A Nonlinear Amplifying Loop Mirror Operating with Wavelength Division Multiplexed Data

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Signal recovery in lightwave systems is a critical function that must be performed in order to insure error-free data transmission in fiber-optic links, to restore the signal integrity in optical networks, and to alleviate the stringent requirements on receiver sensitivity. The pulse distortion and dispersive wave generation that occurs in short pulse RZ systems with long spans presents a problem to systems performance[1]. In addition, narrow band cross talk generated from imperfect optical components[2], double reflections[3], and nonlinear processes such as four wave mixing[4] or optical demultiplexing[5] can also seriously impact the performance of lightwave communications networks. A method for compensating for the loss and improving the signal integrity is desirable. The nonlinear amplifying loop mirror (NALM) has been proposed and successfully demonstrated to reduce background noise in high-bit-rate single wavelength RZ transmission experiments[6 7]. The WDM NALM is constructed just as NALM, except it takes as its input a number of wavelength division multiplexed signals[8]. In this paper, we extend the functionality of the NALM to a multi-channel RZ WDM system by demonstrating the NALM as a single module for amplification and background noise suppression for four WDM data channels simultaneously.

Figure 1 shows a schematic of the experimental setup. A passively mode-locked polarization locked fiber laser generates 350fs nearly transform limited pulses at a fundamental repetition rate of R=199.63MHz and with an average power of 0.2mW [9]. After amplification, a series of 3dB fiber couplers are used in a row in conjunction with optical delay lines to passively multiplex this pulse train up to a partially filled pulse train so that every 1/R seconds there is a burst of 4 bits at 2.6 GHz. Half of the signal from this multiplexing stage is used as the clock input to a pulse pattern generator (PPG). The PPG is programmed to generate a 31200 (~ 2^{15}-1, PRBS) bit long pattern which pseudo randomly modulates the pulses from the other half of the multiplexing stage by use of a $LiNO_3$ modulator. Spectral broadening and slicing produces four different wavelength data channels spaced every 1.6 nm and spanning approximately 6nm[10]. A "coarse" time delay of approximately 1/R seconds is introduced between each of the four wavelength channels by use of fiber delay lines. "Fine" variations are accomplished with free space time delays. The four wavelength channels are recombined using a star coupler, amplified, and sent into the input port of the NALM. The delays mentioned above are adjusted so that, if the channel whose wavelength is λ_1 enters the NALM at $T_{\lambda 1}=0$, then time that the other channels enter the NALM are $T_{\lambda i} = i$ (20 ps + 1/R) so that there is absolutely no possibility for any cross phase modulation between the different wavelength channels. The 3-dB bandwidth and pulse width for each input channel is 0.7nm and 3.5ps, respectively. The NALM itself consists of an Er-doped fiber amplifier (EDFA) (70mW saturated power) placed at one end of a 500m long length of single mode fiber (SMF) and joined in a loop by a 3dB fiber coupler. The dispersion of the SMF is D_{SMF}=15ps/nm/km and the dispersion of the 20 m long section of gain fiber is D_G=-20ps/nm/km. The EDFA is pumped symmetrically by a pair of 980nm laser diodes.

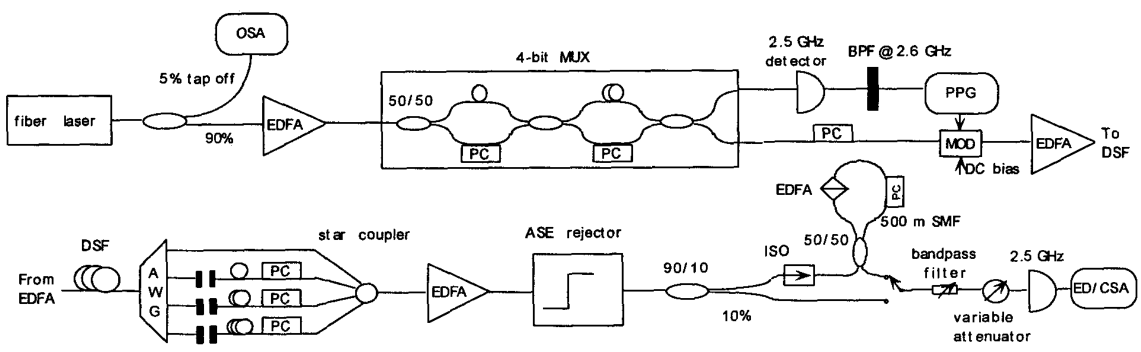

Fig. 1 Experimental setup for the WDM NALM experiment.

