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All-optical fiber-based devices for ultrafast amplitude jitter magnification

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Abstract: We propose two fiber-based architectures that enable the all-optical magnification of ultrafast amplitude fluctuations of picosecond or femtosecond pulse trains. An increase of the fluctuations by more than one order of magnitude is experimentally achieved.
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1. Introduction

Detecting low power fluctuations with an easy-to-implement device is of practical interest for many photonic applications such as pulse characterization or biophotonics. Several solutions have already proved their efficiency such as synchronous detection, radio-frequency analysis [1] or autocorrelation measurements [2]. However, they require the use of dedicated and onerous instruments. We report here two simple and efficient alternatives based on single-mode fibers and taking advantage of the nonlinear effects affecting an ultrashort optical pulse propagating in the regime of anomalous dispersion. Their common principle lies in the transfer function (TF) which links the pulse peak powers before and after the device. If for a working power P_0, this TF can be locally approximated by a linear function having a x-intercept P_C with $0 < P_C < 2P_0$, then the relative level of amplitude jitter will increase [3]. We first implement this concept for picosecond pulses at telecommunication wavelengths where the targeted TF is generated thanks to self-phase modulation (SPM) followed by optical bandpass filtering [3]. A second implementation is proposed in order to deal with femtosecond pulses delivered around 1µm [4].

2. Implementation for picosecond pulses at telecommunication wavelengths

In a first configuration, we investigate the amplitude jitter of a 10-GHz picosecond pulse train delivered by an actively mode-locked erbium doped fiber laser at telecommunication wavelengths. An intensity optical modulator driven by an arbitrary waveform generator artificially imprints a controlled level of amplitude jitter on the signal. The resulting pulses are then amplified in an erbium doped fiber amplifier before experiencing SPM in a 1-km long highly nonlinear fiber. At the output of this fiber, an optical bandpass filter made of a fiber Bragg grating (central wavelength identical to the signal central wavelength and spectral width of 200 GHz) is used to carve into the expanded spectrum. The resulting signal is detected by means of a usual photodetector combined with a high speed sampling oscilloscope.

Figure 1a illustrates the resulting TF that exhibits a close-to-linear part for pulse energies between 1.2 and 1.5 pJ. Consequently, the fluctuations of the input pulse train (Fig. 1a1) are significantly enhanced (Fig. 1a2). Accurate measurements of the level of these input and output amplitude jitters (Fig. 1b) demonstrate a magnification by a factor above 10. Quite remarkably, given the linearity of the transfer function over the range of interest, the device does not distort the statistical distribution of the fluctuations but preserves it as illustrated in Fig. 1c where modulation of the pulse train by low-frequency low-amplitude sinusoidal or triangular waves has been tested. The resulting histograms exhibit the expected double-peak structure or constant distribution respectively.

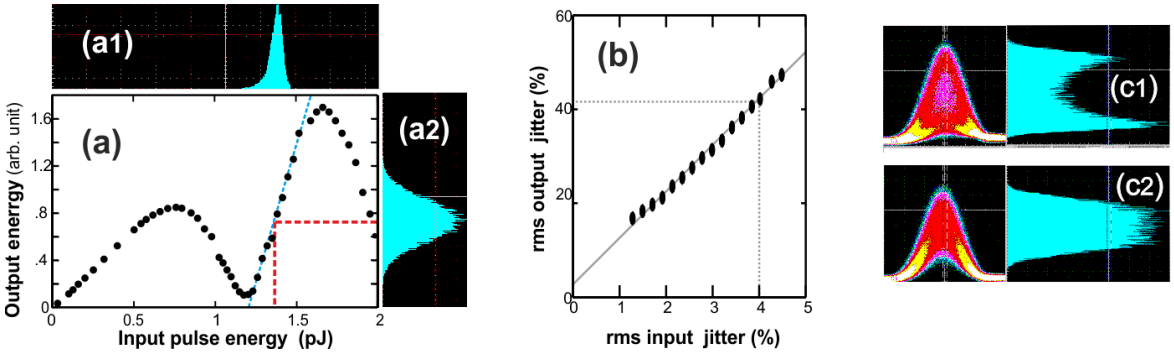

Fig. 1 : (a) Experimental transfer function of the device. Subplots (a1) and (a2) illustrate the statistical distribution of the peak powers of the input and output pulse trains. (b) Relative output jitter versus input jitter. (c) Eye-diagrams and associated histograms recorded after the optical jitter magnifier for a pulse train modulated by a low frequency sinusoidal wave (c1) or by a low frequency periodic triangular wave (c2).

