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Modal analysis of optical frequency comb's dynamic

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Abstract

We study the dynamic of optical frequency combs using a multimode approach to the noise analysis. The covariance matrices of the amplitude and phase quadratures of the field are computed thanks to a multipixel homodyne detection. The noise on the laser's physical parameters is recovered by identification with the eigenmodes of the covariance matrices. We further investigate the correlations between amplitude and phase noises which may gives information on the modelocking process taking place in the laser's cavity.

Mode-locked femtosecond lasers, or optical frequency combs (OFCs), have become a prevalent tool in metrology. They are commonly used in spectroscopy, ranging, as well as for optical clocks. Precision of the measurement is ultimately limited by the stability of the OFCs. Consequently, understanding the dynamic of OFC, i.e. the noises affecting them, may provide a way to improve those measurements.

For a single frequency laser, noises are separated in amplitude noises (i.e. variation in the photon number), and phase ones (i.e. variation in frequency). However, for an OFC, composed of roughly 10^5 spectral lines, amplitude and phase noises affect each of them individually. Thus, a complete characterisation of the dynamic is almost impossible due to the gigantic number of degrees of freedom. Yet, it has been theorised that the noise dynamic of an OFC can be described by four distinct parameters namely, the pulse energy, the carrier envelope offset (CEO), the repetition rate and the central wavelength of the spectrum, which indicates non-negligible correlations between the different spectral lines. A particular mode of the electric field can be associated to each of those quantities [1]. A variation in one of the physical parameter can be seen as the addition to the unperturbed mean field mode of the noise mode associated to the parameter.

We analyse the dynamic of an optical frequency comb using a multipixel homodyne detection. This scheme allows the measurement of the laser's noises at the quantum limit in separated spectral bands as well as their correlations. The noise modes are retrieved by eigendecomposition of the phase and amplitude covariance matrices. Those eigenmodes are found to be in good agreement with the theoretical ones associated to the four previous parameters [2]. We are thus able to characterise the dynamic by identifying each noise individually. Further investigation will try to identify the different "knobs" to act on in order to reduce one particular noise. Correlations between phase and amplitude noises are also investigated [3]. Those correlations have only been studied by a few groups, leaving open a wide field of studies, which may bring new insight on the mode-locking process. A theoretical study will be conducted. Starting from the master equation or the rubber band model we will try to understand the correlations observed experimentally.

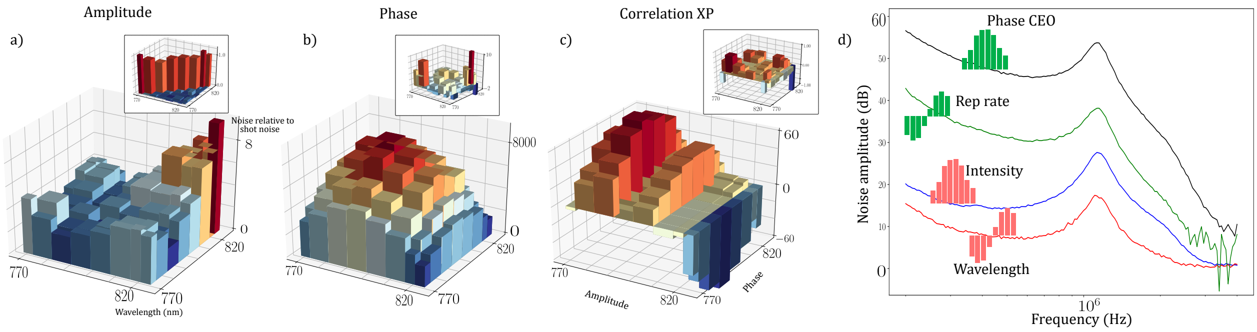

Figure 1: **Covariance matrices and noise modal decomposition**. a) Amplitude covariance matrix, b) phase and c) amplitude and phase correlation matrix, for noises at 500 kHz. In inset, matrices for noises at 4 MHz, the laser is only affected by the shot noise. d) Mode decomposition of amplitude (red) and phase (green) covariance matrices on the modes predicted in [1].

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