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# All-optical fiber-based amplitude jitter magnifier

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## ABSTRACT

We describe the concept of an all-fibered device that enables the optical magnification of the amplitude jitter of low-fluctuation pulse trains, facilitating the measurement of the statistical properties by usual photodiodes and electronic equipments. Taking advantage of a highly nonlinear fiber with anomalous dispersion followed by central optical bandpass filtering, we experimentally demonstrate an amplification of small-scale fluctuations by a factor 10.

**Keywords:** all-optical signal processing, jitter measurement, statistics.

## 1. INTRODUCTION

With the advent of highly stable ultrashort optical sources, it has become of crucial importance to benefit from accurate means of characterization of low optical jitters. Such a measurement is still very challenging when the repetition rate of the source is of a few tens of gigahertz. In this context, several dedicated methods have been proposed to evaluate the root mean square value of the timing and amplitude jitters. Assuming an adequate mathematical treatment, those data can be extracted from the optical second harmonic autocorrelation [1] or from the analysis of the harmonics constituting the electrical radio frequency spectrum of the periodic signal [2, 3].

We report here an easy-to-implement technique that is fully compatible with widely spread photodiodes, oscilloscopes and communication signal analyzer softwares. The main issue is to design a device able to characterize relative fluctuations of a few percents only. For such a reduced level of fluctuations, the noise contribution of the electronic detection chain should not be neglected as it may translate into serious artifacts. Our solution relies on a nonlinear fiber-based device that enables the optical magnification of the fluctuations in such a way that they become easily and reliably detectable by usual electronics.

We first describe the experimental set-up we use and the operating principle of the optical amplitude jitter magnifier. We then present a set of experimental results assessing the performance of the proposed device at telecommunication wavelengths. A magnification of a factor 10 is achieved and quite remarkably, the probably distribution of the fluctuations is conserved.

## 2. EXPERIMENTAL SET-UP AND PRINCIPLE OF THE APPROACH

The situation we investigate is sketched in Fig. 1a. The experimental set-up relies on commercially available components for optical telecommunications. A low jitter fiber laser source is actively mode-locked by a 10-GHz RF signal and delivers Fourier-transform-limited picosecond pulses. An intensity optical modulator driven by an arbitrary waveform generator artificially degrades the high quality pulse train. The resulting signal is affected by a controlled level of amplitude jitter and is sent into an erbium-doped fiber amplifier (EDFA) with a moderate output average power of 12 mW. The amplified pulse train then propagates into a 1 km-long highly nonlinear fiber with low anomalous dispersion. The nonlinearity of the fiber leads to a spectral expansion of the pulses. At the output of the fiber, an optical bandpass filter (OBPF) made of a fiber Bragg grating associated with an optical circulator (OC) is used to carve into the expanded spectrum and the resulting signal is detected by means of a usual photodetector combined with a high speed sampling oscilloscope.

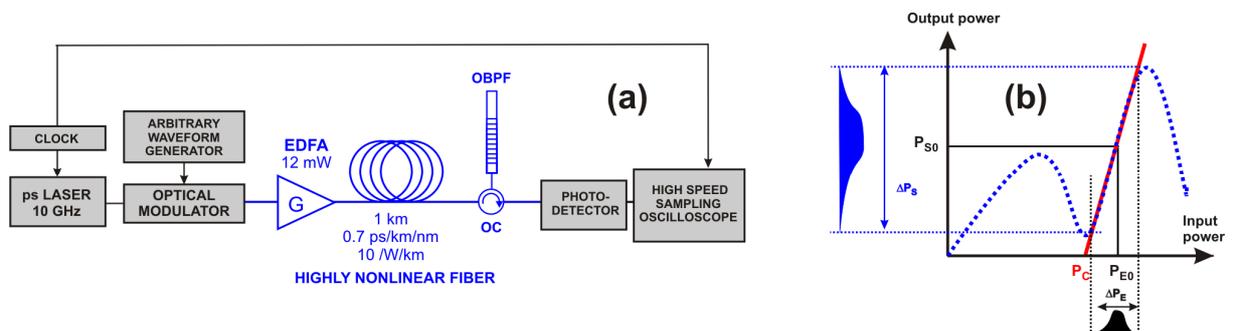


Figure 1. (a) Experimental set-up  
(b) Typical transfer function of the device and principle of operation

