Studies of longitudinal instabilities in the ALS

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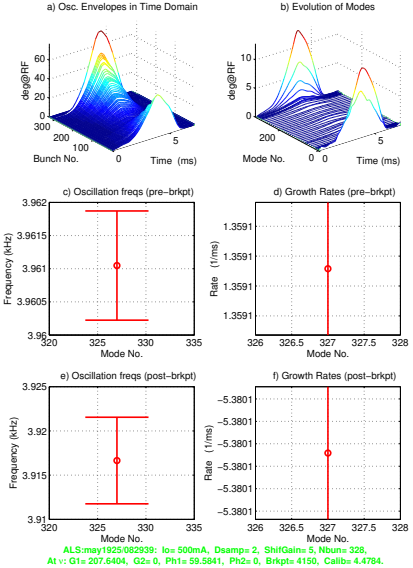
[2]Dimtel, Inc., San Jose, CA, USA

May 28, 2025

Grow/Damp at 500 mA



- Production fill pattern: 1–276, camshaft in 308;
- 4 ms off time, no excitation;
- Fast growth of low frequency modes (-1, 0, 1);
- Fast damping;
- Three modes are strongly coupled, not true eigenmodes.

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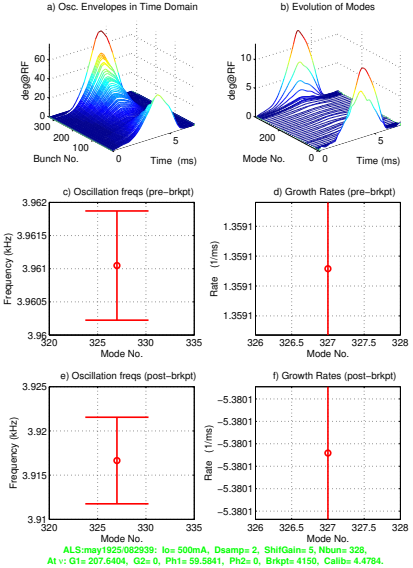

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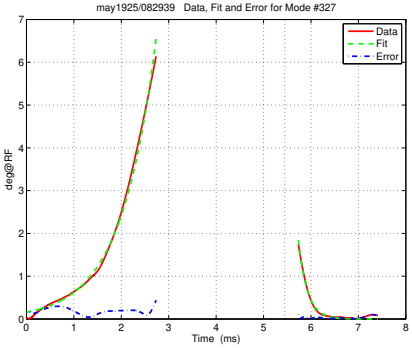

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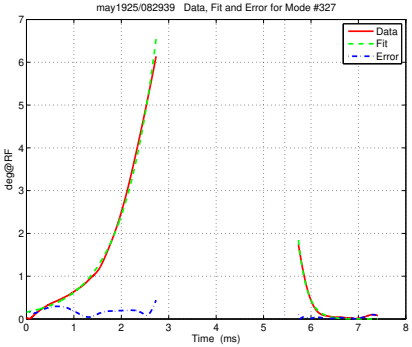

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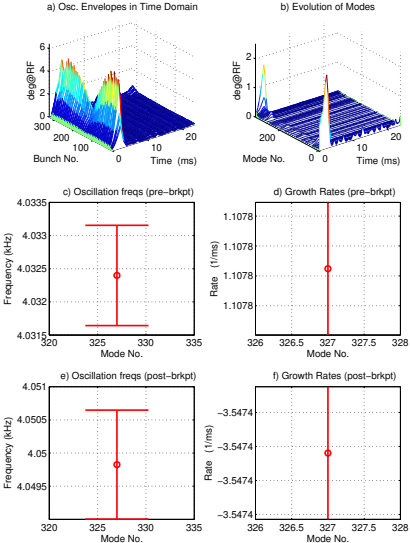

- Special fill pattern: 1–320;
- For this transient growth and damping rates are in line with those measured in May 2025;
- During that shift we observed big changes in low mode growth rates;
- Still see modes -1, 0, and 1;
- Growing modes seem to be phase locked, suggesting one underlying eigenmode;
- Needs more investigation, frequency of 4 kHz suggests mode 0 instability.

