Wavelength Conversion by Injection Locking to an Optical Comb for Optical Frequency Transfer Applications

Joonyoung Kim[1], David S. Wu[1], Guiseppe Marra[2], David J. Richardson[1], and Radan Slavík[1]

1. Optoelectronics Research Centre, University of Southampton, UK

2. National Physics Laboratory, Teddington, UK

The transfer of ultra-stable optical frequencies through existing telecommunication fibre links is required to enable comparison of the most advanced optical clocks which are generally housed in National Metrology Institutes and typically separated by distances of a few 100 km to 1500 km [1]. To meet the need for transparency in optical communication networks it is necessary to be able to shift the carrier wavelength between ITU-T channels in the C-band (1530 – 1565 nm). Here, we propose use of optical injection locking of a semiconductor laser to an optical comb to enable wavelength conversion in precision optical frequency transfer applications. The optical comb source used (from OptoComb Inc.) comprises a $LiNbO_3$ phase modulator (PM) within a resonant cavity and generates a comb which spans the full C-band with a line spacing of 25 GHz.

Fig. 1 (a) presents a schematic of the set-up we used to implement and evaluate wavelength conversion based on injection locking to an optical comb. The output of the CW master laser at 1555.7 nm (< 10 kHz linewidth) is amplified by an Erbium Doped Fibre Amplifier (EDFA) with 90 % of the output (15dBm) fed to the OptoComb for comb generation. The OptoComb is driven by a 25 GHz microwave signal at a power of 29 dBm. Its output (without any optical filtering) is injected into the slave laser (discrete mode semiconductor laser, 200 kHz linewidth). The injected power of the relevant comb tone is about -30 dBm. The slave laser is thermally tuned to injection lock to an individual comb tone so that it emits at the same frequency as the comb tone, but with a higher power. The 10% of amplified master laser power in the reference arm is used for the measurement of temporal waveforms and jitter. Fig. 1 (b) shows the measured optical spectra (left) and temporal waveforms (right) for three offset frequencies (25 GHz, 200 GHz, and 500 GHz) measured with an optical sampling oscilloscope (OSO) which also performs timing jitter analysis. With an offset frequency of 25 GHz (0.2 nm), the timing jitter was measured to be about 640 fs which corresponds to a phase error variance of 0.010 rad^2, which is comparable to that in Refs.[2,3]. We attribute this to the phase noise from the 25 GHz microwave signal (>175 fs), timing jitter of the OSO gate (150 fs), and phase noise associated with injection locking of the slave laser. Based on our previous work, we believe the noise can be reduced by electronically locking the slave laser with a feedback loop [3,4]. In our experiment, we were able to perform wavelength conversion up to 500 GHz (4 nm) which was limited due to the tuning range of the slave laser (as well as the 500GHz bandwidth of the OSO).

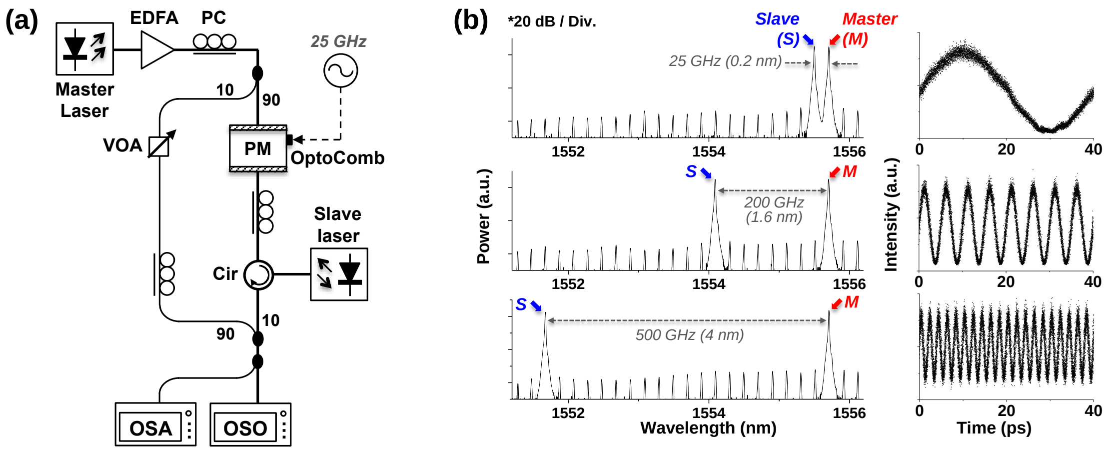

Fig. 1 (a) Schematic diagram for implementation and evaluation of the wavelength conversion and (b) the measured optical spectra (left) and temporal waveforms (right) for various offset frequencies (PC: Polarisation Controller, VOA: Variable Optical Attenuator, Cir: Circulator, OSA: Optical Spectrum Analyser).

References

[1] S. Droste, F. Ozimek, Th. Udem, K. Predehl, T.W. Ha¨nsch, H. Schnatz, G. Grosche, and R. Holzwarth, "Optical-Frequency Transfer over a Single-Span 1840 km Fiber Link," Phys. Rev. Lett. **111**, 11081, (2013).

[2] L. A. Johansson and A. J. Seeds, "Millimeter-Wave Modulated Optical Signal Generation with High Spectral Purity and Wide-Locking Bandwidth Using a Fiber-Integrated Optical Injection Phase-Lock Loop," IEEE Photon. Technol. Lett. **12**, 690-692, (2000).

[3] D. S. Wu, R. Slavík, G. Marra, and D. J. Richardson, "Direct Selection and Amplification of Individual Narrowly Spaced Optical Comb Modes Via Injection Locking : Design and Characterization," IEEE J. Lightwave Technol. **31**, 2287-2295, (2013).

[4] J. Kim, D. S. Wu, G. Marra, D. J. Richardson, R. Slavík, "Stability Characterization of an Optical Injection Phase Locked Loop for Optical Frequency Transfer Applications," CLEO 2014, SW3O.7, (2014).