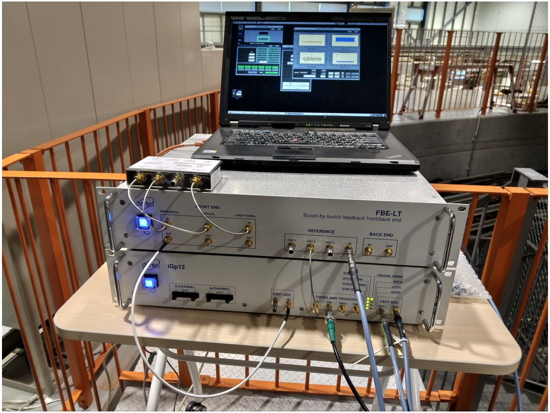
Bunch-by-bunch Feedback Demo in Aichi-SR

D. Teytelman, et.al.

Dimtel, Inc., San Jose, CA, USA

October 26, 2018

Bunch-by-bunch Feedback Setup



- FBE-500LT multi-channel front/back-end;
- iGp12 bunch-by-bunch feedback processor;
- BPMH-20-2G BPM hybrid;
- Inputs: MO reference, fiducial, 4 buttons;
- Outputs: Power amplifier drive.

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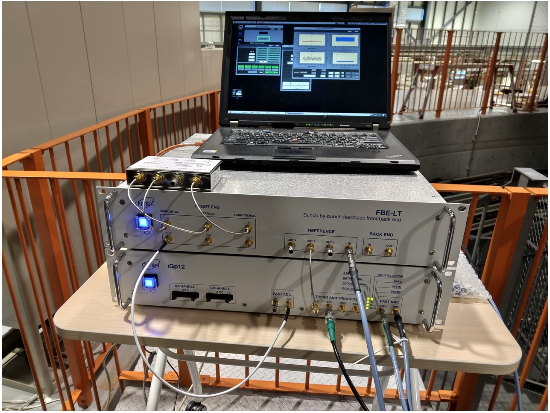

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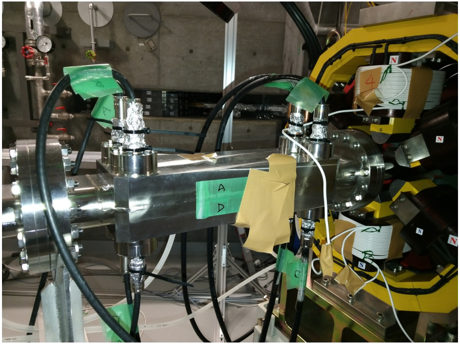
Kickers and Amplifiers



- We have tried two different kickers:
  - 30 cm stripline;
  - 15 cm stripline.
- As well as two power amplifiers:
  - 100 W R&K A220-100-R;
  - 10 W modified Quantum Technology P3500-10W.
- R&K amplifier has limited bandwidth and significant ringing, not usable;
- Settled on the longer stripline.

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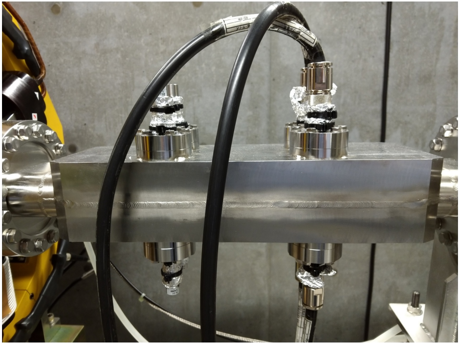

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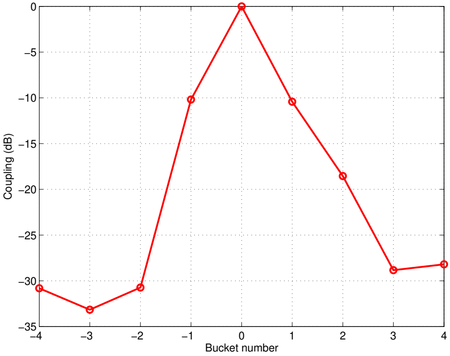

- Measuring back-end coupling from bunch to bunch;
- iGp12 drives a single filled bucket at ν_x;
- Moving the kick we can measure coupling to surrounding RF buckets.
- P3500 and 30 cm stripline, poor isolation of 10 dB due to reflections in the kicker;
- Used back-end shaper filter to correct for those reflections, isolation improved to 25 dB;
- Both measurements for comparison.

