Compensation Of Chromatic Dispersion By Chirp Control In All-Optical Regenerator Based On Asymmetric Sagnac Loop

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Abstract: We describe the compensation of chromatic dispersion by control of the chirp in an all-optical regenerator, based on SOA in an asymmetric Sagnac loop. We demonstrate the transmission of a 10Gb/s NRZ signal up to 200 km.

Introduction

The transmission of high-speed optical signals through very long fibers requires transponders or regenerators. Such devices are distributed along a communication line and should overcome noise and interference by repeatedly reading and transcribing the optical signal. Regenerators, however, are not generally designed to compensate for chromatic dispersion. This is routinely achieved using dispersion compensating fiber (DCF). Alternative methods for dispersion compensation which have been proposed include chirped Bragg grating, etalons and ring resonators, to name a few. While chromatic dispersion management is required in telecommunication systems operating at data rates of 10 Gbit/s or higher, in principle, compensation in long-reach transmission links is only required between successive transponders. Furthermore, in short reach links where no transponders are required, dispersion needs to be compensated between the transmitter and the receiver. A widely used strategy for managing chromatic dispersion link is a pre-chirping of the modulated signal. The magnitude of the negative chirp is carefully adjusted so that the initial time-compression of the optical pulse is exactly balanced by the broadening as the pulse propagates. This strategy can be used only for a specified length of the fiber link, whereas control of the chirp in different length links requires individual adjustment. Schemes employing a semiconductor optical amplifier (SOA) to control the chirp of a signal have been proposed for transmission over 600 km of SMF, with chromatic dispersion of 17 ps/nm/km [1].

In this paper, we present dispersion compensation, together with all-optical regeneration and wavelength converter, based on an asymmetric Sagnac loop containing an SOA. The device acts as an all-optical wavelength regenerator and wavelength-converter, for NRZ and RZ optical signals. Dispersion compensation is achieved by introducing negative chirp to the output signal using an interferometric process inside the Sagnac loop. The amount of chirp can be fine-tuned to adjust for a given transmission distance in SMF without additional means of dispersion compensation.

Asymmetric Sagnac Loop All-Optical Regenerator

The asymmetric Sagnac loop regenerator (ASLR) configuration is depicted in Fig.1. Originally the scheme was proposed for RZ modulation [2,3], but it can be extended to NRZ operation [4] by adjusting the working conditions of the SOA and the configuration of the Sagnac loop. A coupler (C1) splits the incident CW beam into two counter-propagating beams. Both the clockwise and counter-clockwise CW beams experience a nonlinear phase shift induced in the SOA by the input signal (Pn). The Sagnac loop is not symmetric; the SOA is shifted from the center of the loop. Due to the offset time, (ΔT) (see Fig.1), the phases of the two beams are not synchronized at the output coupler. By fine-tuning the polarization controller (PC2) it is possible to manipulate the polarizations of the two beams in such a way that at the output coupler one of the beams gains a certain phase shift relative to the other. When this phase shift exactly equals the maximum absolute phase difference between the two beams, the interferometric process that takes place at the coupler reveals the regenerated signal in the converter wavelength (λ2). Clearly, in this configuration there is no fundamental restriction for the time delay. In principle any time delay which is shorter than the bit period, and that can be compensated by polarization manipulation, will suffice. Since the interferometer actually subtracts the two delayed beams, all of the low frequency components of the noise associated with input signal are removed from the resultant signal. Moreover, since the output from the SOA is approximately proportional to the integrated input signal, high frequency components of the noise are also absent from the output of this device. A key advantage of the Sagnac loop configuration over other interferometric configurations with SOAs (e.g. [5,6,7]) is its immunity to thermal and mechanical noise [7].
Regeneration and Dispersion Compensation

The eye diagram of the output of the ASLR with a high-OSNR (38 dB/0.1 nm), 10 Gb/s NRZ input signal, is shown in the inset of Fig. 1. The back-to-back BER curve (Fig. 2) indicates a power penalty of -0.7 dB for a high OSNR signal, and an improvement of 1.5 dBm for a noisy (24 dB/0.1 nm) signal.

