TWO COLOR BALANCED OPTICAL CROSS CORRELATOR TO SYNCHRONIZE DISTRIBUTED LASERS FOR SHINE PROJECT

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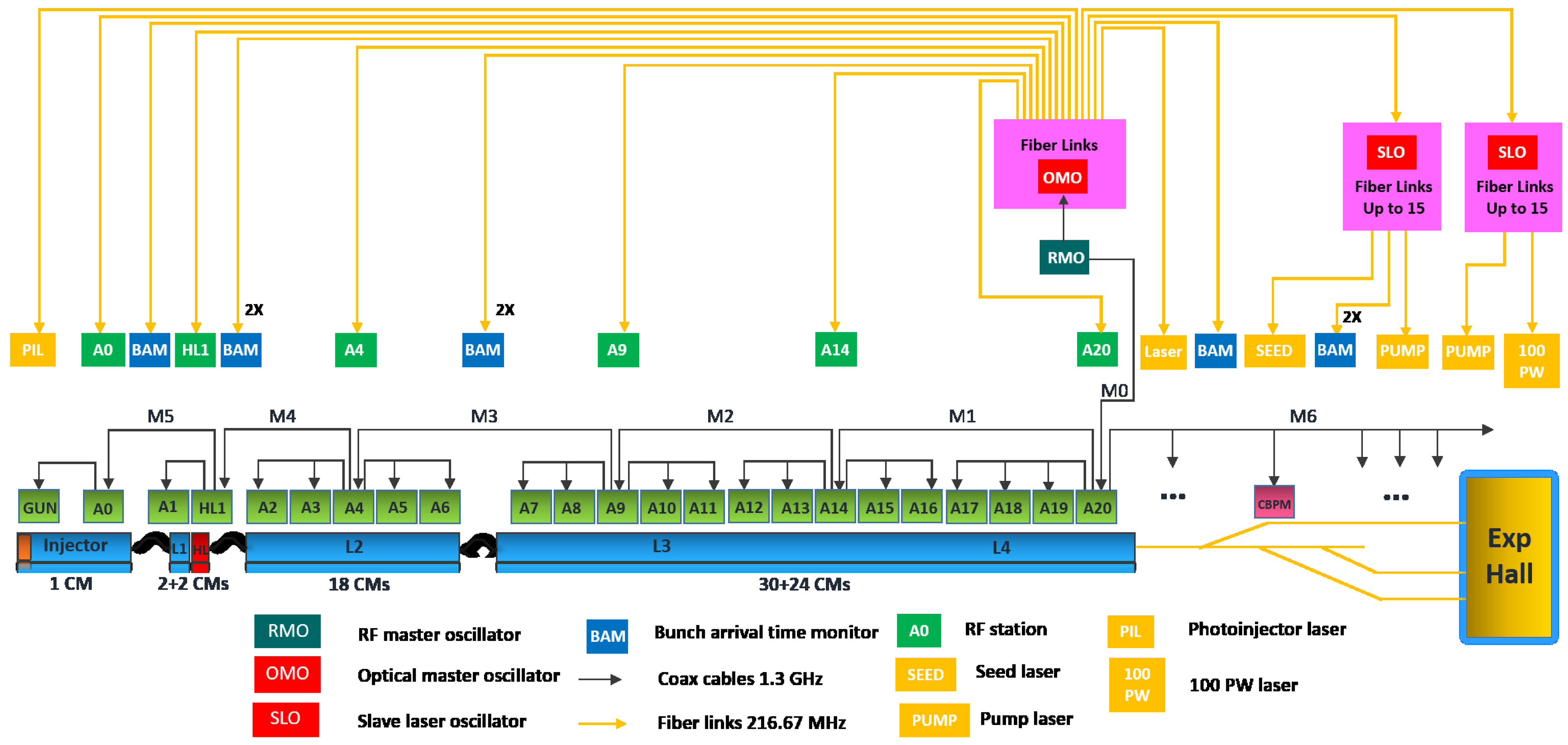
Abstract

- High precision timing synchronization systems are critical for FELs because X-ray temporal duration is highly sensitive to the overall synchronization between the injector laser, the Linacs, and the bunch compressors.
- It is crucial to synchronize various slave laser oscillator (drive laser, seed laser, pump-probe laser) to the master reference laser with a long term stability of better than 10fs.
- Two color balanced optical cross correlator (TCBOC) for locking slave laser to master laser is under developing.
- TCBOC with a sensitivity 6.31mV/fs is being tested by linking a commercial Ti:sapphire oscillator to a locally installed timing reference source.

