2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Optical rogue waves as an indicator for the loss of intrapulse coherence

Günter Steinmeyer(1) and Ayhan Demircan(2)
(1) Max Born Institute, Max-Born-Str 2A, 12489 Berlin, Germany
(2) Leibniz University Hannover, Welfengarten 1, 30167 Hannover, Germany
*e-mail: steinmey@mbi-berlin.de

Coherence is a fundamental concept for assessing the applicability of a light source for interferometric measurements and it is unambiguously defined for a continuous light source, e.g., a single-frequency laser. Transfer of this concept to repetitively pulsed light sources is not straightforward, as interference fringes can be observed both within a delay range of the order of the pulse duration and then again at integer multiples of the cavity roundtrip time (or inverse repetition rate) of that laser. So far, one has typically only considered the latter and defined the coherence as pulse-to-pulse coherence rather than on an intrapulse scale. Interpulse coherence is a highly successful concept to explain the compressibility of pulse trains [1]. If interpulse coherence is preserved within a spectral broadening process then the resulting white-light pulses exhibit essentially identical spectral phases and can therefore be compressed close to the bandwidth limit by a static dispersion compensation scheme. However, if this type of coherence is destroyed then successive pulses feature completely different spectral phases and would therefore require a rapid update of the dispersion compensator, which is not possible for the multi-megahertz repetition rates of mode-locked oscillators.

Recently, a different definition for the coherence of a short pulse train was suggested [2], referring to a fixed phase difference between different wavelength portions of the pulses

$$\Gamma^{(\mathrm{CEP})} = \frac{|\langle \tilde{E}_i^2(2\lambda)\tilde{E}_i^*(\lambda)\rangle|}{\langle|\tilde{E}_i^2(2\lambda)\tilde{E}_i^*(\lambda)|\rangle}$$

Specifically, this intrapulse definition is applicable to gauge the phase-coherent transfer of nonlinear optical processes in supercontinuum generation, which, in turn, is the key for all-optical frequency synthesis. Any loss or degradation of intrapulse coherence therefore affects the obtainable phase noise density in a similar way as in conventional electronics based on phase-locked loops. In marked contrast to conventional radio-frequency electronics, however, we found that this loss of coherence may easily be catastrophic, amounting to several radian rms phase jitters, which render practical application virtually impossible. We analyzed several optical scenarios, and our finding is that a loss of interpulse coherence does not automatically imply a loss of intrapulse coherence and vice versa.

For the case of supercontinuum generation by soliton fission, it is long known that it is difficult to maintain a reasonable degree of interpulse coherence, which practically implies that these pulse trains are difficult to compress to anywhere near their Fourier limit with a static dispersion compensation scheme. Nevertheless, despite these apparent problems, soliton fission has rather successfully worked for all-optical frequency synthesis, enabling optical frequency measurements with relative precisions exceeding 10^{-15}. In some preliminary simulations, we found that intrapulse coherence is much more resilient than its interpulse counterpart when we increase the pulse duration. In these simulations, we found that intrapulse coherence collapses at the same time when optical rogue waves appear. This appears quite interesting as, previously, optical rogue wave have been considered as quite harmless and not doing any damage whatsoever. Our findings indicate the opposite: in fact, the appearance of optical rogue waves seems to be indicative of a loss of intrapulse coherence, which, in turn, destroys the coherent link in frequency metrology. In conclusion, therefore, the wording “optical rogue wave” seems to be much more appropriate than often appreciated. Optical rogue waves actually do some harm, but it is not mechanical or material; it is really only affecting the phase relationship of waves with different frequency. Nevertheless, the wording “rogue wave” seems much more apt than often appreciated.

[1] J. M. Dudley, G. Genty, and S. Coen, Rev. Mod. Phys. **78**, 1135 (2006).
[2] N. Raabe, T. Feng, T. Witting, A. Demircan, C. Brée, and G. Steinmeyer, Phys. Rev. Lett. **119**, 123901 (2017) .