Implementation of the feed forward correction for the FLASH photo injector laser and future plans for a feedback system

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FLASH Seminar, 2008/12/02

Outline

Motivation and Introduction

During **FEL operation of FLASH** SASE intensity highly sensitive to changes of the gun RF gradient (0.2%) and the phase (0.2 deg).

Understanding of all subsystems beginning with the gun is crucial.

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Observations

- slope in gun RF phase: $\approx$ 4 deg over 800 μs
- can be corrected for with RF gun feedback system
- remaining phase unstability traced back to the EOM of the injector laser

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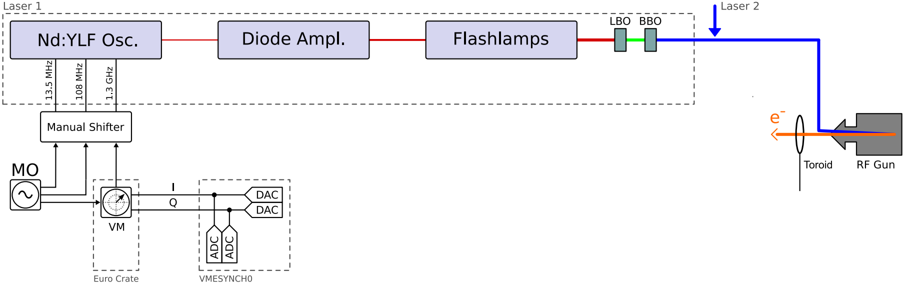
The laser itself should be stabilized (especially the arrival time).

- Step 1: feed forward system to correct for the phase slope
- Step 2: feedback to stabilize the arrival time

Synchronization to the optical timing reference and monitoring is desirable to correlate arrival time jitter of the injector laser with other diagnostic systems.

Feed Forward: Hardware Installation



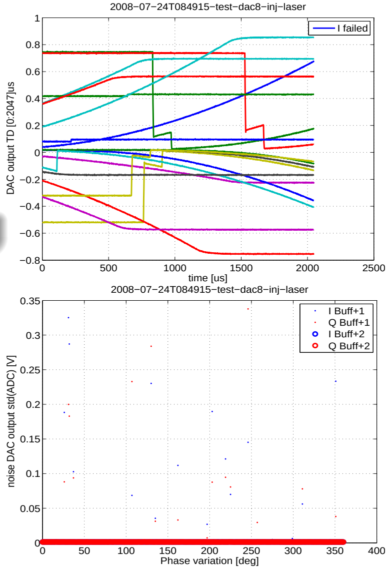
- Vector Modulator incorporated into the 1.3 GHz branch driving the electro-optic modulator (EOM) inside the pulse train oscillator (PTO) of injector laser 1
- *I* and *Q* set-points delivered by a DAC installed in `VMESYNCH0`, simultaneously monitored by an ADC
- DAC is controlled by a new DOOCS server to set the feed forward tables

Commissioning of the Hardware

Step 1: Investigation of the DAC output

- DAC values should be constant, but:
- not machine-synchronous writing observed, 5% error rate
- modification of DOOCS server necessary

⇒ DAC writing errors resolved

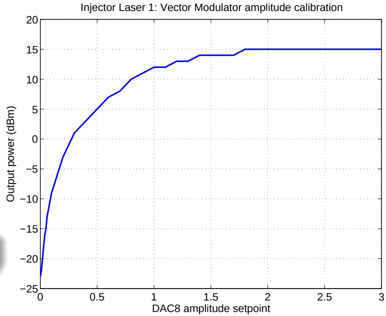


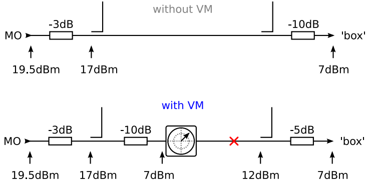
Commissioning of the Hardware

Step 2: Power calibration

- cable extended approx. by 75 cm
- 7 dBm at RF input of the VM
- VM set to 12 dBm output level, 5 dB attenuator after coupler

