Impact of Fiber Nonlinear Effects on 10 Gb/s WDM Systems over 600 km of SMF and NZDSF

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***Abstract* – We carry out numerical simulations to compare the impact of the fiber nonlinear effects on transmission of 40 and 80 WDM channels modulated at 10 Gb/s, for three different fiber types, standard single mode fiber, large effective area NZDSF, and reduced dispersion slope NZDSF. By comparing the results with single channel transmission, we explain the contribution of the main nonlinear effects to the power penalties obtained.**

I. INTRODUCTION

The strategy used to upgrade the capacity of optical transmission systems is of critical importance for the choice of fiber type to be installed. The option for higher channel rate leads to the choice of low dispersion fibers, in order to reduce the cost on dispersion compensation. Nevertheless, the option for larger number of channels leads to the choice of fibers with non-zero dispersion value to reduce the nonlinear inter-channel crosstalk. Non-zero dispersion shifted fiber (NZDSF) is a good trade-off between these characteristics, since it can be used for transmission of many channels at high bit rate over long distances[1,2]. However, because of smaller effective area and lower dispersion, NZDS fibers might induce interchannel nonlinear crosstalk for WDM systems with closely spaced channels. Although standard single-mode fibers (STD-SMF) have large dispersion, they can be a very good option for transmission of channels closely spaced, provided that group velocity dispersion (GVD) is properly managed[3].

Results of numerical simulations [4] and experimental investigations [5-7] have been reported on the comparison of standard single-mode fiber and small effective area non-zero dispersion shifted fiber. In [8], the authors simulate the impact of four wave mixing and cross phase modulation on 40 channel WDM transmission by treating these effects as noise-like impairments, for four types of transmission fibers: two effective areas and two dispersion slopes NZDS fibers.

In this letter, we compare the transmission impairments caused by nonlinear effects and GVD for three different transmission fiber types commercially available for the moment, STD-SMF, reduced dispersion slope NZDSF (NZDSF1) and large effective area NZDSF (NZDSF2). The investigation was carried out through computer simulations of WDM transmission of 40 and 80 channels modulated at the bit rate of 10 Gb/s over a link of 600 km. We show that the two main nonlinear effects for the launched power range studied are self-phase modulation (SPM) and cross-phase modulation (XPM), combined with GVD.

II. RESULTS

The simulation was carried out for 40 and 80 WDM channels transmitted over 6x100 km of fiber. The channels are modulated at the bit rate of 10 Gb/s. Five optical in-line amplifiers were used to compensate for the link losses. The main characteristics of the three fibers investigated are presented in Table I.

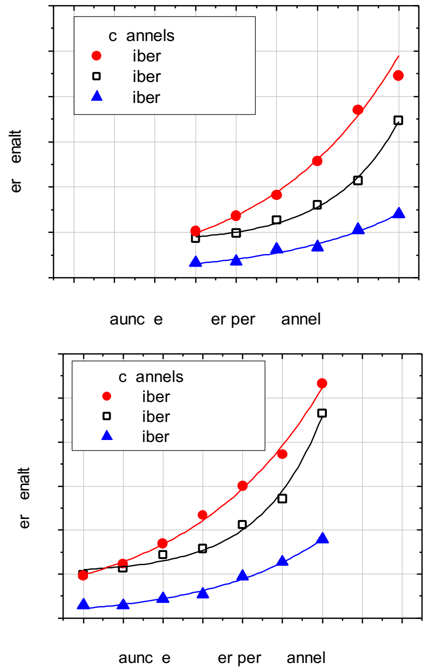
TABLE I
Characteristics of the fibers used in the computer simulation

Fiber Type	NZDSF1	NZDSF2	STD-SMF
Dispersion @ 1545 nm (ps/nm.km)	3.75	3.5	16.8
Dispersion Slope @ 1545 nm (ps/nm^2.km)	0.05	0.1	0.06
Effective Area (μm^2)	55	72	80
Loss (dB/km)	0.25	0.25	0.25

The first channel is at the wavelength of 1530.3 nm and the last one is at 1561.4 nm. For STD-SMF, the dispersion was compensated at each in-line amplifier and at the receiver terminal, using dispersion compensation fibers (DCF) with -1680 ps/nm at 1545 nm. For STD-SMF, the residual dispersion ranges from -163 ps/nm (channel 1) to +149 ps/nm (channel 40).