3. Implementation for femtosecond pulses at 1033 nm

In a second configuration, we have focused on a 48-MHz mode-locked pulse train at 1033 nm propagating in a 2-m long highly nonlinear photonic crystal fiber with anomalous dispersion. In this context, SPM-induced spectral broadening is not the main effect driving the nonlinear dynamics of the ultrashort pulses anymore. The 190-fs pulses are indeed mainly affected by the intrapulse Raman response of silica that progressively shifts their central frequency towards higher wavelengths. The experimental spectra plotted in Fig. 2a illustrate this soliton self-frequency shift. Note that the dispersive properties of the PCF under use in this experiment have been carefully chosen in order to avoid multi-peak structures [5]. Here, we combine the SSFS process with a long-pass filter blocking the low-wavelength components, thus acting as an optical thresholder that efficiently discriminates the pulses according to their initial peak power. Indeed, the pulses having a peak-power not high enough (below P_1) to be sufficiently frequency shifted are vanished whereas the other pulses (with a power above P_2) pass through the filter. Interestingly and as can be seen in Fig. 2b, the transition between the two regimes is rapid and close from being linear, which is obviously extremely beneficial for the targeted application.

Therefore, operating at a power P_0 enables an efficient magnification of the input fluctuations and we have experimentally demonstrated an increase of the amplitude jitter by a factor close to 20. Using a careful control of the input statistical distribution of the fluctuations, we have been able to check once again that our magnification process does not affect the distribution shape of these fluctuations (Fig. 2c).

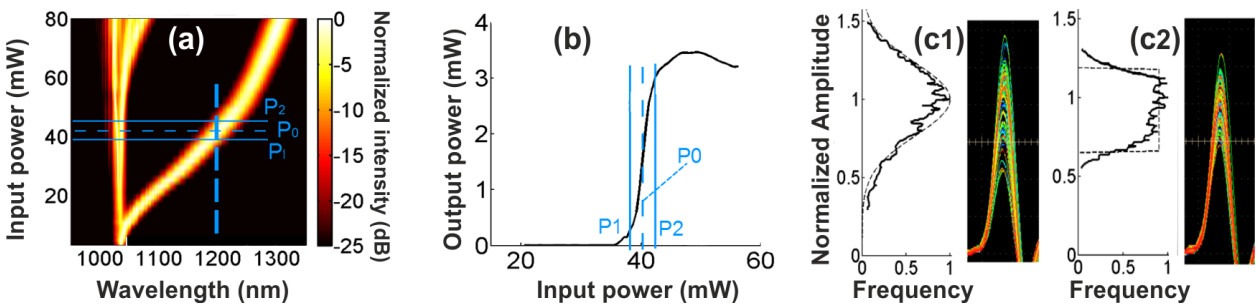

Fig. 2 : (a) Experimental evolution of the spectrum recorded after the PCF. (b) TF obtained after long pass optical filtering at 1200 nm (c) Statistical distribution of the fluctuations (probability and amplitude are normalized to 1 for the most likely event) and electrical eye-diagram of the pulse train when working at power P_0. Results obtained for a Gaussian initial distribution of the fluctuations (c1) are compared with the results based on a uniform distribution (c2). The experimental results are compared to Gaussian and rectangular fits respectively (dashed lines).

4. Conclusion

We have proposed two fiber-based architectures to increase the level of amplitude fluctuations of a pulse train in order to make them more easily detectable by simple electronics. Both techniques rely on a non-proportional transfer function exhibiting a linear part. For picosecond pulses, we have generated such TF by central filtering of the SPM-broadened spectrum. For femtosecond pulses, we have taken advantage of the soliton self-frequency shift followed by long pass optical filtering. In both cases, we have experimentally achieved a magnification factor above 10 and quite remarkably, we have shown that the statistical distribution of the amplitude fluctuations is preserved after magnification. The choice of the working power is crucial and for input powers which do not lie in the linear part of the TF, a strong reshaping of the statistical distribution can be observed, leading to heavily tailed statistics.

5. References

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