RF-based Synchronization of the Seed and Pump-Probe Lasers to the Optical Synchronization System at FLASH

Introduction to the otical synchronization system and concept of RF generation for locking of Ti:Sapphire oscillators

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HELMHOLTZ ASSOCIATION

DESY

Motivation

Seed Laser

- The temporal overlap is mandatory for the seeding process
- Right now there is no high resolution monitor for the synchronization (streak camera has ~1ps resolution)
- Electron bunch duration with 3rd harmonic module is ~120 fs, HHG pulse ~40 fs
- Requiring synchronization better than 40 fs rms

Pump-Probe Laser

- The arrival time of the FEL pulse is given by the electron bunch
- Pump-probe experiments can make use of an electro-optic arrival time monitor to sort the data in time, after the experiment
- Resolution is in the order of 80 fs but users request more precise synchronization for some experiments
- If the timing can be set on a10 fs scale, entire movies of a process can be recorded within one burst, without the need of sorting the data

Roadmap for Precise Synchronization

Establish a machine reference that is cabable of providing a point-to-point synchronization better than 10 fs

→Pulsed optical synchronization system

Make sure, the beam arrival time is synchronized to the timig reference

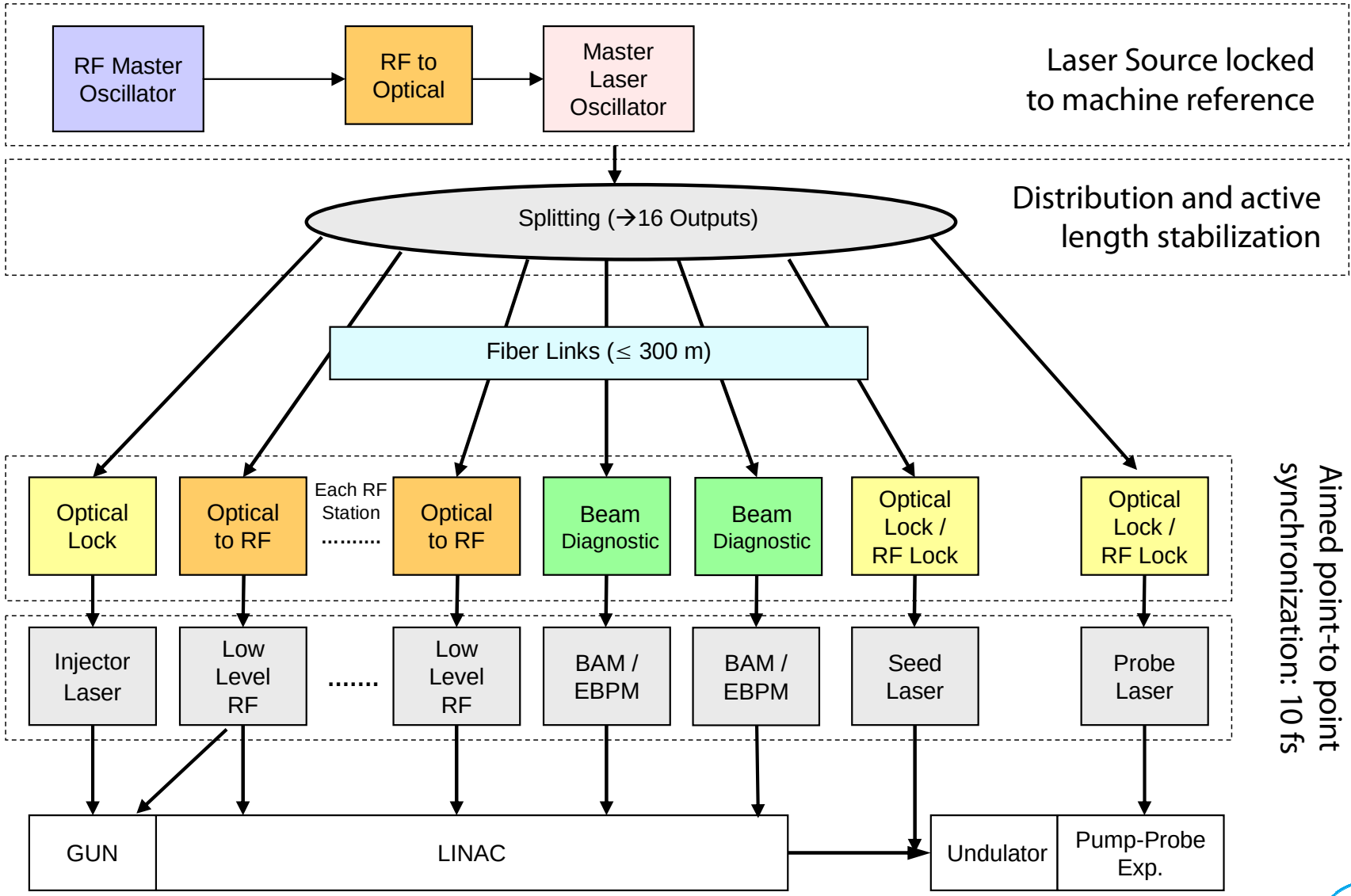
→Beam-based feedback

Synchronize external lasers to the same reference

→First step: RF-based
→Finally purely optical

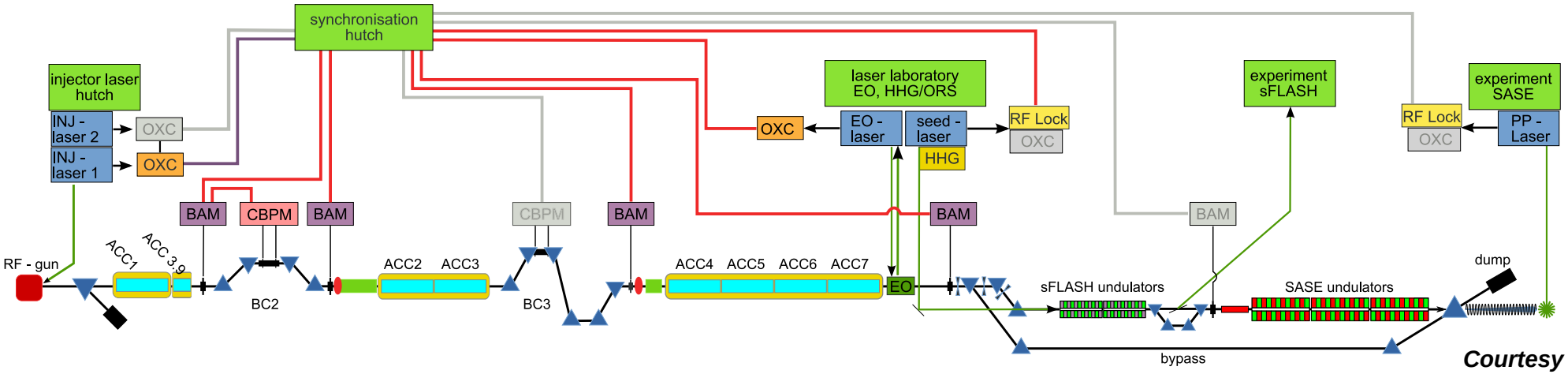
General Layout of an Optical Synchronization System

The reference timing information is encoded in the precise repetition rate of an optical pulse train



