Generation of compressed optical pulses beyond 160 GHz based on two injection-locked CW lasers

F. Parmigiani[1]*, R. Slavík[1], R. Phelan[2], P. Petropoulos[1], J. O'Gorman[2], and D. J. Richardson[1]

1. Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK
2. Eblana Photonics Inc., Dublin, Ireland
** frp@orc.soton.ac.uk*

Abstract: Two CW signals separated by either 160GHz or 200GHz are phase locked to each other and combined together forming a highly stable pulsed seed for a nonlinear compressor based on four-wave mixing in fibre.

OCIS codes: (190.4410) Nonlinear optics, parametric processes, (140.3520) Lasers, injection-locked.

1. Introduction

High repetition rate optical pulse generators are interesting in many fields including telecommunications, THz generation, and metrology. The best candidate for delivering low amplitude/phase noise pulses at high repetition rates (100 GHz and over) are frequency-stabilized harmonically mode-locked lasers [1]. However, they require complicated control and/or suffer from limited frequency tunability. Another possibility is the filtering of highly-stable low repetition rate optical combs with, e.g., Fabry-Perot etalons [2]. This scheme, however, requires highly precise control of ultrahigh finesse etalons and suffers from low energetic efficiency.

Here, we propose and experimentally demonstrate a new simple technique that promises a similar level of low amplitude/phase noise to those described above without suffering from low energy efficiency. It is based on stable injection locking of two semiconductor lasers (with a frequency separation corresponding to the required repetition rate) to an optical comb, then simultaneously performing narrow-bandwidth filtering and amplification. The two phase-locked lasers are then combined together, amplified and coupled into a highly non-linear fiber to generate additional spectral components via four-wave mixing (FWM). This process, which inherently preserves the phase information, ensures coherent and low-noise spectral broadening and allows temporal pulse compression when properly dispersion compensated (e.g. by propagation in a standard single-mode fiber).

2. Experimental Setup and Results

A 1555.4-nm fiber Fabry-Perot laser (Rock, NPhotonics with a 3-dB linewidth below 10 kHz) was fed onto a 10-GHz spaced optical frequency comb generator (OFCG, OptoComb Inc.), which is based on the resonant driving of a phase modulator placed inside a high-finesse Fabry-Perot cavity thereby allowing broadband comb generation (over several THz) [3]. The comb was then coupled into two discrete mode semiconductor lasers [4], operating at different wavelengths, via a circulator and a 100-GHz arrayed waveguide grating (AWG), see Fig.1, so as to injection-lock the two sources to their closer comb lines, and consequently phase-lock them together. The narrow-bandwidth of the AWG channels was beneficial in improving the optical signal to noise ratio (OSNR) of the two phase-locked beams to the >70 dB level, see Fig. 2. The two combined phase-locked CW signals, with a power level of 3 dBm per channel, were then amplified up to about 30 dBm and launched into a 2-m-long highly nonlinear bismuth oxide fiber (Bi-NLF – Asahi Glass Co.). Its nonlinear coefficient, dispersion, dispersion slope and loss at 1550 nm are: 1100 $W^{-1}km^{-1}$, -260 ps/nm·km, 0.95 $ps/nm^2/km$ and 0.9 dB/m respectively. Both ends of the Bi-NLF are spliced to a standard telecom single mode fiber (SMF-28) with splice losses of ~3 dB each.

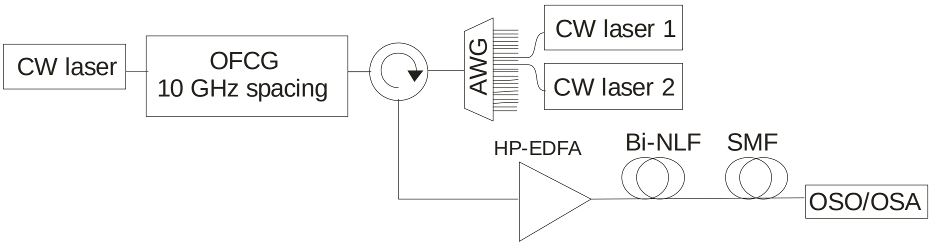

Figure 1: Experimental setup, CW: continuous wave, HP EDFA: high power erbium doped fibre amplifier, OSO: optical sampling oscilloscope, OSA: optical spectrum analyzer.

