Method of compensating cross phase modulation in 10 Gbit/s WDM systems over nonzero dispersion shifted fibre

R.A. Saunders, A. Robinson, D. Garthe, R. Hui and M. O'Sullivan

A novel technique for compensating crosstalk in wavelength division multiplexed systems due to cross phase modulation is demonstrated experimentally, using phase prechirp of an interfering channel. Residual crosstalk levels as low as 10% of the uncompensated value are obtained.

Introduction: The use of wavelength division multiplexing (WDM) and optical amplification as a method of increasing the information capacity and/or reach in optical fibre systems has led to significant propagation impairments owing to fibre nonlinearity [1]. Important nonlinear effects causing inter-channel crosstalk in WDM systems are four wave mixing (FWM) and cross phase modulation (XPM).

FWM can be managed by increasing the system dispersion or by using unequal channel spacing [2]. Neither of these approaches, however, decreases the system impairment due to XPM [3 – 5]. We demonstrate a novel technique which can compensate for XPM by prechirping the signal channel with a filtered version of an interfering WDM channel at the transmitter.

Theory: The power modulation spectrum, $p_K(\Omega,0)$, in channel k generates phase modulation in the signal channel j, by the fibre nonlinearity. This is then converted to amplitude modulation by the fibre chromatic dispersion, β''. The effect of group delay walk-off between the signal and interfering WDM channel causes a low pass filtering effect on the XPM. The electric field transfer function is given by

$$X_j(\Omega, z) = Kp_k(\Omega, 0)\frac{i\sin\left(\frac{\beta''\Omega^2 z}{2}\right)}{1 - i\tau_\omega\Omega} \tag{1}$$

where

$$\tau_\omega = \frac{\Delta\lambda.D}{\alpha} \tag{2}$$

and K is a nonlinearity factor, $\Delta\lambda$ is the channel spacing, D is the dispersion and α is the fibre attenuation.

The walk-off induced lowpass filter is a simple single pole response. For this XPM precompensation scheme, the prechirp signal must be lowpass filtered by a single pole electrical filter. If the sign of walk-off (τ_Ω) is positive, the impulse response is causal. However, if the sign is negative, the impulse response is non-causal, i.e. the crosstalk signal appears in time before the interfering edge arrives. This is important in the design of the low pass filter for XPM compensation, to achieve the correct phase, as well as amplitude, response.

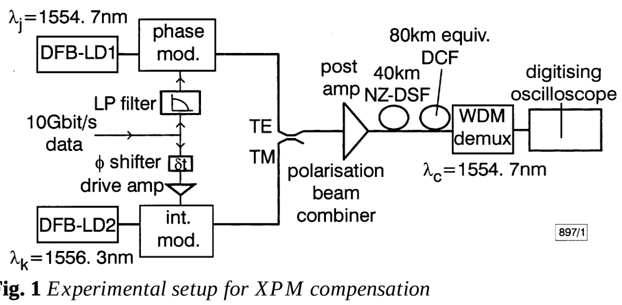

Fig. 1 *Experimental setup for XPM compensation*

Experimental setup: The experimental setup implemented to demonstrate XPM compensation for a two channel WDM transmitter is shown in Fig. 1. For this measurement, the signal channel was operated in CW mode, so that the only modulation on this channel at the receiving oscilloscope was due to XPM from the interfering channel. The fibre used for XPM generation was negative dispersion non-zero dispersion shifted fibre (NZ-DSF) with dispersion = –0.3 ps/nm.km. A section of dispersion compensating fibre (DCF) was also included to increase the PM to AM conversion rate, and hence SNR, of the measurement. The mean power in the interfering channel was +12 dBm.

Results: In terms of XPM, and its compensation, there are two different dispersion regimes for NZ-DSF. For the low walk-off regime ($|\tau_\Omega| < 30$ ps @ 10 Gbit/s), the interfering channel does not require low pass filtering before connection to the phase modulator. This is because the pole frequency of the XPM filtering ($= 1/2\,\pi\tau_\Omega$) is higher than the information bandwidth. For the medium walk-off regime ($|\tau_\Omega| > 30$ ps @ 10 Gbit/s), the pole frequency is < 5 GHz and filtering of the prechirp signal is necessary.

