Simultaneous Processing of 43 Gb/s WDM Channels by a Fiber-Based Dispersion-Managed 2R Regenerator

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Abstract *We demonstrate 43 Gb/s multi-channel 2R regeneration in a single dispersion-managed fiber, based on SPM-induced spectral broadening and subsequent offset filtering.*

Introduction

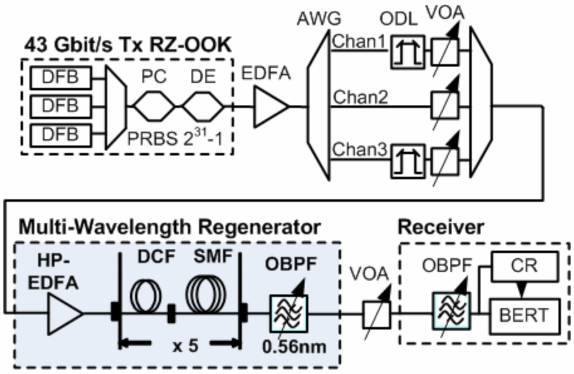
All-optical regeneration relying on self-phase modulation (SPM)-induced spectral broadening and subsequent off-center filtering (known as Mamyshev technique [1]), has attracted particular interest due to its simplicity and ability to suppress both power variation in the mark- and noise in the space-level of return-to-zero (RZ) amplitude modulated signals. Unfortunately, the Mamyshev concept requires an expensive amplifier and nonlinear fiber for each channel. To reduce the costs related with the nonlinear element it has been shown, that the nonlinear fiber can be shared by simultaneously processing two counterpropagating signals [2]. More recently, simulations have indicated that the technique should be compatible with true multi-wavelength regeneration by sharing a single amplifier and a properly designed dispersion managed fiber assembly with several copropagating signals [3],[4]. And indeed, a conceptional demonstration with one 10 Gb/s channel based on alternating sections of nonlinear fiber and periodic-group-delay devices (PGDD) has indicated feasibility. In this approach the PGDDs were used in order to ensure unidirectional walk-off between the pulses of adjacent channels [3],[5]. In another approach alternating sections of dispersion compensating fibers (DCF) and standard single mode fibers (SMF) have been used to demonstrate regeneration with 4×10 Gb/s, utilizing, however, low-duty cycle RZ pulses (~8.3%) [6].

In this paper we demonstrate 43 Gb/s multi-wavelength regeneration using the simplified approach based on alternating sections of DCF with SMF for regenerating three 33% duty-cycle RZ channels.

Experimental setup and results

To demonstrate multi-wavelength regeneration with two and three 43 Gb/s channels, respectively, we built the setup shown in *Fig. 1*. It comprises a three channel transmitter, a signal decorrelation stage, the regenerator and a preamplified receiver.

The transmitter consists of three distributed feedback (DFB) lasers on a 600 GHz grid, amplitude modulated at 43 Gb/s by a 2^{31}-1 long PRBS. A series of optical delay lines (ODL) and variable optical attenuators (VOA) between two arrayed-waveguide gratings (AWG) provided some pattern decorrelation and adjustment of the relative time delays on a bit basis.



	Length (m)	Dispersion (ps/nm/km)	Dispersion slope (ps/nm²/km)	Nonlinear coefficient (/W/km)	Loss (dB/km)
DCF	134	-120.5	-0.432	5.3	0.45
SMF	1060	16.4	0.058	1.3	0.23

Fig. 1: Experimental setup, configuration of the 2R regenerator and parameters of the DCF and SMF. PC – Pulse Carver, DE – Data Encoder, CR – Clock Recovery.

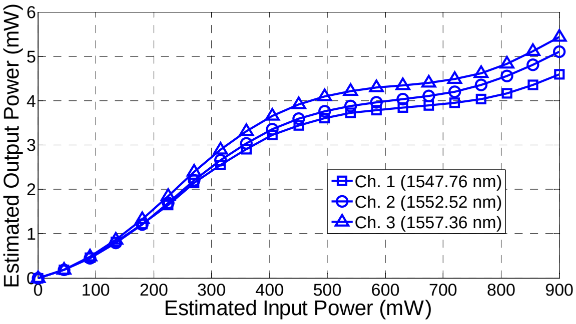


Fig. 2: Experimental average-power TFs, measured for each channel while the others were turned off.

The subsequent regenerator consists of a high-power optical amplifier, the fiber assembly and a 0.53 nm tuneable optical band-pass filter (OBPF) that allowed for the individual selection of channels. The filter was detuned by -0.6 nm from the center wavelength. The 5.97 km-long fiber assembly contained five DCF-SMF pairs with the parameters given in *Fig. 1*. The length of each DCF exhibited a maximum differential group delay of ~150 ps between the three channels, while the total length of SMF offered a slight overcompensation of the dispersion with a residual dispersion of ~6 ps/nm at 1550 nm [6].