Optical Synchronization System at FLASH

Currenty installed and planned infrastructure



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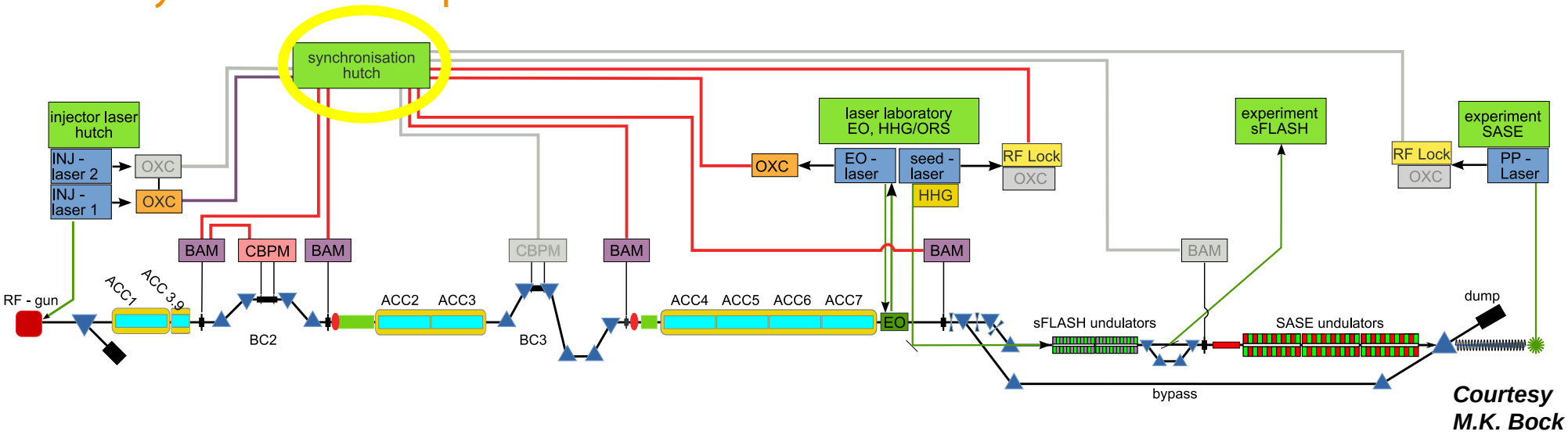

- Synchronization Hutch
  - Two redundant Master Laser Oscillators (MLOs) locked to the machine reference
  - Free-space laser beam splitting to up to 16 ports
  - Erbium-doped fiber amplifiers at each port
  - Up to 16 Link stabilization units, each supplying one fiber link

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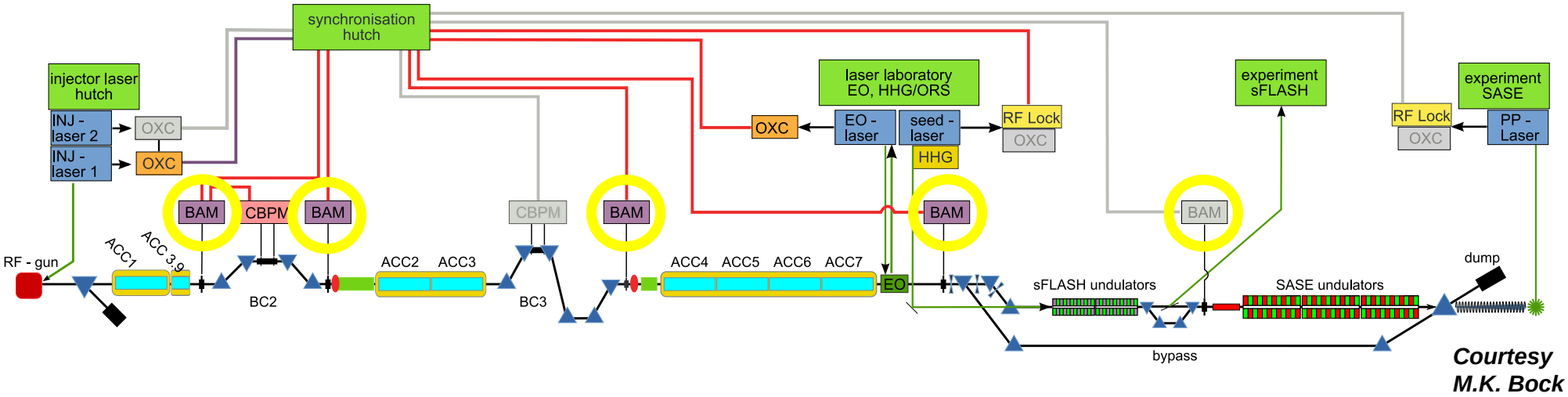

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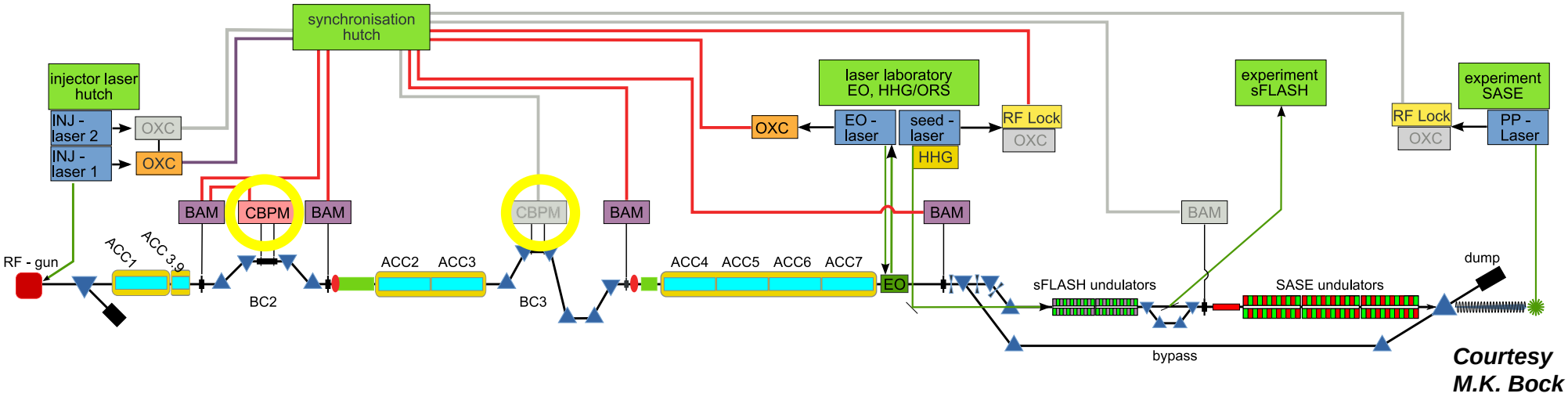

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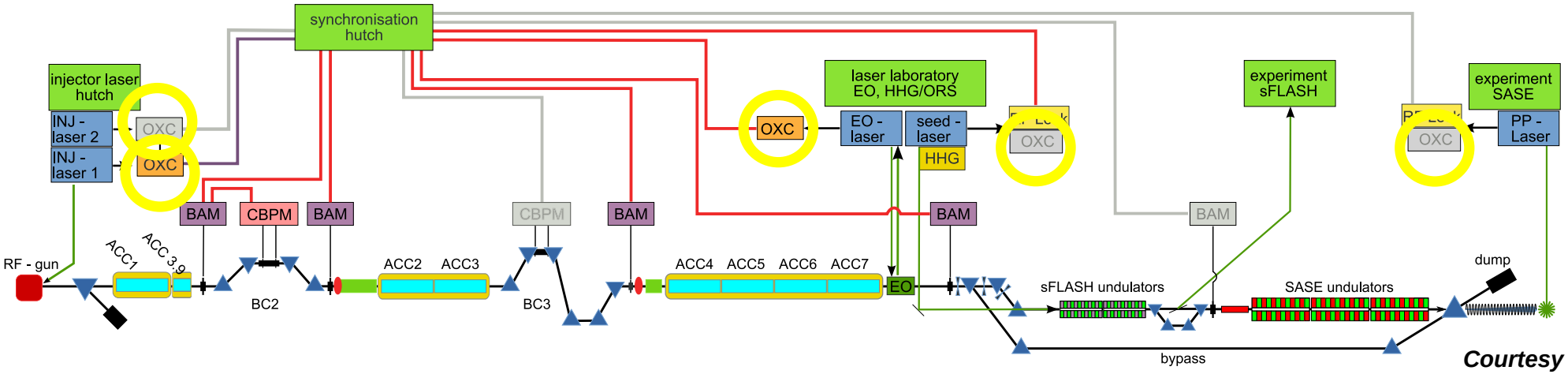

