Calibration and Measurement Techniques in the LLRF systems of the Fermilab PIP-II Linac

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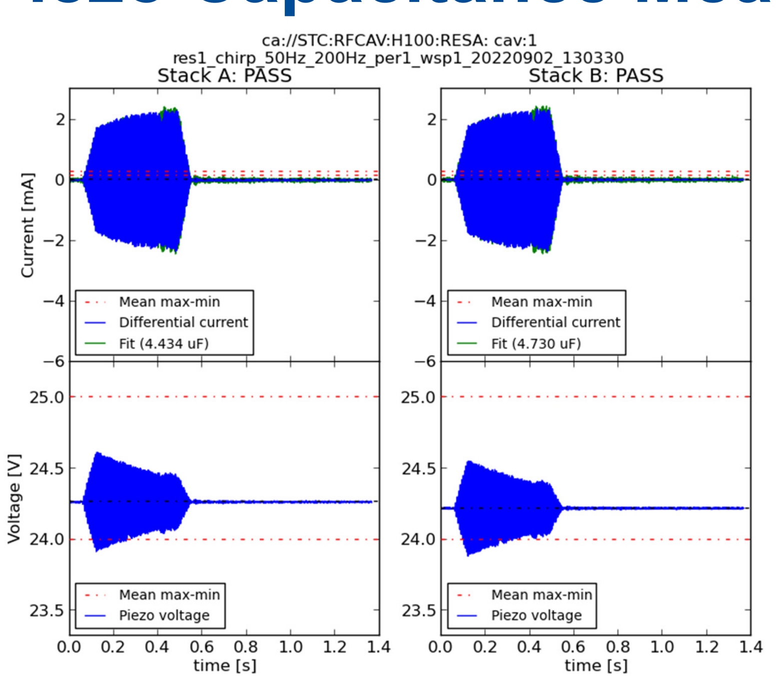
ID 16

Introduction

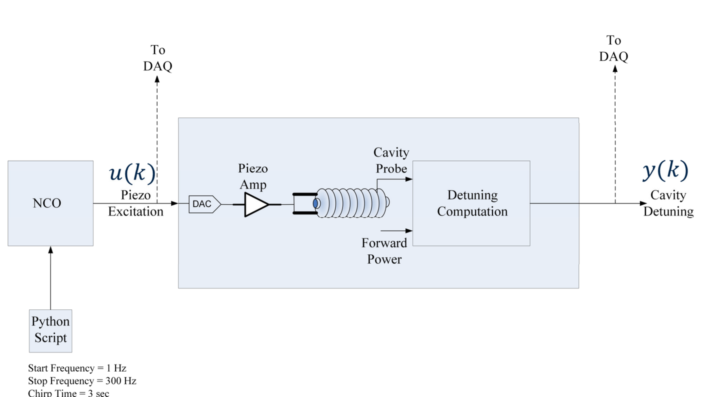
The PIP-II Accelerator is an 800 MeV superconducting Linac in the injection chain of the Fermilab accelerator complex. The LLRF systems are a based on two different hardware platforms controlling a variety of cavity types and resonance control systems including temperature, pneumatic and piezo tuners. The various calibrations required prior to beam operation include, signal power, gradient, amplifier characterization, cavity Q measurement and detune constants. Measurements such as piezzo capacitance, cavity piezo transfer function help in determining tuner health and in devising microphonics control strategies.

