Beam Induced Microphonics in High Current Synchrotrons

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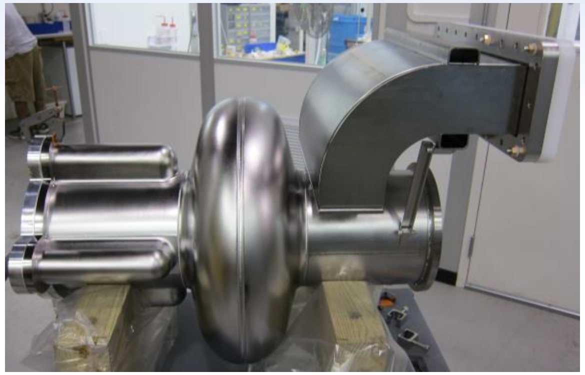
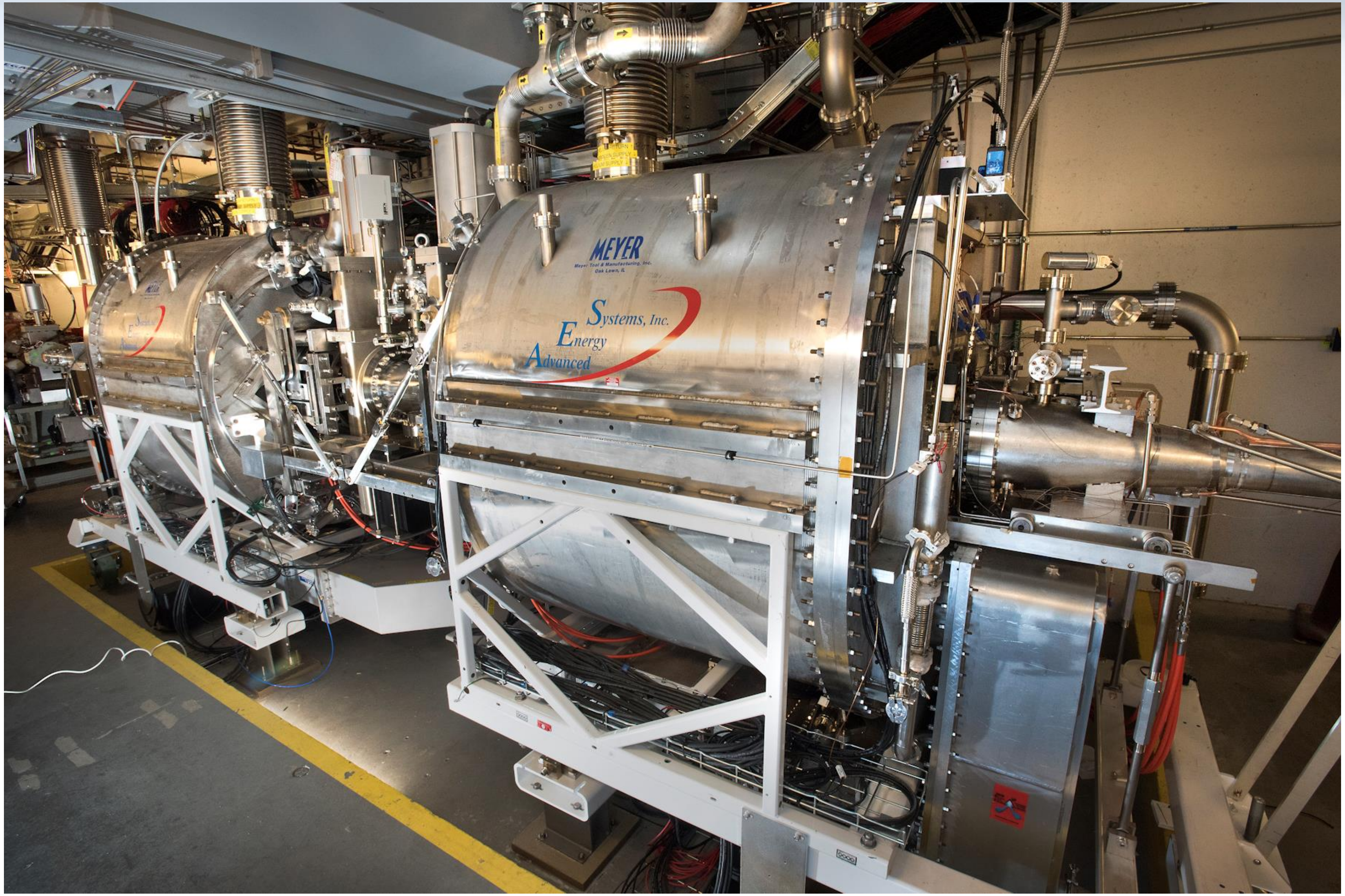
On behalf of the NSLS-II RF group

October 26, 2018

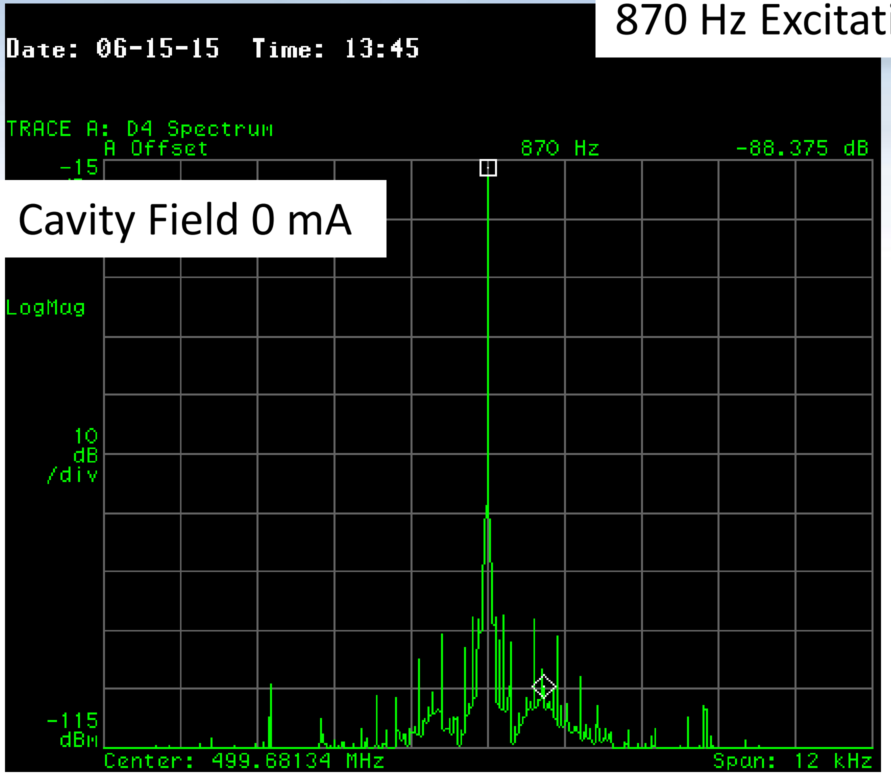
Introduction

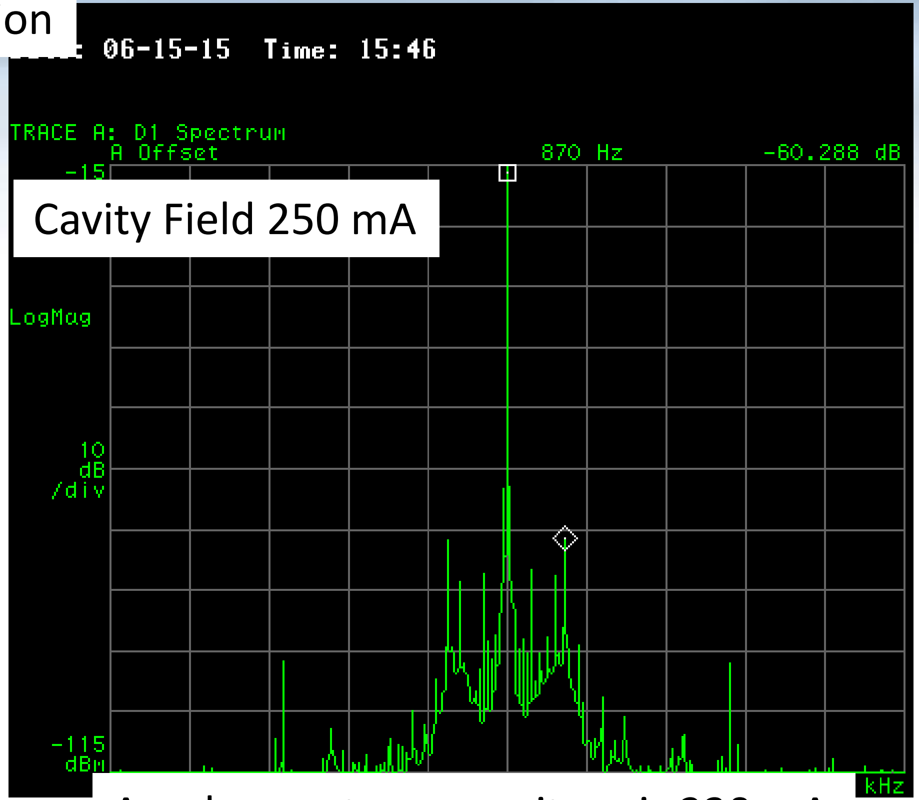




NSLS-II operates with 500MHz CESRb type SRF cavities.
In 2015, during 250mA beam studies with the first installed cavity we came across a beam instability