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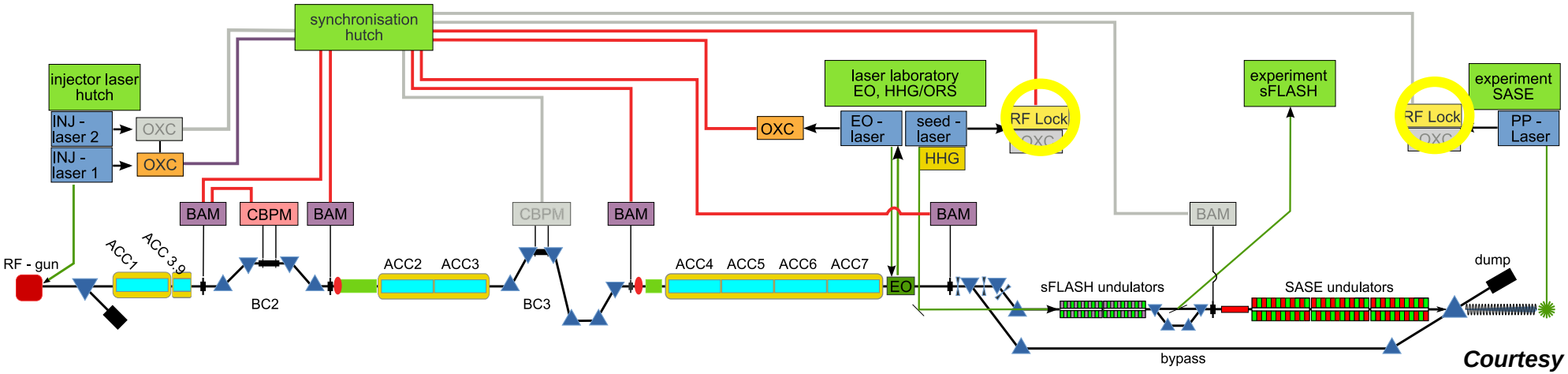

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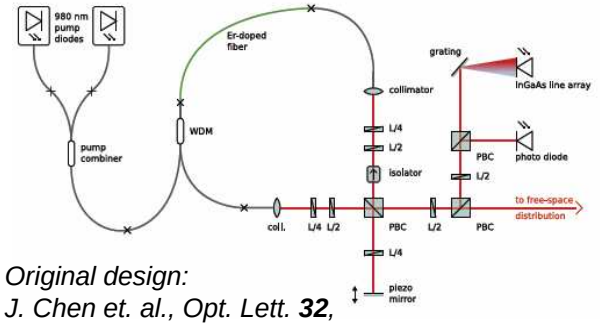
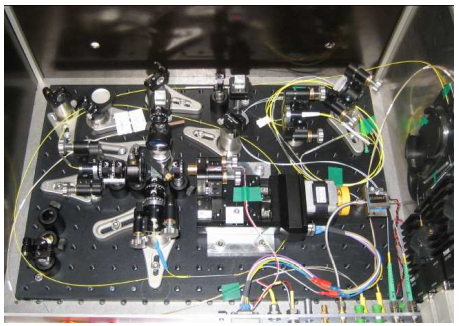
  - RF generation

Master Laser Oscillator

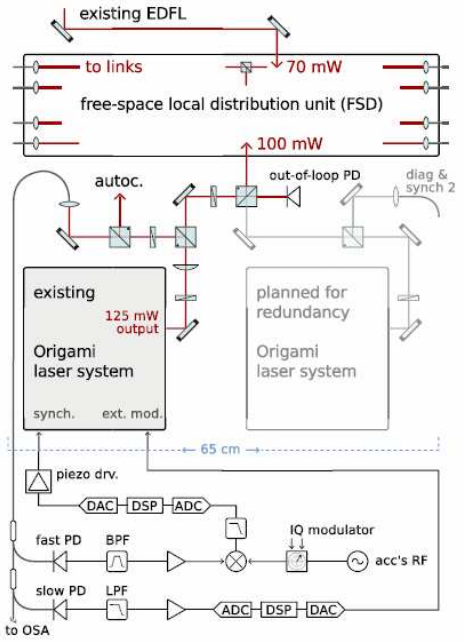
For many years self-built fiber lasers based on self phase modulation have been used

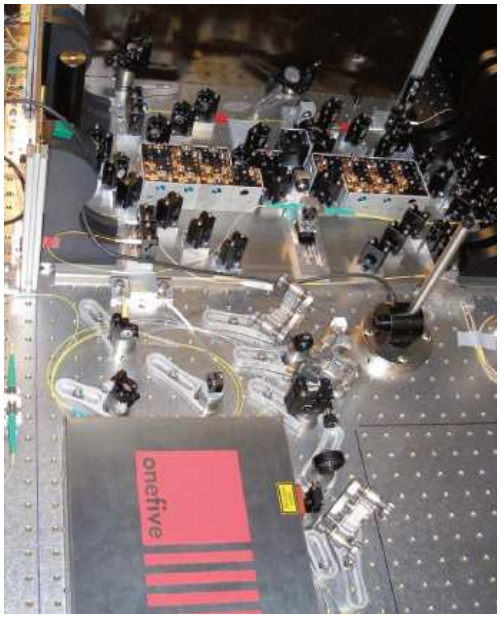


Original design:
J. Chen et. al., Opt. Lett. ***32****, 1566-1568 (2007)*



Recently a commercial SESAM-based laser was installed and tested





S. Schulz et al, this conferenceTHPA05

1550 nm telecommunication wavelength

repetition rate of 216.66 MHz (1.3 GHz /6)

Important Issues

- o Phase Noise
- o Frequency stability – tuning range
- o Piezo stroke & bandwidth (resonance)

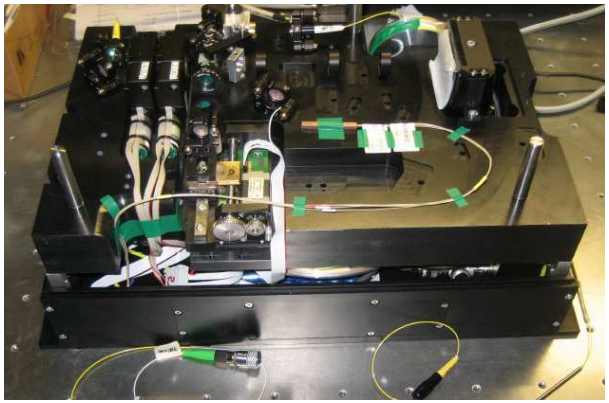
- o Amplitude Noise
- o Modulation input range & bandwidth
- o Output Power

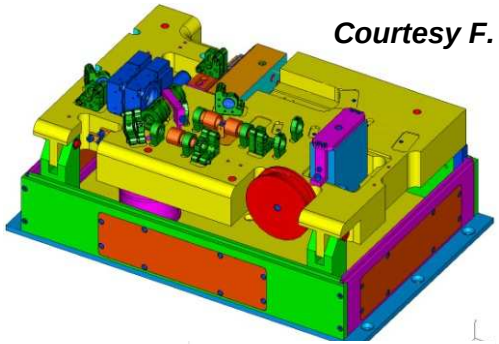
- o Pulse width
- o Spectrum (peak and bandwidth)

- o Robustness & reproducability
- o Lifetime
- o Formfactor

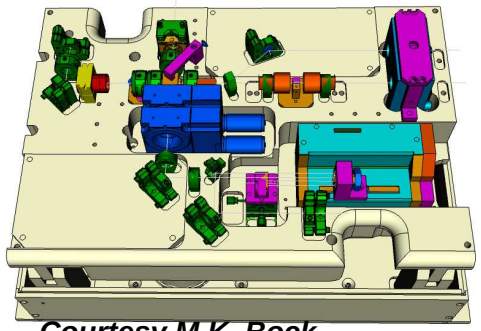
Link Stabilization Unit

Industrialized design in operation for about one year
Improved version being manufactured right now