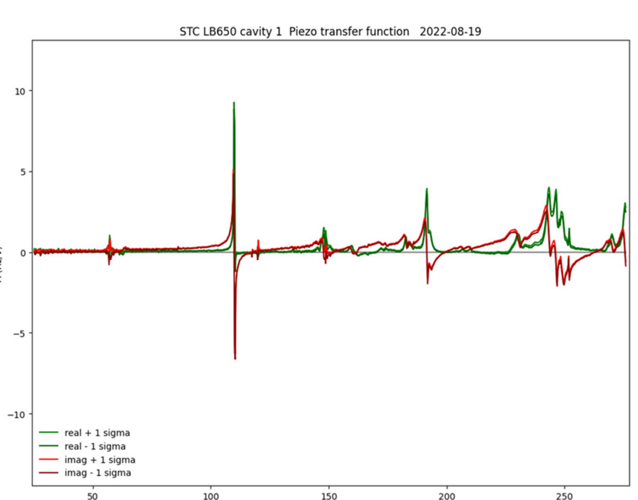
Piezo Capacitance Measurement



stack A mean voltage : 24.00 < 24.266 < 25.00 V OK
stack A peak-peak voltage : 0.60 < 0.700 < 1.00 V OK
stack A rms I common-mode : 0.00 < 0.056 < 0.20 mA OK
stack A peak-peak I common-mode : 0.00 < 0.086 < 0.40 mA OK
stack A mean I diff-mode : 0.00 < 0.014 < 0.30 mA OK
stack A fit capacitance : 3.00 < 4.434 < 6.20 uF OK
stack A rms fit error : 0.00 < 0.082 < 0.10 mA OK
stack A: PASS
stack B mean voltage : 24.00 < 24.221 < 25.00 V OK
stack B peak-peak voltage : 0.60 < 0.669 < 1.00 V OK
stack B rms I common-mode : 0.00 < 0.011 < 0.20 mA OK
stack B peak-peak I common-mode : 0.00 < 0.042 < 0.40 mA OK
stack B mean I diff-mode : 0.00 < 0.027 < 0.30 mA OK
stack B fit capacitance : 3.00 < 4.730 < 6.20 uF OK
stack B rms fit error : 0.00 < 0.088 < 0.10 mA OK
stack B: PASS

