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Fibre Bragg Grating Based Rectangular Pulse Switching Technology for Timing Jitter Tolerant OTDM Data Demultiplexing

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Abstract: The use of fiber Bragg grating based rectangular pulse switching technology for timing-jitter tolerant data demultiplexing in a high speed OTDM system is reviewed. Error-free demultiplexing operation with significant timing jitter-tolerance is easily achieved by simply adding a grating to the system. A substantial power-penalty improvement can also be achieved compared to demultiplexing without the grating.

Keywords: Fibre Bragg grating, nonlinear optical switching, OTDM systems

I. Introduction

All-optical time division multiplexing (OTDM) system technology has developed significantly in recent years and has resulted in the demonstration of terabit/s single channel data rates [1]. As the data rates increase, and the Return-to-zero (RZ) pulses used get correspondingly shorter, OTDM systems suffer increased sensitivity to source noise, and the effects of nonlinearity, group velocity dispersion (GVD), polarization mode dispersion (PMD) and environmental sensitivity associated with the transmission line. These effects generally manifest themselves in terms of increased amplitude jitter, timing jitter and absolute timing drift at the receiver [2]. The synchronization requirements placed on the locally generated pulses required to control an optical demultiplexer at the receiver end can thus become a significant practical limiting issue.

The key to obtaining sufficient timing jitter tolerance in such devices is to establish a rectangular switching window [3,4,5]. This reduces the absolute accuracy required for temporal bit alignment and allows for optimal resilience to timing jitter-induced errors.

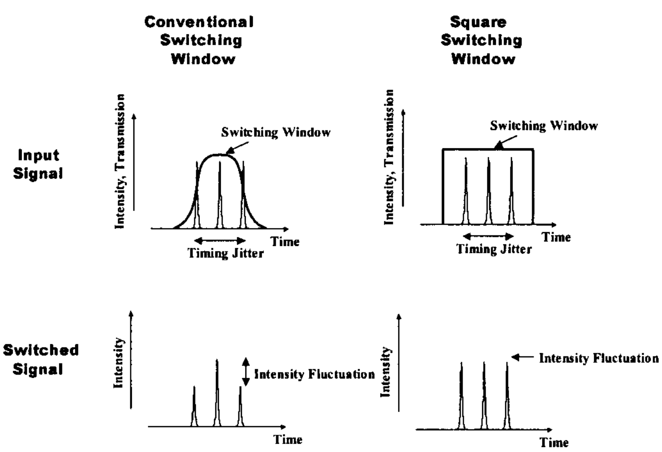

Figure 1: Comparison of functionality between conventional switching window and rectangular shape switching window

Fig. 1 shows a comparison of the operation of an optical switch with a conventional switching window (assumed to approximate to a Gaussian) and a switch with a rectangular shape switching window. Conventional optical switches are seen to generate a large intensity variation of the output signals as the relative timing drifts between the input and clock signals due to the window shape, which then result in a significant system power penalty. However, a flat-top rectangular switching window enables us to operate the switching system with considerable tolerance to relative timing difference over relatively wide timing drift ranges. This provides increased resilience to timing jitter.

To this end we have demonstrated a simple and robust method to generate a rectangular switching window within nonlinear optical devices based on pulse-shaping superstructured fiber Bragg gratings (SSFBG) [5,6]. This technique has a range of advantages such as simple implementation, polarisation insensitive operation, and robust, flexible applicability to various optical switches based on semiconductor or optical fibre. Recently C. Schubert et al. demonstrated a pulse shaper based on both a HiBi fiber and a polarization beam splitter which can be used to obtain a rectangular switching window [7]. However, the polarization sensitivity of this approach could be a practical limiting issue for its application within real systems.

In this paper, we review our SSFBG based rectangular pulse switching technology for data demultiplexing in a high-speed OTDM system and discuss possibilities for the application to over 160 Gibt/s OTDM systems.

II. Pulse-shaping superstructured fibre Bragg gratings

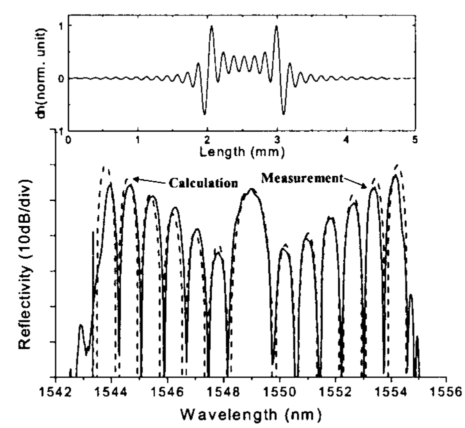

Figure 2: Refractive index modulation profile of the SSFBG converting 1.7 ps soliton pulses into 10 ps rectangular pulses and the corresponding spectral response.

