

Bunch-by-bunch feedback commissioning at BESSY-II

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al.

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January 8–11, 2013



Outline

- 1 **Hardware Setup**
 - System Installation
- 2 Timing and Calibration
 - Calibration
 - Transverse Power Amplifier Setup
- 3 Beam Studies
 - Injection Transient
 - Longitudinal Grow/Damp Measurement
 - Transverse Grow/Damp Measurements
 - Synchronous Phase Transient
 - Steady-state Residual Motion



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.

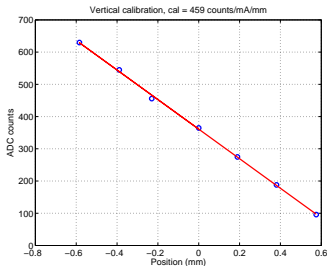
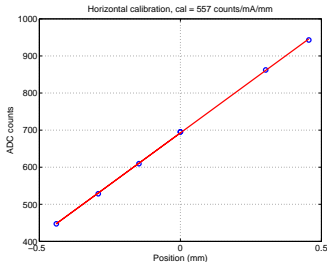


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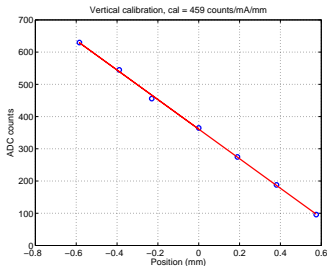
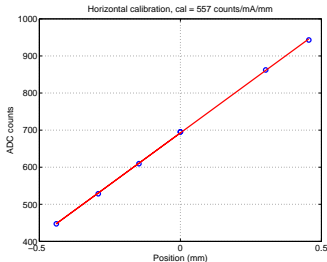
Front-end Calibration: Transverse Plane



- 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).



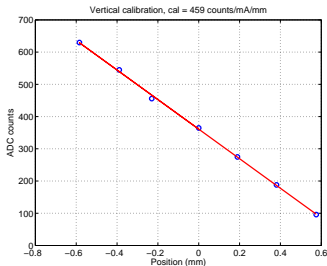
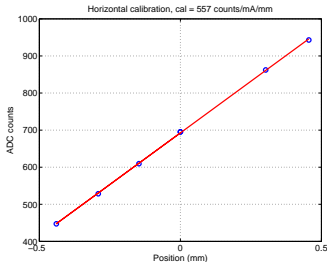
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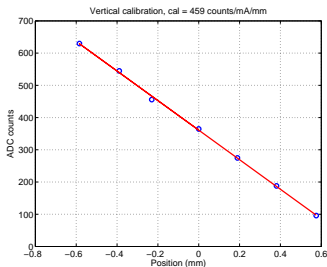
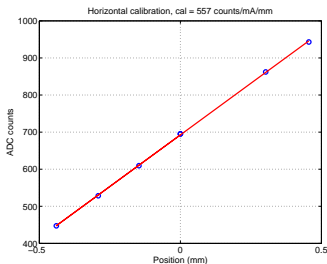
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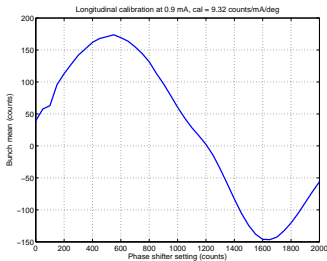


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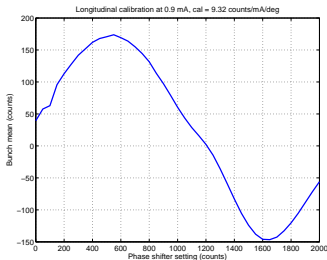
Longitudinal Calibration



- 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).