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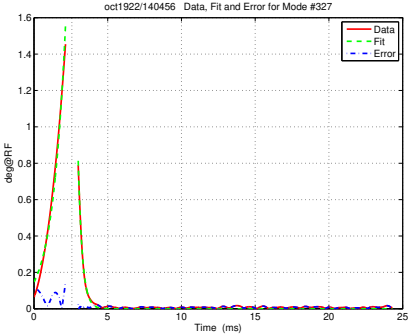

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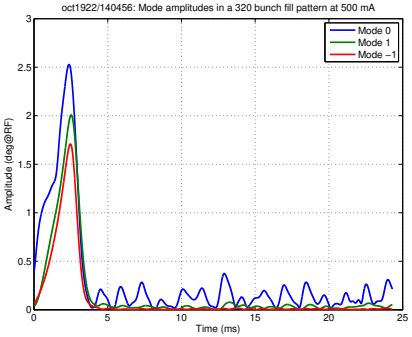

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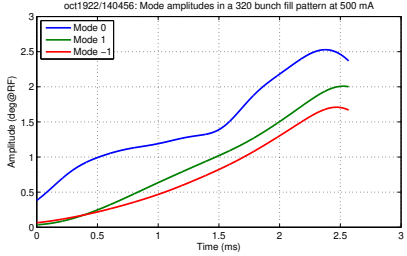

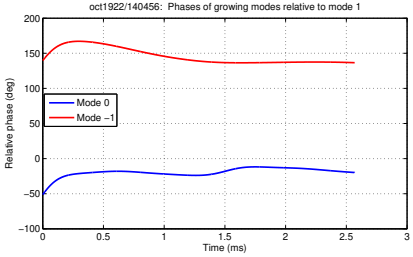

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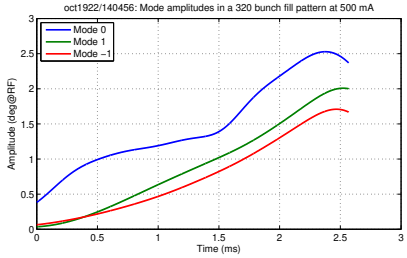

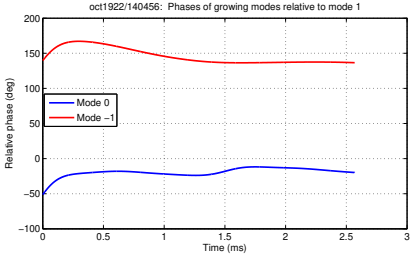

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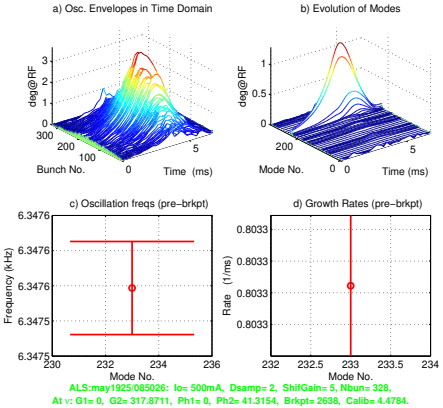

- In order to measure mode 233 we apply excitation at 6.5 kHz below 95 $\times$ f_{rev};
- On trigger feedback and excitation are turned off and data acquisition starts;
- Filtered around 6.4 kHz, excludes low modes;
- Textbook clean fits;
- Histograms of 12 data sets.

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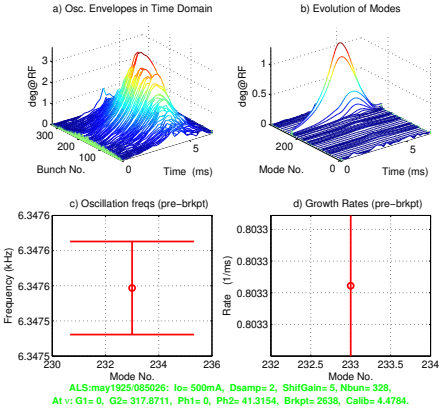

