Cost-Efficient Pulse Source for Broadband Photonic Communication Systems

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EXTENDED ABSTRACT

The current state of the art in commercial Wavelength Division Multiplexed (WDM) systems allows telecommunication operators install fixed WDM systems in which each channel can operate at a bit rate of 10 Gb/s, with a channel spacing of around 100 GHz. However, with the drive to develop long-haul transport networks exhibiting multi-Tb/s capacities, it is anticipated that these WDM systems will be upgraded by deploying higher wave counts (at 10 Gb/s) or higher capacities per wavelength. The latter seems to be the better alternative especially taking into account the numerous advantages such as lower overall cost for capacity and better terminal density. One of the factors that has been attracting a lot of attention, with the move to higher line rates, is the coding used at the transmitter. Most of the current systems, 2.5 - 10 Gb/s, have tended to employ Non-Return-to-Zero (NRZ) coding. However, in order to achieve line rates of 40 Gb/s and higher, it may become necessary to use Return-to-Zero (RZ) coding. RZ (pulse) modulation formats offer a number of advantages over NRZ modulation schemes, especially in long haul transmission, which result in higher signal-to-noise ratio and lower system bit error rate translating to better overall system performance. Hence, the development of picosecond optical pulse sources with excellent temporal and spectral properties is vital for future implementation of high capacity optical communications systems using OTDM and hybrid WDM/OTDM technologies.

Short optical pulses can be generated by employing several different techniques such as mode locking, gating continuous wave light with an external modulator or by gain switching. Mode locking of semiconductor or fibre lasers is a common technique used to generate short optical pulses operating at high frequencies. However, the cavity complexity and limited tunability of the mode locking repetition rate and emission wavelength act as major disadvantages associated with this technique. Pulse shaping using external modulators is another technique that is gaining popularity. The need for an additional costly component (high-speed modulator), high insertion loss of the modulator, large driving voltages act as deterrents in the commercial acceptance of this technique. Alternatively gain-switching offers smaller footprint, efficient wavelength-stable performance and the ability to produce high-repetition rate pulses. Nevertheless, this technique also portrays a few shortcomings such as the generated pulses exhibiting quite a large degree of timing jitter and a degraded side mode suppression ratio. Both these deficiencies could be alleviated by externally injecting light into the gain-switched laser. However, one of its major drawbacks is the spectral purity of the generated pulses. The time varying carrier density in the active region of the device causes a frequency chirp across the pulse, which degrades the performance of these pulses when used in practical optical communication systems. It has been reported how this chirp can be used to compress the pulses using dispersion compensating fibre or linearly chirped fibre Bragg gratings (LC FBG), to obtain near transform-limited pulses. However, due to the chirp being nonlinear in the wings of the pulse, this compression typically results in pedestal formation on either side of the pulse. By using more elaborate arrangements involving nonlinear amplifying loop mirrors (NALM), external modulators, spectral windowing or semiconductor optical amplifiers in conjunction with shifted filtering after the linearly compressed pulse, it is possible to greatly reduce the pedestal. The above-listed methods, to optimize the TPSR of the pulse source, leads to the source becoming more complex, bulky and expensive. In previous work, we reported a simple, yet systematic approach, to design a pulse source exhibiting excellent temporal and spectral purity, with the aid of a non-linearly chirped fibre Bragg grating (NC FBG) placed after an externally injected gain-switched laser diode (EI GSLD). This approach of using a tailor made grating has an additional bonus in that it has the potential to be integrated with the gain switched laser diode.

In this paper, we initially show the design of the pulse source based on the EI GSLD employing a NC FBG. The design of the NC FBG is based on an initial complete characterization of the gain-switched pulse using a technique known as Frequency Resolved Optical Gating (FROG). We subsequently use the measured non-linear chirp across the pulse to design and fabricate an NC FBG. This process involves the initial creation of the group delay response for the FBG based on the group delay data derived from the FROG measurements of the externally injected gain-switched pulse. The FBG target group delay response is simply selected as the inverse to the pulse group delay response, which should result in the pulse having a constant group delay profile over

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the pulse bandwidth after it has been reflected from the FBG. In addition to a constant group delay profile across the pulse bandwidth, for an optimized pulse source, we also require the pulse to exhibit a Gaussian spectrum. The reflection profile of the NC FBG is constructed as the difference between the spectral amplitude of the gain-switched output and a Gaussian profile, which should result in the compressed pulse portraying a Gaussian spectrum. We also fabricated a linearly chirped fibre Bragg grating (LC FBG) which had a chirp profile that was opposite to a linear approximation of the chirp across the gain-switched pulse. By employing the tailor made NC FBG after the gain-switched laser, we can achieve direct compression of the gain-switched pulses to obtain near transform-limited pulses. Experimental results show the generation of 3.5 ps pulses (FWHM) at a repetition rate of 10 GHz and an associated spectral width of 130 GHz resulting in a Time Bandwidth Product of 0.45. These pulses also portray an excellent Temporal Pedestal Suppression Ratio of 35 dB, which is achieved not only by the non-linear group delay of the grating but also by ensuring the grating has a specially adapted transfer characteristic. The spectral and temporal characteristics of such a pulse source would make it suitable for use as a transmitter in 80 Gb/s OTDM or hybrid WDM/OTDM systems.

In addition to describing the make-up of the cost-effective RZ transmitter, we also characterize the performance of an 80 Gb/s OTDM system employing two gain switched pulse sources, one compressed with a NC FBG that achieves an excellent TPSR (> 40 dB), and the other with a LC FBG that achieves a poor TPSR (~20 dB). The degraded performance, in the case of the latter, (power penalty of 3.5 dB in 80 Gb/s system) even though both sources generate pulses that are transform-limited, exhibit widths < 30% of the 80 Gb/s bit slot and portray SMSRs of > 30 dB, is attributed to the presence of pulse pedestals which cause coherent interactions between individual OTDM channels, thereby resulting in severe intensity fluctuations. We define the TPSR (P_1/P_2) as the difference in power between the peak of the pulse (P_1) and the peak of the next highest pedestal (P_2). A commercially available TMLL pulse source was also used to bench mark the experimental system performance characterization.

Keywords: pulse source, gain-switching, wavelength division multiplexing, optical time division multiplexing, frequency resolved optical gating.

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