Symbol Rate Dependency of XPM-induced Phase Noise Penalty on QPSK-based Modulation Formats

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Abstract

Systematic investigation of XPM impact on QPSK signals reveals that higher symbol rates are advantageous for reducing both intra-span generation and multi-span accumulation of phase noise.

Introduction

With increasing demand for transmission capacity network operators are looking for upgrading their networks based on 10Gbit/s/ch with higher data rate channels such as 40Gb/s and 100Gb/s. In order to achieve this goal, spectrally efficient modulation formats, in particular the ones based on phase-shift keying (PSK), are very attractive. Such formats include variants of QPSK-based formats, e.g. RZ-DQPSK [1], DP-QPSK [2], OFDM-QPSK [3], and DP-OFDM-QPSK [4, 5]. The use of dual-polarization and/or OFDM allows further reduction of transmission symbol rate, which leads to improved tolerances to linear distortions such as polarization mode dispersion, chromatic dispersion (CD), and pass-band narrowing due to optical filters. On the other hand, there are some concerns with lowering symbol rate, which is not only the higher complexity of transceiver implementation but also the reduced tolerance to nonlinear impairments, such as cross-phase modulation (XPM) [6-9]. In this paper we provide a systematic study on the symbol rate dependency of XPM tolerance of QPSK formats by numerical simulation and discuss its underlying mechanism.

Generation of XPM-induced phase noise

When various symbol rate PSK channels are transmitted along with OOK channels, the performance of PSK signals can be degraded due to XPM-induced non-linear phase noise. Here, the power variations in the co-propagating OOK channels can cause bit-pattern dependent XPM induced non-linear phase noise on PSK signals, which can directly impair PSK detection. However, XPM penalty strongly depends on the symbol walk-off among different channels that is determined by CD map, channel plan and transmission symbol rate. In order to better understand the mechanism of XPM-induced signal degradation, we studied 2 scenarios: (1) XPM phase noise generation within a single span, and (2) XPM phase noise accumulation in multiple spans system.

The XPM impairments in hybrid RZ-DQPSK /NRZ WDM system were investigated for various RZ-DQPSK symbol rates from 10GBaud to 60GBaud, while the symbol rate of NRZ channels was fixed to 10Gbaud. Here, we defined XPM-induced Q-penalty as a difference between Q-factors with and without NRZ channels. Fig. 1 and Table 1 summarises the simulation model and parameters. A CD map with 95% in-line post-compensation was used. Tuneable CD compensator (TDC) was included at the receiver side for RZ-DQPSK channel. RZ-DQPSK signal was received with differential detection receiver, which tends to show superior tolerance to XPM phase noise than coherent detection.

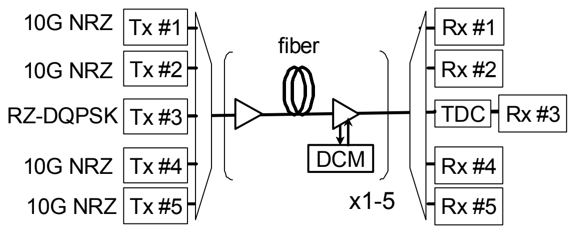

Figure 1: Simulation model

Fiber loss coefficient	0.25 dB/km
CD coefficient @1545 nm	SMF 17 ps/nm/km NZ-DSF 3.83 ps/nm/km
CD slope coefficient @1545 nm	SMF: 0.057 ps/nm^2/km NZ-DSF: 0.083 ps/nm^2/km
Nonlinear coefficient	SMF: 3.14x10^{-10} /W NZ-DSF: 3.27x10^{-10} /W
Transmission distance	1-5 x 80km
Channel spacing	50GHz, 100GHz and 150GHz

Table 1 : Simulation parameters

Results and discussion

First, we investigated the XPM phase noise generation within a single span. Fig. 2(a, b) shows the XPM-induced Q-penalty as a function of RZ-DQPSK symbol rate for various channel spacing and for SMF and NZ-DSF fibres. Note that we set relatively high values of fibre input powers to induce visible Q-penalties. Since higher CD coefficient results in lower XPM penalty, we needed 4 dB higher fibre input power for SMF in order to observe similar penalties as in NZ-DSF. Fig. 2 clearly shows that XPM penalty is smaller with higher RZ-DQPSK symbol rate and larger channel spacing. It is interesting to note that all curves have similar trend against the symbol rate, where the XPM penalty shoots up when the RZ-

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DQPSK symbol rate becomes lower than 25Gbaud. This can be explained by the temporal walk-off between co-propagating channels in a span, which is proportional to the channel spacing and which tends to average out the XPM phase noise induced at different points in a span. This explanation is consistent with the fact that the symbol rates for a 1-dB Q-penalty for 50, 100 and 150 GHz spacing are approximately in the ratio of 6:3:2 (=1/50:1/100:1/150) for the both fibre types.