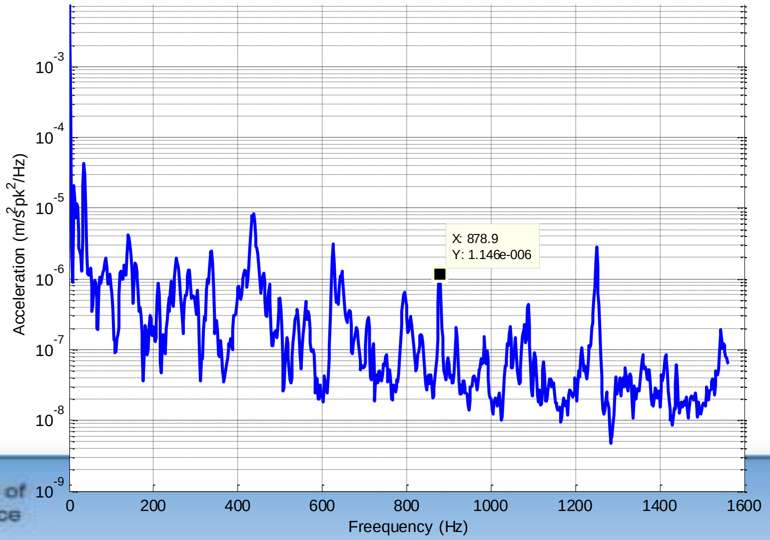
870 Hz Excitation



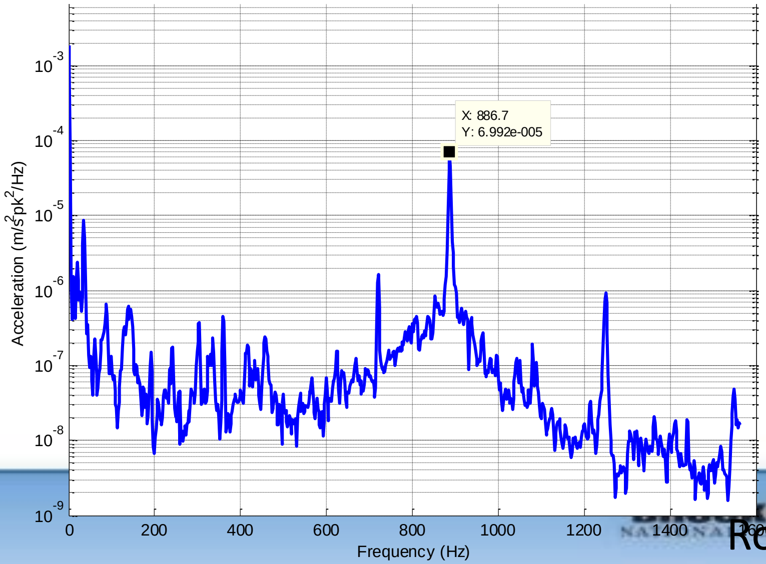


We asked ourselves if microphonics were driving the beam unstable?

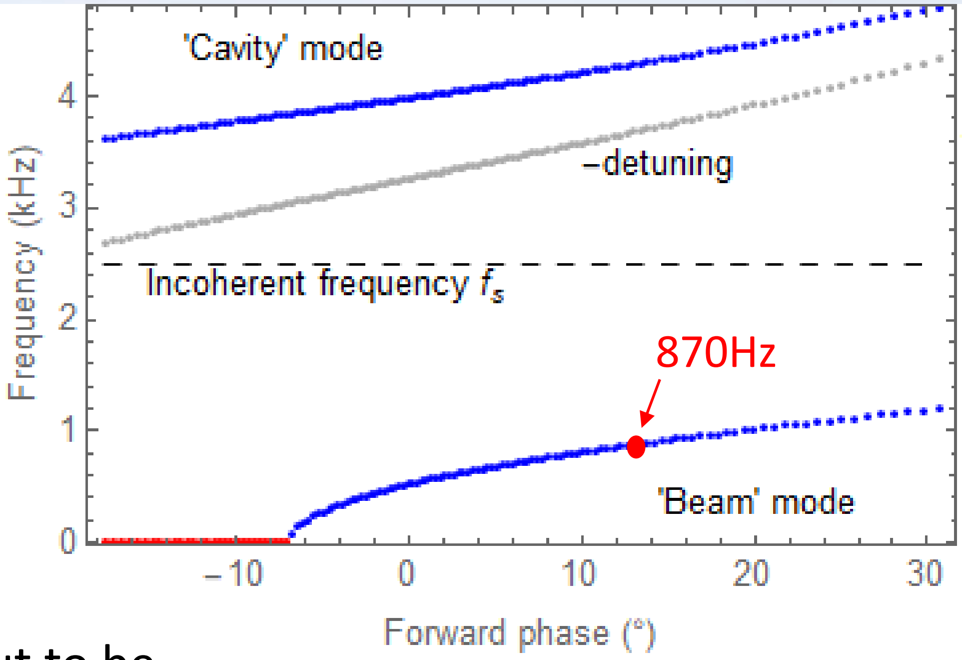
Accelerometer on cavity axis 75 mA

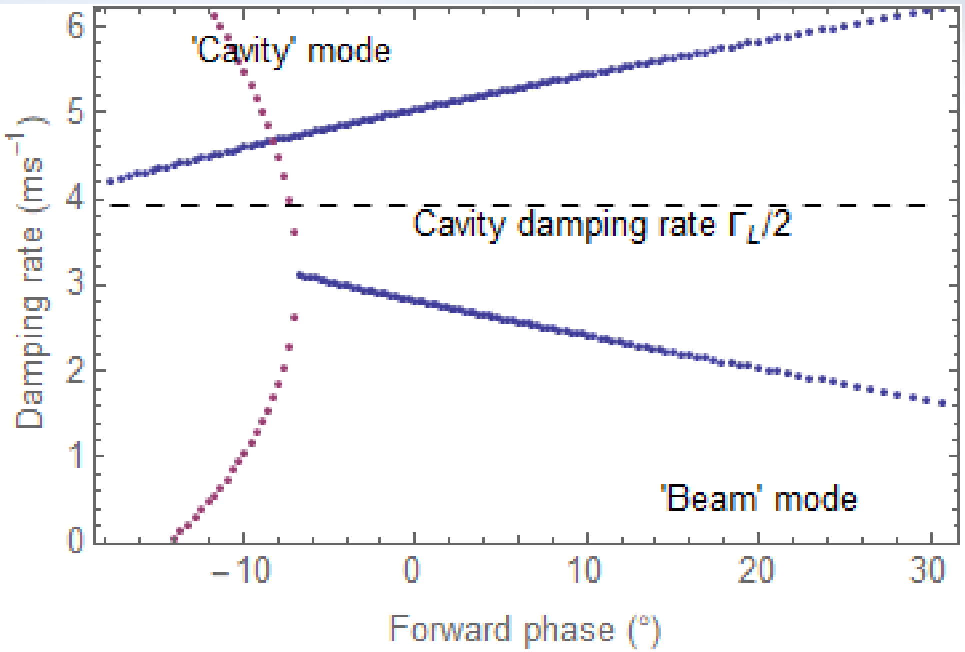


Accelerometer on cavity axis 230 mA



Longitudinal dipole modes – coherent cavity mode and beam mode





It turned out to be a beam instability that was driving the cavity vibrations through pondermotive forces

$$(\Omega^2-\omega_s^2)(\Omega+\Delta-j\Gamma)(\Omega-\Delta-j\Gamma)=If(\Omega)$$

frequency detuning $\Delta=h\omega_0-\omega_{res}$

$$\Gamma\equiv\omega_{res}/2Q$$

$$f(\Omega)\equiv-\xi[\omega_c(\Omega-\Delta-j\Gamma)-\omega_c^*(\Omega+\Delta-j\Gamma)]$$

$$\xi\equiv ek_0\alpha/T_0E_0$$

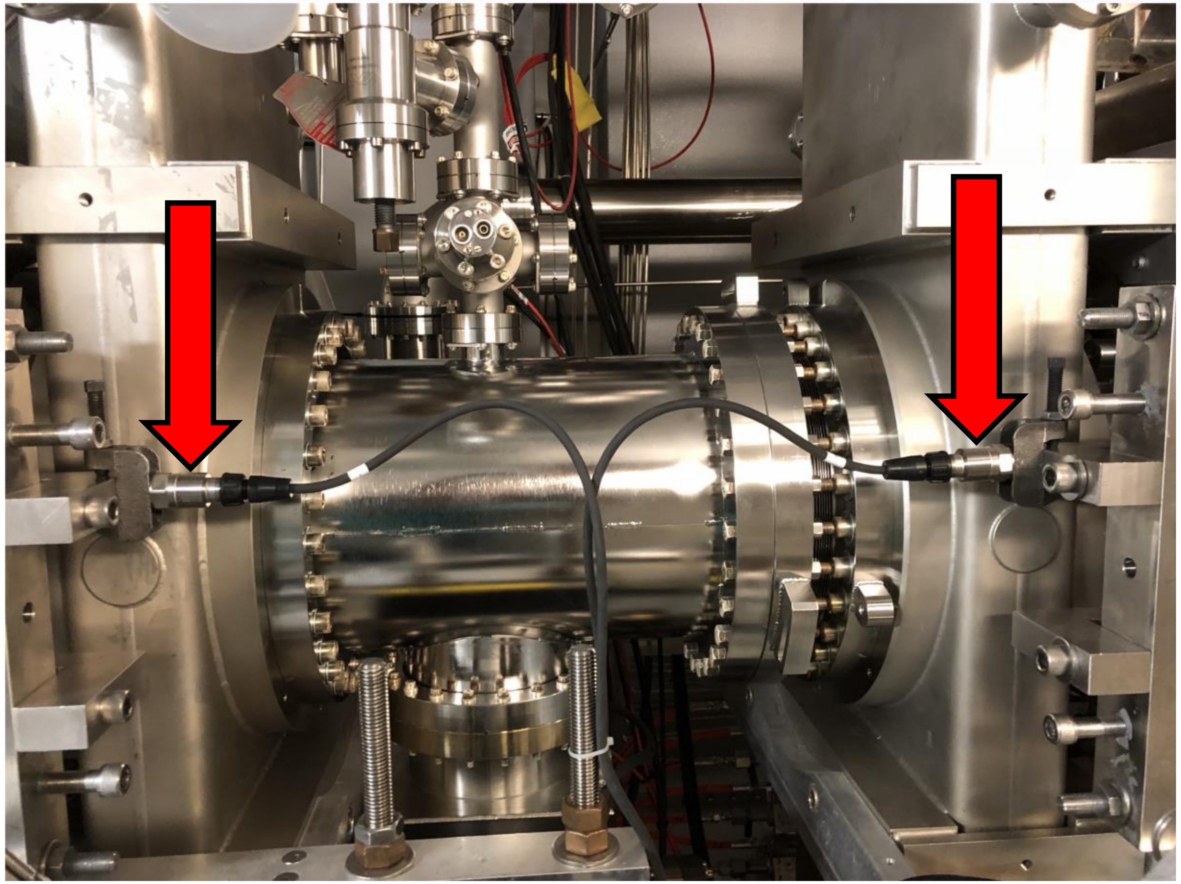
$$\omega_c\equiv\omega_{res}+j\Gamma.$$

"beam current"	0.25"A"
"cavity detuning"	−3.68kHz
"forward phase"	12.98"°"
"rf voltage"	1700kV
"forward power"	88.71kW
"reverse power"	16.68kW
"delivered power"	72.03kW
"generator current"	0.106"A"
"beam – induced voltage"	1529.1kV
"generator – induced voltage"	323.1kV
"synchrotron frequency"	2.496"kHz"
"QL"	199960.0079984003
"RshL"	8998.200359928014kΩ
"loss factor"	0.071"V/pC"

[ref]: N. Towne and J-M Wang, Spectrum of single bunch longitudinal dipole modes, PhysRevE.57.3461.

