Bunch-by-bunch feedback commissioning at BESSY-II

F. Falkenstern[1], R. Müller[1], A. Schälicke[1], D. Teytelman[2], et. al.

[1]BESSY, Berlin, Germany
[2]Dimtel, Inc., San Jose, CA, USA

January 8–11, 2013

Outline

Work Summary

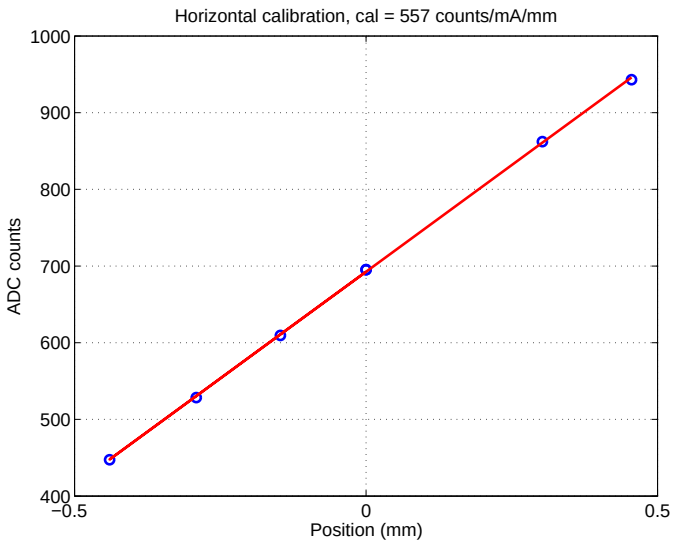
- Prepared all 4 iGp12 units for operation on the control network;
- Three baseband processors and the front/back-end are installed in the rack and connected to:
  - RF reference;
  - Fiducial;
  - BPM hybrid outputs;
  - Power amplifiers.
- Checked and adjusted power amplifier drive levels;
- Vertical plane has two combiners between iGp12 and power amp, need to recheck the drive level at some point.

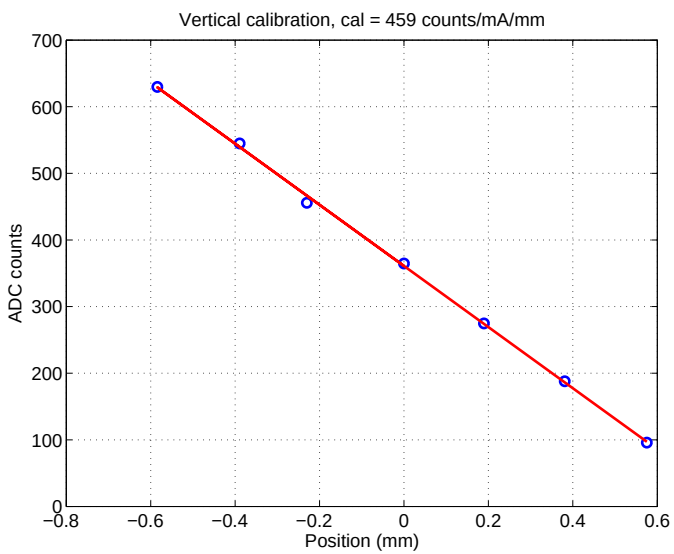
Feedback Hardware

- Dimtel hardware installed in the ring;
- Fiducial signals use splitters:
  - Long transition times, significant jitter (1 ns) — need to find a sharper edge with better stability;
  - Using 6 dB attenuator to avoid magnetic saturation;
  - Try a DC block with low cut-off to eliminate the attenuator.

Outline

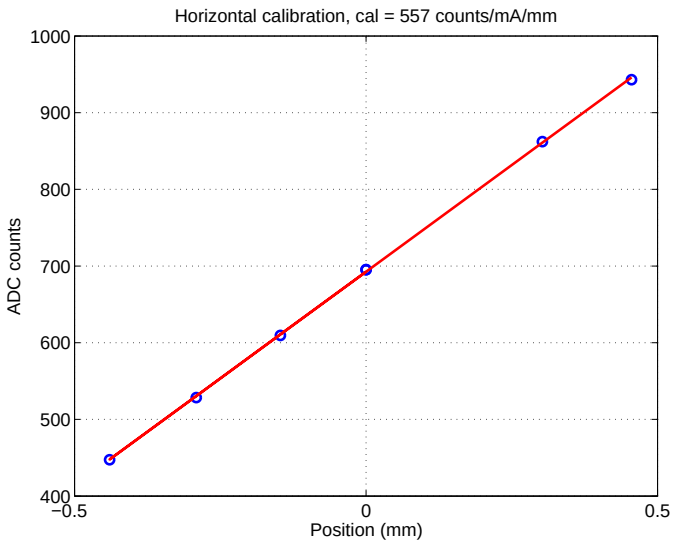
Front-end Calibration: Transverse Plane

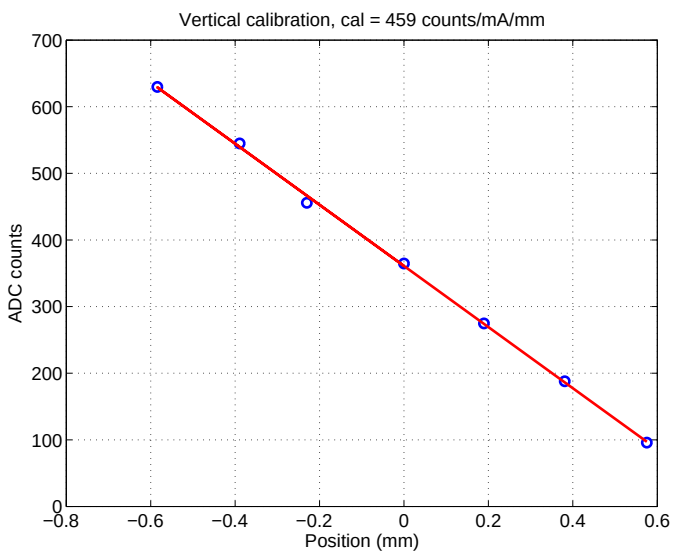




- Set up controlled orbit bumps in X and Y;
- Measure bunch signal displacement in ADC counts;
- At 1 mA per bunch ADC LSB is to 1.8 and 2.2 μm in X and Y respectively;
- To accommodate camshaft bunches had to increase X attenuation by 11 dB, Y — by 4 dB (6.4 and 3.5 μm LSB).

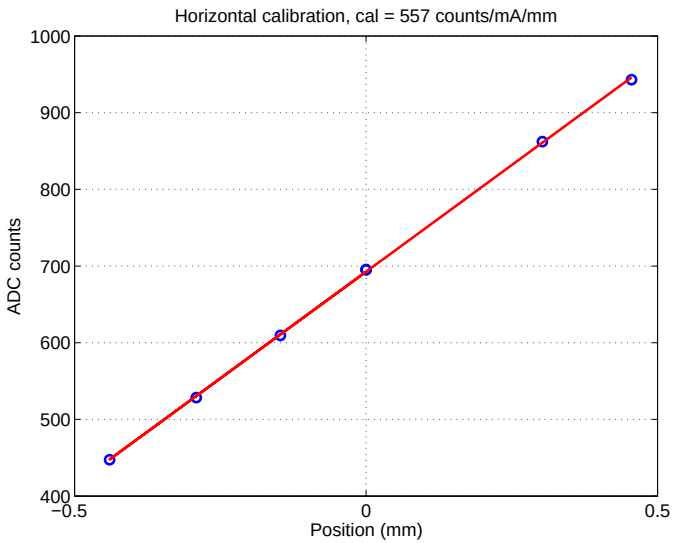
Front-end Calibration: Transverse Plane

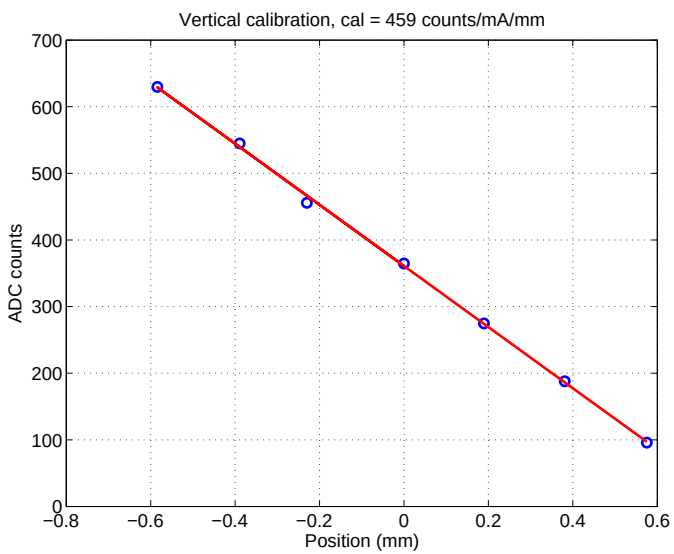




- Set up controlled orbit bumps in X and Y;
- Measure bunch signal displacement in ADC counts;
- At 1 mA per bunch ADC LSB is to 1.8 and 2.2 μm in X and Y respectively;
- To accommodate camshaft bunches had to increase X attenuation by 11 dB, Y — by 4 dB (6.4 and 3.5 μm LSB).

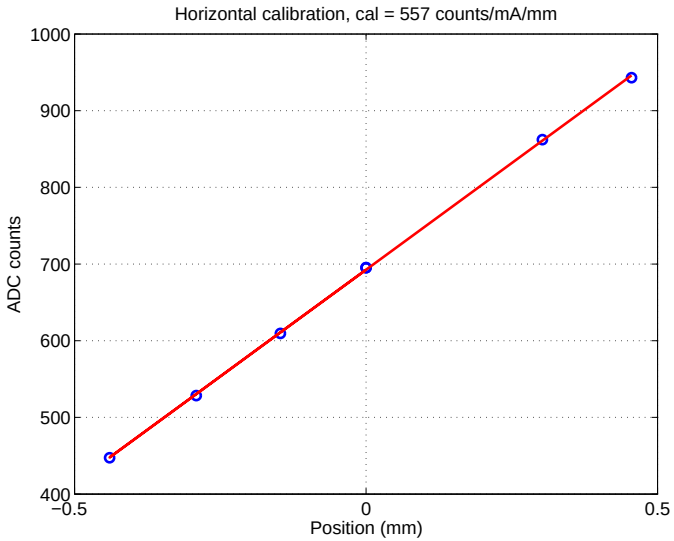
Front-end Calibration: Transverse Plane

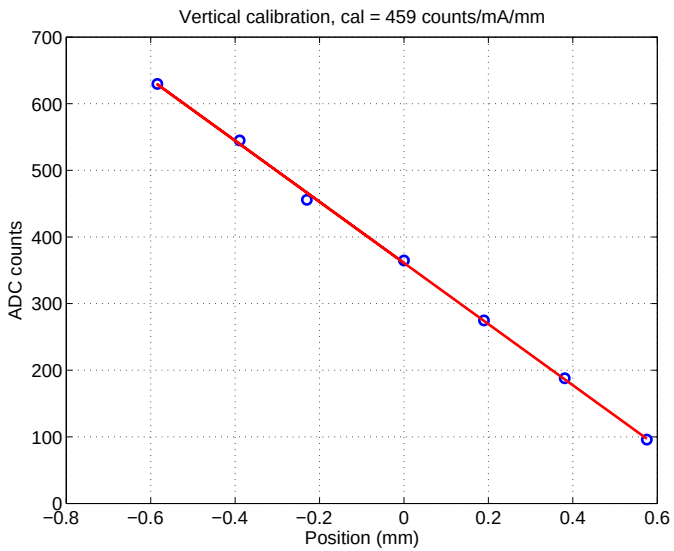




- Set up controlled orbit bumps in X and Y;
- Measure bunch signal displacement in ADC counts;
- At 1 mA per bunch ADC LSB is to 1.8 and 2.2 μm in X and Y respectively;
- To accommodate camshaft bunches had to increase X attenuation by 11 dB, Y — by 4 dB (6.4 and 3.5 μm LSB).

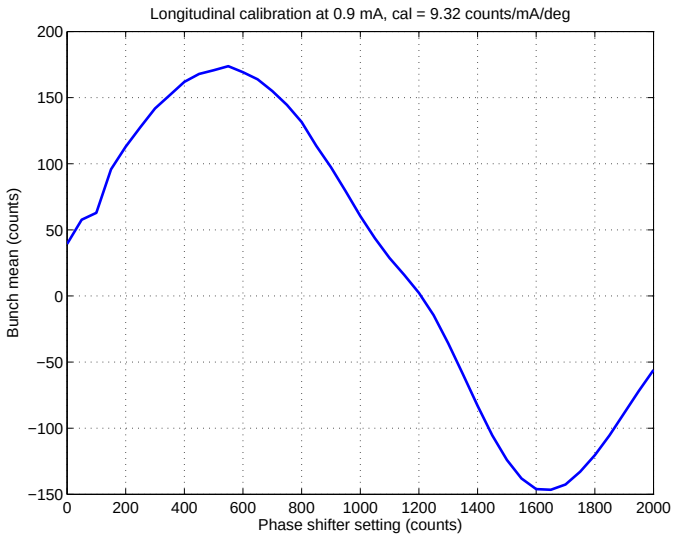
Front-end Calibration: Transverse Plane





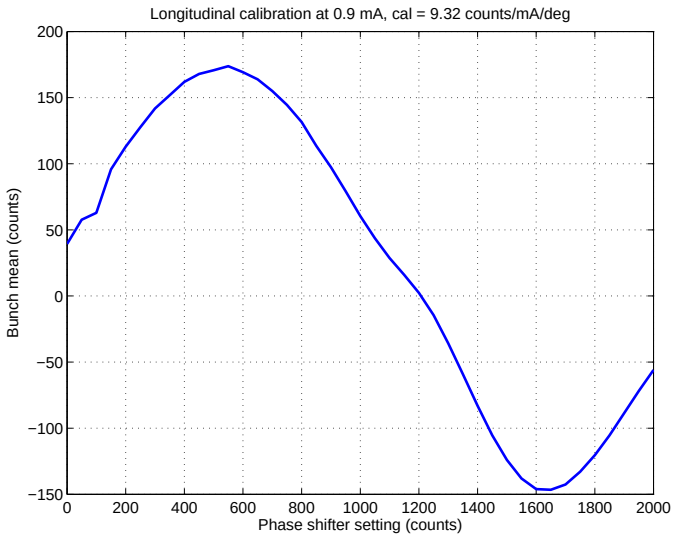
- Set up controlled orbit bumps in X and Y;
- Measure bunch signal displacement in ADC counts;
- At 1 mA per bunch ADC LSB is to 1.8 and 2.2 μm in X and Y respectively;
- To accommodate camshaft bunches had to increase X attenuation by 11 dB, Y — by 4 dB (6.4 and 3.5 μm LSB).