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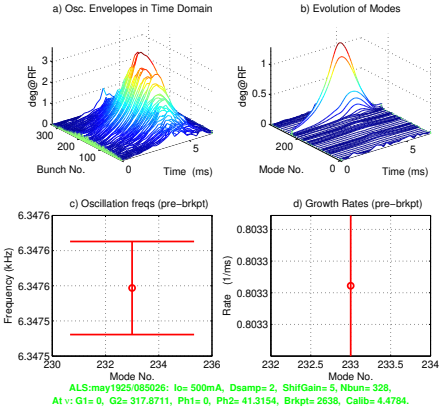

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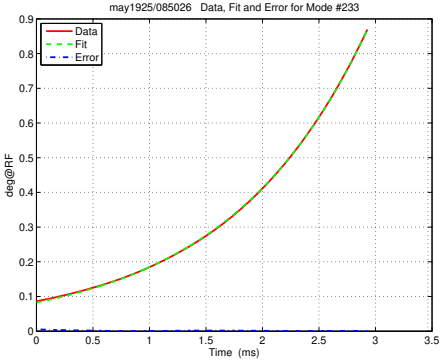

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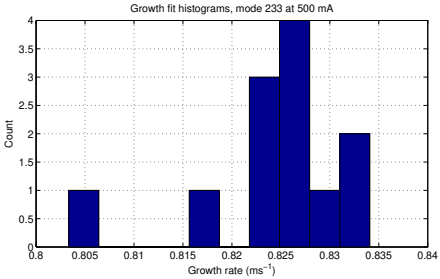

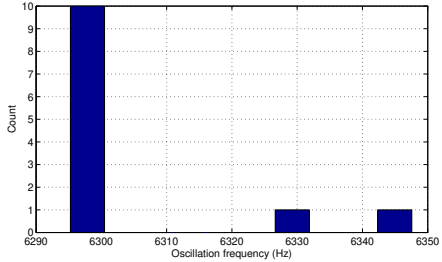

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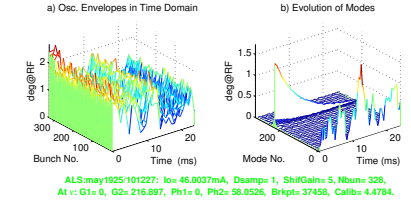

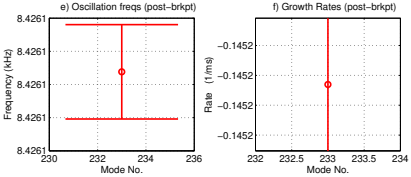

- Uniform fill pattern at 40–50 mA;
- Fully stable;
- One mode at a time is excited with sinusoidal drive, then open-loop damping transient is captured;
- Moving from mode 233 to 95 $= 328 - 233$;
- Damping transient is fitted to extract the complex eigenvalue;
- Mode 233 is anti-damped, mode 95 is damped relative to the radiation damping baseline.

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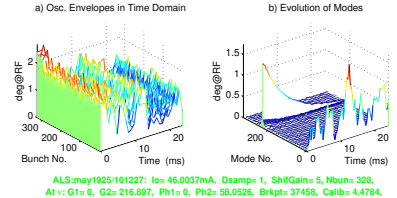

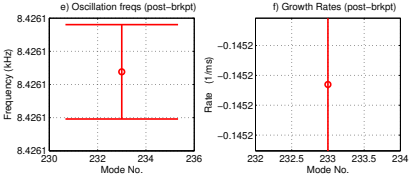

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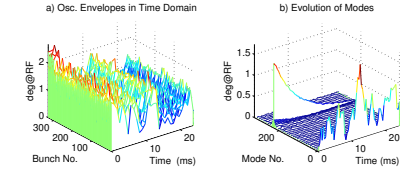

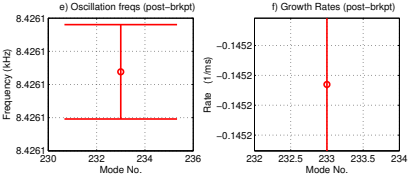

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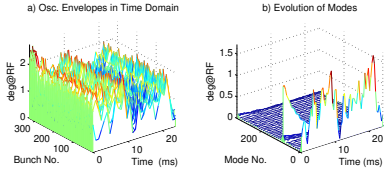

