Strong Self-Phase Modulation in Data Erasing Beyond 20 Gb/s Using Saturated Ultra-Long SOA

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***Abstract*—Optical data extinction using ultra-long SOA is evaluated up to 56 Gb/s. The analysis of the deleterious effects such as spectral broadening and imperfect erasing predicts useful carrier wavelength reuse up to 20 Gb/s.**

***Keywords*—Optical Carrier reuse, Optical Data Processing, Semiconductor Optical Amplifier.**

I. Introduction

The proposed techniques for Fiber-To-The-Home (FTTH) systems must incorporate the wavelength-division-multiplexed passive optical networks (WDM-PON) with centralized light sources (CLS) due to their large transmission capacity, network security, and data transparency [1].

The WDM-PON is a hopeful approach to accomplish future access networks demands. In firsts schemes, one optical carrier for the upstream and another for the downstream signal were used [1]. However, with wavelength reuse (WR), no necessity of an additional wavelength occurs [2]. The WR by optical data erasing (DE) and further rewriting was achieved using: two modulators [3], semiconductor optical amplifier (SOA) with feed-forward gain control technique and optical modulator [4], SOA as eraser/modulator [2], reflective SOAs (RSOAs) [5], interferometric filter & RSOAs [6], phase modulated downstream and amplitude modulated (AM) upstream [7-9], and deeply saturated ultra-long (UL) SOA [10, 11]. However, the inherent erasing capacity is not substantial in many of those cases, even so more restricted when considering pseudo random bit stream (PRBS) and/or AM signals with input extinction ratio (ER_{in}) greater than 8 dB, as well as for high bit rates (above 10 Gb/s). The use of gain-saturated SOA for DE was first proposed in [12] and implemented in [4] using cascaded SOAs.

The more recent scheme is based on deep gain saturation in ultra-long SOA (L_Z = 8 mm) to provide AM data extinction (AMDE) [10], and a local optical modulator to rewrite the upstream data over the erased carrier [11]. This scheme achieved good performance for bit rates up to 12.5Gb/s with ER_{in} up to 12.4 dB. Here we analyze the deleterious effects of UL-SOA based AMDE such as (erased carrier) spectral broadening and red shift. It is shown that deleterious effects may limit the maximum bit rates to 20 Gb/s, with two main characteristics: the erased carrier has bandwidth enlargement (up to 1 nm for 56 Gb/s) together with a red shift, and a large phase noise after 20 Gb/s.

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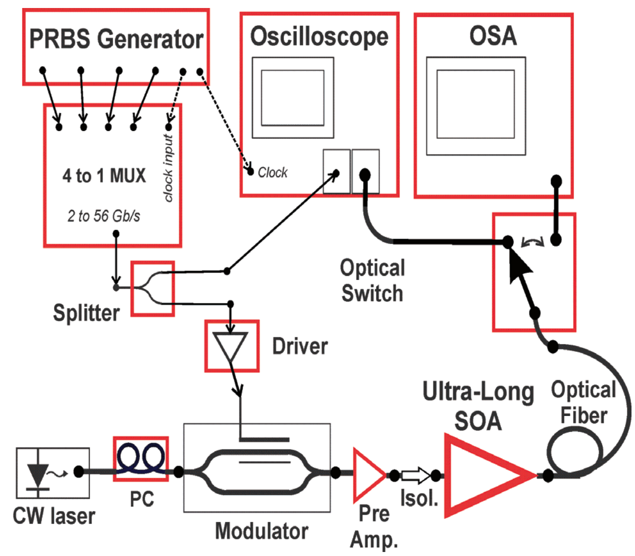

Fig. 1. Experimental setup

II. Experimental Setup and Results

The experimental setup is shown in Fig.1– the downstream source, ie. a 2 to 56 Gb/s generator/driver composed by a 14.2 Gb/s PRBS, a clock doubler, a 4:1 multiplexer and a driver amplifier. The optical carrier is MZ modulated in non-return to zero (NRZ) PRBS with SOA (pre-amplifier), optical isolator and UL-SOA. The quality of input and output (erased) data streams were analyzed by OSA and sampling oscilloscope.