Longitudinal Calibration



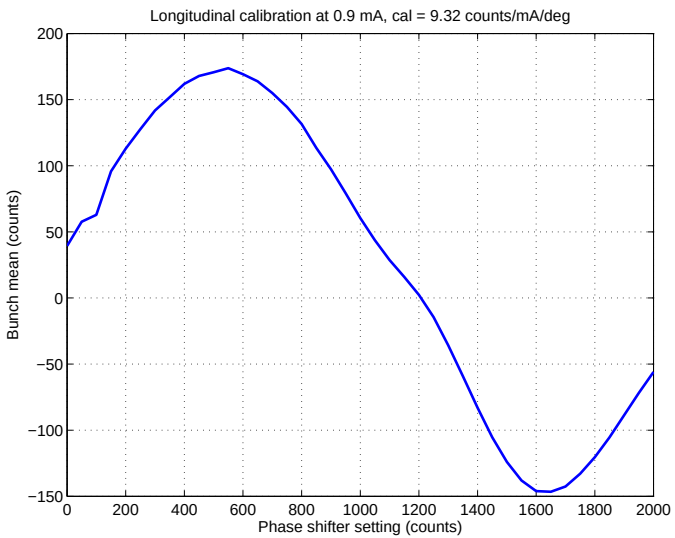
- Sweep phase shifter over 360°;
- Record bunch signal (average);
- Calibration factor of 9.32 counts/mA/degree;
- At 1 mA per bunch ADC LSB is 107 milli-degrees (600 fs);
- At 300 mA in nominal fill pattern the ADC range is only partially used, can lower the attenuation (18 dB now).

Longitudinal Calibration



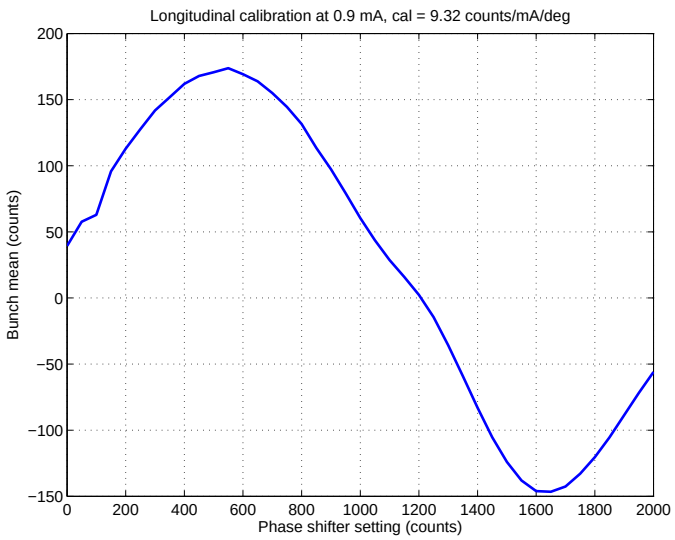
- Sweep phase shifter over 360°;
- Record bunch signal (average);
- Calibration factor of 9.32 counts/mA/degree;
- At 1 mA per bunch ADC LSB is 107 milli-degrees (600 fs);
- At 300 mA in nominal fill pattern the ADC range is only partially used, can lower the attenuation (18 dB now).

Longitudinal Calibration



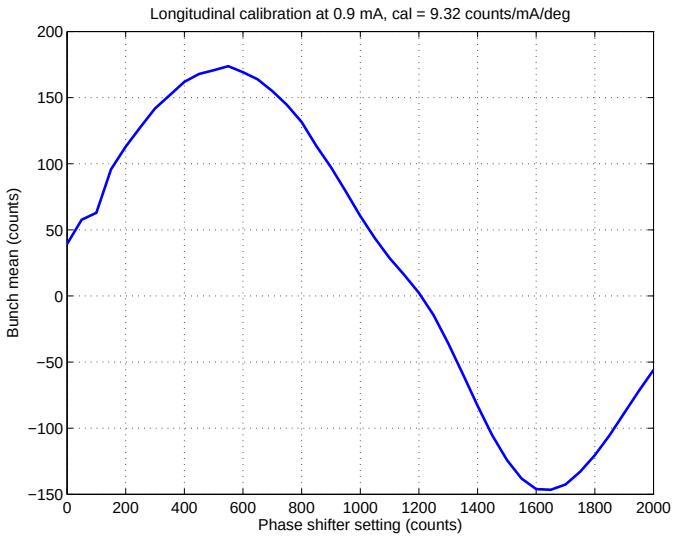
- Sweep phase shifter over 360°;
- Record bunch signal (average);
- Calibration factor of 9.32 counts/mA/degree;
- At 1 mA per bunch ADC LSB is 107 milli-degrees (600 fs);
- At 300 mA in nominal fill pattern the ADC range is only partially used, can lower the attenuation (18 dB now).

Longitudinal Calibration



- Sweep phase shifter over 360°;
- Record bunch signal (average);
- Calibration factor of 9.32 counts/mA/degree;
- At 1 mA per bunch ADC LSB is 107 milli-degrees (600 fs);
- At 300 mA in nominal fill pattern the ADC range is only partially used, can lower the attenuation (18 dB now).

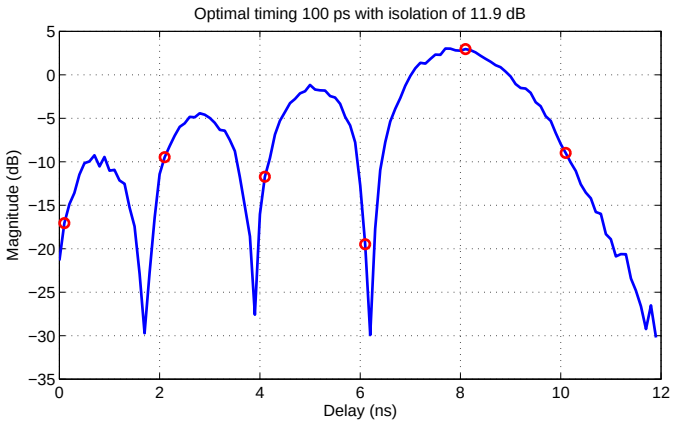
Longitudinal Calibration



- Sweep phase shifter over 360°;
- Record bunch signal (average);
- Calibration factor of 9.32 counts/mA/degree;
- At 1 mA per bunch ADC LSB is 107 milli-degrees (600 fs);
- At 300 mA in nominal fill pattern the ADC range is only partially used, can lower the attenuation (18 dB now).

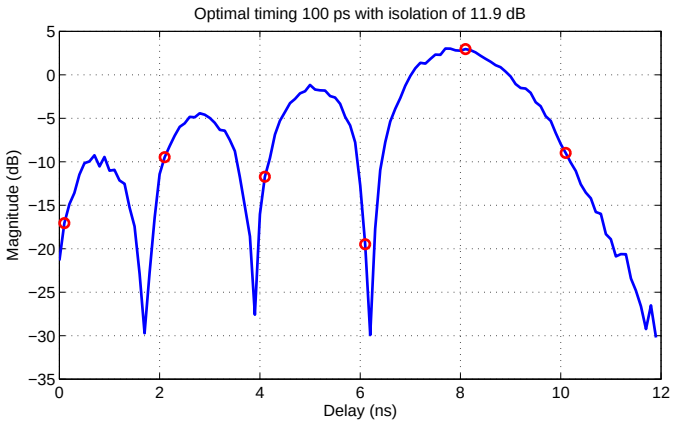
Outline

Vertical Amplifier Response



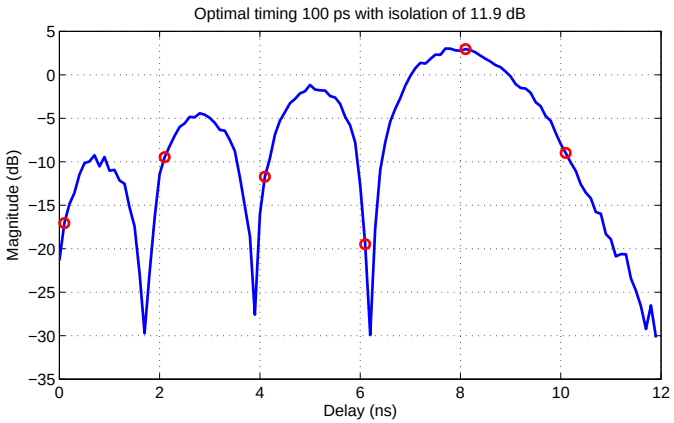
- Drive the single bunch at the betatron frequency;
- Adjust back-end delay;
- Record betatron oscillation magnitude;
- Optimal timing has 11.9 dB isolation;
- Can extract impulse response of the DAC/amplifier/kicker chain.

Vertical Amplifier Response



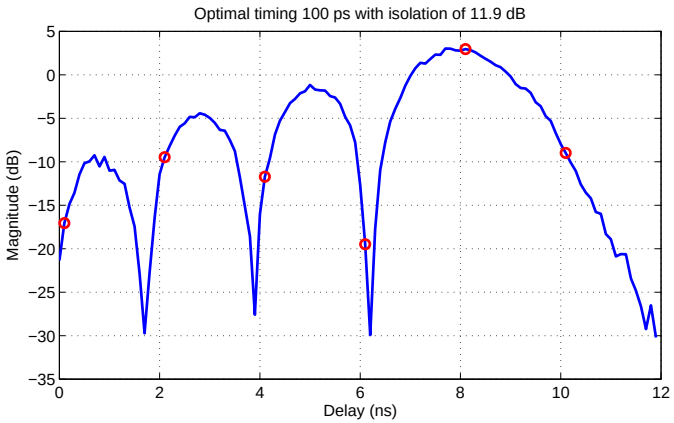
- Drive the single bunch at the betatron frequency;
- Adjust back-end delay;
- Record betatron oscillation magnitude;
- Optimal timing has 11.9 dB isolation;
- Can extract impulse response of the DAC/amplifier/kicker chain.

Vertical Amplifier Response



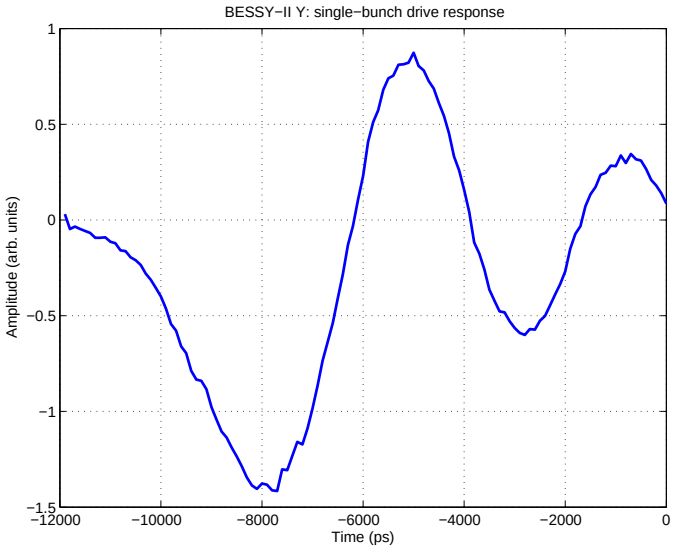
- Drive the single bunch at the betatron frequency;
- Adjust back-end delay;
- Record betatron oscillation magnitude;
- Optimal timing has 11.9 dB isolation;
- Can extract impulse response of the DAC/amplifier/kicker chain.

Vertical Amplifier Response



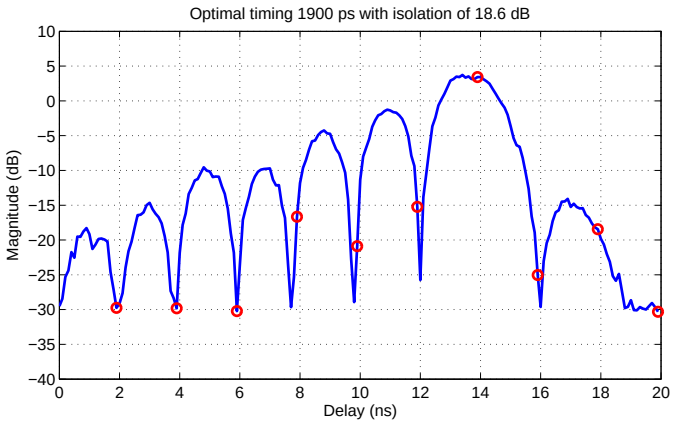
- Drive the single bunch at the betatron frequency;
- Adjust back-end delay;
- Record betatron oscillation magnitude;
- Optimal timing has 11.9 dB isolation;
- Can extract impulse response of the DAC/amplifier/kicker chain.

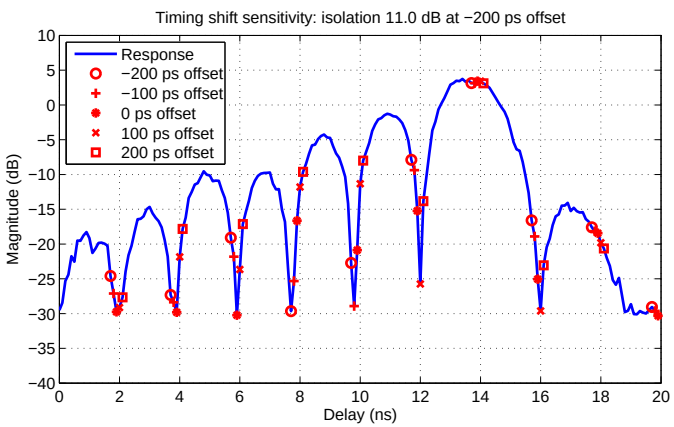
Vertical Amplifier Response



- Drive the single bunch at the betatron frequency;
- Adjust back-end delay;
- Record betatron oscillation magnitude;
- Optimal timing has 11.9 dB isolation;
- Can extract impulse response of the DAC/amplifier/kicker chain.