Since our SSFBG based pulse-shaping technique is a purely passive-filtering process, we require a well-defined input pulse form to filter and thereby reshape. As a input source we used soliton pulses (1.7 ~2.5 ps) generated from a harmonically mode-locked erbium-doped fiber ring laser. The grating was designed and fabricated with the correct phase and amplitude reflectivity profile to convert the input transform-limited soliton pulses into target rectangular pulses [5,6]. The refractive index modulation profile and the spectral response of the SSFBG for the 10 ps rectangular pulse generation are shown in Fig. 2. We accommodated 13 spectral lobes within the available 12 nm spectral bandwidth and apodized the output spectrum using a Gaussian profile to reduce temporal shape distortion due to the spectral truncation (Gibbs phenomenon). The length of the grating was 5.1 mm, corresponding to t = 50 ps in the time domain. Note the high (<10 μm) spatial superstructure resolution required of the grating writing process as shown in Fig. 2.

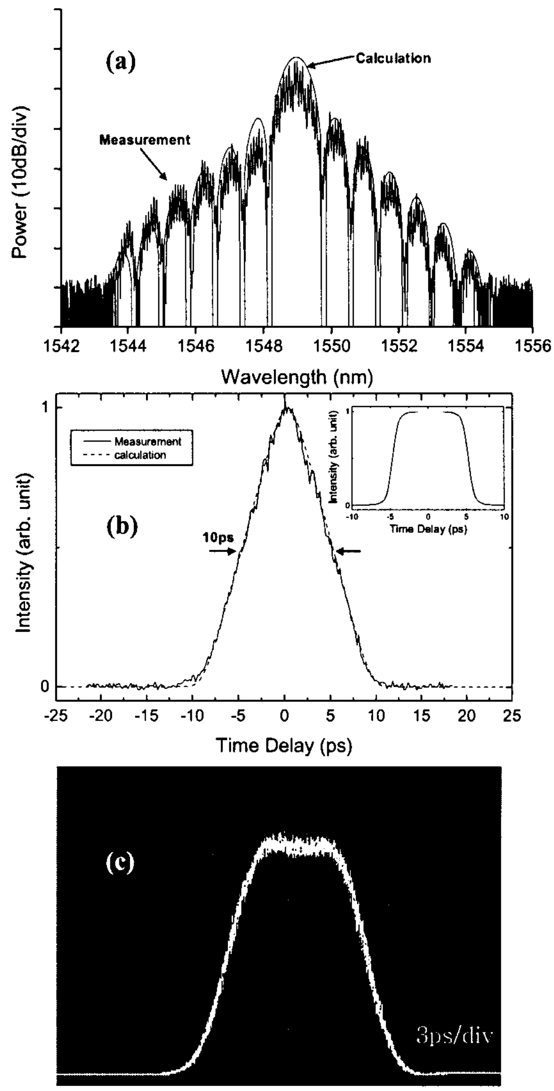

Figure 3: (a) Optical spectrum of the rectangular pulses from the SSFBG described in Fig. 1. (b) Theoretical and experimental SHG autocorrelation traces of the rectangular pulses; Inset: Theoretically calculated temporal shape of the rectangular pulse. (c) Optical sampling scope trace of the rectangular pulse

The measured optical spectrum of the pulses from the SSFBG is shown Fig. 3(a) together with that of the theoretically calculated single rectangular pulse. Excellent agreement between theory and experiment is obtained highlighting the quality of our grating writing process. Temporal characterisation of the rectangular pulses was next performed using a SHG autocorrelator (resolution <100 fs). The measured and theoretically calculated triangular autocorrelation traces are shown in Fig. 3(b) together with the calculated temporal shape of the pulses. Excellent agreement between theory and measurement is obtained implying high quality rectangular pulses. Next, an optical sampling oscilloscope measurement based on four-wave mixing in highly nonlinear fibre (HNLF) was performed with 2 ps temporal resolution [8]. The measured trace is shown in Fig. 3(c) and the high quality of the pulses is clearly evident. Using the same SSFBG technology we could easily generate 20 ps rectangular pulses from 2.5 ps soliton pulses