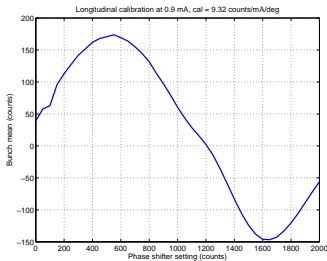
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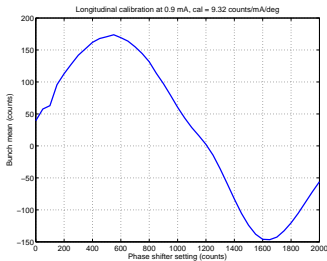
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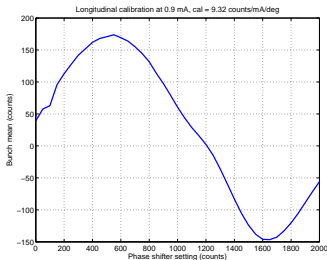
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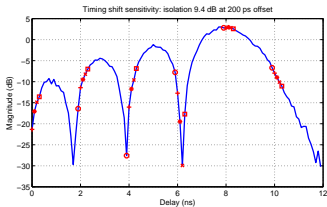
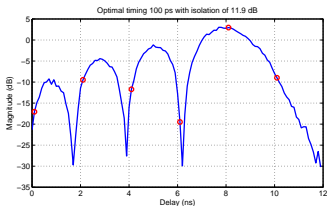


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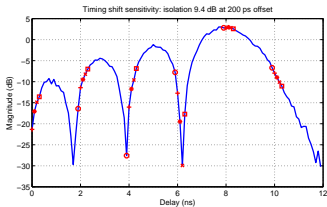
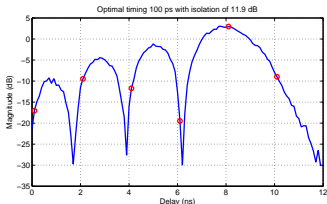


Vertical Amplifier Response



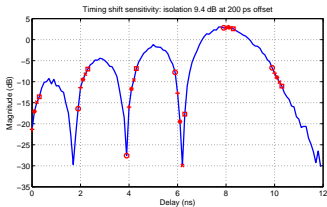
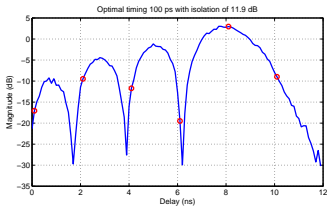
- Drive the single bunch at the betatron frequency;
- Adjust back-end delay;
- Record betatron oscillation magnitude;
- Optimal timing has 11.9 dB isolation;
- Can extract impulse response of the DAC/amplifier/kicker chain.

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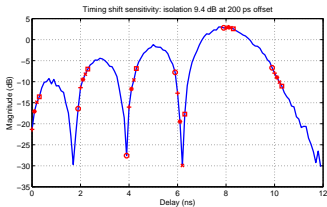
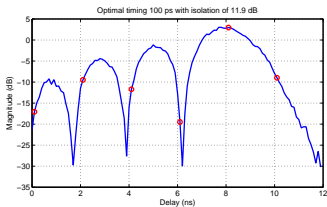
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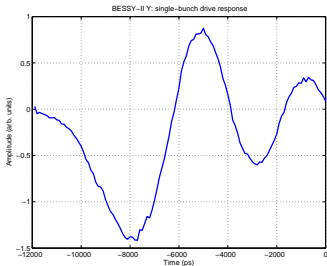
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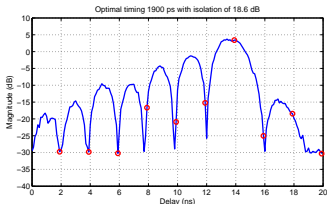
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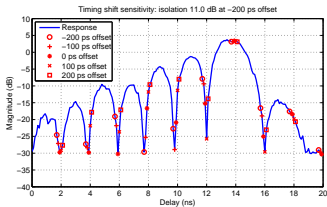


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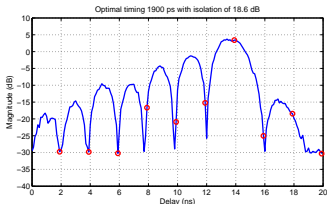
Vertical Amplifier: FIR Shaper



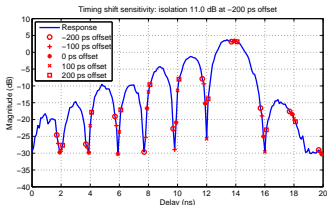
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- Response with shaper FIR $[-0.3 \ 1 \ 0.15]$;
- Isolation improved to 18.6 dB;
- Compare with the impulse response derived signal.



