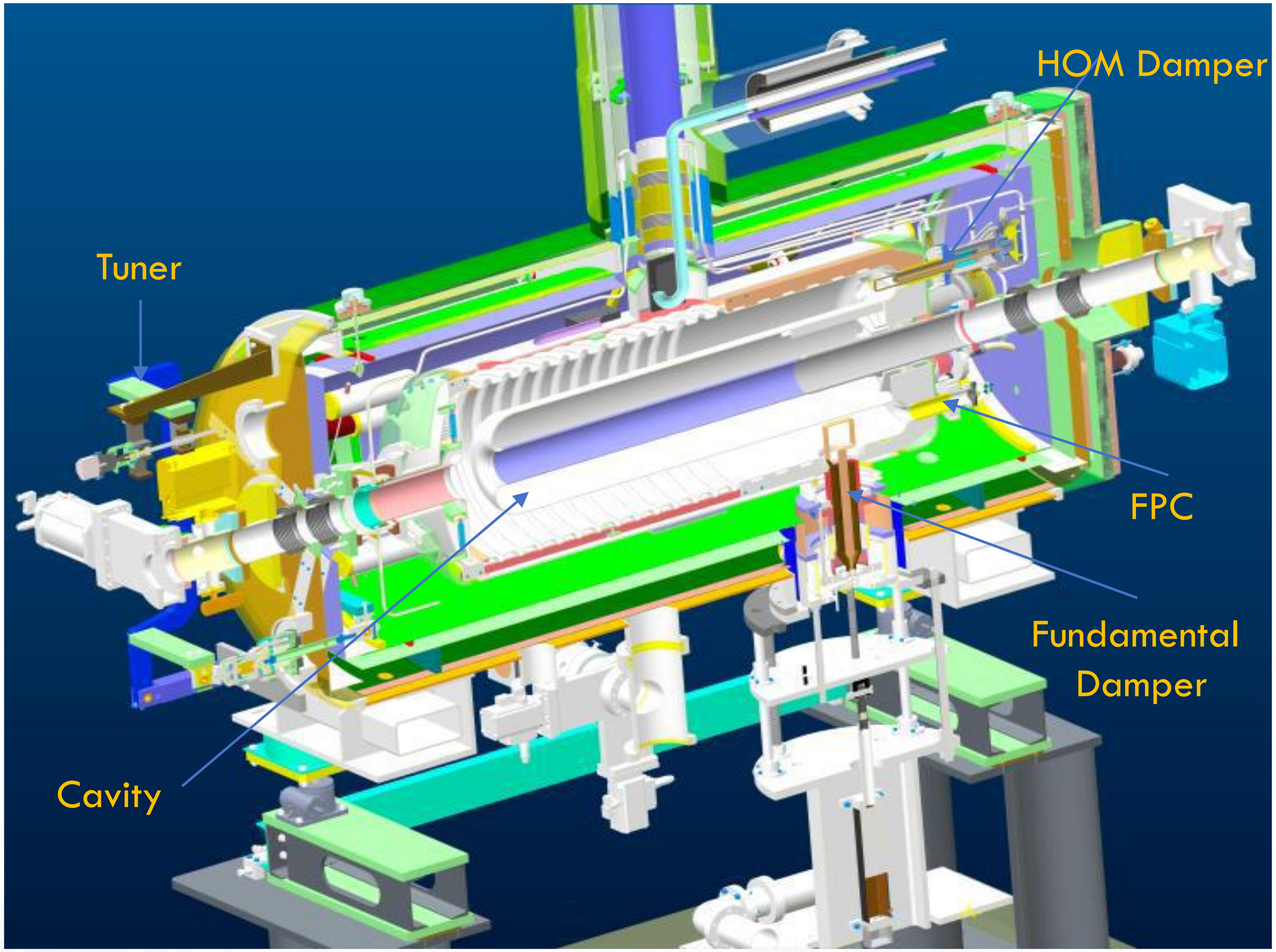
BROOKHAVEN NATIONAL LABORATORY

Presentation Overview

- Cavity Design Parameters
- Operation and Control Requirements
- Resonance Control Challenges
- Operational Parameters Achieved
- Identifying Sources of Microphonics
- Tuning System Transfer Function Characterization
- Initial Results Using Active Piezo Compensation
- Summary