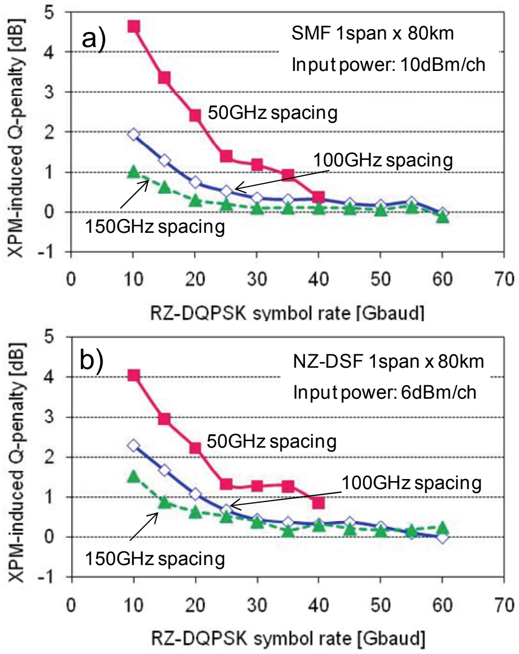

Figure 2: Q-penalty vs. RZ-DQPSK symbol rate in 1span x 80km of (a) SMF and (b) NZ-DSF

Next, we investigated the XPM phase noise accumulation in multi-span transmission. Figure 3 shows XPM-induced penalty as a function of the number of spans for various RZ-DQPSK symbol rates and for 50GHz and 100GHz channel spacing. The transmission over 80km per span of NZ-DSF with fibre input power 0dBm/ch was investigated. Here, four observation key points should be noted: (1) the XPM-induced penalty accumulation is steeper with lower symbol rate and with smaller channel spacing, (2) the penalty accumulation is almost linear for all cases, (3) the results are very similar for two specific cases, such as 20Gbaud with 50GHz spacing and 10Gbaud with 100GHz spacing, (4) 40Gbaud signal has little penalty. With regards to key points (2) and (3) we need to consider the temporal walk-off between adjacent channels induced by the residual CD per span, which is 12.3ps/span and 6.1ps/span for 50GHz and 100GHz spacing, respectively. Since this is less than 1 unit interval (UI) per span for all symbol rates, the result (2) seems natural. Similarly, in result (3) the two cases (20Gbaud with 50GHz spacing and 10Gbaud with 100GHz spacing) share the same symbol walk-off of 0.12 UI/span between adjacent channels. This logic, however, fails to explain the different XPM penalties for another set of cases that has the same symbol walk-off of 0.49 UI/span, i.e. 40Gbaud with 50GHz spacing and 20Gbaud with 100GHz spacing. This effect as well as result (4) can be explained by considering the impact of waveform change due to span residual CD (15.3ps/nm/span). While this small CD hardly affects the 10Gbaud and 20Gbaud cases, it provides some suppression of XPM phase noise for higher symbol rate signals such as 40Gbaud.

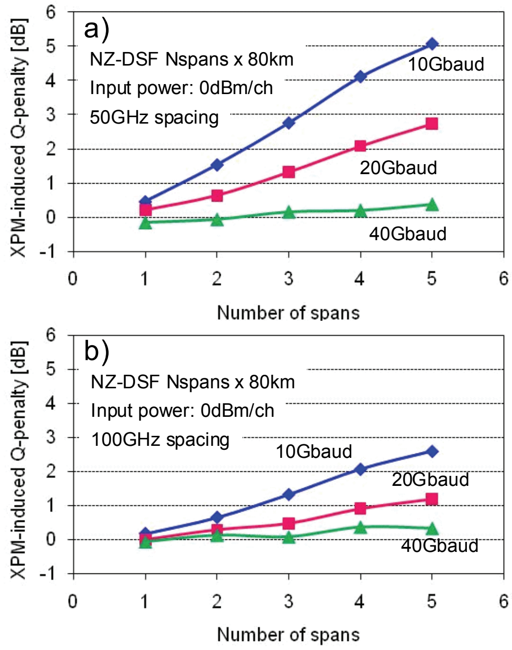

Figure 3: Q-penalty vs. span number for various RZ-DQPSK symbol rates in (a) 50GHz- and (b) 100GHz-spaced WDM system

Conclusion

We have studied the XPM-induced phase noise dependency on symbol rate of the QPSK signals co-propagating with 10Gb/s NRZ signals. We showed that lower symbol rate signal can be degraded by higher generation rate of phase noise within a span as well as higher accumulation over multiple spans. Thus, careful consideration of the trade-off between linear and non-linear impairments is required in choosing suitable modulation format for high bit rate WDM transmission systems.

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