Schematic of Synchronization System for Shanghai High Repetition Rate XFEL and Extreme Light Facility (SHINE)



Theoretic Frame of TCBOC

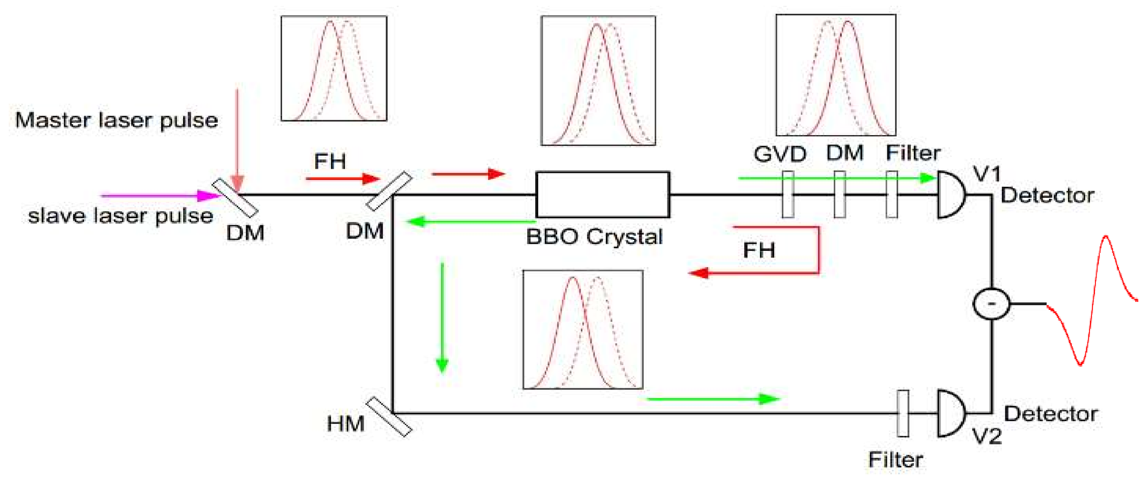


Figure 1: Principle of timing detection using TCBOC [1].
FH: Fundamental harmonics of input pulses; DM: Dichroic mirror; HM: high reflective mirror; GVD: Silica slab for group velocity delay.V1 and V2: output voltage from photodetector.

Supposing two Gaussian-shaped input pulses with their intensities $I_1(t)$ and $I_2(t)$, the intensity $I_{sum}(t)$ of generated sum frequency light is expressed by the convolution of the two input pulses:

$$I_{sum}(t) = \frac{1}{\sqrt{2\pi(\sigma_1^2+\sigma_2^2)}} exp\left\{-\frac{(t-\Delta t)^2}{2(\sigma_1^2+\sigma_2^2)}\right\}$$

Intensity changes $I_{sum}(t)$ of sum frequency pulse is a measure for the timing changes.

- Δt is relative timing between the two input pulses;
- σ_1, σ_2 are relative to the full width at half maximum (FWHM) of input pulses according to

$$\text{FWHM} = 2\sqrt{2ln2}\sigma \approx 2.354\sigma$$

The repetition period difference ΔT between the two pulse trains

$$\Delta T = \frac{1}{f_M} - \frac{1}{f_M + \Delta f} = \frac{\Delta f}{{f_M}^2 + f_M \Delta f} \approx \frac{\Delta f}{{f_M}^2}$$

- Δf is the frequency difference;
- f_M is master laser oscillator frequency, $\Delta f \ll f_M$;

