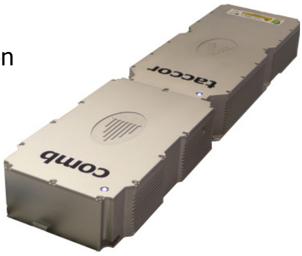
taccor comb

High-power frequency comb with 1GHz mode spacing

- Turn-key GHz femtosecond **taccor** laser
- Extension module for CEO frequency detection and stabilisation
- Repetition rate stabilisation via **TL-1000**
- Large mode spacing of 1GHz
- High-power per mode (typ. 1µW)
- Large modulation bandwidth for feedback loop (typ. 250kHz)
- Stable and robust



Overview

To support applications of the **taccor** as a frequency comb, Laser Quantum has added the comb extension module to its successful range of 1GHz lasers, now making the **taccor comb** available to the market. It consists of a matched dispersion compensation module, supercontinuum generation, and a nonlinear f-to-2f interferometer, all sealed in a compact housing which is attached to the turn-key femtosecond **taccor** laser system. The extension module consumes around 800mW of the **taccor**'s output power so that up to 1W can be made available for experiments via a dedicated exit port or can be further broadened to a supercontinuum spectrum using an optional second extension module.

In addition to the repetition rate RF signal at f_R, the **taccor comb** provides a long-term stable RF signal at the carrier-envelope offset (CEO) frequency f_{CEO} (Fig. 1) with more than 40dB signal-to-noise ratio (Fig. 2). Feedback electronics to stabilise f_R and f_{CEO} are provided in the form of Laser Quantum's **TL-1000** unit and the XPS800-E from our partner, Menlo Systems. The **taccor comb** provides the ideal solution for customers who seek to have a comb source with easy access to the visible and NIR spectral range at a high mode power level in a sealed, plug and play architecture. The high repetition rate of 1GHz leads to a large mode spacing and high power per mode on the order of typically 1µW after broadening (Fig. 3). The repetition rate of the **taccor comb** also enables generation of significantly more supercontinuum average power in a PCF compared to systems at 100MHz (100x more) or 250MHz (16x more) before significant coherence loss via nonlinear noise amplification is suffered (Fig. 4). This leads to a significantly enhanced signal to noise ratio for heterodyne beat measurements or direct frequency comb spectroscopy applications.

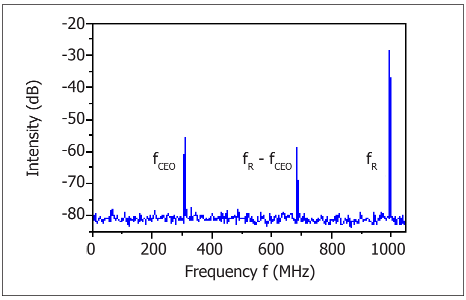


Fig. 1 RF output of the comb module (before amplification and filtering of f_{CEO}).

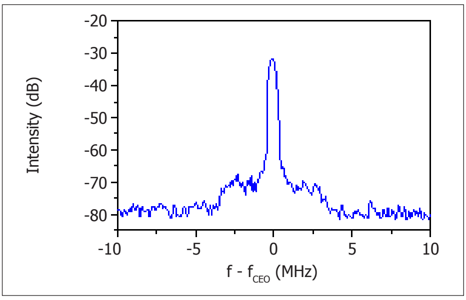


Fig. 2 Close-up of the unlocked f_{CEO} signal after amplification and filtering showing a SNR larger than 40dB measured with a resolution bandwidth of 100kHz.

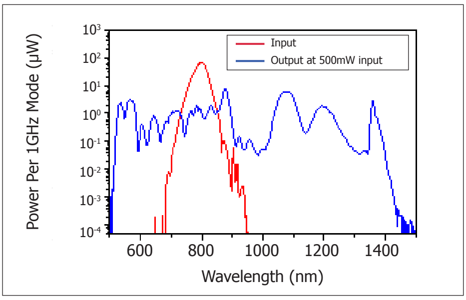


Fig. 3 Red: Typical **taccor** output spectrum used for CEO detection and comb applications. Blue: Output spectrum after 1m photonic crystal fiber.

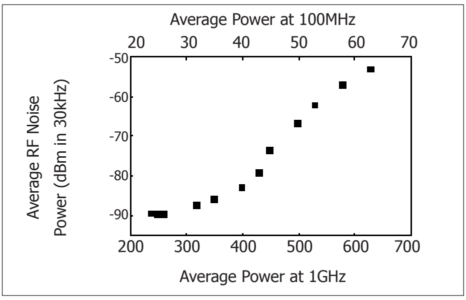


Fig. 4 Typical average RF noise in the CEO detection as function of power coupled through a PCF for supercontinuum generation for a 100MHz laser (top scale) and a 1GHz laser (bottom scale). Above a threshold pulse energy of around 30pJ, nonlinear noise amplification quickly renders the PCF output incoherent, thus heavily favoring a 1GHz system. Data taken from reference [1].

