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Ahmed, Md Shakil and Glesk, Ivan (2016) Recent advances in all-optical signal processing for performance enhancements of OCDMA interconnects. In: Transparent Optical Networks (ICTON), 2016 18th International Conference on. IEEE, Piscataway. ISBN 9781509014675 , <http://dx.doi.org/10.1109/ICTON.2016.7550537>

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Recent advances in all-optical signal processing for performance enhancement of OCDMA interconnects

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ABSTRACT

In ultra-high speed incoherent optical communication systems chromatic dispersion is considered a key impairment. Tuneable dispersion compensation for the signal data ultra-short carrier pulses propagated through the fibre optic cable is an effective way of overcoming this problem. The transmission system performance could be improved by manipulating the inbound pulses through the chirp control by SOA. To investigate the tuneable dispersion compensation, an experiment was carried out where the data signal was allowed through an SOA and by adding a local clock signal simultaneously at the same SOA input, it was possible to compress or expand the data carrier pulse-width. This way, the propagating signal was chirp controlled by varying the clock power at the input of SOA for different SOA pump currents. A reasonable dispersion management for the optical transmission system such as interconnects could be achieved by this technique.

Keywords: optical communications, chromatic dispersion, semiconductor optical amplifier, chirp, clock power, dispersion compensation.

1. INTRODUCTION

The basic elements of a fibre optic communication system based on return to zero (RZ) transmission format are: pulsed laser to generate optical carrier for RZ data, fibre optics transmission medium, a data modulator, data amplifier, and receiver with photo-detector. The spectrum of laser source comprises of a finite linewidth which means they emit at more than one wavelength [1]. We know that, the index of refraction of the fibre optics core is a wavelength dependent quantity. As such different wavelengths of light propagate at different speeds. Consequently, the propagating data pulse widens as the transmission distance increases. This is known as chromatic dispersion in the fibre optic communication systems. The mathematical expression for total chromatic dispersion can be expressed as:

$$\sigma = D_C \Delta\lambda L \quad (1)$$

Here, σ is the total broadening of an optical pulse, D_C is the dispersion coefficient for the optical fibre in ps/nm.km, $\Delta\lambda$ is laser linewidth in nm, and L is the total fibre length in km. The chromatic dispersion effect can be tolerable for shorter distances of transmission which is easier to satisfy for a “lower” bit rate of data communication. However, for higher data rates, where the relative pulse broadening value due to chromatic dispersion is more significant, the inter symbol interference, ISI (overlap of adjacent pulses) becomes a serious issue [2]. The ISI effect becomes very severe for ultra-high data rates with ultra-short data pulses. Here at some point the communication can completely stop for excessive dispersion of signals. There is a rule of thumb for maximum distance at which the data can be transmitted considering the broadening of data pulse in relation to bit period. The dispersion limited distance L_D is given by the following expression [3]:

$$L_D = \frac{1}{D \cdot B \cdot \Delta\lambda} = \frac{1}{D \cdot B \cdot (cB)} \propto \frac{1}{B^2} \quad (2)$$

Here, B is the bit period, D is the dispersion value, $\Delta\lambda$ is the spectral linewidth, and c is speed of light. As for example, for a single mode optical fibre, $D = 17$ ps/nm/km, $L_D = 52$ km. A more exact calculation shows that the dispersion induced power penalty is less than 1 dB [4]. The power penalty rises exponentially with transmission distance for uncompensated dispersion. At 40 Gb/s, the signals are 16 times more sensitive to chromatic dispersion than that at 10 Gb/s [3]. Therefore, it is necessary to control the chromatic dispersion in the optical transmission system. Network operators usually use dispersion compensating fibre (DCF) to compensate CD but additional fine tuning of the chromatic dispersion ‘manually’ can be a cumbersome and time consuming process. As such there is a need for simple tuneable chromatic dispersion compensators for use in transmission networks. Several research initiatives such as automatic dispersion compensation using FBG or AWG have been carried out in this respect [5-7]. In this regard, an investigation of tuneable dispersion compensation in photonic transport system (PTS) by following a technique of varying the local optical clock signal power at the input of SOA was carried out.

