Pulsed Timing and Synchronization Systems

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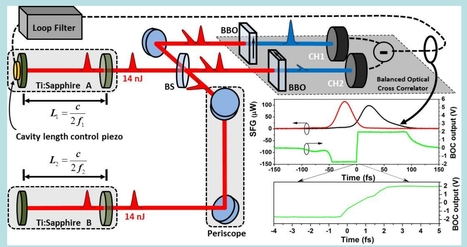
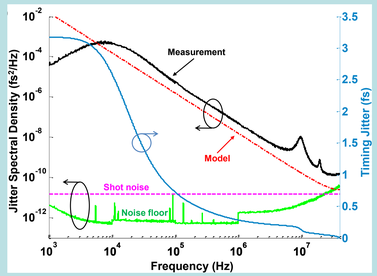
Abstract

Reliable timing transfer has been demonstrated. For a 340 m link of single mode fiber, we have achieved 5 fs rms drift (< 1Hz) over 7 days of operation. Using the same link, we have shown timing transfer between remote lasers with 3.7 fs of drift (< 1 Hz) over 5 hours of operation. We have also characterized fundamental jitter of mode locked lasers and have shown 13 as of integrated jitter (10 kHz – 40 MHz) for an 80 MHz Ti:Sapph laser, and 2.6 fs of integrated jitter (1 kHz – 40 MHz) for an 80 MHz Er-doped fiber laser (EDFL). Using a simulation based model we also determine the requirements for a future FEL light source.

Ti:Sapph Jitter Measurement with BBO



80 MHz EDFL



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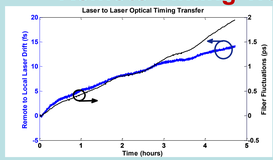
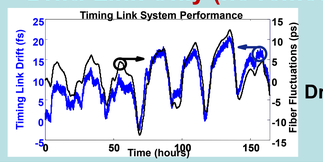
Remote Timing Transfer: Drift

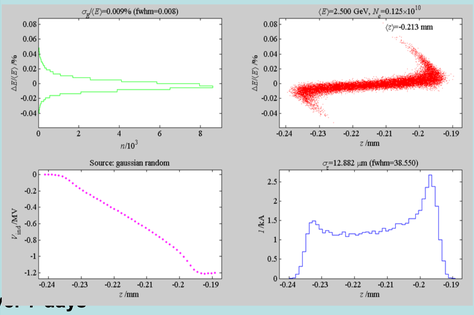


- **3.7 fs (RMS) (<1 Hz BW) over 5 hours**
- Mostly slow thermal drift in opto-mechanics

Drift: Link Only (no remote laser)

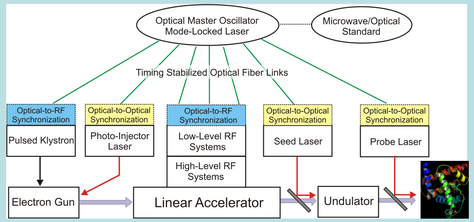


Drift: 5 fs (RMS) ov



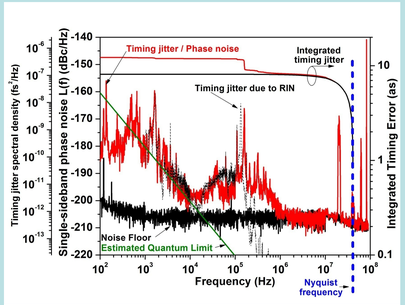
Electron beam properties after two-stage compression and acceleration to final energy of 2.5 GeV.

Precision Long Range Timing Distribution



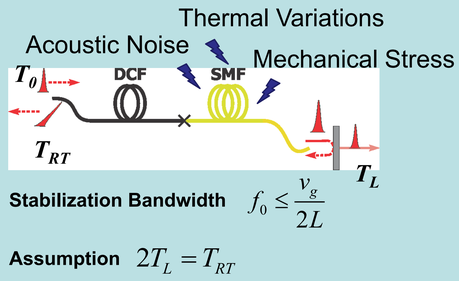
fs X-ray laser pulses

80 MHz Ti:Sapph



Submitted to Nature Photonics.