Cavity Design Parameters

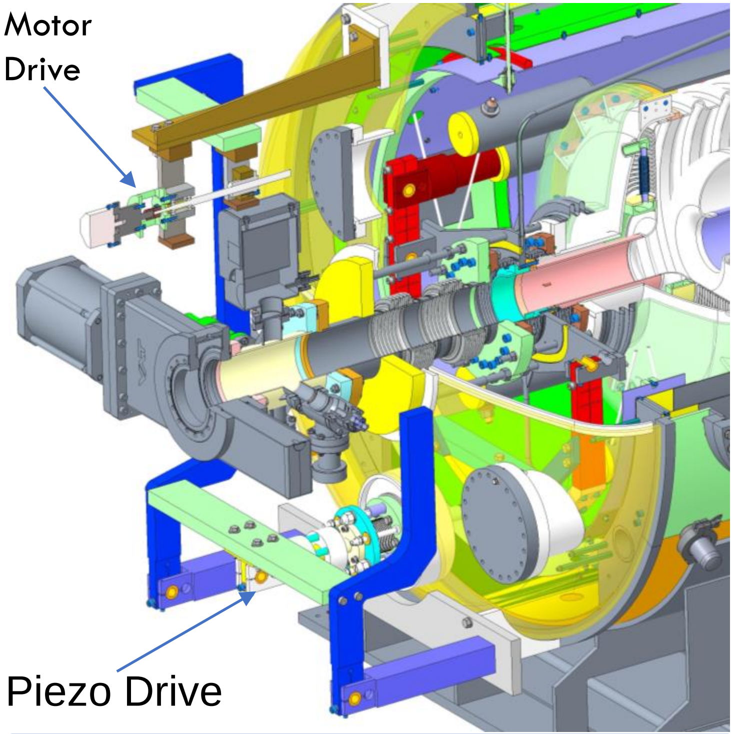


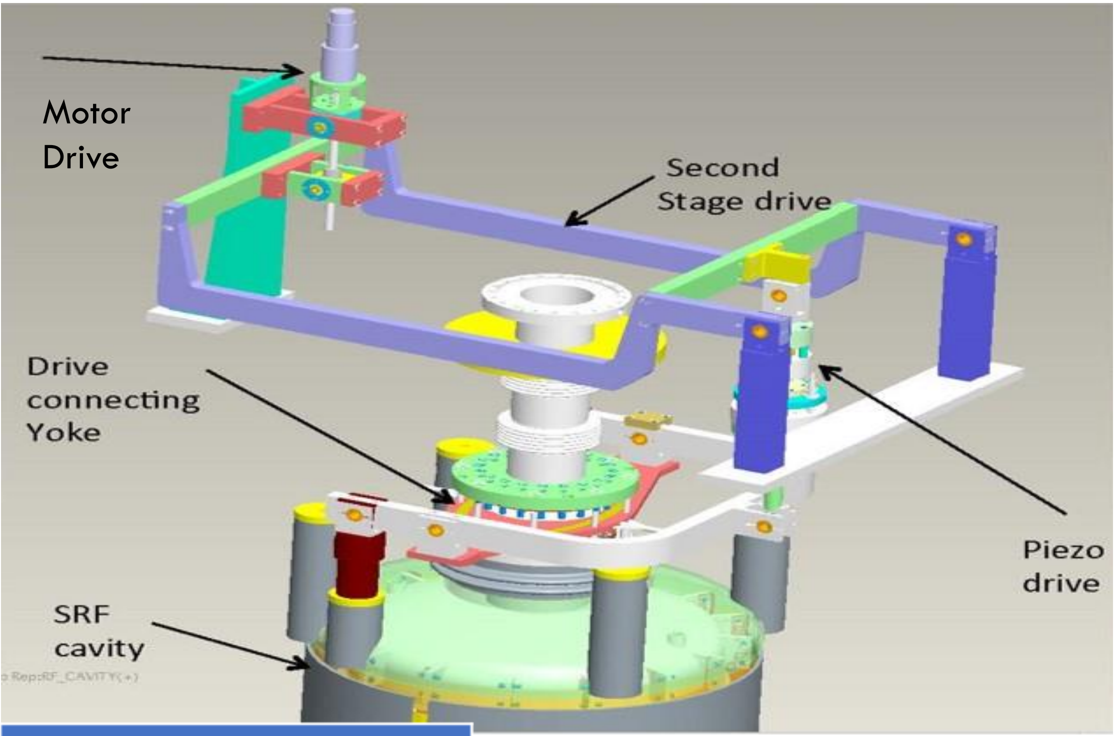
Cavity Design Parameters

- Cavity is a Quarter Wave Resonator
- Hadron Beam Driven Superconducting Cavity

Cavity Parameter	Value
Cavity Operating Temperature	4.2 K
Resonant Frequency	56.285 MHz
Gap Voltage	2.0 MV
Q_o	2e9
Q_{loaded} Range (Movable FPC)	~8e7 to ~1.7e6
R/Q_{ckt}	40 Ω
Design RF Drive Power	1 kW

Tuner Design Parameters





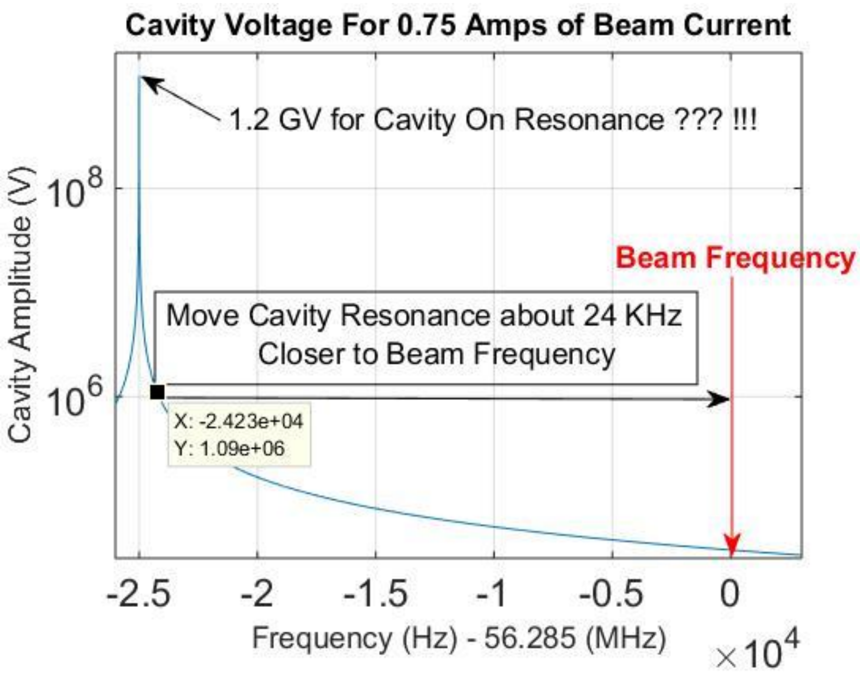
Parameter	Value
Stepper Tuning Range	~ 25 kHz
Stepper Tuner Sensitivity	17 kHz/mm | 3Hz / Step
Piezo Tuning Range	~ 60 Hz
Piezo Tuner Sensitivity	0.06 Hz / V
Design Microphonic Peak Detuning	~1 Hz

Operation and Control Requirements

$|Zcav| = \frac{R_0}{1+j(2*\text{Qext}*\frac{\Delta f}{f_0})}$ ==➔ $|V_{cav}|=I_{h=720}*|Z_{cav}|_{h=720}$

$|Z_{cav}|_{f0} = R_0 = 1.6E9$ ohm !!! ($Q_{ext} = 4E7$, $Q_0 = 3E9$)

Beam Current @ Harmonic 720 ==➔ $I_{h=720} =$ 0.75A (~2e9 per bunch, 111 bunches, 2 beams)