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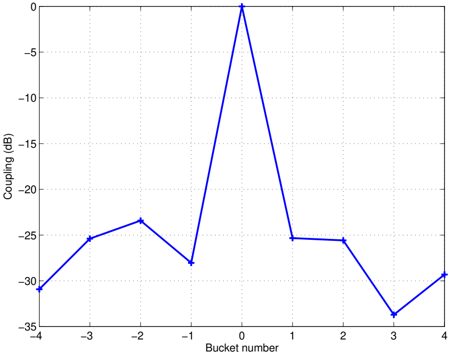

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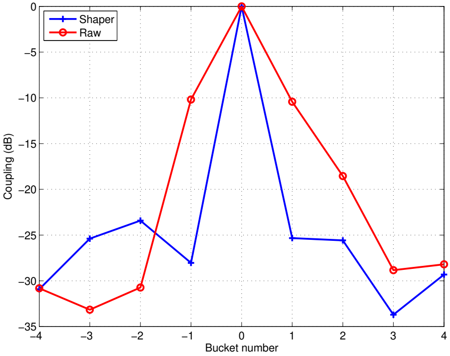

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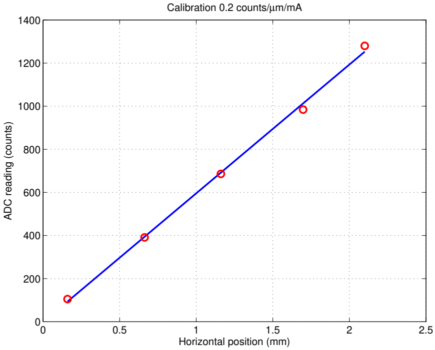

- With single bunch in the ring, adjusted steering magnet to produce horizontal orbit shift;
- First recorded horizontal position with 4 BPM cables connected to the standard BPM processor;
- Then reconnected BPMH/FBE-500LT/iGp12 and recorded ADC readings for the stored bunch;
- Calibration factor 0.2 counts/µm/mA.

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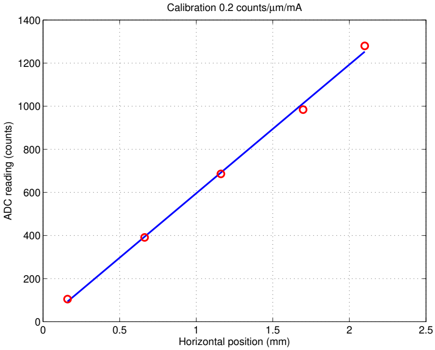

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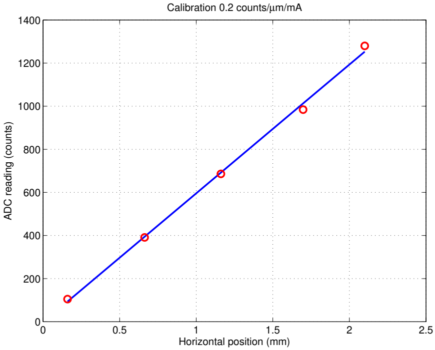

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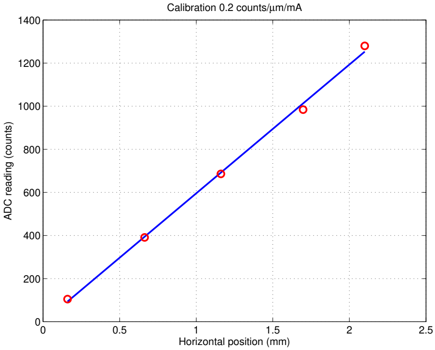

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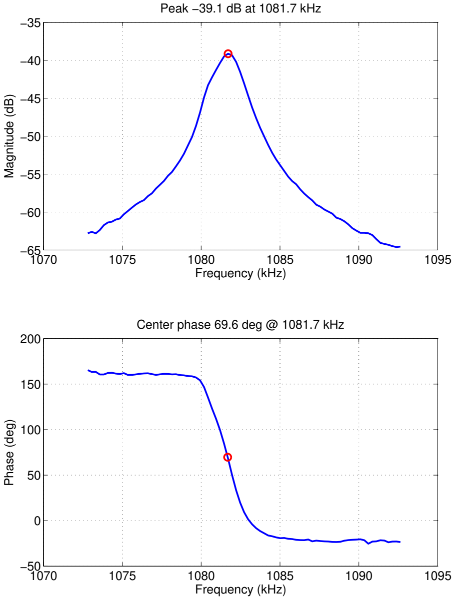
Beam Transfer Functions



- Single bunch transfer function measurement:
  - Swept frequency excitation;
  - Transfer function estimated from measured response by cross-correlation method.
- Single bunch at 3 mA;
- First bunch in a 110 bunch train at 301 mA;
- A comparison.

