Chirp management in communication systems with picosecond data carriers using a single SOA

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ABSTRACT
To preserve the integrity of fiber transmission in incoherent systems using picosecond carriers the chromatic dispersion must be controlled with the high accuracy. This can be very challenging task especially in a multiwavelength environment under varying conditions. Under these circumstances the tunability of the control mechanism is desired. In this respect we have investigated the use of a Semiconductor Optical Amplifier (SOA) for tunable dispersion control in the multiwavelength environment via chirp modification of data carriers. The successful demonstration of this technique was conducted in a 16 km long outdoor fiber optic testbed.
Keywords: chirp control, group velocity dispersion, chromatic dispersion, semiconductor optical amplifier, tunable chromatic dispersion compensation.

1. INTRODUCTION

A chirp control in incoherent optical fiber systems needs to be well manged in order to guarantee a high data rate communication. The same is true when using ultra-short multiwavelength OCDMA code carriers in Optical Code Division Multi Access (OCDMA) systems. Here having a tunable dispersion control is highly desirable [1, 2, 3, 4]. As shown in [4], even a meagre 50 m of SMF-28 fiber mismatch from the fully dispersion compensation state would lead to a 1 dB power penalty. To develop tunable means of dispersion compensation, a good number of techniques such as chirped fiber Bragg gratings (CFBG), adaptive tunable dispersion control, dispersion equalization by monitoring an 'extracted-clock power level', virtually imaged phase arrays (VIPA), micro-electro-mechanical systems (MEMS) and others have been explored [5, 6, 7, 8, 9]. In [5], the fiber Bragg gratings (FBGs) with on-fiber integrated heaters are used to achieve a tunable chirp and dispersion compensation. In [10], a planer lightwave circuit (PLC) based on a dispersion equalizer formed of a number of cascaded asymmetric Mach-Zehnder interferometers is used for both positive and negative dispersion compensation. In [7], a variable dispersion compensation method utilizing the virtually imaged phase array (VIPA) was demonstrated to mitigate the dispersion tolerances in 40 Gb/s DWDM system. Compared to FBG and PLC devices, the periodical characteristics of VIPA based compensators were found advantageous because fewer modules were required to cover the whole C or L bands. In [6], an adaptive tunable dispersion compensation technique was demonstrated, where first an error was calculated from the time-domain waveform of the device's output then the dispersion compensation was achieved by minimizing this error. In [11], the fiber CD penalty was measured as a function of modulation chirp parameter using a Ti:$LiNbO_3$ based optical modulator. By adjusting the frequency chirp the impairments due to dispersion were minimized for the given transmission links.

In this paper we demonstrate and compare the use of a single Semiconductor Optical Amplifier (SOA) for both, pre- and post- CD compensation in order to mitigate chromatic dispersion effects in a fiber transmission link used by an incoherent OCDMA system.

2. CODE CARRIERS' CHIRP

The time dependence of an optical carrier's instantaneous frequency is known as the chirp [12]. During the propagation of an optical pulse in a transparent medium, the pulse can acquire a chirp due to the chromatic dispersion and nonlinearities. The chirp can also result from changes of the refractive index associated with variations of carrier densities. The effect of chirp C on the recovered OCDMA auto-correlation envelope $S_L(t)$ can be described as [1]:

$$S_L(t) = \sum_{k=0}^{w-1} P \exp\left[-2.77(1+iC)\left(\frac{t-k\Delta\tau_0}{\tau-\Delta\tau_0}\right)^2\right] \quad (1)$$

Here, w is a number of OCDMA code carriers (wavelengths) also known as the code weight. The numerator $(t - k\Delta\tau_0)$ represents time skewing among wavelength carriers due to chromatic dispersion (CD) and the denominator $(\tau - \Delta\tau_0)$ reflects their spectral broadening caused by CD effects and

$$\Delta\tau_0 = D_{CD} \times L \times \Delta\lambda_j \quad (2)$$

where, $D_{CD} = -0.157$ ps/(nm•km) represents the dispersion of our partially compensated fiber testbed, L = 16 km is the testbed length, $\Delta\lambda_j = \Delta\Lambda_j = 0.8$ nm represent a pulse j's spectral width/channel spacing, respectively. The initially measured temporal FWHM value of the wavelength code carrier j is τ.

The SOA based chirp control was demonstrated in [13] where the transmission system comprised an electro-absorption (EA) modulator producing a positive chirp. An SOA was used to control the generated chirp by utilizing the phase modulation via the SOA [14].

