Exact, agile, optical frequency synthesis using an optical comb generator and optical injection phase lock loop

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Abstract: A novel optical source for use in agile dense wavelength division multiplexing (DWDM) networks is described. This source combines reference limited stability, wide tuning range, high spectral purity, narrow line width and fast wavelength switching.
Key words: tuneable laser; optical communications, optical injection phase lock loop, optical frequency comb generator.

Simple techniques for exact channel frequency synthesis are of considerable interest for the development and testing of high spectral efficiency dense wavelength division multiplexed (DWDM) networks [1].

This paper presents a new DWDM synthesiser system which has channel-frequency exactly determined by supplied optical and microwave reference frequencies so that DWDM guard bands (typically 3GHz - 5 GHz) can be completely eliminated. Channel-lasers (SG-DBR or SSG-DBR) are incorporated within optical-injection phase-lock loop (OIPLL, Fig.1) blocks [2], phase-locked to output lines from an optical-frequency comb-generator (OFCG, Fig. 1, 10GHz) [3]. The comb line spacing is exactly equal to the microwave reference frequency (10 GHz in these experiments), while the exact optical frequency of each comb line is determined by the optical reference source. The OIPLL combines the rapid acquisition and linewidth tolerance of optical injection locking with the large tracking ability of the optical phase lock loop. The combined technique also eliminates the requirement for extremely short loop propagation delay of optical phase lock loops when used with wide (MHz) linewidth semiconductor lasers.

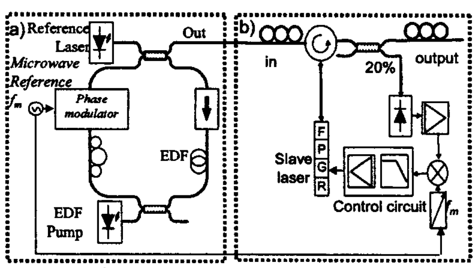

Fig. 1: Experimental optical frequency comb generator (OFCG, a) and optical injection phase lock loop (OIPLL) with a four-section tuneable laser (b).

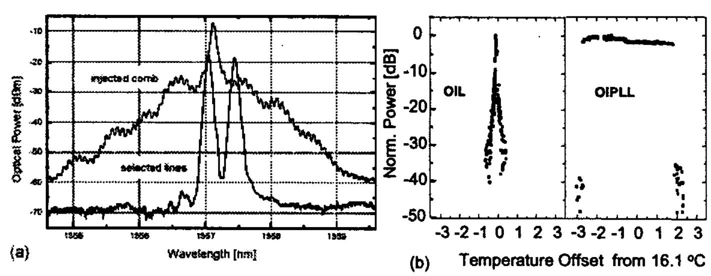

Fig. 2: a) Comb generator spectrum and output spectrum from two OIPLLs locked to channels spaced by 50 GHz, b) Detected heterodyne signal from two OIPLL (or OIL) locked laser diodes (channel spacing 50 GHz).

Figure 2a. shows the output spectrum from the comb generator and the spectrum from two OIPLLs locked to comb lines separated by 50 GHz. Unwanted comb lines are seen to be suppressed by > 40 dB below the wanted output over a > 1.8 THz range. By heterodyning the output from the two lasers on a high-speed photodetector and analysing the resultant signal in an electrical spectrum analyzer, the accuracy of the OIPLL locking could be investigated. Figure 2b. shows the detected heterodyne output power measured within a 1kHz bandwidth centered

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on 50 GHz, as the temperature of one channel laser was varied. This proved the quality of the locking over the temperature range, since we obtained an inter-channel frequency error <1 kHz (electrical spectrum analyzer resolution limited). Furthermore, the 5 K temperature range is equivalent to an 80 GHz locking range, compared with < 2 GHz when only the optical injection locking technique is used.

The system was then tested for wavelength switching by applying a current pulse to the rear grating section of the slave laser, corresponding to a wavelength jump between 1,570 nm and 1,532 nm. The tuning transient was measured using a Fabry-Perot interferometer scanned by a precision D/A converter under computer control. For such hopping at a frequency of 100Hz, the new wavelength is acquired to the system measurement accuracy of <500MHz, within <5µs, limited by the speed of the laser current controller, and there was no measurable long-term drift under active-locking (Fig.3). The optical output power stabilises within 15µs.

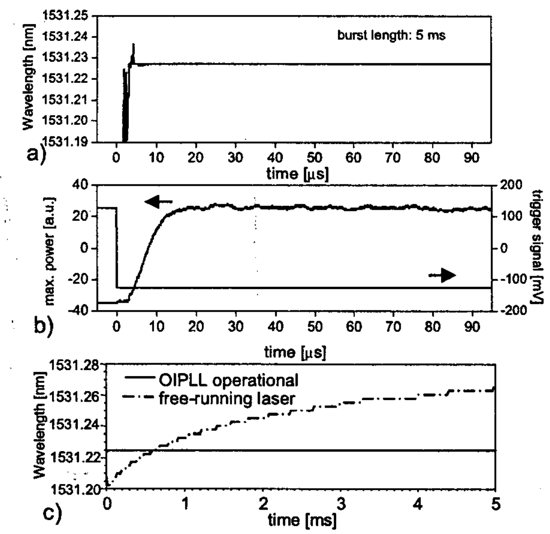

Fig. 3: Channel-hopping transient 1570-1532nm (resolution 1pm): Wavelength stabilization is achieved within 5 µs of the onset of the electrical trigger signal (a), whilst the optical output power stabilizes within 15 µs (b). The OIPLL removes any wavelength drift (solid line) as compared to the unlocked tuneable laser (dash-dot line) (c).

In summary, all fibre-based OIPLL circuits were used with widely tuneable lasers to create an optical frequency sythesiser offering zero-frequency-error relative to the reference signals supplied. Use of the OIPLL technique enables wide locking ranges (> 80 GHz) to be obtained with wide (> 10 MHz) linewidth slave lasers, without the need for short loop delay optics or electronics. Channel frequency errors remained below the measurement limit of 1 kHz while laser chip temperature was tuned over a 5K range. Furthermore the side mode suppression ratio remained better than 35 dB. Finally, wavelength hopping times of <5µs were obtained, without subsequent thermal equilibration drift. Such sources are likely to find application in metrology for existing DWDM networks and for future burst routed DWDM networks. Future work will concentrate on increasing the resolution and speed of the channel hopping test system to determine the ultimate hopping speed of the transmitter (expected to be in the ns region [2]).

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