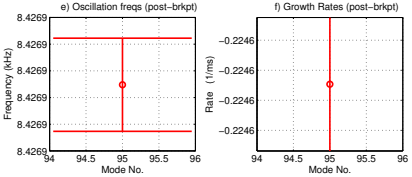

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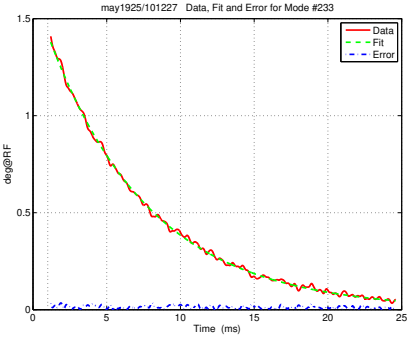

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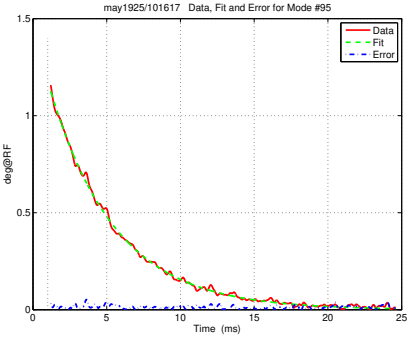

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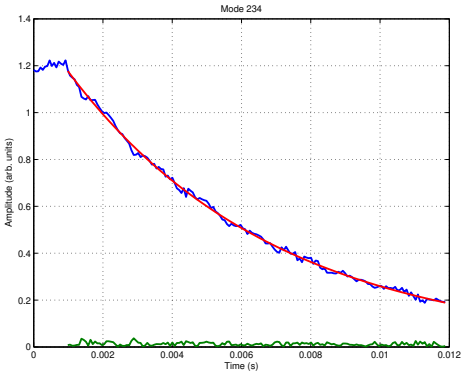

- 12 ms transients with 1 ms before the trigger, 0.3 full-scale excitation;
- 327 modes, 4 measurements per mode, 15.5 minutes, 15 GiB.
- Automated analysis extracts modal signals, then fits to extract eigenvalues;
- All modal eigenvalues plotted, positive modes in blue, negative in red (mode -1 is $327 - h$);
- A curious split between upper and lower sideband frequencies, to be explained shortly.

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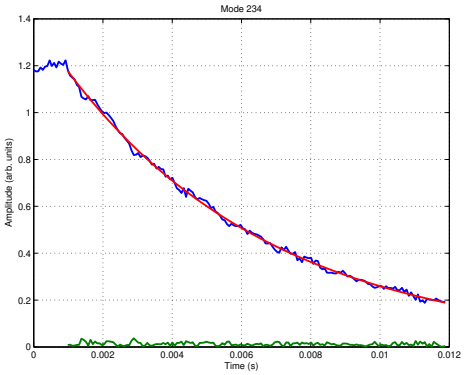

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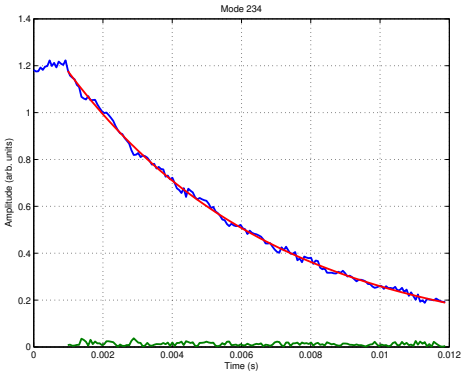

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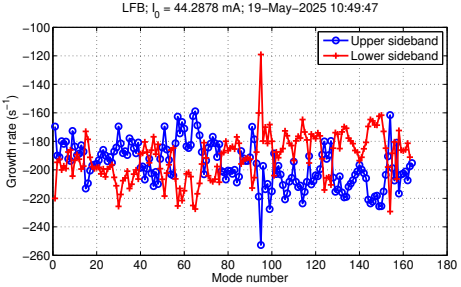