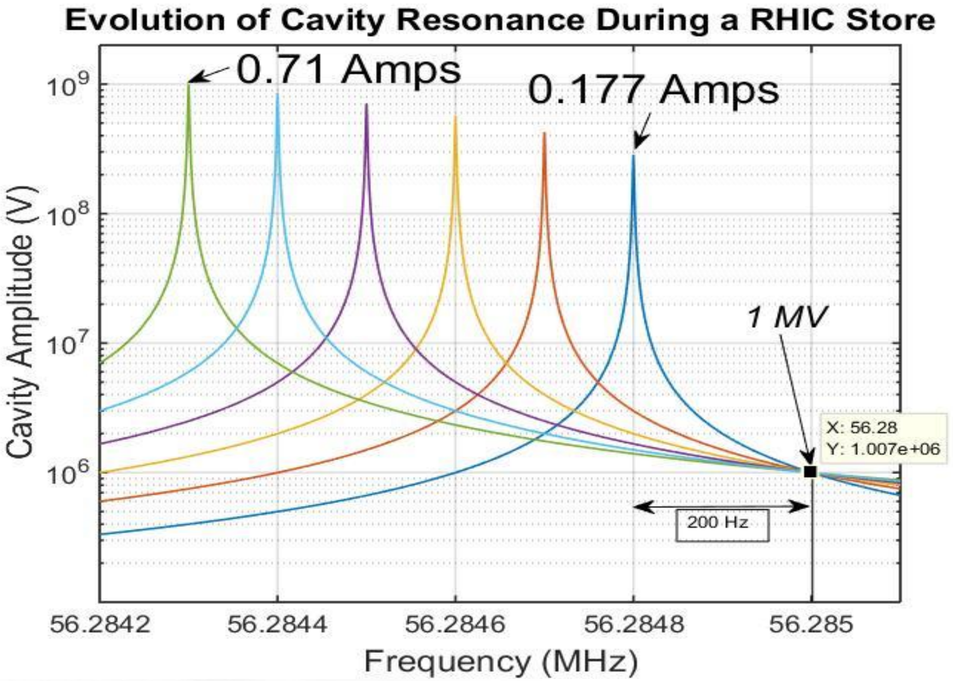


Cavity Voltage For 0.75 Amps of Beam Current

1.2 GV for Cavity On Resonance ??? !!!

Move Cavity Resonance about 24 KHz Closer to Beam Frequency

Beam Frequency



Evolution of Cavity Resonance During a RHIC Store

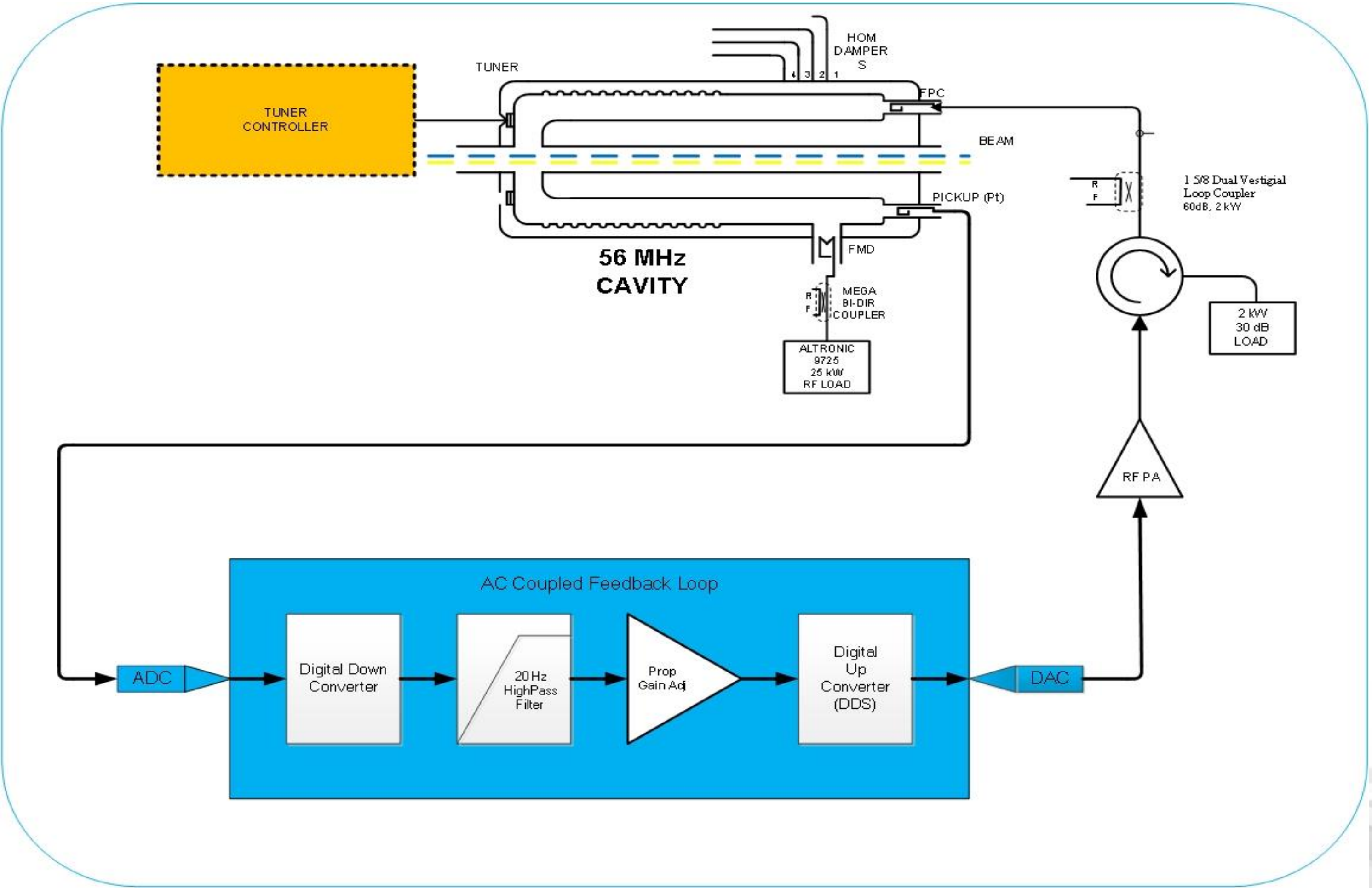
0.71 Amps

0.177 Amps

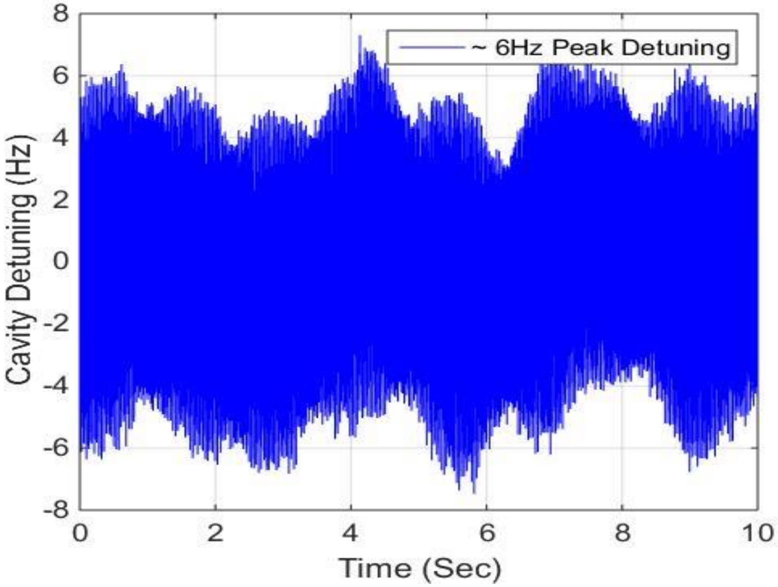
1 MV

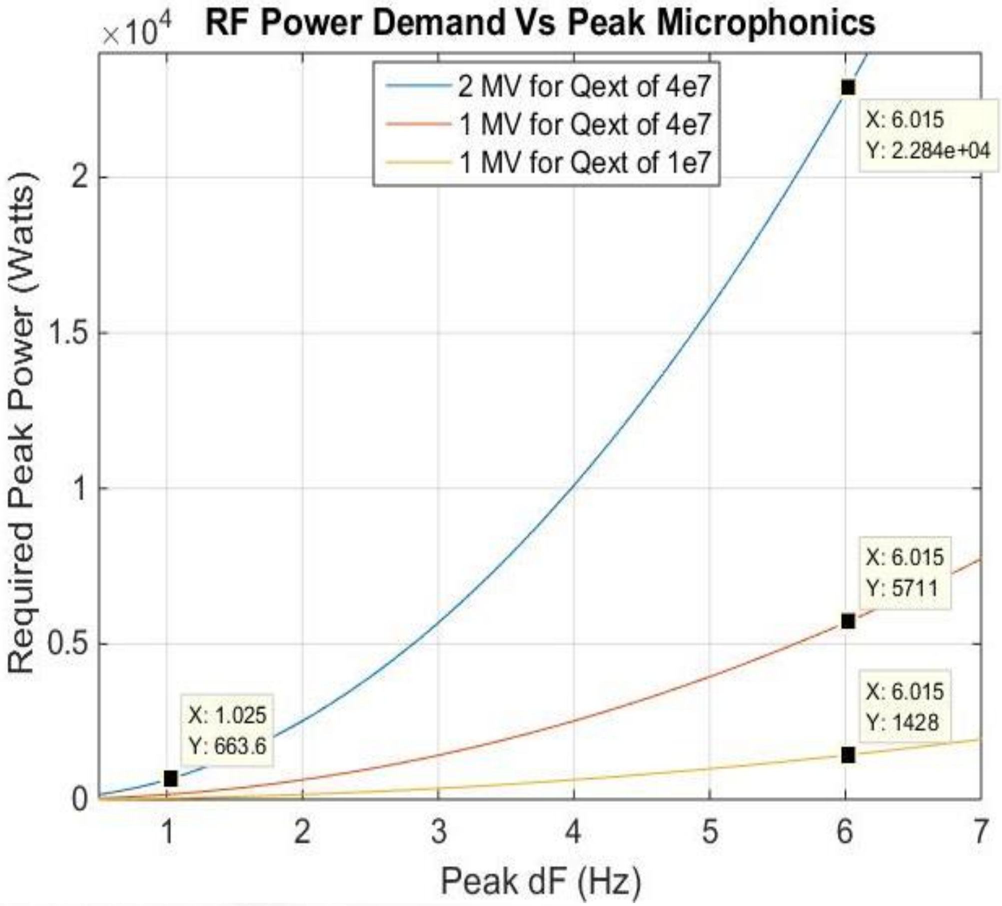
Operation and Control Requirements

- Beam Driven Cavity