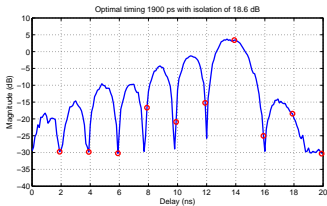
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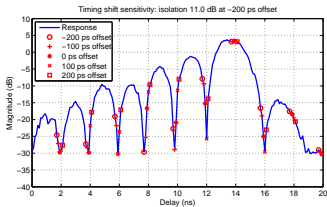
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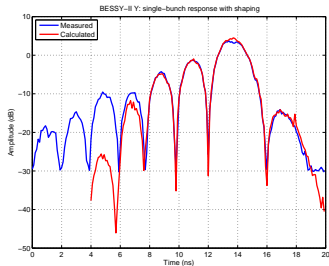
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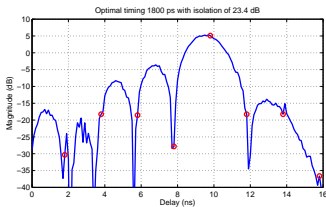


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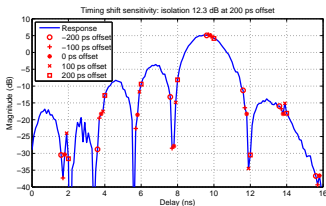
Vertical Amplifier: Optimized FIR Shaper



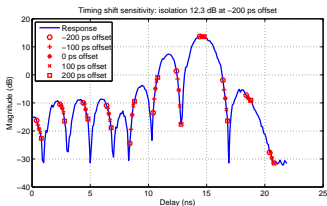
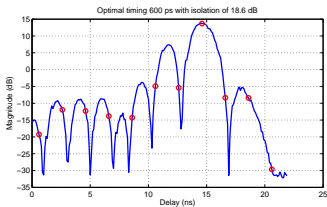
- Using the measured impulse response, optimize shaping coefficients and timing;

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.

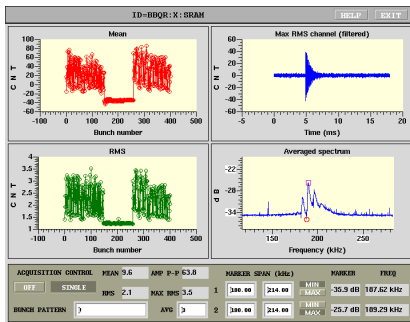
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Injection Transient

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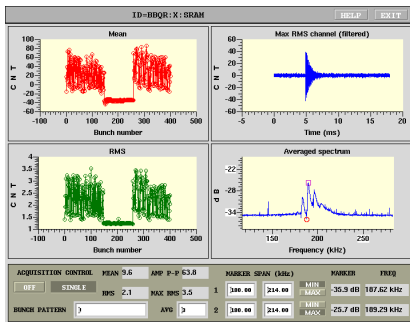


- Injection transient captured on the waveform panel;
- Large excitation in the horizontal plane;
- Visible in the vertical plane as well.



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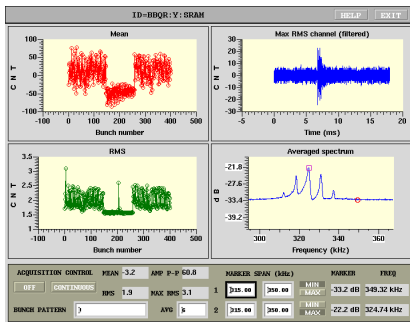


