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Dispersion Management in Long-Haul 111-Gb/s POLMUX-RZ-DQPSK Transmission Systems

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Abstract *We compare the nonlinear tolerance of 111-Gb/s POLMUX-RZ-DQPSK modulation for dispersion managed and unmanaged transmission systems on SSMF. It is shown that unmanaged transmission reduces XPM penalties and therefore allows for the highest nonlinear tolerance.*

Introduction

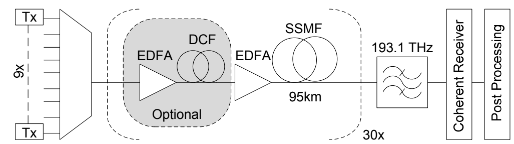
Next-generation high-capacity long-haul transmission systems will use data rates of 100Gb/s per wavelength channel in order to satisfy the ever increasing demand for transmission bandwidth [1, 2, 3].

The most suitable modulation format for 100G transport is 111-Gb/s polarization-multiplexed return-to-zero differential quadrature phase shift keying (POLMUX-RZ-DQPSK) in combination with digital coherent receivers. It is compatible with the 50 GHz channel spacing, and provides, through digital signal processing, a considerable tolerance against linear transmission impairments such as polarization mode dispersion (PMD), and chromatic dispersion (CD) [1]. The use of digital signal processing therefore gives us an increased flexibility in transmission link design. Instead of the traditional dispersion map for the compensation of chromatic dispersion (e.g. dispersion-managed transmission) it allows us to realize long-haul transmission without any dispersion management (e.g. dispersion unmanaged transmission). Dispersion unmanaged transmission can therefore reduce the complexity of long-haul transmission systems, as it no longer requires a complex dispersion map and allows for simpler amplifiers without mid-stage access. However, the impact of dispersion unmanaged transmission on the nonlinear tolerance is less straightforward and important to understand for the design of next-generation 100-Gb/s transmission systems.

In this paper we discuss the nonlinear tolerance of transmission of 111-Gb/s POLMUX-RZ-DQPSK over SSMF and detail the impact of dispersion unmanaged transmission on both single-channel and multi-channel nonlinear impairments.

Simulation setup

Figure 1 depicts the simulated transmission system setup. At the transmitter, the output of a laser is pulse-carved using a Mach-Zehnder modulator (MZM) driven with a clock of 27.75-GHz. Subsequently the signal is split in two tributaries. Both tributaries are DQPSK modulated using a nested-MZM. The two drive signals of the nested-MZM consist of a PRBS with length 2^{12} at a data rate of 27.75-Gb/s. The drive signals are shifted over 3 symbols with respect to each other in order to generate a pseudo-random hexadecimal sequence (PRHS) with length 16^3. Both DQPSK modulated signals are then combined by means of a polarization beam splitter (PBS) in order to generate 111-Gb/s POLMUX-RZ-DQPSK modulation. To properly model multi-channel transmission, the modulated sequence is shifted over 63 bits for de-correlation between each 50-GHz spaced wavelength division multiplexed (WDM) channel, and the polarizations of all WDM channels are aligned. The transmission link consists of 30 spans of SSMF, each with a length of 95 km (2850 km in total). The SSMF and DCF parameters are summarized in Figure 1. Note that the launch power into the DCF is set to -7-dBm with respect to the SSMF launch power.



	Dispersion [ps/nm/km]	Slope [ps/nm^2/km]	γ [1/W/km]	α [dB/km]
SSMF	16.8	0.058	1.14	0.21
DCF	-170	matched	5	0.5

Figure 1: Transmission system and fiber parameters.

At the receiver first the center channel is filtered out using a 4^{th} order optical Gauss filter with a 3-dB bandwidth of 45-GHz. The resulting signal is demodulated using a digital coherent receiver as described in [1]. The local-oscillator (LO) is running at exactly the frequency of the transmitter laser, in order to exclude a performance impact due to carrier recovery and the LO-to-signal ratio is set to 18-dB. The accumulated dispersion is compensated for in the receiver using frequency domain equalization. For the single channel case the carrier phase estimator (CPE) averaging interval is set to 20 symbols, and for the 9 channel case to 5 symbols, to provide near optimal performance in the presence and absence of XPM [3], respectively.