  - AC coupled feedback loop to damp microphonic induced voltage fluctuations.
- AC coupled I&Q feedback on first implementation. Later switched to AC magnitude feedback.
- Large cavity voltage fluctuations would induce pondermotive instabilities.
- Amplitude fluctuations on the cavity voltage < 0.1% (~2 kVpp) for operation with beam.



Resonance Control Challenges

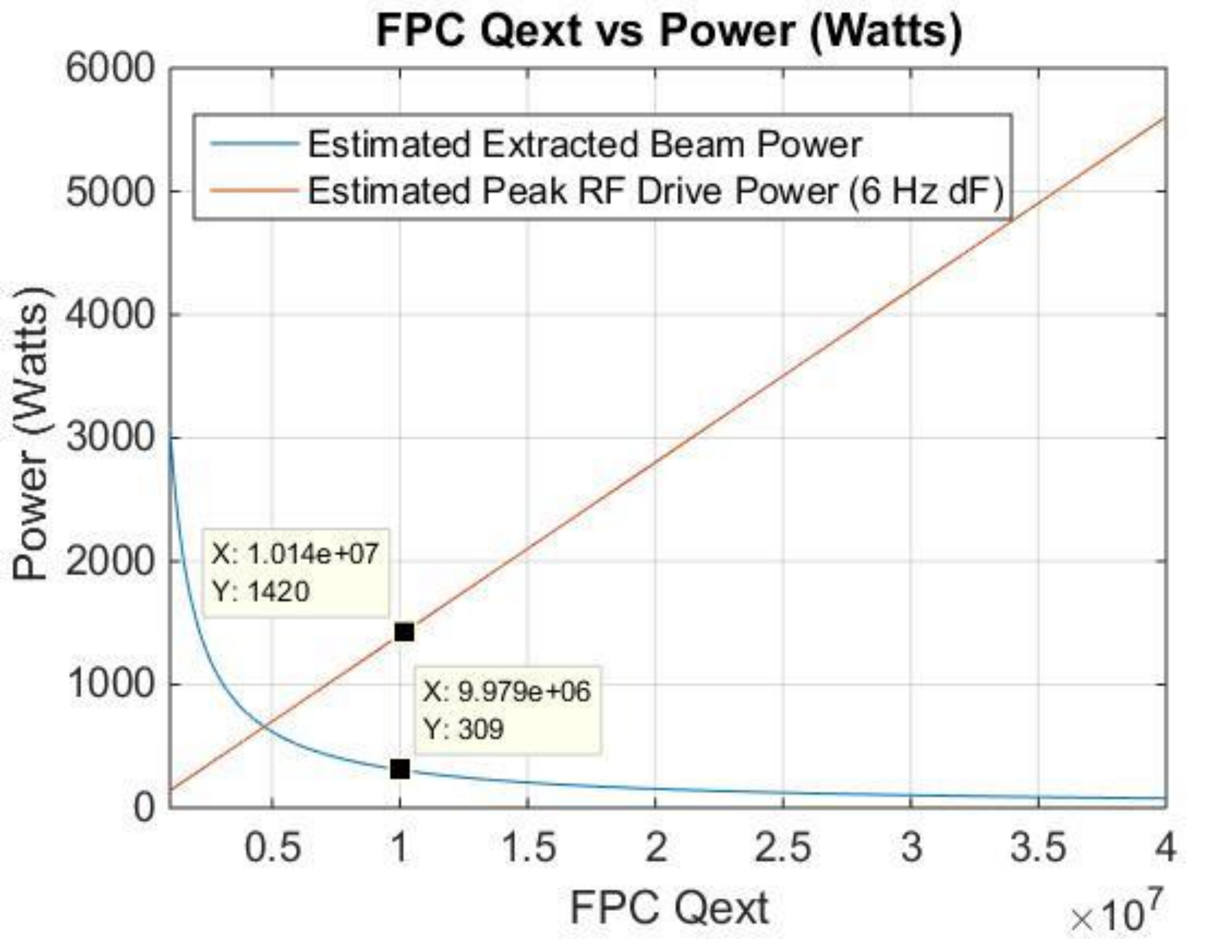




- Microphonic detuning turned out to be 6X larger than expected.
- Required RF power would be 36X bigger for a given Qext & Vc.