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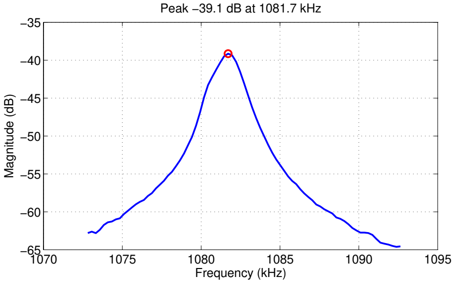

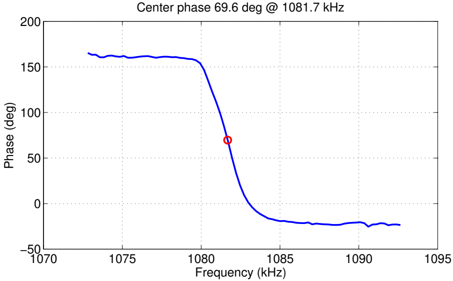

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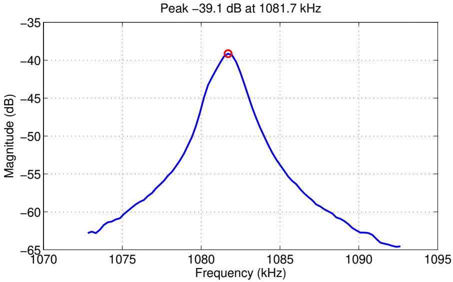

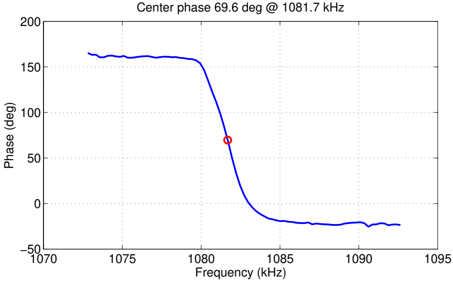

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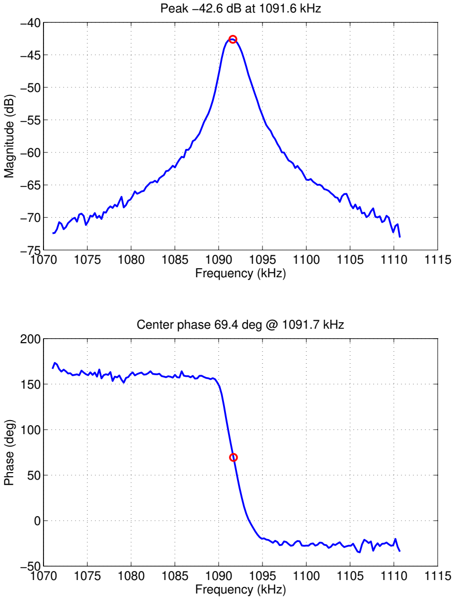

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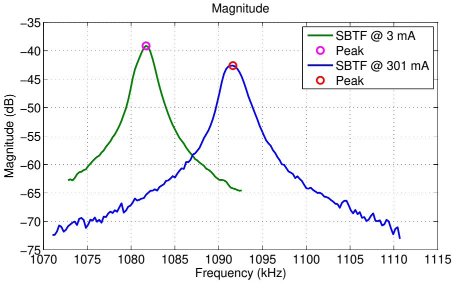

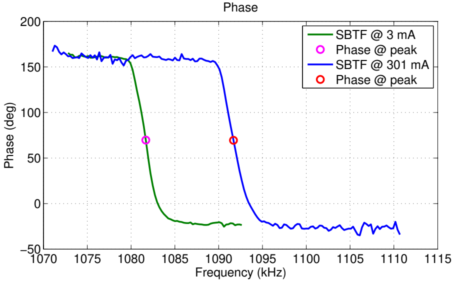

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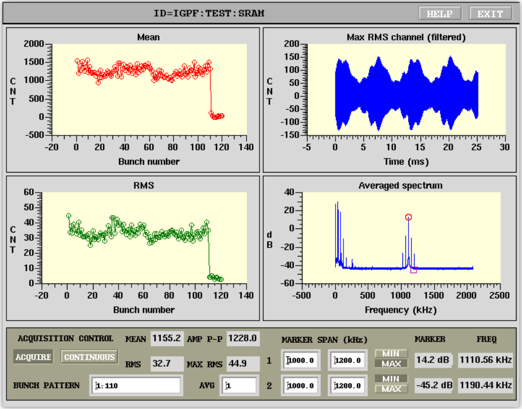

- U7 gap at 33 mm;
- Feedback off;
- Feedback on!