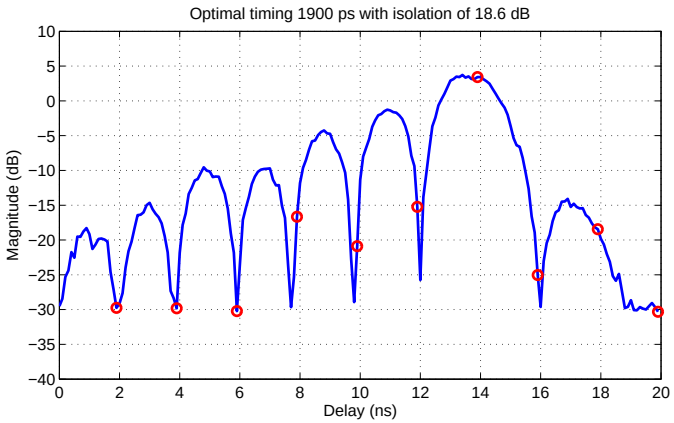
Vertical Amplifier: FIR Shaper

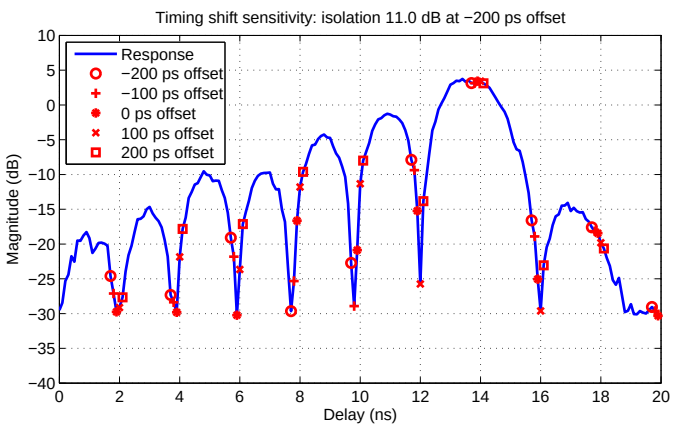




- FIR shaper in iGp12 can pre-distort the kick to correct amplifier/kicker induced coupling;
- Response with shaper FIR [−0.3 1 0.15];
- Isolation improved to 18.6 dB;
- Compare with the impulse response derived signal.

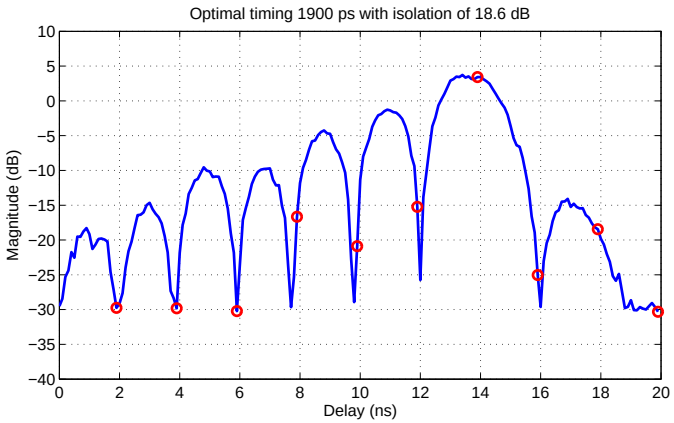
Vertical Amplifier: FIR Shaper

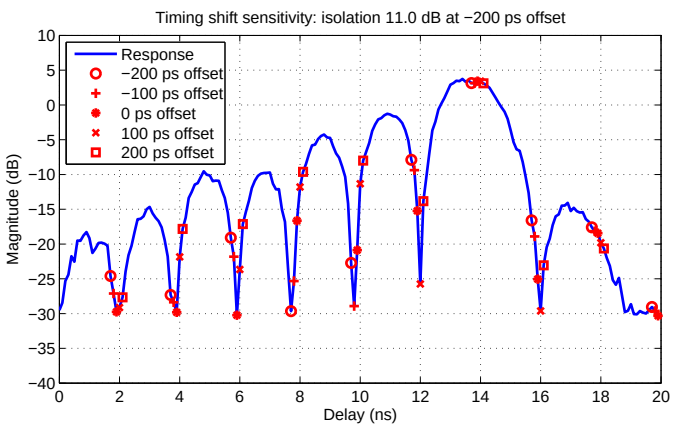




- FIR shaper in iGp12 can pre-distort the kick to correct amplifier/kicker induced coupling;
- Response with shaper FIR $[-0.3 \;\; 1 \;\; 0.15]$;
- Isolation improved to 18.6 dB;
- Compare with the impulse response derived signal.

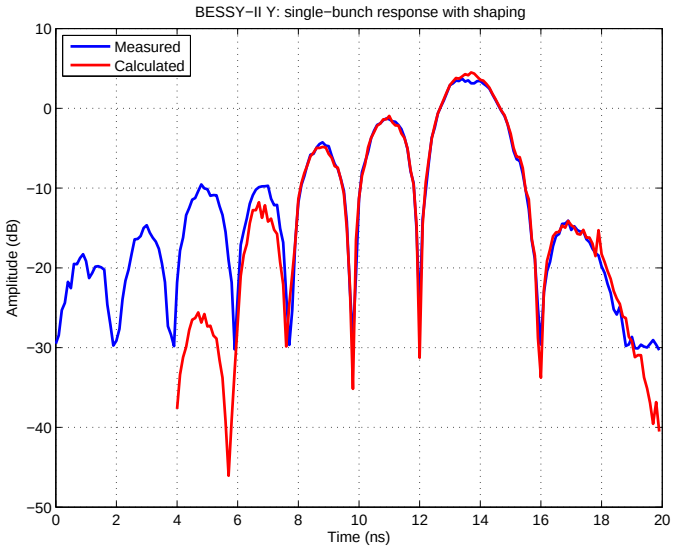
Vertical Amplifier: FIR Shaper





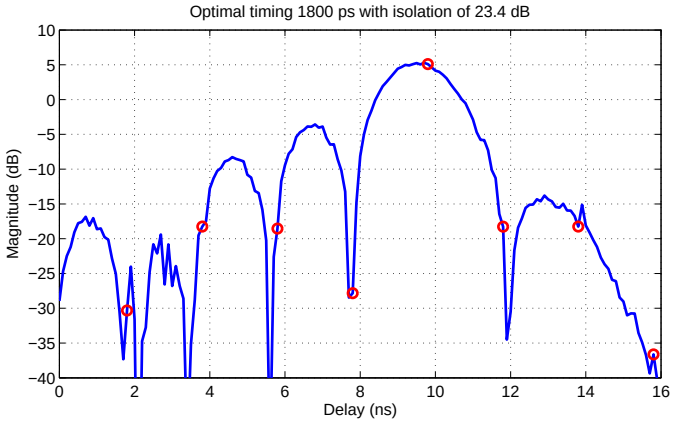
- FIR shaper in iGp12 can pre-distort the kick to correct amplifier/kicker induced coupling;
- Response with shaper FIR $[-0.3 \;\; 1 \;\; 0.15]$;
- Isolation improved to 18.6 dB;
- Compare with the impulse response derived signal.

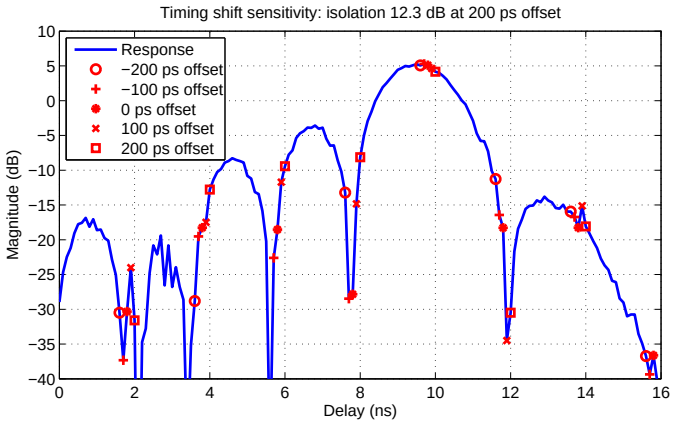
Vertical Amplifier: FIR Shaper



- FIR shaper in iGp12 can pre-distort the kick to correct amplifier/kicker induced coupling;
- Response with shaper FIR $[-0.3 \;\; 1 \;\; 0.15]$;
- Isolation improved to 18.6 dB;
- Compare with the impulse response derived signal.

Vertical Amplifier: Optimized FIR Shaper

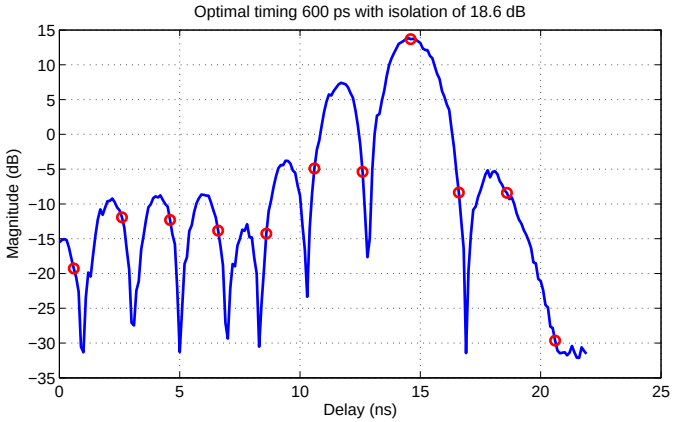


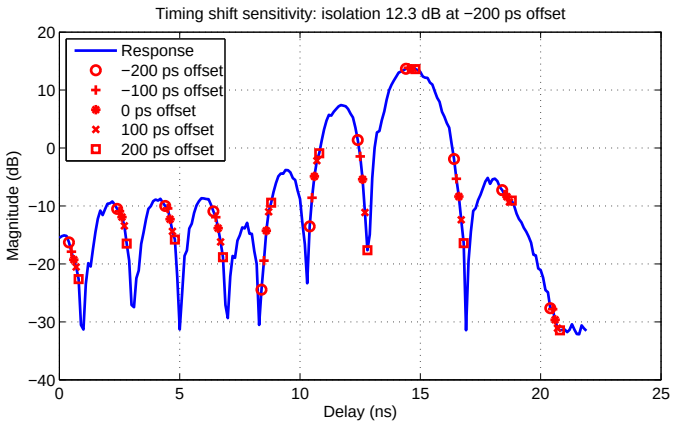


- Using the measured impulse response, optimize shaping coefficients and timing;

Isolation vs. Config	
No shaping	11.9 dB
Empirically optimized	18.6 dB
Numeric optimization	23.4 dB

Horizontal Amplifier: FIR Shaper

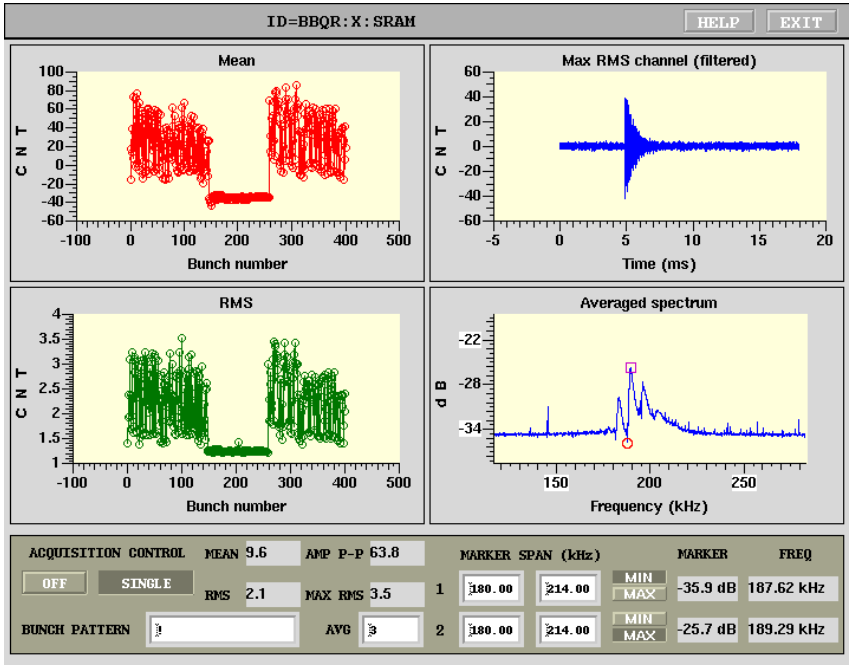




- Performed empirical FIR shaper optimization in X;
- Achieved the same isolation as in Y plane;
- Should redo the timing to get a raw response sweep and optimize.

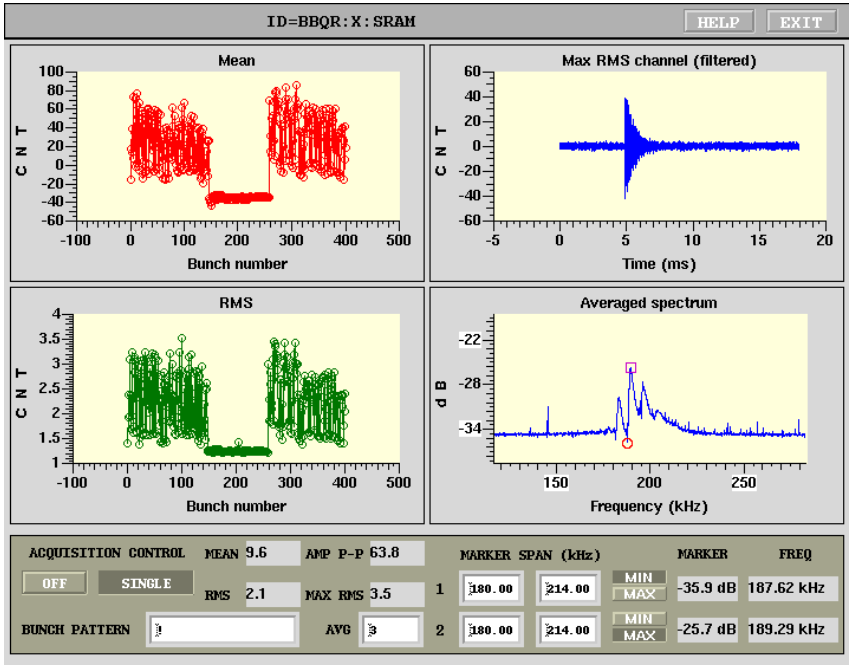
Outline

Injection Transient



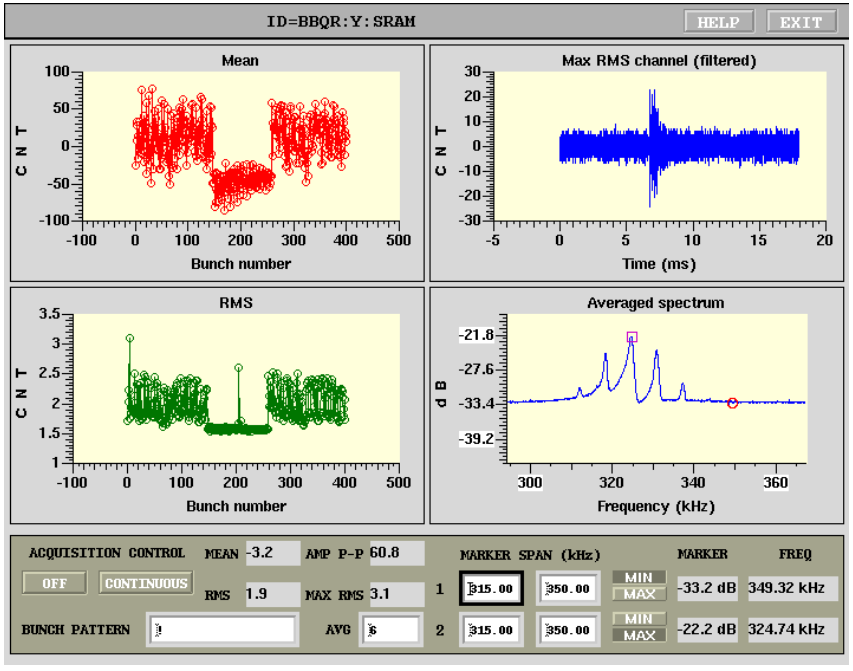
- Injection transient captured on the waveform panel;
- Large excitation in the horizontal plane;
- Visible in the vertical plane as well.