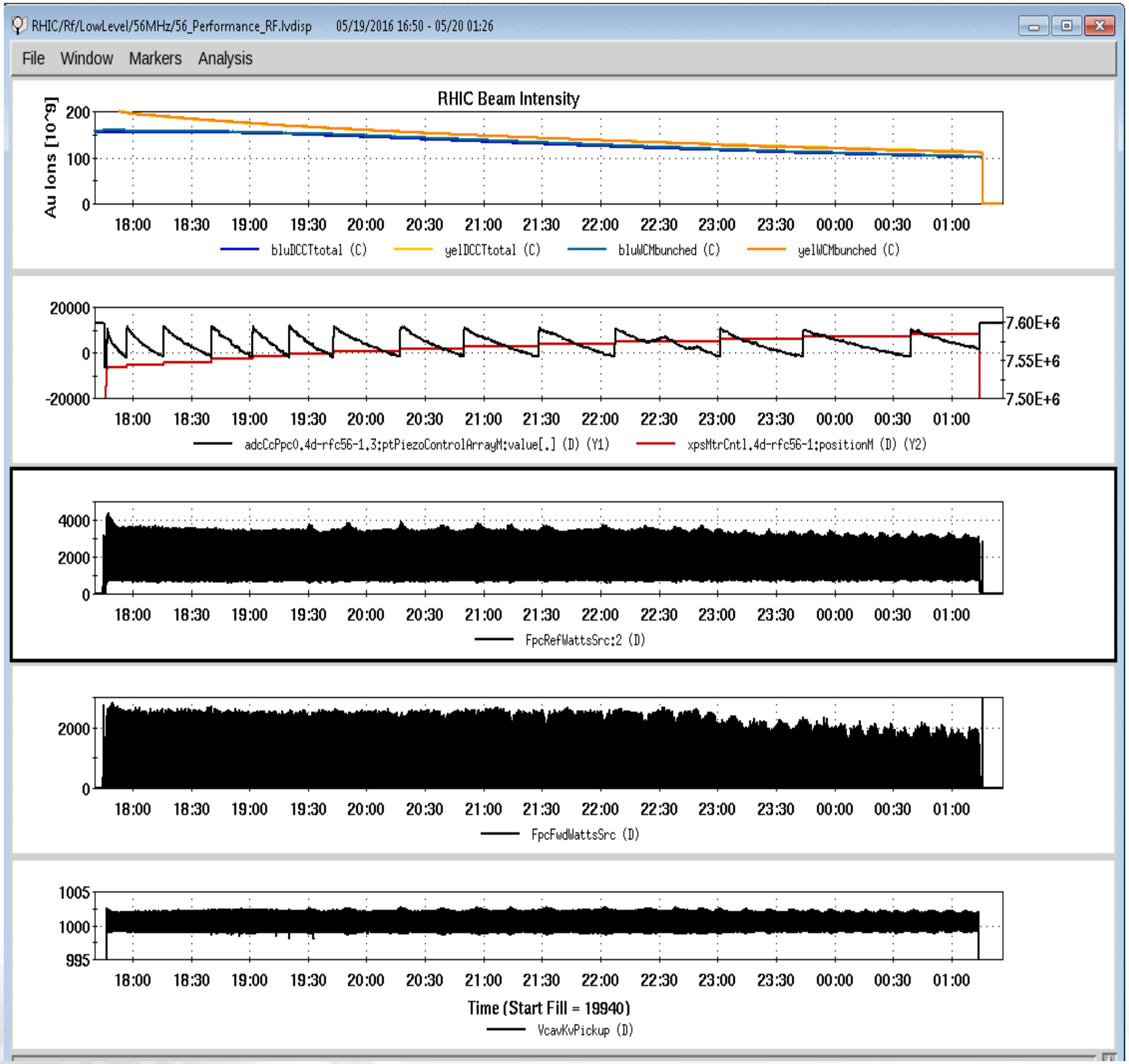
$$P_{forw\_pk} = \frac{V_c^2}{R/Q} \cdot Q_{ext} \cdot \left(\frac{d\omega_{micr\_pk}}{\omega} \right)^2$$

Resonance Control Challenges



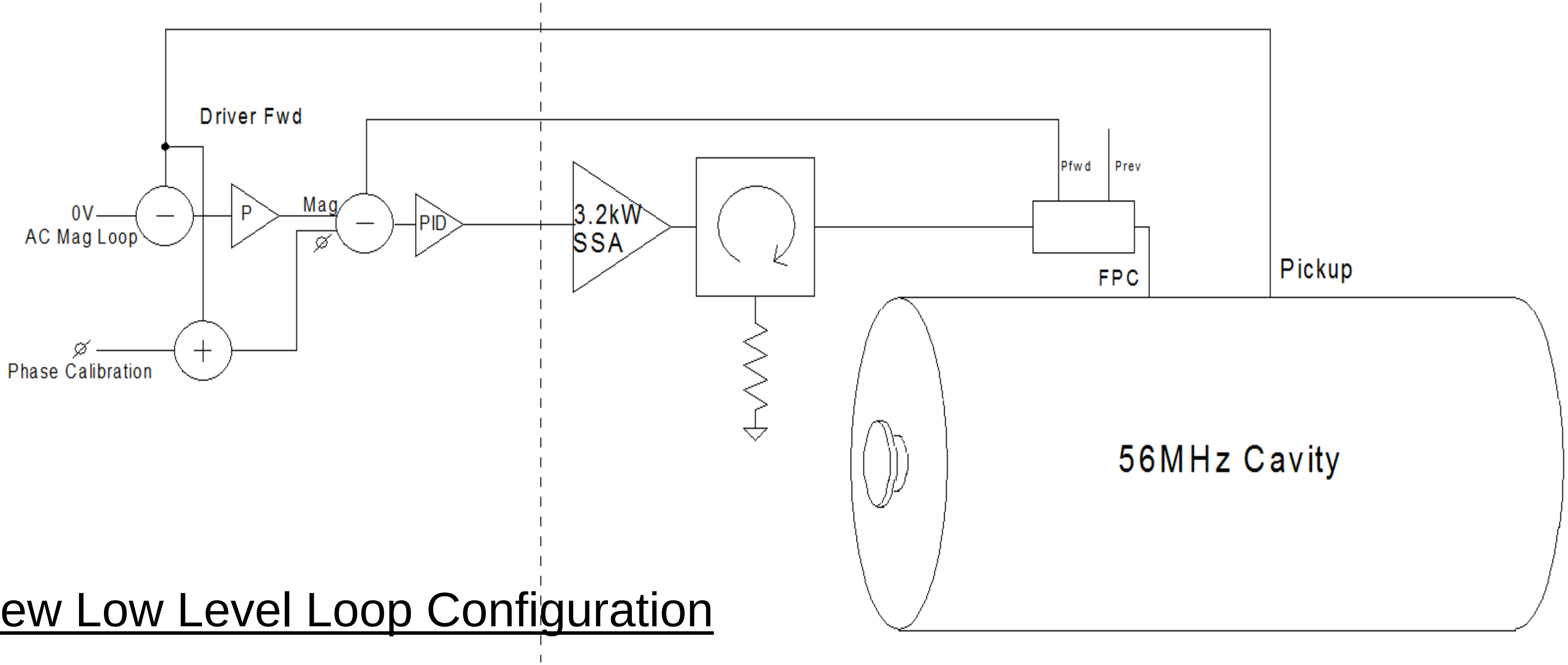
- Empirically optimized FPC position (Qext)
  - Trade offs between FPC emitted power and PA forward power required for stabilization.
  - Required drive power
    - Needed high power amplifier
    - 3.0 kW Amplifier
- Limit goal to operate with beam 1 MV

Operational Parameters Achieved



- 1MV operational with beam.
- Exposed weaknesses in the cavity and RF
  - Found 45 (deg) phase drift in the RF forward path (high power circulator due to water temperature and amplifier non linearities).
  - Limited CW power handling in the FPC.
- Provided validation of the LLRF feedback loops used to stabilize the cavity.