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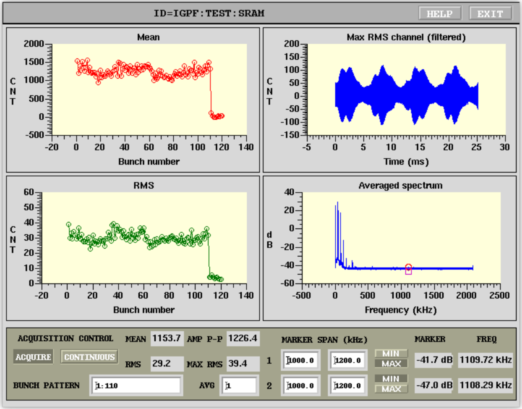

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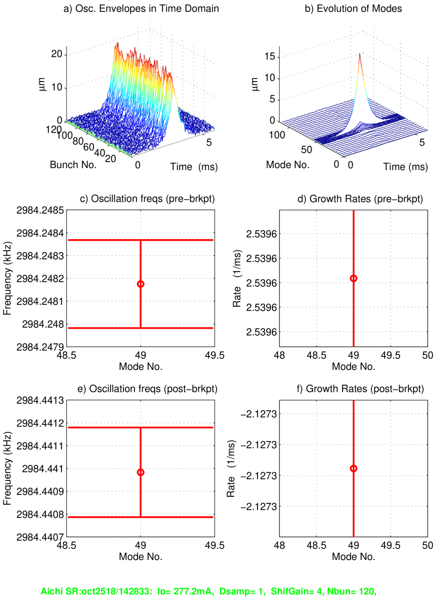
Grow/Damp Measurement



- 110 bunches, 277 mA total current, U7 at 24 mm;
- Fast growth and damping of mode 49 (impedance at $293 + N \times 500$ MHz);
- On short timescales tune is constant, can extract frequency and growth/damping rate;
- Nicely exponential transients.

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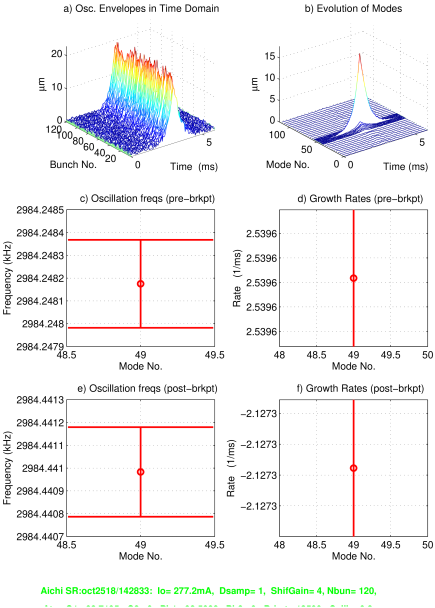

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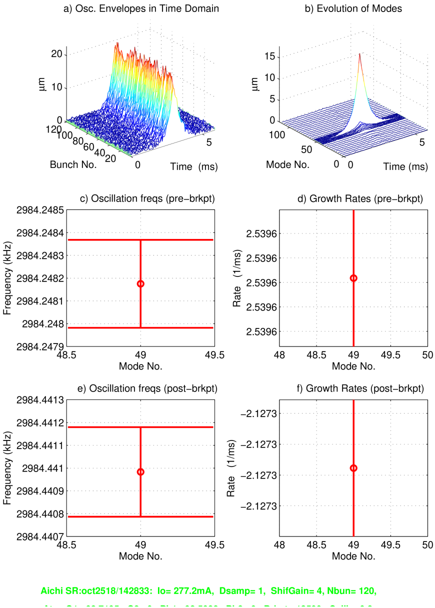

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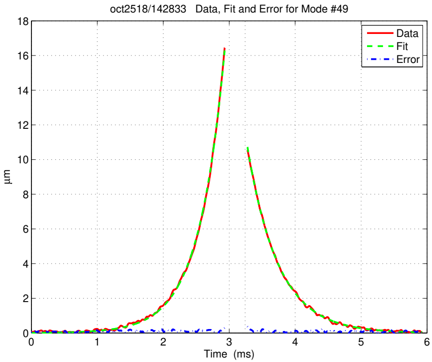

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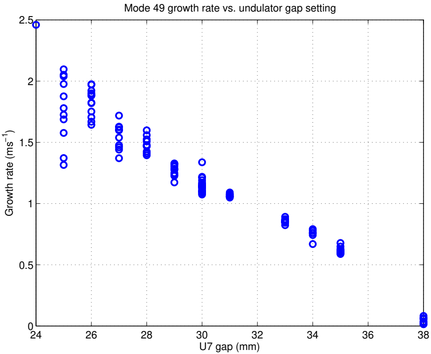

- Instability threshold at 38 mm gap is 300 mA;
- Feedback damping (difference between open and closed loop) is nearly constant;
- Drop around 33–35 mm is due to feedback acting reactively, not adjusted to compensate for tune shift;
- Damping rates were getting marginal at 26 mm, doubled the gain.

