Optimized BOMPD demonstrates attosecond timing precision

Synchronizing laser sources with their microwave signals is important for many applications. For those applications that require high timing precision, the Balanced Optical Microwave Phase Detector - BOMPD - offers a solution. But is the BOMPD also the right tool for the applications requiring attosecond resolution?

The BOMPD measures the phase difference between a microwave signal and optical laser pulses by comparing the signals directly in the optical domain. This offers very low jitter below 20 femtoseconds and has proven the BOMPD as an established tool for high precision synchronization tasks. However, there are some experiments that require synchronous laser-microwave networks with even higher timing precisions at the attosecond level.

Such challenges Dr. Ming Xin and Dr. Kemal Shafak from the Center for Free-Electron Laser Science (CFEL) in Hamburg were facing, when they investigated timing distribution systems for next generation X-ray free-electron lasers (see Figure 1). In 2017, they could show that an "optimized BOMPD" can offer even attosecond performance.

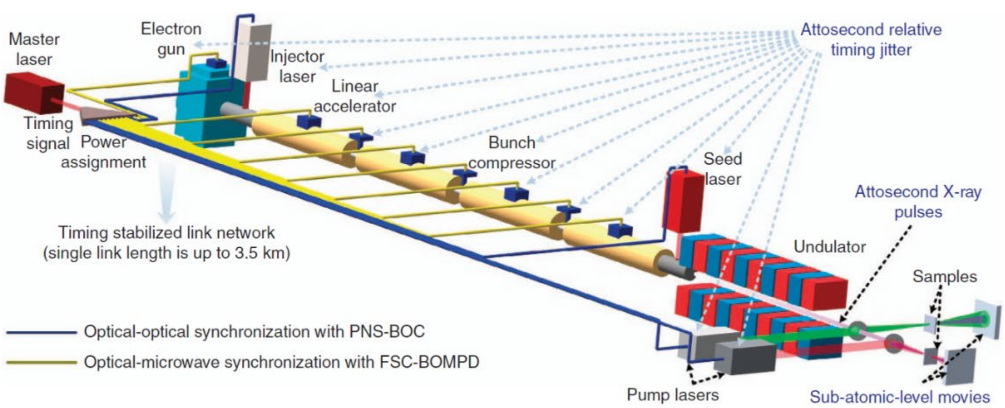

Figure 1 Layout of a timing distribution system for next-generation free-electron lasers. (from [1])

To identify areas for improvement, the scientists thoroughly analyzed the potential noise sources in such timing distribution systems. And they proposed new ideas on how to eliminate these noise contributions in the system. One of the obstacles in achieving attosecond precision with a BOMPD was the long-term drifts caused by the environment. To eliminate this drift, they addressed multiple components: they replaced the microwave phase shifters with optical delay lines, built a compact fiber-based Sagnac interferometer, and invented a new modulation scheme to increase the signal-to-noise ratio (SNR) at photodetection (see Fig.2).

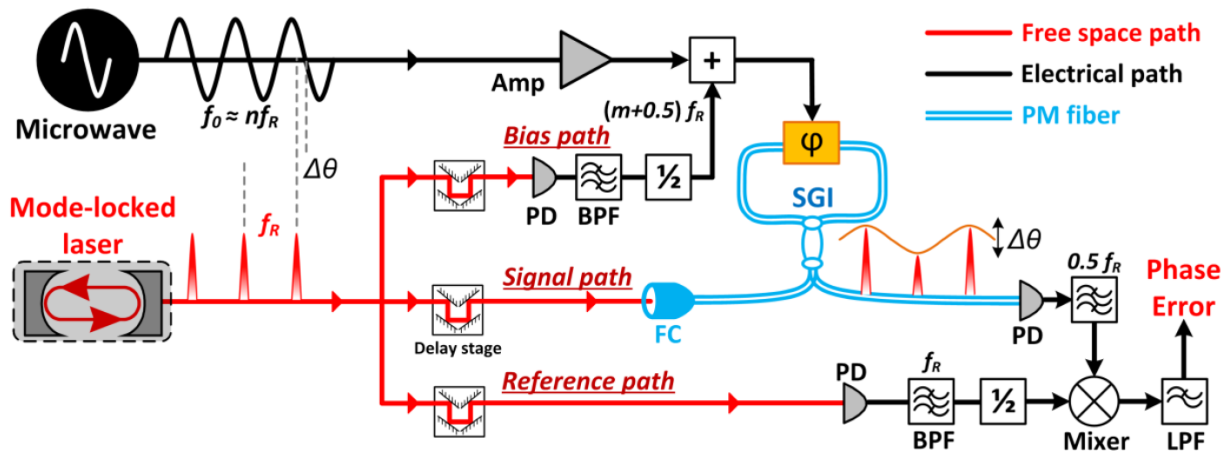

Figure 2 Schematics of a free-space-coupled BOMPD for attosecond timing precision (Abbreviations: Δθ: Phase error between the microwave and optical pulse train; PD: photodetector; BPF: bandpass filter; ½: frequency divider; +: microwave diplexer; Amp: electronic amplifier; LPF: lowpass filter; φ: phase modulator; SGI: Sagnac-interferometer; FC: fiber collimator).

The added optical delay lines allowed precise phase tuning without backlash, microwave reflection and loss. This novel BOMPD architecture effectively reduced the long-term drifts caused by the environment. And it provided a high SNR and > 10x improvement in terms of long-term timing stability. Further, it showed an improved timing sensitivity of 0.25 mV/fs, which is crucial for tight locking of lasers and microwave sources.

To verify the improved design, the team around the CFEL scientists measured the phase difference between a remotely synchronized laser and microwave sources in a kilometer-wide laser-microwave network. With their measurements, they could show that the whole laser-microwave network now had a long-term precision of 670 as RMS drift over 18h. Which is more than an order of magnitude improvement compared to the previous best results using optical frequency-combs.

The demonstrated timing precision paves the way for atomic and molecular movies at the attosecond timescale. And it opens up many new research areas in biology, drug development, amongst others. Kemal Shafak confirms: "The experiments show that the BOMPD with the demonstrated improvements is the right tool for attosecond precision." After finishing his PhD at CFEL, he is now working as the head of timing at Cycle GmbH, a DESY-Spin-off company for precise timing products.

He continues: "But not everyone needs this precise time resolution. At Cycle, we offer a simpler BOMPD with < 20fs timing precision as our standard product. It provides a good tradeoff between precise timing, reliability and pricing." And then he adds with a scientist's smile: "But if you need higher resolution and even attosecond precision, I am definitely looking forward to your challenge."

References

1. M. Xin, K. Safak, M. Y. Peng, A. Kalaydzhyan, W.-T. Wang, O. D. Mücke, and F. X. Kärtner, "Attosecond precision multi-kilometer laser-microwave network," Light: Sci. Appl. 6(1), e16187 (2017).