Multi-Wavelength EAM based Optical Sampling for Performance Monitoring in High Bit-rate WDM Systems

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Abstract *The intensity and phase profiles of eight 10 Gbit/s WDM channels on a 200 GHz grid have been simultaneously measured using a spectrally resolved optical gating technique, based on sampling with a single electro-absorption modulator.*

Introduction

High bit-rate WDM systems designed to meet the needs of future networks place stringent requirements on the optical pulses used to transmit the data and the properties of the transmission channel. The effects of chromatic dispersion, fibre nonlinearities and polarization mode dispersion on the transmission of the data pulses have to be carefully monitored and controlled. It will be important to develop an efficient method for signal monitoring that allows for detection and control of these multiple transmission impairments. Conventional monitoring techniques such as sampling oscilloscopes and BER measurements are unsuitable for the short pulses used in these high bit rate systems, and do not provide sufficient information in the case when several transmission impairments such as fibre dispersion and nonlinearities interact simultaneously.

Several different spectrographic techniques for the complete characterisation of the intensity and phase of periodic signals have been demonstrated, including frequency resolved optical gating (FROG) [1]. Dorrer et al. [2-3] recently demonstrated a variation on this pulse characterisation technique that employs linear optical sampling using an electro-absorption modulator (EAM). This technique has several advantages: the use of a linear gating process increases the sensitivity, making it more compatible with low power communications pulses; the EAM is polarization insensitive; and the technique is based on a crosscorrelation so does not suffer from the temporal ambiguity in the measured fields that is associated with SHG-FROG. To date the technique has been shown to be capable of resolving pulses with durations down to 5 ps at pulse energies as low as 10-17 J and has focused solely on the characterisation of a single wavelength channel.

Here we demonstrate a multi-wavelength sampling scheme for the simultaneous measurement of multiple high bit-rate WDM channels. This multi-wavelength optical sampling scheme exploits the potential of optical systems for parallel processing by using a single EAM to sample multiple wavelength channels simultaneously. This synchronous sampling has the potential to provide further information than that provided by separate channel measurements, such as the relative timing between the pulses in different channels, whilst the complexity and cost of the monitoring system is minimised, compared to individual channel monitoring.

Description of the technique

The EAM based multi-wavelength sampling scheme is shown in fig. 1. Part of the WDM pulse stream is split off, and a single channel is filtered out, before optical-to-electrical conversion to provide the self-referenced clock signal. The clock is then amplified to 5.8 Vp-p and used to drive the EAM, which is biased at -5 V producing a sampling window of 21 ps in duration. The WDM data stream is sampled by the EAM, after passing through a computer controlled delay stage. This results in the cross-correlation between the WDM signal and the EAM sampling window. This signal is then spectrally resolved as a function of the delay, using an optical spectrum analyser, to produce the spectrogram.

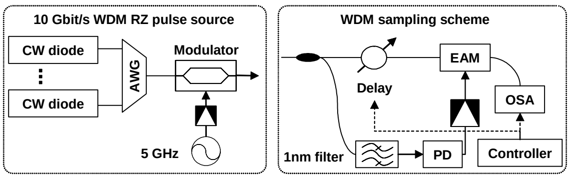

Fig. 1. WDM source and EAM sampling scheme.

In the results presented here, the WDM pulse stream is created by carving a WDM comb of 8 CW DFB laser diodes, on a 200 GHz grid, between 1550 and 1560 nm. A LiNbO3 modulator that is overdriven with a 5 GHz sinusoid creates 8 channels of synchronously carved 10 GHz RZ pulse streams with a duty cycle of ≈33%. In this experiment the 1560 nm channel was chosen as the reference channel thus the timing of the other channels is measured with respect to this channel. The self-referenced sampling scheme readily allows the technique to be used throughout the transmission system. The measured spectrogram allows for the complete characterisation of the pulse intensity and phase of each of the channels via a numerical retrieval algorithm [4], which is not limited by the duration of the gate.

