8-CHANNEL WDM SOLITON AMPLIFICATION AND SIGNAL RECOVERY

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We demonstrate the signal recovery and amplification of eight soliton WDM channels using a single nonlinear amplifying loop mirror. The eight channels are amplified by 12dB and nonlinear filtering provides 10dB of noise suppression.

Introduction

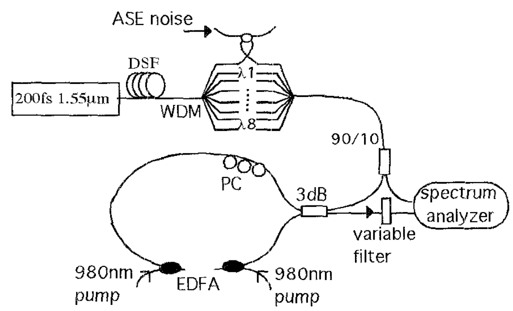
Soliton transmission systems have successfully employed guiding soliton techniques and dispersion management to achieve nearly unlimited propagation distances [1,2]. In these systems a critical design parameter is the amplifiers spacing which must be separated by distances that are much shorter than the soliton period. As transmission speeds increase to 40Gbit/s and beyond, the soliton pulse widths are reduced to several picoseconds and the soliton period may be as short as hundreds of meters. In such high speed soliton systems it becomes impractical to apply the same amplifier spacing design. An alternative approach of using nonlinear amplifying loop mirrors (NALMs) that can be separated by distances corresponding to many soliton periods was recently proposed and successfully demonstrated [3,4,5].

In this paper we extend the functionality of the NALM to a multi-channel soliton WDM system. We demonstrate the NALM as a single module for amplification and noise suppression for eight simultaneous soliton WDM channels. This is the first time, to our knowledge, that a NALM has been used with more than two wavelength channels for WDM applications. The self-switching action of the NALM is used to provide gain, amplified spontaneous emission (ASE) noise suppression and thereby overall signal-to-noise ratio enhancement for the eight soliton wavelength channels, simultaneously, in a single all-fiber module.

Functionality of the WDM NALM

The WDM NALM module shown in the experimental configuration (Figure 1), consists of an Er-doped fiber amplifier (EDFA) section placed asymmetrically in a fiber loop, and a section of dispersion shifted (DSF) fiber with zero dispersion at 1550 nm. The EDFA is pumped by 2 980nm laser diodes (SDL-2500-150) symmetrically which are carefully adjusted to ensure equal gain for the counter-propagating signals in the Sagnac loop. The 8 wavelength channels separated by 3.2 nm and spanning from 1538 nm to 1561 nm are generated from a single broadband 200 fs pulse source by spreading the spectrum via nonlinear propagation in 16m of DSF fiber followed by a WDM waveguide splitter. The 8 channels are recombined with an 8x1 fiber star coupler. In each of the 8 WDM channels, the pulses are approximately 3 ps long in time and 1 nm wide in bandwidth. An ASE noise source generated from a separate EDFA is coupled into one of the 8 data channels. The 8 input data channels which include some low level noise on the zero rails introduced by the coupled ASE source, are injected into the top port of the 3-dB coupler. These signals are split by the coupler and propagate around the loop in both the clockwise (cw) and counter-clockwise (ccw) directions.

Fig. 1: Experimental Configuration.