Injection Transient



- Injection transient captured on the waveform panel;
- Large excitation in the horizontal plane;
- Visible in the vertical plane as well.

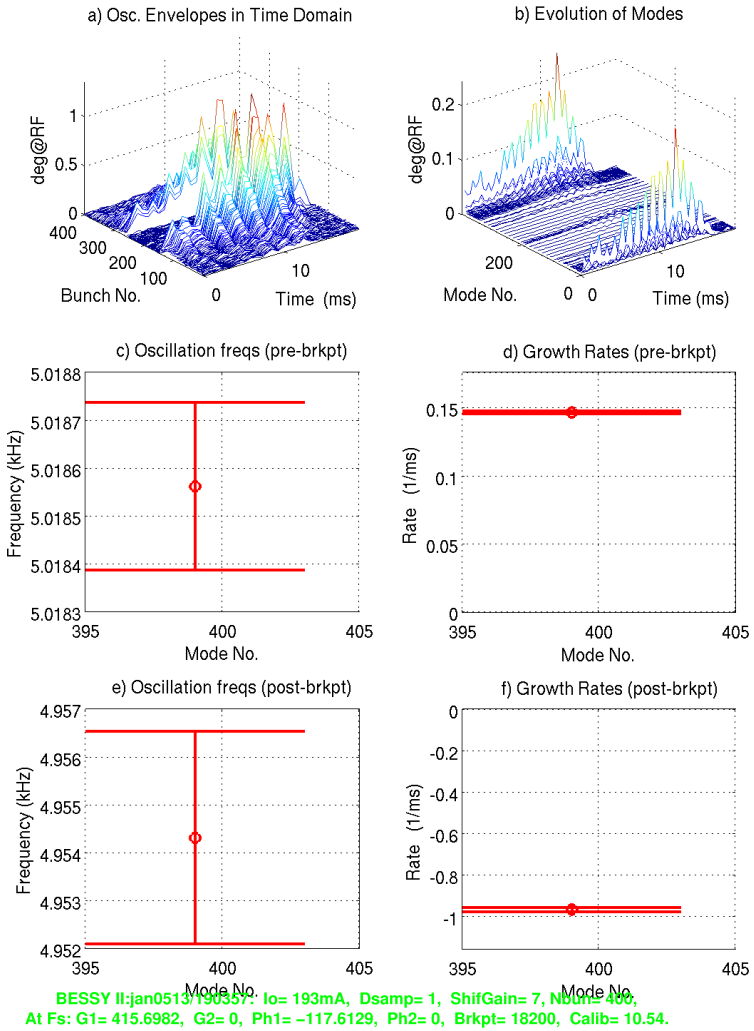
Injection Transient



- Injection transient captured on the waveform panel;
- Large excitation in the horizontal plane;
- Visible in the vertical plane as well.

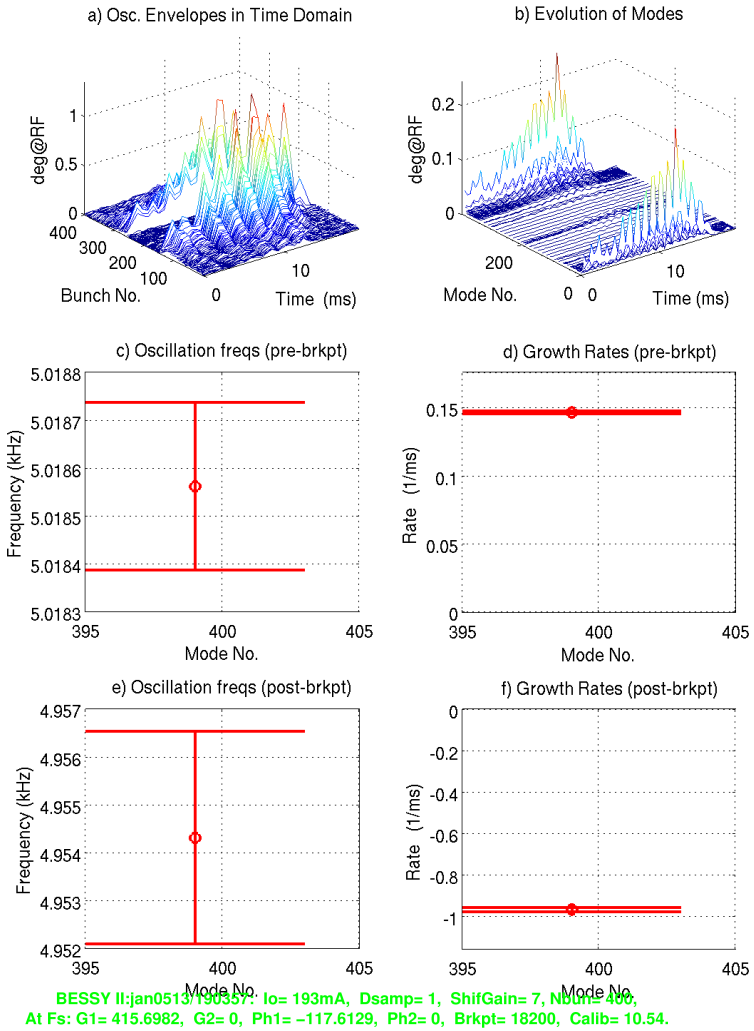
Outline

Longitudinal Grow/Damp Measurement



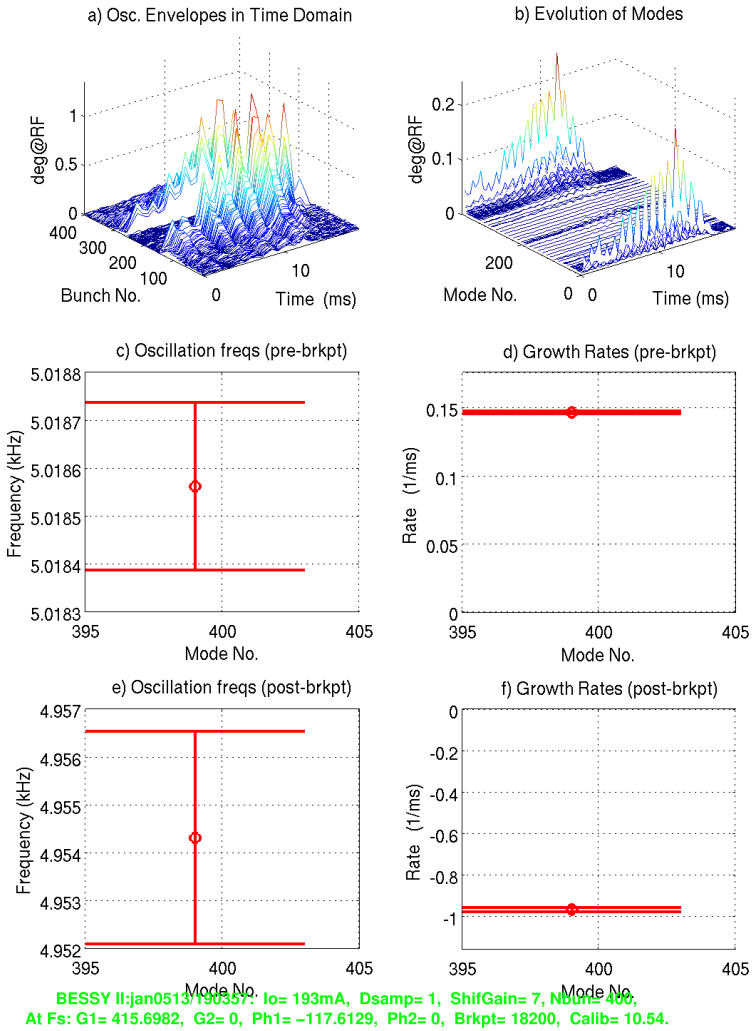
- The beam is longitudinally unstable around 200 mA, stable at 300 mA;
- Open-loop growth shows mode -1 (399);
- Fast feedback damping;
- Beating is due to mode 0 (driven motion) interference.

Longitudinal Grow/Damp Measurement



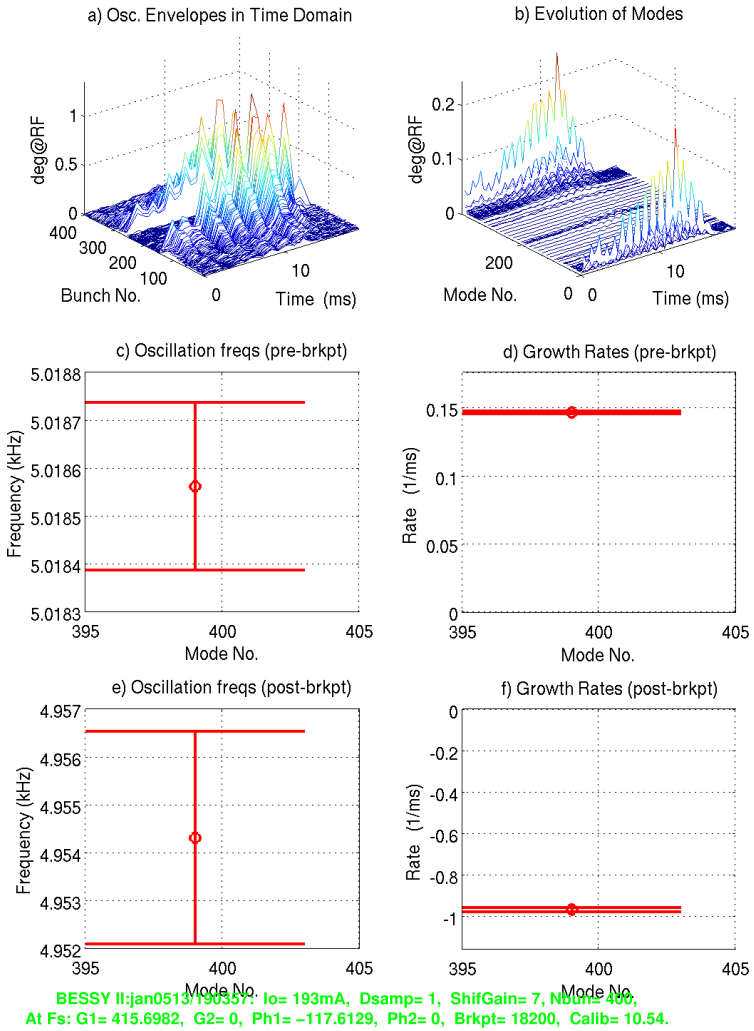
- The beam is longitudinally unstable around 200 mA, stable at 300 mA;
- Open-loop growth shows mode -1 (399);
- Fast feedback damping;
- Beating is due to mode 0 (driven motion) interference.

Longitudinal Grow/Damp Measurement



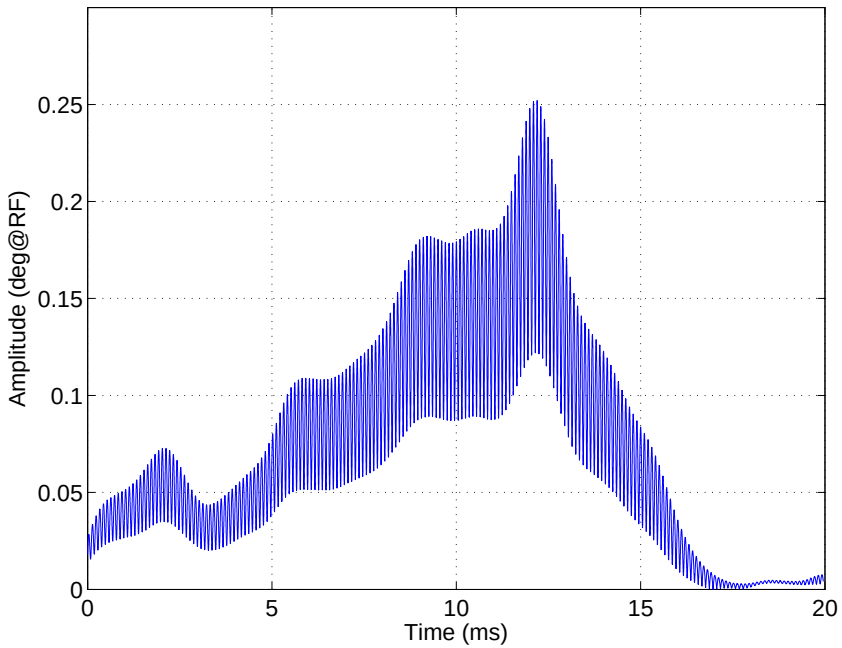
- The beam is longitudinally unstable around 200 mA, stable at 300 mA;
- Open-loop growth shows mode -1 (399);
- Fast feedback damping;
- Beating is due to mode 0 (driven motion) interference.

Longitudinal Grow/Damp Measurement



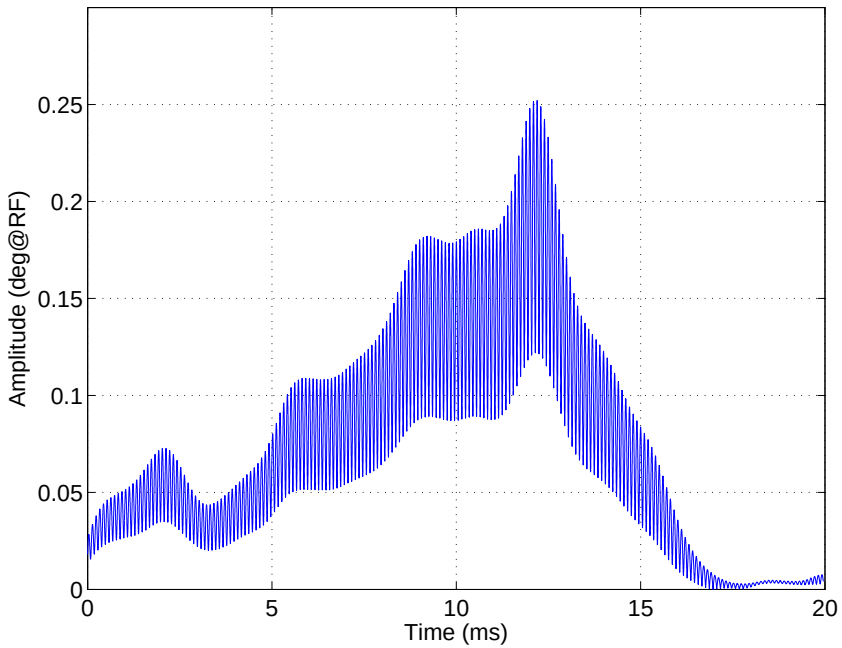
- The beam is longitudinally unstable around 200 mA, stable at 300 mA;
- Open-loop growth shows mode -1 (399);
- Fast feedback damping;
- Beating is due to mode 0 (driven motion) interference.