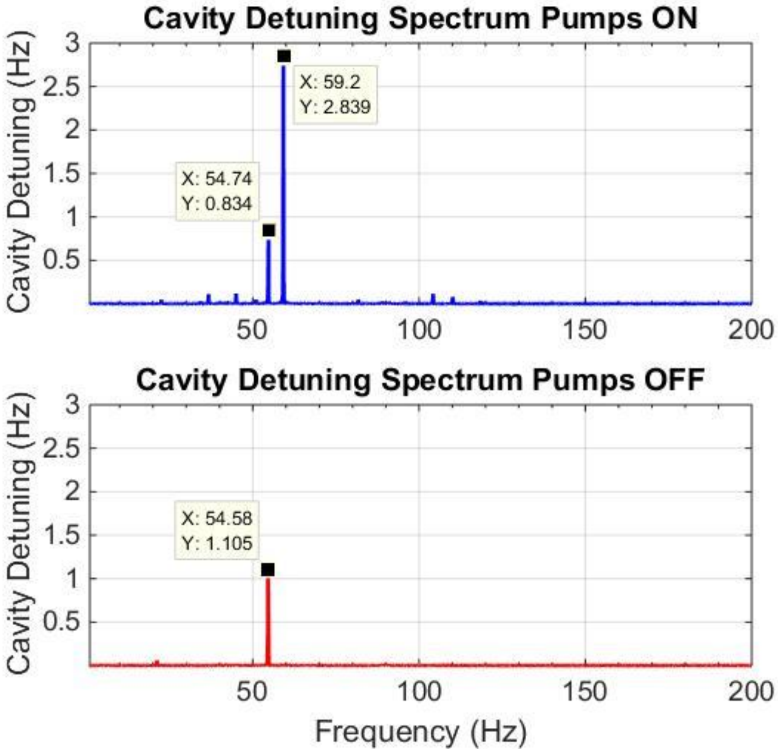
RF Feedback Improvements

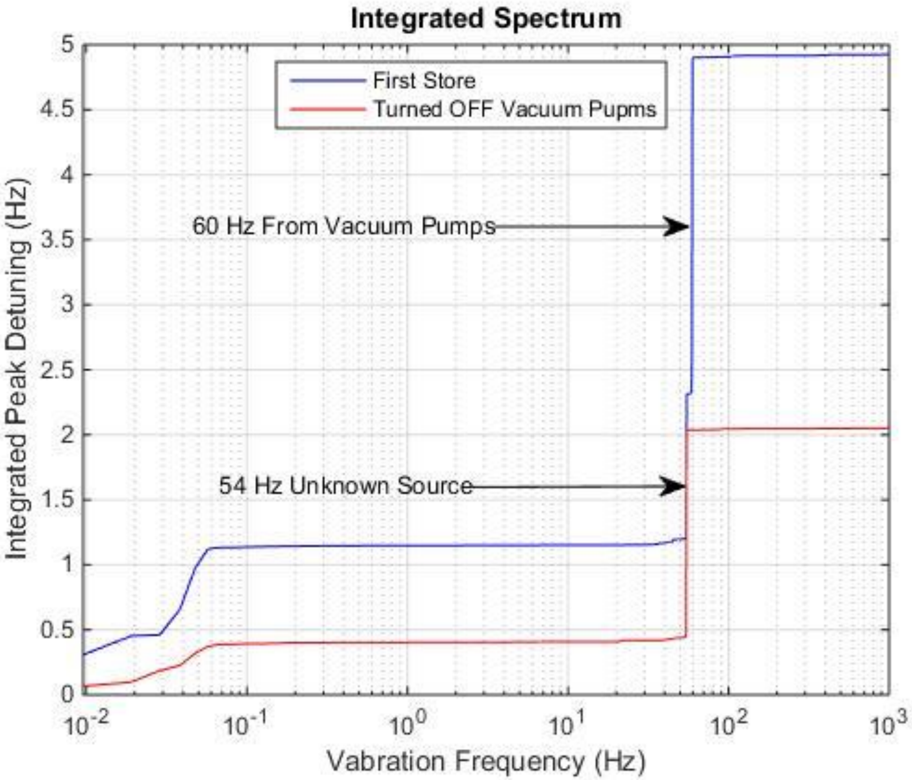


New Low Level Loop Configuration

- Drive chain feedback was implemented around the amplifier and circulator in firmware.
- Replaced I&Q AC coupled feedback around cavity with AC coupled magnitude feedback.
- Combined improvement should reduce required RF drive by a factor of 2.

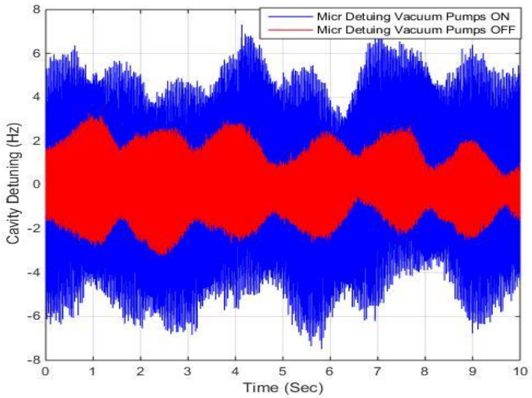
Identifying Sources of Microphonic





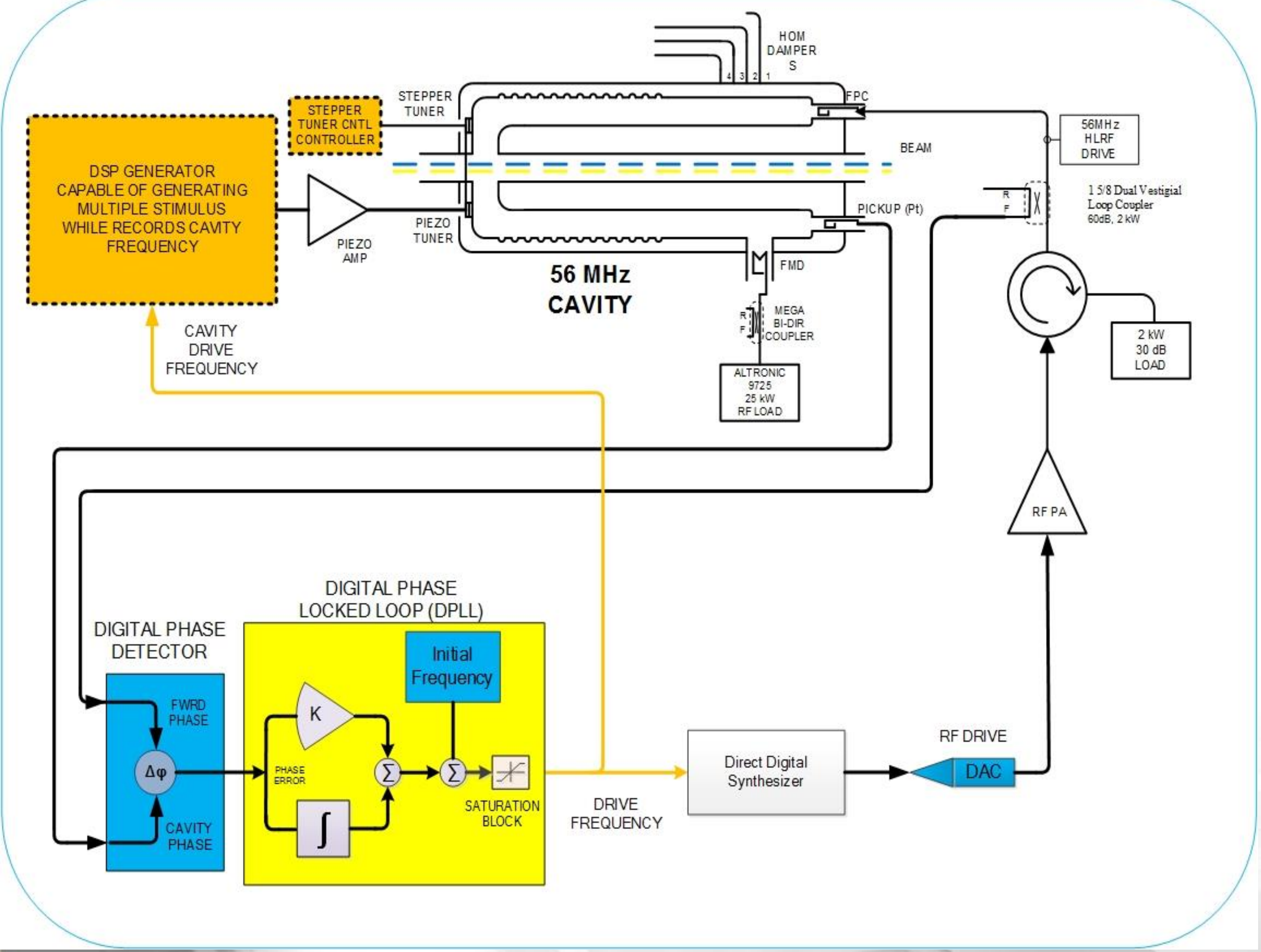
60 Hz From Vacuum Pumps

54 Hz Unknown Source



Tuning System Transfer Function Characterization

- Low Level RF controller to measure piezo to cavity tuning transfer function.
- The process consists of a digital PLL setup with high gain to closely track the cavity resonance frequency by keeping phase error small. This is done while driving the piezo amplifier with some kinds of stimuli.



