Pulse Width Restoration and PMD Suppression using Fiber Self-Phase Modulation

Bengt-Erik Olsson and Daniel J. Blumenthal

University of California, Electrical and Computer Engineering
Santa Barbara, CA 93106, USA
beo@ece.ucsb.edu

Abstract: Restoration of the optical pulse width using spectral broadening with subsequent optical band-pass filtering is experimentally demonstrated.The output pulse width remains constant for input pulse widths between 9 to 20 ps. The scheme is also applied to restore 40 Gbit/s data suffering from PMD.

Introduction

With the advent of optical communication systems using return to zero (RZ) data format operating at very high bit-rates, i.e. 40 Gbit/s and beyond, there will be a need for technologies to combat transmission effects that give rise to pulse broadening that can not easily be compensated for. Such effects are for example polarization mode dispersion (PMD) and higher order chromatic dispersion. In this paper pulse restoration using self-phase modulation (SPM) in a dispersion shifted fiber with subsequent optical band-pass filtering is demonstrated. This technique has previously been demonstrated to improve the extinction ratio of RZ-data /1/. The basic idea is to significally broaden the spectrum using SPM and subsequently slice the spectrum with an optical band-pass filter that will determine the output pulse width, in the same way as in a super continuum source /2/. In principle the output pulse width should be independent of the input pulse width as long as the SPM broadened spectrum is broad enough. In the case of signal degradation due to PMD, the effective pulse width will vary over time, due to variation in signal polarization state relative to the principal states of polarization (PSP) in the system, as well as variation in the total differential group delay (DGD), and also the PSPs of the system /3,4/. Here, a pulse width restorer is demonstrated to restore 40 Gbit/s data that suffers from pulse broadening due to PMD.

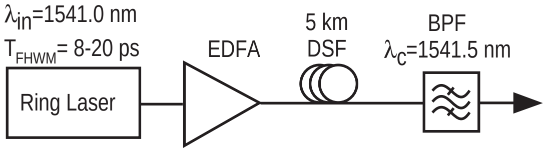

Figure 1. Experimental set-up for pulse restoration.

Pulse width restoration

To demonstrate the concept of pulse width restoration a simple experimental set-up, as shown in figure 1, was used. Pulses at 10 GHz from an actively mode-locked fiber ring laser with variable pulse width at a wavelength of 1541 nm were amplified to an average power of +16 dBm before entering a 5 km dispersion shifted fiber (DSF) with a zero dispersion wavelength at 1543 nm. At the output of the DSF an optical band-pass filter with either 0.2 nm or 0.7 nm band width was used to slice the SPM broadened spectrum. The center frequency of the band-pass filter was 1541.5 nm and the output pulses were investigated using a 40 GHz photodetector on a 50 GHz sampling oscilloscope.

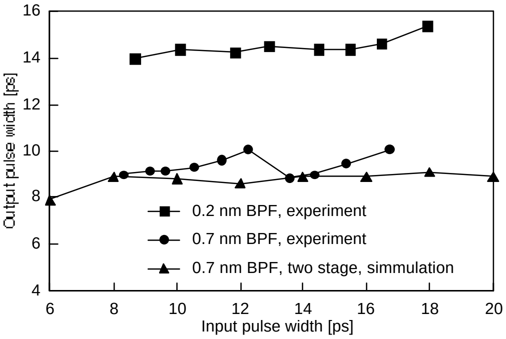

Figure 2. Experimental and simulated results of pulse width restoration.

Figure 2 shows the output pulse width versus input pulse width for the two different filter bandwidths. The optical average input power to the fiber was kept constant, +16 dBm, due to stauration of the EDFA. In the case of a 0.2 nm BPF, trace A, the output pulse width is almost constant at 14.5 ps for input pulsed widths between 9 ps and 16 ps. In the case of a 0.7 nm BPF, trace B, the output pulse widths varies between 9 ps and 10 ps for input pulse widths from 8 ps to 17 ps. The small jump around an input pulse width of 13 ps is probably due to a higher intensity derivative of the SPM broadened spectrum that moves in to the transmission window of the BPF. It is important to note that the even though the average power out of the EDFA is constant, the peak power will change according to the input pulse width and thus less SPM broadening will occur for broader pulses. However as long as the spectrum is broad enough, the output pulse width will remain constant. One disadvantage with the scheme in figure 1 is that a small wavelength shift between input and output signal is inevitable. One solution to that problem could be to make a two-stage device where SPM in a subsequent DSF once again generates a broadened spectrum. A second BPF can then be positioned at the original wavelength, giving pulse width restoration without wavelength translation. Trace C in figure 2 shows simulated results for such a two-stage pulse width restoration device. The output pulse width is now constant 9 ps for all input pulse widths from 8 ps to 20 ps. Simulations also show that the output pulse width is more constant with variation in input pulse width from a two stage device compared to a single-stage device.

