Optimized Pulse Source Based on a Gain-Switched Laser Diode in Conjunction With a Non-Linearly Chirped Grating for 40 Gbit/s Systems

A. Kaszubowska[1], A. Clarke[1], D. Reid[2], G. Edvell[3], S. Roumieux[1], P. Anandarajah[1], L.P. Barry[1] and J.D. Harvey[2]

[1]RINCE, School of Electronic Engineering, Dublin City University, Ireland. [2]Physics Dept. Auckland University, New Zealand.
[3]Redfern Optical Components, Eveleigh NSW 1430, Australia.

SUMMARY

With the demand for bandwidth showing no sign of declining, increasing the overall capacity of the existing telecommunication networks is necessary. Current trends and technology maturity favor the deployment of optical communication systems, operating at line rates 40 Gb/s and beyond [1]. This makes it more likely that Return-to-Zero (RZ) coding be used for data transmission, as it is easier to compensate for dispersion and non-linear effects in the fiber by employing soliton like propagation [2]. Hence the design of an optical transmitter, capable of generating pulses with adequate temporal and spectral purity for acceptable operation in high-speed optical communication systems, is crucial. There are many techniques available to generate pico-second optical pulses, and it is readily recognized that the gain-switching technique is amongst the simplest of these. One of the major problems associated with gain-switched laser pulses is the frequency chirp across them. It has been reported how this chirp can be used to compress the pulses using dispersion compensating fibre [3] or linearly chirped gratings [4], to obtain near transform limited pulses. However, due to the chirp being non-linear across the pulse, this compression typically results in pedestals on either side of the pulses that make them unsuitable for use in practical systems.

Our technique is based on the design of an optimized source of pico-second optical pulses, which exhibits excellent temporal and spectral purity. The procedure entails an initial complete intensity and chirp characterization of pulses, from an Externally Injected-Gain Switched Laser (EI-GSL), using the technique of Frequency Resolved Optical Gating (FROG). This characterization yields the parameters that are required for the design of a Non-linearly Chirped Fibre Bragg Grating (NC FBG) with a chirp profile that is opposite to that measured across the 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 pedestal-free, near transform-limited, 7 ps pulses.

The experimental set-up employed in this work is shown in Fig. 1. A high-speed 1550 nm DFB laser diode is gain-switched at 2.5 GHz using a signal generator and a high power RF amplifier.

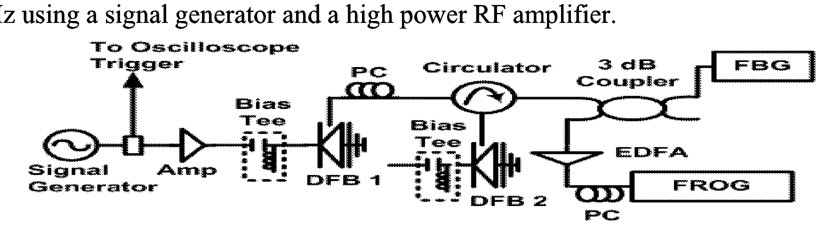

Figure 1: Experimental set up for the generation of compressed externally injected gain switched pulses

To overcome the poor Side Mode Suppression Ratio (SMSR~15 dB) and timing jitter of the gain-switched pulses, we use external injection from a second DFB (2) laser (via an optical circulator). A polarization controller was also used to ensure that the light being fed back was aligned with the optical axis of the laser. The external light injection improves the SMSR to around 30 dB and reduces the timing jitter to < 1 ps. The generated pulses can then be characterized using an optical spectrum analyzer, a high-speed oscilloscope in conjunction with a 50 GHz pin detector, and also a FROG measurement system [5]. From the latter we can accurately characterize the intensity and chirp profile across the generated optical pulses (as shown in Fig. 2 (a)). We can clearly see how the frequency chirp becomes non-linear in the wings of the 16 ps pulse generated, due to the gain-switching mechanism.

We subsequently use the measured non-linear chirp across the pulse to design and fabricate a NC FBG with a chirp profile opposite to that measured across the pulse. We also fabricated a linearly chirped fibre grating which had a chirp profile that was opposite to a linear approximation of the chirp across the gain-switched pulse. By placing the fibre gratings after the EI-GSL we subsequently characterize the pulse compression in the fibre gratings using the FROG technique. Fig. 2 (b) and (c) show the measured intensity and chirp profile of the gain switched optical pulses after compression with the linearly and non-linearly chirped fibre gratings respectively. In both cases we can see that the gratings have eliminated any frequency chirp across the centre of the pulses. However, when the linearly chirped grating is used we can see how the non-linearity of the chirp directly from the gain-switched laser, results in significant pedestals on the leading and trailing edge of the pulse. These pedestals, which are around 23 dB down from the peak of the pulse, would clearly pose significant problems (through inter-symbol interference) for the use of these pulses in high-speed OTDM signals.