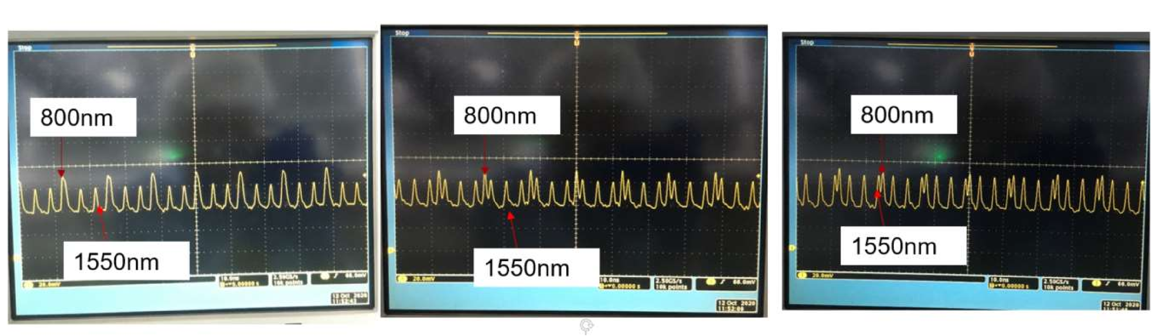


Figure 2: Pulse sliding due to frequency difference.
- Master laser f_M is a harmonics of the slave laser f_s;
- 1550nm laser oscillator is 238MHz;
- 800nm Laser oscillator is 79.33MHz;

Recorded time scale in oscilloscope has to be converted to the relative time scale between the pulses by a factor ξ

$$\xi = \frac{\Delta f}{f_M}$$

Experimental Setup

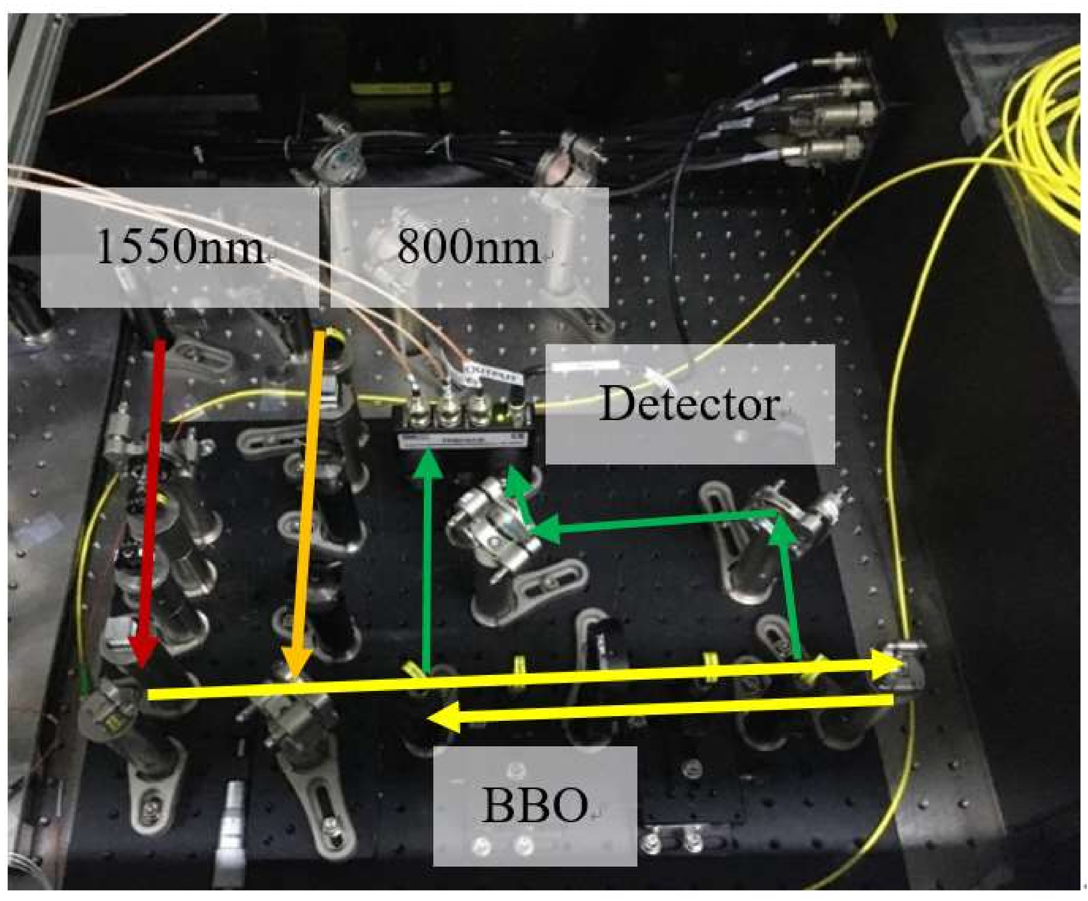
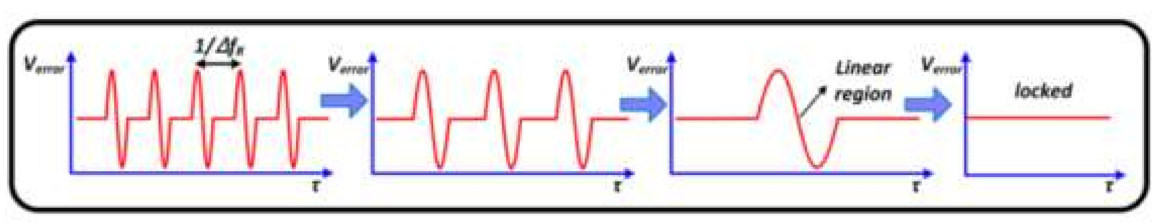