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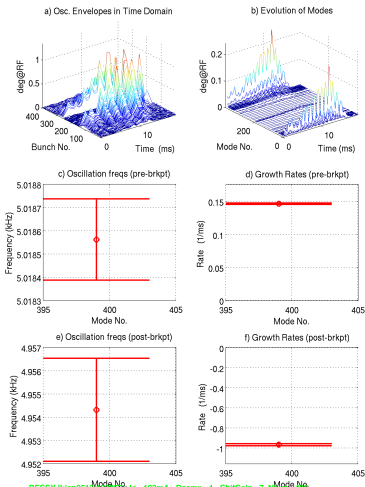
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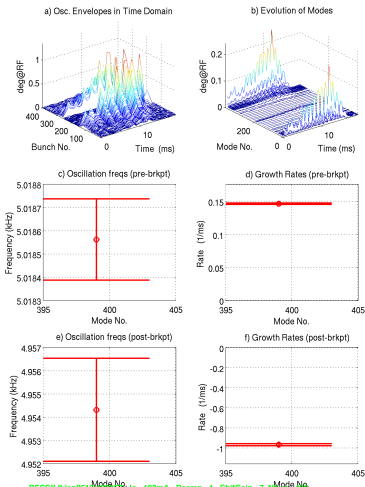
BESSY II: jan0513, Mode No. = 193mA, Dsamp=1, Shf/Gain=7, NMode=3
At Fs: G1= 415.6982, G2= 0, Ph1= -117.6129, Ph2= 0, Brkpt= 18200, Calib= 10.54.

- 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

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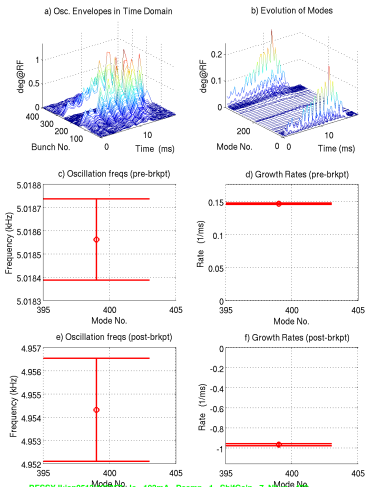
BESSY II: jan0513, Mode No. = 193mA, Dsamp=1, Shf/Gain=7, NMode=10
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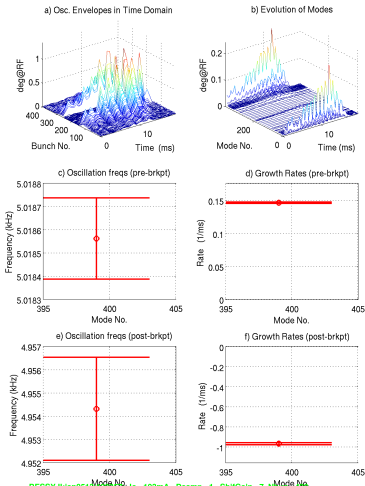
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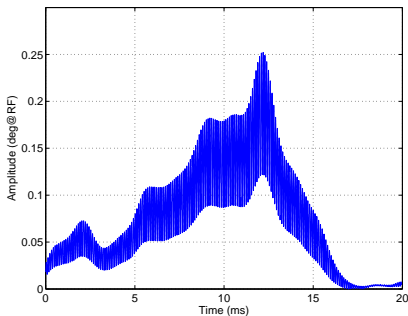


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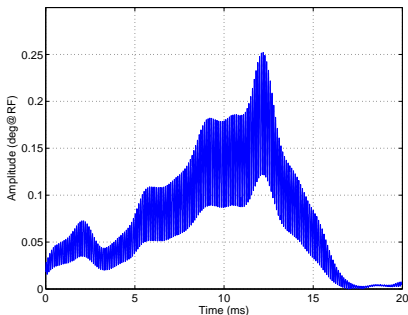
Separating the Eigenmode



- 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.