⇒ original power levels restored

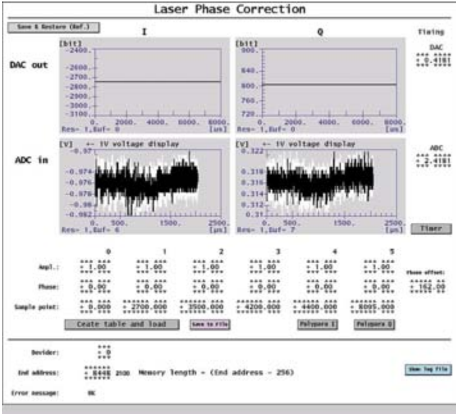




DOOCS Server & Panel for the Feed Forward Tables

Principle of operation:

- linear interpolation between six nodes: t, (A, ϕ)
- memory writing process triggered by VME interrupt and finished before machine trigger



a) `DOOCS > Crates > Synch Crates > VMESYNCH0 > Laser Phase Control`
b) `Injector > Laser > PhaseCtrl`

- Simple control of the feed forward system suited for operators!

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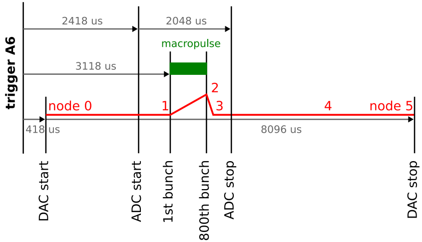
  - chosen with respect to known DAC bug
  - additional node allows more complex pattern



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- features: e.g. SR (auto)

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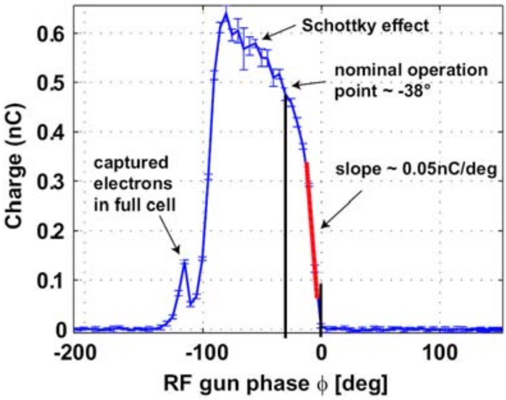
First Measurements with installed Vector Modulator



Measurement Principle

"gun detuning"

- precise charge measured with toroid translates to phase

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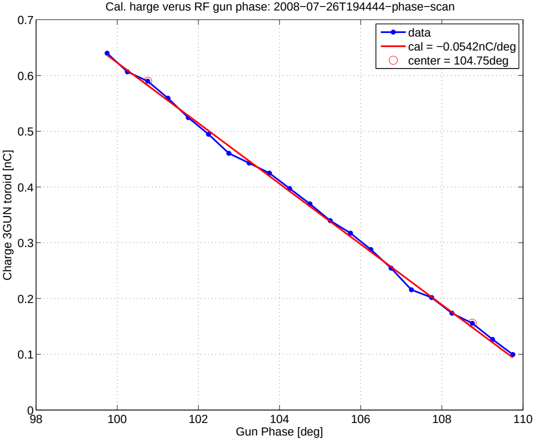

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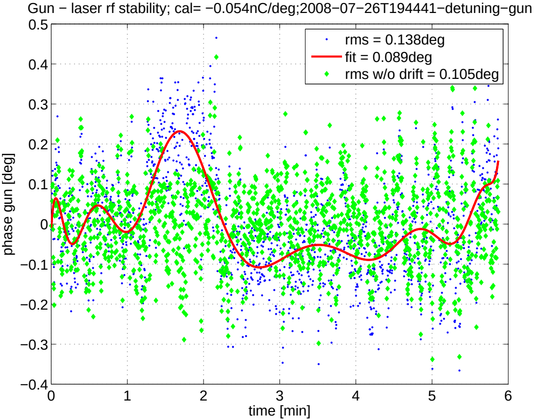

