Investigation of Cross-Phase Modulation in WDM Systems with AM-PSK Modulation Formats

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Abstract: We investigate the impact of cross-phase modulation on optical AM-PSK modulation formats, namely duobinary, PSBT and dicode, as function of channel wavelength separation and channel power.

1. Introduction

In the past three years high spectral efficiencies have been achieved in WDM systems using duobinary modulation [1,2,3]. The main advantages of this format are increased tolerance to chromatic dispersion and improved spectral efficiency. Three-level electrical PRS systems other than duobinary can be considered for use in optical communication systems, namely modified duobinary and dicode. The impact of fibre nonlinearities on systems using these AM-PSK modulation formats has not received much attention. Some work regarding SPM [1,5] and FWM [4] was reported. However, with the rapidly increasing capacity requirement, a push for wavelength spacing narrowing to increase the channel count and higher channel bitrate will lead to a severe cross-phase modulation effect [6,7]. The impact of CPM in WDM systems with these PRS schemes was never the subject of any study, to the best of our knowledge.

The aim of this paper is to investigate by numerical simulations the impact of cross-phase modulation in WDM systems using AM-PSK duobinary and dicode signals in single-span links. Modified duobinary signals were not considered based on previous results [8].

2. Model

The model used was based in [9]: two channels are used, one, referred as a probe, is a CW signal, and the other carries binary data and is referred to as the interfering or pump channel. The probe's intensity fluctuations at the fibre output can then be used as a measure for the interference caused by XPM.

Several modulation formats were considered: NRZ (used as reference), duobinary, duobinary generated by a single low-pass Bessel filter (3 dB cut-off at ~ ¼ the bitrate) – also called by some authors as PSBT [10] - and dicode. The optical AM-PSK transmitters models were based in [11]. The transmitter consists of a chirp-free dual arm $LiNbO_3$ Mach-Zender modulator, operated in a push-pull configuration. The fibre was 80 Km of standard SMF: 0.2 dB/Km, chromatic dispersion of 16 ps/nm/Km and dispersion slope of 0.06 ps/nm^2/Km; non-linearity coefficient of 1.2 1/W/Km. An ideal PIN photodetector and a 5th order 7.5 GHz cut-off Bessel filter represented the optical receiver. The optical filter bandwidth was 2R, where R is the channel bitrate. Data was generated by a 10 GB/s 2^7-1 pseudo-random sequence. All the simulations were carried out using the commercial package OptSim® v. 3.0 by ARTIS.

3. Results and discussion

In all our simulations the probe average power launched into the fibre was 1 mW.

The standard deviation σ of the probe output intensity, normalised to the average probe intensity at the receiver is plotted in Fig. 1 as function of the wavelength spacing between the two signals. In part (a), ideal electrical signals were considered, with instantaneous rise and fall time. In part (b) symmetrical rise and fall time of 30% of the bit period was considered.

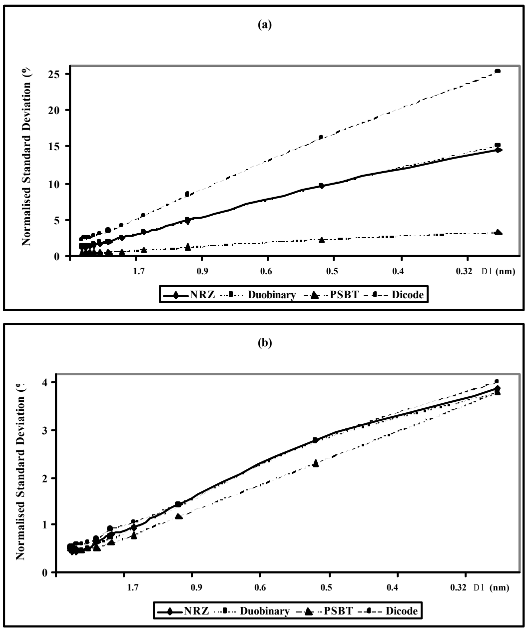

Figure 1: XPM as function of wavelength separation with pump power of 10 dBm (note the 1/Dl scaling of the horizontal axis).