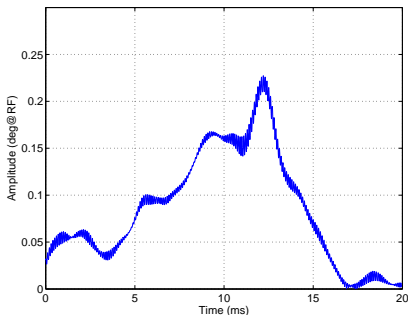
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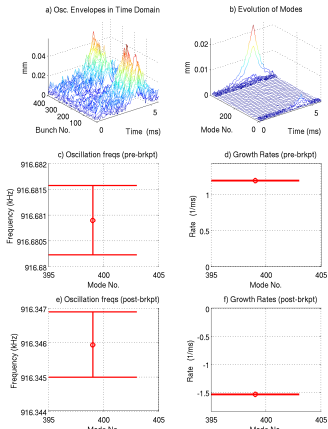


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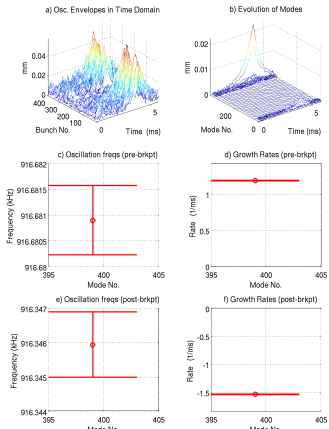


BESSY #jan05132006, Mode No. = 263mA, Dsamps = 1, SHtGain= 4, Nbeam= 1000
At Fs: G1= 115.2642, G2= 0, Ph1= 132.4734, Ph2= 0, Brkpts 4981, Collib= 145.1485.

- 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.



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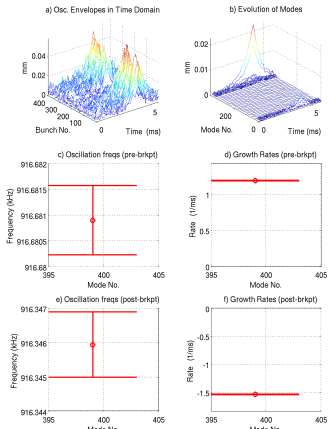
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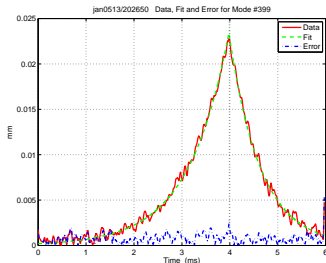


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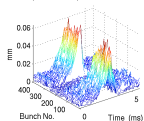


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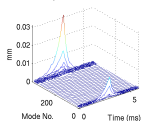
Transverse Grow/Damp Measurements

A Horizontal Grow/Damp Measurement

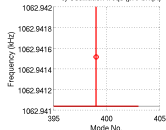
a) Osc. Envelopes in Time Domain



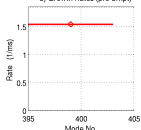
b) Evolution of Modes



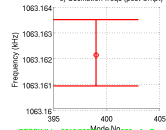
c) Oscillation freqs (pre-brkpt)



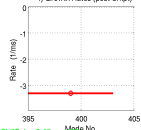
d) Growth Rates (pre-brkpt)



e) Oscillation freqs (post-brkpt)



f) Growth Rates (post-brkpt)



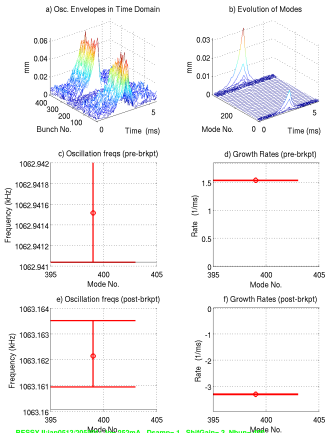
- Horizontal grow/damp at -3.0 units, 245 mA, no camshaft;
- Modes -1;
- Very fast damping.

BESSY II Jan0513:20597, I=252mA, Disamp=1, ShiftGain=3, Nbu=16, Mode=1
At F: G1=52.7247, G2=0, Ph1=1.4513, Ph2=0, Brkpts 3732, CallB=156.9839.