The regenerating properties of the device are also exhibited in the recirculating loop experiments, where two ASLRs were incorporated within a 100 km SMF fiber span, with an appropriate compensation for dispersion and compensation for 25 dB loss of the span. We were able to transmit the signal for 50 consecutive loops, totaling a 5000 km transmission distance, without evidence of a BER floor.

When the SOA is operated in a gain-saturated mode with sufficient input power, phase modulation results in negative chirp [1]. With increasing input power, the chirp increases in magnitude and can be used to control the positive chirp of EA modulators, or the small amount of frequency chirp associated with LiNbO$_3$ modulator. There is, however, a significant drawback with this scheme, particularly with modulation rates above 2.5 Gb/s. First, at high bit rates, the SOA suffers from considerable intersymbol interference (ISI), particularly when operated in gain-saturation. Second, the transient chirp becomes prohibitively high if the signal propagates beyond a few tens of kilometers. The ISI and the amount of chirp can be controlled by operating the SOA in cross gain modulation (XGM) scheme where the input is converted to the CW wavelength. However, the signal is then inverted, resulting in positive chirp of the output signal, and cannot be used for dispersion compensation. Since XGM is accompanied by phase modulation, the output can be inverted once again using interferometric techniques [4].

We have successfully used the ASLR for inverting the signal by controlling the relative phase of the clockwise and counter clockwise beams in the Sagnac loop, as described above. Fig. 3 depicts the situation when the ASLR is tuned to invert the XGM (left panel) and non-invert (right panel) mode. The transient chirp follows the same pattern with essentially the same magnitude (-5 GHz to 5 GHz). In Fig. 4 we compare the performance LiNbO$_3$ modulator and the ASLR after 200 km SMF using no DCF. The operation of the ASLR as an all-optical regenerator, together with a device for managing chromatic dispersion, is demonstrated in Fig. 5. The input of the ASLR is a noisy signal (OSNR 18 dB/0.1 nm). The device is used to regenerate the signal, and retransmit it over 90 km without DCF. It is evident that both signals suffer from impairments induced by chromatic dispersion, but considerably less so for the signal from the ASLR.
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Figure 3. Chirp of output signal of ASLR adjusted to inverted XGM and non-inverted XGM mode. Transient frequency chirp remains with the same magnitude and direction.

Fig 4. Transmission over 200 km SMF without DCF: (a) bit pattern. (a) Lower trace corresponds to a LiNbO$_3$ modulator, while the upper trace corresponds to the ASLR. (b) BER curves.

Fig 5. Regeneration of noisy input signal (OSNR 18 dB/0.1 nm) and retransmission over 90 km SMF without DCF: (a) Lower trace corresponds to a LiNbO$_3$ modulator, while the upper trace corresponds to the ASLR. (b) BER curves.

In Fig. 5, in addition to the “spiking” due to dispersion, the original signal is also degraded by noise. Here the regenerative properties of the ASLR lead to a reduction in noise, which complements the compensation of chromatic dispersion.

Conclusions

We have demonstrated a device, called the ASLR, that simultaneously operates as an all-optical regenerator and tunable chromatic dispersion compensator. The device is based on cross-gain and cross-phase modulation in an SOA placed inside an asymmetric Sagnac loop. Compensation of chromatic dispersion is accomplished by negative chirp control of the output signal. We were able to transmit the signal at different distances up to 200 km SMF without DCF, with BER less than $10^{-12}$. The simultaneous regenerative and dispersion compensation capabilities of this device are demonstrated in re-transmission of a noisy signal over 90 km of SMF without DCF. The excellent performance and robustness of the ASLR makes it a very promising solution for realizing all-optical regeneration and dispersion compensation in optical communication lines.

References