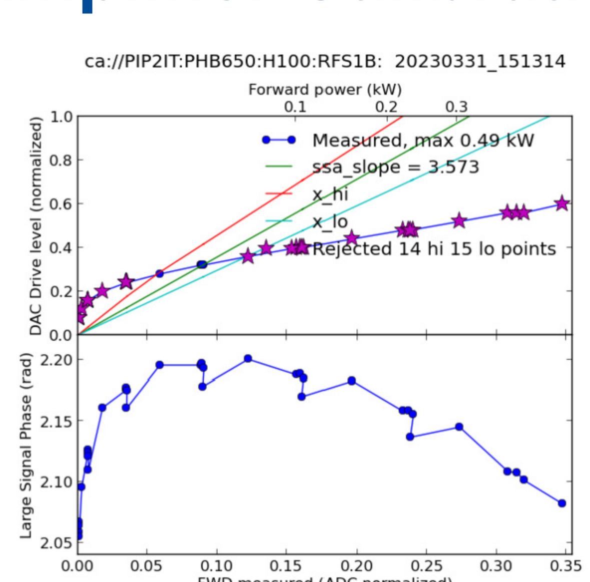
Piezo Transfer Function



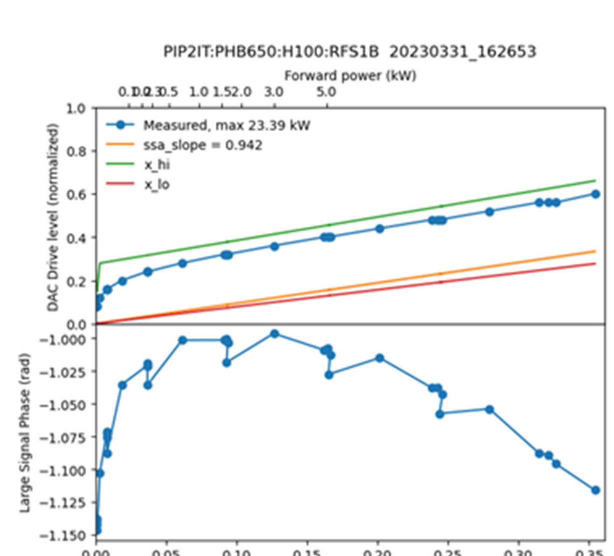


Chirp Input from Resonance Controller
Detune output from LLRF Controller

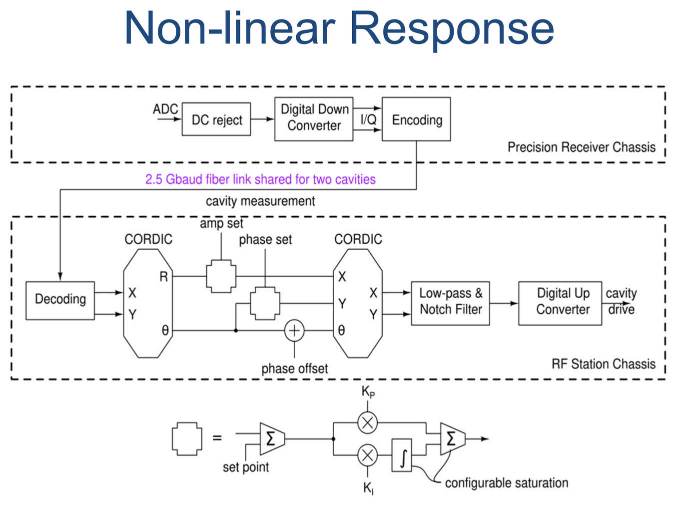
Amplifier Calibration

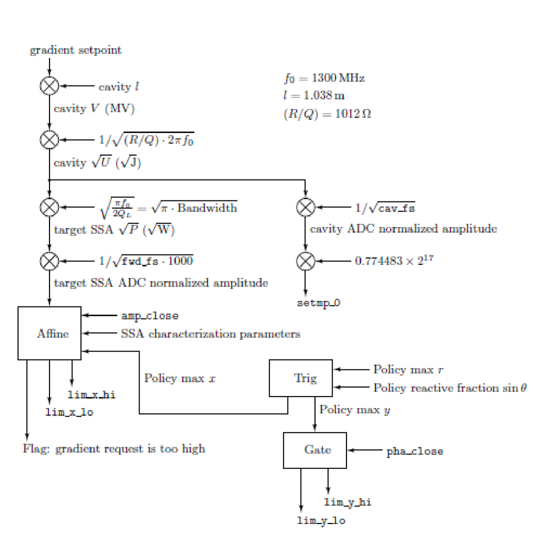


Non-linear Response

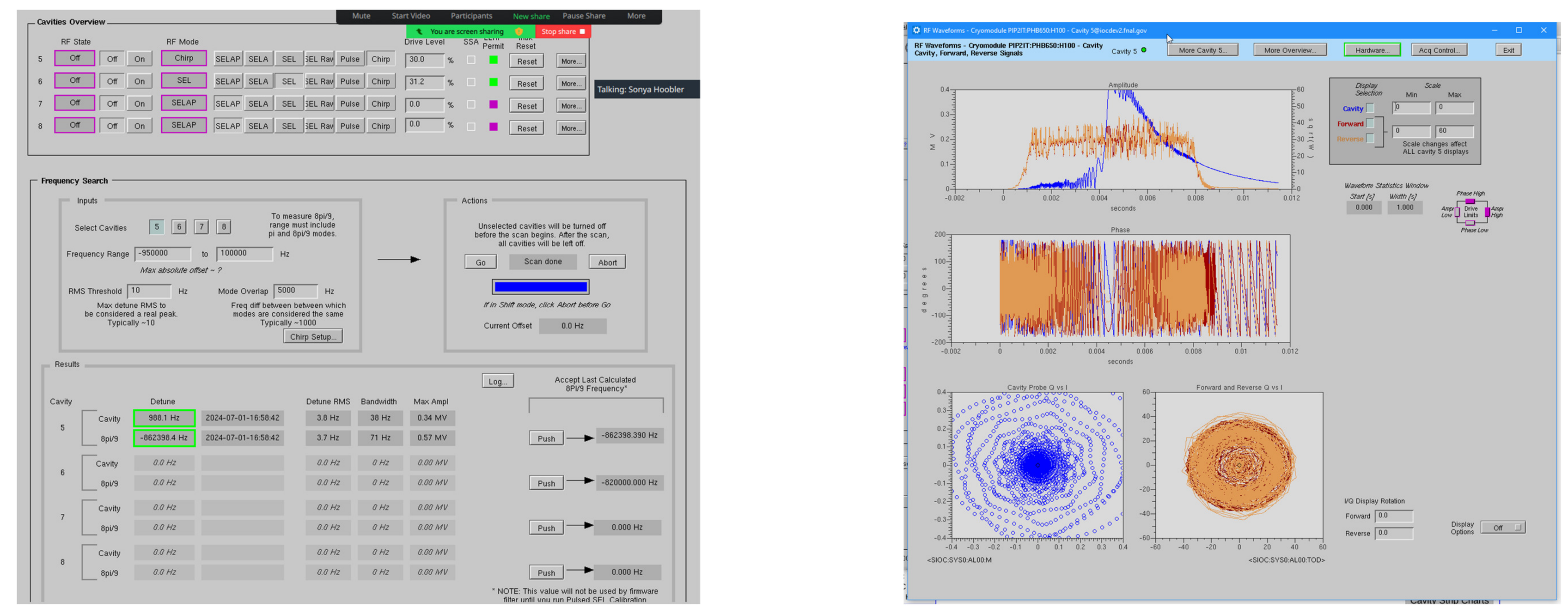


Modification for Non-Linearity



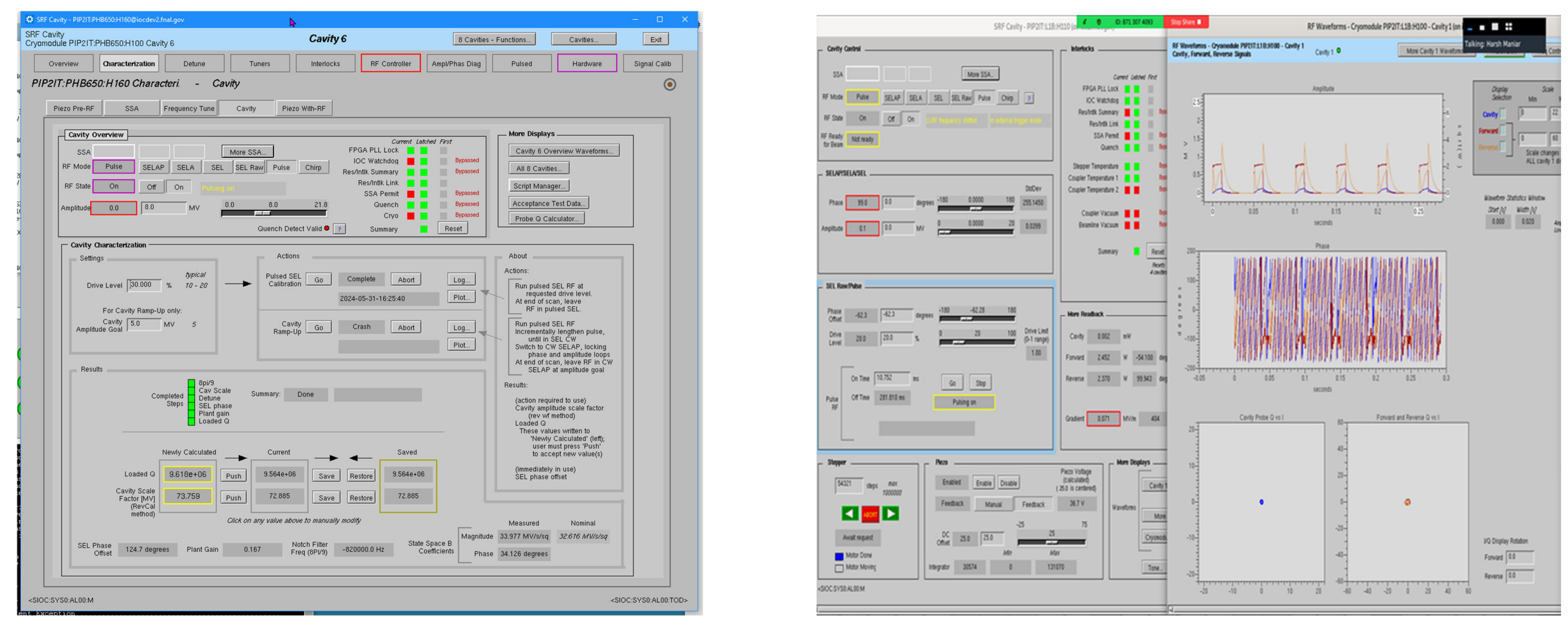


Cavity Resonance Search - Passband modes



Notch Filter coefficients computed from detected modes