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The use of the optimized dispersion map facilitates high local dispersion, which minimizes the inter-channel nonlinear effects (four-wave mixing (FWM) and cross-phase modulation (XPM)), and low average dispersion, which retains the integrity of the pulses and the potential for SPM-induced spectral broadening of each channel. Further, In *Fig. 2*, the step-like average-power transfer functions (TFs) of the individual channels are shown.

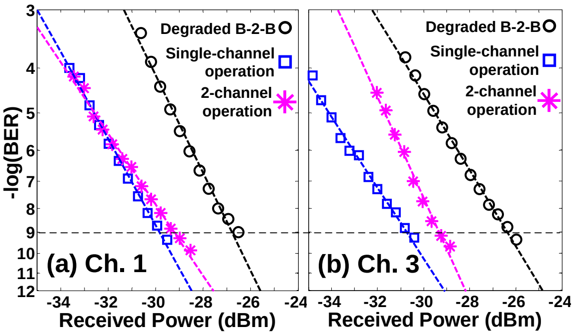

Fig. 3: BER measurements in single- and dual-channel operation (1200 GHz channel spacing) with degraded input signals: a) Ch.1 and b) Ch.3.

The regenerator performance was first evaluated considering two channel operation with Ch.1 (1547.76 nm) and Ch.3 (1557.36 nm) only. The input signals were deterministically degraded by choosing a non-optimum modulator bias-voltage, resulting in peak power variation and limited extinction ratio (ER) for both channels. In *Fig. 3*(a)-(b) the bit-error-rate (BER) curves are presented for each channel, each one related to the input, the regenerator output in single-channel operation and the output in dual-channel operation (presence of interfering channel), respectively.

The power per channel entering the fiber assembly was optimized to ~360 mW, while in dual-channel operation worst cases for the relative delays were selected by adjusting the two ODL “on the fly”. Actual regeneration and limited degree of residual nonlinear crosstalk can be identified in *Fig. 3*, with the lowest power penalty improvement at the level of BER=10^{-9} being 2.5 dB for Ch.1 in dual-channel operation.

In order to identify the performance limitations of the current regenerator design, a third channel, allocated at 1552.52 nm, was added in-between the two channels, allowing for a three-channel operation study with 600 GHz channel spacing.

For the same degraded input signal as before an error-floor was observed for Ch.2 and Ch.3 in 3-channel operation (although no additional penalty was induced by the regenerator when undegraded input signals were used). In order to identify the origin of this behaviour, eye diagram-based Q-factor, ER and timing jitter measurements were made on the input and output signals. Five randomly chosen combinations of relative time delays were considered, and the results in *Fig. 4*(a)-(b) reveal (Q-factor)^2 and ER improvement ranging from 1.7 to 2.8 dB and 1.6 to 2.1 dB respectively. Nevertheless, the eye diagrams of *Fig. 4*(f)-(h), corresponding to the worst delay case for each channel with respect to output Q-factor, indicate that the XPM-induced timing jitter of the outputs is the main reason for the performance deterioration at 600 GHz channel spacing.

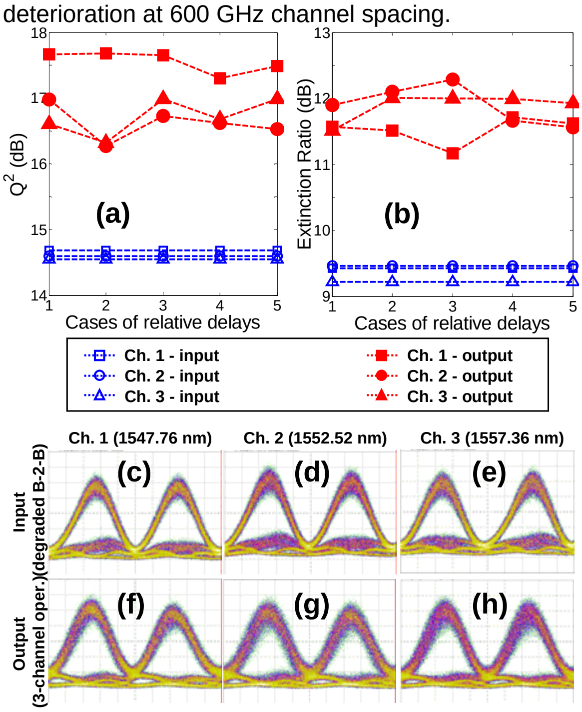

Fig. 4: (a) Q-factor and (b) ER measurements in three-channel operation (600 GHz channel spacing), (f)-(h) output eye diagrams in three-channel operation with degraded input signals (c)-(e).

Conclusions

Experimental investigation at 43 Gb/s of a fiber based dispersion-managed 2R regenerator is presented utilizing pulses of 33% duty-cycle. Dual-channel regeneration at 1200 GHz channel spacing is reported, with power penalty improvement over 2.5 dB for degraded input signals.

Acknowledgements

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