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All optical regeneration

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Abstract. All-optical signal regeneration techniques are reviewed: fiber and semiconductor based devices are addressed, and some 2R and 3R signal regeneration experiments are discussed

1. INTRODUCTION

Record terabit/s point-to-point transmission systems over more than 2000 km have recently been reported [1], based on dispersion managed non-linear transmission techniques, without need for any regeneration device, except for simple linear optical amplifiers. However, if terrestrial photonic networks featuring dynamic routing capability are considered, more sophisticated regeneration schemes could be necessary in order to compensate for signal quality discrepancies between high data rate WDM channels which could be routed at different times over variable distances. Although classical optoelectronic regenerators constitute an attractive solution for single channel, single data rate transmission, it is not clear whether they could be a cost effective solution in a tremendously growing data bandwidth scenario. All optical regenerators, based on components which can process low as well as high bit rates signals could be an interesting alternative. In this summary, we briefly review 2R (reshaping repeater) and 3R (retiming, reshaping repeater) optical regeneration schemes for high speed optical signal processing, based on different technologies such as fibers or semiconductors.

2. MAIN SIGNAL DEGRADATIONS

Main signal degradations in fiber systems arise from amplified spontaneous emission (ASE) due to optical amplifiers, pulse spreading due to group velocity dispersion (GVD), which can be corrected through passive dispersion compensation schemes, polarisation mode dispersion (PMD), and finally non-linear effects due to Kerr non-linearity contributing to signal distortion and jitter above 10 Gbit/s.

3. BASIC PRINCIPLE OF OPTICAL REGENERATION

3.1 2R regeneration

If time jitter is negligible, simple amplification and reshaping processes are usually sufficient to maintain signal quality over long distances by preventing from noise and distortion accumulation. A 2R regenerator mainly consists of a linear optical amplifier followed by a data-driven non-linear optical gate (NLOG) which modulates a "clean" (low noise) CW laser light source. If the characteristics of gate transmission versus signal intensity yields a thresholding and limiting behaviour, then signal extinction ratio can be improved and ASE amplitude noise partly reduced In addition, the accumulated chirp can be wiped off. One can consider 2 different operating schemes:

i) cross-regeneration scheme, which is the above described scheme in which it is possible to avoid (or reduce) the noise transfer on both "1" and "0" symbols.

ii) self-regeneration scheme, in which the incident signal propagates on the same optical carrier throughout the reshaping gate. In this case, part of the incident noise fluctuations is transferred without reduction (typically noise on symbol "1" for a saturable absorber gate, and noise on symbol "0" for a saturable amplifier gate). This regeneration scheme is less efficient, but it does not need an auxilliary local laser beam.

3.2 3R Regeneration

When jitter accumulation is also a problem, e.g. owing to cross-phase modulation (XPM) in WDM systems, or pulse edge distortions due to finite response time of non-linear signal processing devices (e.g. wavelength converters), or uncompensated polarization mode dispersion, then 3R regeneration might be necessary. Fig. 1 shows the basic structure of an optical 3R regenerator [2], which mainly consists of an optical amplifier, a clock recovery block providing an unjittered short pulse clock stream, which is then modulated by a data driven non-linear optical gate block.

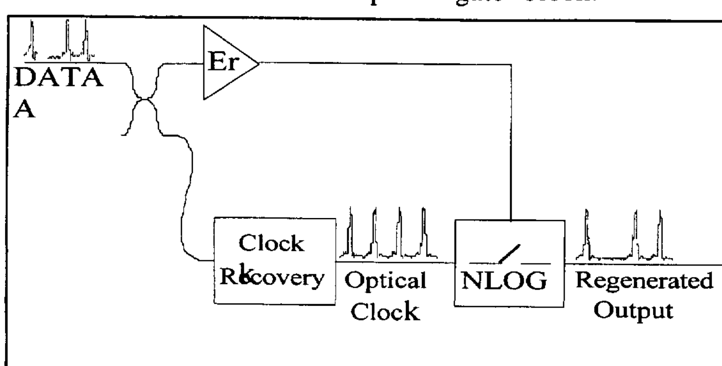

Figure 1: Principle of optical 3R regeneration

Let's now review some recent approaches for these different building blocks.

4 REGENERATOR MAIN BUILDING BLOCKS

The core of an optical regenerator is a non-linear gate featuring signal extinction ratio enhancement and noise reduction. An optical clock recovery stage is required for 3R regenerators.

4.1 Fibre based gates

Kerr-shutter [3] and non-linear optical loop mirror (NOLM) [4] are probably the first studied gates for regeneration applications. The ultra fast response of Kerr non-linearity is a major advantage of these devices for high speed signal processing. Using a Kerr-shutter, a 40 Gbit/s optical regenerator has been reported [3]. But the weak silica fiber non-linearity requires typical peak power x length products of 0.5 W x km. Long fibre lengths (several km) and polarisation sensitivity to incoming signal are drawbacks for WDM field deployment. Recently, a new polarisation insensitive gate based on self phase modulation spectrum filtering was reported [5], with a good thresholding-limiting characteristics.