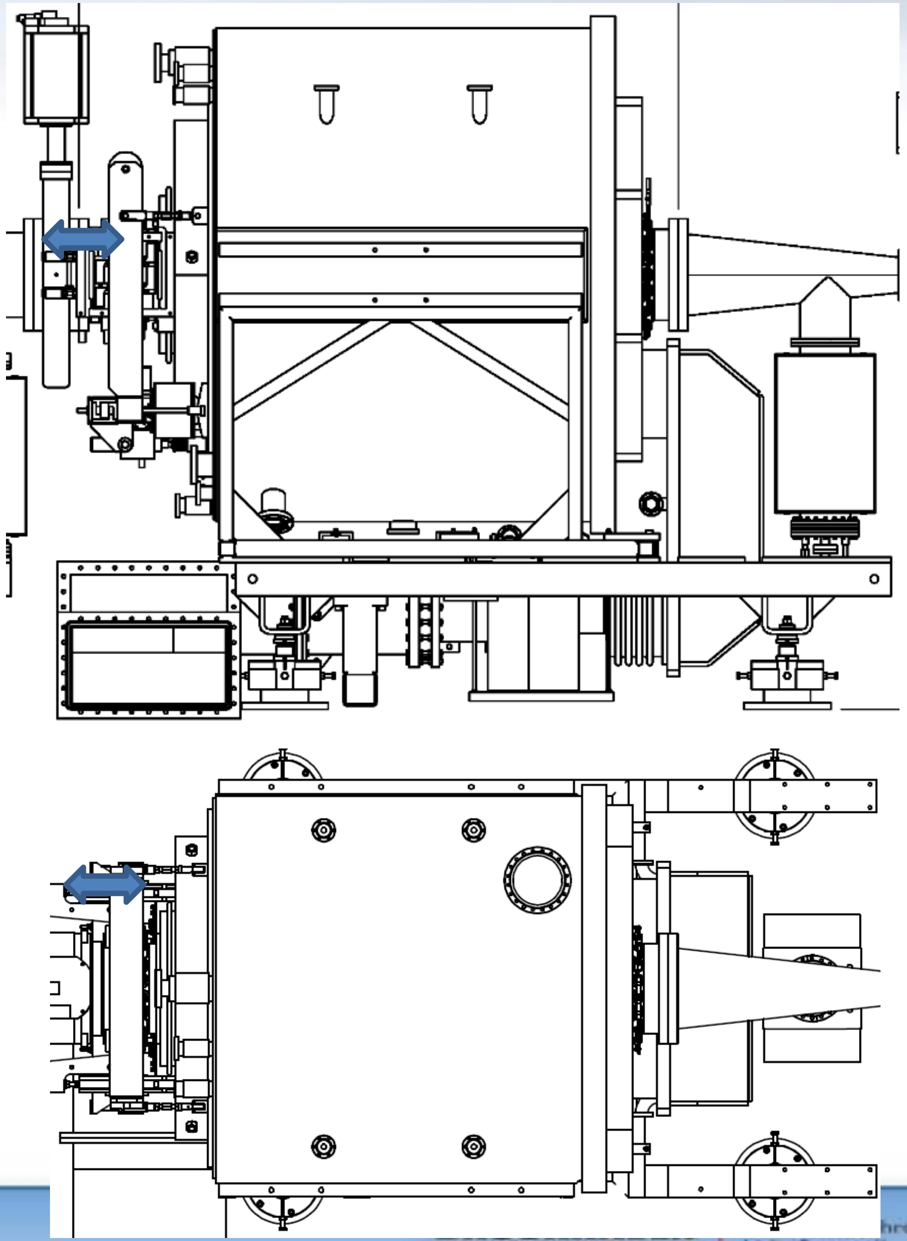
We have recently repeated the studies with two cavities and 450mA beam