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Phase Stability over 6 Minutes

- after removing slow drifts 0.105 deg (rms)

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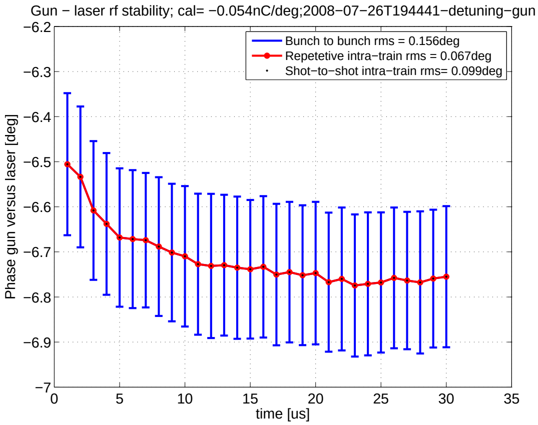

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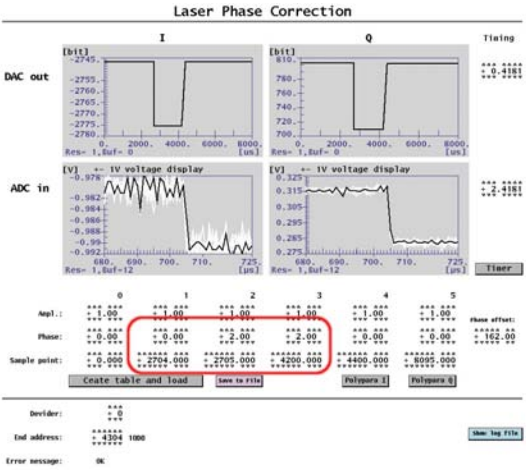
Phase Stability across Macro Pulse

- bunch-to-bunch 0.156 deg (rms)

Laser Response to EOM Phase Jumps



Applying Phase Steps to EOM

- $\Delta\phi \in \{-2, -1, 0, 1, 2\}$ deg

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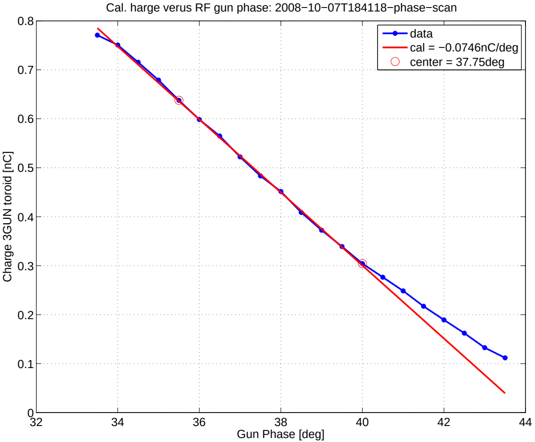

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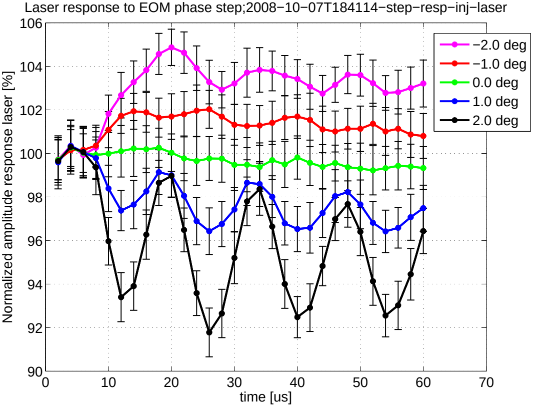