2. PRINCIPLE OF OPERATION

The concept of chirp control in SOA was shown in [8] where a transmission system comprising of an electro-absorption modulator a positive chirp was produced. To overcome this, an SOA was added with EA modulator where the SOA produces the negative chirp in the active medium and thereby compensate the positive chirp of

EA modulator. This conversion of positive chirp into negative chirp is accomplished utilizing the phase modulation of SOA [9]. The negative chirp increases with the increase of optical power at the SOA input. Disturbance of data signal due to positive chirp produced in EA modulator can be compared with the disturbance of the same due to anomalous chromatic dispersion in a typical fibre optic transmission system. We need to develop a tuneable system so that the anomalous dispersion produced in the transmission line can be compensated by passing it through an SOA. By manipulating this incoming signal by passing it through SOA, i.e., by changing the positive chirp into negative chirp, we can in fact compress or expand the pulse width of the optical data carrier. The gain changes in SOA give rise to refractive index changes in the active medium of SOA (biased SOA). The gain changes can also be accomplished by changing the optical input power at the SOA. Since the input power (P_{in}) increases, carrier depletion happens in SOA which induces gain saturation [10]. The chirp of SOA can be represented as [8]:

$$\alpha = \alpha' \frac{dG}{dP_{out}} = \alpha' \frac{\frac{dG}{dP_{in}}}{1 + \frac{dG}{dP_{in}}} \quad (3)$$

Here, P_{in} and P_{out} represent the respective SOA input and output power. G is the optical gain and α' is the linewidth enhancement factor (LEF) of a material. Under saturation condition of SOA, the gradual increase in input intensity decreases the amplifier gain ($\frac{dG}{dP_{in}} < 0$). As $\alpha' > 0$ in gain medium such as SOA, α is negative for gain saturated condition of SOA. From the analysis as mentioned in Ref [8, 10], it is found that when the input power is larger than the saturation value of SOA, the chirp parameter rapidly falls to negative value. Note, P_{in} can also be increased by adding locally generated optical clock pulses synchronized with the data pulses at the SOA input. Here, the data signal frequency and the clock frequency should be same (wavelength may vary) in order to introduce desired gain change of the active medium in SOA. This technique of increasing the SOA input power by varying the clock power helps to increase the negative chirp on the transmitted data pulses inside the SOA and can be used to manipulate dispersion compensation of the inbound data pulses.

3. EXPERIMENTAL RESULTS

The setup for the chirp control in SOA by varying the locally generated optical clock power is shown in Fig. 1. From the supercontinuum generator four pulses are sliced using FBG based spectral slicer. These four pulses of different wavelengths ($\lambda_1 = 1551.72$ nm, $\lambda_2 = 1550.92$ nm, $\lambda_3 = 1552.52$ nm, $\lambda_4 = 1550.12$ nm) are passed

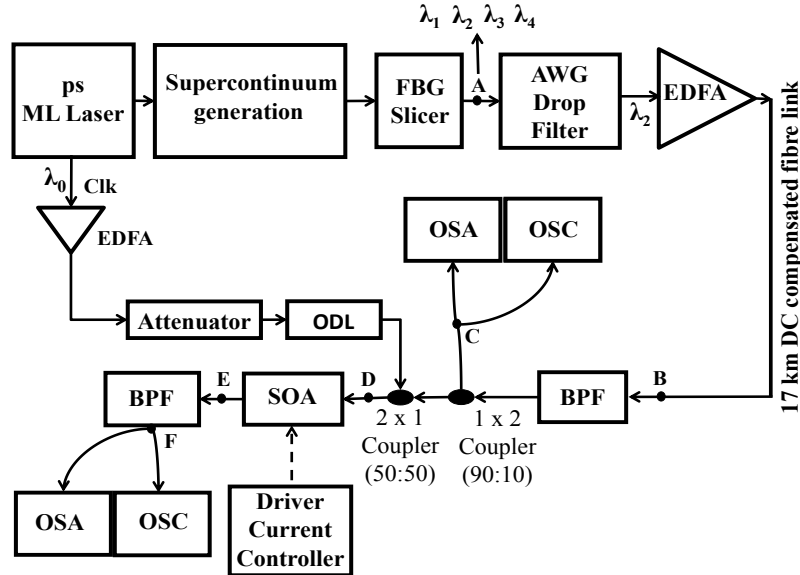


Figure 1. Experimental setup for automatic dispersion compensation using clock power where ps is picosecond, ML Laser-Mode Locked Laser, OSA-Optical Spectrum Analyser, OSC-Sampling Oscilloscope, BPF-Band Pass Filter, FBG-Fibre Bragg Gratings, AWG-Array Waveguide Grating, EDFA-Erbium Doped Fibre Amplifier, ODL-Optical Delay Line, SOA-Semiconductor Optical Amplifier).

