WH4
9:30 AM – 9:45 AM

XPM penalty mitigation for a 42.7-Gb/s DQPSK channel co-propagating with 10.7-Gb/s OOK channels using SSMF and dispersion map

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***Abstract*—We demonstrate that the XPM penalty on a 42.7-Gb/s DQPSK channel from co-propagating 10.7-Gb/s OOK channels is reduced to less than 3 dB at practical power levels using SSMF and large residual dispersion per span.**

I. INTRODUCTION

Hybrid networks that can accommodate both 10-Gb/s and 40-Gb/s channels provide a cost-effective solution for smoothly upgrading 10-Gb/s wavelength division multiplexing (WDM) system to 40-Gb/s WDM system since they do not require the reconstruction of the currently widely deployed 10-Gb/s infrastructure. Narrow bandwidth modulation formats are required in this approach in order to fit the 40-Gb/s channel's spectrum profile into the 50 GHz channel grid, originally designed for the Non-Return-to-Zero (NRZ) On-Off Keying (OOK) channels modulated at 10-Gb/s.

Differential Quadrature Phase Shift Keying (DQPSK) is attractive due to its high spectrum efficiency, good optical-signal-to-noise ratio (OSNR) sensitivity, and excellent tolerance to chromatic dispersion (CD) and polarization mode dispersion (PMD) [1]. However, when co-propagating with OOK channels, DQPSK channels suffer severe limitation from cross phase modulation (XPM) effect, through which the intensity fluctuation of OOK channels is converted into the phase noise of DQPSK channels [2]. Reduced launch power [1], large channel spacing [3] and channel planning [4] are reported to suppress XPM penalty. However, these approaches are either unsuitable or inflexible for ultra-long distance transmission in the currently deployed 10-Gb/s infrastructure.

Dispersion map was also reported to reduce the XPM penalty in [4]. In this paper, we obtain similar results, but find that using standard single mode fiber (SSMF) instead of NZDSF (Non-zero dispersion shifted fiber, e.g. LEAF fiber) with large residual dispersion per span (RDPS) can better mitigate the XPM penalty of 42.7-Gb/s DQPSK channel from co-propagating 10.7-Gb/s OOK channels.

II. SYSTEM SETUP

The hybrid system setup is shown in Fig. 1. The transmitter consists of 17 channels generated by DFB lasers in the C-band ranging from 193.1 THz to 193.9 THz spaced by 50 GHz on the ITU-T grid. All channels are modulated with 10.7-Gb/s NRZ-OOK format except the center one (λ_9) being modulated with 42.7-Gb/s 33% RZ-DQPSK. The DQPSK channel has the worst-case XPM penalty in this kind of channel occupancy [4]. The NRZ-OOK format is generated with a single drive Mach-Zehnder modulator (MZM) driven with 2^{31}-1 length pseudo random bit sequences (PRBS) at 10.7-Gb/s. To produce the RZ-DQPSK format, the first dual-drive MZM is driven sinusoidally with a 10.7-Gb/s clock signal generating 33% RZ pulse and the second nested $LiNbO_3$ MZM is driven by two 21.3-Gb/s PRBS precoded data of length of 2^{15}-1 bits. By tuning the variable optical attenuators (VOA), the channel's launch power can be varied to study the XPM effect. The polarization controllers are used to adjust the polarization of each channel so that all channels are launched copolarized to study the worst case XPM effect. A 50/100-GHz interleaver (INT) combines all channels into the recirculating loop.

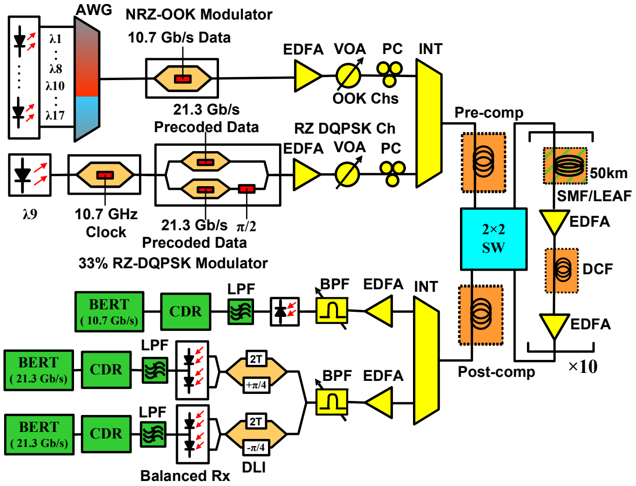

Figure 1. Schematic of the hybrid system setup.

The recirculating loop consists of ten 50 km-long spans of a given fiber (SMF or LEAF). By changing the fiber types, we compare the XPM effect for different fiber types. Additionally, by changing the residual dispersion per span, we can evaluate the XPM effect for different dispersion maps. The location and length of the dispersion compensation fiber (DCF) are optimized according to the dispersion maps being investigated.

After transmission, the 50/100-GHz interleaver separates the 10.7-and 42.7-Gb/s channels. The DQPSK channel is selected with a 0.3-nm tunable optical band pass filter (BPF). Differential demodulation is performed using an optical two-bits (one-symbol) delayed Mach-Zehnder interferometer.

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The two outputs of I or Q component are differentially detected with a balanced receiver. A clock data recover (CDR) recovers the clock to measure errors with a bit error rate tester (BERT).