Courtesy F. Loehl



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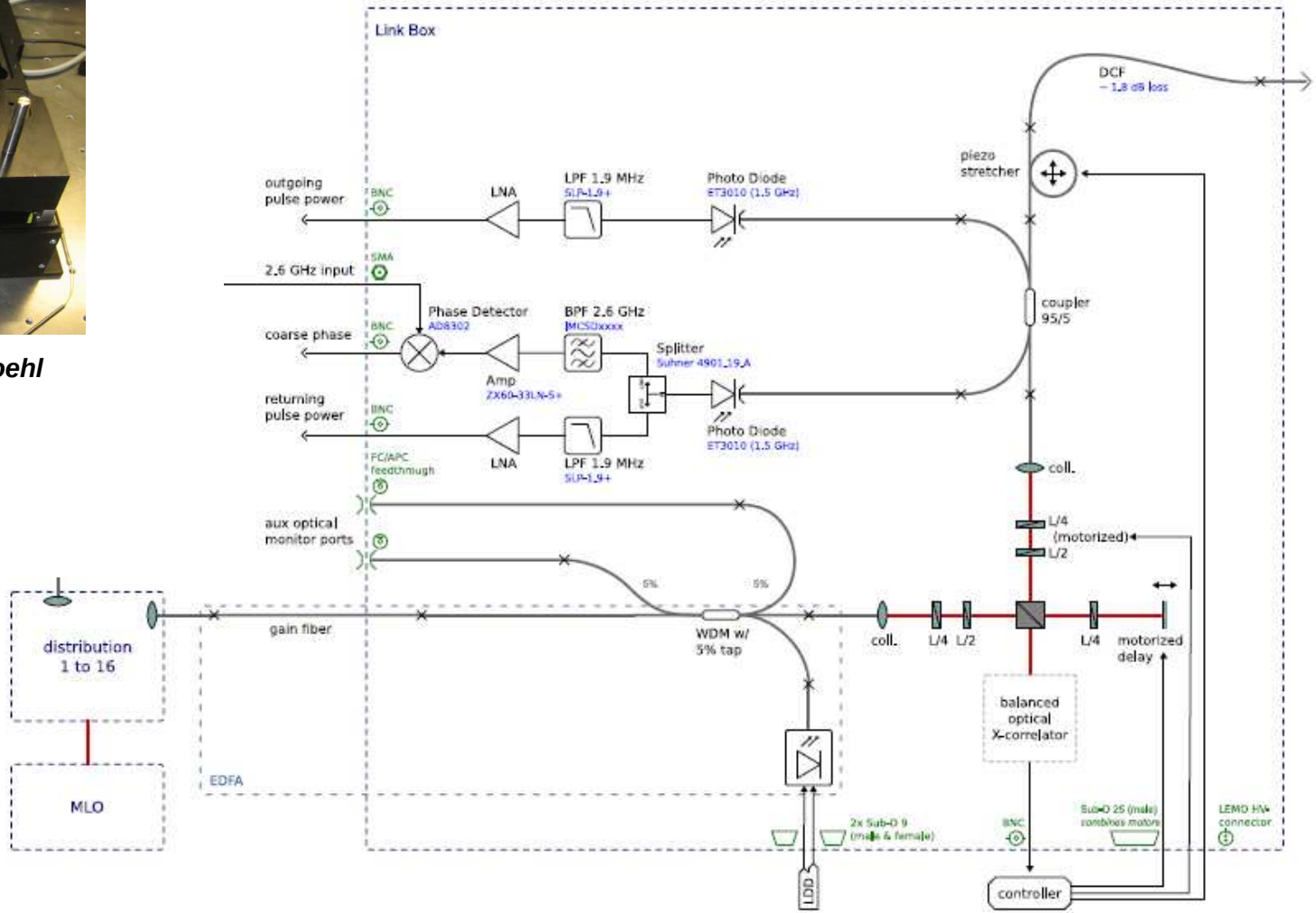
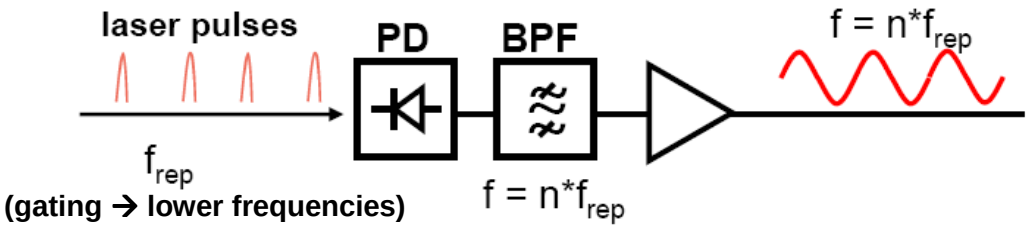
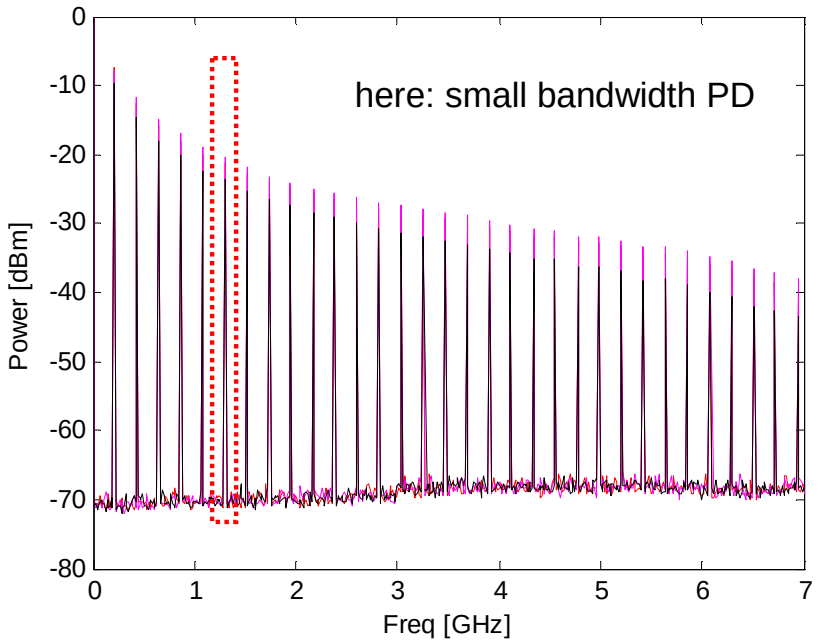