Turn-key design for stable performance

The extension module in the **taccor comb** preserves the long-term stability of the turn-key **taccor** laser. The system delivers a stable RF output at f_{CEO} over many days without realignment or signal loss (Fig. 5a). The drift in the free-running f_{CEO} (Fig. 5b) is due to day/night variations in the laboratory temperature.

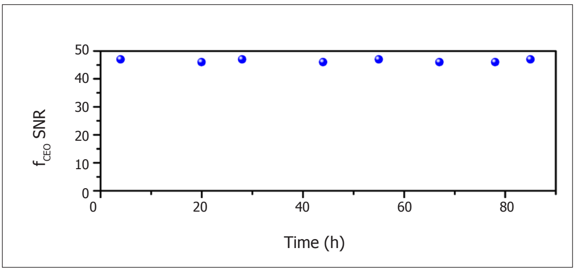


Fig. 5a Signal-to-noise ratio of f_{CEO} measured over 80h without realignment.

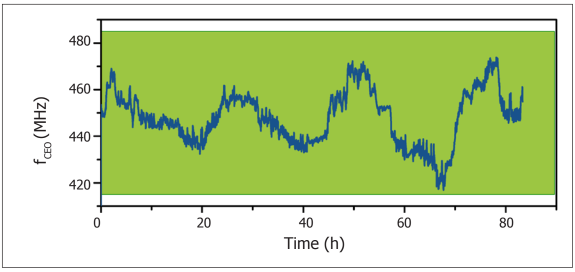


Fig. 5b Free-running f_{CEO} measured over 80h.

Carrier envelope phase stabilisation

The **finesse pure CEP** pump laser built within the **taccor** features our patented CEPLoQ™ technology and allows direct modulation of the 532nm pump light leading to a faster and more stable response than traditional methods, e.g. using an AOM. Thus, a very high feedback bandwidth can be applied to phase-lock the CEO frequency to an external reference.

Phase detection between the measured f_{CEO} and a given reference signal is performed and converted into a feedback signal to the **finesse pure CEP** input using the XPS800-E stabilisation unit by Menlo Systems (Fig. 6 & 7).

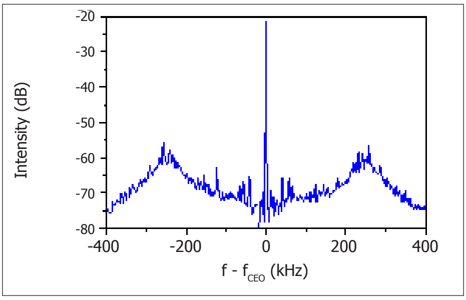


Fig. 6 Close-up of the phase-locked f_{CEO}. The data is acquired using a resolution bandwidth of 200Hz. The servo bandwidth is about 250kHz as indicated by the symmetrical peaks around the carrier.

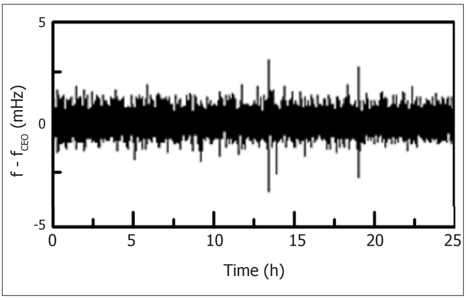


Fig. 7 Long term deviations from the lock point of a CEO beat stabilised at 310MHz over 25h showing exceptional stability (limited by RF reference input).

Repetition rate stabilisation

Laser Quantum offers the timing stabilisation unit, **TL-1000**, as an accessory to the **taccor** series of high-speed femtosecond oscillators. The **TL-1000** allows the tight phase-lock of an oscillator's repetition rate to an external reference such as a synthesiser or another modelocked laser, with a residual timing jitter below 100fs. A low timing jitter option is available that suppresses the timing jitter to typically below 10fs (Fig. 8, 9 & 10). A suitable 10GHz reference synthesiser must be provided by the customer. Stabilisation is performed at a higher repetition rate harmonic.

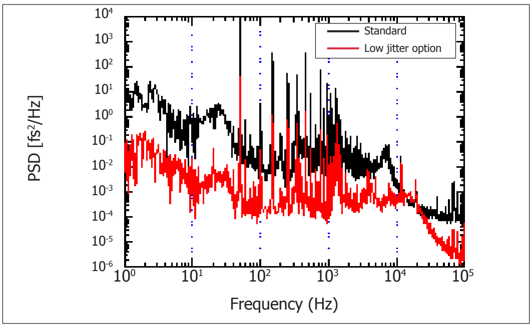


Fig. 8 Phase noise measurements of the **taccor** repetition rate f_R stabilised using the **TL-1000**. Black and red graphs correspond to stabilisation using the standard and low jitter configurations of the **TL-1000** unit.