through an AWG drop filter to select one pulse of wavelength λ_2 which is then amplified and passed through a 17 km long dispersion compensated fibre link. This signal is then passed through an SOA with an intention of controlling and fine tuning the residual dispersion of the coarsely chromatic dispersion compensated 17 km long fibre optic transmission link. At the same time, an optical clock signal locally generated by the picosecond mode locked laser was introduced at the SOA input using a 2x1 coupler. An optical attenuator was used to set different

clock power levels during the experiment. Optical Spectrum Analyser (OSA) Agilent 86146B and Sampling Oscilloscope (OSC) Agilent Infiniium DCA-J 86100C with 64 GHz optical sampling head were used for monitoring the optical data at various test system points A-F. During the experiment, the optical clock power was varied from 0 to 12.5 mW. The full width at half maximum (FWHM) of the incoming data pulses at the input of SOA (point D) was measured as 23 ps [11]. Here, an optical delay line (ODL) is used to synchronize the data signal with the clock to affect the gain in active region of SOA and thereby increases the negative chirp as predicted by equation (3). As a result, the desired compression of the data signal pulses is achieved. The different pulsewidth ratios between output and input optical data pulses vs clock power for different SOA drive currents are shown in Fig. 2. From the experiment, it is seen that below the SOA drive current of 100 mA and different clock power settings, only the pulse compression happens. But at above the SOA drive current of 100 mA such as 200 mA, both pulse compression and expansion can be achieved for different settings of optical clock powers. Mentionable here that SOA gain become saturated at a drive current of ~150 mA [11]. This means, the pulse compression occurs bellow SOA saturation point. Above SOA saturation conditions, only expansion of data pulses occurs. We have found that input data pulsewidth 23 ps FWHM can be compressed up to 15 ps FWHM at SOA drive current of 29 mA with clock power setting of 12.5 mW. The maximum pulse expansion observed was 25 ps FWHM at the SOA drive current of 200 mA and optical clock disabled condition.

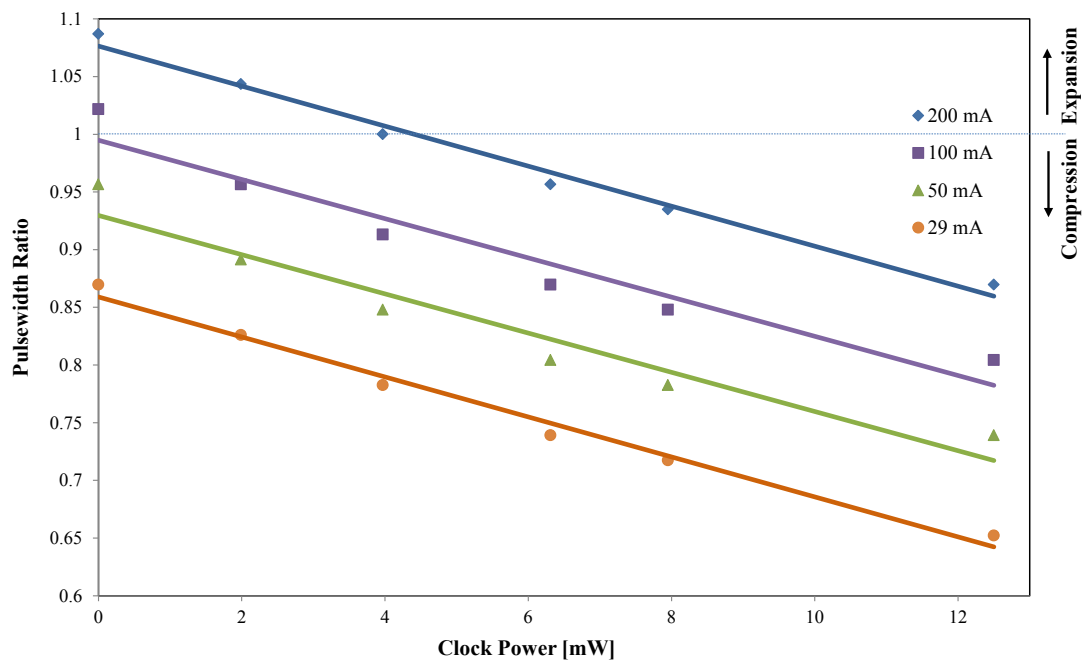


Figure 2. Data Output/Input Pulsewidth Ratio vs Clock Power for Different SOA Drive Currents.