RF generation from optical pulse train

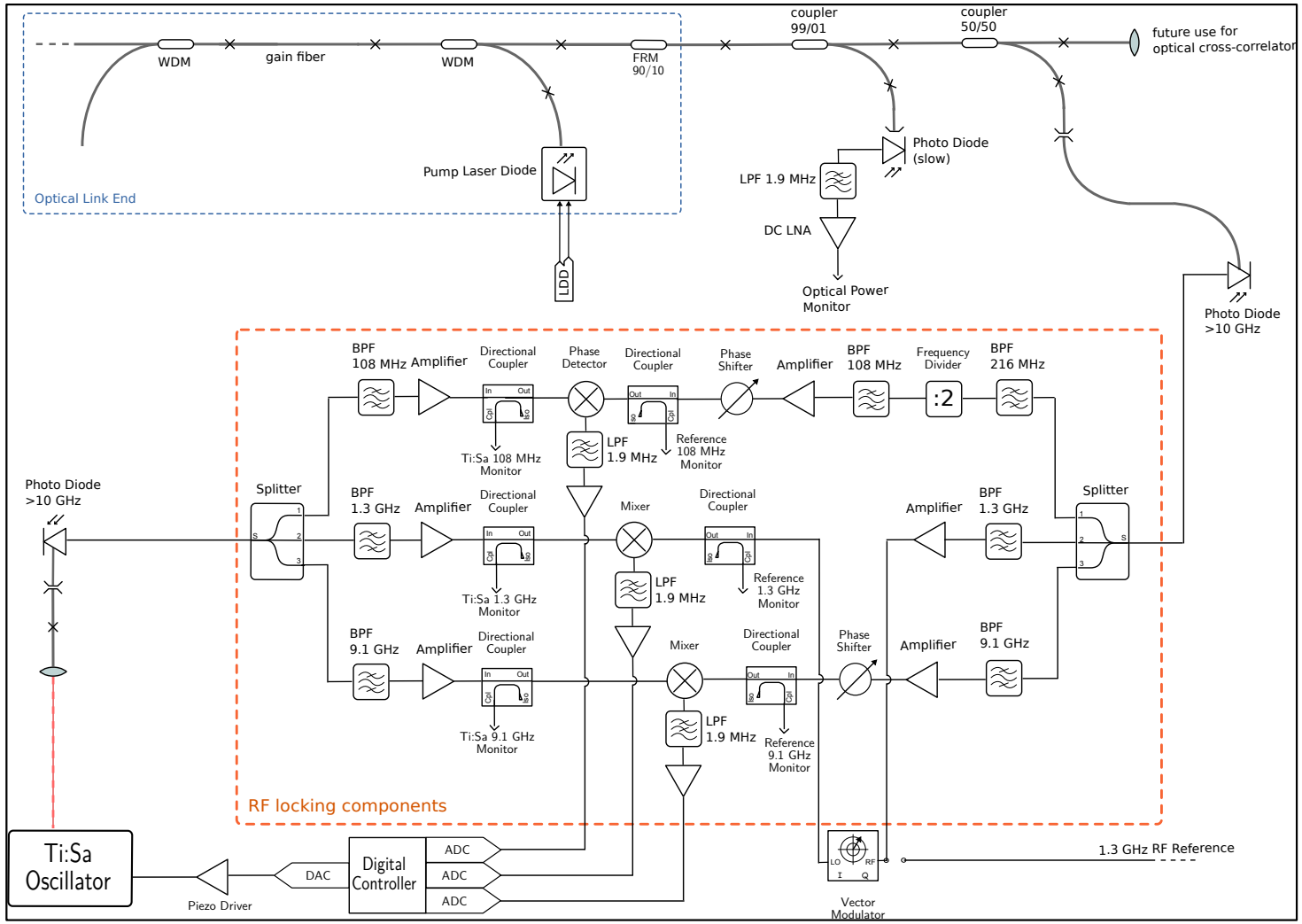


Direct Conversion

- \+ Drift: 10.7 fs over >15 h @ 1.3 GHz
  (M. Felber, PAC09, TH6REP088)
- \+ Jitter: 3.3 fs [1kHz,10MHz] @ 3 GHz
  (S. Hunziker, DIPAC09, TUPB43)
- \+ small and robust
- \+ 5-10 mW P_{opt} sufficient
- \+ relatively cheap (<2k€)
- − Small output power vs. amplifier drift
- − Am-to-PM conversion: 1-4 ps/mW
- − Temperature dependency ~350 fs/°C



Concept for RF-based synchronzation of lasers



Pump-Probe oscillator frequency: 108 MHz

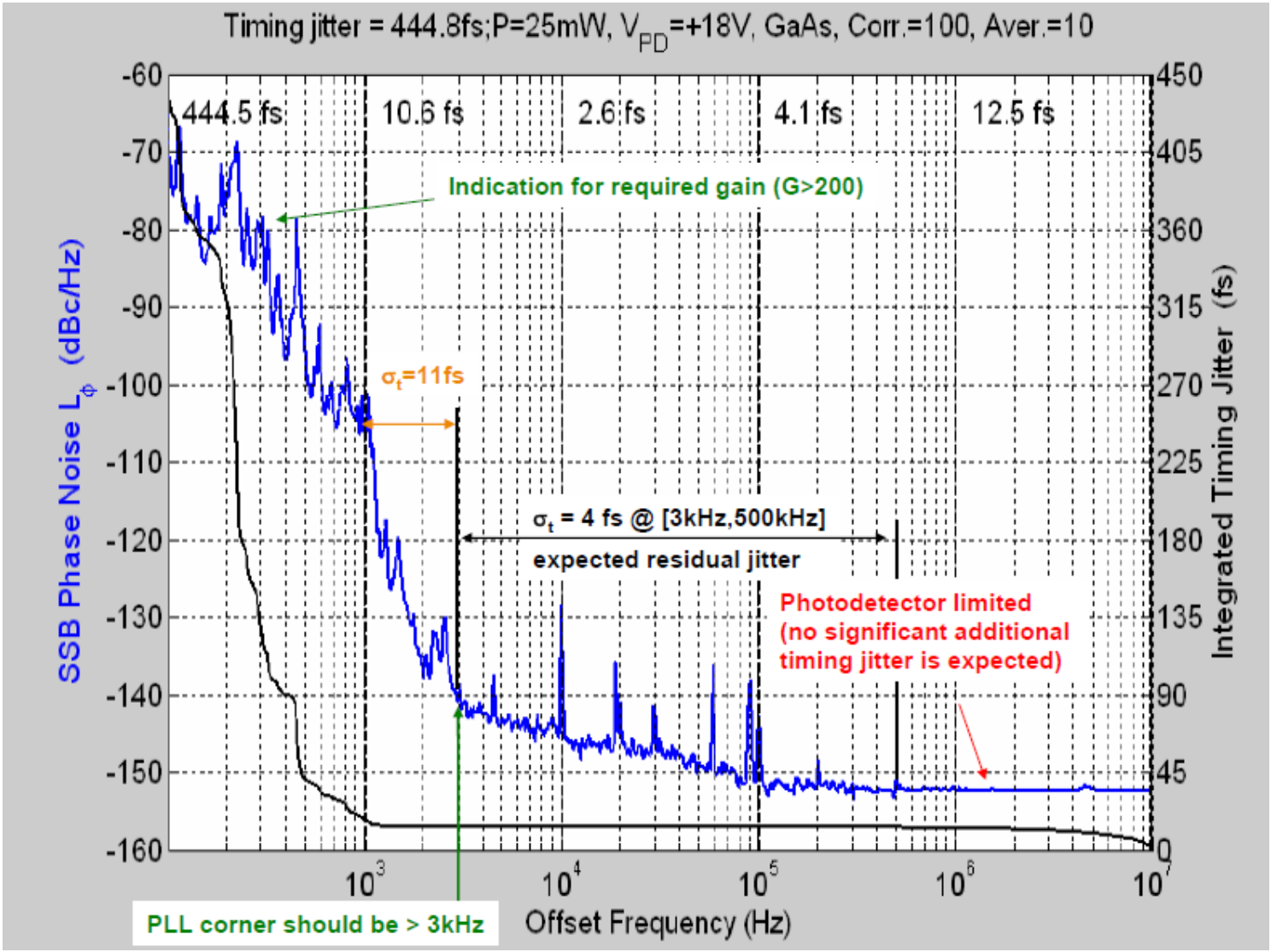
HHG laser oscillator frequency: 81 MHz, likely to be upgraded to 108 MHz

Three frequencies are generated from reference- and Ti:Sa pulse trains

First adjustment with 1.3 GHz IQ modulator, then set other phases

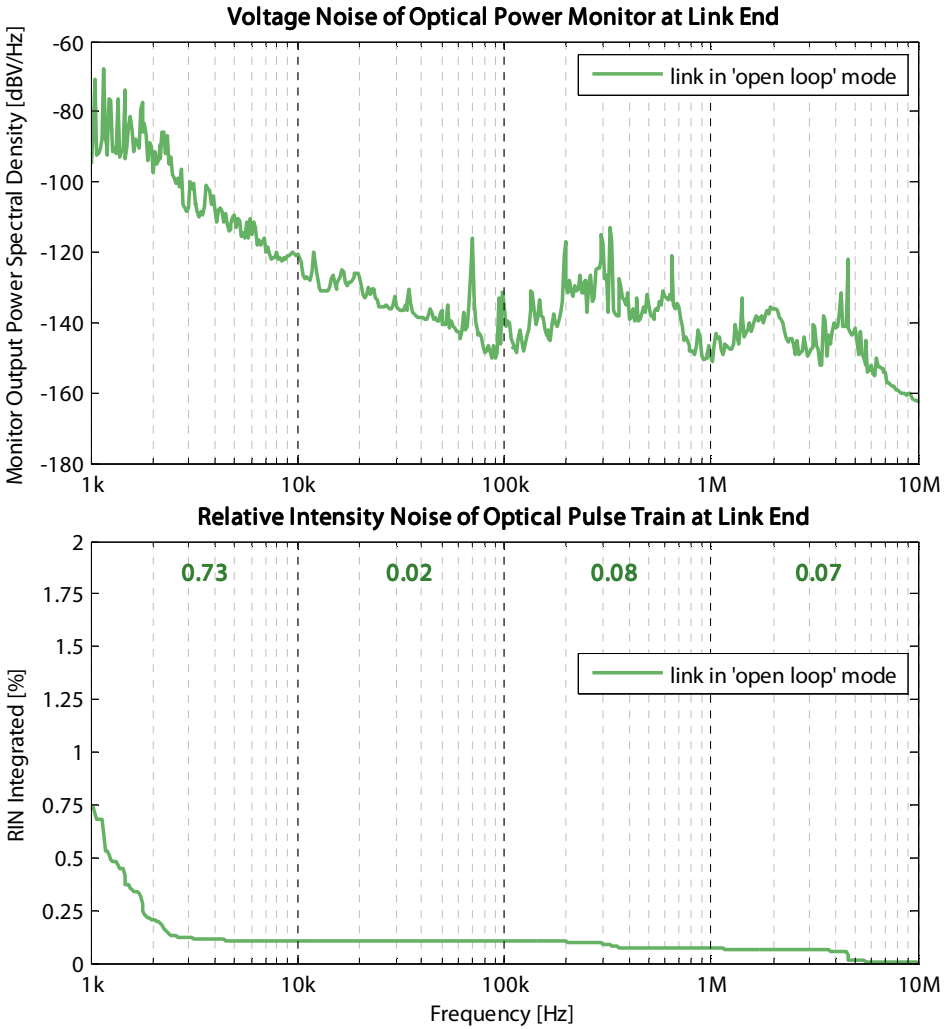
Lock from coarse to fine in steps at 108 MHz, 1.3 GHz, and 9.1 GHz