For both NZDS fibers, the dispersion was compensated only at the terminals, using two different DCFs, one with -1345 ps/nm and the other with –672 ps/nm at 1545 nm. The residual dispersion ranges from –139 ps/nm to +646 ps/nm for NZDSF1 and from -727 ps/nm to +988 ps/nm for NZDSF2.

The power penalties at 10^{-12} BER for all three fiber types are presented in Fig. 1 as a function of the launched power per channel. We show the results of the simulations for both 40 (Fig. 1a) and 80 (Fig. 1b) channels, corresponding to channel separations of 100 and 50 GHz, respectively.



(a)

(b)

Fig. 1 – Power penalty due to nonlinear effects and GVD versus launched power per channel, for fibers NZDSF1, NZDSF2 and STD-SMF. (a) 40 channels transmitted and (b) 80 channels transmitted. For each power level, the channel selected is the one with the highest penalty. The solid lines are the best fit to the calculated data.

The power penalties shown in the graphs of Fig. 1 were obtained taking into account only the fiber transmission impairments (nonlinear effects and GVD). The amplifier ASE is not considered here, since the objective is to investigate the nonlinear effects.

In systems where XPM is present, changes in the bit pattern affect the system performance more strongly than changes in the dispersion map [9]. The calculations were done for various combinations of bit patterns to guarantee that the variation of the penalty is not due to some particular combination of bit sequences. For all three fiber types, we selected the highest power penalty among all combinations and among all channels.

The power penalty simulated for fiber NZDSF2 with 40 channels and launched power of +2 dBm per channel (1.1 dB) is in good agreement with the experimental result reported in [1] (0.9 dB).

We observe that for both 40 and 80 channels, the STD-SMF has the lowest power penalty, followed by NZDSF2. NZDSF1 has the highest penalty, for the power range investigated. For 40 channels, the maximum launched power in order to keep the power penalty below 1 dB is +4 dBm for the STD-SMF and 0 dBm for both NZDSFs. For 80 channels, the maximum launched power in order to keep the power penalty below 1 dB is +1 dBm for the STD-SMF and –3 dBm for both NZDSFs.

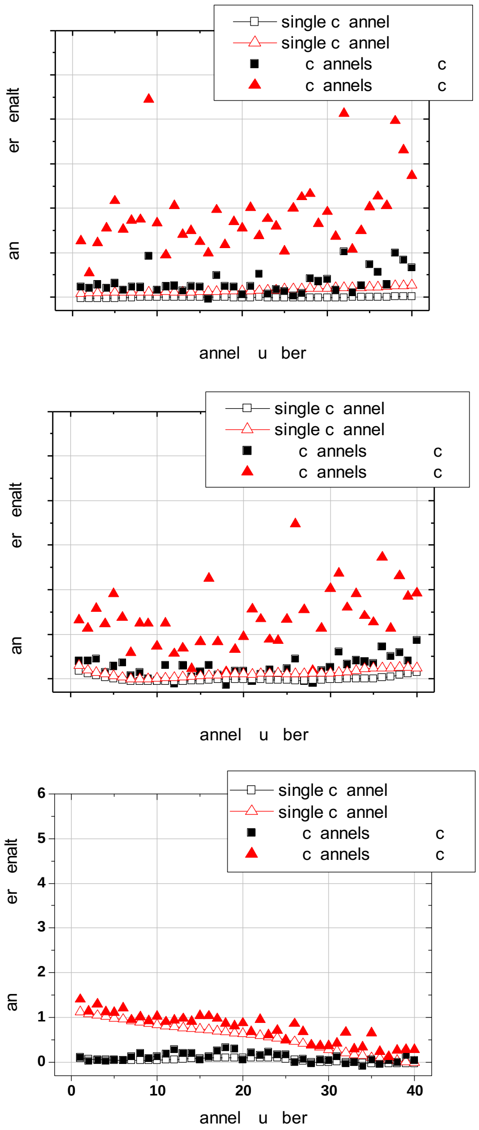
In order to ascertain the impact of Four Wave Mixing (FWM) on the calculated power penalties, we have sampled several output spectra by switching off some of the channels. Table II shows the crosstalk obtained due to the intermodulation products from the output spectra for 40 and 80 channels and for the highest launched power. According to [10], the worst crosstalk (80 channels for NZDS fibers) corresponds to a significant FWM induced power penalty. For all the other cases (40 channels and for STD-SMF), the FWM penalty should be well below 1 dB [10].