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Charge Measurement

- normalized to first 3 bunches
- phase jump may induce amplitude modulation

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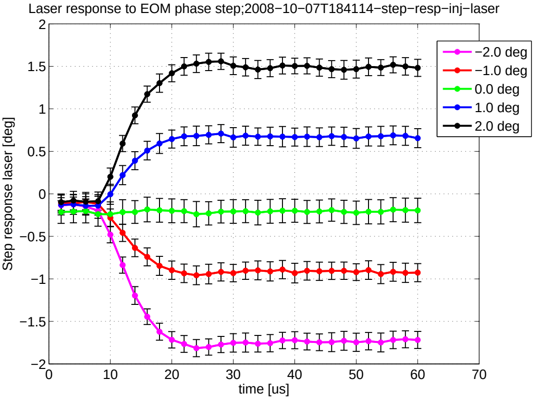

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Response to Phase Jumps

- corrected with charge measurement
- nominal value not reached
- systematic error?

Notes on the Measurements

- recently a very good charge stability had been observed

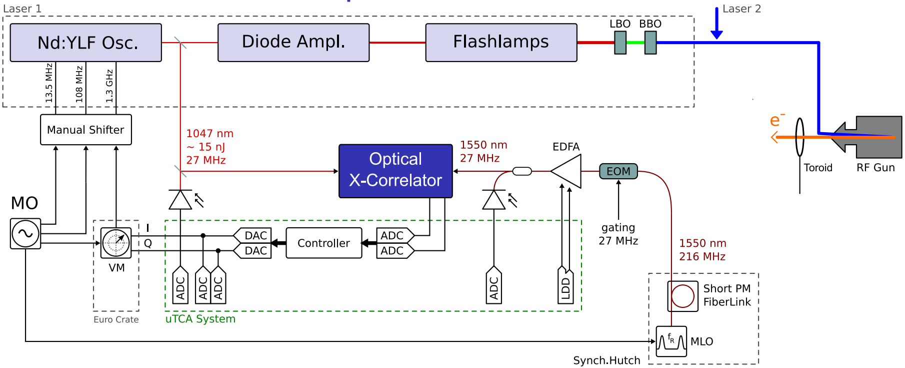
- operation with EOM phase shifted by 180 deg possible, but then PTO slow feedback does not work
- results are somehow academic (only slope expected)
- phase steps advantageous to optimize feedback

Future investigations must include

- long pulse trains
- amplitude modulation of the laser oscillator
- phase relation of the AOMs and the EOM
- ...

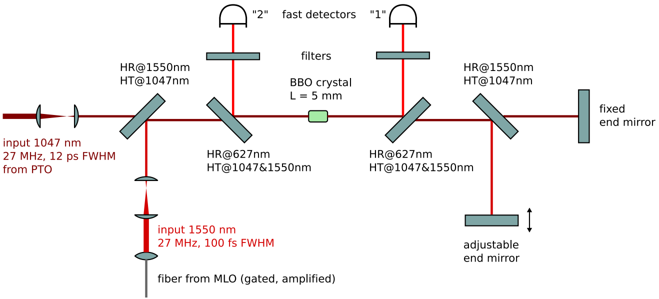
and taking these into account in the measurement routine

Feedback: Planned Implementation



- master laser oscillator (MLO) delivers precise timing information over a "Short FiberLink"
- gating to repetition rate of PTO with an EOM and amplification by an EDFA
- measuring timing jitter between PTO and reference on $\mathcal{O}(10\text{ fs})$ level with the optical cross-correlator
- stabilize 1.3 GHz phase of the PTO's EOM by closing a control loop implemented in a uTCA system driving the VM

Balanced Optical Cross-Correlation I



- collinear overlap of incoming pulses (⇒ collinear phase matching)
- sum-frequency generation I_+ and detection "1" after dichroic mirror
- seperation of the pulses and generation of a "temporal swap"
- sum-frequency generation I_- of backward travelling pulses and detection "2"