Transverse Grow/Damp Measurements

A Horizontal Grow/Damp Measurement

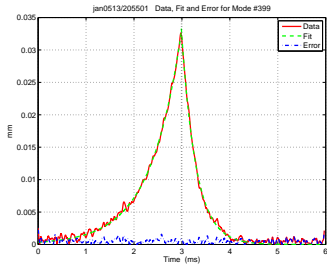


- Horizontal grow/damp at -3.0 units, 245 mA, no camshaft;
- Modes -1;
- Very fast damping.

BESSY II Jan0513:205497, P1=252mA, Disamp=1, ShiftGain=3, Nbu=1000
At F: G1=52.7247, G2=0, Ph1=1.4513, Ph2=0, Brkpts 3732, Callib=156.9839.

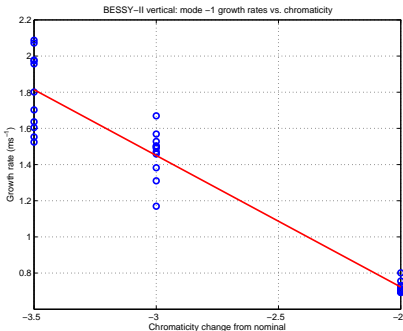


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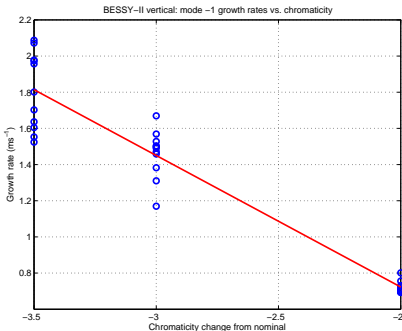
Vertical Growth Rates vs. Chromaticity



- 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.

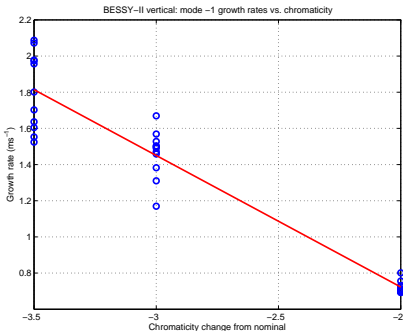


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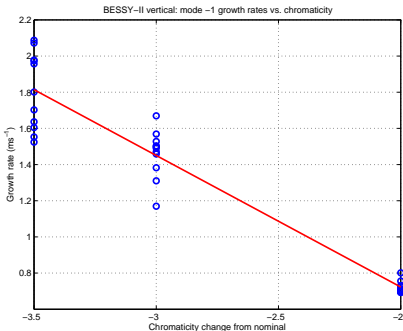
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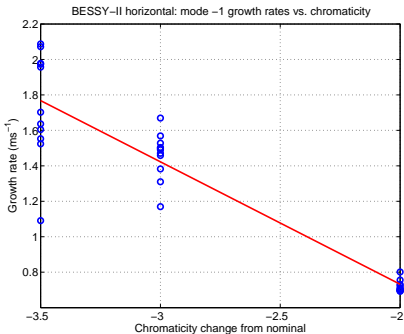
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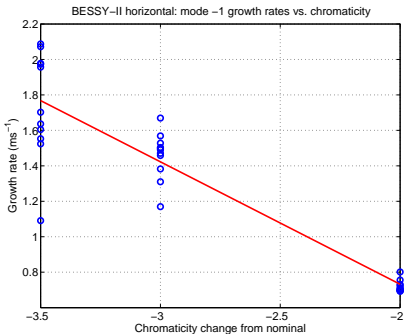


Horizontal Growth Rates vs. Chromaticity



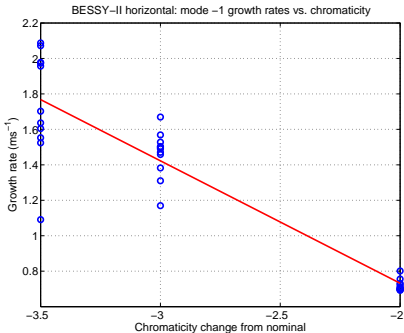
- Automated analysis of multiple data sets, no cleanup;
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Horizontal Growth Rates vs. Chromaticity