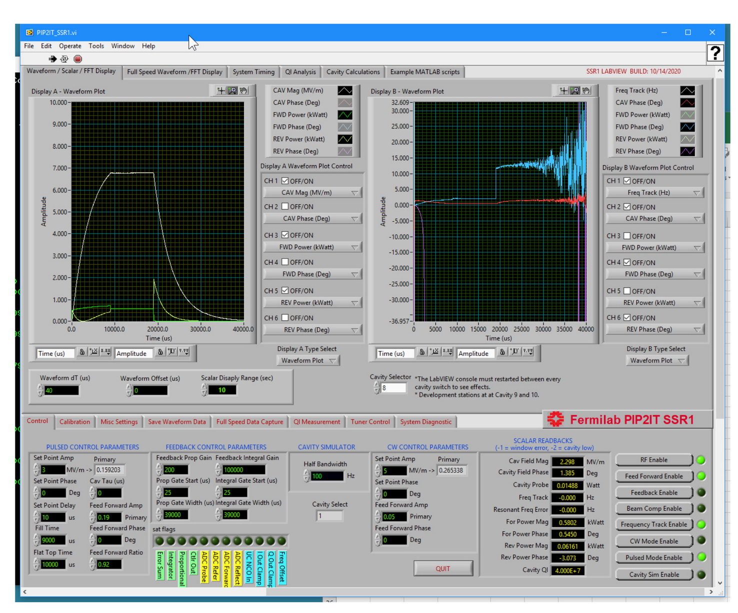
Cavity Pulse Calibration



Measured Parameters

- Bandwidth
- Loaded Q
- Detune frequency
- Coupling coefficients
- Plant gain
- SEL phase offset
- Probe calibration based on emitted energy
- Circulator S_22

RF Detune Calibration



$$\ddot{V}(t) + \frac{\omega_0}{Q_L}\dot{V}(t) + \omega_0^2 V(t) = \frac{\omega_0 R_L}{Q_L}\dot{I}(t)$$

$$\frac{d\vec{V}}{dt} = (-\omega_{1/2} + j\Delta\omega)\vec{V} + R_L\omega_{1/2}\vec{I}$$

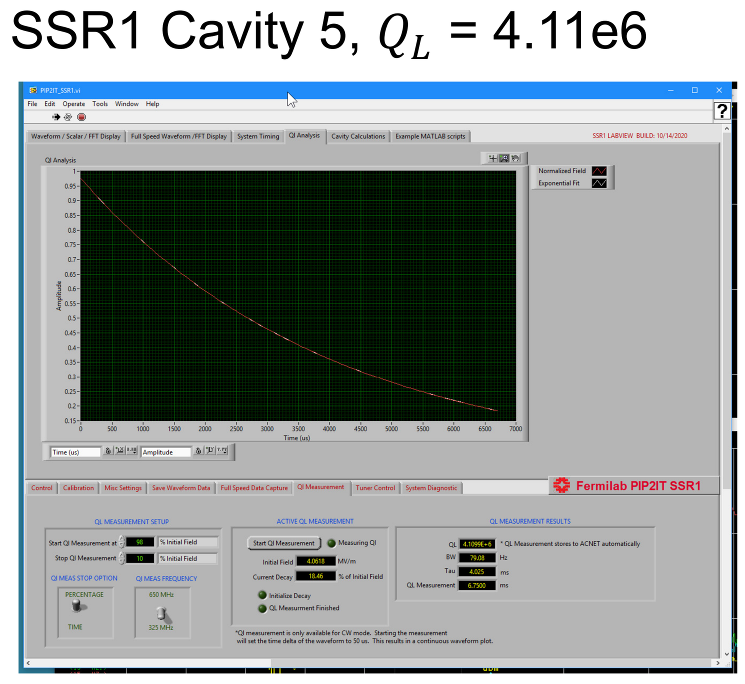
