Femtosecond Stable Laser-to-RF Phase Detection for Optical Synchronization Systems.

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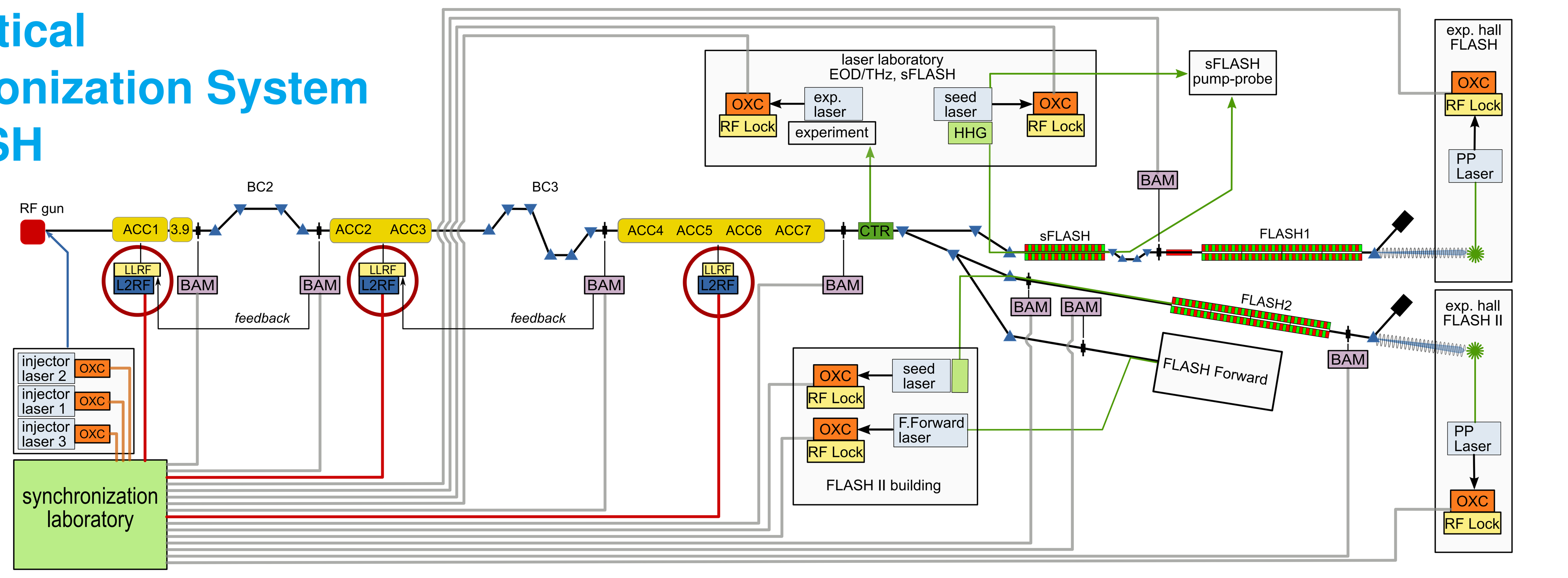
Introduction