⇒ difference signal $I_- - I_+$ ("S-curve") is control signal for feedback loop

Balanced Optical Cross-Correlation II

Beta barium borate (BBO)

- large birefringence ($n_o > n_e$, $\Delta n \approx 0.13$)
- low temperature sensitivity
- large phase-matching bandwidth

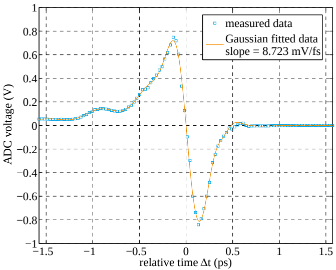
Some considerations

- collinear type-I^- phase matching
  $\Rightarrow$ walk-off of sum frequency component
- focussing
- pulse lengths
- GVD
- effective length
- ...

$\Rightarrow$ optimal crystal length 5 mm
$\Rightarrow$ conversion efficiency $> 1.5\%$

Control Signal

- SFG intensities $I_-(t) - I_+(t)$
- slope near zero crossing highly sensitive to timing jitter



(SFG-Control signal measured with center wavelength of 800 nm and 1550 nm in another X-Correlator setup)

Detectors and the uTCA-System

Planned feedback control loop

- detection of SFG intensities with fast photo diodes or photo multipliers
- 2 ADC input channels
  - *minimum sampling rate is 27 MHz*
- FPGA-based algorithm
  - *clock speed up to 500 MHz possible*
  - *signal filtering easy and cheap*
  - *implementation not started yet*
- DAC output for Vector Modulator control
- latency and signal propagation delay might be a problem
  $\Rightarrow$ *investigations necessary*
- fall-back is proven but very slow VME system

First non-prototype uTCA-system running at FLASH.

Tentative Schedule and Summary

- Jul 2008: Hardware installation and commissioning for the feed forward system (done)
- Jul & Oct 2008: First measurements and investigations with the feed forward system (done)
- Oct 2008: Installation of optical fibers from synch hutch to both lasers (done)

- Sep – Nov 2008: Ordering of optics and opto-mechanics (mostly done)
- Nov – Dec 2008: Installation and commissioning of the optical synchronization system (infrastructure ready, systems to be installed)

- Dec 2008 – Feb 2009: Setup and commissioning of the optical cross-correlator (using unstabilized fibers)
- Mar 2009: Installation and Commissioning of the uTCA system
- Apr 2009: First measurements and results
- May 2009: Completion and Installation of the Short-FiberLink

Acknowledgements

Thank you for your attention!

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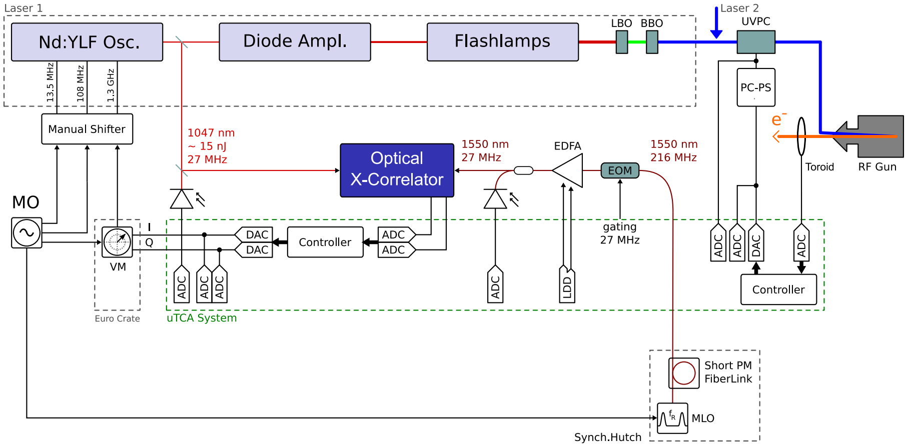
Further Idea: Amplitude Stabilization



Further Idea: LO Generation