Figure 3: Experimental setup of two color balanced cross correlator

- Onefive Origami-15, 1550nm±10nm pulses, 17.7mW;
- Ti:sapphire laser oscillator(Micra, Coherent) ,800nm±40nm, 45mW;
- A free space balanced amplified photodetector (PDB210A/M, Thorlabs) with gain of 500×10³V/A;
- Beta barium borate (BBO) with a thickness 5mm;

Phase match angle is 22.2 Degree; collinear type- Ⅰ configuration(ooe); sum frequency signal of 527nm[3].



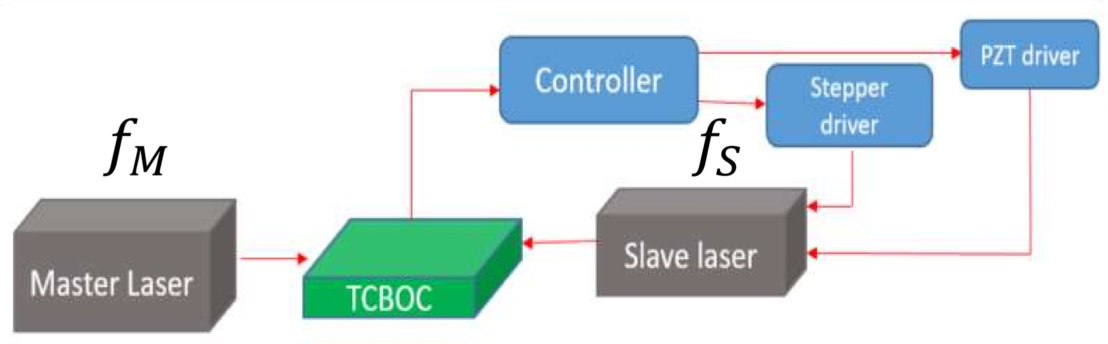


Figure 4: Schematic of TCBOC feedback control system to synchronize the pulse trains of two ultrafast laser at different wavelength [1]