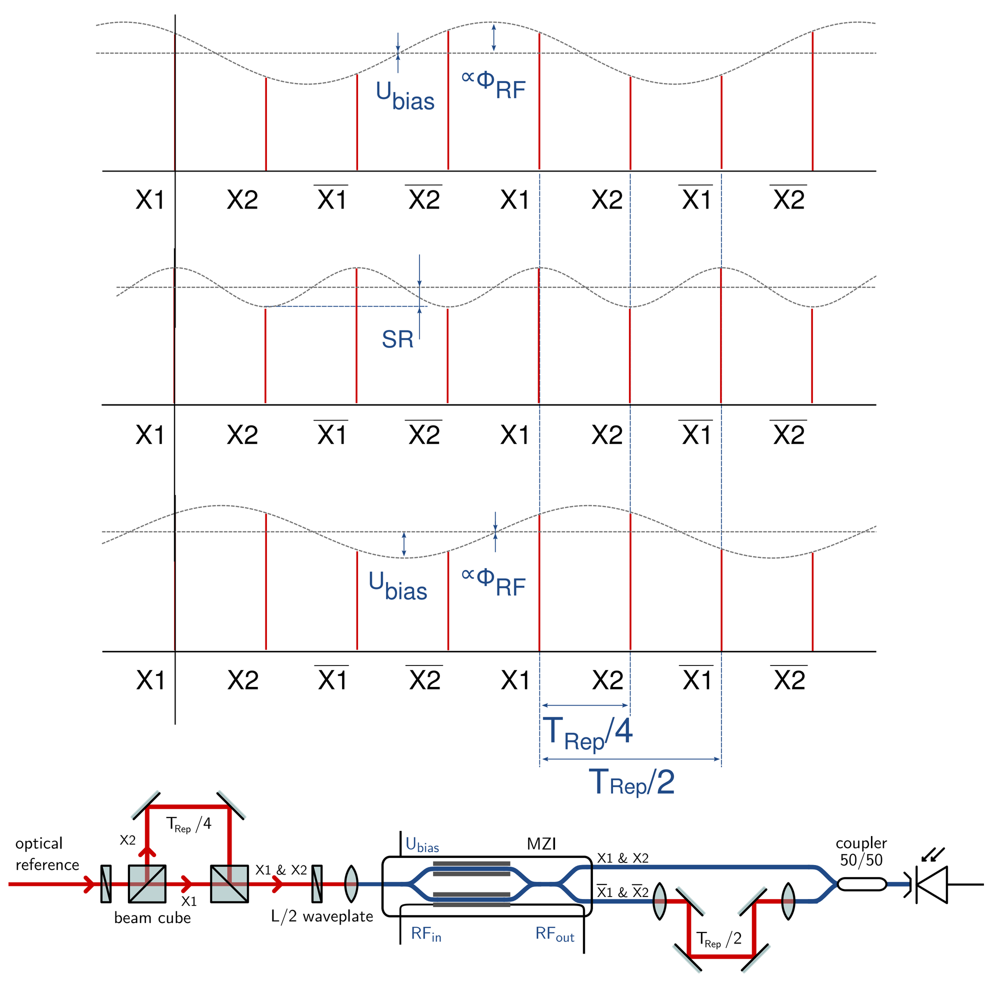
- **balanced Laser-to-RF detection** scheme using electro-optical modulators
- a **dual port Mach-Zehnder interferometer** is used as electro optical modulator.
- an error signal for the **active bias feedback** is provided by the detector as well
- scheme offers the possibility to **supply a precise synchronization signal to RF endstations**, derived from the pulsed optical synchronization system
  - laser pulses are transported from the master laser oscillator via **actively length stabilized fiber links**
  - local PLL in the accelerator, used to phase lock the 1.3GHz RF to the optical pulse train
- **out-of-loop measurement** in the laboratory showed a **stability of 3.5 fs over 24 h**

The Optical Synchronization System at FLASH



Principle of Operation

- **RF wave is sampled by laser pulses**
  - f_{RF} = 1.3GHz, f_{Rep} = 216.66MHz
  - laser pulses are split, **delayed by $T_{Rep}/4$** and **recombined** prior to the MZI
  - they **sample a positive and a negative slope** of the 1.3GHz RF Signal
  - a **second delay line ($T_{Rep}/2$)** is located in one output behind the dual port MZI
  - the recombined and **amplitude modulated pulse train** is guided onto a photo detector
- the amplitude modulation is **mixed down to baseband** in an IQ demodulator chip
- different errors in the MZI yield a different amplitude modulation of the laser pulses
- each modulation pattern can be individually detected by the readout electronics