- The DSP system simultaneously records cavity frequency data generated by the PLL and the corresponding piezo stimuli.
- The best transfer function was obtain by applying a sinusoidal signal at discrete frequency steps shifting frequency after a 3 s of delay in steps of 0.1 Hz.
- How slow is slow enough?

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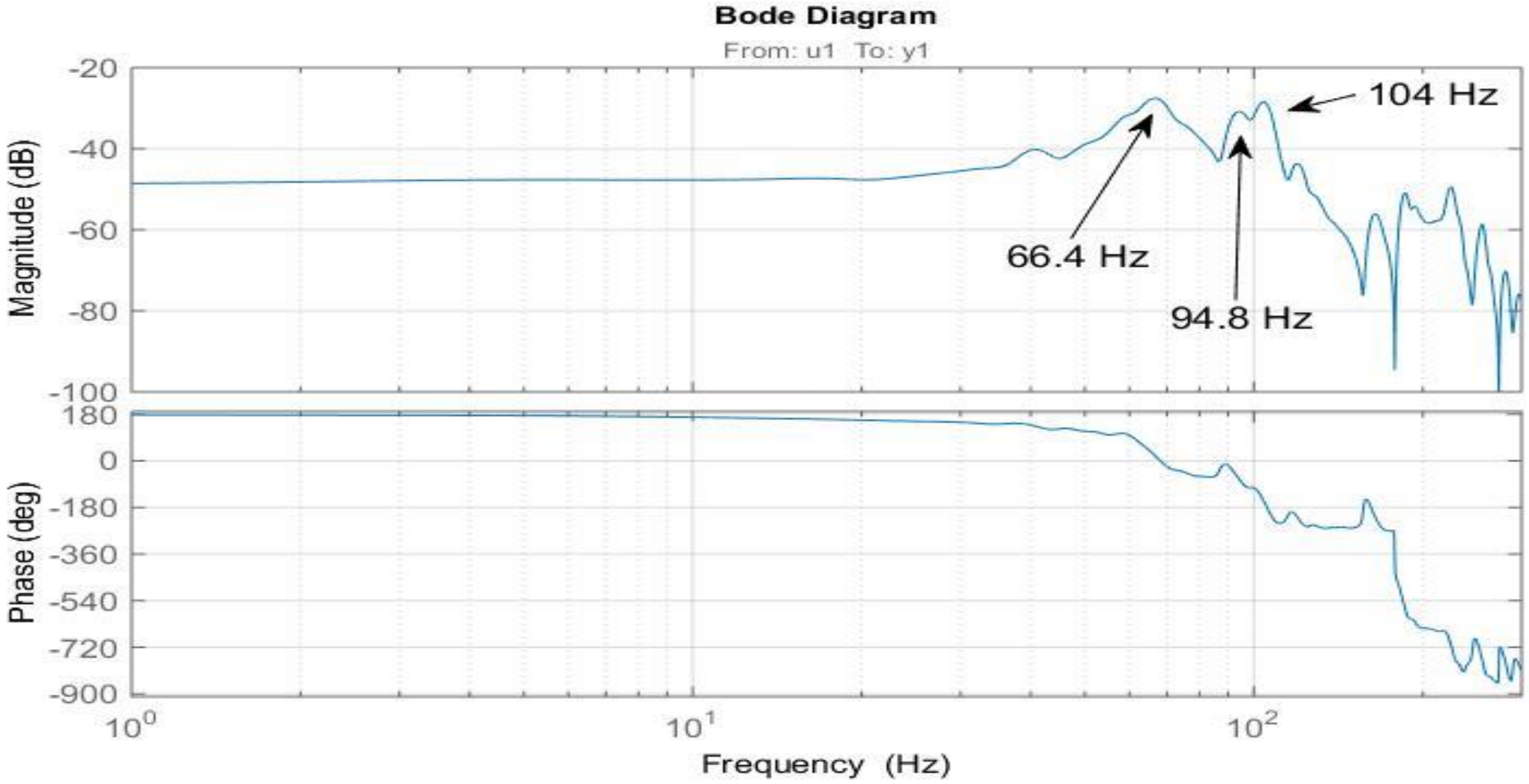
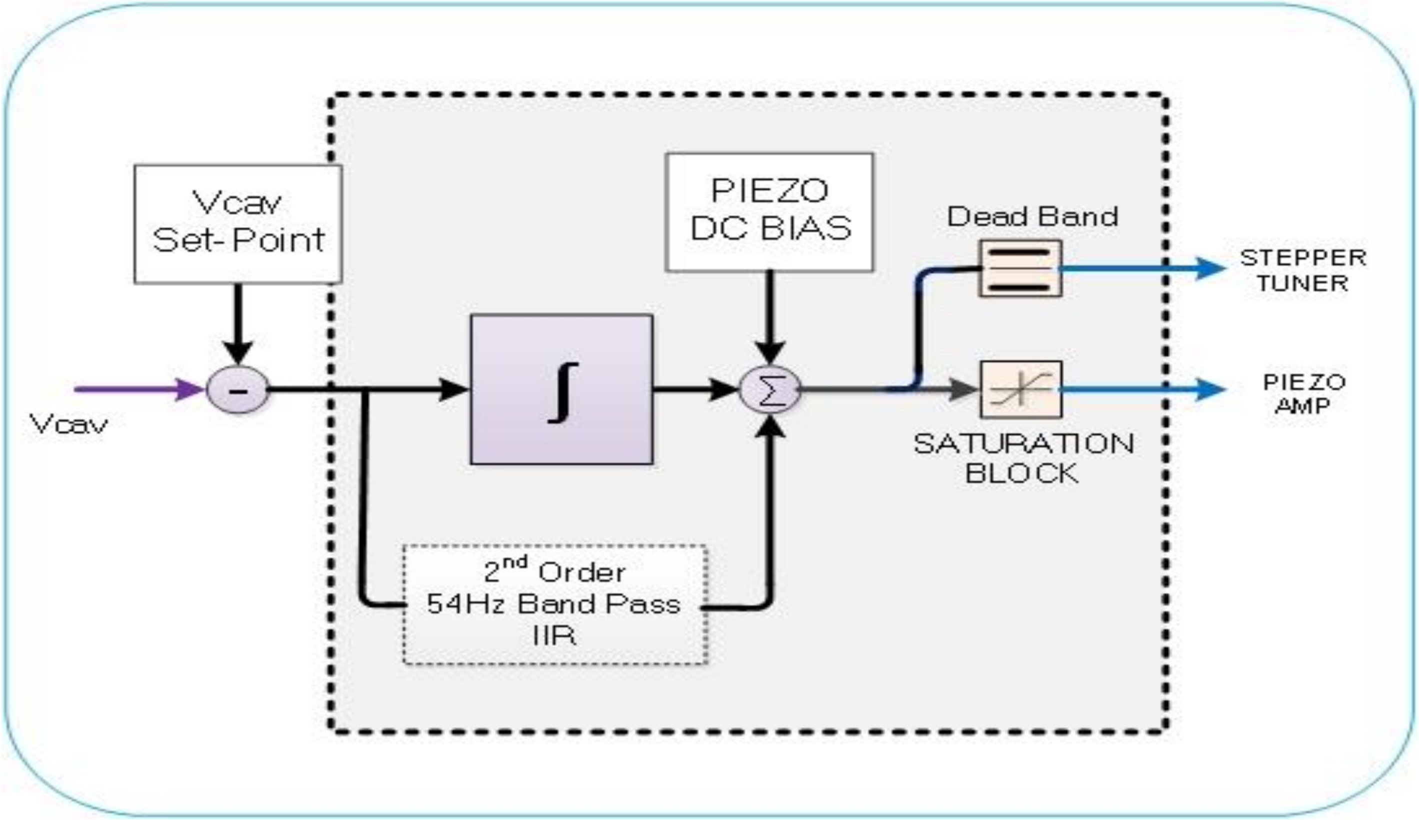
Tuning System Transfer Function Characterization