In this investigation a comparative study has been conducted using an OCDMA transmission system seen in Fig. 1 where the SOA was located at its transmission (Option-1) or receiving (Option-2) site, respectively. We have investigated in what extent a placement of a single SOA would play a role in mitigating the chromatic dispersion impairments i.e., the spreading and time skewing which are affecting the recovered OCDMA auto-correlation at the receiving site.

3. EXPERIMENTAL SETUP

Our setup for investigating a chirp control by the single SOA is shown in Fig. 1. The OCDMA transmitter *Tx* produces a Two-Dimensional Wavelength-Hopping Time-Spreading (2D-WH/TS) OCDMA code based on four different wavelengths (λ_1 = 1551.72 nm, λ_2 = 1550.92 nm, λ_3 = 1552.52 nm, λ_4 = 1550.12 nm). The generated code is then amplified by an Erbium Doped Fiber Amplifier (EDFA-1) and passed through a 16 km long partially chromatic dispersion (CD) compensated fiber testbed connecting the University of Strathclyde and the University of Glasgow. At the system receiving end (point-4), the OCDMA auto-correlation is recovered by an OCDMA receiver *Rx* which matches the OCDMA *Tx* encoder. Here, the amplifier EDFA-2 is used for signal amplification and an optical spectrum analyser OSA (Agilent 86146B) and a digital oscilloscope OSC (Agilent Infiniium DCA-J 86100C) with 64 GHz optical sampling head are used for data analyses.

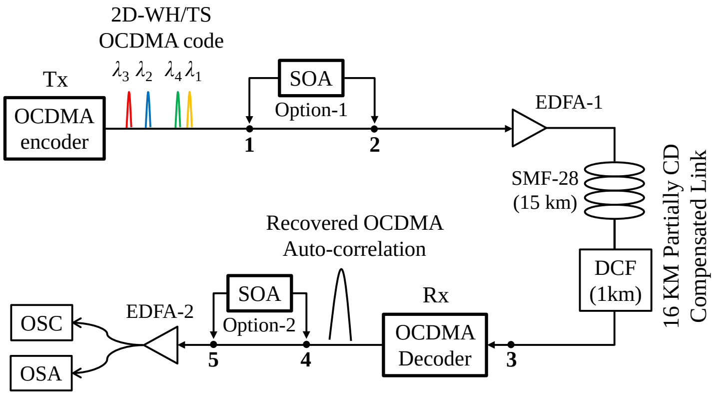

Figure 1. Experimental setup. Tx – OCDMA Transmitter/Encoder, SOA – Semiconductor Optical Amplifier, EDFA – Erbium Doped Fiber Amplifier, DCF – Dispersion Compensating Fiber, SMF – Single Mode Fiber, Rx – OCDMA Receiver/Decoder, OSC – oscilloscope, OSA – Optical Spectrum Analyser.

4. EXPERIMENTAL RESULTS

First we have performed a back-to-back measurement at Point-1. The obtained OCDMA auto-correlation FWHM was found to be 10 ps. Then the measurement was repeated after 16 km of propagation in a CD affected transmission link (Point-5). In this case the recovered OCDMA auto-correlation width was found to be 14 ps. Both measurements were performed by a digital oscilloscope DCA-J 86100C with a 64 GHz optical sampling head, OSC. Next we investigated how using the SOA placed either in position Option-1 or Option-2, would be effective in CD link compensation via controlling the chirp of picosecond multiwavelength OCDMA code carriers.

4.1 CD Management by a Single SOA on *Tx* Site

First, the SOA was placed in the testbed as indicated by Option-1 (See Fig. 1). Let us now define a value *R* as a

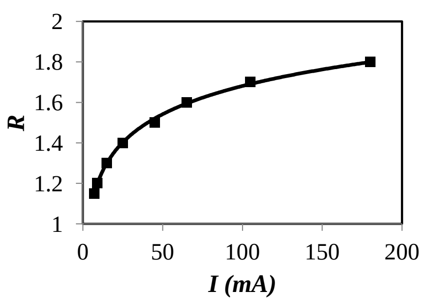

Figure 2. R as a function of the SOA bias current I. SOA is placed at the Tx site.

ratio of a measured OCDMA auto-correlation FWHM value at Point-5 and its back-to-back value of 10 ps found at Point-1. The obtained values of R as a function of SOA bias current I are plotted in Fig. 2. We can see that the SOA by controlling the OCDMA code carriers chirp was very effective in restoring the distorted FWHM value of the 2D-WH/TS OCDMA auto-correlation (note $R \rightarrow 1$). A detailed explanation can be found in [1]. In short, the positive chirp of the OCDMA code carriers generated by OCDMA *Tx* and propagated in the testbed makes the speed of the longer wavelength code carriers propagate faster than of those with a shorter wavelength. By reducing the carriers chirp through the SOA bias current adjustments will reduce the speed of the longer wavelengths and increase the speed of the shorter wavelengths code carriers. This way the individual code carrier's temporal width narrows aided further by the GDV induced anomalous propagation through the SMF-28 fiber [15].