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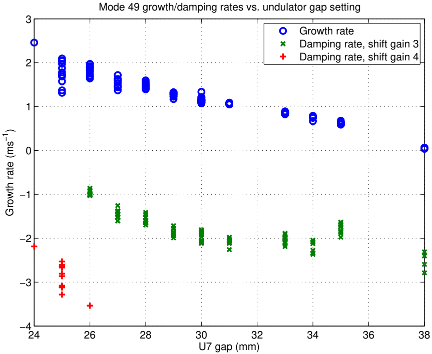

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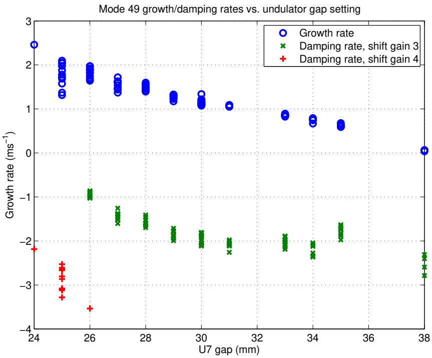

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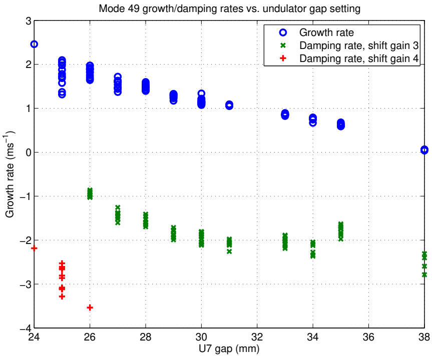

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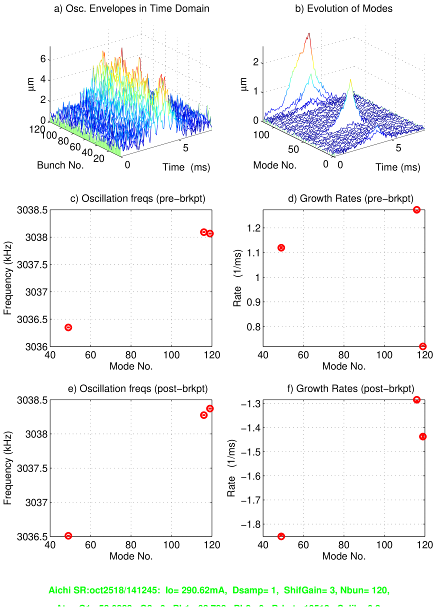

- At all gap settings below 38 mm we see mode 49;
- Between 28–33 mm we also observed low-frequency modes -1 (119) and -4 (116);
- Mode -1 is typically driven by resistive-wall impedance;
- Reasonably clean transients, could measure better in uniform fill pattern without a gap.

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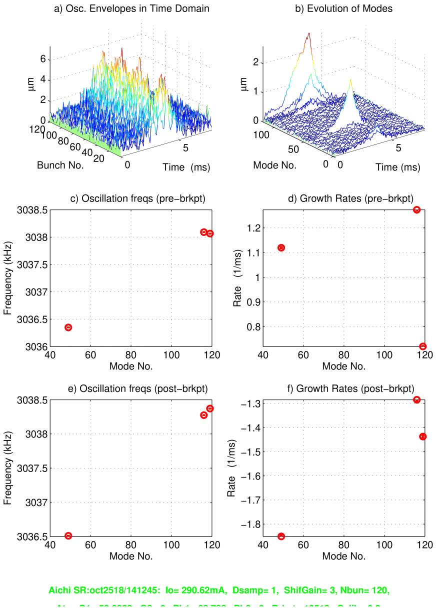

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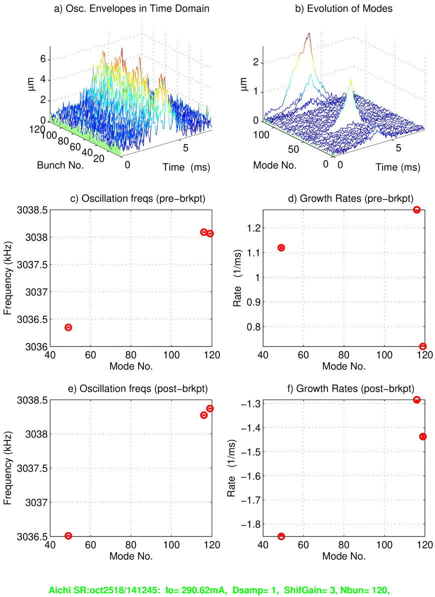

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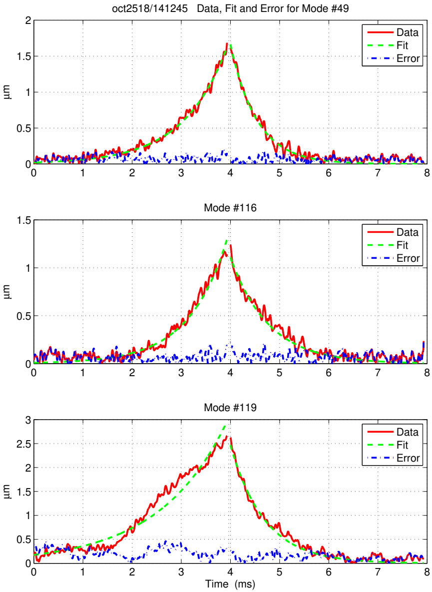