The linear SOA (illustrated as Pre-amplifier in Fig.1) provided a gain variation from 4.3 dB to 10 dB, to search the deep saturation regime and so optimal performance. The CW signal was sent at 1565 nm, the peak of the UL-SOA amplified spontaneous emission noise, contributing to achieve the deeper gain saturation.

The UL-SOA (8-mm long) has four sections – 1-3-3-1 mm [13]. The I_{bias} were always lower than 1,2 A (150+450+450+150 mA), less than 50% of device maximum power; higher currents were not necessary in this application, giving no better performance but higher ASE noise. Typical eye-diagrams are in Fig. 2, input at 14 Gb/s and outputs at different rates (14 Gb/s, 28 Gb/s, and 56 Gb/s).

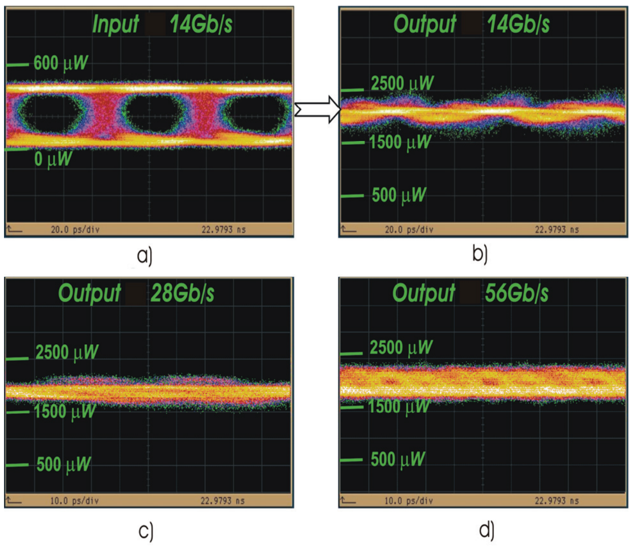

Fig. 2. Eye diagrams for the eraser´s (a) input signal (ex. 14 Gb/s); output (erased) signals for input at (b) 14 Gb/s, (c) 28 Gb/s and (d) 56 Gb/s.

The observation of those time signals might lead to the conclusion that AMDE is almost insensitive to the data bit rate. However, this is not the case in the frequency domain, due to the UL-SOA self phase modulation (SPM) effect, as shown in Fig. 3 - the 56 Gb/s input signal spectrum is presented as reference. The side bands can be noted in Fig. 3 and the input spectra at other data rates are similar (not shown here). To observe SPM, the spectra after the UL-SOA are shown in Fig. 3 for three bit rates: 14 Gb/s, 28 Gb/s, and 56 Gb/s. First we should note that all spectra are broadened and presents asymmetries; further that a shift towards the "red" (longer wavelengths) can be noted for all bit rates. However, the AMDE technique needs a clear carrier to be remodulated.

At the 14 Gb/s, the "red shift" side band are at least 15 dB below the carrier peak and the remodulated signal can have good quality as showed before [10-12]. But when the data rate increases, the carrier power central peaks decrease (-2 dB for 28 Gb/s and -4 dB for 56 Gb/s) and the "red shift" side band level increases (around 2 dB and 7 dB respectively). For 56 Gb/s it is also difficult to distinguish the carrier from the side bands.