Phase Noise and Timing Jitter of the Seed Laser at 1.3 GHz



First measurements of refernce signal in HHG laboratory

Amplitude noise of optical pulse train



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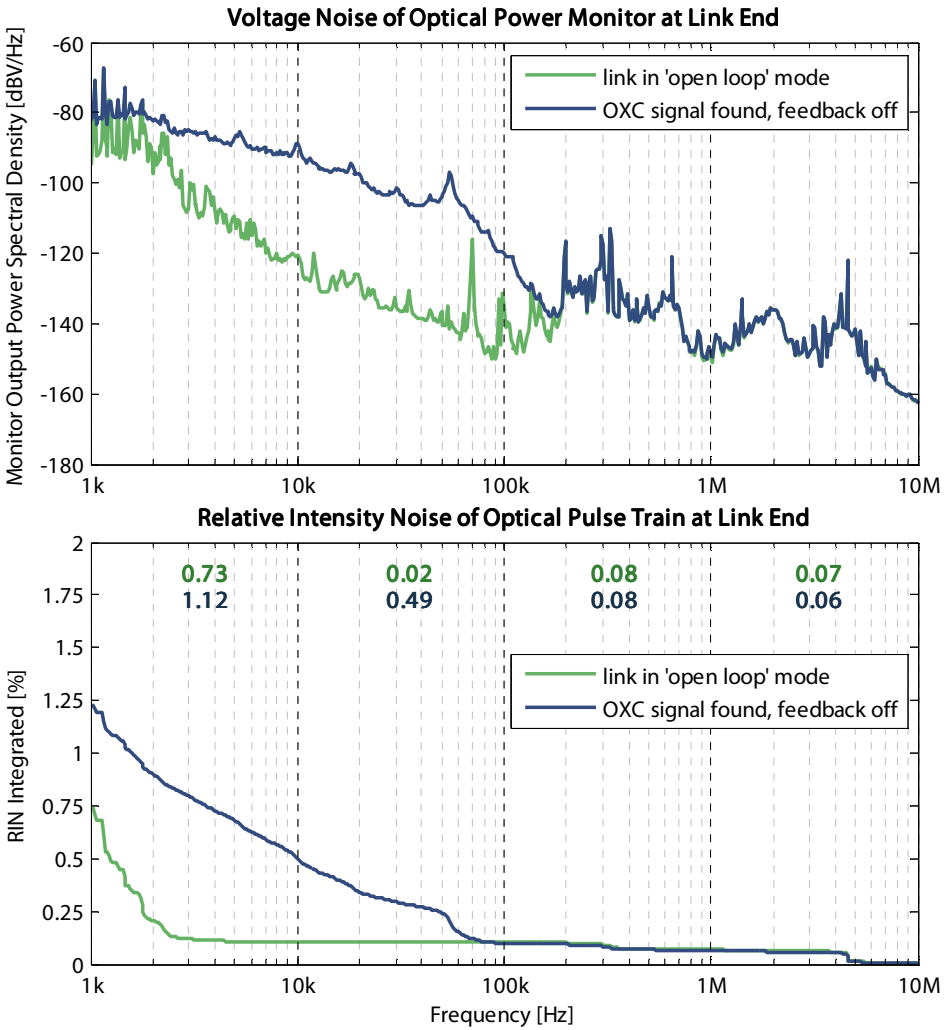

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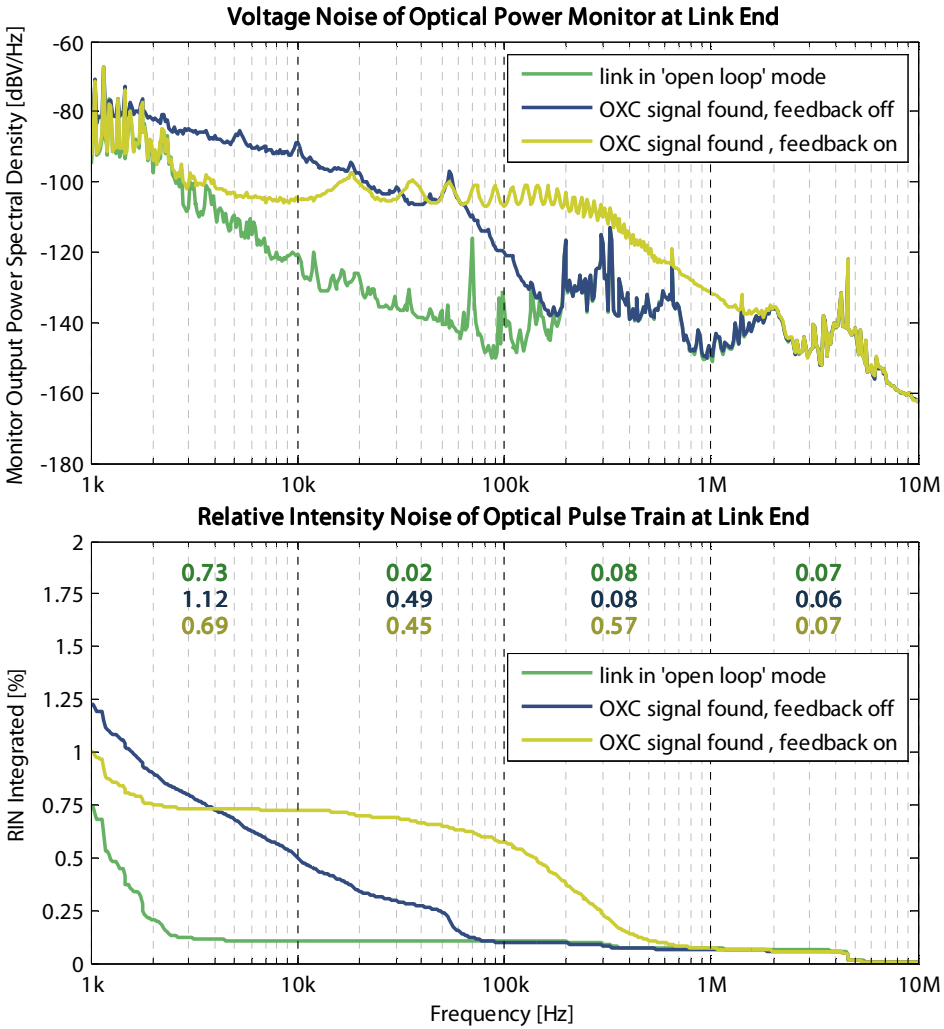