Tuner C and D Accelerometer Placement



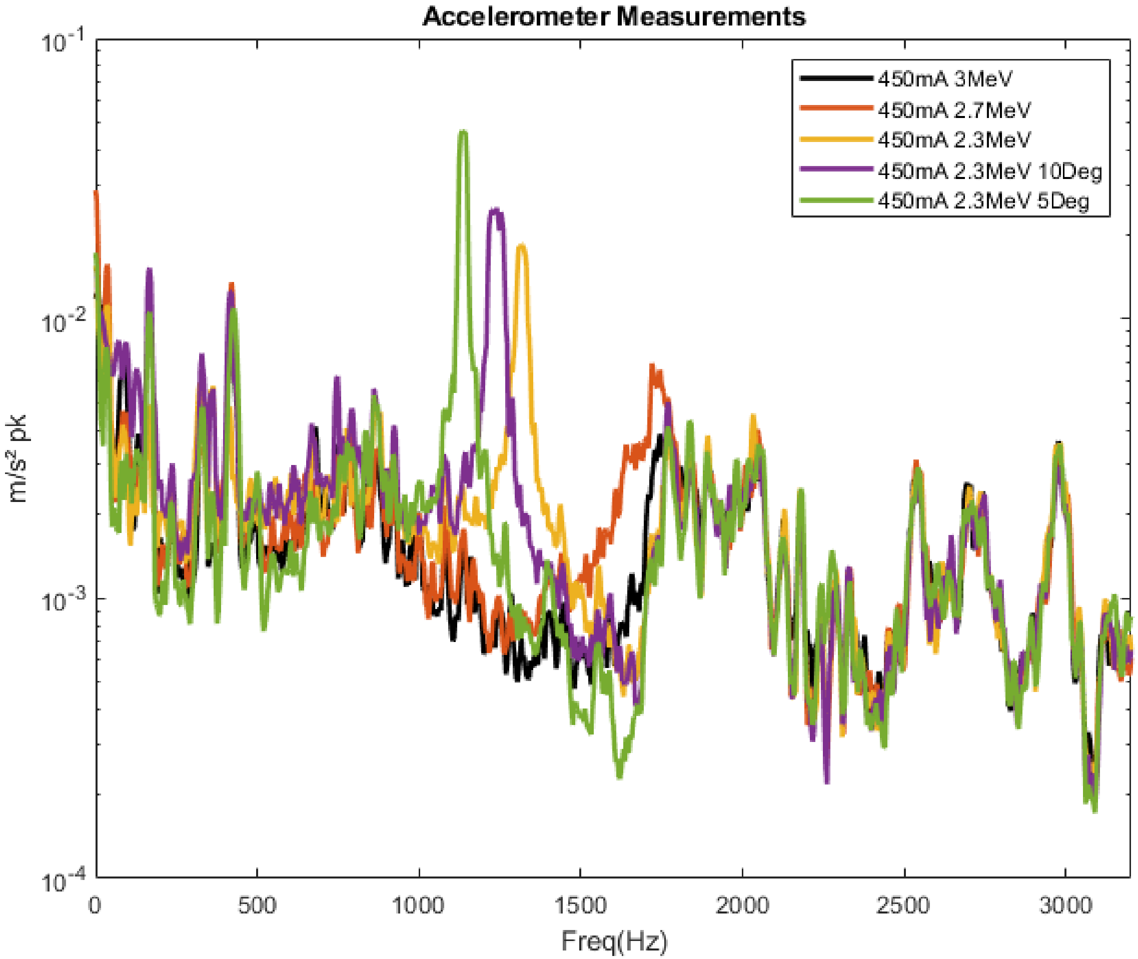
Side View

Top View

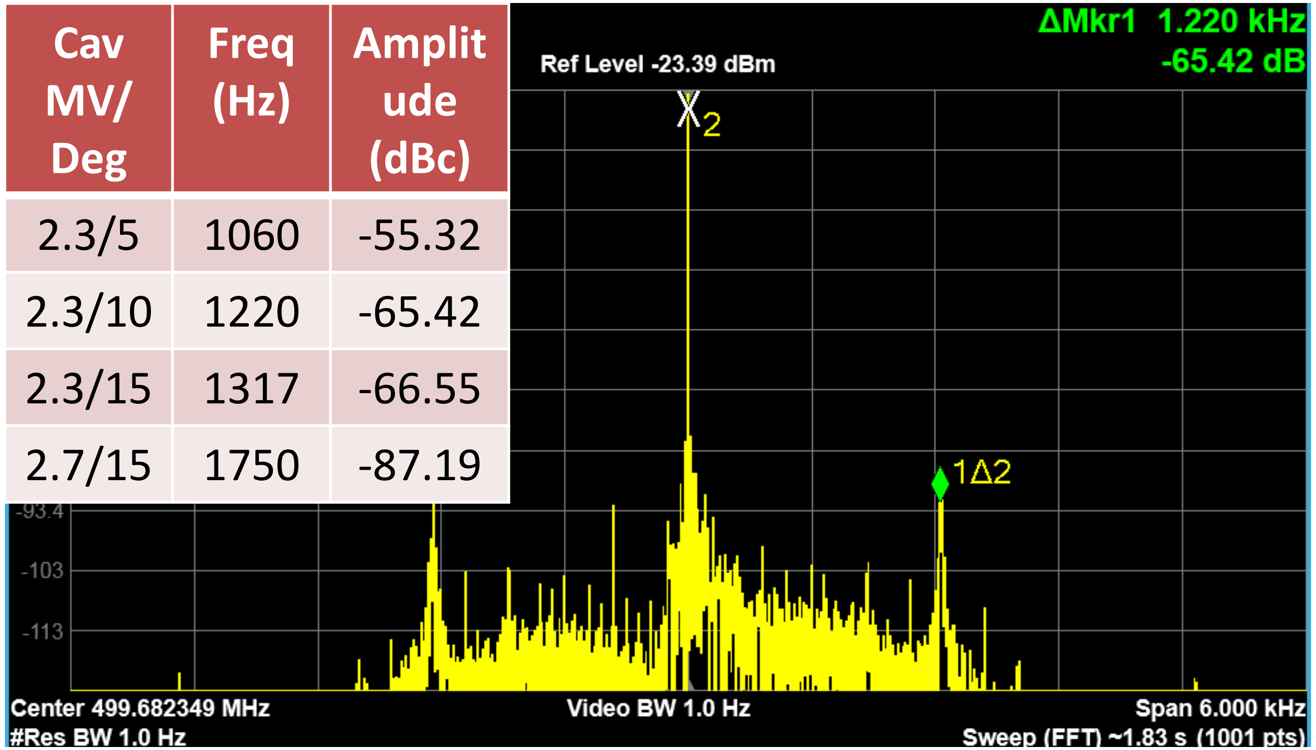


Accelerometer Location
And Directionality

Accelerometer Measurements
Cavity C With 450 mA

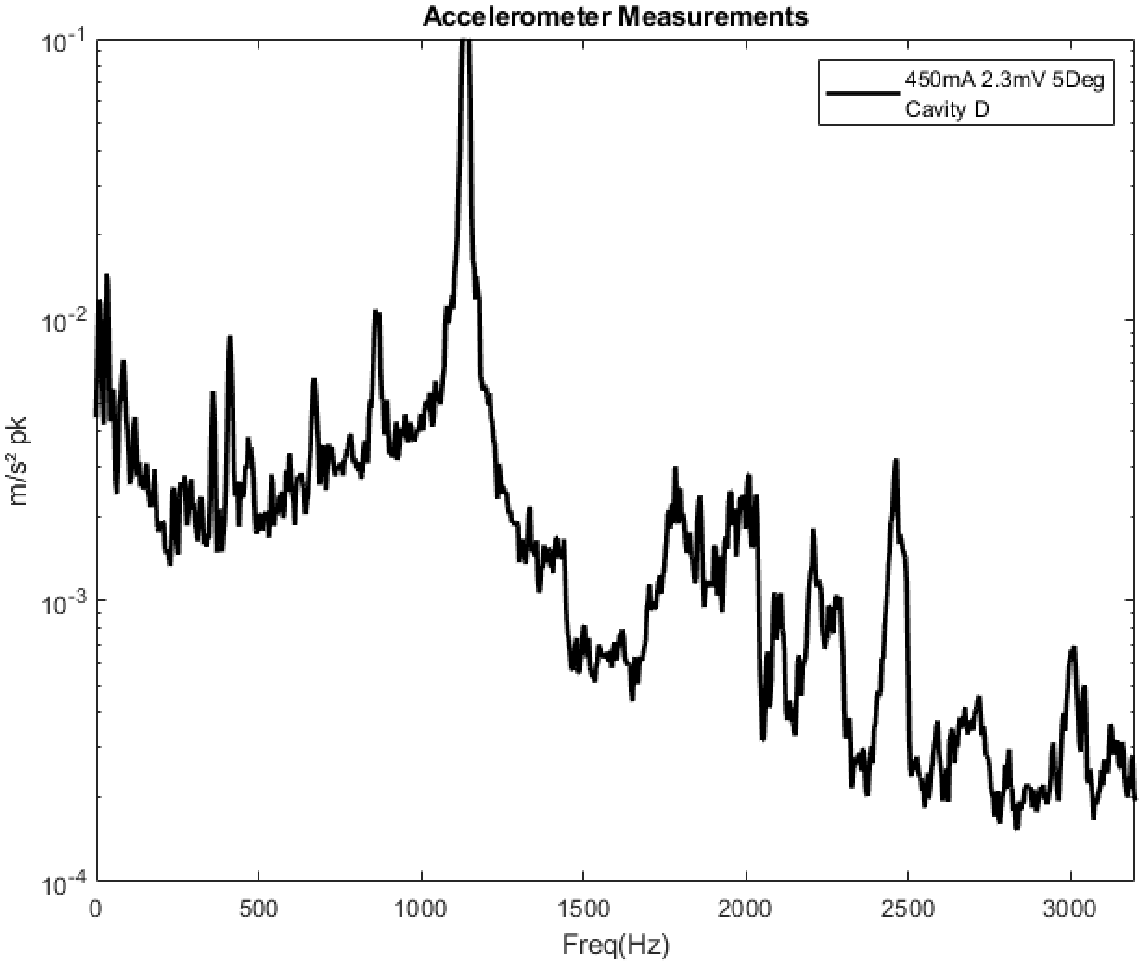


Cav MV/ Deg	Freq (Hz)	Amplitude (dBc)
2.3/5	1060	-55.32
2.3/10	1220	-65.42
2.3/15	1317	-66.55
2.7/15	1750	-87.19