Separating the Eigenmode



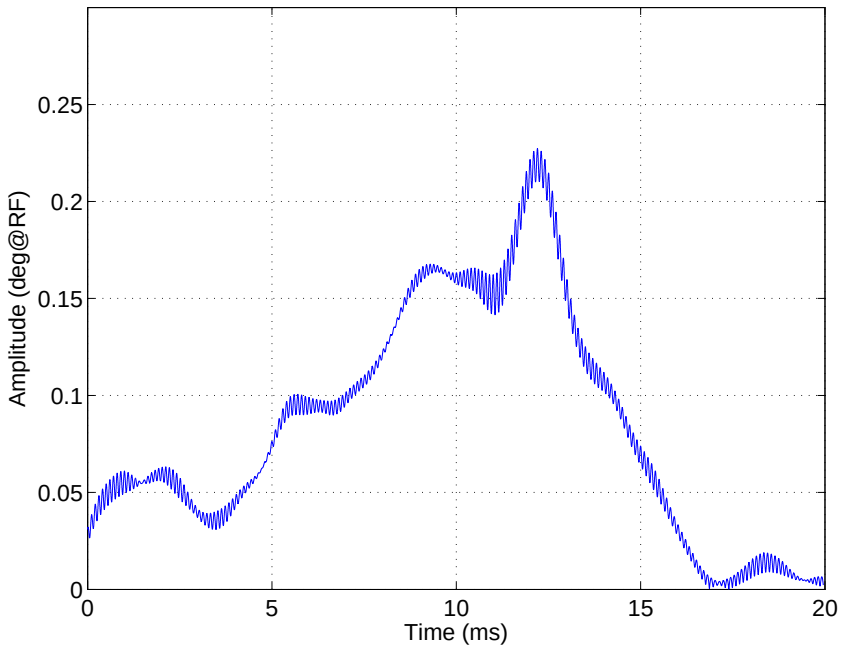
- The beating can be eliminated by transforming to the true eigenmode basis;
- Assume signals in EFEM 0 and 399 are linear combinations of the true eigenmodes;
- A linear combination of these two modes can almost perfectly remove the beating.

Separating the Eigenmode



- The beating can be eliminated by transforming to the true eigenmode basis;
- Assume signals in EFEM 0 and 399 are linear combinations of the true eigenmodes;
- A linear combination of these two modes can almost perfectly remove the beating.

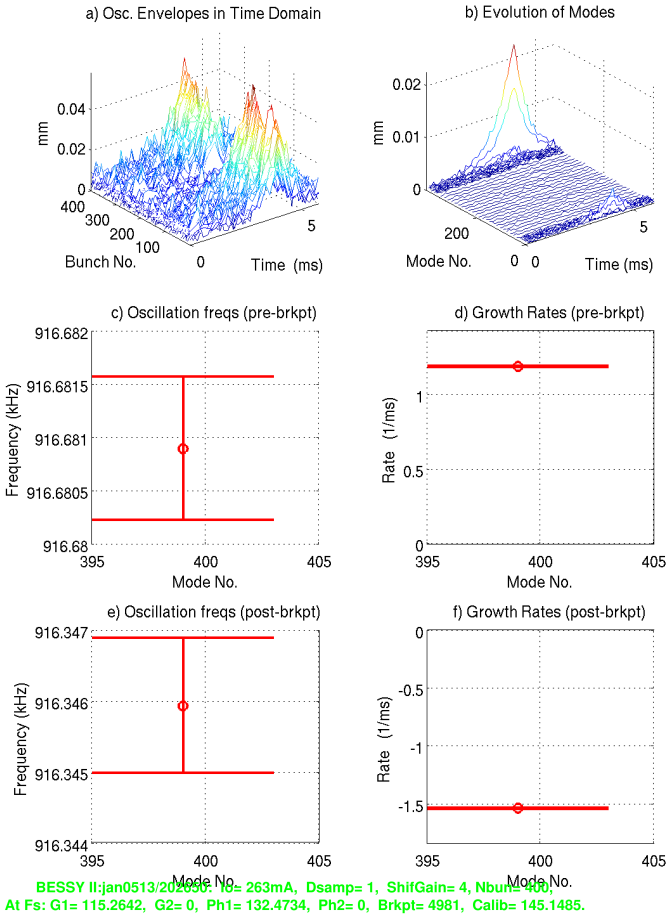
Separating the Eigenmode



- The beating can be eliminated by transforming to the true eigenmode basis;
- Assume signals in EFEM 0 and 399 are linear combinations of the true eigenmodes;
- A linear combination of these two modes can almost perfectly remove the beating.

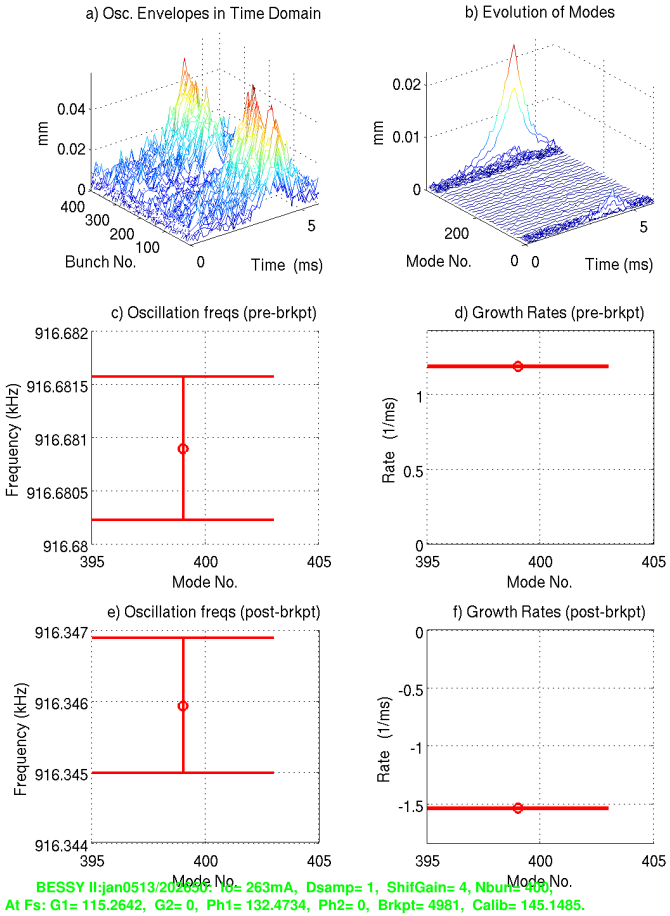
Outline

A Vertical Grow/Damp Measurement



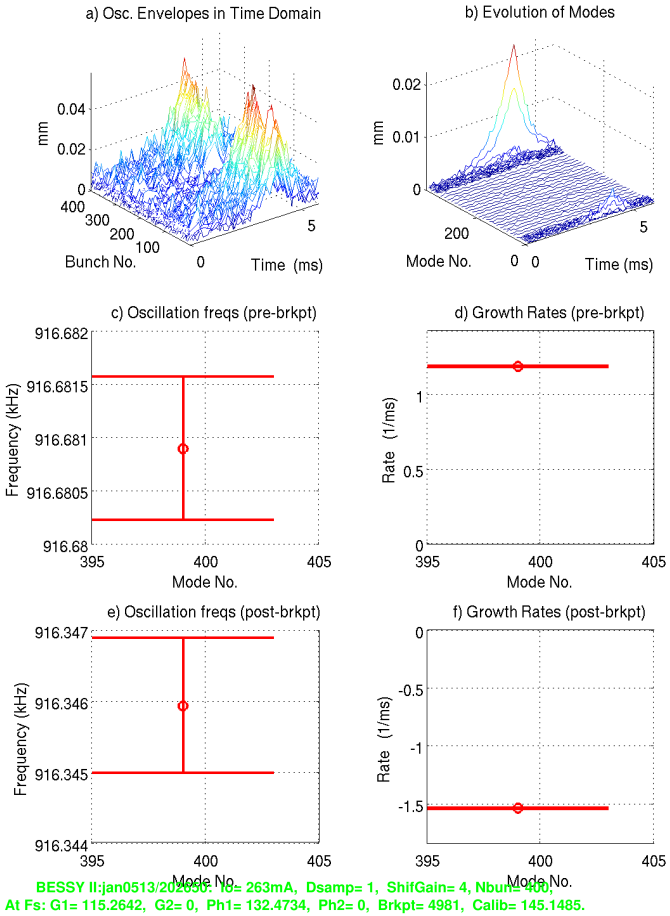
- The beam is transversely stable at nominal chromaticity;
- Vertical grow/damp at -3.0 units, 263 mA, no camshaft;
- Modes -1 — typical resistive wall;
- Excellent fit in both open and closed loop.

A Vertical Grow/Damp Measurement



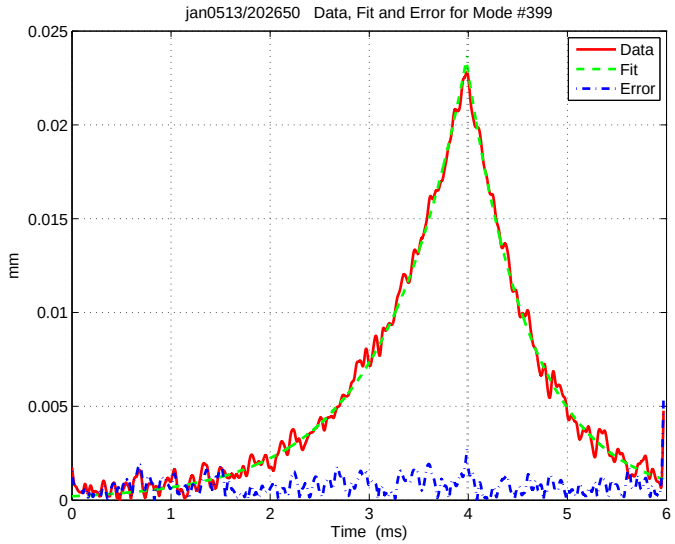
- The beam is transversely stable at nominal chromaticity;
- Vertical grow/damp at -3.0 units, 263 mA, no camshaft;
- Modes -1 — typical resistive wall;
- Excellent fit in both open and closed loop.

A Vertical Grow/Damp Measurement



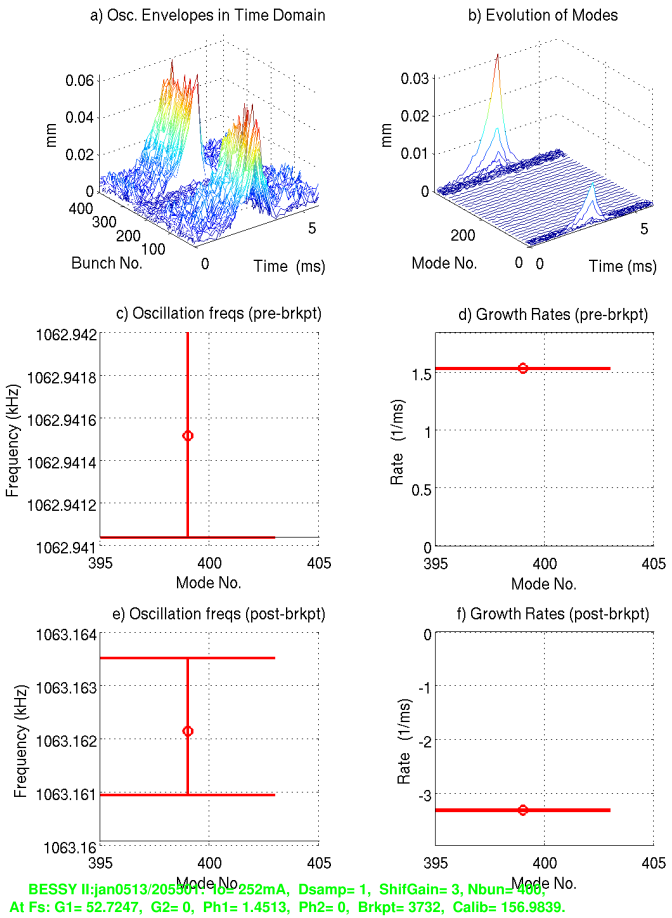
- The beam is transversely stable at nominal chromaticity;
- Vertical grow/damp at -3.0 units, 263 mA, no camshaft;
- Modes -1 — typical resistive wall;
- Excellent fit in both open and closed loop.

A Vertical Grow/Damp Measurement



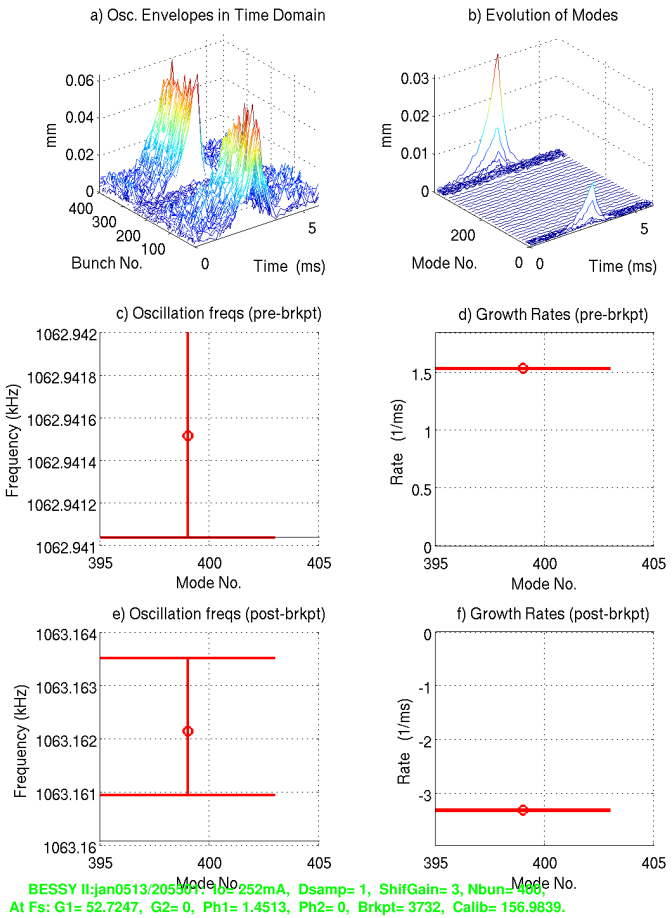
- The beam is transversely stable at nominal chromaticity;
- Vertical grow/damp at -3.0 units, 263 mA, no camshaft;
- Modes -1 — typical resistive wall;
- Excellent fit in both open and closed loop.