III. MITIGATING XPM PENALTY

Firstly, we compared the XPM penalty over the two different fiber types (SSMF and LEAF) with different local dispersion (16.7 ps/nm/km and 4 ps/nm/km). For a dispersion map with a pre-compensation of -2000 ps/nm, a residual dispersion per span (RDPS) of 420 ps/nm and at a DQPSK channel launch power of 2dBm, the Q penalty of the DQPSK channel measured with respect to the OOK channel launch power is shown in Fig. 2. As expected, the Q penalty for both types of fiber increases with the OOK channels' launch power due to the XPM effects. Moreover, the DQPSK signal co-propagating in LEAF suffers more XPM penalty than in SSMF. This can be explained from lower local dispersion of LEAF. Consequently, there is insufficient walk-off between OOK and DQPSK channels to reduce the XPM. Due to this inter-channel interaction, the launch power of OOK channels is limited, thereby setting an additional maximum reach on OOK channels beyond the one set by the maximum nonlinear tolerable power.

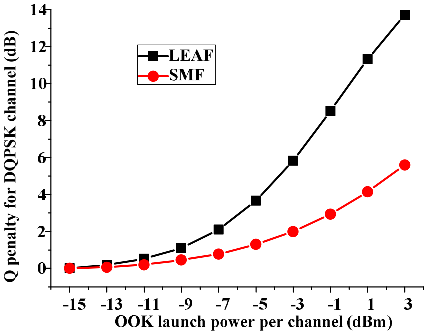

Figure 2. Q penalty on the DQPSK channel vs. OOK channel launch power

The XPM penalty was further compared for different dispersion map schemes over the two types of fiber. Chromatic dispersion and dispersion compensation are linear processes. Hence, dispersion compensation can be inserted at any location as long as the total amount of compensation is equal to the total amount of fiber dispersion. By changing the length of DCF in the loop, we can set different RDPS values while the total residual dispersion is compensated through pre-compensation and post-compensation. Fig. 3 shows the transmission performance for the DQPSK channel over SSMF and LEAF fibers for RDPS values of 0, +420, and +840 ps/nm. The Q penalty of DQPSK channel at a given OOK launch power for both types of fiber decreases as the RDPS increases, staying below 3 dB for the case of SSMF fiber with 840 ps/nm RDPS up to 3 dB OOK launch power per channel.

To quantitatively compare the performances, Fig. 4 shows the OOK launch power per channel at which the XPM penalty of the DQPSK channels reaches 3 dB for different RDPS values. When the RDPS is increased from 0 to +840 ps/nm, OOK launch power tolerance is increased by 10 dB for DQPSK in LEAF and 8 dB for DQPSK in SSMF. For the same RDPS value, the DQPSK channel in SSMF has a larger power tolerance than that in LEAF. The largest tolerance to OOK launch power is 3 dB per channel, occurring when the co-propagating OOK and DQPSK channels are transmitted over SSMF with large RDPS value. This can be understood from the fact that large local dispersion and large RDPS are two ways that can provide larger walk-off between the OOK and DQPSK channels. The price to pay for this approach is that larger post-compensation techniques, either optical or electrical, are required at the receivers due to large RDPS.

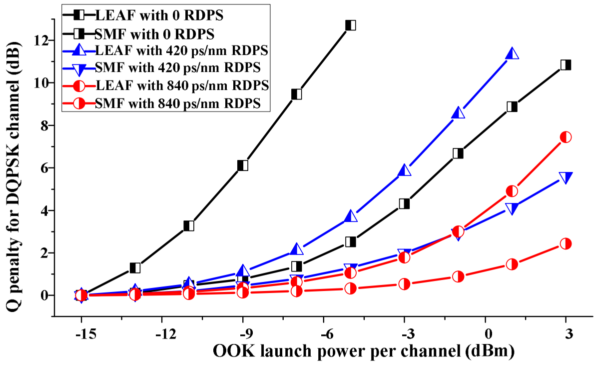

Figure 3. Q penalty on the DQPSK channel over SSMF and LEAF with different RDPS values

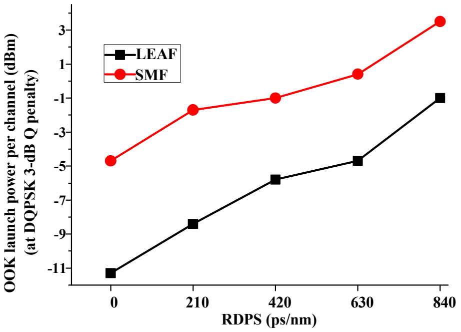

Figure 4. OOK launch power per channel at DQPSK 3-dB Q penalty.

IV. CONSLUSION

In this paper, XPM penalty on 40-Gb/s DQPSK channel in 10G/40G hybrid system over SSMF and LEAF fiber has been investigated for different dispersion map schemes. The comparison results show that the XPM penalty has a large dependence on local dispersion of fiber and residual dispersion per span as they can provide some walk-off between co-propagating channels to suppress the XPM penalty. Because of low local dispersion, LEAF is often seen to be superior to SSMF. However, this advantage becomes a drawback when the LEAF is used in 10G/40G hybrid systems. Using SSMF, together with large residual dispersion per span, XPM penalty can be mitigated to below 3 dB at practical launch power levels.

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