4.2 CD Management by a Single SOA on *Rx* Site

Now, the SOA was placed right after the OCDMA receiver/decoder (Option-2) as is indicated in Fig. 1. The experiments were repeated and the obtained values of R as function of the SOA bias current I are plotted in Fig. 3. In this configuration, the SOA has the opposite effect on the values of R when compared to pre-chirping by the SOA described in sec. 4.1. We can see that R increases with an increasing SOA bias current, i.e. the FWHM of the OCDMA auto-correlation recovered at Point-5 is becoming wider with the larger values of I. Because the SOA at the output of the OCDMA *Rx* decoder is facing four times more optical peak power compare to its Option-1 position, SOA becomes gain saturated which leads to a self-phase modulation induced broadening [16].

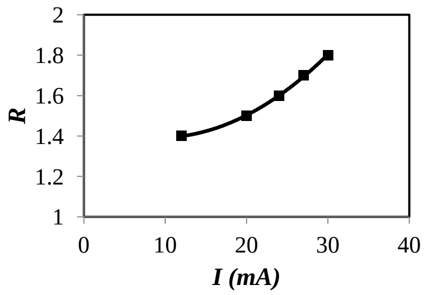

Figure 3. R as a function of the SOA bias current I. SOA is placed at the Rx site.

4.3 Investigation of Using SOA to Manage Impact of GVD on OCDMA Auto-correlation

Here we have investigated the effect of a varying value of a transmission link average residual group velocity dispersion, GVD (parameter β_2) on the OCDMA auto-correlation FWHM as a function of changing chirp C. The obtained results are shown in Fig. 4. Our investigation was done for β_2 between (0.10 – 0.20) ps^2/nm. We can see that for varying the values of chirp C and β_2 the values $R \in (0.93 – 1.41)$.

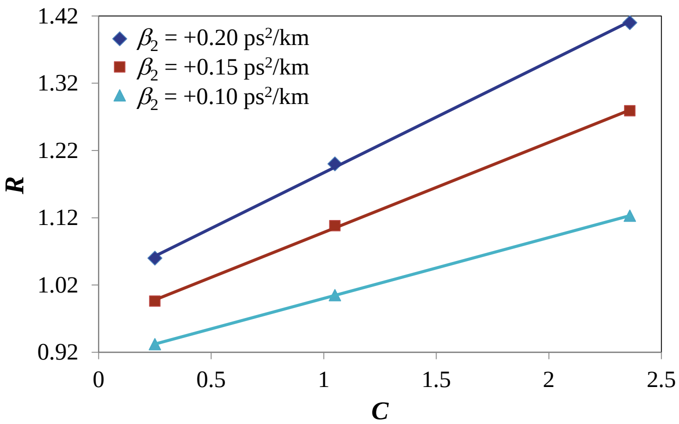

Figure 4. R as a function of chirp C for different values of β_2. SOA is placed at the Tx site.

5. DISCUSSION

The investigation of the effect of OCDMA code carriers' chirp on the OCDMA auto-correlation and its width were carried out by placing the SOA either at the OCDMA transmitter (*Tx*) or at the receiver (*Rx*) site. The OCDMA code carriers' chirp was controlled by varying the SOA gain dynamics through its bias current changes. We have shown that with the SOA at the *Tx* site, the OCDMA auto-correlation recovered at the transmission link's receiving end and its width can be varied between 1.1 to 1.8 of its back-to-back value. However, when the SOA was placed at the receiving end (right after the OCDMA decoder), its width could be varied from 1.4 to 1.8 of its back-to-back value. We have also shown that for varying fiber transmission link GVD, $\beta_2 \in(0.10 - 0.20)$ ps^2/nm, the SOA at the transmitter site can be used to manage the OCDMA auto-correlation distorted width between values $R \in (0.93 - 1.41)$ by controlling the code carriers' chirp C.