The key element in this set-up is the optical transfer function (TF) that links the output power to the input power. According to the choice of parameters of the fiber, the TF shape may significantly vary [4]. Let us note that in most of the previously studied configurations, the goal of similar arrangements was not to increase optical fluctuations but to limit output pulse train jitter and to act as an all-optical limiter in a regeneration context [5-7]. This requires a TF with a large plateau characterized by an inflexion point, i.e. the slope of the tangent to the TF should be null. On the contrary, the application we target dictates the use of a transfer function presenting a very pronounced slope as illustrated in Fig. 1b : for the powers under consideration, the TF should be ideally monotonous and should be approximated over a wide range by its tangent. By positioning adequately the working power  $P_{EO}$  compared to the threshold  $P_C$  of the device (defined as the abscissa at the origin of the tangent), an efficient magnification of the relative power fluctuations of the signal can be achieved.

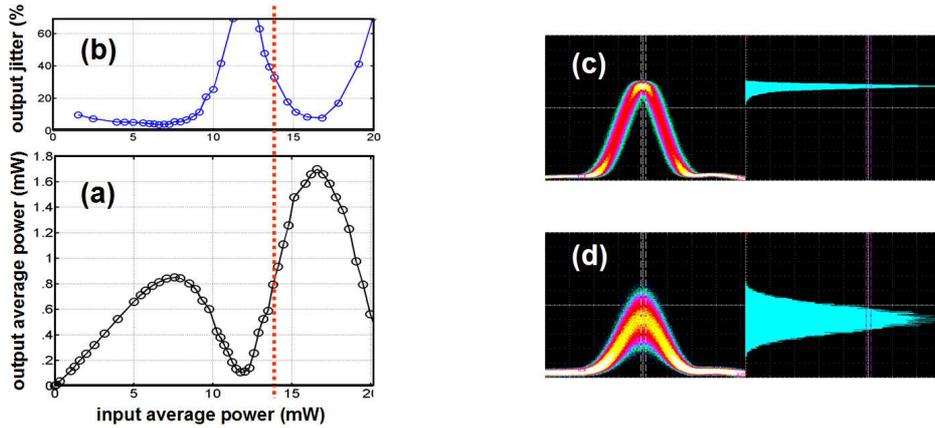


Figure 2. (a) Experimental transfer function of the device (b) Evolution of the relative output jitter according to the working power (an initial jitter of 3% is superimposed on the modelocked train). (c) Eye-diagram of the incoming pulse train and associated statistics (d) Eye diagram after optical magnification of the fluctuations and associated statistics for an initial power of 14 mW.

The experimental transfer function, displayed on Fig. 2a, presents the expected features so that we can anticipate that working with an average power of 14 mW will provide the expected magnification of the jitter. This is confirmed by a systematic measurement of the output jitter according to the input average power (Fig. 2b). In more details, between 0 and 5 mW, the measurement is mainly impaired by electronic noise and is roughly constant due to the proportional nature of the section of the TF. Between 5 and 8 mW, a small decrease of the fluctuations can be noticed, which can be explained by the previously mentioned optical limiting properties of the device [4]. For increasing initial average power (8-12 mW), a significant increase of the jitter is detected. However, given the negative slope of the curve, this range of powers is not the best suited for an accurate monitoring of the statistical properties, as the resulting histogram will suffer from an inversion. It is indeed more convenient to work at higher powers, typically between 13 and 15 mW where the TF is monotonously increasing. Figures 2c and 2d clearly illustrate the benefits of the device : whereas the initial optical fluctuations could be hardly differentiated from the electronic noise, after magnification, the fluctuations are clearly distinct and can be straightforwardly analyzed.

### 3. EXPERIMENTAL RESULTS

#### 3.1 Magnification factor and linearity of the device

We have carried out additional measurements in order to evaluate the magnification factor of our device. Results are reported in Fig. 3a and demonstrate an amplification factor that has been found slightly above 10. By varying the level of initial fluctuation that is superimposed over the initial signal, we have checked that this amplification factor does not depend of the initial level of jitter as long as it remains below 5%, which is fully consistent with the purpose of the device.

Another very important feature we have experimentally checked is the ability of the set-up not to distort the statistical distribution of the fluctuations. We have indeed tested various kinds of statistical fluctuations that we have accurately controlled thanks to the electrical arbitrary waveform generator. Preliminary results based on a white Gaussian noise (Figs. 2c and 2d) have been confirmed with more complex fluctuations such as modulation of the pulse train by low-frequency low-amplitude sinusoidal or triangular waves. The resulting histograms exhibit the expected two peak structure or constant distribution respectively.