III. Experimental setup and results for OTDM data demultiplexing

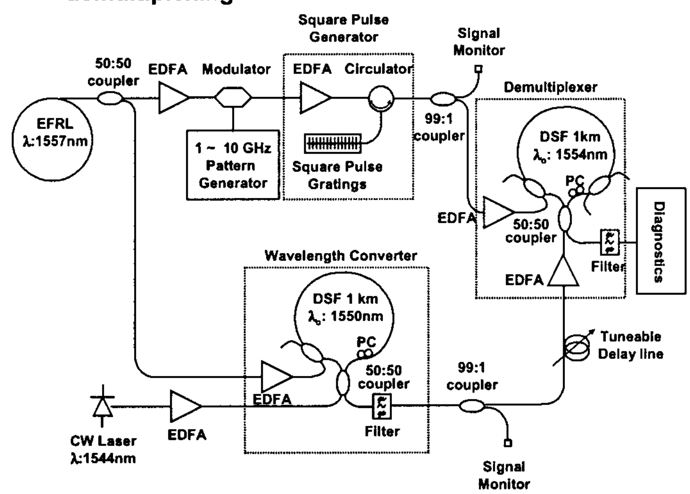

Figure 4: Experimental setup for the SSFBG based rectangular switching technology

The performance evaluation of our SSFBG based rectangular switching technology was first performed with 20 ps rectangular pulses. The corresponding experimental setup for 10-to-2.5 Gbit/s OTDM data demultiplexing is shown in Fig. 4. 2.5 ps soliton pulses were first generated from a 10 GHz harmonically mode-locked erbium-fiber ring laser (EFRL) with two output channels. The first channel was modulated to provide a pseudorandom data sequence of 2.5ps pulses at 2.5 Gbit/s. These pulses were then fed onto a pulse-shaping SSFBG to convert the 2.5ps solitons into 20 ps rectangular pulses. The other component of the 10 GHz, 2.5ps pulse stream split-off from the laser was first amplified and then fed to the control port of a dual-wavelength NOLM, and that we employed as a wavelength converter (WC). We generated a 10 GHz train of high-quality, 3.5ps pulses at 1544nm. As a data demultiplexing switch we used another dual-wavelength NOLM similar to that used for the wavelength conversion process. The 1544nm pulse train incident to the switch was first passed through a tuneable delay line to allow us to adjust the relative arrival time of the 1544nm pulses relative to the rectangular control pulses. By adjusting and measuring this relative arrival time delay and monitoring the loop output at 1544nm, (for a suitable control pulse power), we were able to determine the switching window of the device and to establish its sensitivity to timing-jitter. Next we investigated switching window performance and obtained ~ 20 ps rectangular shape switching window using the SSFBG. We then performed BER measurements on the data demultiplexing performance. These results are summarized in Figs. 5(a) and (b). Error-free, penalty-free performance was readily achieved over a +/- 7ps delay range for the square pulse driven switch versus a +/- 1ps range for the switch driven directly with the 2.5ps laser pulses.

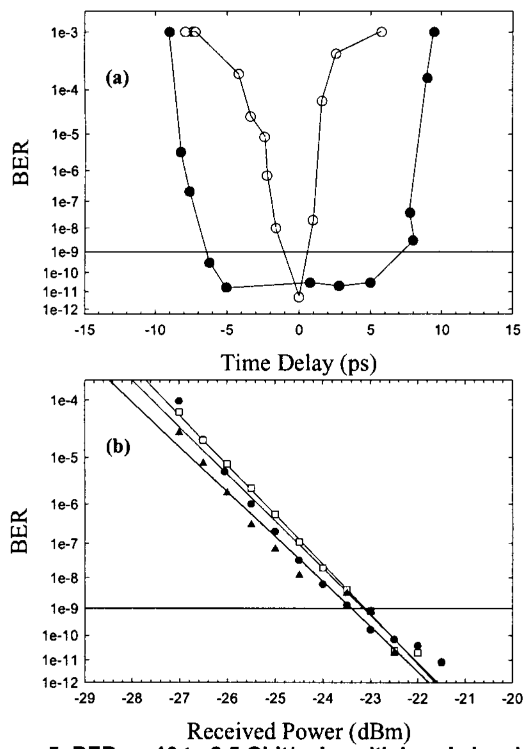

Figure 5: BER on 10 to 2.5 Gbit/s demultiplexed signals; (a) at the fixed received power of -20dBm (●: 20ps rectangular control pulses, O: 2.5ps soliton control pulses), (b) under optimal time synchronization between control pulses and data pulses (□: wavelength converted signal, ●: switched output using 20ps square control pulses ▲: switched output using 2.5ps soliton control pulses).