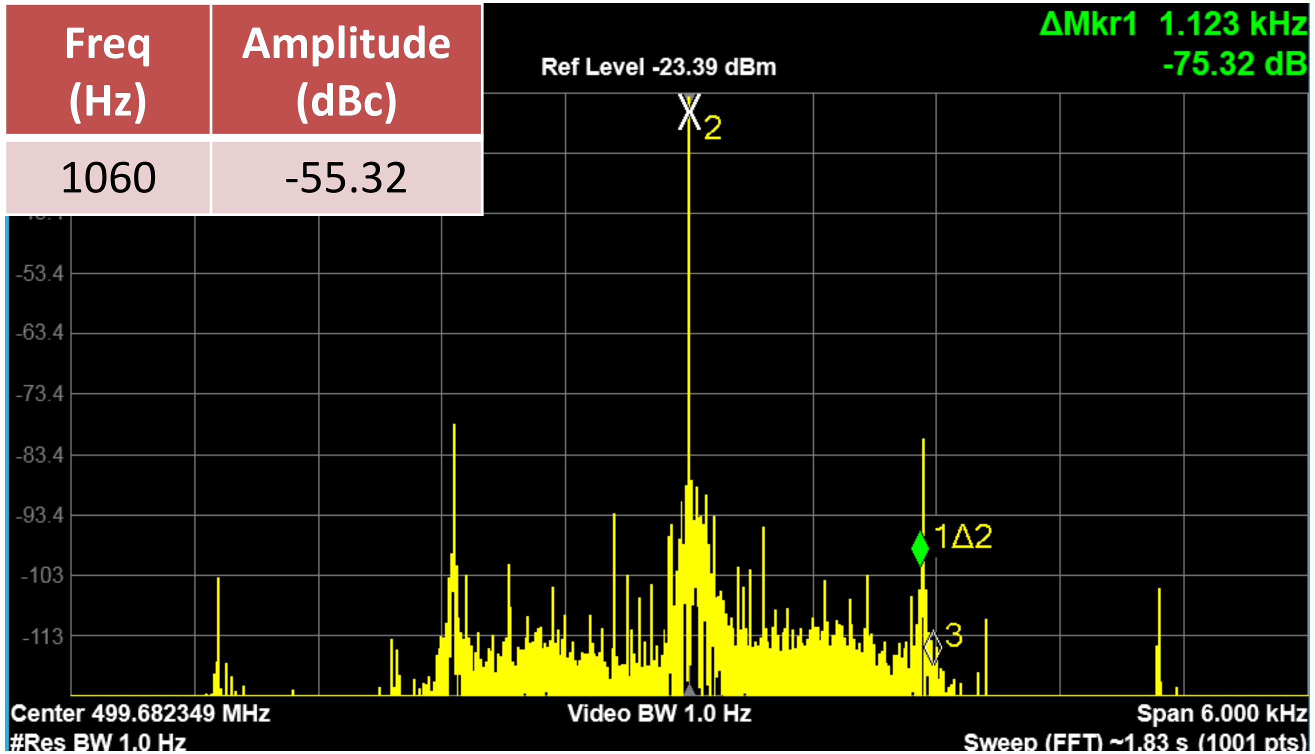


Cavity C Spectrum

Accelerometer Measurements
Cavity D With 450 mA



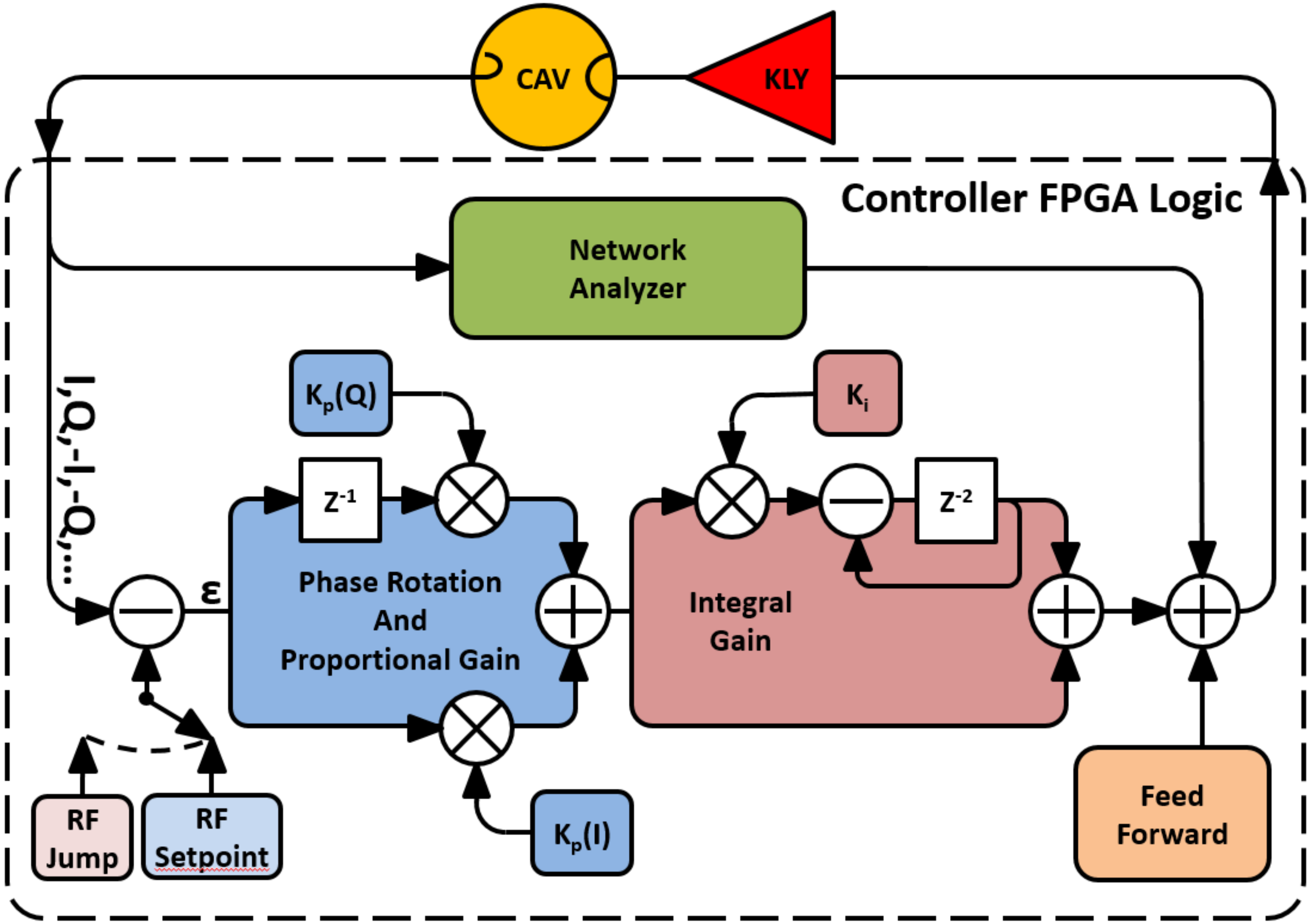
Freq (Hz)	Amplitude (dBc)
1060	-55.32

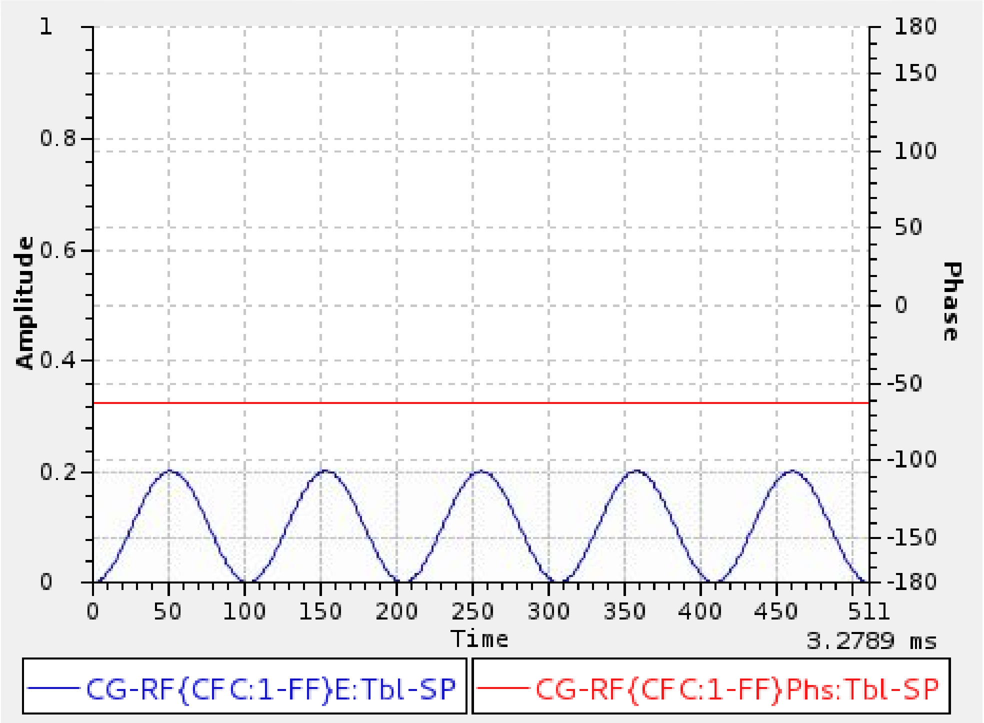


Cavity C Spectrum

Studies of cavity microphonics by amplitude modulation of RF

Simplified CFC Block Diagram and CSS Interface FF table



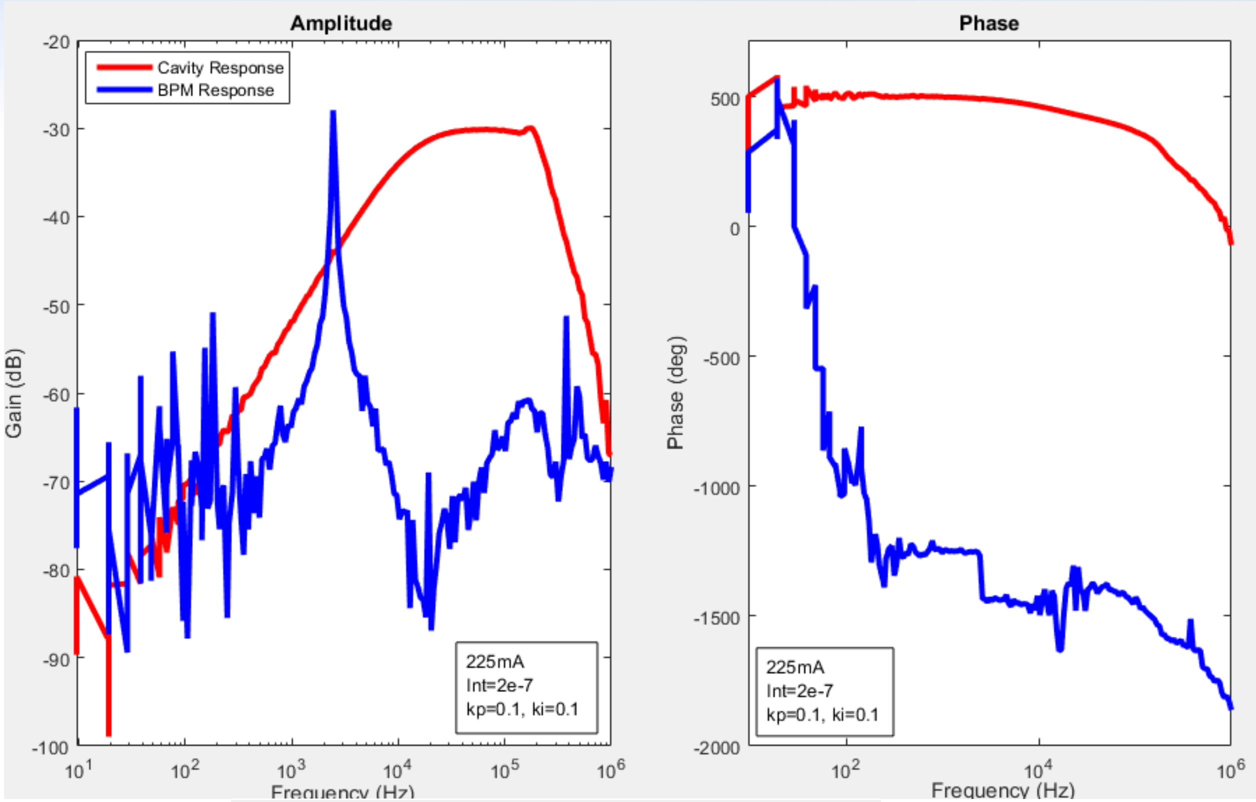


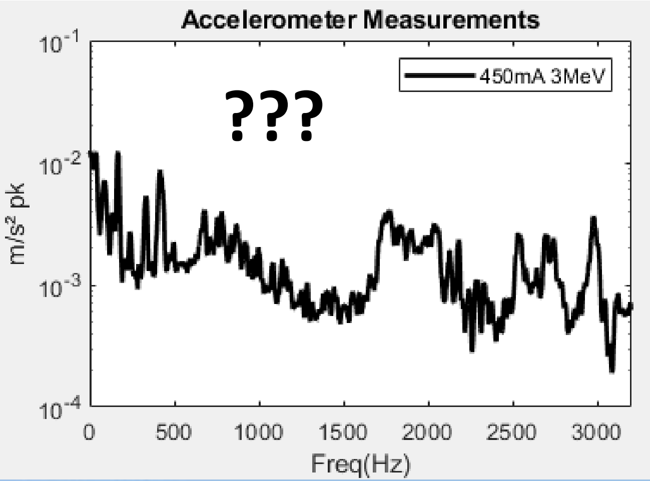
$$A + A\sin\left(2\pi k\left(\frac{t-t_f}{t_0-t_f}\right) - \pi/2\right)$$