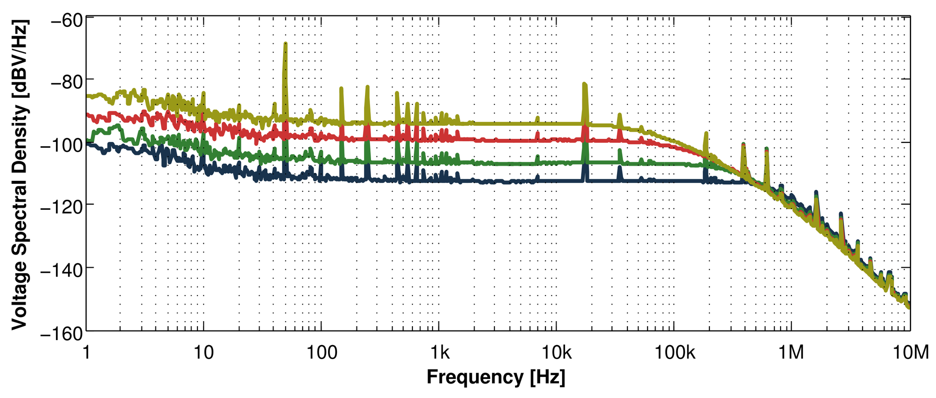
RF Cable Characterization at 25 °C

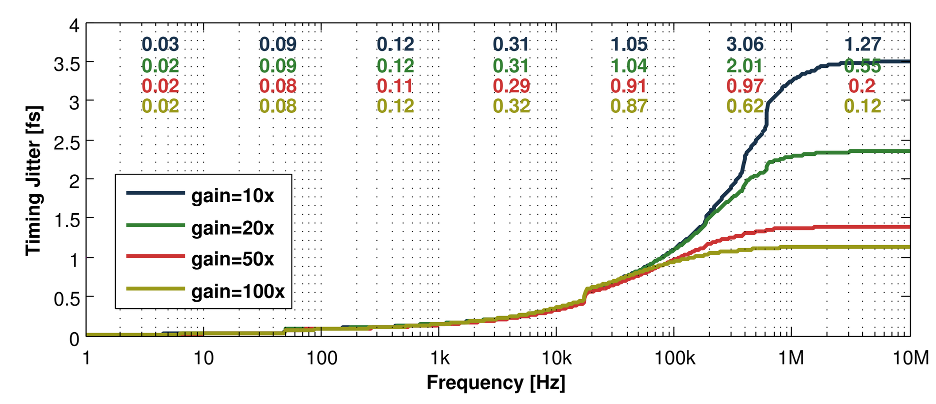
cable type	fs/%RH m	fs/K m
Pasternack		
PE-SR402FL	9.6	-183
Huber & Suhner		
Sucoflex 404	3.5	26
Teledyne Storm Microwave		
Phasemaster 190-874	3.4	15

Noise Floor Measurements

- the achievable accuracy of the L2RF phase detector is limited by the noise floor of the electronics
- the output noise has been determined without RF
- the integrals have been converted to femtoseconds using the given calibration constants
  - for a gain of 100, the noise over the **full bandwidth (1 Hz to 10 MHz) amounts to only 1.1 fs**
  - for frequencies **up to 50 kHz all curves accumulate about 0.8 fs noise floor**

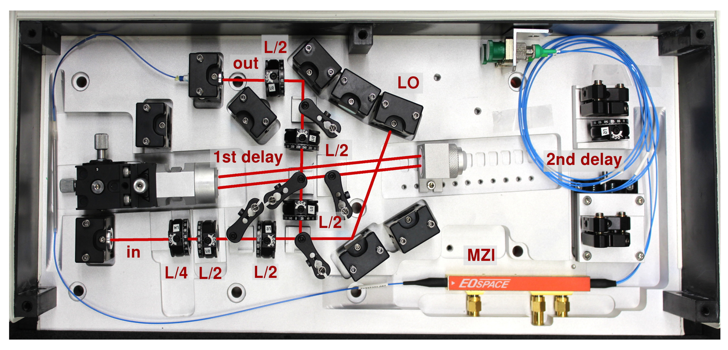
gain	10	20	50	100
K_φ [V/ps]	0.72	1.41	3.48	5.73

