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TRANSMISSION OF <10PS PULSES OVER 318KM STANDARD FIBRE USING MIDSPAN SPECTRAL INVERSION.

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Abstract

We report experimental results on transmission of 5.7ps input pulses over 318km standard fibre. The minimum output pulsewidth was 9.5ps. In line filters, third order chromatic dispersion, and polarisation mode dispersion are the dominant broadening effects.

Introduction

Midspan spectral inversion (MSSI) using optical phase conjugation [1], [2], is one of the several promising methods for compensating the high chromatic dispersion at 1550nm in standard non dispersion shifted telecommunication fibre. Recently, high bitrate transmission over long distances have been demonstrated in wavelength division multiplexed (WDM) [3] and optical time domain multiplexed (OTDM) [4] systems using MSSI. In the latter, 40Gbit/s OTDM transmission over 200km of standard fibre was achieved. However, as the fibre length increases and the pulse width decreases, some pulse broadening will appear even if group velocity dispersion (GVD) is completely cancelled.

In this paper we present experimental results on linear transmission of short pulses over long spans and show that the initial pulsewidth is not fully recovered. Contributions to this pulse broadening from other sources than GVD, which may be a limitation in future systems, are presented.

Experiments

The experimental setup is shown in figure 1. A sliding frequency laser generates transform limited sech^2 pulses at 1533nm. The full width half maximum (FWHM) of the pulses is 5.7ps and the repetition rate is approximately 100MHz. After transmission over 160.6km fibre, the pulses are spectrally inverted and then transmitted over a second link of 157.0km. The length difference in the two links compensates for the difference in dispersion and wavelength in the two links. The average second and third order dispersion in the transmission fibres is 15.5ps/nmkm and 0.06ps/nm^{2}km. The conjugate signal at 1538 nm is generated using four wave mixing in 13km dispersion shifted fibre. An in line amplifier is used in each link to compensate for loss. An autocorrelator is used for pulse width measurements. A sech^2 pulse shape is assumed and the autocorrelation FWHM is then 1.55 times the FWHM of the pulse. Figure 2 shows autocorrelation traces measured at the input and after 317.6km. Pulse widths measured for different lenghts of the second link are shown in figure 3 together with results for a similar experiment with 119km fibre. In the case of the 119km span the initial pulsewidth was 5.0ps. The offset is the difference between the real length of the second link and the length which was calculated to give cancellation of GVD.

Results and discussion

As seen from figure 3, in the case of 318km transmission, the pulsewidth at the optimum offset was 9.5ps and is 3.8ps broader than the input pulse which was 5.7ps. In the 119km experiment, the minimum output pulsewidth was 7.5ps while the input pulsewidth was 5.0ps. There was no significant broadening due to SPM/XPM. The pulse width was not reduced by reducing the power levels in the two spans or in the conjugator, and no spectral changes were observed. The broadening due to nonlinearities is therefore estimated to be less than 0.5ps broadening. We have investigated the following possible causes for this increase in pulsewidth: in line filters, third order chromatic dispersion, and polarisation mode dispersion (PMD).

Two optical band pass filters with 3dB bandwidths of 1nm and 3nm were employed in the system. Compared to the 0.5nm spectral width of the pulses, we expect 10-15% increase in pulsewidth.

Using MSSI, the second order chromatic dispersion can be fully compensated, while the third order dispersion is not compensated due to asymmetric phase change in the optical spectrum. Third order dispersion can give asymmetric pulses with an oscillating tail if the input pulses is narrow. For 5 and 5.7ps pulses, the pulse distortion is not very large and is calculated to give an increase in estimated pulsewidth from autocorrelation measurements of 0.2 and 0.5ps in the 119 and 318km experiments respectively. The input pulses have been assumed to be transform-limited.

The polarisation mode dispersion in the transmission fibre was measured using the wavelength scanning method giving a differential group delay (DGD) $<\Delta\tau>$ of 1.5ps for 119km and 1.8ps for 318km. It is difficult to quantify the broadening due to PMD, since it is a stochastic process which is timevarying and depends on transmitted and detected polarisation. As an approximation we assume the broadening to be equal to $<\Delta\tau>$.

The estimated broadening from the above considerations is presented in table 1. The table also shows the difference between measured and estimated total pulse broadening which is 0.3 and 1.0ps for 119km and 318km transmission respectively. These deviations are within the uncertainties associated with the pulsewidth measurements and the interpretation of broadening due to PMD.