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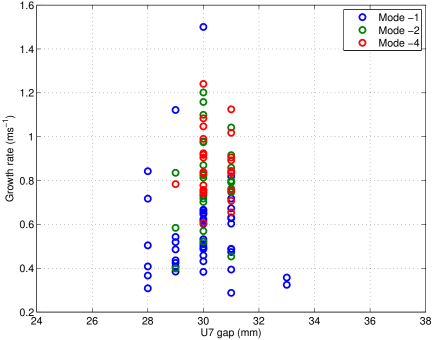

- A lot of scatter in growth rate measurements;
- At 30–31 mm gap, growth rates for low-frequency modes are comparable to those of mode 49;
- First guess would be to look for orbit shifts, no obvious explanation.

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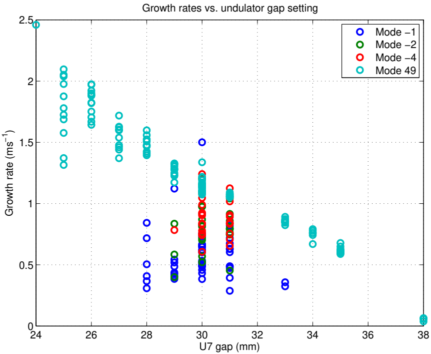

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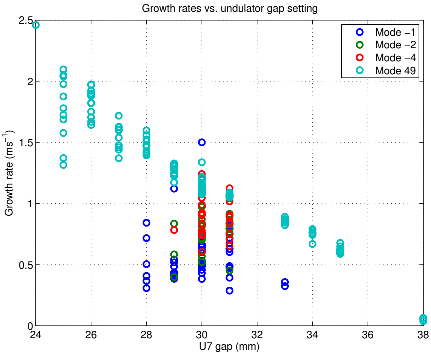

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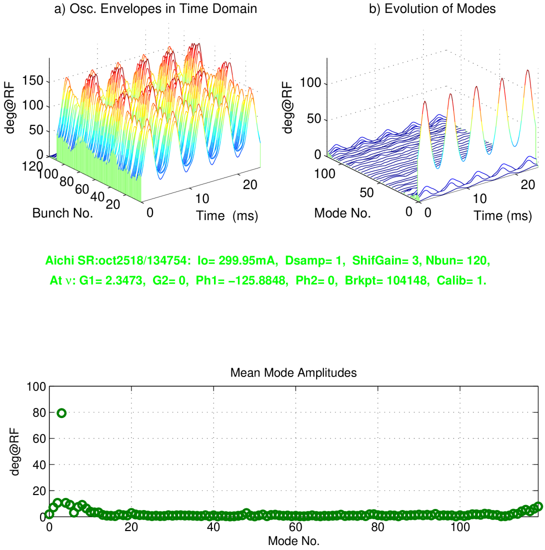

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- Dominated by mode 3 (impedance at $12.5 + N \times 500$ MHz).

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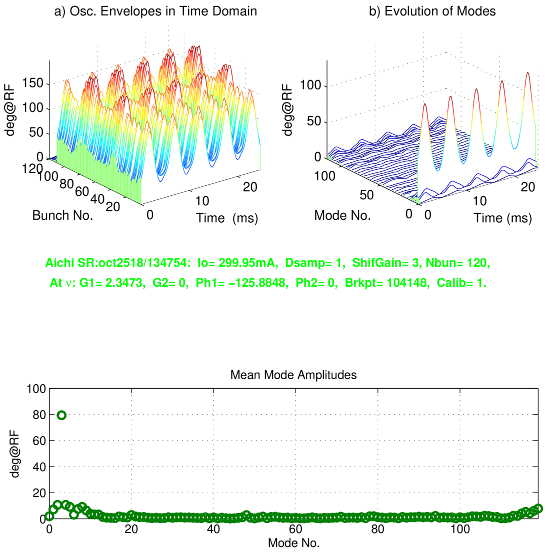

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Power Stage Estimation: Gain and Kick Angle