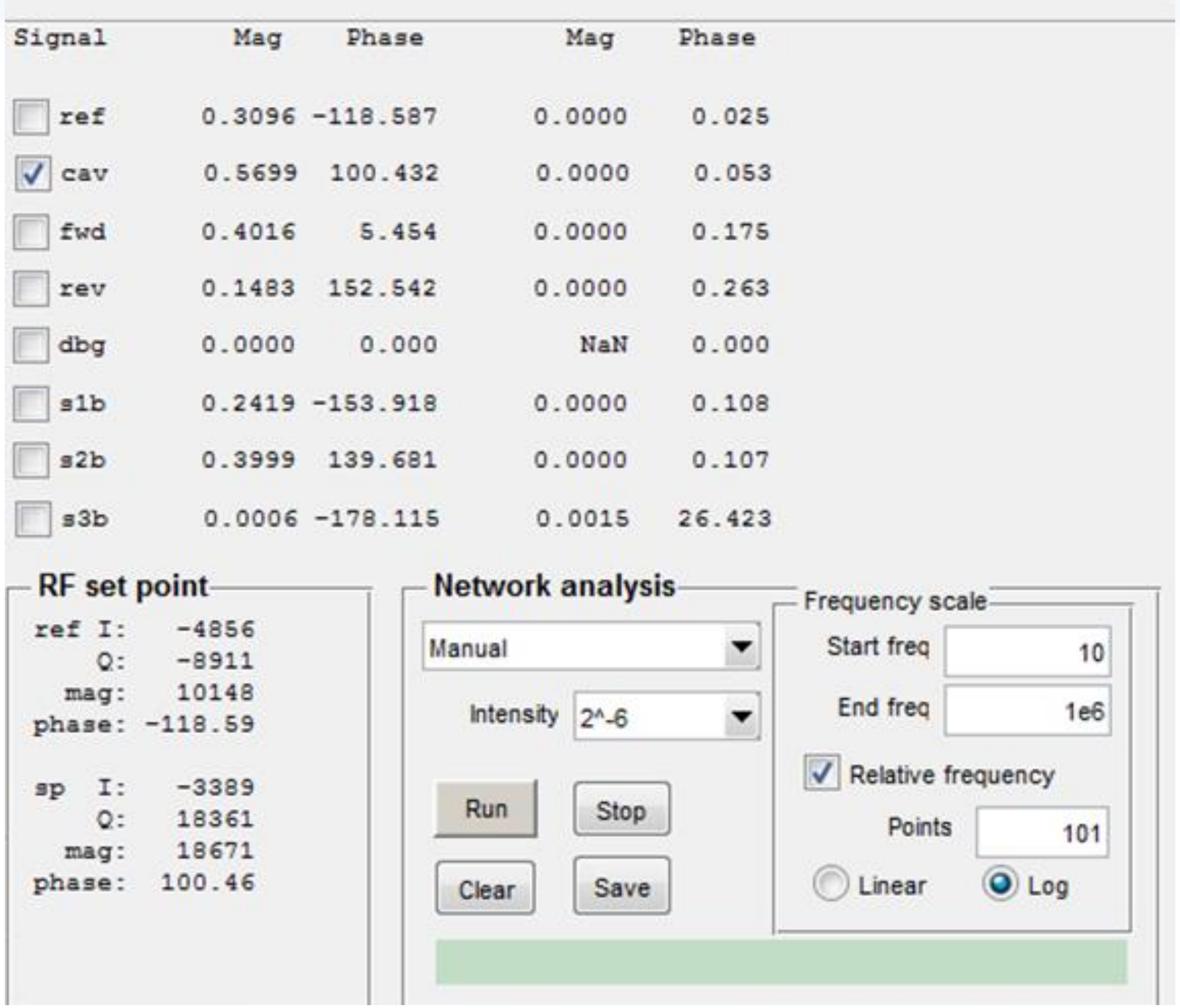
$t_0 = \text{start time}$ $\quad t_f = \text{final time}$

