Whitepaper

The evolution of Carrier Envelope Phase (CEP) stabilisation

Abstract: The photonics industry is driving technology to achieve even shorter pulse durations with the single-cycle limit getting even closer. With only a few cycles in each pulse, the phase relationship between the carrier and its envelope becomes increasingly important. This paper looks at two innovative technologies to deliver a CEP stabilised, self-mode locking and maintaining laser, whilst still achieving sub two cycle, sub 5.5 fs pulses, as shown in Laser Quantum's venteon CEP5, a high efficiency and maximum power laser.

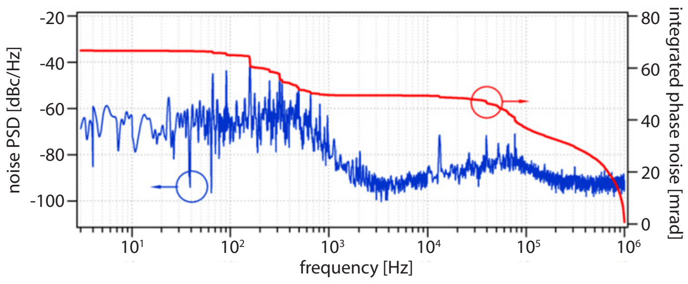

Figure 2: Integrated phase noise 68 mrad (1 MHz - 3 Hz)

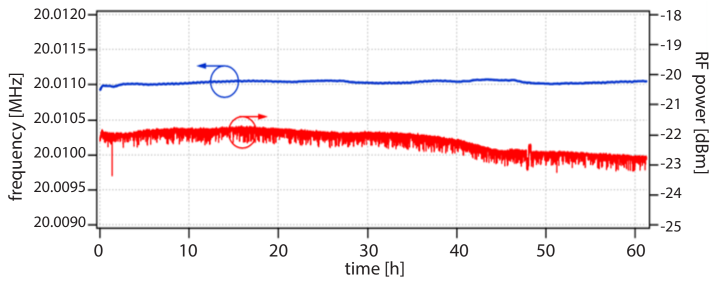

Figure 3: Long-term CEP tracking of stabilised beat note. RBW 7.5 Hz, SPAN: 1 kHz; measurement interval 10000 ms

Photonics technology is driving the ability of lasers to achieve shorter and shorter pulse durations with the single-cycle limit getting ever closer. Laser Quantum is leading this development with lasers such as the **venteon ultra,** which is capable of few cycle pulses well below 5.5 fs, with the electric field exhibiting less than two full cycles. These systems allow researchers to explore a whole new field of extreme nonlinear physics where the relationship between the phase of the carrier wave and its envelope becomes crucial to the observed phenomena. In ultrashort laser pulses, the maximum electric field and hence intensity of successive pulses in the pulse train can vary if the slippage caused by a difference in group and phase velocity is not controlled.

The ability to control or stabilise the CEP offset has been achievable for several years and relies on taking a portion of the output beam, self-referencing it with an f-to-2f interferometer and feeding the resultant information back into the laser. The standard method of control is to modulate the power of the pump laser to control the phase slippage. The optical self-referencing, using an f-to-2f interferometer, relies on being able to interfere two parts of the spectrum from the laser beam, where one part is twice the wavelength of the other.

CEP stabilisation techniques have evolved through a number of technology advancements including the use of PCF fibres to create the required bandwidth, and PPLN for beat signal generation to obtain the feedback signal and using AOM devices to control the pump power output in feedback mode, or even in the output beam itself in feed forward mode. In this case, AOM devices are used which are known to add a certain amount of (higher order) dispersion as well as an angular spatial chirp in the diffracted beam, the pointing stability of which depends on the stability of the RF grating. With recent developments at Laser Quantum, the **venteon CEP5**, using two key technological advances, brings the latest generation of CEP control and has demonstrated long term and low phase noise CEP stable operation over days (figure 1,2 & 3).