In other words, after calibration, the linear nature of the TF enables not only a convenient measurement of the initial rms amplitude jitter but also preserves the shape of the statistical distribution of the fluctuations. As a consequence, and contrary to technics [1-3], no assumption such as a Gaussian distribution is required.

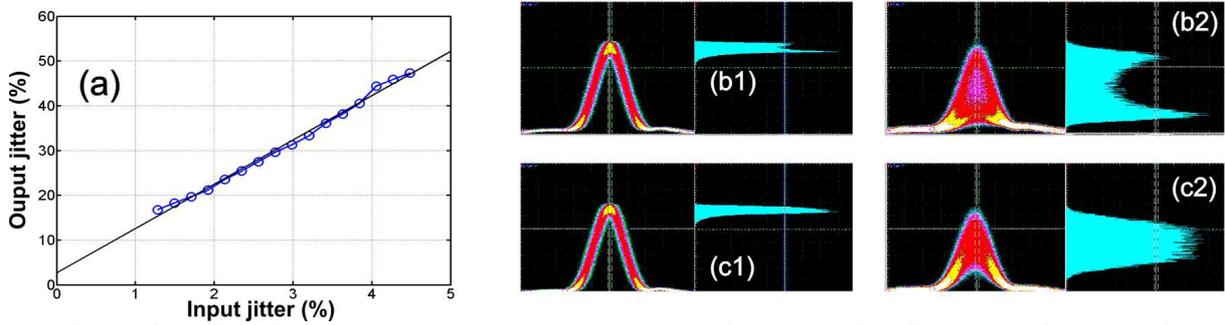


Figure 3. (a) Relative output jitter versus input jitter (rms values). Eye-diagrams and associated histograms of a pulse train modulated by a low frequency sinusoidal wave (subplots b) or by a low frequency periodic triangular wave (subplots c). The results recorded before the magnifier (subplots 1) are compared with the results obtained at the output of the device (subplots 2)

### 3.2 Sensitivity of the device

As a final proof of the very high sensitivity of the device, we present an experiment where four trains at 10 GHz are time-interleaved in order to obtain a 40 GHz pulse train. Time interleaving is achieved through a widely spread optical bit rate multiplier made of optical delay lines and couplers and where a careful balance of the powers of the four channels has to be found. Visual level equalization made with the direct detection on the oscilloscope leads to the record presented on Fig. 4a where no difference in the level of the interleaved channels can be distinguished. After evolution in the optical magnifier, differences in the level of the 10 GHz trains is readily apparent, which may facilitate further fine level adjustment.

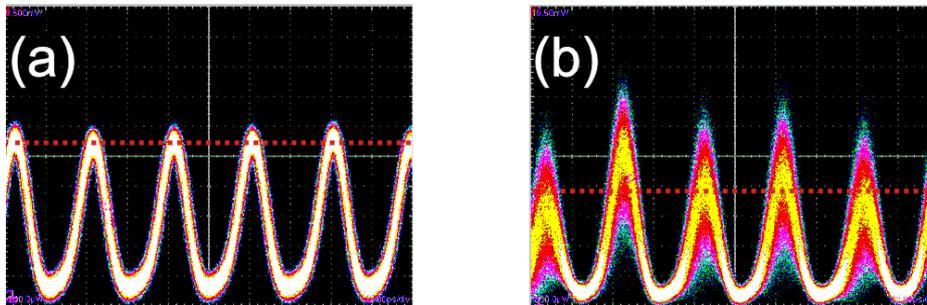


Figure 4. 40-GHz pulse train made of four time-interleaved 10 GHz pulse trains. Eye diagrams recorded before (a) and after (b) the jitter magnifier

## 4. CONCLUSIONS

To conclude, we have demonstrated a practical fiber-based device that provides an all-optical magnification of the amplitude jitter by a factor 10. This facilitates the measurement of the jitter level of stable ultrafast pulse trains and also provides an easy way to get access to the associated statistical distribution of the fluctuation.

Our set-up relies on an anomalous highly nonlinear fiber combined with central bandpass spectral filtering. However, similarly to the wide range of optical solutions that have been developed for fiber-based optical regeneration, other experimental schemes could provide alternative such as normally dispersive fibers with spectral offset filtering [8, 9] or nonlinear optical loop mirrors [10]. We may also anticipate that the technic will benefit from the recent progresses in highly nonlinear waveguides [11].

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