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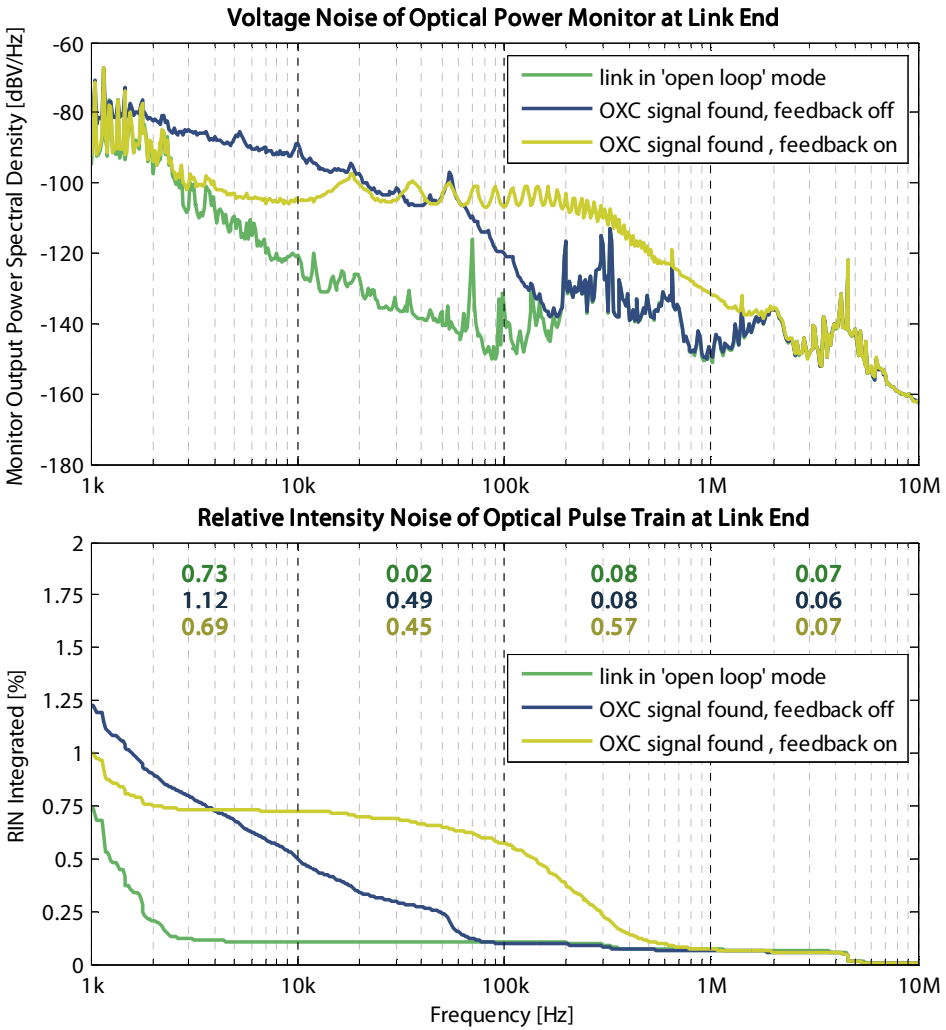
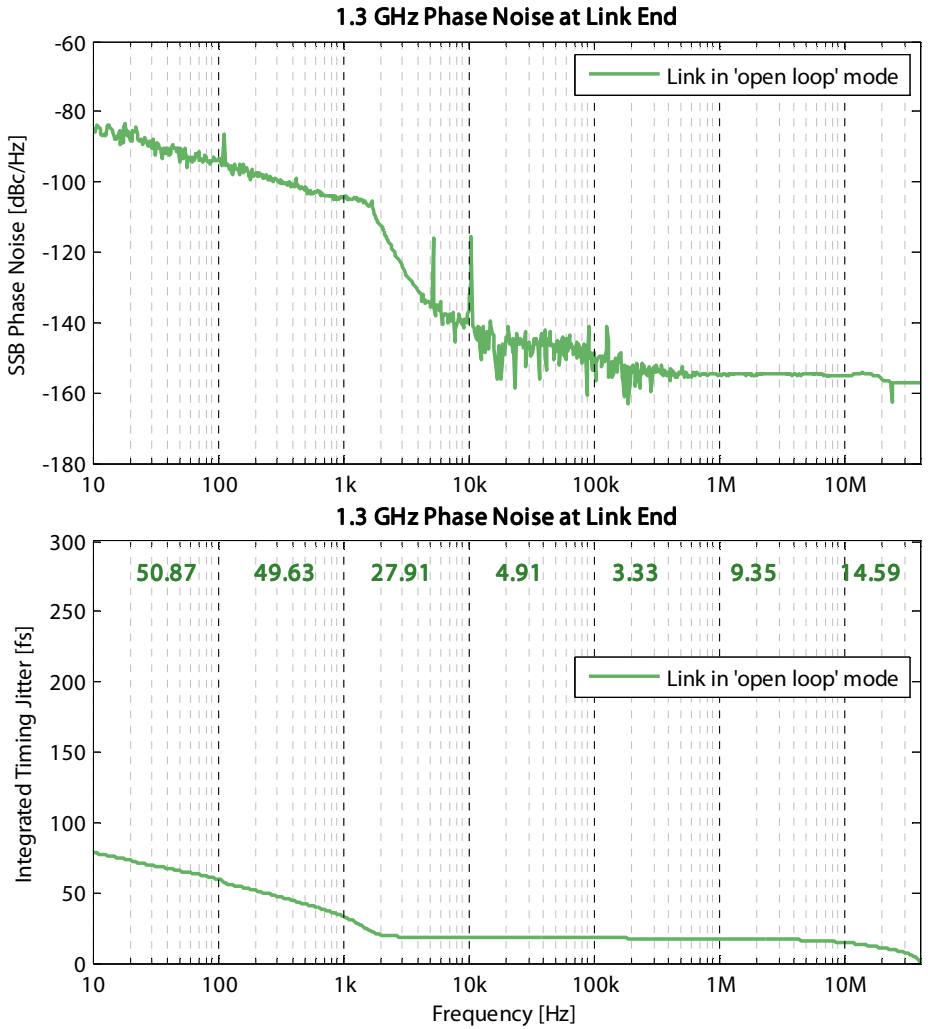


- The problem is understood. First test showed already strong suppression of the effect
- It does not influence BAMs because of high-pass characteristic
- The new link design eliminates the effect

First measurements of refernce signal in HHG laboratory

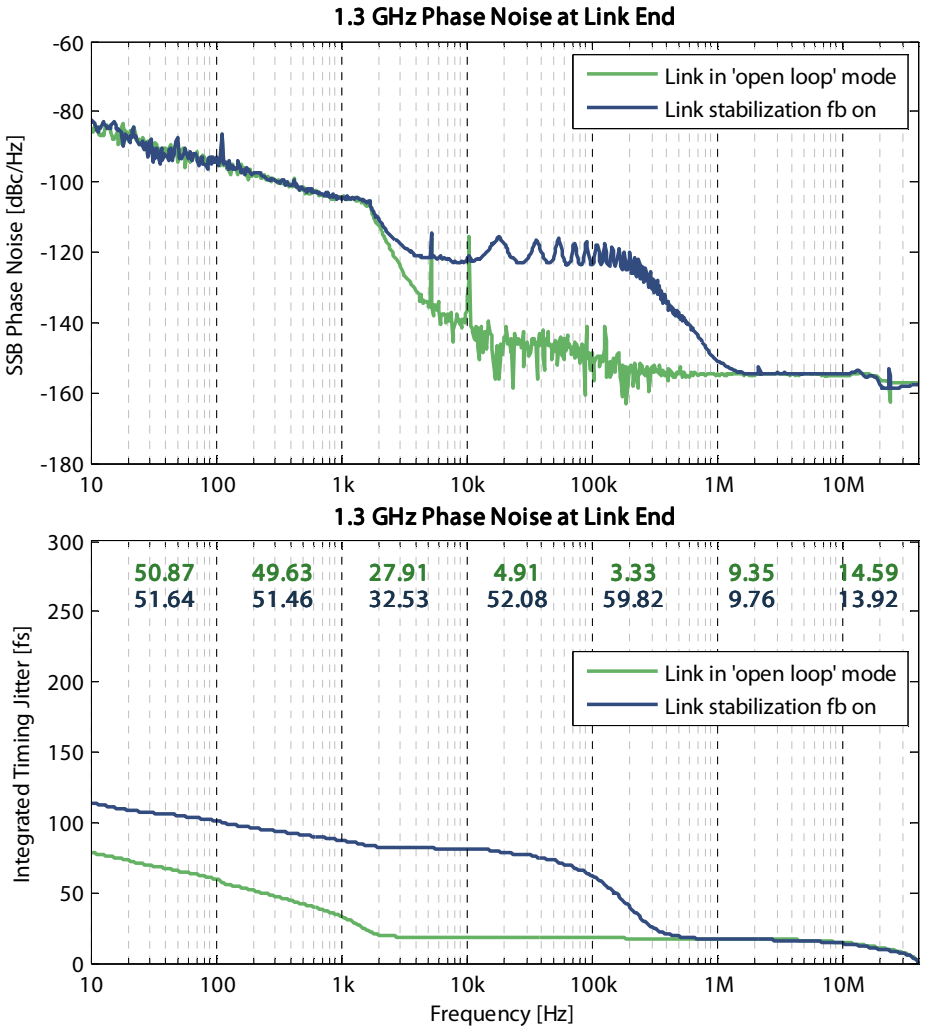
Phase noise of electrical signal after photo diode