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Because we do not have a gain equalizing component for the EDFA inside the loop, we adjust the input signal power level separately for each of the wavelength channels in order to achieve equalized switched powers. Simulations of the pulse propagation by use of the beam propagation method show good agreement with both the frequency and time domain measurements.

To demonstrate the amplitude filtering capabilities of the NALM, the bias of the modulator is adjusted for incomplete extinction of the input pulse train. Figs. 2a through 2d show the eye diagrams for each of the four input channels prior to injection into the NALM. After the NALM, the noise level on the zeros is reduced significantly as shown in the eye diagrams of Figs. 2e – 2h. BER measurements performed on each of the channels both before and after the NALM are shown in figure 3 and compared to the back-to-back BER curves. An average signal gain of greater than 13 dB is obtained and a dramatic power penalty improvement of about 2.5 dB can be seen for each of the wavelength channels. Note that the initial penalties are moderately different for the 4 wavelength channels with channel 3 the worst, yet this does not seem to affect the relative improvement. We also note that the loop bias and all experimental parameters remained fixed as the BER and eye diagram measurements were taken on the individual channels, demonstrating the simultaneous WDM operation of the NALM.

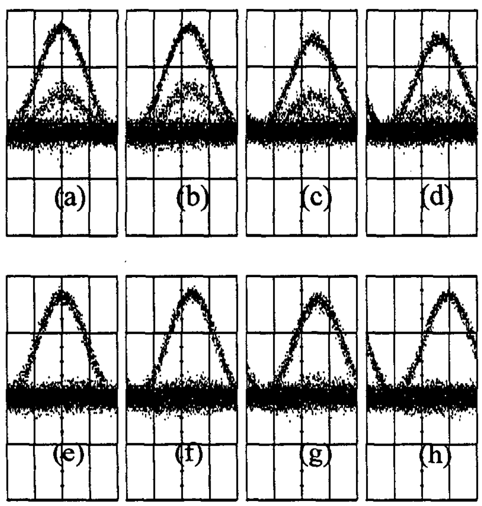

Fig. 2 Eye diagrams for input channels 1 to 4 (a to d) and output channels 1 to 4 (e to h) respectively

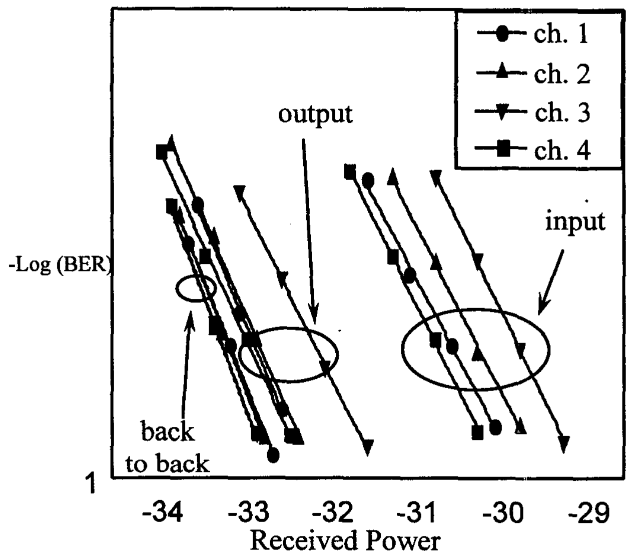

Fig. 3 Input, output, and back to back BER curves for each of the WDM channels.

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