Transmission Impairments due to Four-Wave Mixing in the 1310 nm Window

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High speed optical transmission in the 1310 nm window might have a potential for ACCESS and METRO applications considering the restricted distances and the virtual absence of dispersion related system penalties. On the other hand Four-Wave Mixing (FWM) is expected to play a major role in WDM transmission. The effects of FWM has been evaluated in a four channel 10 Gbit/s WDM experiment with 100 GHz channel spacing over 100 km Standard Single Mode Fibre employing semiconductor optical amplifiers (SOA's) as a booster, in-line and preamplifier. Successful suppression of FWM penalties was achieved by using an unequal spaced channel allocation scheme.

Introduction

One of the trends in optical transmissions systems research is to increase and reuse capacity of the existing optical transmission systems. The second optical transmission window, around 1310 nm wavelength, has a big potential to fulfill the increasing needs for the transmission bandwidth. To compensate fibre losses in the second optical transmission window, which are higher than in the third transmission window (1550 nm), SOA's can be used. Because of the use of SOA's and the fact that dispersion value for standard single mode fibre (SSMF) is close to the zero in the second transmission window, non-linear effect, as Four-Wave Mixing (FWM) can be a source of high system penalties in the optical transmission systems. FWM effect products can be generated in the fibre and the SOA as well. Previous experiments [1], [2] were done in the system configuration where FWM was alleviated by using fiber with a high dispersion value or very large channel spacing. In our experiments penalties induced by a FWM effect were eliminated by special channel allocation scheme.

Four-wave mixing (FWM)

In the four-wave mixing effect two of three waves, co-propagating in the nonlinear medium, interact with each other and new waves are generated at the frequencies according to the Equation 1 [3].

$$f_{ijk} = f_i + f_j - f_k, \qquad i,j \neq k \tag{1}$$

The example of the three co-propagating waves and newly generated nine waves is presented on Figure . As we can see some of the FWM products can appear on the frequencies of the initial waves, what can cause crosstalk penalties in the transmission system.
The source of the FWM in fiber lies in the Kerr effect: dependence of the fibre refractive index on the intensity of the propagating signals. Increasing input signal power, decreasing channel spacing and using low dispersion value fibre increases power of the FWM

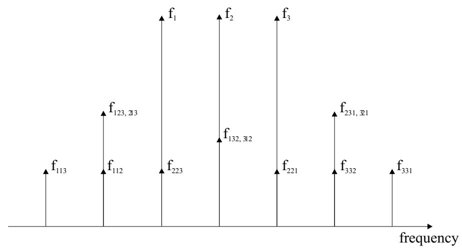

Figure 1: Example of the FWM effect for three co-propagating waves

products. In the SOA working under saturation effects like carrier depletion, spectral-hole burning, carrier heating starts to play important role making optical gain of an active semiconductor devoice dependent on the optical field intensity. When two or more channels are propagating through semiconductor amplifier and their combined powers are near the saturation power, nonlinear effects occur that generate beat frequencies at the cross-product of the optical carrier waves. The power of the FWM products in the SOA depends on the channel spacing, input signal power and saturation output power. In the optical transmission systems with SOA's as optical amplifiers accumulation of the FWM effect products generated in the fibre and the SOA's can occur.

Experimental set-up

To observe and verify penalties induced by Four-Wave Mixing in the transmission systems working in the 1310 nm window with low dispersion value we used a set-up as depicted in Figure .

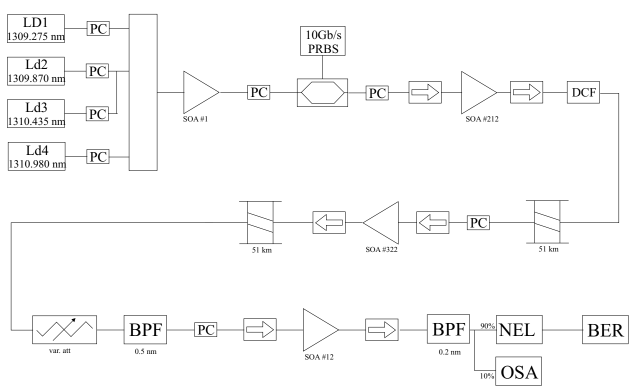

Figure 2: Experimental set-up

We can distinguish three parts: transmitter side, 100 km transmission link and an optically preamplified receiver end. The transmitter consists of the four DFB lasers operating in CW (continuous wave) condition at wavelengths 1309.275 nm, 1309.870 nm, 1310.435 nm, 1310.980 nm. The wavelength spacing is equal to 100 GHz. All four signals are combined in 4×2 power coupler and amplified in SOA #1 to the power level 0 dBm per channel. Following SOA Mach-Zender modulator modulates simultaneously all four signals at the bit rate 10 Gbit/s with $2^{31}-1$ pseudo-random bit sequence (PRBS) pattern length. After second SOA #12 optical signals pass through 5 km of dispersion shifted fibre (DSF) to decorrelate bit pattern.

The transmission link consists of the two 51 km SSMF spans and one, placed between them, in-line SOA amplifier to compensate the fibre losses. The average 51 km fibre span losses are 18 dB and an average dispersion at 1310 nm is equal to -2.5 ps/nm*km.
The receiver contains SOA#12 acting as a preamplifier and two band-pass filters placed before and after SOA#12. The filter bandwidth is respectively 0.5 nm and 0.2 nm. Output of the second filter is connected using 90-10 power coupler to optical spectrum analyser (OSA) and NEL receiver module. The NEL receiver module consists of the 10 Gbit/s O/E converter with post/limiting amplifier module and 10 Gbit/s clock and data recovery module. The clock and the data output of the NEL receiver module are connected to the bit error rate (BER) test-set.