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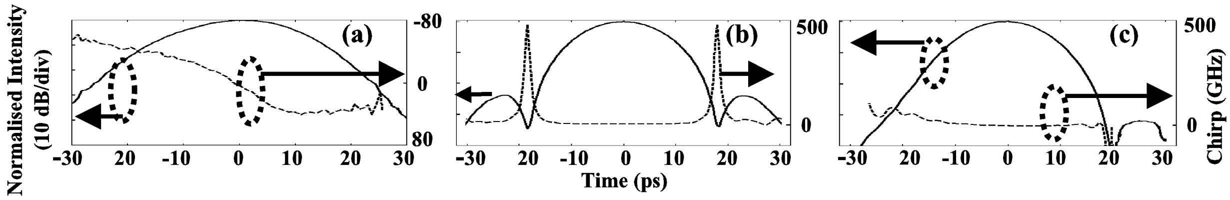

Figure 2: Intensity and chirp of pulses (a) from EI-GSL (b) after linearly chirped FBG and (c) after NC FBG.

When the non-linearly chirped fibre grating is employed, the pedestal is completely eliminated on one side of the pulse and reduced to around 32 dB down from the peak of the pulse on the other side. The slight imperfection in the compression can be attributed to the fabricated non-linearly chirped grating not being a perfect match to compensate the chirp of the gain-switched pulse. In both cases (linear and non-linear grating) the duration of the compressed pulse is around 7 ps, compared with 16 ps pulse-width directly from the gain-switched source. However, the non-linearly chirped grating is vital for ensuring a high level of pedestal suppression.

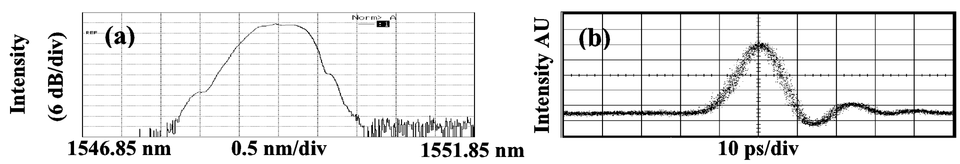

Figure 3: (a) Optical spectrum and (b) oscilloscope trace of compressed pulse after NC FBG

The spectrum of the generated optical pulses as measured using an optical spectrum analyser, in addition to the non-averaged oscilloscope trace of the detected pulse (after the non-linear grating) are shown in Fig. 3. The spectrum, which is in excellent agreement with the pulse spectrum obtained from the FROG measurement, shows that the spectral width is around 0.56 nm (70 GHz), thus giving a time bandwidth product of around 0.49. The low temporal jitter on the generated pulses is clear from the non-averaged oscilloscope trace, and the ringing in the detected pulse is due to the pulse duration being shorter than the response time of the detector (~10 ps).

Simulations carried out using Virtual Photonics Incorporated (VPI) provided an insight into system penalties introduced by poor a Temporal Pedestal Suppression Ratio (TPSR). Two 40 Gb/s OTDM systems were built, one based on linearly compressed 8 ps gain switched pulses and the other employing 8 ps transform limited gaussian pulses. The former exhibited a TPSR of ~20 dB due to the uncompensated non-linear chirp in the wings of the pulse (Fig 4 a). The latter on the other hand portrayed an excellent TPSR of over 60 dB (Fig. 4 b). A plot of the BER as a function of received optical power (Fig 4 c) shows that the system employing compressed gain switched pulses incurs a power penalty of 6 dB (@ BER of 10^{-9}) in comparison to the system that uses transform-limited pulses.

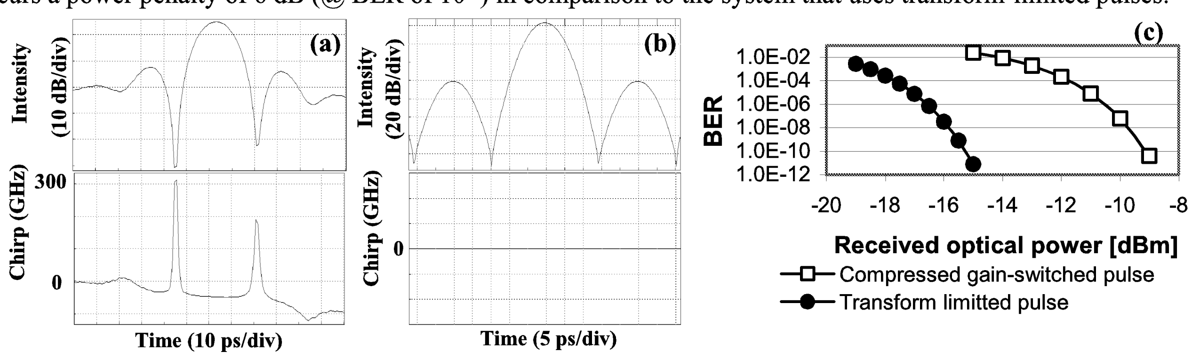

Figure 4: Intensity and chirp of (a) compressed gain switched pulses (b) Transform limited pulses (c) BER vs received optical power

We have demonstrated the use of NC FBGs for ensuring a sufficient TPSR of the compressed gain-switched pulses. The resulting 7 ps pulse source comprising of an EI-GSL followed by a NC FBG would be suitable for use in 40 Gbit/s transmission systems. The system viability, characterized by simulations, portrays a 6 dB difference in performance between a pulse source with insufficient TPSR and one that exhibits adequate TPSR (≥ 30 dB).

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