The signal in the time and spectral domains at different points along the system are shown in Figs. 2 and 3, respectively, when the frequency spacing between the two injection-locked lasers was 160 GHz and 200 GHz, respectively. The frequency spacing was controlled (in 10-GHz steps) by varying the operational temperature of the injected lasers. In practice, significantly higher frequency spacing could be achieved by a proper choice of the two CW laser wavelengths. The temporal waveform was measured using an optical sampling oscilloscope (EXFO Inc.), which was electrically triggered by the OFCG. The temporal intensity profile of the two combined CW lasers corresponds to a sine wave with a repetition rate of 160/200GHz with pulses of a full width at half maximum (FWHM) corresponding to half of the signal period (~3 ps). The signal was then launched into the Bi-NLF to generate new spectral components via FWM, see Fig. 2, and, due to the normal dispersion they temporally broadened to 4.5 ps (160 GHz) and 3.5 ps (200 GHz) at the output of the Bi-NLF, see Fig. 3. A few tens of meters of SMF-28 with dispersion of 17 ps/nm·km were sufficient to compress the pulses down to 1.8 ps (160 GHz) and 1.5 ps (200 GHz) respectively, see Fig. 3, corresponding to a compression factor of 1.7 and yielding pulses with a time-bandwidth product of ~0.46 in both cases. Note that the compression factor could be further improved by increasing the launched power into the Bi-NLF or using a better optimised nonlinear fibre.

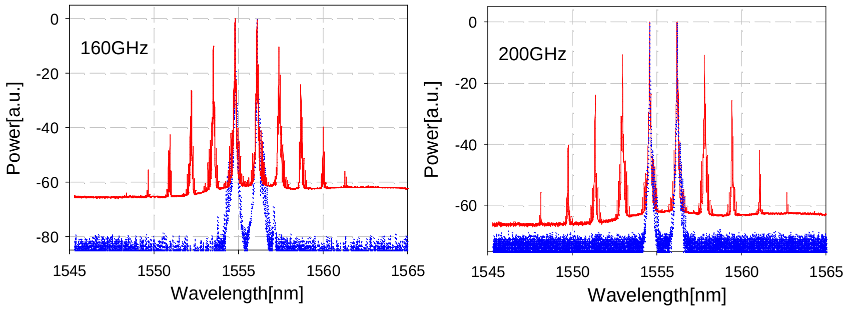

Figure 2 Spectral traces at 160GHz and 200GHz spacing at the input/output of the system.

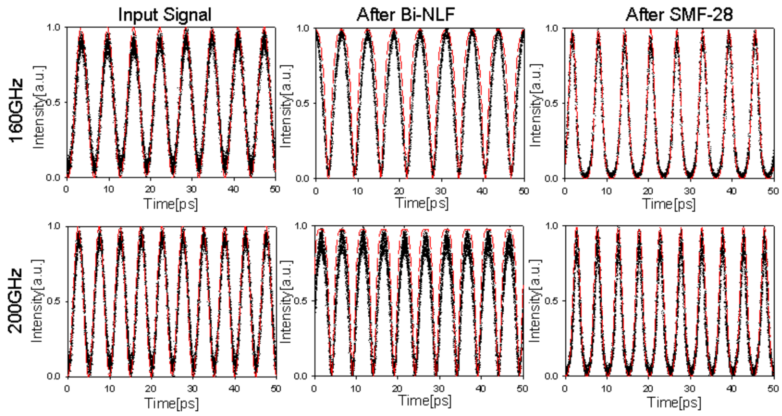

Figure 3 Measured (dotted line) and simulated (dashed lines) temporal traces at 160GHz (top line) and 200GHz (bottom line) spacing at various points of the system. OSO temporal resolution 800fs.

4. Conclusions

We generated short high quality, ultra-high repetition rate pulses formed by two phase locked CW lasers and nonlinearly compressed in a 2m-long bismuth oxide fiber followed by a dispersive element. Although only repetition rates up to 200 GHz were experimentally demonstrated, higher values of up to 3 THz can be envisaged simply by using CW lasers of a broader frequency spacing in the injection-locking process.

This research has received funding in part from the European Communities Seventh Framework Programme FP/2007-2013 under grant agreement 224547 (PHASORS)

5. References

[1] S. Gee, et al., “Simultaneous optical comb frequency stabilization and super-mode noise suppression of harmonically mode-locked semiconductor ring laser using an intracavity etalon,” IEEE Photon. Technol. Lett. 17, 1999 (2005).

[2] S. A. Diddams, et al., “Improved signal-to-noise ratio of 10 GHz microwave signals generated with a mode-filtered femtosecond laser frequency comb,” Opt. Express **17**, 3331 (2009).

[3] T. Kobayashi, et al., Appl. Phys. Lett. 21, 341-343 (1972).

[4] R. Phelan, et al. “- 40 oC < T < 95 oC mode-hop free operation of an uncooled AlGaInAs-MQW discrete-mode laser diode with emission at λ = 1.3 µm.” IEE Electronics Letters, vol. 45, no 1, pp43-45, 2009.