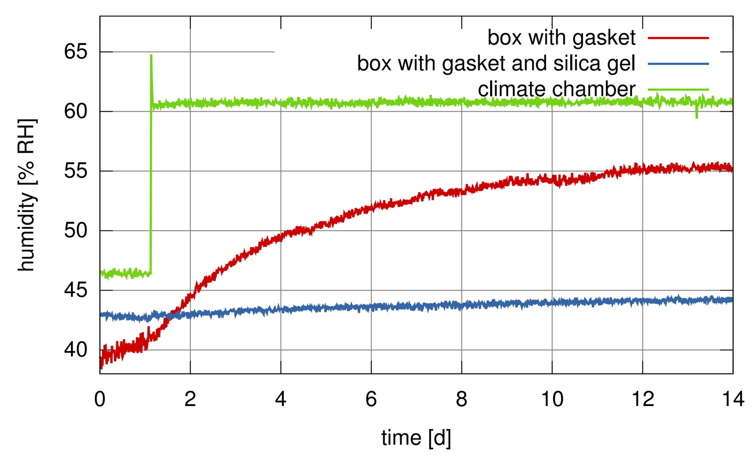


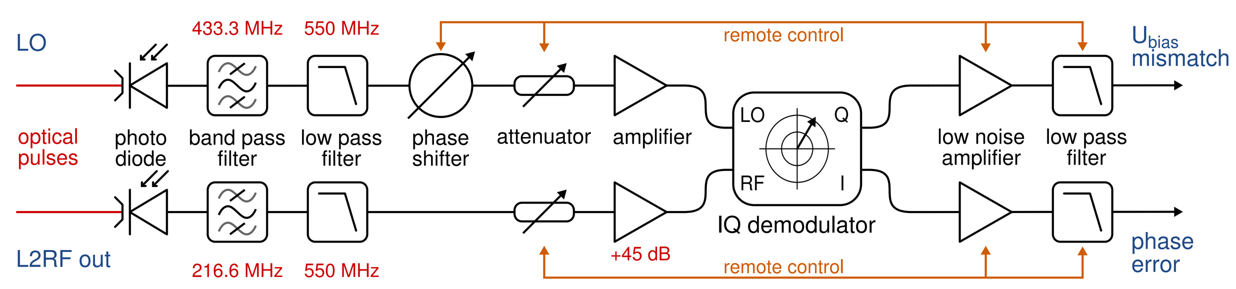


L2RF Engineered Components

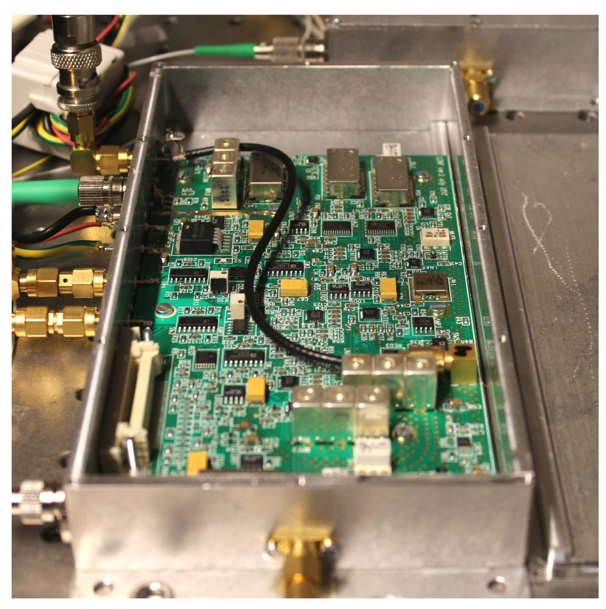
- **temperature stabilized aluminum base plate**
  - two peltiers provide temperature control
- MZI mounted directly to base plate
- performace evaluated to be (accelerator environment) **between 0.01 K and 0.1 K, depends on the position on the base plate**
- **humidity sealed housing** (HD-PE, gaskets)
- special silica gel provides humidity buffering
- 15 %RH outside change translate to **2.3 %RH change within two weeks**





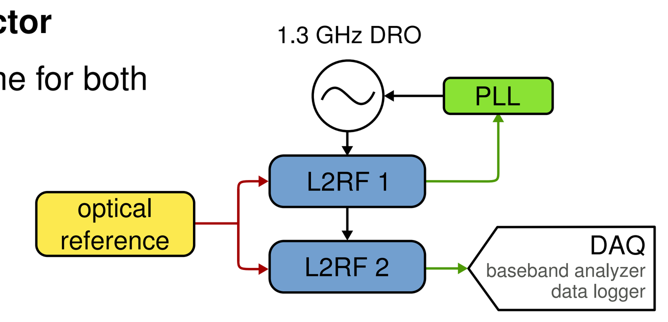


- detector electronics fully integrated
- compact design
- all on-board features are **remote controllable**
- ready for deployment in the accelerator
- **output signals for bias mismatch, phase drift** and splitting ratio of the first delay line