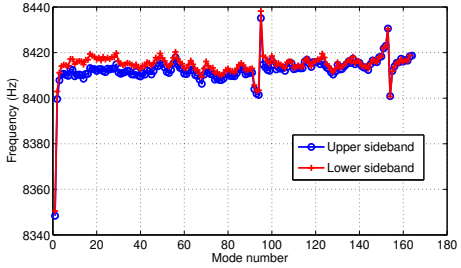

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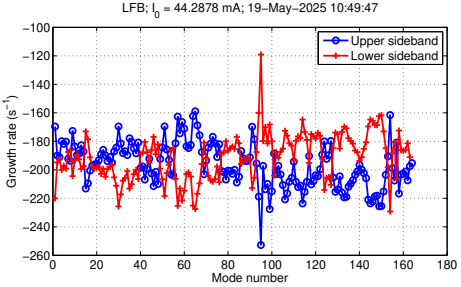

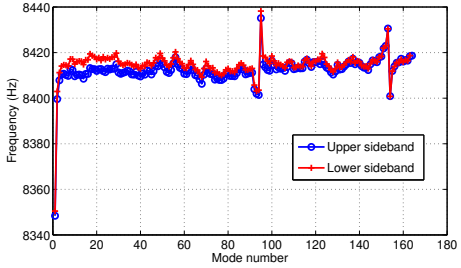

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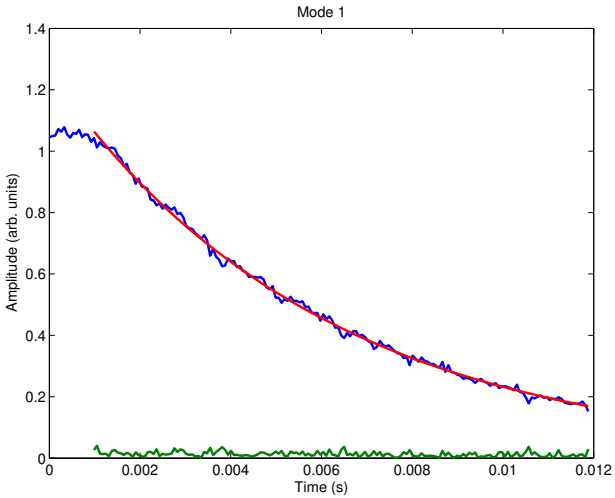
Fitting Animation



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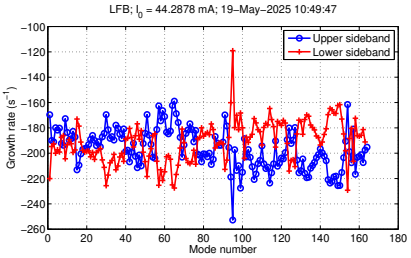

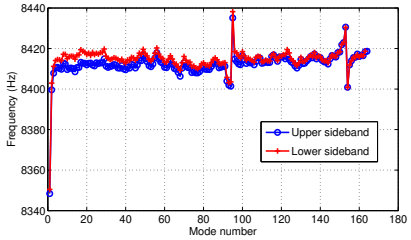

- From a single scan several clear features can be identified;
- Mode 233, HOMs at 2353 and 2853 MHz in the main RF cavities;
- Mode 154, unknown source, resonance between 153 and 154;
- Mode 1 — harmonic cavities parked between $3 \times f_{\mathrm{rf}}$ and $3 \times f_{\mathrm{rf}} + f_{\mathrm{rev}}$.

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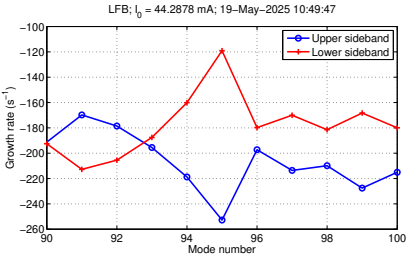