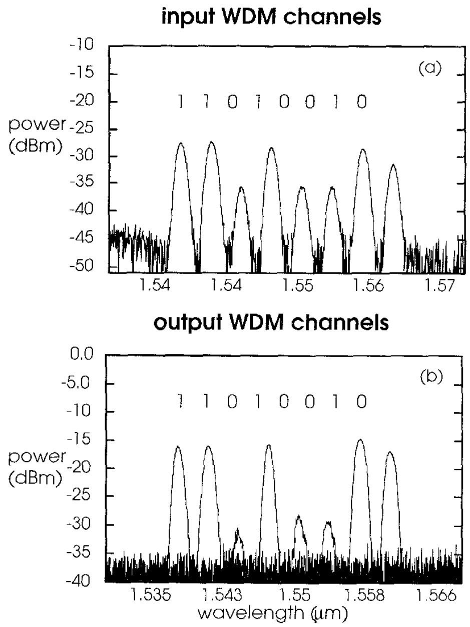


The cw propagating component of the signal is amplified by the EDFA soon after it enters the loop and as it continues to propagate it acquires a significant nonlinear phase by the time it reaches the 3-dB coupler. However, the ccw propagating component of the signal does not get amplified until it has nearly reached the other side of the loop and therefore does not accumulate as much nonlinear phase. These two components will interfere at the coupler and if the total accumulated phase difference is π, all of the signal will exit through the lower port of the coupler [6]. This interference in is sensitive to the polarization states of the counter-propagating signals, and it is therefore important to ensure their proper alignment at the 3dB coupler. In contrast, the low level noise accumulates approximately the same amount of phase shift in both the cw and ccw directions because the nonlinearity is not as strong and is therefore mostly reflected back through the top port of the coupler. Thus, the transmitted signal is both amplified and cleaned by nonlinearly filtering the noise. In this manner the NALM may be used to suppress ASE noise as well as dispersive waves generated in the transmission system.

Eight-Channel Amplification and Noise Suppression

To demonstrate the performance of the WDM nonlinear amplifier and filter, two of the input channel powers were reduced to approximately 20% of the signal level to model the noise channels. The input 8-channel WDM signal is shown in Figure 2 (a). A polarization controller was employed and adjusted such that the transmission for the noise channels was minimal. A tuneable bandpass filter with a 1-nm bandwidth was used to measure each channel individually. The results in Figure 2 (b) show that the output signal channels are amplified with an average gain of 12 dB per channel while the accompanying noise channels see almost no gain. The signal-to-noise ratio is correspondingly increased from 7 dB to 17 dB. Like all other EDFA-based devices, this module is subject to the structured gain spectrum of the EDFA and gain equalization techniques were employed to flatten the NALM's gain response for the eight channels.

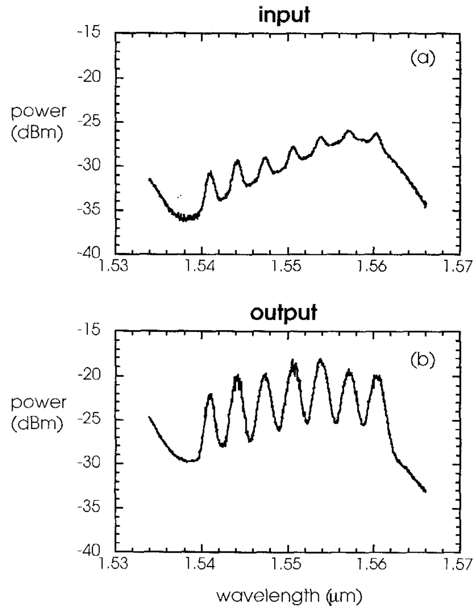
Fig. 2: Optical spectra of (a) input 8 wavelength channels signals and (b) amplified cleaned output.



ASE Noise Subtraction and Signal Recovery

The WDM NALM can be viewed as a passive saturable absorber device for reducing ASE noise in soliton systems [4]. We demonstrate this intensity thresholding functionality by injecting ASE noise along with seven WDM signal channels. For this experiment the WDM NALM fiber length was shortened to minimize the wavelength dependence of the interference due to random birefringence. The polarization controllers could be adjusted once and the NALM operation remained stable. The seven input signals accompanied by the broadband ASE noise (injected through an additional input channel) shown in Figure 3 part (a) are amplified by the WDM NALM by an average of 8dB per channel while the ASE noise background has been subtracted increasing the overall signal-to-noise ratio by an average of 6dB as shown in Figure 3 part (b). For these measurements the 1nm output filter was removed. Similar nonlinear filtering could be performed to reduce dispersive wave radiation as well as ASE noise in high speed soliton transmission systems.

Fig. 3: Optical spectra of (a) input 7 wavelength channels with ASE noise and (b) amplified signals output with suppressed ASE noise.



Summary

We have demonstrated the NALM operation with eight soliton WDM channels as an effective ASE noise suppression and signal recovery module. The WDM NALM may have important applications in high speed soliton WDM systems where the amplifiers spacing is considerably larger than the characteristic soliton period.

References

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