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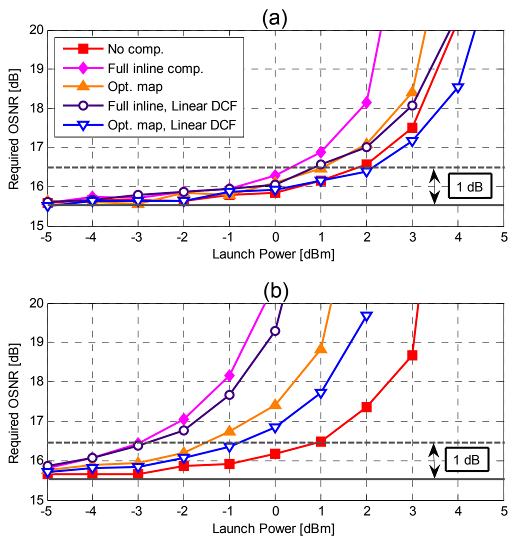

Figure 2: Launch Power vs. Required OSNR for a BER of 10^{-4} at a distance of 2850km; (a) single channel and (b) 9 channel, 50-GHz channel spacing.

Simulation Results

Figure 2 shows the transmission results over 2850km of SSMF in terms of the required OSNR at the receiver in order to obtain a BER of 10^{-4}. For the single channel case, depicted in Figure 2a, it can be seen that in case of full inline compensation (i.e. 0% inline under compensation) a 1-dB penalty is reached at a launch power of +0.3-dBm. Conversely, when no inline compensation is applied (i.e. 100% inline under compensation), the link is more robust to SPM and a launch power of +1.8-dBm will cause a 1-dB penalty.

When we consider an optimized dispersion map as typically used for 10-Gb/s and 40-Gb/s transmission systems, e.g. -1000-ps/nm of pre-compensation and a 60-ps/nm inline under-compensation (see for example [4]), the robustness to SPM is increased compared to the full inline compensation map. However, it still performs slightly worse (i.e. 1-dB penalty at +1-dBm launch power) compared to the dispersion unmanaged link. However, when we consider linear DCF's this optimal map is the most robust to SPM (1-dB penalty at +2.1-dBm launch power). This clearly shows that the higher SPM tolerance of a dispersion unmanaged link is predominantly the result of removing the highly nonlinear DCF, rather than an advantage of removing the dispersion map.

For WDM transmission with 50-GHz channel spacing, the impact of XPM can be clearly observed (Figure 2b). It is evident that XPM has a higher impact on the dispersion-managed link compared to the dispersion unmanaged transmission. For the case of full inline compensation a 1 dB OSNR penalty is obtained for a -3-dBm launch power, whereas for the unmanaged link a launch power as high as +1-dBm is allowed.

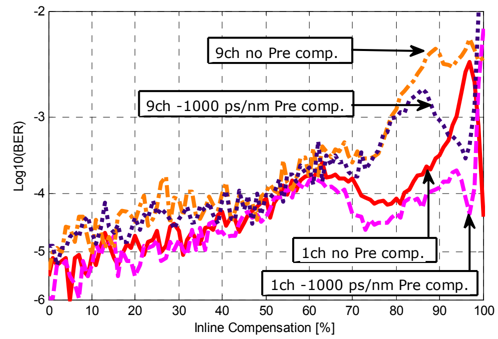

Figure 3: Inline Comp. vs. BER after 2850km SSMF at a +1-dBm launch power into the SSMF.

This indicates that the faster walk-off between neighbouring WDM channels in case of dispersion unmanaged transmission averages out the impact of XPM and as such increases the (inter-channel) nonlinear tolerance for high-dispersive fiber types such as SSMF.

Similar results can be observed in Figure 3, which shows the percentage of inline compensation versus the BER at a launch power of +1-dBm per channel. For the single channel case, the BER increases for higher values of inline compensation. This is partially the result of a somewhat higher received OSNR for a lower inline compensation (the lower mid-stage loss reduces the amplifier noise figure), but preponderantly the penalty that arises is due to the accumulated nonlinearities in the dispersion compensation modules.

For the case of WDM transmission it is seen that increasing the inline compensation from 0% towards 75% results only in a minimal XPM penalty. However, when inline compensation is further increased to close to 100%, XPM becomes the limiting nonlinear impairment [5].

Conclusions

We discussed by means of simulations the nonlinear impairments that occur in transmission of 111-Gb/s POLMUX-RZ-DQPSK over SSMF. We show that for single channel transmission optimized dispersion-managed and unmanaged links roughly provide the same nonlinear tolerance. For WDM transmission with a 50-GHz channel spacing, the dispersion unmanaged link results in the most robust transmission due to the faster walk-off between neighbouring channels.

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