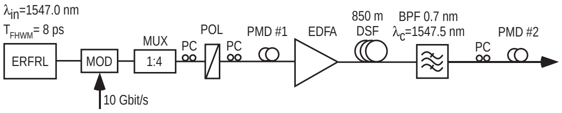

Figure 2. Experimental set-up for PMD restoration. ERFRL: Erbium-doped fiber ring laser; MOD: LiNbO3 modulator; MUX: passive 10 to 40 Gbit/s multiplexer; PC: polarization controller; POL: polarizer; PMD #1: PMD emulator with 10 ps DGD; EDFA: erbium-doper fiber amplifier; DSF: dispersion shifted fiber; BPF: optical band-pass filter; PMD #2: PMD emulator with 6 ps DGD.

PMD restoration

To demonstrate restoration from PMD distortion, an experiment as depicted in figure 3 was performed. 10 Gbit/s data was encoded on 8 ps pulses from an actively mode-locked fiber ring laser at a wavelength of 1547 nm. The 10 Gbit/s data was then passively time multiplexed to 40 Gbit/s using a split, delay, and interleave type of multiplexer based on 50/50 fiber couplers and variable optical delay lines. A polarizer was placed at the output of the multiplexer to ensure equal state of polarization of the 40 Gbit/s data stream. This is important since otherwise each channel will be impaired differently by the PMD. The 40 Gbit/s data was sent through a PMD emulator consisting of 12 sections of birefringent fiber spliced with random angles giving a differential group delay of 10 ps at 1547 nm. A polarization controller was used at the input of the PMD emulator to adjust the input polarization state to equally excite the principal states of polarization in the emulator. In this way the PMD emulator causes maximum distortion of the data. The distorted data was then set through a pulse width restorer as described above. In this experiment an EDFA with 1 W average output power was used and thus only 850 m of DSF was needed to achieve sufficient SPM broadening of the 40 Gbit/s data. Again a 0.7 nm optical band pass filter was used to slice the SPM broadened spectrum to restore the pulse width. The restored data was then send through another PMD emulator consisting of 8 sections of birefringent fiber spliced with random angles, giving a differential group delay of 6 ps at 1547 nm. The receiver contained a phase-locked loop based clock recovery circuit utilizing an electro-absorption modulator to recover a 10 GHz clock from the 40 Gbit/s data. This allowed stable visualization of the PMD distorted data on a sampling oscilloscope. Figure 4a shows the input 40 Gbit/s data, and figure 4b shows the data distorted by 10 ps DGD in the PMD emulator. The eye patterns look more open due to the broader pulses caused by the DGD, but the pulse width is now about 15 ps. Figure 4c shows the data after restoration in the pulse width restorer and the pulse width comes down to 10 ps. Figure 5 shows the data after the second PMD emulator with and without the pulse width restorer. In the case of retransmitting the previously restored data, the eye patterns are still clearly open, while without restoration the eye patterns are heavily distorted. However, if the data suffers too much PMD, i.e. the pulses get too broad, the pulse shape can not be restored since the adjacent data channels starts to interfere. This interference distorts the slopes of the pulses that give rise to the spectral broadening in the SPM fiber. In the case of PMD restoration it is thus important that the data does not suffer from too much PMD before being restored, but once restored it can suffer from more PMD again. The amount of allowed PMD before restoration depends then on the input pulse width and pulse shape to the system, as well as the bit-rate.

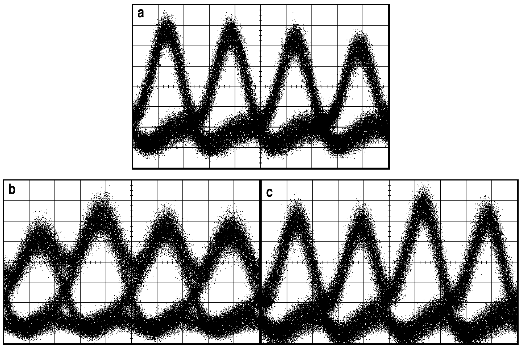

Figure 4. Input 40 Gbit/s data(a), data after 10 ps DGD (b), and data after pulse width restoration (c).

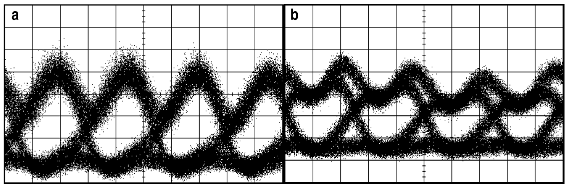

Figure 3. 40 Gbit/s data after additional 6 ps DGD with restored pulses (a) and without restoration (b). 10 ps/div

Conclusions

Restoration of pulse width using self phase modulation in a dispersion-shifted fiber with subsequent filtering has been demonstrated. The output pulse width can be constant 10 ps, ±1 ps, for input pulse widths between 8 to 16 ps. The scheme was also applied to restore 40 Gbit/s data suffering from PMD. The device could potentially be used in transmission links to restore from both PMD and remaining uncompensated chromatic dispersion, e.g. higher order dispersion which may be difficult to compensate for. An interesting extension of this scheme could be to make SPM spectral broadening an integral part of the transmission properties of a communication system and have filters placed through out the system to perform the pulse restoration.

References

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