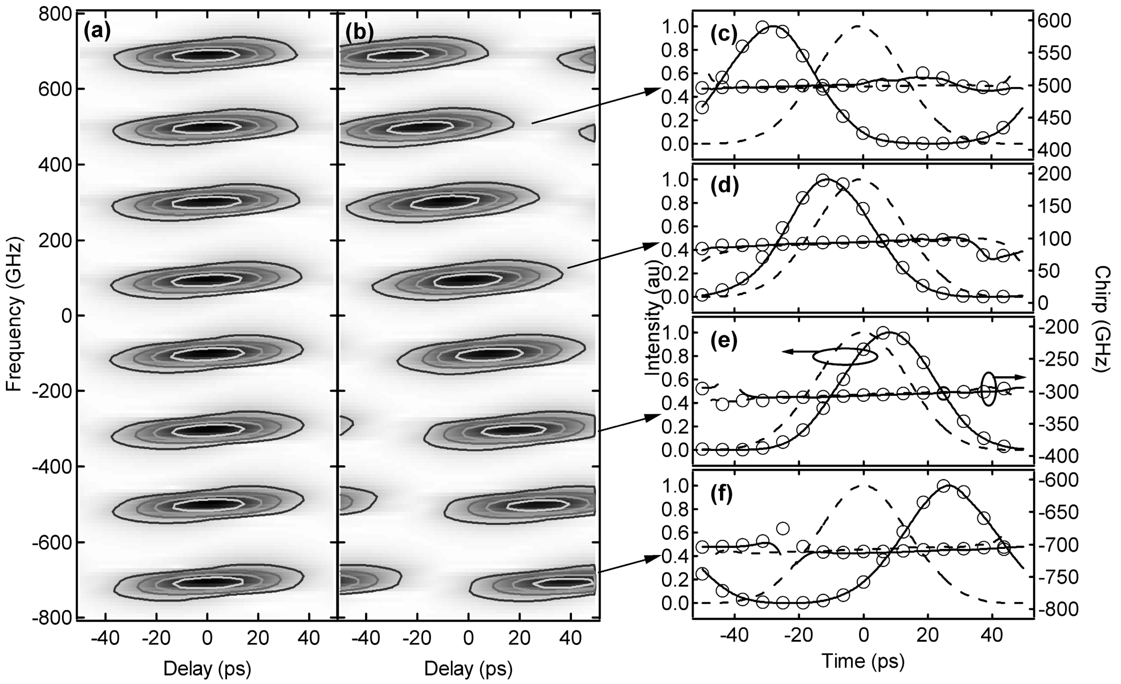

Fig. 2 Experimentally measured spectrograms of an eight wavelength channel (200 GHz spacing), 10 Gbit/s pulse stream before (a) and after (b) propagation through 350 m of SMF28 (The square root of the spectrogram intensity is plotted here to highlight the 40 dB dynamic range of the measurement). (c-f) Shows the intensity and chirp before (dashed line) and after (solid line) propagation, retrieved from the measured spectrograms (only four channels are shown for clarity). The intensity and chirp (circles) from a simulated propagation of the fields before the fibre shows excellent agreement with the directly measured results.

Results

Fig. 2 (a) shows the measured spectrograms of an eight channel 10Gbit/s WDM pulse stream before and after propagation over 350 m of SMF28 (D = 16 ps/nm/km). The effect of the fibre dispersion on the different channels is readily seen by comparing the two spectrograms and the relative temporal positioning of the features. The skew of each of the individual channel features is also indicative of the chirp on the pulses, however the skew observed here is dominated by the chirp imposed from the EAM sampling. The WDM pulses are almost transform limited as is shown by the flat chirp slope obtained in the retrieved fields. The numerical retrieval is carried out on the entire spectrogram and independently recovers the WDM signal field and EAM sampling function. Subsequently the individual channels are spectrally filtered out from the retrieved WDM signal spectral field to obtain the temporal intensity and phase of the pulses in each channel. The RMS retrieval error was around 0.005 for both measurements and the retrieved spectra agreed well with the independently measured spectra, indicating the quality of the retrieval. In fig. 2(c-f) we show the intensity and chirp for four of the retrieved channels before and after propagation. The retrieved pulse durations ranged from 30.9 to 32.6 ps in good agreement with the expected 33% duty cycle. The dispersive walk-off between the channels is also clearly observed. Also shown here is the intensity and chirp from a simulated propagation of the retrieved fields before transmission, which shows an excellent agreement with the directly measured results after propagation.

Conclusion

A multi-wavelength sampling scheme has been used to characterise the intensity and phase profiles of 10 Gbit/s RZ pulses in eight WDM channels simultaneously. The spectrogram was generated by spectrally resolving the simultaneously sampled WDM channels using a single EAM. Both the spectrogram and the retrieved fields of the individual channels yield information about the pulses that can be used either in system design, or for the fine-tuning of the transmission system, such as dynamic dispersion compensation or individual channel retiming. It is anticipated that with further EAM developments to reduce the wavelength sensitivity it will become feasible to extend this scheme in order to simultaneously characterise WDM channels across the entire c-band. Also with appropriate drive electronics the self-referenced EAM sampling window can be reduced to around 10 ps readily allowing for the characterisation of 40-80 Gbit/s systems.

References

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