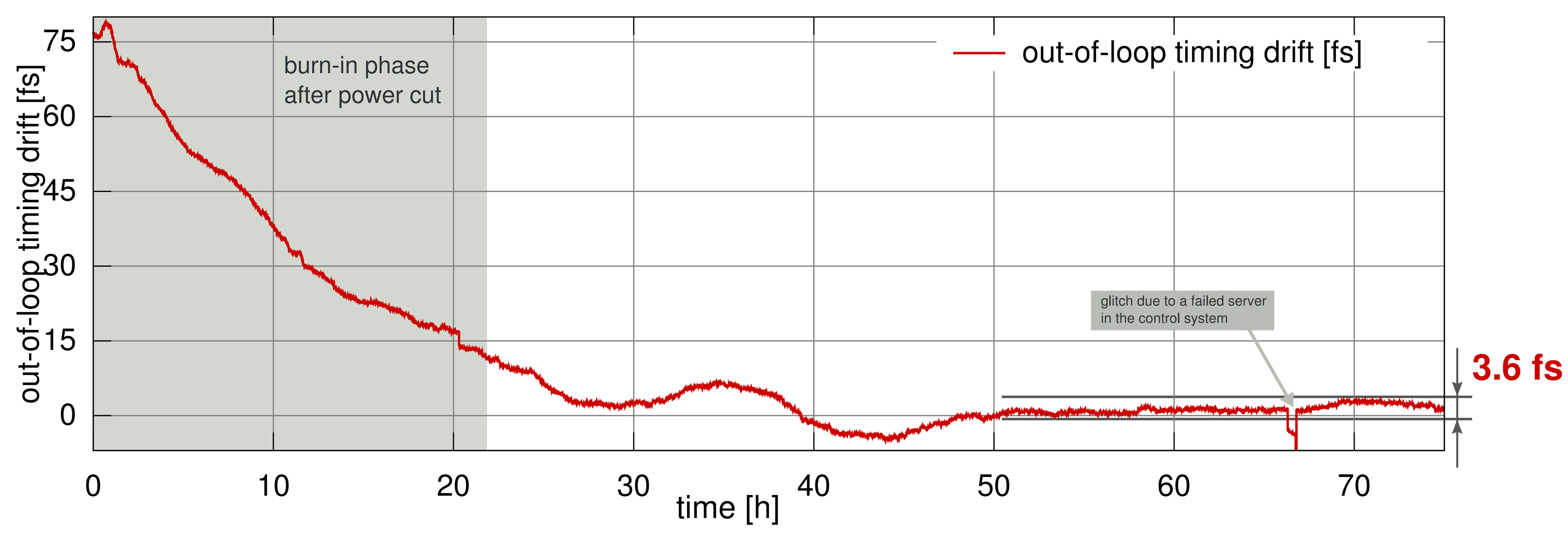


Long-Term Drift Measurement

- the stabilized **RF from the in-loop MZI** is guided through a second phase detector of the same kind, which is used as **out-of-loop detector**
  - the optical reference is the same for both Laser-to-RF setups
- K_φ = 1.41mV/fs (in-loop)
- K_φ = 0.73mV/fs (out-of–loop)



- **long-term measurement results (0.1Hz bandwidth):**
  - a first measurement was interrupted by a power cut
  - during the first 24 h the setup stabilizes from the power outage (humidity in RF cables)
  - **12fs peak-to-peak over 48 h and 3.6fs peak-to-peak over 24h**



Outlook & Summary

- the **integration of the opto-mechanics and the read out electronics** for the Laser-to-RF converter **are finished**
- the performance of the integrated components was **evaluated successfully**
- the measured peak-to-peak stability is **12 fs for 48 h and 3.6 fs for 24 h**.
- **the performance** for a 1.3 GHz laser-to-RF phase-locked loop is **worldwide unmatched**
- the stability requirements of sub-10 fs for the complete chain including the optical fiber link is reachable.
- integration of the components into a 19inch crate will start soon
- **two first prototypes will be assembled and tested at FLASH as soon as possible**
- the units tested at FLASH are the prototypes for the European XFEL

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