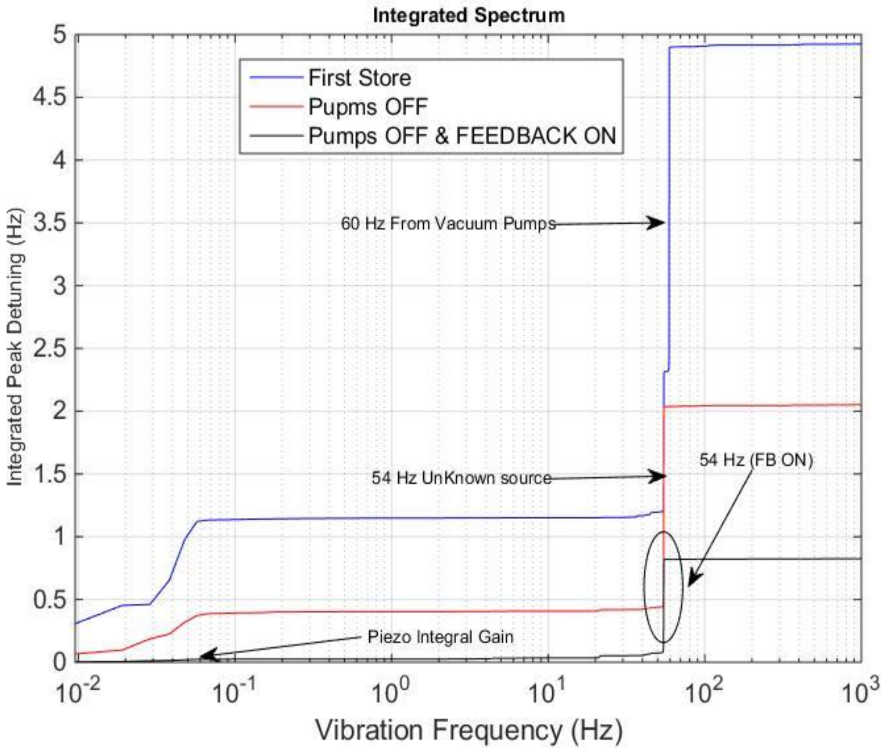
- A slow sweep type stimuli works well enough.
- Here we used (120 sec long sweep from 1Hz to 300 Hz.
- Used matlab to compute transfer function.

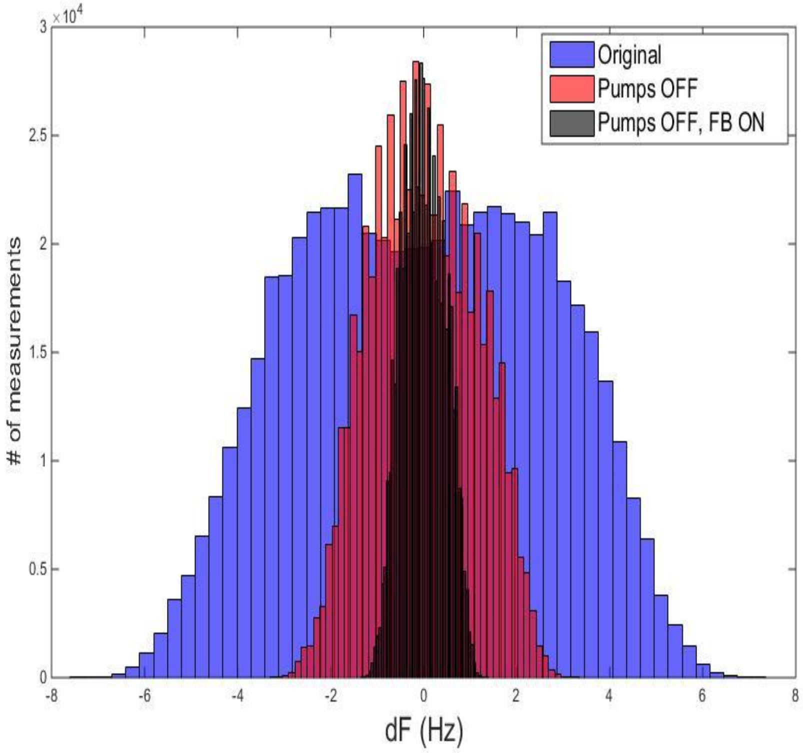
Piezo to Compensate Microphonic Detuning



- Implemented piezo control feedback on a DSP to include an integrator and a 54 Hz band pass to target largest mechanical vibration at 54 Hz.
- Optimize loop gain based on measured open loop transfer function.

Piezo to Compensate Microphonic





- Reduced peak microphonic detuning by a factor of 2.5, about 8 dB.
- Tested concurrent operation of RF AC coupled magnitude feedback and piezo feedback without beam.
- Peak microphonic detuning was reduced to about ~1 Hz peak.

Summary

- Reduced required RF power enough to operate at 2 MV with beam.
  - Improved RF feedback to reduced phase shift.
  - Improved FPC power handling tested at 3.2 kW.
  - Passive elimination of source of microphonic.
  - Active compensation using piezo.
  - Achieved about < 1.5 Hz peak detuning.
  - Required RF power and beam extracted power will be 1 kW for 2 MV.
- Plan to improve active microphonic compensation algorithm
  - Computed system model for this and other SRF cavity's piezo transfer function.
  - Plan to start working on implementing adaptive type compensation.

Thank you

- Kevin Smith, Salvatore Polizzo, Tom Hayes, Kevin Mernick, Geetha Narayan, Scott Seberg, Loralie Smart, Qiong Wu, Alex Zaltsman, Carlos Ramirez, Freddy Severino, more…