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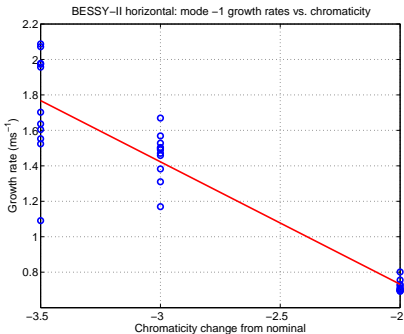
Horizontal Growth Rates vs. Chromaticity



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Horizontal Growth Rates vs. Chromaticity



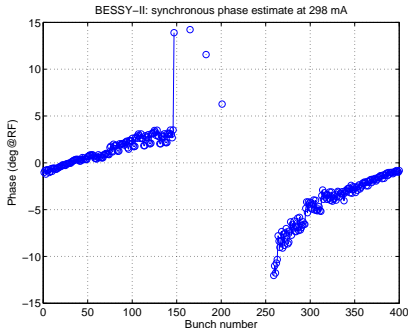
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Outline

- 1 Hardware Setup
 - System Installation
- 2 Timing and Calibration
 - Calibration
 - Transverse Power Amplifier Setup
- 3 **Beam Studies**
 - Injection Transient
 - Longitudinal Grow/Damp Measurement
 - Transverse Grow/Damp Measurements
 - **Synchronous Phase Transient**
 - Steady-state Residual Motion

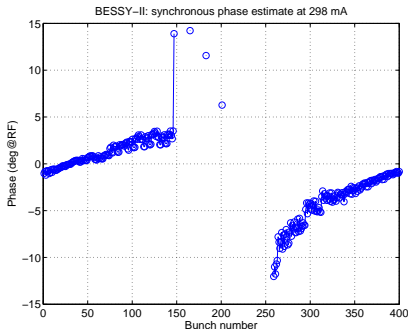


Synchronous Phase Transient



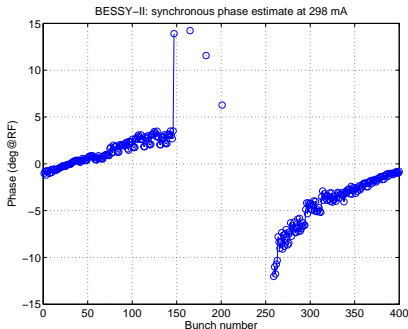
- Computed from a closed-loop measurement right after injection to 300 mA;
- Fill pattern estimated as 5 mA in each camshaft bunch, 278 mA in the train;
- Large transient of 26° peak-to-peak.

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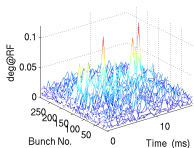
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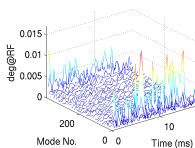


Longitudinal Plane

a) Osc. Envelopes in Time Domain

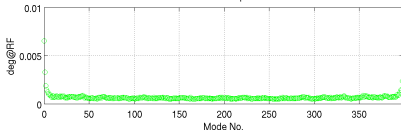


b) Evolution of Modes



BESSY II:jan0513/213910: Io= 298mA, Dsamp= 1, ShfGain= 6, Nbun= 292,
At Fs: G1= 210.6183, G2= 0, Ph1= -117.9857, Ph2= 0, Brkpt= 22434, Callb= 10.54.

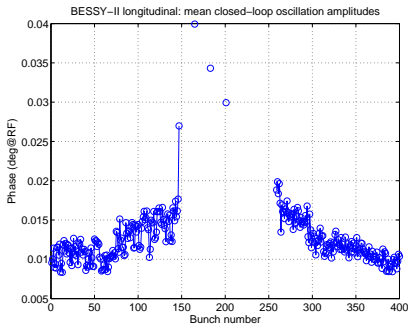
Mean Mode Amplitudes



- 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.