4.2 Semiconductor based optical gates

Although not as fast as fibre based devices, these gates are much more compact. One can consider " active devices ", i.e. that require an electrical power supply like semiconductor optical amplifier (SOA) based devices, and " passive devices ", like saturable absorbers [6].

Among active semiconductor gates, work has been focused on bistable lasers [7] and mostly on SOA based devices . First reported SOA based optical gates was a Sagnac interferometer incorporating one SOA as the non-linear element [8,9]. However these gates are much better suited for high speed OTDM demultiplexing [10] than for 3R regeneration which requires a gate with a well shaped rectangular window when switching data pulses are somewhat large. Other high speed and well shaped optical gates are SOA-based Mach-Zehnder or Michelson interferometers [11,12], which can be data driven with polarisation independence up to 40 Gbit/s, with excellent performances [13]. Main features of interferometric non-linear gates are signal extinction ratio enhancement and noise variance reduction. 100 Gbit/s optical logic gate based on an ultrafast nonlinear interferometer (UNI) using an SOA in a birefringent interferometer was reported [14], while feasibilility of data regeneration at 40 Gb/s with this gate was demonstrated [15].

Multi-quantum well based saturable absorbers have been known for long. However, the contrast ratio of a transmitting saturable absorber is usually weak, because the thickness of the MQW stack cannot be too high. This is not a problem for Laser mode-locking applications. However, for applications under consideration here, a contrast ratio of at least 5 dB is required. This has been achieved by placing the MQW absorber inside a reflective microcavity [6]. Now, the absorption recovery lifetime is typically in the range of nanoseconds, without some special processing. In order to reduce this lifetime, different techniques are presently investigated in the InGaAsP/InP system: low temperature epitaxial growth [6], high energy ion bombardment **[16 IEF]**, and more recently iron doping **[17 INSA]**.

4.3 Clock Recovery

For optical 3R regeneration, a synchronous unjittered short pulse stream clock has to be recovered from incident signal. Many solutions meeting these requirements have been reported, which cannot all be reviewed here. We only focus on polarisation independent and potentially ultrahigh speed schemes for RZ formats. All-optical clock recovery through optical injection of mode-locked lasers, either in semiconductor [18] or Erbium doped fibre [19] could yield low jitter, short pulse clocks. Phase locked loop techniques using a high speed non-linear optical element as phase comparator [20], could also yield good performance above 100 GHz. Recently, a self-pulsating laser clock recovery was demonstrated at 40 GHz [21, 22].

5 SOME RECENT RESULTS ON OPTICAL REGENERATION

We briefly review here some recent results on polarisation independent regeneration schemes for data rates above 10 Gbit/s.

5.1 2R regeneration

Although 2R regeneration looks very attractive because of its simplicity and bit rate flexibility [23], it is not clear whether it could be used above 10 Gb/s with a high degree of cascadability, because it would require devices with a very short transition time response. However, self-regeneration in a microcavity saturable absorbers has recently been used in order to increase by 30 % the transmission length of a 20 Gbit/s system laboratory experiment, enabling a 7200 km transmission [24].

5.2 3R regeneration

" All-electronic " signal processing is rapidly progressing, with recent demonstration of a 40 Gbit/s optoelectronic repeater using InP-HEMT technology [25]. Several 3R optical regenerator architectures have also been demonstrated. All optical fibre devices were first reported, and have shown now 20 [26], and 40 Gbit/s [3] operation capability. On the semiconductor technology side, hybrid regenerator structures using optoelectronic clock recovery stage and all optical SOA based non-linear interferometric gates have been demonstrated (with BER assessment) at 10 [27], 20 [28,29] and 40 Gb/s [30]. Cascadability of up to 100 regenerators in recirculation loop at 40 Gbit/s has been reported [31] with multistage interferometric gates (cascaded non-linear gates improve signal regeneration [32]).
Finally, InP electro-optic modulators have successfully been used for polarisation insensitive in-line amplitude and phase synchronous modulation of soliton signals up to 40 Gb/s, enabling error-free transmission over more than 20 000 km [33].

6 CONCLUSION

High speed WDM photonic networks will probably require signal regenerators. Although significant progress has been achieved these two last years, it is not yet clear to-day whether all building blocks of a 3R all optical regenerator will be as easily integrated as for an electronic device, with cost effective targets, particularly in a dense WDM context. This means that optical signal processing solutions should yield superior or not otherwise available functionalities, such as bit rate flexibility, or better: simultaneous regeneration of several WDM channels in a single chip. In this latter case, new materials have to be developped, such as quantum box (or at least dot) materials with controlled dot sizes.

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