- Related, but distinct qualities: feedback gain and peak kick angle;
  - Required feedback gain depends on maximum instability growth rates;
  - Can often operate with very small kick angle (low shunt impedance/amplifier power) if there are no significant perturbations;
- Peak kick angle is determined by external beam perturbations;
- Design procedure: determine required feedback gain based on known/expected growth rates;
- Measure/estimate largest perturbations (injection, etc.);
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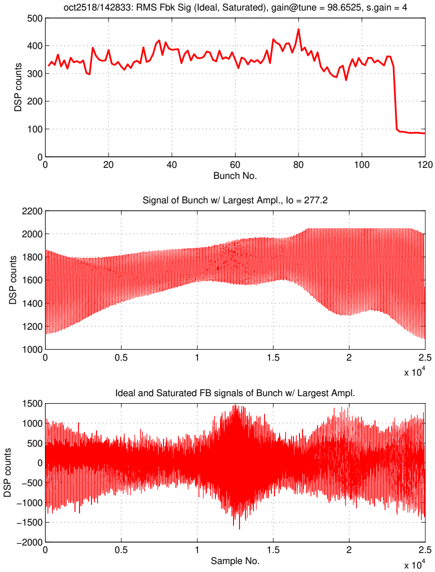
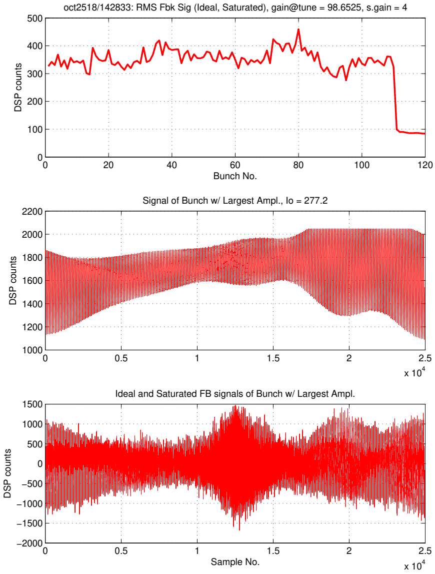


- Feedback output during a grow/damp (24 mm gap, max growth rate, 22 µm peak amp.);
- Output reaches 73% FS, saturation point around 30 µm;
- Important observation — output kick contains significant response to longitudinal motion;
- Averaged spectrum — longitudinal components are 1–2 orders of magnitude larger.

Power Stage Estimation: Kick Output During a Grow/Damp



- Feedback output during a grow/damp (24 mm gap, max growth rate, 22 μm peak amp.);
- Output reaches 73% FS, saturation point around 30 μm;
- Important observation — output kick contains significant response to longitudinal motion;
- Averaged spectrum — longitudinal components are 1–2 orders of magnitude larger.

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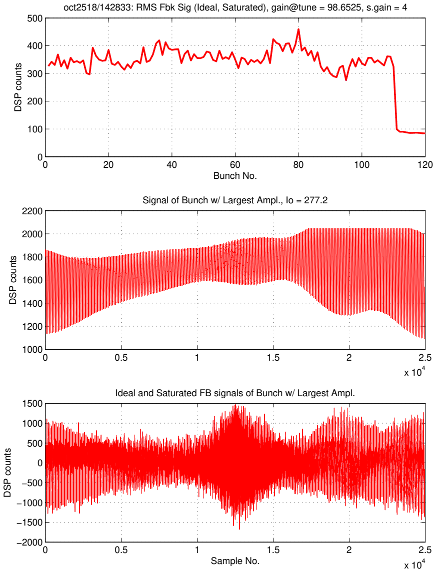

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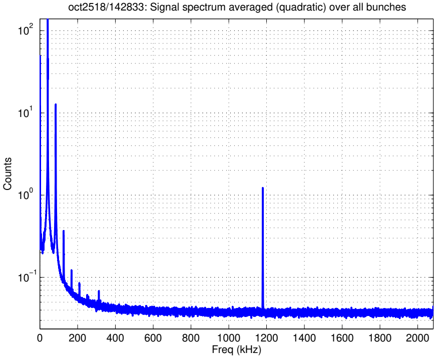

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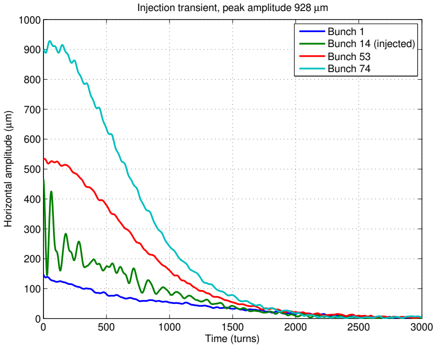
Power Stage Estimation: Kick Output During an Injection Transient



- Injection transient;
- Peak amplitude 928 µm, but short duration;
- Feedback output is heavily saturated (factor of 12.7);
- Simple-minded calculation gives required power to stay linear as $10 * 12.7^2 = 1613$ W;
- If we drive all four striplines, we gain a factor of 4, so only need 4 amplifiers of 100 W each;
- R&K A009K251-5050R?