In a practical system using 2-6 ps pulses, the limitation from narrow filters can be overcome by increasing the filter bandwidth. However a limitation to increased bandwidth may occur due to EDFA noise accumulation or by the wavelength difference between conjugate and pump/signal wavelength. Third order dispersion is likely to give a pulsewidth limitation of 3-4 ps for 100km propagation. Excess spectral width due to non-transform-limited pulses can increase the distortion. Similarly, PMD is an important limitation and may be severe in real systems on cabled fibres which can have much higher DGD than the fibres we used in our experiments.

These results shows that third order chromatic dispersion and polarisation mode dispersion may limit the bitrate for >100Gbit/s >100km OTDM MSSI systems with linear transmission in non dispersion shifted fibre. Operation with a degree of nonlinearity may overcome some of these limitations.

Conclusions

We have investigated the limits of dispersion compensation in high bandwidth MSSI linear transmission systems. Short pulses have been transmitted over 318km (119km) non dispersion shifted fibre. The FWHM pulsewidth was observed to broaden from 5.7ps (5.0ps) to 9.5ps (7.5ps) due to transmission. In line filters, third order chromatic dispersion, and polarisation mode dispersion have been found to contribute to the broadening of the pulses. The latter two are likely to limit the bandwidth of future OTDM MSSI systems.

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Table 1: Pulse broadening

Estimated broadening factors	**119 km experiment**	**318 km experiment**
In line filters	0.5 ps	0.5 ps
Third order chromatic dispersion	0.2 ps	0.5 ps
Polarisation mode dispersion	1.5 ps	1.8 ps
Sum estimated broadening	2.2 ps	2.8 ps
Measured broadening	2.5 ps	3.8 ps

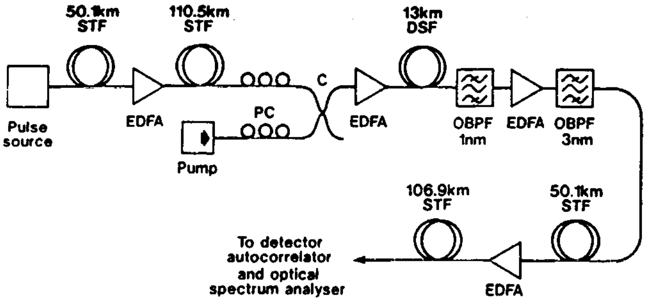

Figure 1. **Schematic of experimental setup for 318km experiment.**
DSF: dispersion shifted fibre, STF: standard singlemode fibre, PC: polarisation controller, EDFA: erbium doped fibre amplifier, OBPF: optical band pass filter, C: 50% coupler.

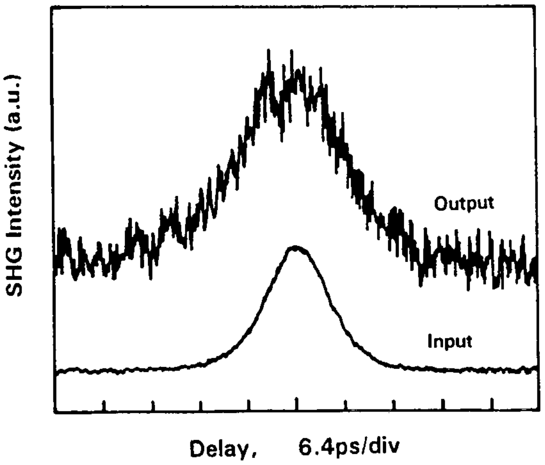

Figure 2. **Autocorrelation trace of output pulse after 318km and input pulse.**

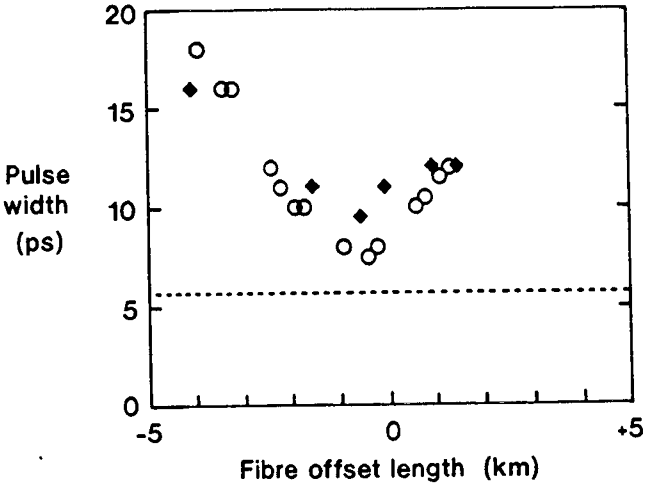

Figure 3. **Pulsewidth versus offset length.**
Square and circles is results for the 318km and 119km experiment respectively. Dotted line is input pulsewidth in 318km experiment.