$k = \text{wave number}$ $\quad A = \text{amplitude}$

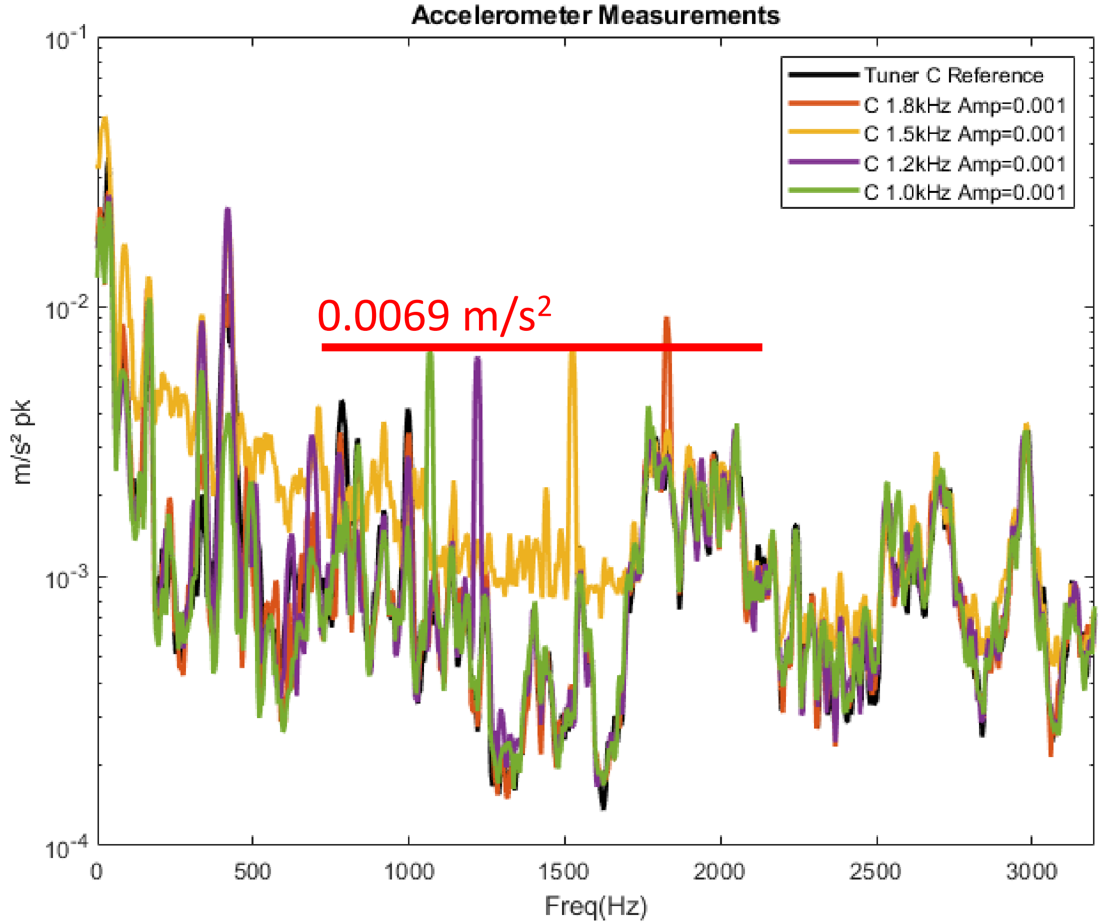
Experiment Using Network Analyzer





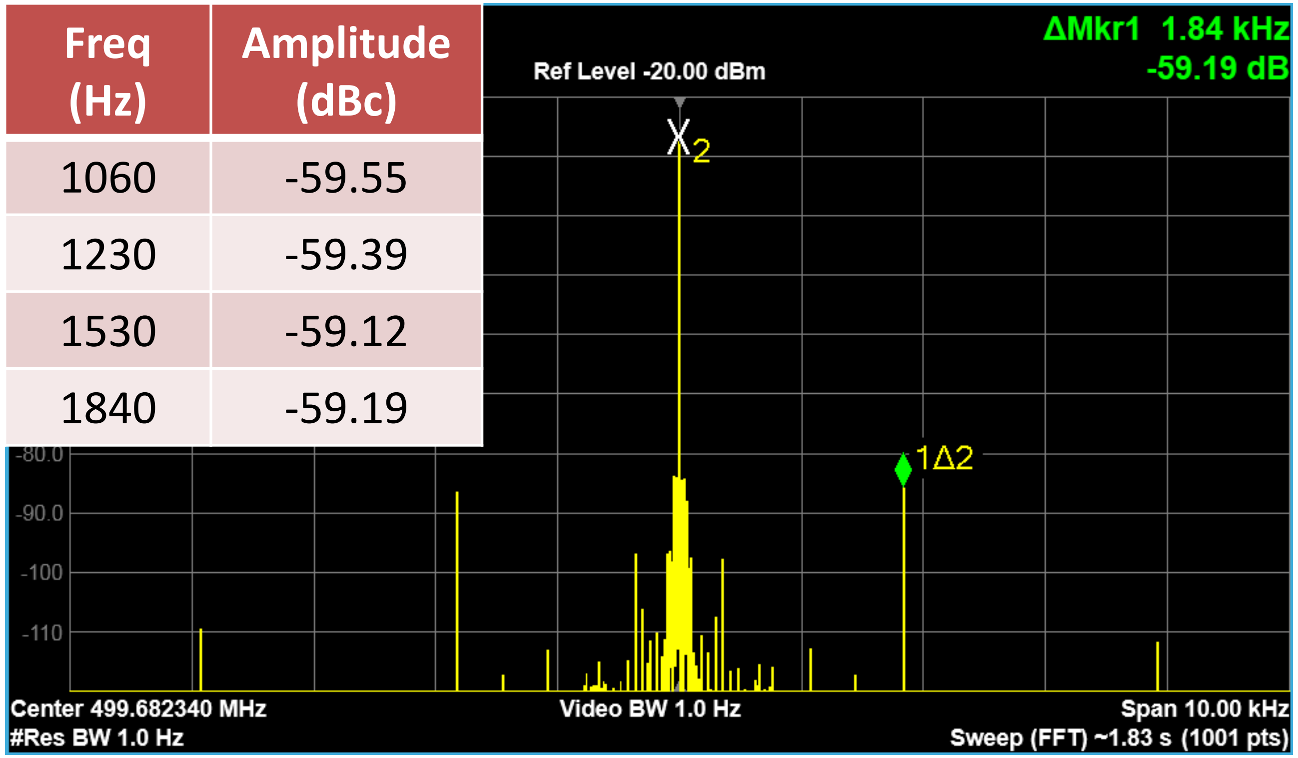


Accelerometer Measurements
Cavity C RF Modulated



Spectrum Analyzer Measurement

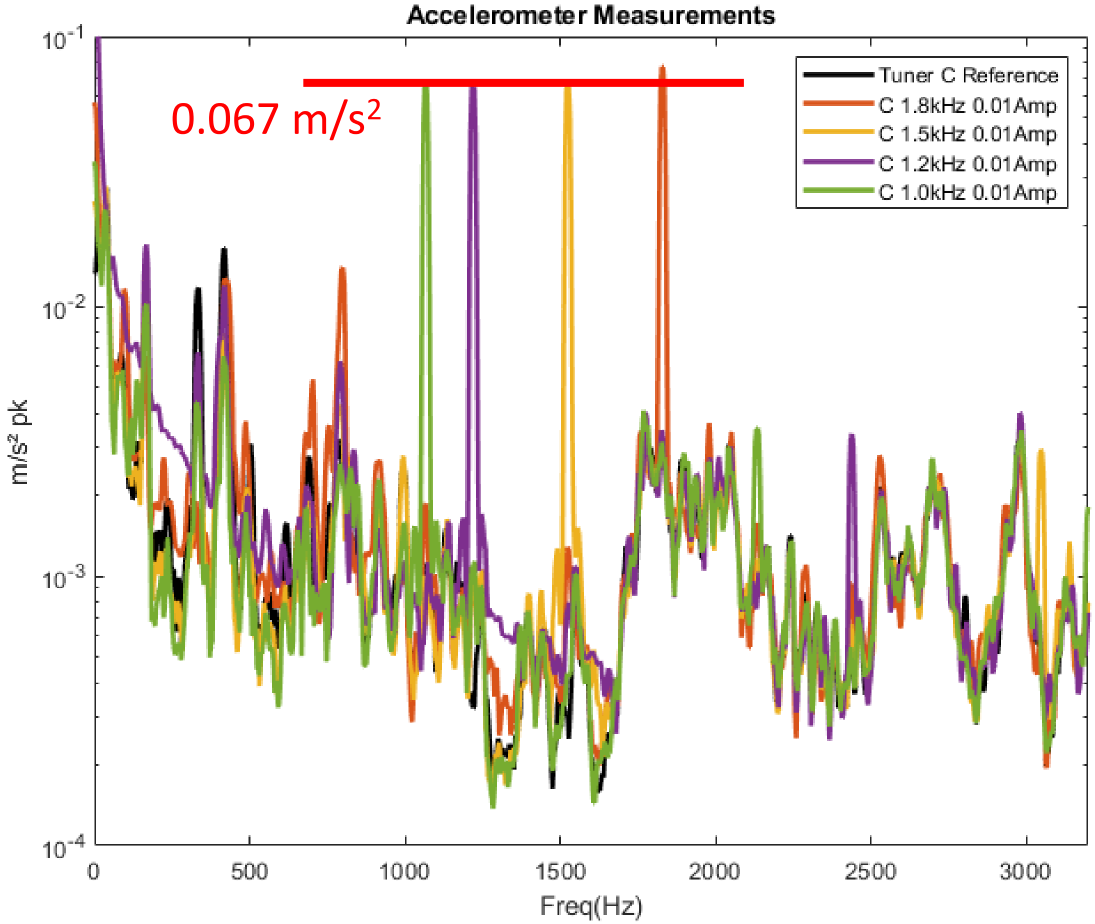
Freq (Hz)	Amplitude (dBc)
1060	-59.55
1230	-59.39
1530	-59.12
1840	-59.19



Cavity C Spectrum

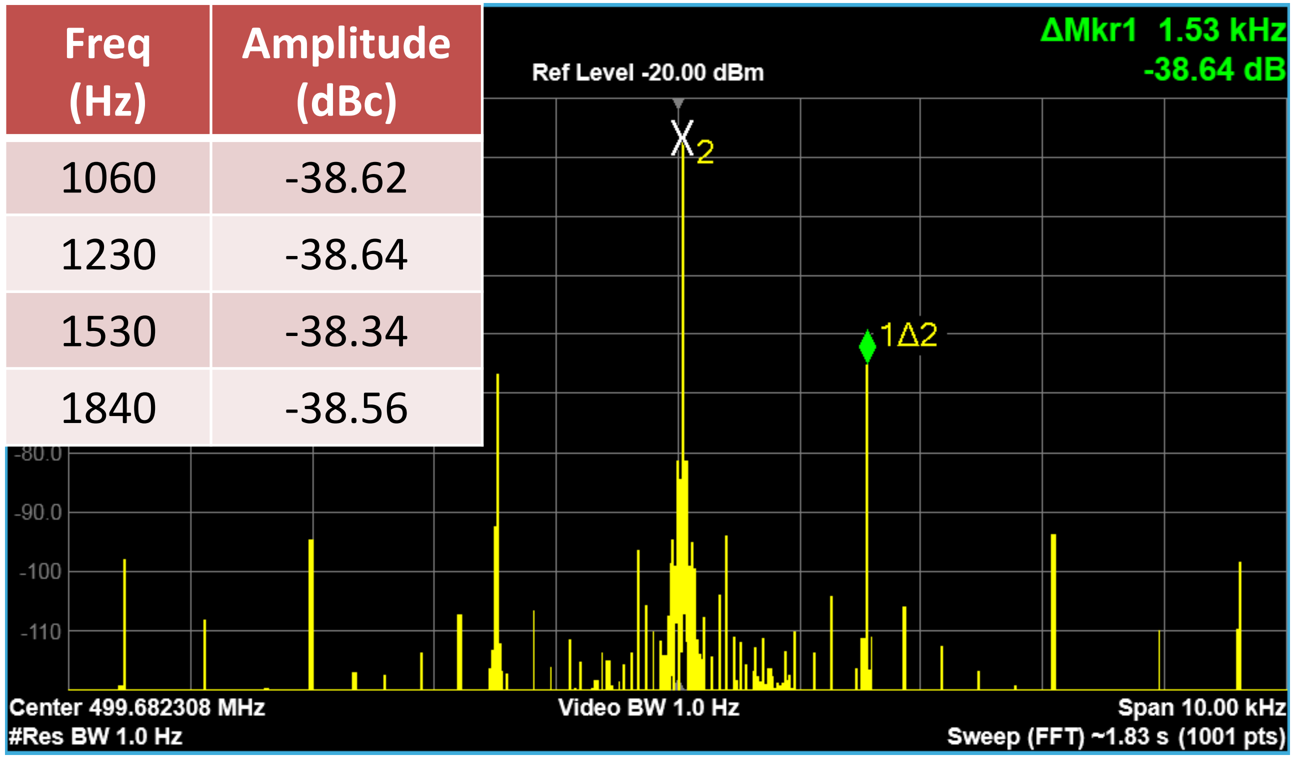
Forward Power = ~102kW
Reverse Power = ~90kW

Accelerometer Measurements
Cavity C RF Modulated



Spectrum Analyzer Measurement

Freq (Hz)	Amplitude (dBc)
1060	-38.62
1230	-38.64
1530	-38.34
1840	-38.56



Cavity C Spectrum

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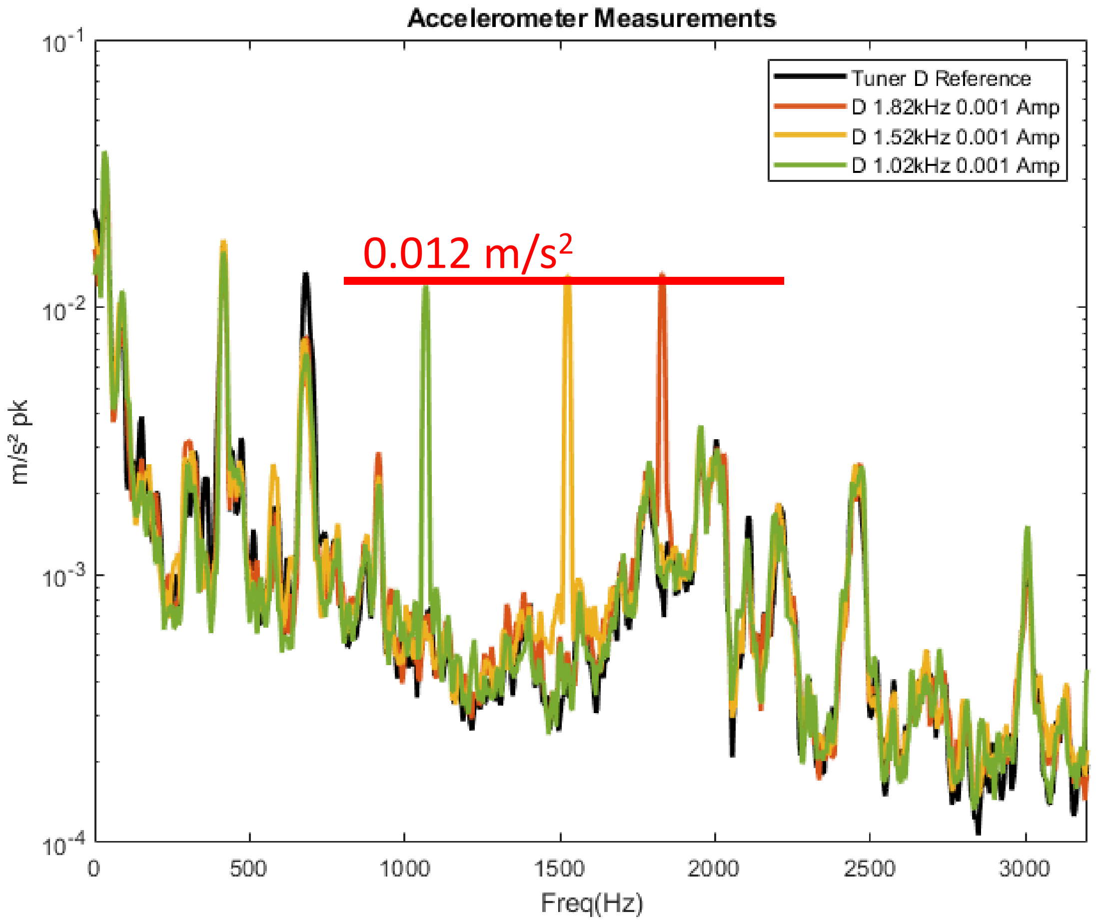
Accelerometer Measurements
Cavity D While Modulating Cavity C RF