Results and Discussion

Evolution of the optical signal power for all four channels (channels are counted from left to right) is presented on Figure . The FWM products are clearly visible on the sides of the transmission channels. FWM effects occurs in the SOA and fiber as well. FWM products which appears at the transmission channels are not visible. Their presence can be only identified as a penalty in the BER measurements. The extra piek around 1312 nm is caused by a poorly suppressed side mode of the laser four.

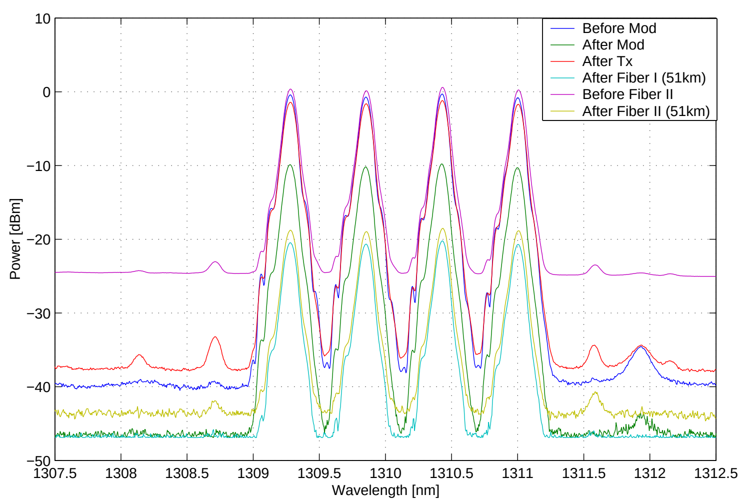

Figure 3: Evolution of the signal power in the experimental set-up. (Lowest wavelength channel 1, highest wavelength channel 4)

The Figure presents BER measurements done for channel one and three in back-to-back and whole system measurement sessions. Measurements were done in two system configuration, with equal 100 GHz channel spacing and with unequal channel spacing (channel 2 was turned off). Unequal channel allocation scheme [3] can guarantee that none of the FWM products will appear on our transmission channels.
As we can see from the graphs, the FWM effect is the dominant cause for the high system penalties. The system penalties for system configuration with unequal channel allocation scheme are much lower than for equal 100 GHz channel spacing. For BER equal to 10^{-9} system penalties for channel one (outermost channel) were 0.25 dB for unequal channel spacing and 1 dB for equal 100 GHz channel spacing. For channel three 1.8 dB and >3.5

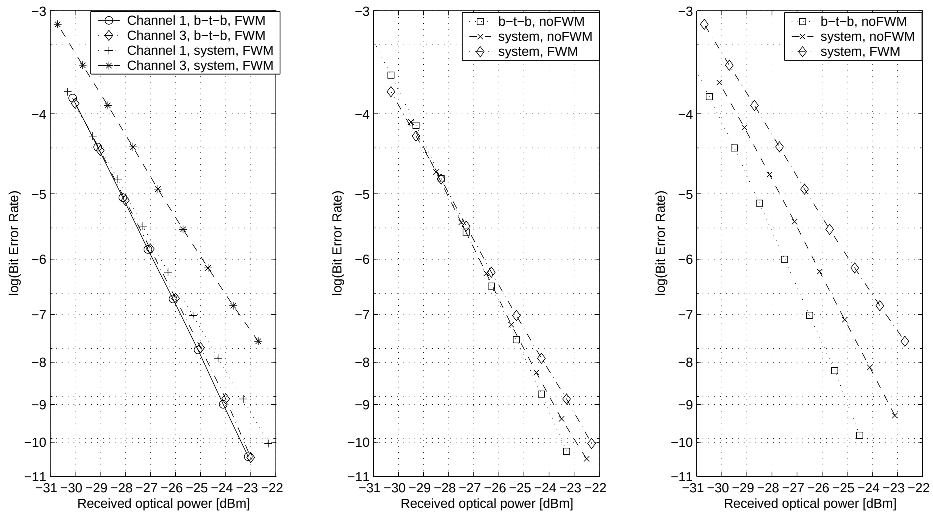

Figure 4: BER measurements graphs. The left graph: channel 1 and channel 3, equal channel spacing. The middle graph: channel 1, equal and unequal channel spacing. The right graph channel 3, equal and unequal channel spacing

dB respectively. The penalties for the channel three are higher than for channel one. This difference is caused by the lower dispersion value for channel three and as such the generation of the FWM effect products in the fiber is more efficient. Moreover channel three has two heighbour channels, not sufficiently suppressed by the 0.5 nm BPF.

Conclusions

FWM effect can be a source of high system penalties in the transmission systems in the 1310 nm transmission window. Elimination of the penalties induced by FWM effect can be done by using unequal channel allocation scheme which can be bandwidth inefficient for systems with large number of channels. Reduction of the FWM effect penalties can be done by increasing channel spacing, lowering the input power or the usage of fibre with a slightly higher value of the dispersion. It was indicated that FWM in the fibre dominates over the FWM in the SOA's.

Acknowledgements

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References

[1] L.H. Spiekman et al., "Transmission of 8 DWDM Channels at 20Gbit/s over 160 km of Standard Fiber Using a Cascade of Semiconductor Optical Amplifiers", *IEEE Photonics Technology Letters*, vol. 12, pp. 717-719, 2000.

[2] J.G.L. Jennen et al., "4×10Gbit/s NRZ Transmission in the 1310 nm Window over 80km of Standard Single Mode Fibre using Semiconductor Optical Amplifiers", in *Proceedings 24th European Conference on Optical Communications-Volume 1*, (Madrid, Spain), 1996, pp. 235-36.

[3] L. Kazovsky et al., Optical Fiber Communication Systems, Norwood: Artech House, 1996