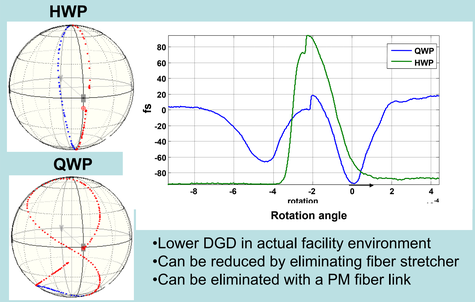
Noise in Timing Link



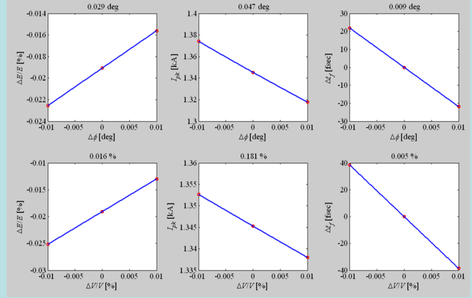
Stabilization Bandwidth $f_0 \le \frac{v_g}{2L}$

Assumption $2T_L = T_{RT}$

PMD - Effects

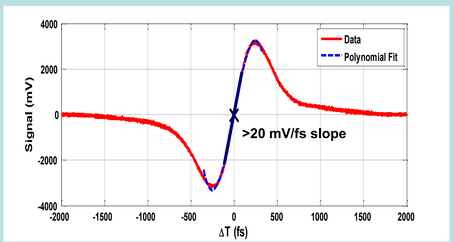


- Lower DGD in actual facility environment
- Can be reduced by eliminating fiber stretcher
- Can be eliminated with a PM fiber link



Jitter studies for linac L1. The plots (L-R) indicate the dependence of energy, peak current, and timing respectively on RF synchronization (upper row) and amplitude (lower row). The value above each plot gives the jitter requirement to meet tolerances of dE/E < .01%, dI/I < 10%, and dt < 20 fs.

Balanced Crosse Correlator Transfer Function



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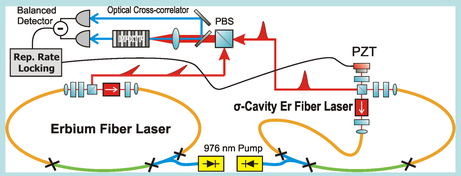
EDFL Jitter Measurement with PPKTP



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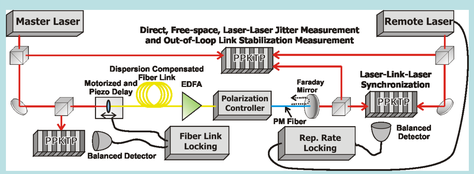
Remote Timing Transfer



- 200 MHz EDFL
- Lasers locked through 300 m fiber link
- Out-of-loop link stabilization measurement

Linear Accelerator Simulation

A simulation model of a 2.5 GeV SRF linac has been developed to test timing synchronization and electron beam, laser, and accelerator requirements for a future FEL light source.

The model assumes 1.3 GHz TESLA-type SRF cavities with 12 MW/m gradient and individual power sources for each cavity. The linac is composed of three sections that accelerate the beam, chirp its energy, linearize the longitudinal distribution, and compress the beam.
The program LiTrack is used to track 50,000 macroparticles. LiTrack models longitudinal time-energy dynamics including effects of RF amplitude and phase jitter, laser arrival time jitter, wakefields, and bunch charge and current jitter.

The facility is especially sensitive to the linac sections that chirp the beam upstream of the bunch compressors. The tightest requirements are on linac L1 for both phase and amplitude. Timing jitter required is dt < 20 fs and energy jitter dE/E < 0.005%

Conclusions

- Fundamental timing jitter of mode locked lasers have been measured with attosecond resolution.
- Long term stable timing transfer between remote lasers is demonstrated
- Using a simulation based model, synchronization, electron beam, and laser beam requirements of future FEL light sources are calculated

References

1. A. J. Benedick, J. G. Fujimoto, F. X. Kärtner, “Ultrashort laser pulses: Optical flywheels with attosecond jitter,” submitted to Nature Photonics.

2. J. Cox and F. X. Kärtner, “A femtosecond-precision, fiber-optic timing transfer system with long-term stable, polarization maintaining output,” submitted to Review of Scientific Instrumentation.