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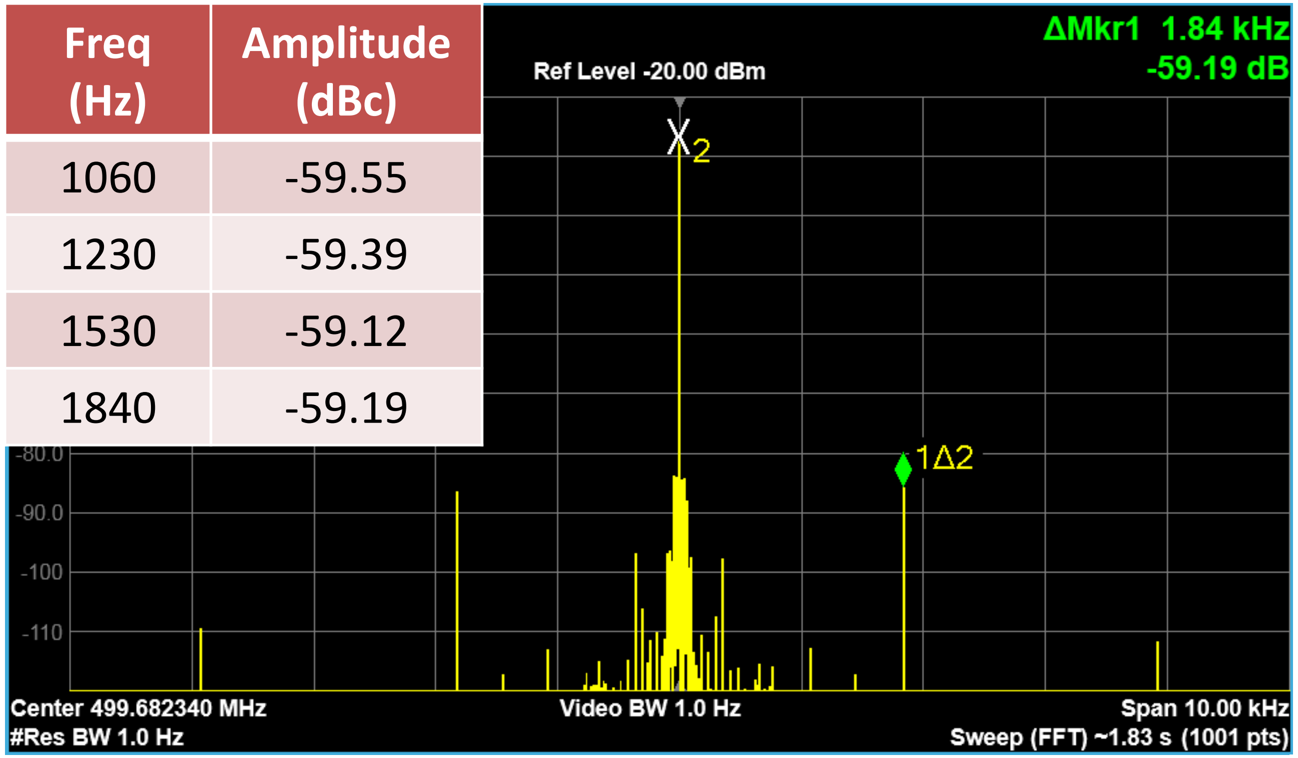

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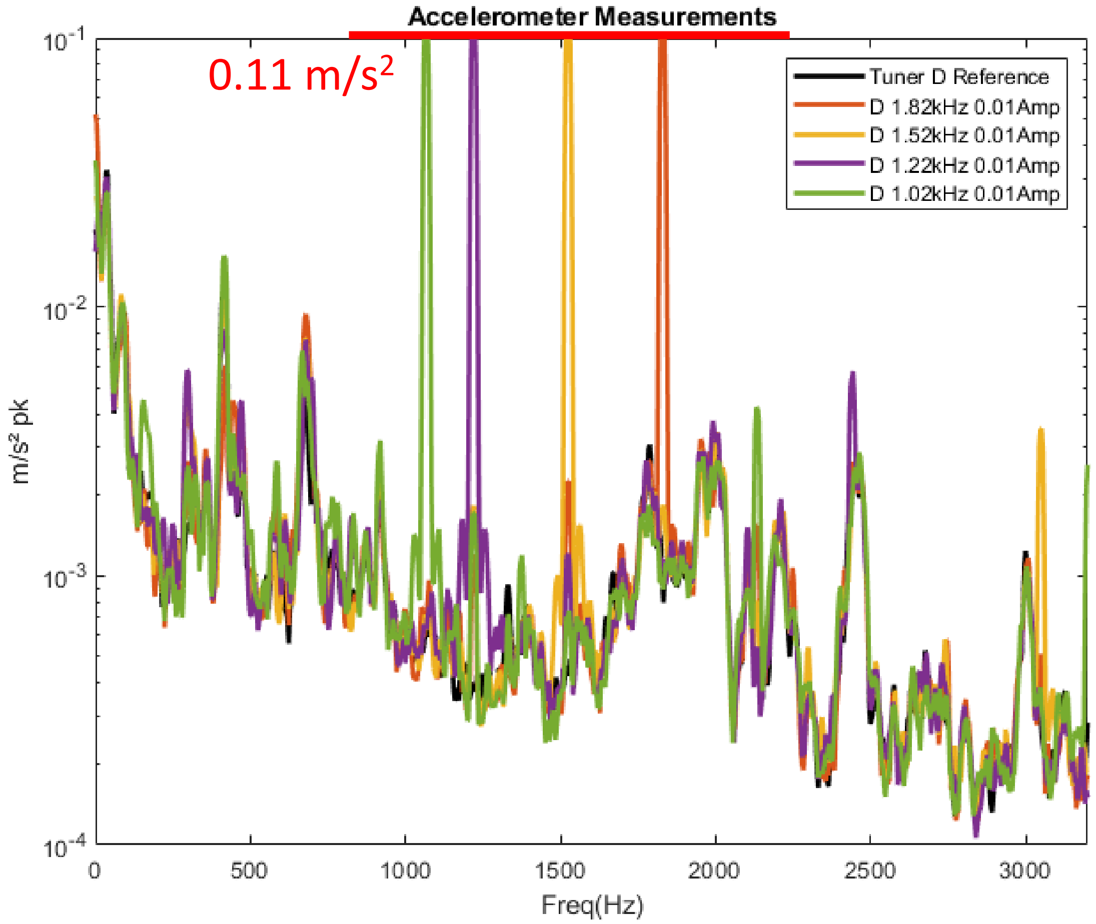

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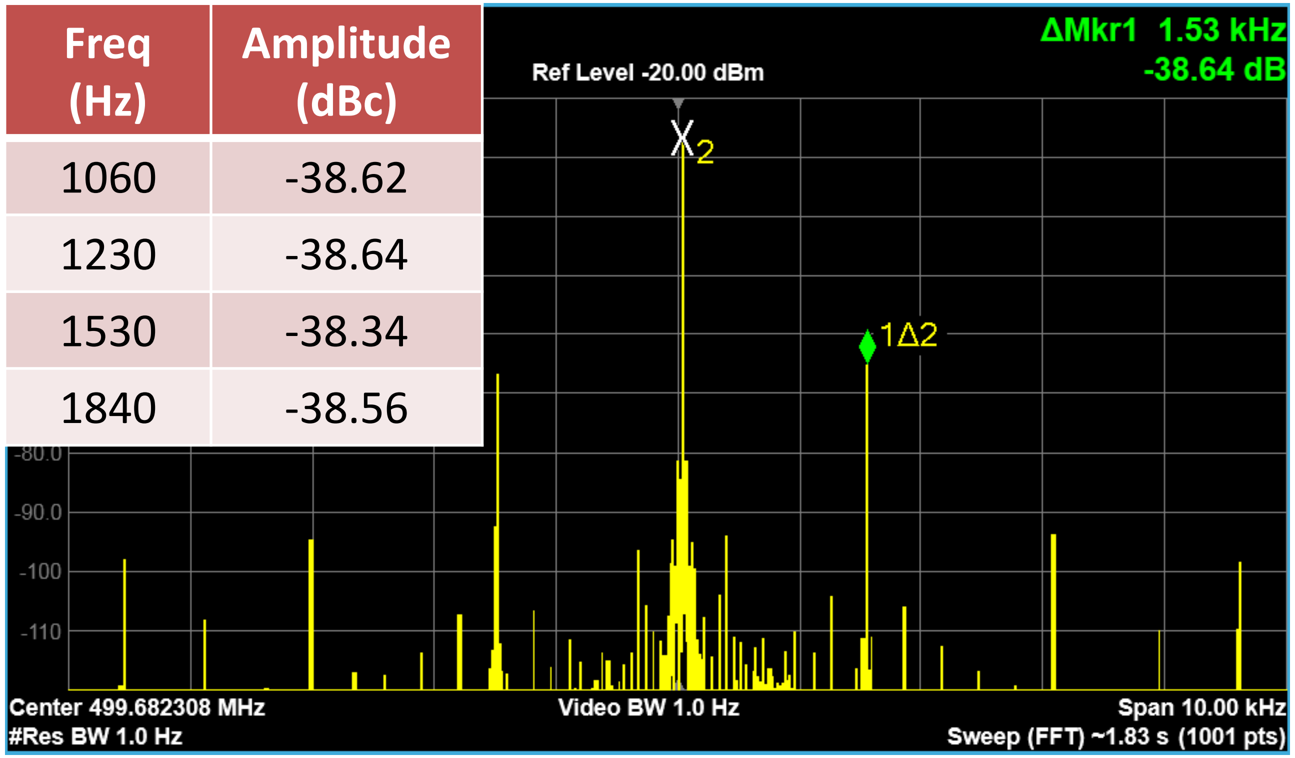

Cavity C Spectrum

Forward Power = ~102kW
Reverse Power = ~90kW

Summary

- We stumbled across a beam instability which drove cavity field modulations which in turn drove mechanical vibrations of the cavity through pondermotive forces
- Using existing tools (applications) in our digital LLRF system we then modulated the cavity fields and confirmed the cavity response to field amplitude modulations
- The feedforward and network analyzer functions in the digital LLRF can provide a powerful tool for development of piezo tuner damping of microphonics by characterizing the mechanical resonances of the system and effectiveness of the piezo tuner feedback on damping rf modulation induced vibrations