IMPROVEMENT OF NONLINEAR TOLERANCE IN 40 Gbit/s TRANSMISSION BY PHASE MODULATION AT 10 GHz

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Abstract *We propose to suppress intra-channel four-wave-mixing (IFWM) in 40 Gbit/s optical transmission by applying a phase modulation at 10 GHz. Both numerical simulations and experiments show that the penalty induced by IFWM is significantly reduced.*

Introduction

One of the major obstacles when upgrading long-haul transmission systems to 40 Gbit/s is the penalty introduced by non-linear intra-channel interactions [1,2]. While intra-channel cross-phase modulation (IXPM), which causes timing jitter, can be effectively suppressed by proper dispersion management [2,3], intra-channel four-wave-mixing (IFWM) is more difficult to combat. IFWM transfers energy between dispersively broadened and overlapped pulses, leading to amplitude fluctuations and generation of ghost pulses in zero bit slots [4].

In this work we propose to apply a 10 GHz phase modulation to a 40 Gbit/s optical signal to reduce the IFWM induced penalty. Several phase modulation schemes for improving optical transmission performance has been previously demonstrated, including chirped RZ (CRZ), carrier-suppressed RZ (CS-RZ) [5] and alternate-chirp RZ [6]. In ref. [7] it was shown that by applying an optimum phase shift to every second bit slot, the phase-sensitive IFWM process could be suppressed. The resulting transmission format is a generalization of CS-RZ for which the phase shift is fixed to 180°. Here we show that applying a phase modulation at one forth of the bit rate can improve performance even more.

Numerical simulations

To evaluate the performance of our proposed phase modulation scheme we consider the transmission system shown in Fig. 1.

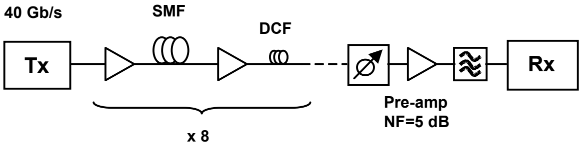

Fig. 1. The system considered in numerical simulations.

In the numerical simulations, a 512 bit 40 Gbit/s random data sequence is imposed on an RZ pulse train consisting of Gaussian pulses with 8 ps full-width-half maximum (FWHM). Before transmission a 10 GHz sinusoidal phase modulation is applied to the signal. The transmission link consists of 8 spans, each comprising an 80 km SMF with dispersion 17 ps/nm/km and a dispersion compensating fiber (DCF) with dispersion –80 ps/nm/km to bring the average dispersion in every span to zero. The output powers of the inline amplifiers in front of the SMF's and DCF's are +6 dBm and 0 dBm respectively. Since we are focused on the non-linear transmission penalty, these amplifiers are supposed to be noise-less for simplicity. The pre-amplifier in front of the receiver has a noise-figure of 5 dB. After the pre-amplifier there is a 160 GHz optical band-pass filter and the receiver includes an electrical 4th order Bessel filter with a bandwidth of 30 GHz. Transmission performance is measured by finding the signal power into the pre-amplifier necessary to achieve a bit-error ratio (BER) of 10^{-9} and calculating the power penalty compared to back-to-back transmission.

First we find the optimum relative delay of the phase modulation and the data signal. Fig. 2 shows the power penalty as a function of the relative delay.

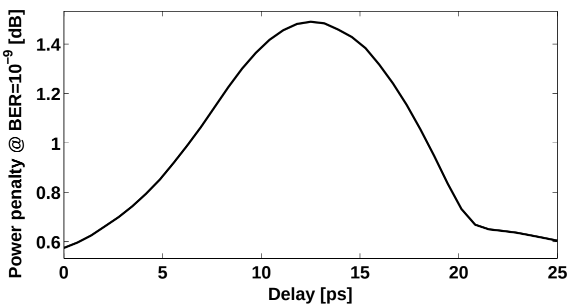

Fig. 2. Power penalty as a function of relative delay between the signal driving the phase modulator and the data signal for 150° peak-to-peak phase modulation.

The transmission performance is almost identical for relative delays of 0 and 25 ps, since the only difference is that the phase modulation is shifted one bit-slot. Fig. 3 illustrates how the optical phase and the pulse-train are correlated for an optimum delay of 0 (left) and the worst-case delay of 12.5 ps (right).

The suppression of IFWM occurs because different pulses involved in an IFWM process acquire a relative phase shift. By optimising this phase shift, destructive interference can be obtained between different IFWM contributions to a certain bit slot [7].

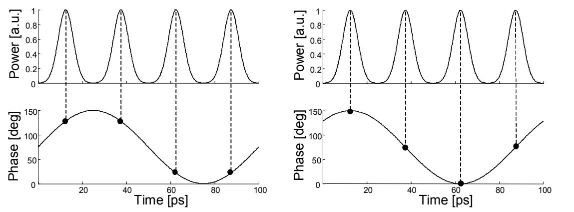

Fig. 3. Optical power and phase when the relative delay between the phase modulation and the data signal is 0 (left) and 12.5 ps (right).