TABLE II

FWM crosstalk for all three fibers with 40 and 80 channels

Number of Channels	NZDSF1	NZDSF2	STD-SMF
40	28	30	29
80	18	19	29

In order to separate the contributions from SPM and XPM, we compare the power penalty obtained for each channel in the WDM transmission with the penalty for a single channel transmission, considering the same residual dispersion in both cases. The results of these calculations are shown in Fig. 2.



(a)

(b)

(c)

Fig. 2 – Power penalty due to SPM and XPM versus channel number for single and multiple channel transmission. The results are presented for two levels of power per channel, 0 and 4 dBm. (a) NZDSF1, (b) NZDSF2, and (c) STD-SMF.

In NZDS fibers, the largest contribution to a channel XPM penalty comes from the closest channels. We have investigated this contribution for fibers NZDSF1 and NZDSF2. Fig. 3 shows the results of the XPM penalty calculations as a function of the number of channels turned on in the WDM system. The channels separation is 100GHz and they are added in pairs, one on each side of the already existing channels. The power per channel is 4 dBm. For fiber NZDSF1, channel 9 was selected and for fiber NZDSF2, channel 26 was selected.

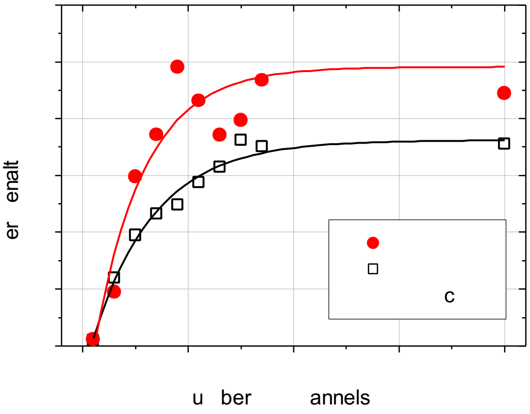


Fig. 3 – Power penalty of channel 9 (for NZDSF1) and 26 (for NZDSF2) versus number of transmitted channels. The power per channel is 4dBm.

The XPM power penalty increases sharply with the inclusion of the initial channels. The addition of channels beyond three pairs does not increase the penalty more than 1 dB. The contribution to the XPM penalty comes mainly from channels allocated within±300 GHz.

III. CONCLUSION

In conclusion, we show that in WDM systems modulated at 10 Gb/s, self phase modulation causes the main impairments for transmission over STD-SMF, whereas cross phase modulation and four wave mixing are the main impairments for both types of NZDSF. For 100 GHz channel spacing, FWM does not contribute significantly to the power penalty. FWM induced penalty is significant for NZDS fibers only with 50 GHz channel separation. The power penalties for reduced slope NZDSF are higher than for the large effective area NZDSF, which are higher than for STD-SMF. In NZDS fibers the XPM penalty comes mainly from channels allocated within ±300 GHz.

IV. ACKNOWLEDGEMENTS

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