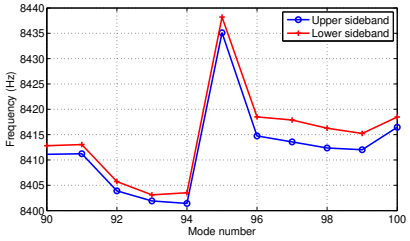

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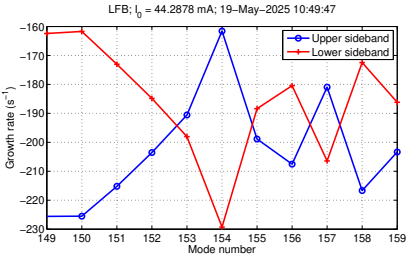

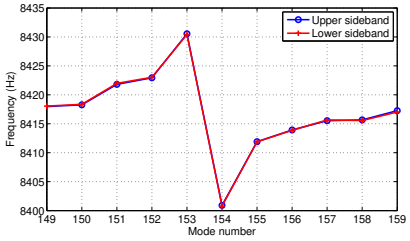

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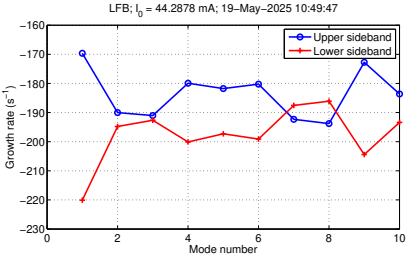
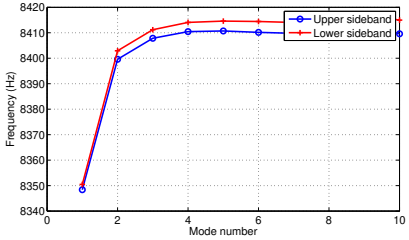
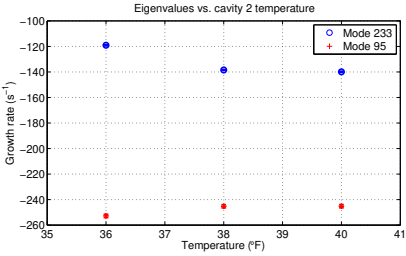
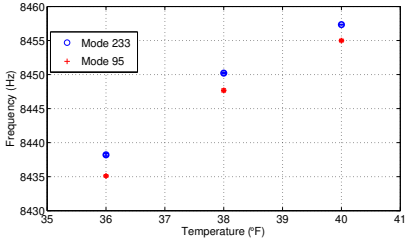




- From a single scan several clear features can be identified;
- Mode 233, HOMs at 2353 and 2853 MHz in the main RF cavities;
- Mode 154, unknown source, resonance between 153 and 154;
- Mode 1 — harmonic cavities parked between $3 \times f_{\mathrm{rf}}$ and $3 \times f_{\mathrm{rf}} + f_{\mathrm{rev}}$.

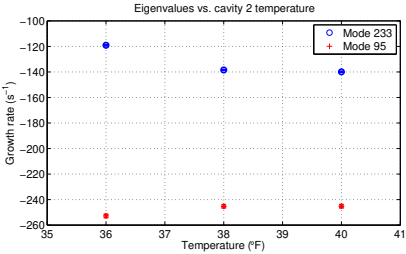
Multiple Scans

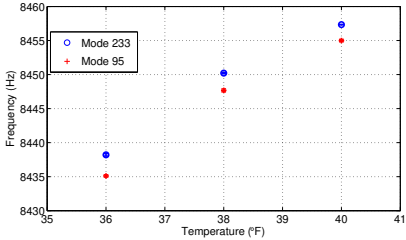




- Three scans at different cavity 2 temperatures;
- Large frequency shift, not really expected from the HOM;
- Selection of modes with little driving impedance shows frequency shift with current;
- Linear fit seems OK.