A Horizontal Grow/Damp Measurement



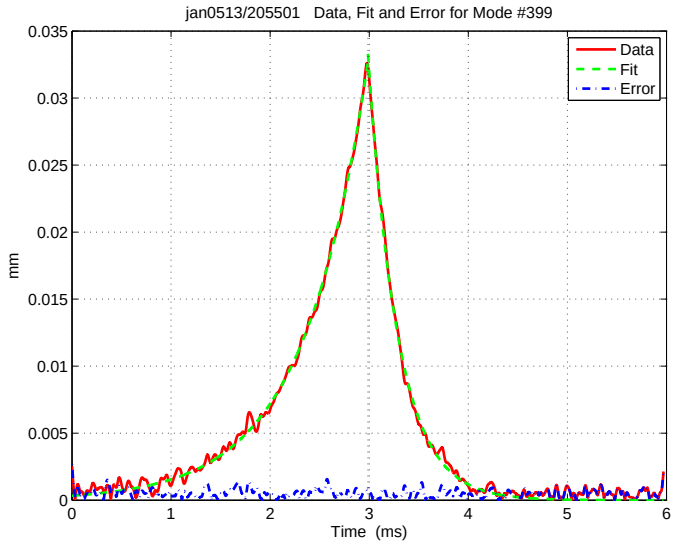
- Horizontal grow/damp at -3.0 units, 245 mA, no camshaft;
- Modes -1;
- Very fast damping.

A Horizontal Grow/Damp Measurement



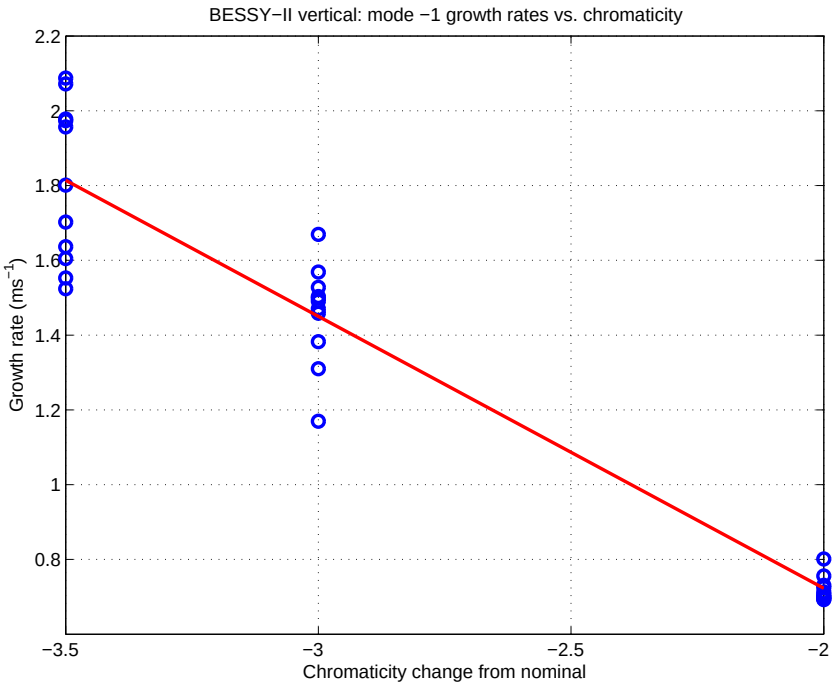
- Horizontal grow/damp at -3.0 units, 245 mA, no camshaft;
- Modes -1;
- Very fast damping.

A Horizontal Grow/Damp Measurement



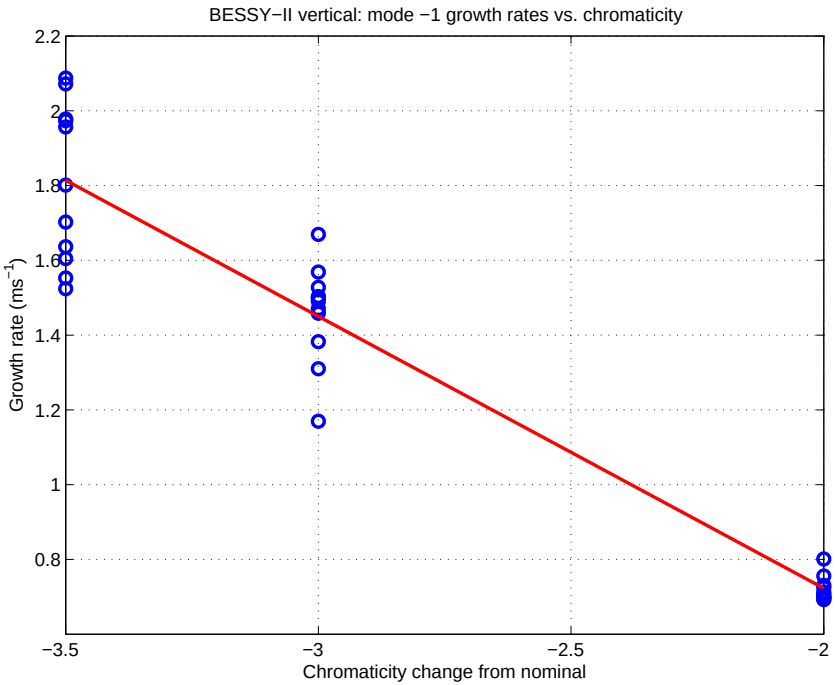
- Horizontal grow/damp at -3.0 units, 245 mA, no camshaft;
- Modes -1;
- Very fast damping.

Vertical Growth Rates vs. Chromaticity



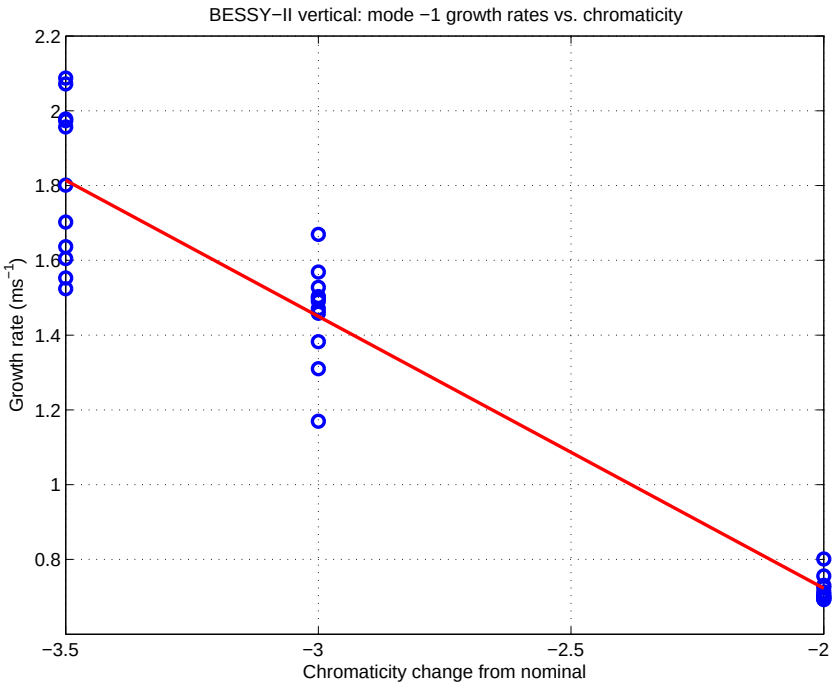
- Automated analysis of multiple data sets;
- More or less linear growth rate increase with chromaticity;
- Not corrected for beam current variation;
- Growth rates are well within the range of the feedback system.

Vertical Growth Rates vs. Chromaticity



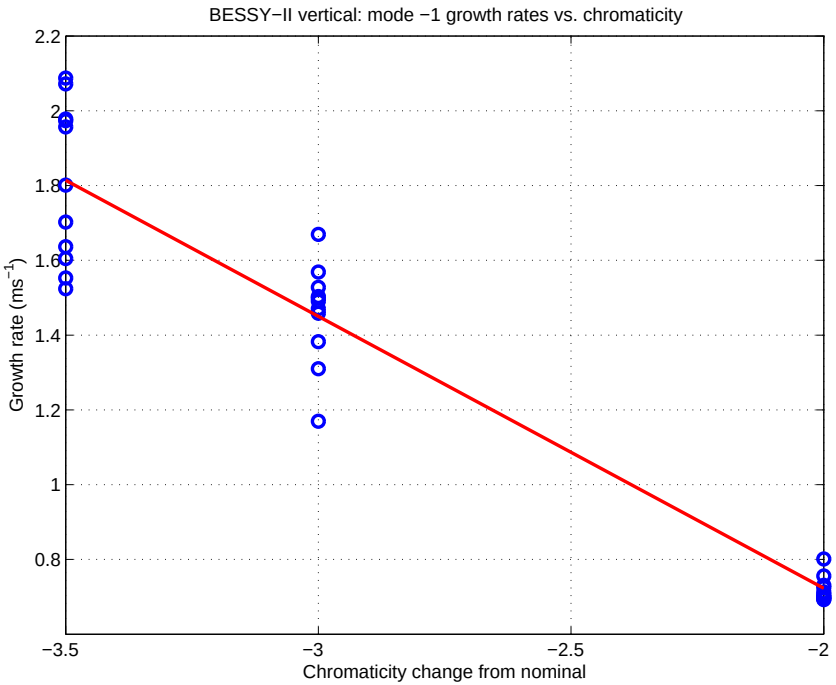
- Automated analysis of multiple data sets;
- More or less linear growth rate increase with chromaticity;
- Not corrected for beam current variation;
- Growth rates are well within the range of the feedback system.

Vertical Growth Rates vs. Chromaticity



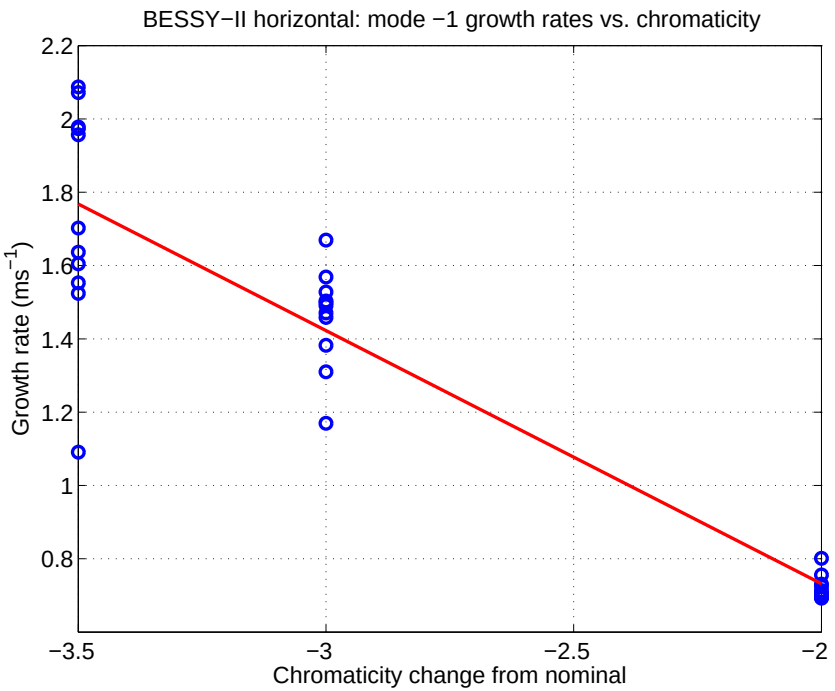
- Automated analysis of multiple data sets;
- More or less linear growth rate increase with chromaticity;
- Not corrected for beam current variation;
- Growth rates are well within the range of the feedback system.

Vertical Growth Rates vs. Chromaticity



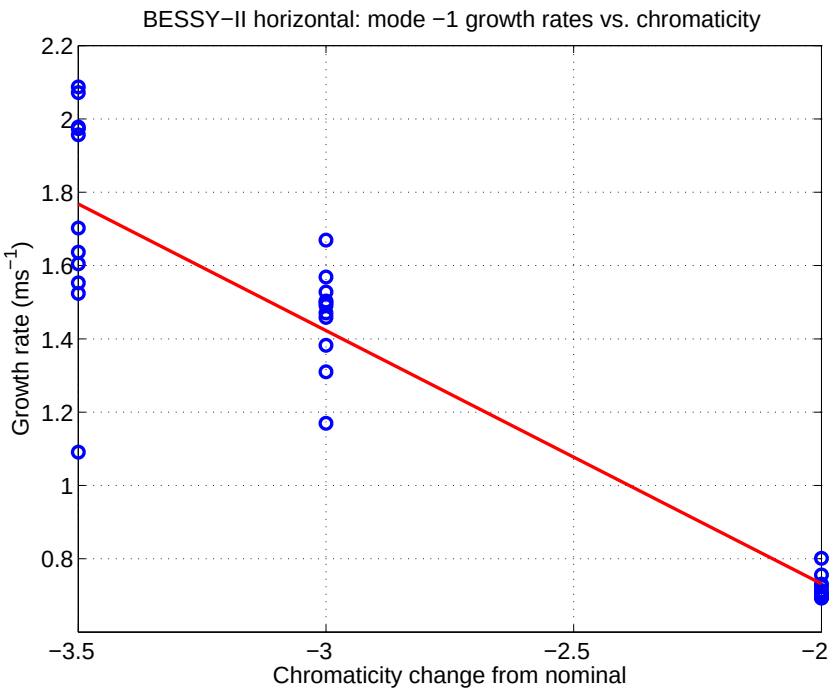
- Automated analysis of multiple data sets;
- More or less linear growth rate increase with chromaticity;
- Not corrected for beam current variation;
- Growth rates are well within the range of the feedback system.