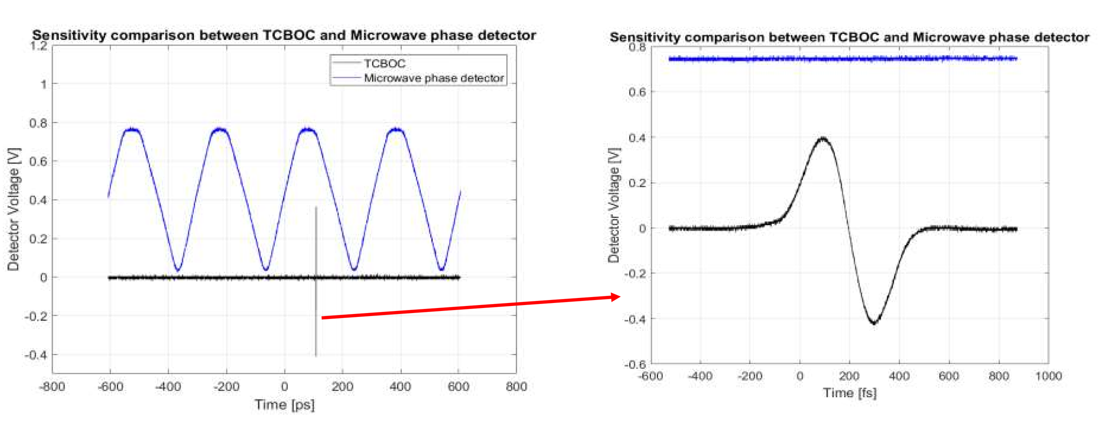


Figure 5: Sensitivity comparison between TCBOC and a microwave phase detector. Sensitivity improved from tens of $\mu V/fs$ to several mV/fs.

Experimental Results

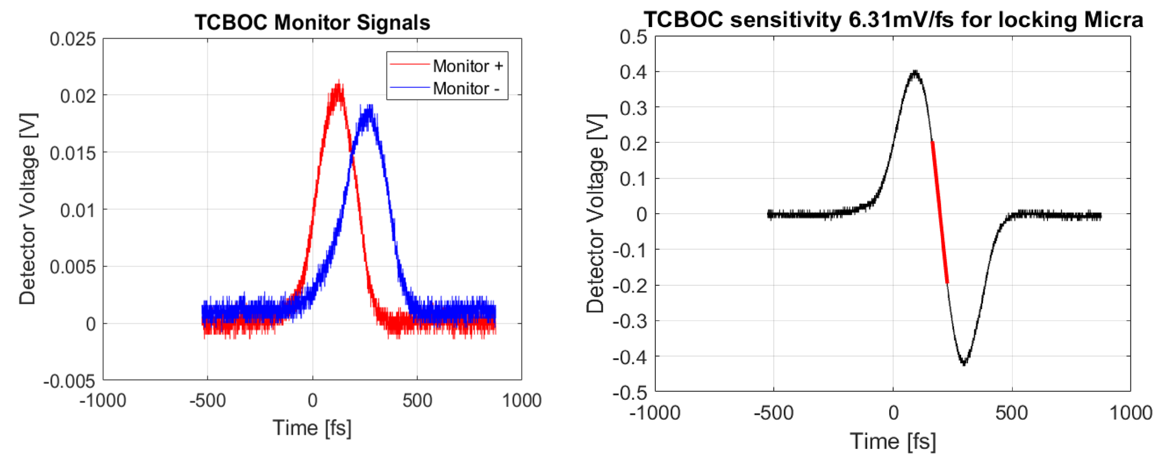


Figure 6: Measured 527nm sum frequency signal intensity on a balanced detector (Left); Measured difference signal by two color balanced optical cross correlator (Right). The slope of red part curve is 6.31mV/fs around zero crossing.

- Select the red part of the curve, which given a voltage difference 0.4V and time difference 63.3fs;
- Extract a slope around the zero crossing of 6.31mV/fs for the feedback control loop;
- Further investigation input pulse length and changing the group delay glass.

Summary

- An two color balanced cross correlator was developed and tested, which will be used to phase lock two individual laser systems operating at different center wavelength and different repetition rates.
- Difference signal of sum frequency have been obtained, which shows a sufficient slope around zero crossing for phase locking.
- The next step is to make short and long term stability measurements with an identical out of loop TCBOC.

Acknowledgements

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References

[1] Kemal Shafak, "Large-scale laser microwave synchronization for attosecond photon science facilities", PhD thesis, *Universität Hamburg*, Hamburg, Germany, 2017.

[2] S. Schulz et al., "An optical cross correlation scheme to synchronize distributed laser systems at FLASH", in *Proc. 11th European Particle Accelerator Conf. (EPAC'08)*, Genoa, Italy, June, 2008, paper THPC160, pp. 3366-3368.

[3] Chunlei Li et al., "Measurements of ultraviolet FEL seed laser pulse width broading in thin β-BBO crystal", in *Proc. 12th International Particle Accelerator Conf. (IPAC'21)*, Campinas, SP, Brazil, May. 2021, paper WEPP20.