In order to investigate the applicability of the SSFBG based rectangular switching technology for ultra-high speed OTDM systems. We performed 80 Gbit/s OTDM data demultiplexing experiments with 10 ps rectangular pulses.The high-speed data demultiplexer we used in this experiment was also based on NOLM using a 1 km length of the HNLF. 10 ps rectangular pulses were generated from 1.7 ps solitons with the SSFBG described in Section II. To confirm the benefits of using rectangular control pulses in practical high-speed OTDM demultiplexing systems, we performed bit-error-rate (BER) measurements on the 80 Gbit/s demultiplexer. At first we measured the BER under optimal time synchronization between control and data pulses for both cases i.e. with and without the pulse shaping SSFBG. The results are summarized in Fig. 6. Error-free demultiplexing operation for all 8-channels was achieved using the 10 ps wide rectangular shape control pulses with 1 dB power penalty relative to the 10 Gbit/s base rate back-to-back. A 2 dB power-penalty improvement was also achieved with respect to data demultiplexing without the SSFBG. We attribute this penalty improvement to the enhanced tolerance to ~ sub-picosecond timing drift inherent to our experimental setup caused by environmental temperature/air flow variations during this particular experiment.

Fiinally, we measured the BER at a fixed received optical power of –31 dBm as a function of relative timing mismatches between control and data pulses and the results are shown in Fig. 7. Error-free performance was readily achieved over a +/-3 ps timing mismatch range for the rectangular pulse driven demultiplexer versus a +/-0.5 ps range for the demultiplexer driven directly with the soliton pulses.

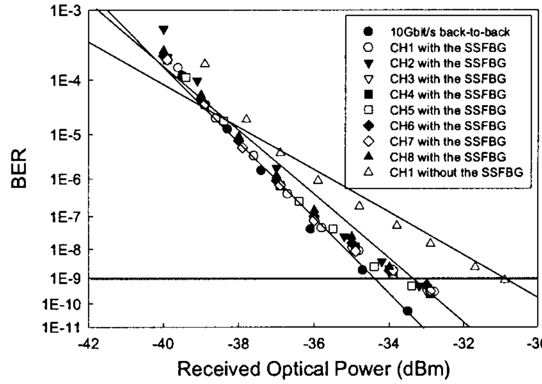

Figure 6: BER at –32 dBm, on the 80 Gbit/s to 10 Gbit/s demultiplexed signals vs received optical power under optimal time synchronization between the control and data.

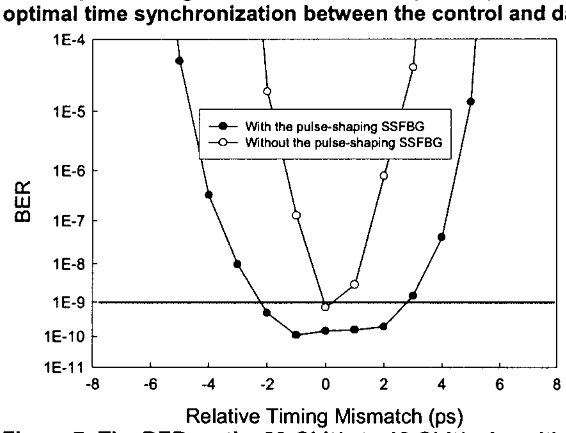

Figure 7: The BER on the 80 Gbit/s to 10 Gbit/s demultiplexed signals, measured at a fixed received optical power of -31 dBm vs relative timing mismatch between control and data.

IV. Discussion and Conclusion

We have shown that SSFBG based rectangular pulse switching technology can be used to provide improved timing jitter tolerance in high-speed OTDM demultiplexing systems. Error-free demultiplexing operation with significant timing jitter tolerance was achieved using rectangular control pulses generated through an SSFBG. This implies that significant OTDM demultiplexer performance enhancements can be achieved simply by adding an SSBFG to the system. This approach could be applied to 160Gbit/s OTDM systems since state-of-the art SSFBG technology should be capable of producing high-quality gratings capable of generating 5~6 ps rectangular pulses with rise/fall time less than 1 ps.

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