Horizontal Growth Rates vs. Chromaticity



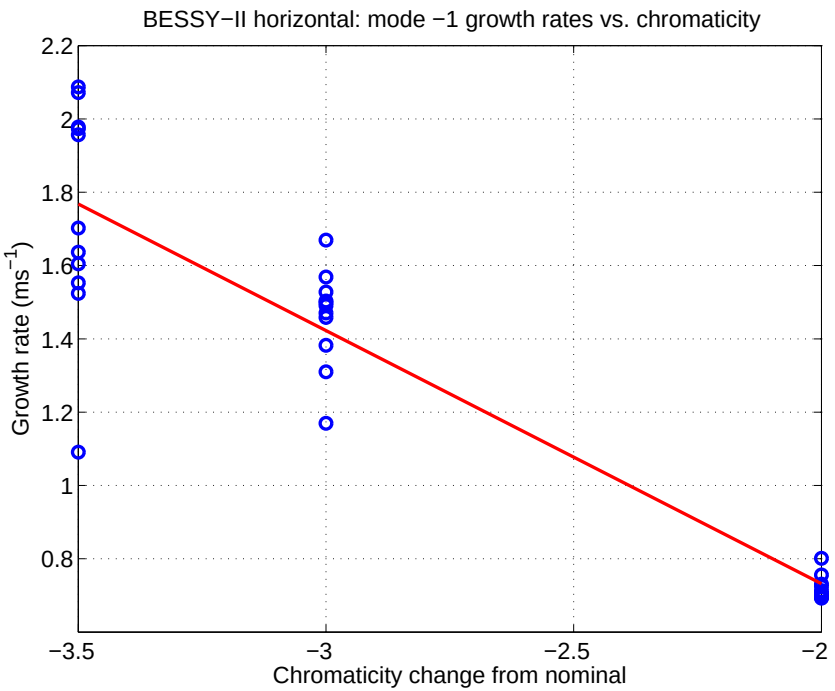
- Automated analysis of multiple data sets, no cleanup;
- More or less linear growth rate increase with chromaticity;
- Not corrected for beam current variation;
- Growth rates are well within the range of the feedback system.

Horizontal Growth Rates vs. Chromaticity



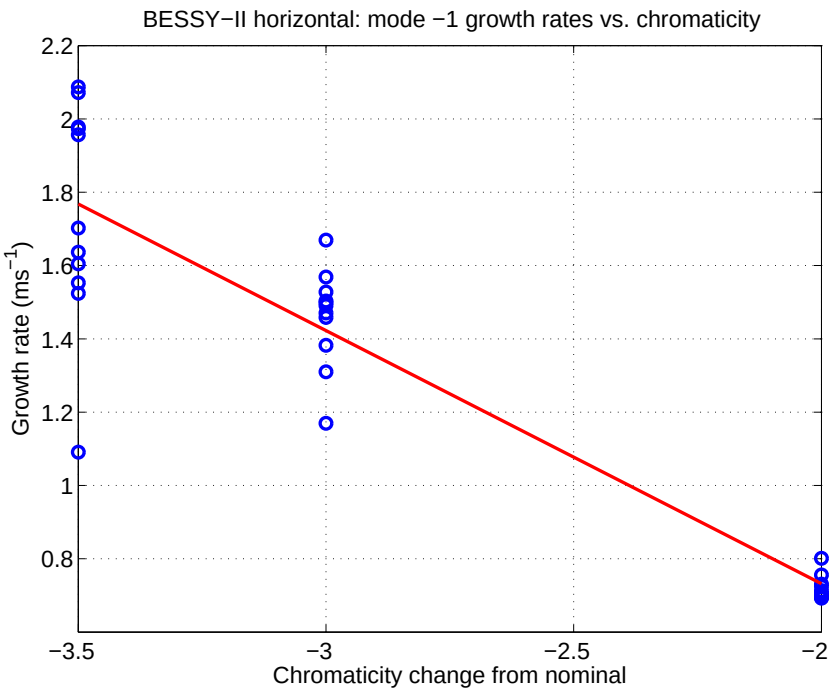
- Automated analysis of multiple data sets, no cleanup;
- More or less linear growth rate increase with chromaticity;
- Not corrected for beam current variation;
- Growth rates are well within the range of the feedback system.

Horizontal Growth Rates vs. Chromaticity



- Automated analysis of multiple data sets, no cleanup;
- More or less linear growth rate increase with chromaticity;
- Not corrected for beam current variation;
- Growth rates are well within the range of the feedback system.

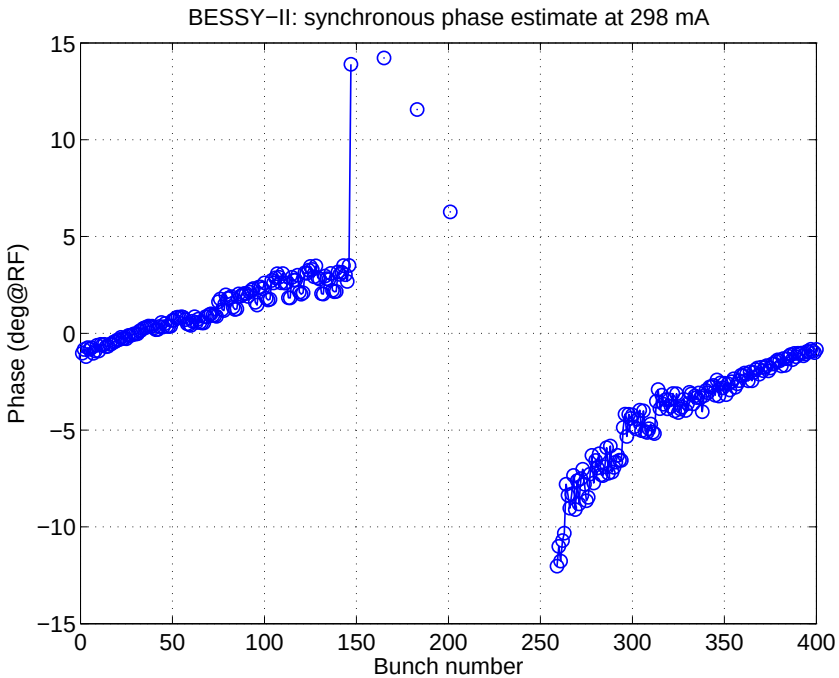
Horizontal Growth Rates vs. Chromaticity



- Automated analysis of multiple data sets, no cleanup;
- More or less linear growth rate increase with chromaticity;
- Not corrected for beam current variation;
- Growth rates are well within the range of the feedback system.

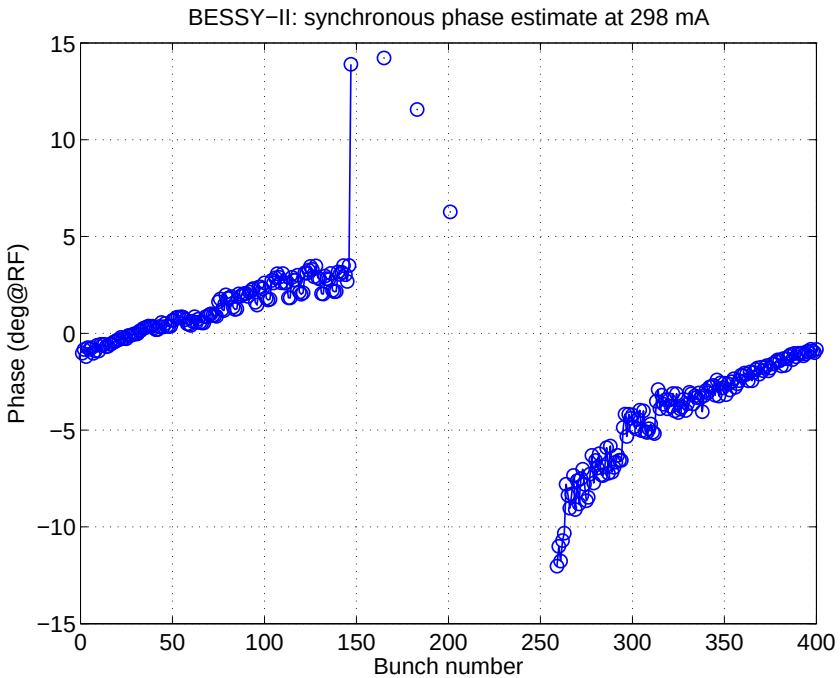
Outline

Synchronous Phase Transient



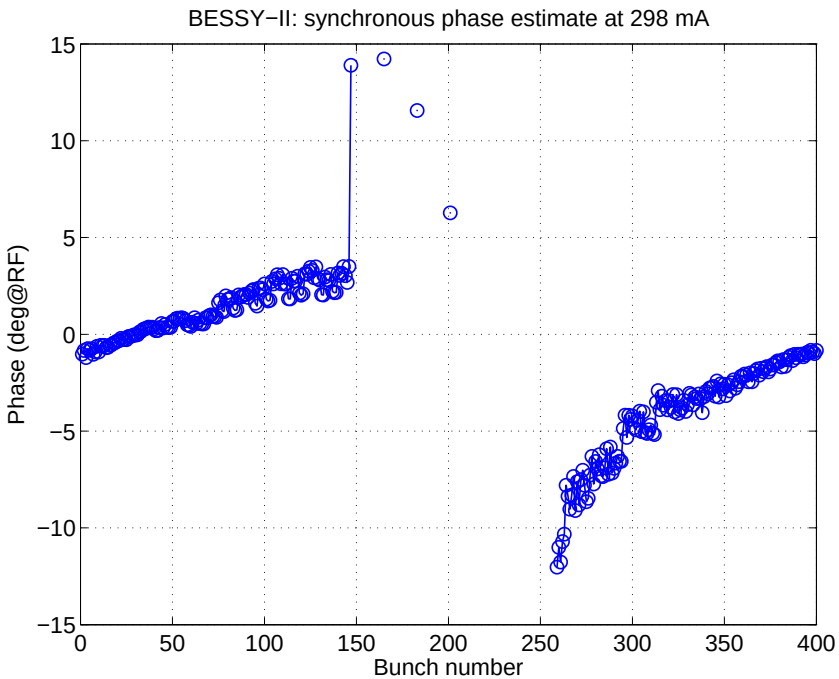
- Computed from a closed-loop measurement right after injection to 300 mA;
- Fill pattern estimated as 5 mA in each camshaft bunch, 278 mA in the train;
- Large transient of 26° peak-to-peak.

Synchronous Phase Transient



- Computed from a closed-loop measurement right after injection to 300 mA;
- Fill pattern estimated as 5 mA in each camshaft bunch, 278 mA in the train;
- Large transient of 26° peak-to-peak.

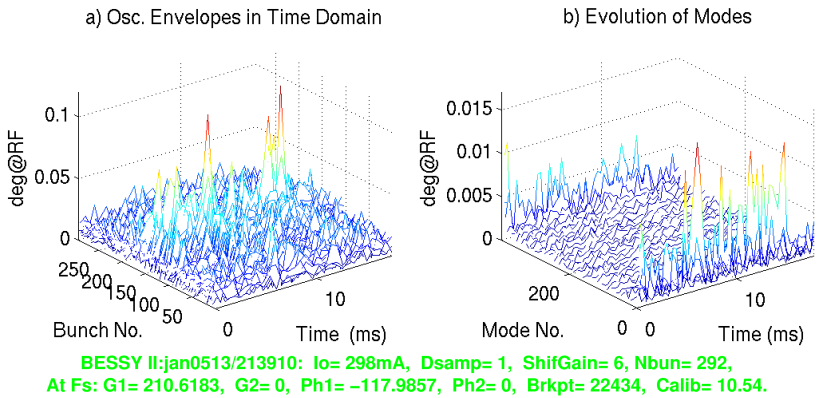
Synchronous Phase Transient

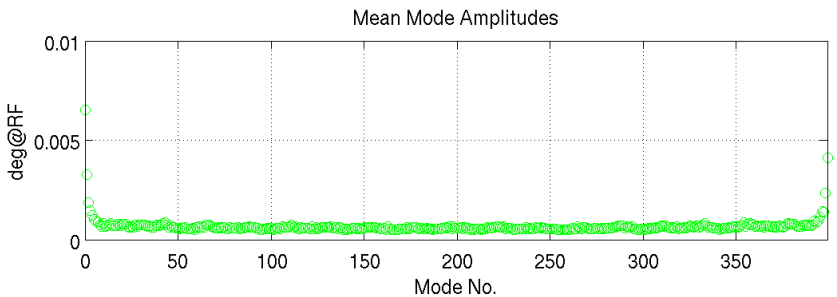


- Computed from a closed-loop measurement right after injection to 300 mA;
- Fill pattern estimated as 5 mA in each camshaft bunch, 278 mA in the train;
- Large transient of 26° peak-to-peak.

Outline

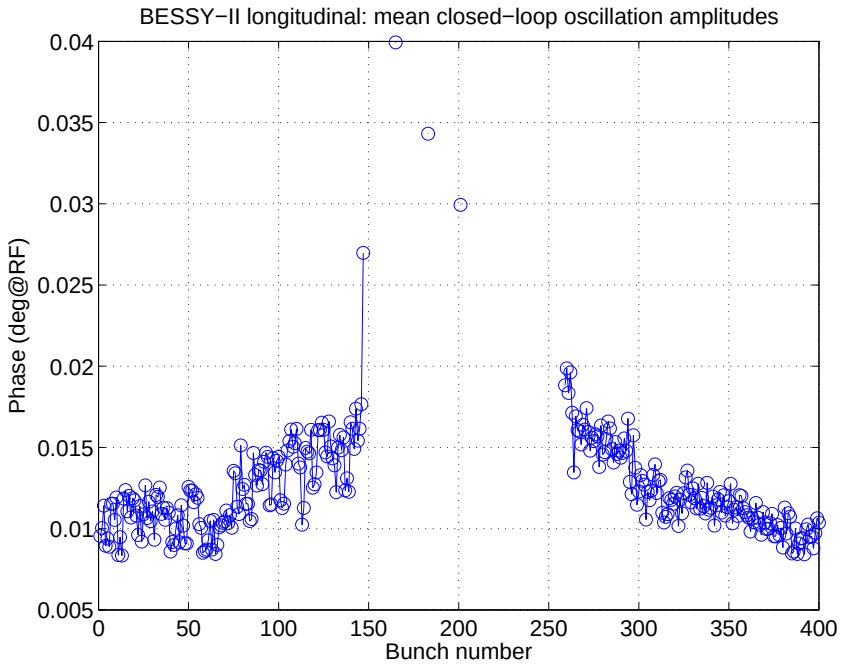
Longitudinal Plane





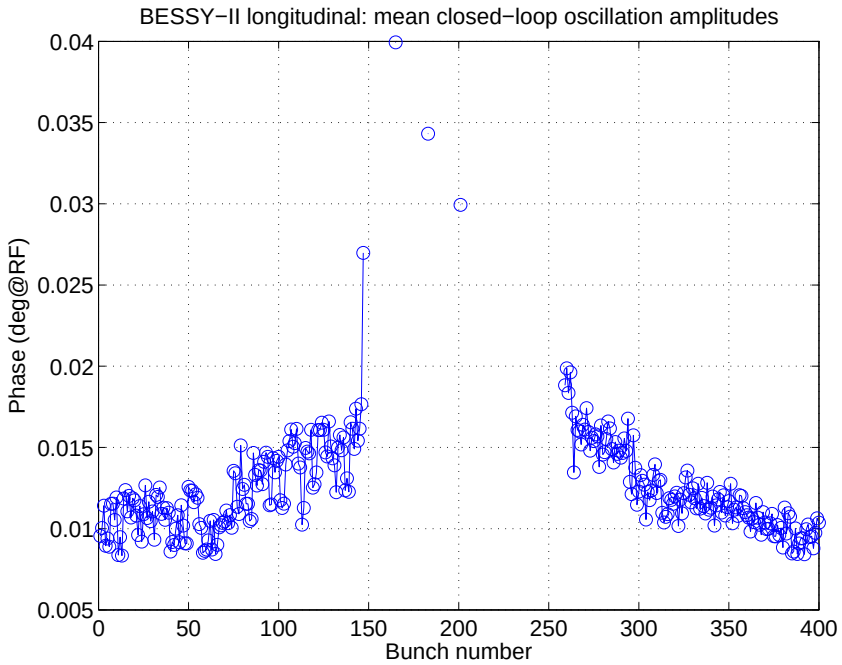
- Filtered with 3 dB bandwidth 3.95–6.25 kHz;
- 0.013° mean, 0.016° RMS, 0.28° peak;
- Variation is consistent with the loop gain loss due to the synchronous phase transient.