- Locking bandwidth of MLO can further be reduced

First measurements of refernce signal in HHG laboratory

Conversion of the amplitude noise to phase noise in photo diodes



- Locking bandwidth of MLO can further be reduced
- The amplitude noise of the electrical pulse train degrades the phase noise of the stabilized link by about 70 fs [1 kHz – 10 MHz]

First measurements of refernce signal in HHG laboratory

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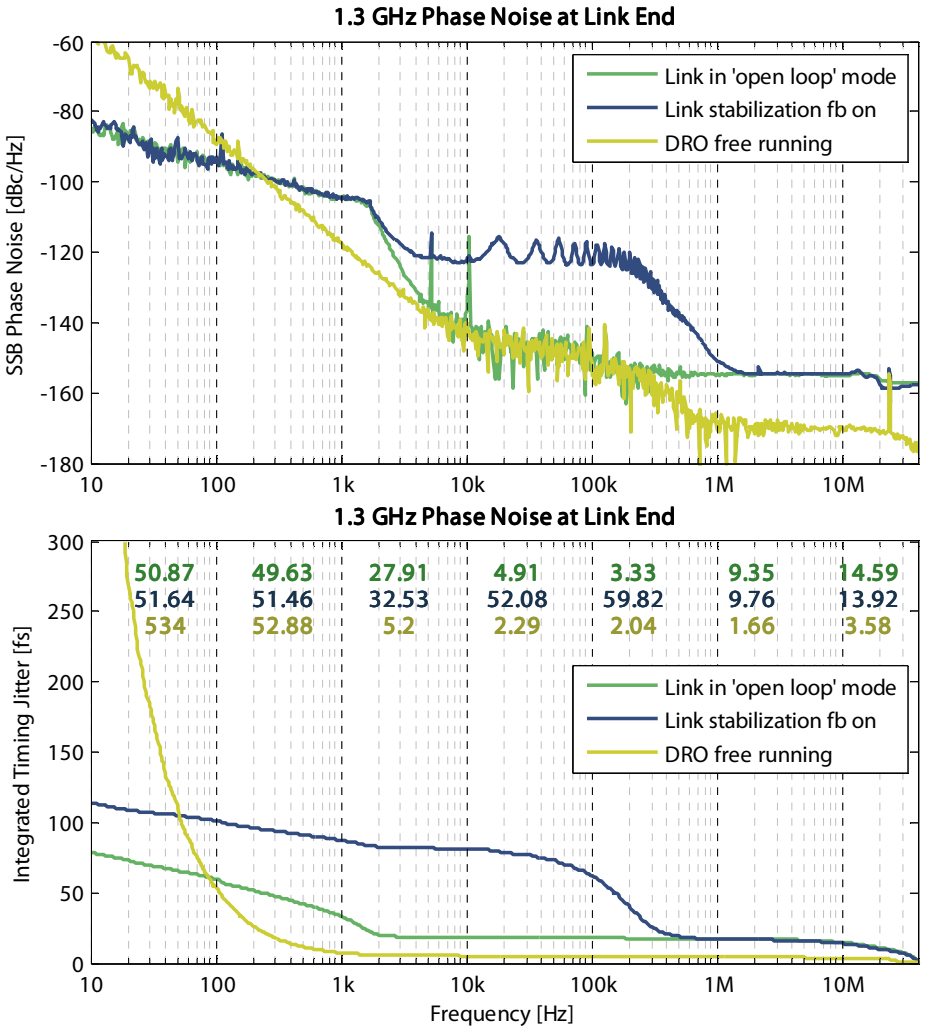

- Locking bandwidth of MLO can further be reduced
- The amplitude noise of the electrical pulse train degrades the phase noise of the stabilized link by about 75 fs [1 kHz – 10 MHz]
- A low noise DRO provides the possibility to filter out this noise

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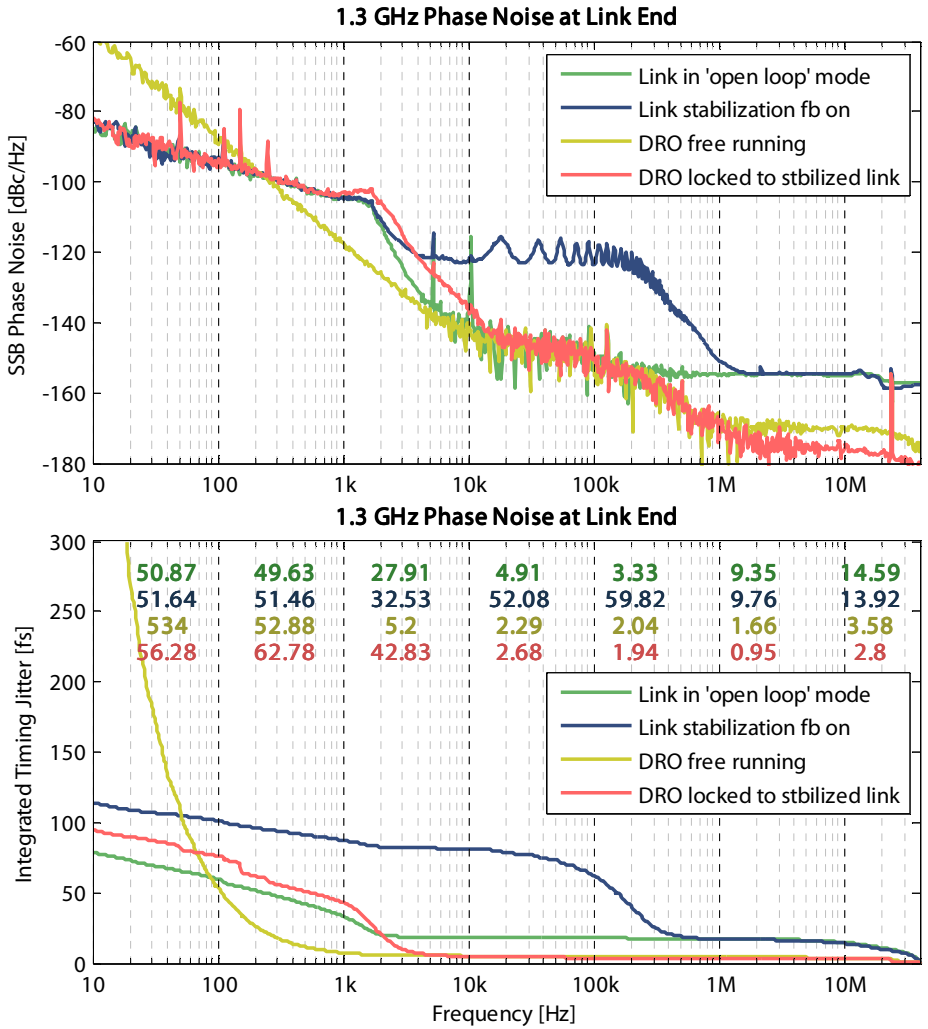

- Locking bandwidth of MLO can further be reduced
- The amplitude noise of the electrical pulse train degrades the phase noise of the stabilized link by about 75 fs [1 kHz – 10 MHz]
- A low noise DRO provides the possibility to filter out this noise
- The locked DRO follows the reference and provides low phase noise at higher offset frequencies

Conclusion and Outlook

- The optical synchronization system at FLASH is continuously improved

- Optical reference link to HHG laser is almost finished
- RF components are investigated and ready for assembly

- Link to pump-probe laser will be installed before end of this year

- Two-color balanced optical cross-correlator is already installed and tested at the injector laser
- It will extend the RF-based synchronization of the seed and pump-probe lasers until summer 2011

Thank you!