6. CONCLUSIONS

We have investigated the use of a single SOA for the tunable chromatic dispersion control in an incoherent OCDMA transmission system based on picosecond multiwavelength 2D-WH/TS codes. The use of a single SOA was tested in two different locations of the transmission link. First, on the transmission site after the OCDMA encoder and then on the receiving site after the OCDMA decoder. It was observed that controlling the chirp of multiwavelength code carriers by a single SOA located at the *Tx* site could effectively compensate for the observed OCDMA auto-correlation broadening resulted from the fiber link chromatic dispersion as well as for the transmission link's residual GVD changes. With a single SOA located at the *Rx* site after the OCDMA decoder, we observed that additional OCDMA auto-correlation broadening could be imposed by increasing the SOA bias current.

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REFERENCES

[1] M. S. Ahmed and I. Glesk: Management of OCDMA Auto-correlation Width by Chirp Manipulation Using SOA, IEEE Photon. Technol. Lett., vol.30, pp.785-788, May. 2018.
[2] M. S. Ahmed, M. S. K. Abuhelala, and I. Glesk: Managing dispersion-affected OCDMA auto-correlation based on PS multiwavelength code carriers using SOA, IEEE/OSA J. Opt. Commun. Net., vol. 9, pp. 693-698, Aug. 2017.
[3] M. S. Ahmed and I. Glesk: Tunable Chromatic Dispersion Management of Optical Fibre Communication Link using SOA, in Proc. 11th International conference Electro 2016, Strbske Pleso, Slovakia. Invited. In press.
[4] I. Glesk et al.: Evaluation of OCDMA system deployed over commercial network infrastructure, in Proc. ICTON, 13th International Conference on (pp. 1-4). IEEE. Jun. 2011.
[5] B.J. Eggleton et al.: Integrated tunable fiber gratings for dispersion management in high-bit rate systems, J. Lightw. Technol., vol. 18, pp. 1418–1432, Oct. 2000.
[6] K. Tanizawa and A. Hirose: Adaptive control of tunable dispersion compensator that minimizes time-domain waveform error by steepest descent method, IEEE Photon. Technol. Lett., vol. 18, pp. 1466-1468. 2006.
[7] H. Ooi et al.: 40-Gb/s WDM transmission with virtually imaged phased array (VIPA) variable dispersion compensators, J. Lightw. Technol., vol. 20, pp. 2196–2203, Dec. 2002.
[8] D. T. Neilson: Advanced MEMS devices for channelized dispersion compensation, in Proc. Tech. Dig. Optical Fiber Communications Conf. (OFC2004), Los Angeles, CA, 2004, vol. 1, Paper WK4.
[9] A. Sano et al.: Automatic dispersion equalization by monitoring extracted-clock power level in a 40-Gbit/s, 200-km transmission line, in Proc. 22nd Eur. Conf. Optical Communication (ECOC'96), Oslo, Norway, 1996, vol. 2, pp. 207–210, Paper TuD.3.5.
[10] K. Takiguchi, K. Okamoto, and K. Moriwaki: Planar lightwave circuit dispersion equalizer, J. Lightwave Technol., vol. 14, pp. 2003-2011, Sep. 1996.
[11] A. H. Gnauck et al.: Dispersion penalty reduction using an optical modulator with adjustable chirp, IEEE Photon. Technol. Lett, vol. 3, pp. 916-918, Oct. 1991.
[12] What is frequency chirp in an optical Pulse? (VIDEO), Accessed: Apr. 5, 2018, [Online], Available:https://www.fiberoptics4sale.com/blogs/wave-optics/what-is-frequency-chirp-in-an-optical-pulse-video
[13] T. Watanabe et al.: Transmission performance of chirp-controlled signal by using semiconductor optical amplifier, J. Lightwave Technol., vol. 18. pp. 1069, Aug. 2000.
[14] G. P. Agrawal and N. A. Olsson: Amplification and compression of weak picosecond optical pulses by using semiconductor-laser amplifier, Opt. Lett., vol. 14. pp. 500–502, 1989.
[15] H. Abramczyk. Dispersion Phenomena in Optical Fibers, Virtual European University on Lasers, Accessed: Apr. 5, 2018, [Online], Available: http://www.mitr.p.lodz.pl/evu/wyklady/
[16] G. P. Agrawal and N. A. Olson: Self-phase modulation and spectral broadening of optical pulses in semiconductor laser amplifiers, IEEE J. Quantum Electron., vol. 25, pp. 2297-2306, Nov. 1989.