Longitudinal Plane



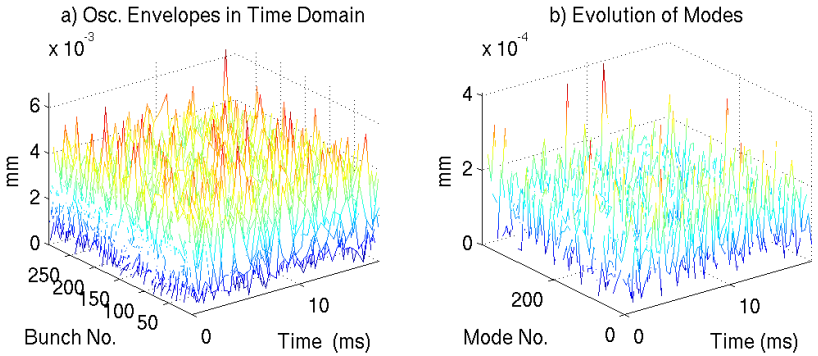
- Filtered with 3 dB bandwidth 3.95–6.25 kHz;
- 0.013° mean, 0.016° RMS, 0.28° peak;
- Variation is consistent with the loop gain loss due to the synchronous phase transient.

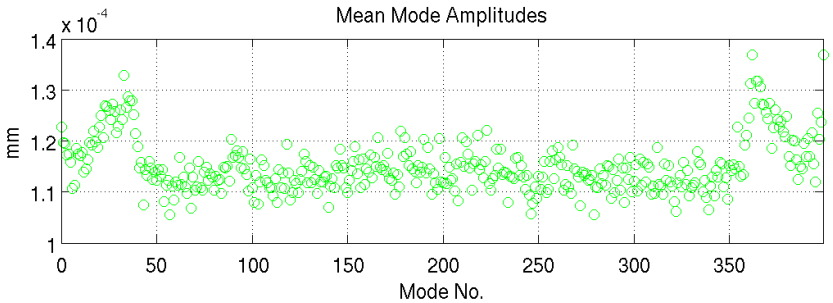
Longitudinal Plane



- Filtered with 3 dB bandwidth 3.95–6.25 kHz;
- 0.013° mean, 0.016° RMS, 0.28° peak;
- Variation is consistent with the loop gain loss due to the synchronous phase transient.

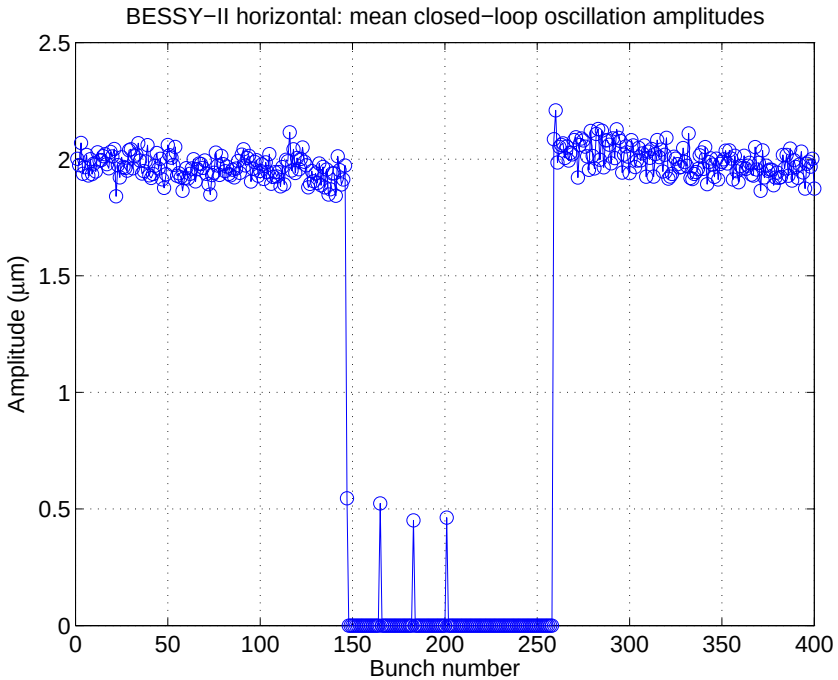
Horizontal Plane





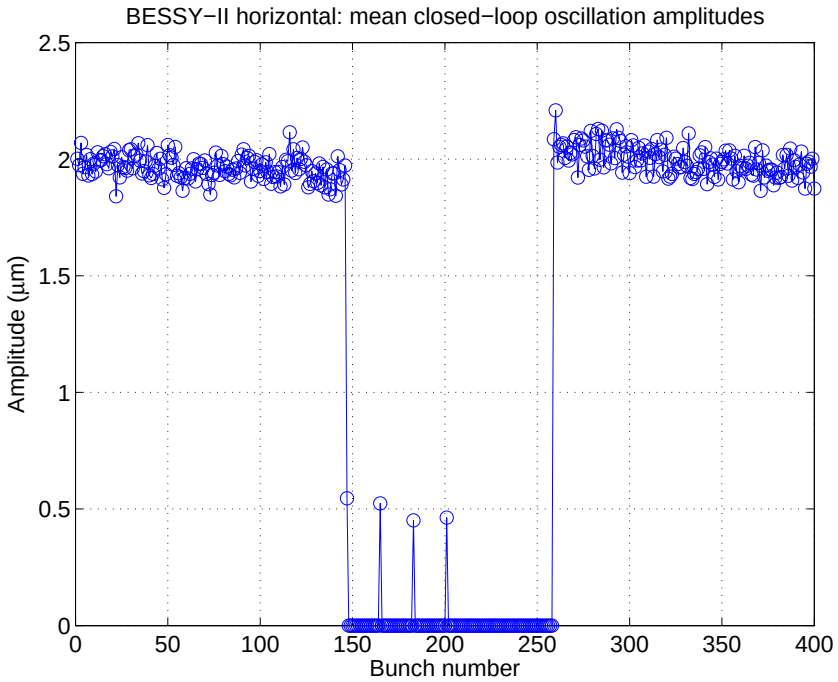
- Transversely, closed-loop data underestimates the true residual amplitudes;
- Filtered with 3 dB bandwidth 174–192 kHz;
- 2 μm mean, 2.2 μm RMS, 8.5 μm peak;
- More indicative of the ADC quantization noise floor, scaled by the bunch current.

Horizontal Plane



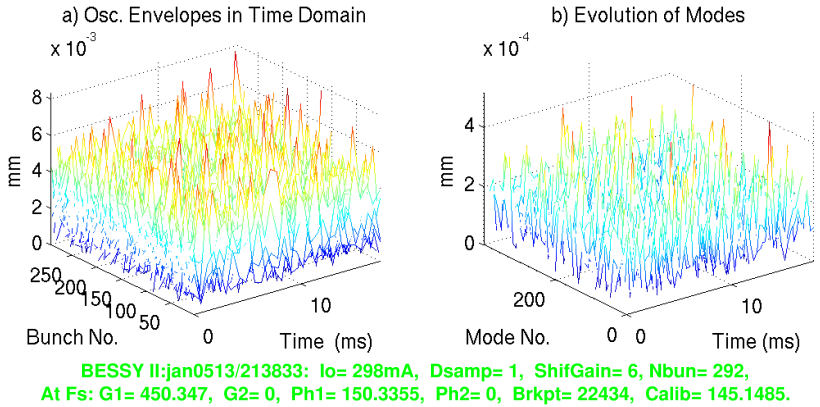
- Transversely, closed-loop data underestimates the true residual amplitudes;
- Filtered with 3 dB bandwidth 174–192 kHz;
- 2 μm mean, 2.2 μm RMS, 8.5 μm peak;
- More indicative of the ADC quantization noise floor, scaled by the bunch current.

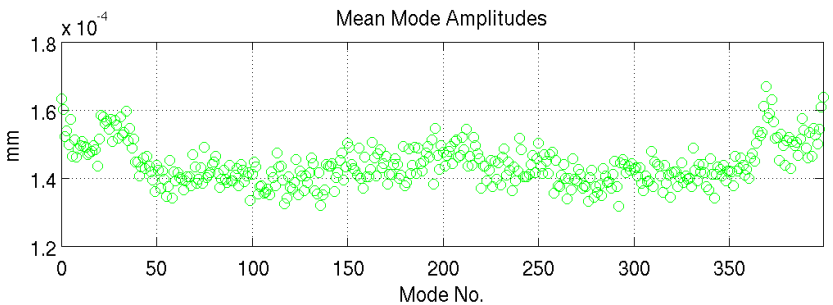
Horizontal Plane



- Transversely, closed-loop data underestimates the true residual amplitudes;
- Filtered with 3 dB bandwidth 174–192 kHz;
- 2 μm mean, 2.2 μm RMS, 8.5 μm peak;
- More indicative of the ADC quantization noise floor, scaled by the bunch current.

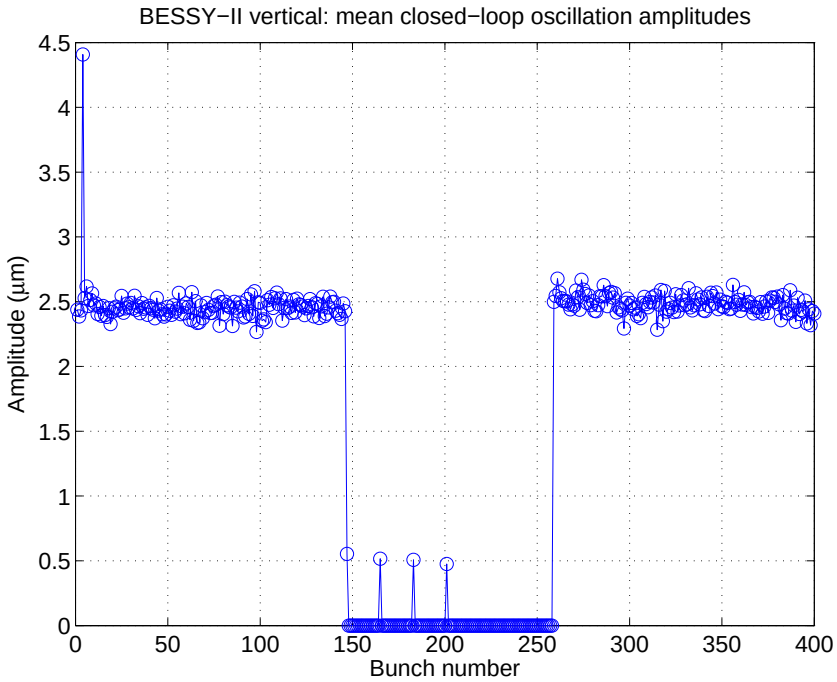
Vertical Plane





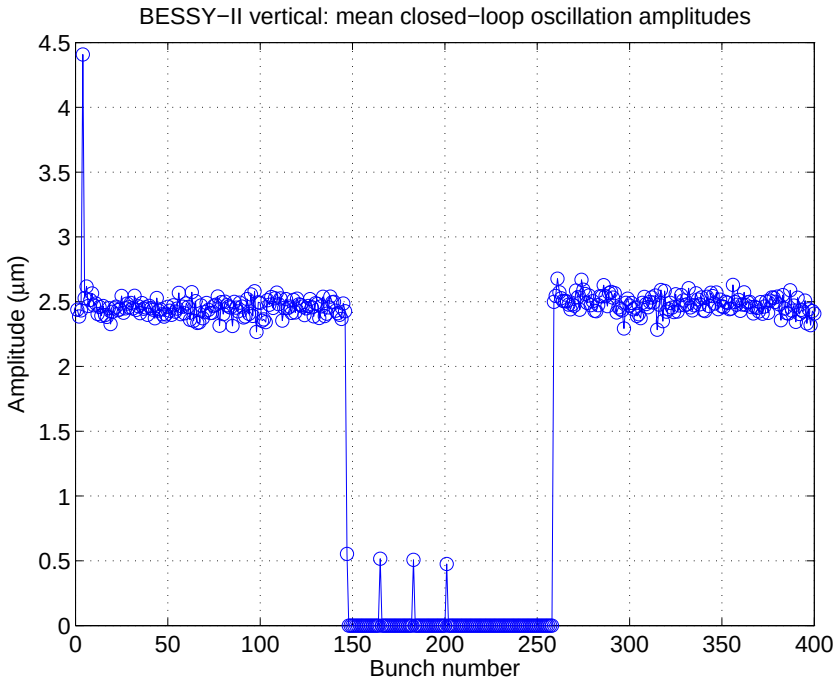
- Filtered with 3 dB bandwidth 323–341 kHz;
- 2.5 μm mean, 2.8 μm RMS, 14.7 μm peak;
- Bunch 4 stands out due to the fiducial jitter coupling.

Vertical Plane



- Filtered with 3 dB bandwidth 323–341 kHz;
- 2.5 μm mean, 2.8 μm RMS, 14.7 μm peak;
- Bunch 4 stands out due to the fiducial jitter coupling.

Vertical Plane



- Filtered with 3 dB bandwidth 323–341 kHz;
- 2.5 μm mean, 2.8 μm RMS, 14.7 μm peak;
- Bunch 4 stands out due to the fiducial jitter coupling.

Summary

- Successfully commissioned bunch-by-bunch feedback in all three planes;
- Strong feedback opens possibilities for lowering chromaticities, changing fill patterns, etc.
- Expect the operating regimes and configurations to evolve with experience and machine requirements.

Summary

- Successfully commissioned bunch-by-bunch feedback in all three planes;
- Strong feedback opens possibilities for lowering chromaticities, changing fill patterns, etc.
- Expect the operating regimes and configurations to evolve with experience and machine requirements.

Summary

- Successfully commissioned bunch-by-bunch feedback in all three planes;
- Strong feedback opens possibilities for lowering chromaticities, changing fill patterns, etc.
- Expect the operating regimes and configurations to evolve with experience and machine requirements.