The **venteon CEP5** uses the same chirped mirror design of the **venteon ultra** to gain the maximum possible bandwidth from the Ti:Sapphire crystal (figure 4). With an octave spanning output from 600 nm to 1200 nm, the **venteon CEP5** uses its natural bandwidth output as a self-referencing supply for the f-to-2f interferometer. This eliminates the need for additional band broadening techniques such as the PCF, or the use of PPLNs for DFG generation. In the **venteon CEP5**, only the extreme spectral wings are used for self-referencing, using less than 10% of the original laser output power resulting in very high efficiency and maximum power available for the application. With optional modifications to the interferometer, a CEP offset frequency of zero is also possible, resulting in a train of identical pulses (versus every fourth) with maximum electrical field.

The second advancement is the feedback system that inputs the f-to-2f interferometer signal directly into the pump laser using CEPLoQ™ technology rather than an AOM system placed before or after the oscillator (figure 5). This is achieved by directly controlling a ±1% power modulation of the pump laser, covering a range of DC to 1 MHz, with better than 90 degrees phase behaviour up to 700 kHz, leading to a more stable locking bandwidth than traditional methods.

The combination of these two innovative technologies delivers a CEP stabilised, self-mode locking and maintaining laser using the most direct and natural scheme possible today with true sub-two cycle sub 5.5 fs pulses in an unaffected high quality output beam in a compact housing that requires minimal maintenance.

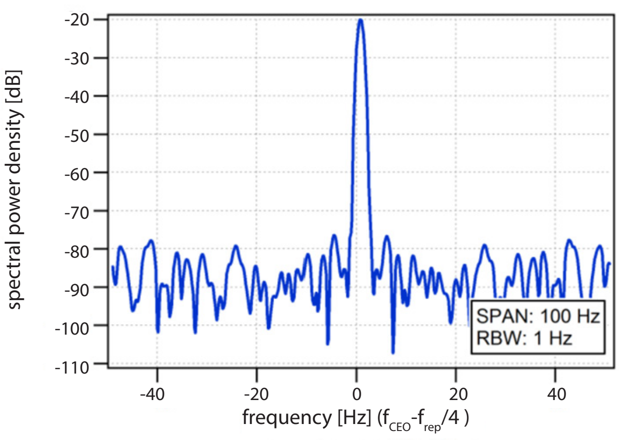

Figure 1: CEP phase noise analysis (measured with 'von-der-Linde' method)

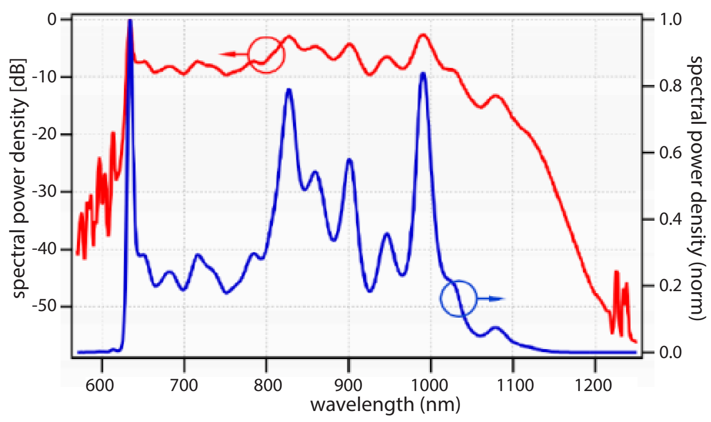

Figure 4: Output spectrum of **venteon ultra**

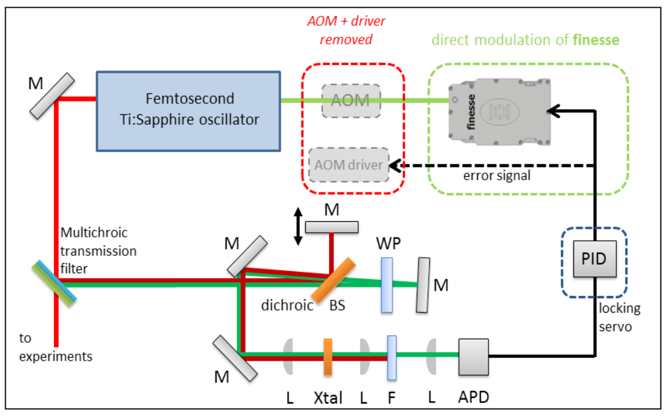

Figure 5: Schematic of CEP5 locking scheme with **finesse pure CEP** using CEP LoQ™ technology

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