The phase pattern corresponding to optimum delay, which can be represented logically as “A,A,B,B”, can also be obtained by driving the phase modulator with a square waveform at a 10 GHz repetition rate. In Fig. 4 we compare the transmission performance for the case when the driving waveform is a sinusoidal and an ideal square wave respectively by plotting the power penalty as a function of peak-to-peak phase modulation. The optimum performance is almost the same in both cases and corresponds to a reduction in power penalty as compared to pure RZ of about 1.6 dB.

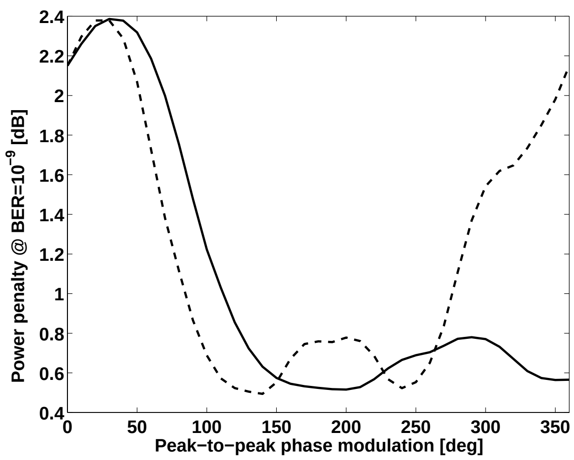

Fig. 4. Power penalty as a function of peak-to-peak phase modulation with a sinusoidal (solid line) and an ideal square waveform (dashed line).

Experiment

To experimentally verify that a phase modulation at one forth of the bit rate improves non-linear tolerance we performed a transmission experiment over one single span consisting of 100 km of SMF post-compensated by DCF (see Fig. 5). The transmitter included a sinusoidally driven electro-absorption modulator (EAM) generating 8 ps FWHM pulses at 40 GHZ, a Mach-Zehnder data modulator and a phase modulator for applying a sinusoidal phase modulation at 10 GHz. The 40 Gbit/s data stream was formed by electrical time-division multiplexing (ETDM) of four 10 Gbit/s 2^{10} -1 PRBS channels. The input powers to the SMF and DCF were 7 dBm and 1 dBm respectively. After transmission the signal was optically demultiplexed to 10 Gbit/s by another EAM and the BER was measured.

Since a 10 GHz phase modulation potentially could affect the four TDM channels differently, we measured the performance improvement for all channels without changing the delay or the amplitude of the phase modulation. Fig. 5 shows BER without phase modulation and with optimum phase modulation as a function of received power at the pre-amplifier in front of the optical demultiplexer. All four channels are improved and the reduction in power penalty at BER=10^{-9} is 1.3 dB, 2.2 dB, 1.6 dB and 1.4 dB respectively. The difference in sensitivity between the channels as well as the short PRBS-length used can be assigned to the performance of the electrical multiplexer.

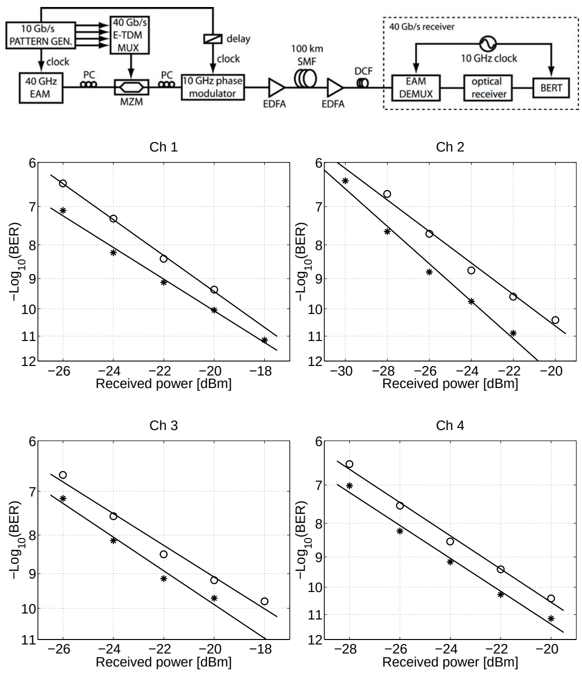

Fig. 5. Experimental setup (top) and BER vs. received power for all four TDM channels with (*) and without (o) phase modulation (bottom).

Conclusion

Applying a phase modulation at one forth of the bit rate provides a simple means for improving the transmission performance significantly in high-speed optical transmission systems by suppressing IFWM.

References

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