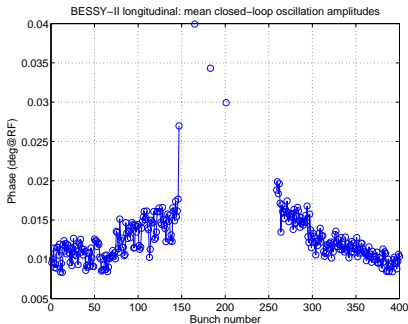


Longitudinal Plane



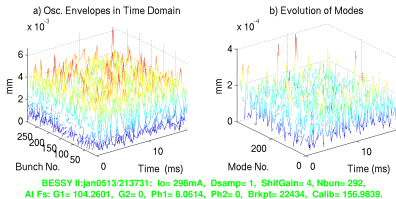
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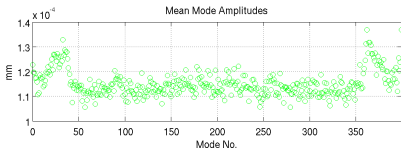


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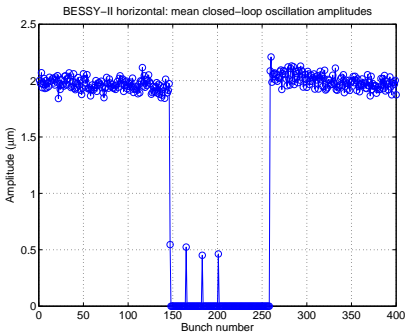
Horizontal Plane



- 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.



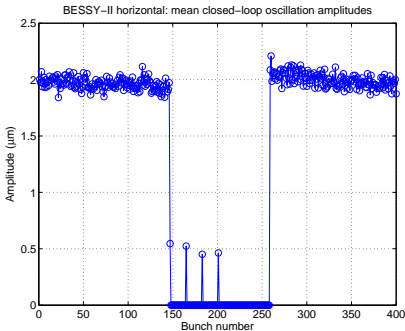
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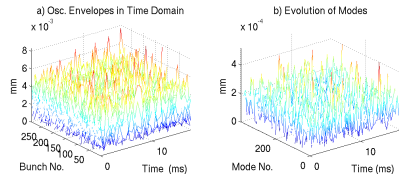
Horizontal Plane



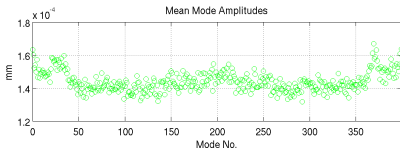
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Vertical Plane



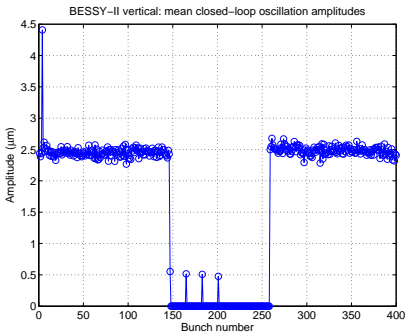
BESSY II: Jan0513/213833: I₀= 298mA, D_{samp}= 1, ShifGain= 6, Nbun= 292,
At Fs: G1= 450.347, G2= 0, Ph1= 150.3355, Ph2= 0, Brkpt= 22434, Callib= 145.1485.



- 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.

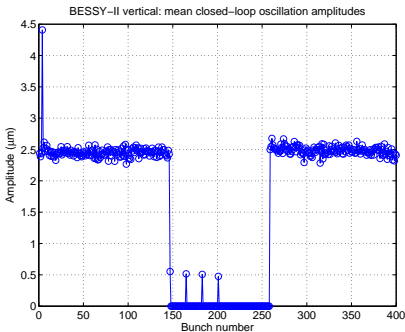


Vertical Plane



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Vertical Plane



- Filtered with 3 dB bandwidth 323–341 kHz;
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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.



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