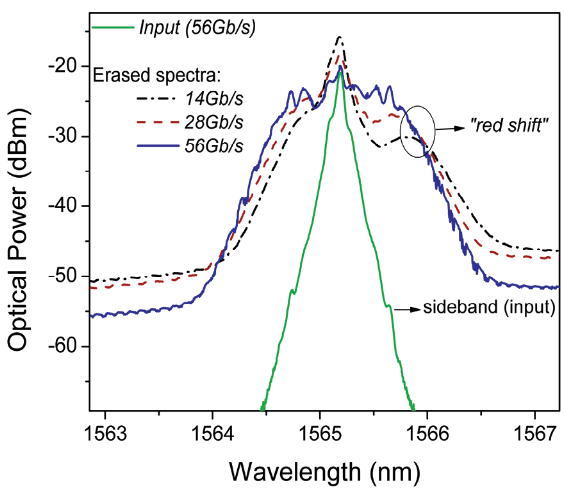

Fig. 3. Power spectra for the input signal (at 56 Gb/s) and the output signals (after the UL-SOA) for 14 Gb/s, 28 Gb/s, and 56 Gb/s

The physical mechanism behind SPM is the SOA gain saturation, which leads to intensity-dependent changes in the refractive index in response to variations in the carrier density [14]. The spectral shift depended on the linewidth enhancement factor, the input pulse energy and the amplifier gain, the last two related to the SOA gain.

Due to this dependence, in the AMDE based on the UL-SOA gain saturation, it was noted an increase of the spectral broadening with the increase of the parameters: ER_{in}, bit rate, UL-SOA bias current, and P_{in} [15].

The enlargement of the spectral bandwidth after the UL-SOA has been measured as a function of the bit rate. Fig. 4 presents the output signal (after UL-SOA) full bandwidth measured at - 3 dB level below the carrier power peak, at - 6 dB, and - 10 dB, as shown in Fig. 4. These results show that the AMDE can go up to 20 Gb/s if the system could support 0.6 nm full bandwidth at the -10 dB level. This spectral broadening is the main drawback of this AMDE technique. In addition, the UL-SOA bias current also exerts influence on the spectral broadening (not shown here), and a very large UL-SOA bias current might cause even higher spectral broadening

The interference between adjacent channels must be considered if the adjacent carrier channels have a much lower power or when those channels are in close proximity one to another fact that can be avoided in sparse WDM-PON. Thus, the spectral broadening only is a problem in DWDM systems. However this kind of multiplexing is not commonly used in PON systems. Therefore, the real problems caused by the large spectral broadening are: the fiber dispersion effects and the difficult to distinguish the carrier from the side bands, which is required for a good remodulation.

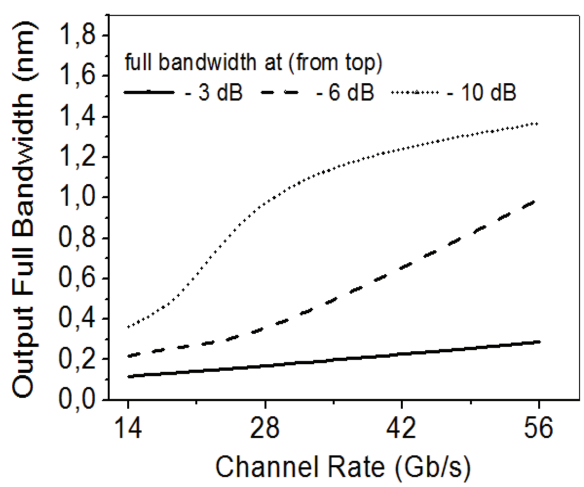

Fig. 4. Full bandwidth after the UL-SOA at - 3 dB below carrier top, - 6 dB, and - 10 dB.

III. CONCLUSION

We presented the SPM issues of an UL-SOA based AMDE sub-system. The system can successfully erasure an AM optical carrier up to 20 Gb/s for wavelength reuse applications but spectral broadening severely impacts the output signal with a bandwidth enlargement increasing with the signal data rate.

Although simple and effective, the scheme needs an UL-SOA and has the above-cited limitations, including optical signal to noise ratio (OSNR) reduction due to amplitude spontaneous emission (ASE) noise accumulation; but the main drawback in the occurrence of SPM since the induced spectral broadening can induce deleterious impacts in further fiber transmission, issue under test now. Nevertheless, we expect to realize efficient use of wavelength resources in WDM networks with centralized light sources (CLS).

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