Multiple Scans





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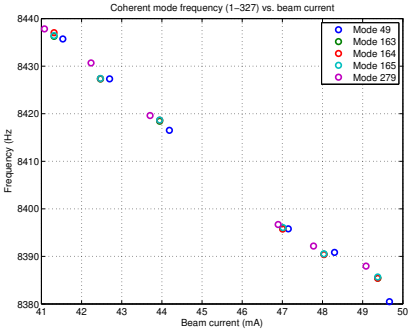

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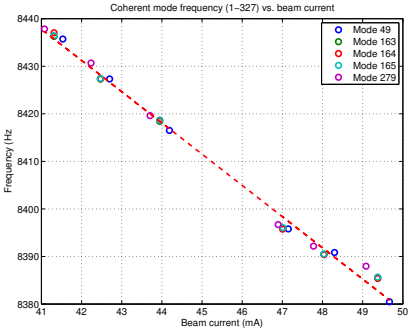

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A Bit About Frequencies

- For a uniform fill in the ALS we expect 328 distinct modes, with 328 complex eigenvalues;
- In zero current limit all eigenvalues tend to $-\lambda_{\mathrm{rad}} + i\omega_s$;
- Beam interacts with constant impedances to shift relevant eigenvalues linearly with current, proportional to real and imaginary parts of the impedance;
- In addition, modes 1–327 shift in frequency due to the harmonic cavity voltage reducing the focusing;
- Mode 0 is special — beam-induced fields in main and harmonic cavities follow mode 0 motion and produce no focusing or defocusing effect;
- Constant RF voltage in main cavities means that generator contribution drops with increasing beam current (larger beam-induced voltage), so focusing for mode 0 reduces with beam current, moving its frequency downwards;
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Beam Current Calibration Approach

- Use archiver data to obtain beam current for each measurement (should capture that directly next time);
- For the imaginary part use the linear fit to the 5 modes shown earlier;
- Correct to 50 mA as $f_n^* = (f_n - f_s(I_0))\frac{50}{I_0} + f_s(50)$;
- For the real part, use radiation damping estimate from modes 163–165 (-194.6s^{-1});
- $\lambda^* = \lambda_{\mathrm{rad}} + (\lambda - \lambda_{\mathrm{rad}})\frac{50}{I_0}$.

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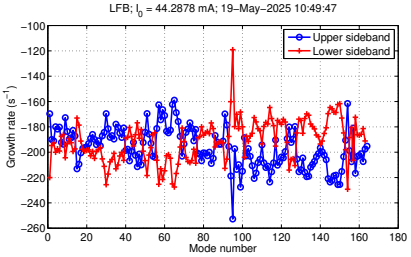

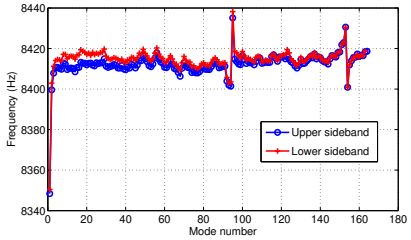

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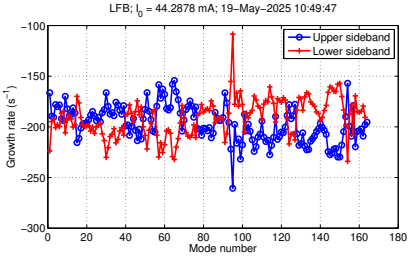

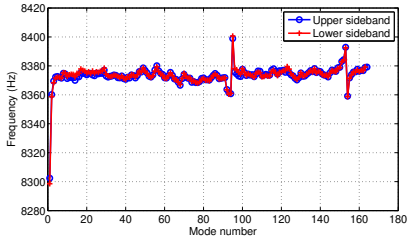

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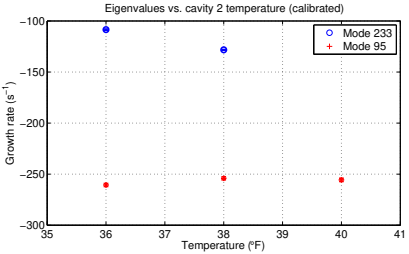

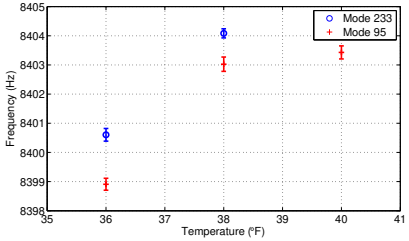

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Summary

- Work needed to plan the actual measurement;
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- Ideally perform all measurements with one fill;
- Can increase the current somewhat (double);
- Explore fitting resonances from multiple modes (232–235, 94–96) without temperature scans.

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