It is clearly seen that the interference is almost proportional to $1/\Delta\lambda$ over the entire simulated wavelength range. The minimum wavelength spacing considered was 0. 3 nm. Note the significative decrease observed for NRZ, duobinary and dicode signals when a rise and fall time was considered. Assuming rise and fall times is equivalent to a strong attenuation of the secondaire lobes of the signal spectrum – a kind of bandlimiting effect that it is effective in extending the dispersion limit. The PSBT due to the fact that was generated by filtering, which resulted in rounded signals, was unaffected in both situations. This latter modulation format yields a marginal reduction of XPM impact comparing to the other signals.

Fig. 2 plots the dependence of XPM-induced intensity interference on the pump signal power. Again, the standard deviation σ of the probe output intensity, normalised to the average probe intensity at the receiver, is the parameter considered as function of the signal interfering average power.

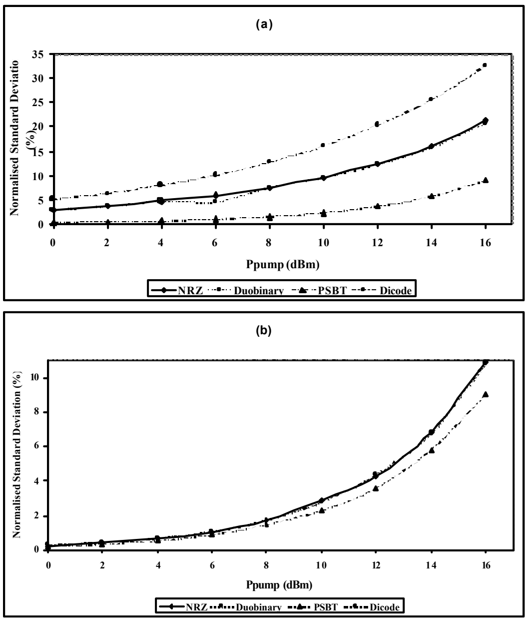

Figure 2: XPM as function of pump average power.

The wavelength spacing considered is 0.5 nm.

From Fig. 2b it can be seen small differences among the modulation formats considered. Comparing the results in (a) against those in (b), a reduction of the XPM-induced interference can be observed. This results from the reduction of the peak power for the various signals.

Note that the dependence is almost linear for low pump powers (< 10 dBm). For sufficient high optical powers other nonlinearities should be considered as SPM, SBS and possibly MI. It was found that the interference due to SPM only and XPM only do not add up to yield the total SPM+XPM interference, since both are complex functions of the input powers. It was also verified that XPM interference was mostly generated near the beginning of the fibre due to higher pump power and the induced nonlinear phase distortion underwent the most subsequent chomatic dispersion.

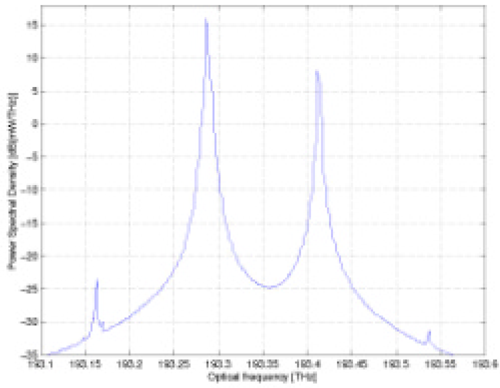

Figure 3: Optical spectrum for spacing of 1 nm.

Fig. 3 shows the optical spectrum at the receiver end for a channel separation of 1 nm and NRZ signalling. Note the presence of sidebands. Their appearance is possibly the result of FWM intermodulation. These components do not significantly impact the system since they do not overlap with existing channels. However, for high channel count care should be exercised.

Neverthless, PSBT shows more robustness to higher pump powers which, with its superior performance regarding SPM /5/, is an improvement regarding repeaterless link distance.

4. Conclusions

Simulation results have shown that WDM systems with AM-PSK modulation formats do not present significative improvement regarding the impact of XPM as function of channel spacing against NRZ signals. Some improvement is gained when channel power is considered but only for PSBT format, which also shows larger robustness to signal shape effects than the other formats.

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