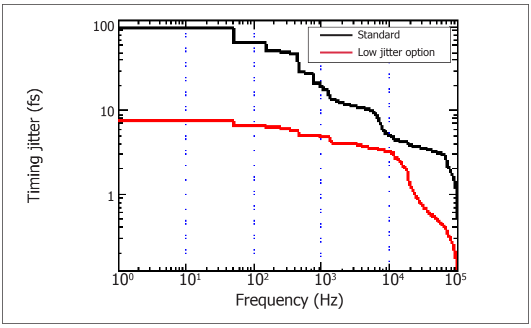


Fig. 9 Timing jitter as acquired by integrating the phase noise from Fig. 8. Stabilisation at the 10th harmonic of f_R leads to a sub-10fs timing jitter.

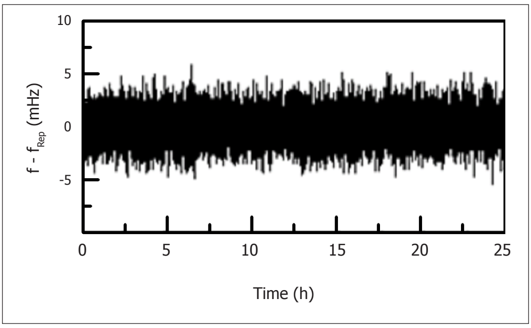


Fig. 10 Long term deviations of the stabilised **taccor** repetition rate over 25h showing exceptional stability (limited by RF reference input).

Upgrades

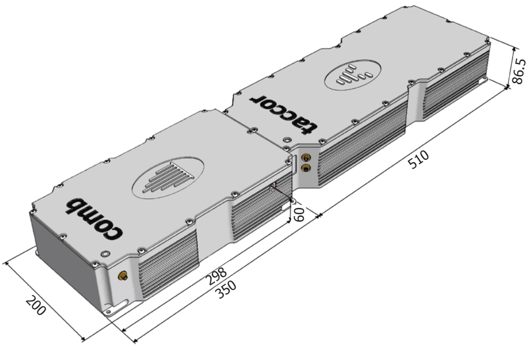
The **taccor comb** can be upgraded by an additional extension module that can include one or two additional photonic crystal fibers for further broadening of the **taccor** laser output, e.g. if a specific supercontinuum spectrum is required for experiments.

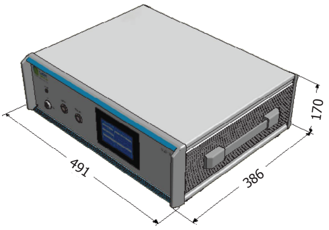
taccor comb

High-power frequency comb with 1GHz mode spacing

Laser QUANTUM

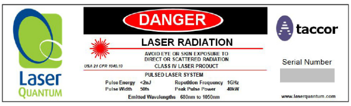
Dimensions (mm)





Other information

- Cooling system included
- f-to-2f interferometer included
- Weight: 50kg
- Umbillical length: 2m



Drawings are for illustrative purposes only. Please contact Laser Quantum for complete engineer's drawings.

Specifications*

	taccor comb
Repetition rate/comb spacing	1GHz
CEO beat signal-to-noise ratio	>40 dB in 100 kHz RBW
Supercontinuum module power per mode	Typically 100 nW to 1µW
Stability	3×10^{-13} in 1s or same as reference[1], whichever applies first
Accuracy	Same as reference[1], 10^{-19} has been demonstrated [2]

* Laser Quantum operates a continuous improvement programme which can result in specifications being improved without notice.
[1] The customer must provide a suitable reference synthesisers for the f_{CEO} and f_R locks, the performance of the system will be determined by these references.

References

[1] L. Hollberg et al., "Optical frequency standards and measurements", IEEE J. Quantum Electron. **37**, 1502 (2001)
[2] L.-S. Ma et al., "Optical frequency synthesis and comparison with uncertainty at the 10^{-19} level", Science. **303**, 1843 (2004)

LASER QUANTUM LTD
tel: +44 (0) 161 975 5300
email: info@laserquantum.com
web: www.laserquantum.com

LASER QUANTUM INC
tel: +1 408 510 0079
email: info@laserquantum.com
web: www.laserquantum.com

LASER QUANTUM GmbH
tel: +49 7531 368371
email: info@laserquantum.com
web: www.laserquantum.com