$$\frac{d\vec{V}}{dt} = a\vec{V} + b\vec{K}_1$$

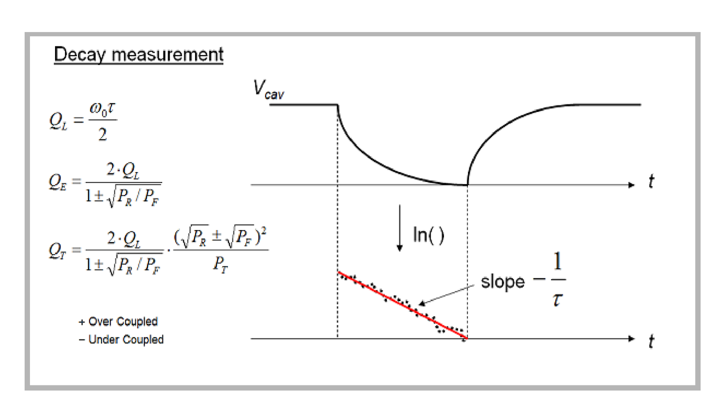
$$a = \frac{1}{\vec{M}_V}\cdot\left[\frac{d\vec{M}_V}{dt} - \beta\vec{M}_K\right]$$

- The cavity is operated in pulse mode with a cavity field ~ 1/2 FS magnitude and the cavity probe and forward waveforms are recorded.
- Numerical analysis of the acquired data provides cavity parameters such as half bandwidth and the detuning constants

Q_L Measurement

SSR1 Cavity 5, Q_L = 4.11e6





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