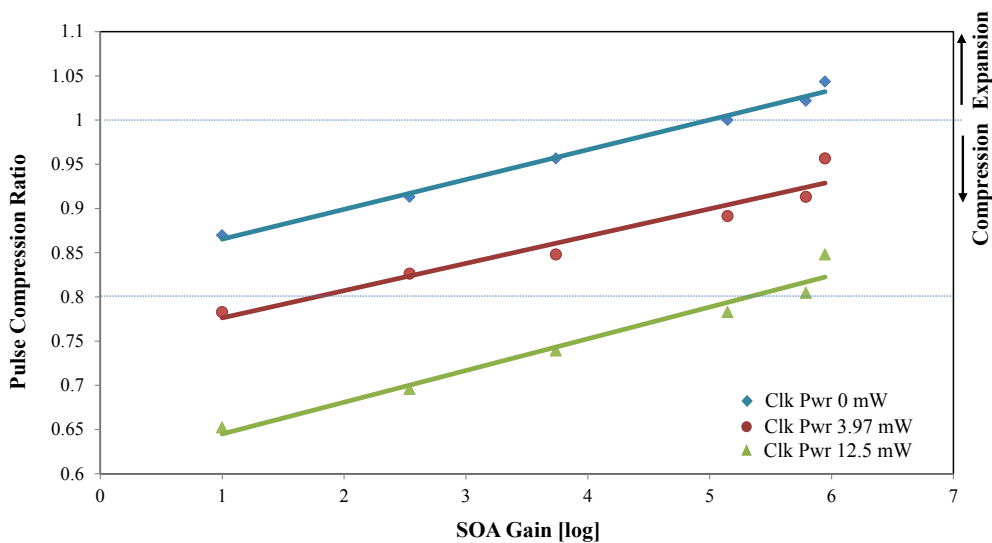


Figure 3. Data pulse compression ratio vs SOA gain at optical clock power levels of 12.5 mW, 3.97 mW and 0 mW (clock disabled).

The pulse compression ratio is also plotted for optical clock power levels of 12.5 mW, 3.97 mW, and 0 mW (clock disabled condition) and different SOA gain values as shown in Fig. 3. It can be seen that, the more the clock power for a particular gain the more the pulse compression can be achieved.

It is also observed that to achieve a pulse compression ratio ~ 0.8 two options of settings are available:

- set SOA gain of 1 to 2 with 3.97 mW of optical clock power at its input or
- set SOA gain of 5 to 6 with 12.5 mW of clock power at its input.

For obvious practical reasons the second option seems preferable because simultaneously allows to improve the signal to noise ratio at the receiver input.

4. DISCUSSION

Managing chromatic dispersion in fibre optic networks is a necessity because a fine readjustment of dispersion compensated fibre links for ultra-high speed incoherent communication is always required. This is becoming even more desirable as the serial signal data rates are approaching Tbit/s rates. We have shown this can be accomplished by using SOA via its chirp control by varying the locally generated optical clock power and SOA's pump current in the harmony with the incoming data when passing through this SOA. By choosing the clock power levels between 0 to 12.5 mW for a different SOA gain levels the inbound data pulsewidth can be efficiently manipulated. We have demonstrated that the pulse compression can be achieved for the SOA pump currents up to 100 mA with a varied optical clock powers. On the other hand, if SOA pump current was set above 100 mA we observed a data pulse expansion (broadening). Using this technique, both pulse compression and expansion are possible.

5. CONCLUSIONS

We have demonstrated a technique for a tuneable chromatic dispersion compensation readjustment of a 17 km long coarsely pre-compensated fibre optic link by using different optical power levels of a locally generated optical clock synchronized with the incoming data signal inside of the biased SOA, via controlling SOA chirp. This technique allowed changing the incoming data pulsewidth (23 ps FWHM) to be compressed back to its original value of 15 ps FWHM or to be more expanded up to 25 ps FWHM. This technique provides an effective approach which offers fine tuning capabilities to readjust chromatic dispersion of already coarsely pre-compensated fibre transmission links.

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