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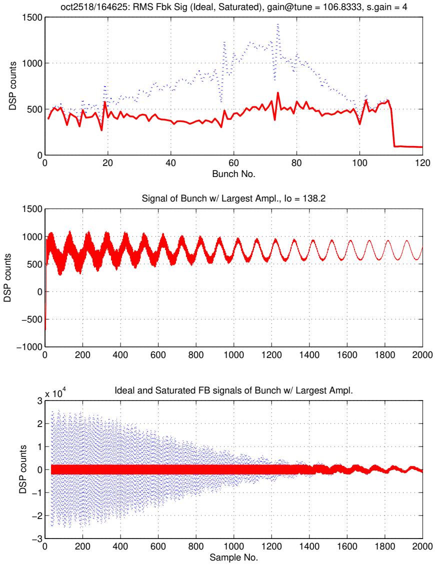

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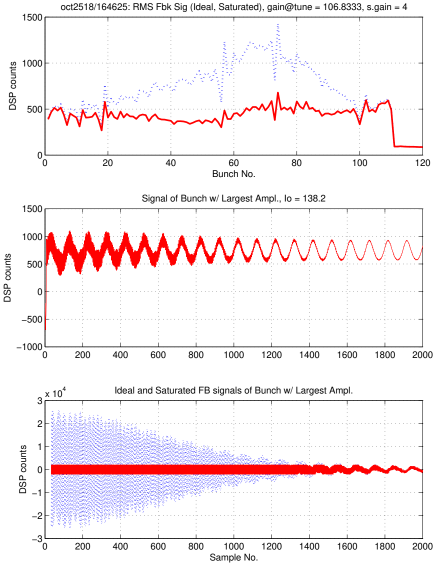

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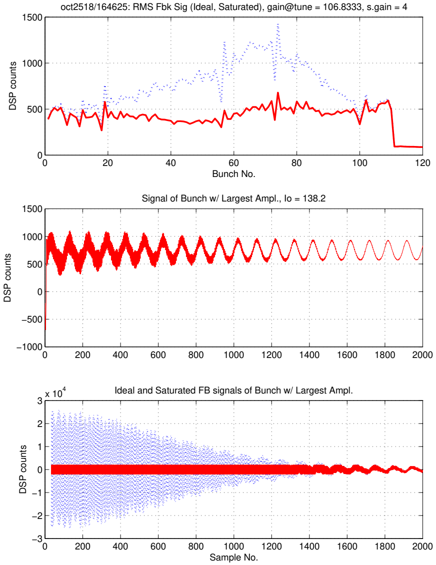

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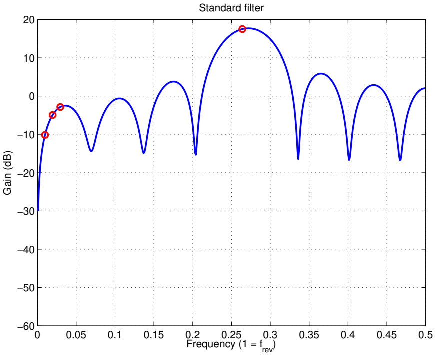
Improved Filter to Reject Longitudinal Signals



- Synchrotron line is 40 dB higher than betatron signals, harmonics 20 dB higher;
- Magnitude response of the standard filter, markers show betatron tune and first three synchrotron harmonics;
- Less than 20 dB attenuation of ω_s line;
- A modified filter gives more than 50 dB suppression.

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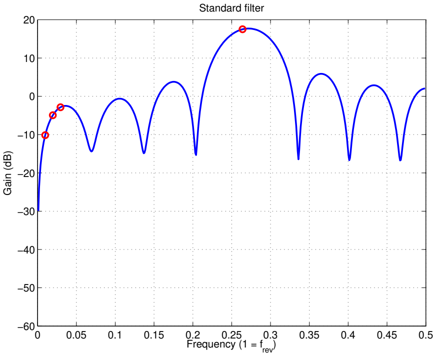

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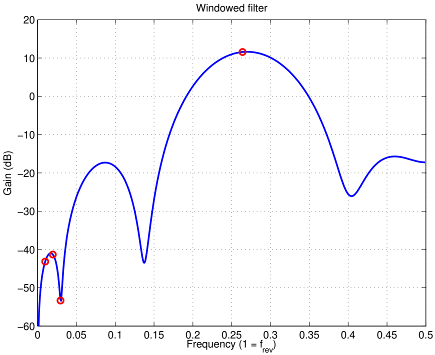

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Summary

- Successfully demonstrated horizontal feedback at Aichi-SR;
- With 10 W amplifier (almost) handled all U7 gap settings;
- For reliable production operation 2–4 good quality 100 W amplifiers would be needed;
- Existing striplines have poor match, ideally replace with an updated design;
- Multiple horizontal modes respond to U7 gap settings, mechanism not quite clear yet;
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