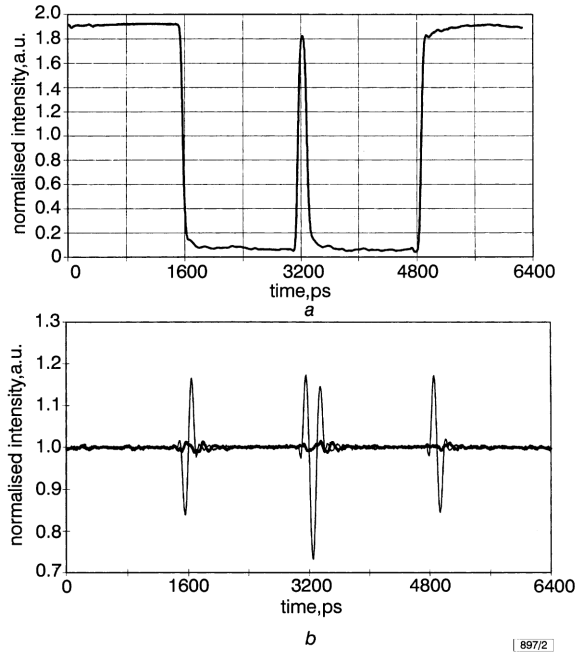

Fig. 2 *XPM compensation on low walk-off NZ-DSF fibre*

a Modulated channel bit sequence
b Compensated XPM on CW channel
——— uncompensated
——— compensated

The 64 bit NRZ sequence applied to the modulated channel is shown in Fig. 2*a*. The resulting XPM crosstalk is shown in Fig. 2*b*. It can be seen that the XPM-induced crosstalk looks like a double differentiation of the interfering data sequence, as is expected in the low walk-off regime. The path lengths for both WDM channels were matched using accurate RF cable lengths. The amplitude of the applied prechirp signal was optimised to match the phase shift in fibre, as shown in Fig. 3. The amplitude of residual XPM crosstalk after precompensation was 10% of its uncompensated value.

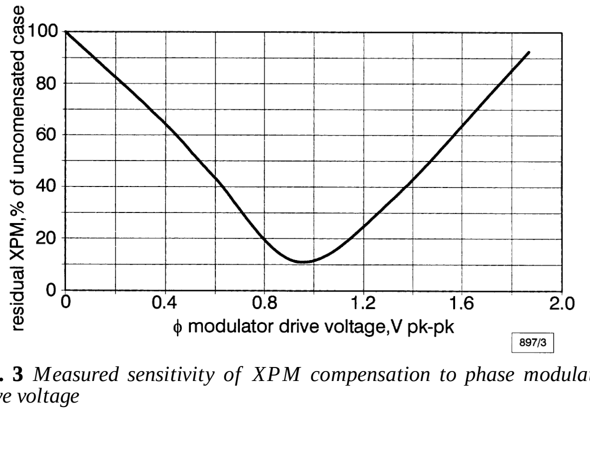

Fig. 3 *Measured sensitivity of XPM compensation to phase modulator drive voltage*

A 4 tap delay line filter, with 50 ps tap delays, was also designed and built for compensation in the medium walk-off regime ($\Delta\lambda$ = 3.2 nm; D = –1 ps/nm.km; τ_Ω = –67 ps; XPM pole frequency = 2.4 GHz). This filter was designed to compensate for negative walk-off (i.e. non-causal impulse response), which necessitated a transversal design. The measured S21 magnitude and group delay responses of this filter are shown in Fig. 4*a* and *b*, respectively. It can be seen that the magnitude and group delay response is reasonably good up to 8 GHz. It can also be seen from Fig. 4*b* that, with the correct absolute delay, the response mimics a non-causal response (low frequency components arriving at an earlier time than high frequency components).

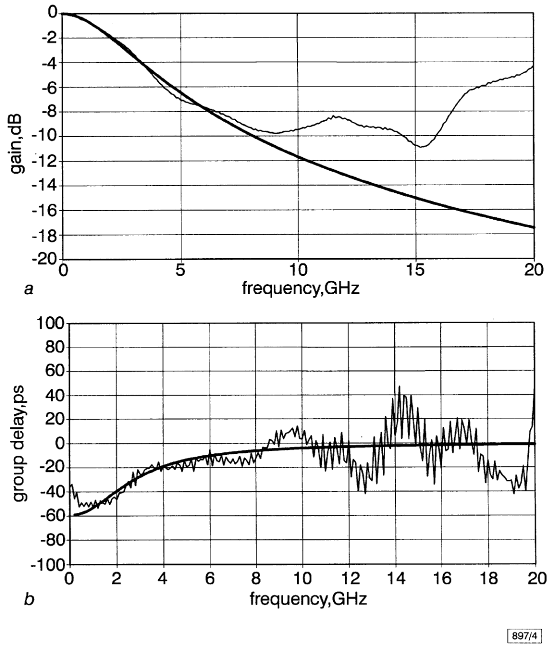

Fig. 4 *FIR tapped delay line filter response*

a S21 magnitude
b S21 group delay
——— ideal response
——— FIR filter response

The residual XPM crosstalk was 30% of its uncompensated value with this precompensation. This would be improved further by increasing the number of taps.

Conclusions: A method has been experimentally demonstrated for compensating for XPM in WDM transmission systems using interfering channel phase prechirp at the transmitter. For a two channel WDM system operating at 10Gbit/s over low dispersion NZ-DSF, the amplitude of residual XPM crosstalk with precompensation was 10% of its uncompensated value. In the medium walk-off regime, residual XPM crosstalk after precompensation was 30% of its uncompensated value, using transversal low-pass filtering of the prechirp.

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