Self-locking of free-running DFB lasers to a single microring resonator for dense WDM

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Abstract: We self-injection lock two DFB lasers to a microring resonator, to enhance frequency-spacing stability, and use these to carry channels with <1 GHz guard-band.

1. Introduction

In optical communications systems, wavelength division multiplexing (WDM) is often used as it allows multiple data channels to be sent at once. In WDM there is a desire to have little to no gap (guard-band) between these channels, to enable high spectral efficiency. Optimising this is increasingly important to maximise throughput in installed fibre infrastructure [1]. In currently deployed optical communication systems using free-running lasers, multiplexing with minimal guard-bands can be difficult. Lasers, particularly free-running lasers, can drift from their nominal wavelength, this can cause wavelength channels to overlap and interfere with each other. Having laser lines that are in some way locked to a frequency reference can mitigate this issue (e.g. [2]).

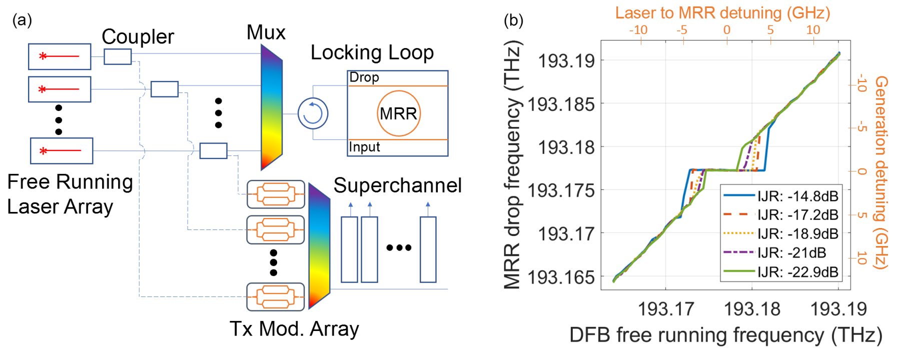

Fig. 1. (a) shows the design of using multiple self-injection locked lasers to build a WDM channel (b) shows the locking curves over one resonance at different injection ratios, when increasing the frequency.

Self-injection locking through an external cavity is a promising technique to stabilize free running lasers [3, 4], without using an active electronic control loop. Microring resonators (MRRs) can be used as passive filtering elements (e.g. [5]), and enable self-injection locking of lasers. There are two approaches to self-injection locking, using back-scattered light from the ring back into the laser (e.g. [6]), or using the drop port to enable a loop-back when on resonance (e.g. [7]). Prior work with self-injection locking has focused on reducing the laser linewidth for single (e.g. [8]) or multiple (e.g. [9, 10]) lasers.

We propose to use this technique to stabilize the frequency spacing of lasers, to enable WDM superchannels (i.e. Fig.1a). By locking multiple free-running Distributed-feedback (DFB) to a MRR a laser array can be built, with each laser locked to a single MRR resonance. After locking, small perturbations to the lasers that would usually cause frequency drift to produce negligible change on the locked lasers' frequency (see Fig.1b), and the well-defined frequency spacing between the resonances helps the locked lasers to support high density WDM. Here we show that frequency locking free-running lasers via self-injection locking to a single moderate quality factor (∼500,000) MRR with ∼19.6 GHz free spectra range (FSR), can enable wavelength multiplexing with small guard band (<1 GHz). This shows that a single MRR can be used to enable a superchannel-compatible multiwavelength source from separate low-precision laser sources through self-injection locking.

2. Experiment setup

Fig. 2 illustrates the design of the locking and the transmission systems of the experiment. Two free-running distributed feedback lasers (DFB) were simultaneously coupled to two neighbouring resonances micro ring resonator with ∼19.6 GHz free spectral range (FSR). The output from the MRR was fed back to the lasers, with each laser locking on to the MRR resonance closest to their free-running frequency. This locks the laser spacing to the FSR of the MRR. The output of the DFBs were then modulated, noise loaded, and received with a coherent detector to evaluate performance.

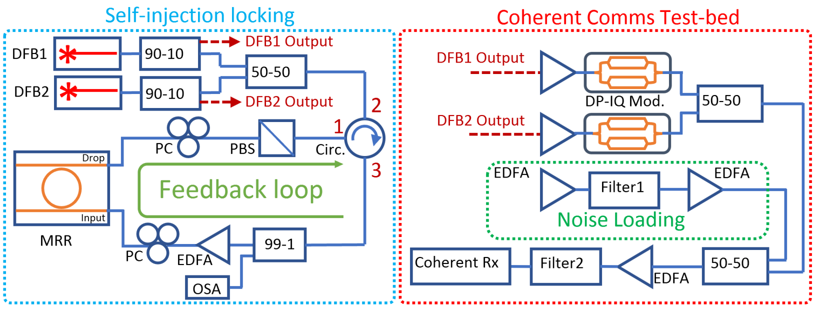

Fig. 2. Schematic diagram of the system setup.

In the self-injection locking part (Fig.2 left, blue dashed box), each DFB laser was connected to a 90/10 coupler. 90% of the optical power was sent to the feedback loop while 10% of the optical power was reserved for the communication testbed. After the 90/10 coupler, a 50/50 coupler was added to couple the two lasers together. This introduced 3dB loss to the laser power that sent to the feedback loop and 3dB loss on the return light. We note that the 90/10 split ratio could be inverted, so that 90% of the laser light could be used for modulation, if using a WDM coupler as in Fig. 1. After the 50/50 coupler, the light entered the feedback loop via the circulator's port 2-to-3. A 99/1 coupler was added in the loop and 1% of the optical power was used for monitoring the lasers spectrum. To boost up feedback power to account for excessive losses coupling to and from the MRR chip (>11 dB for the MRR here, although devices with <3 dB loss are achievable), an erbium doped fiber amplifier (EDFA) was installed in the loop, set to provide ∼15 dBm output power. A polarization controller was placed before the micro ring resonator to align to its operating polarization - ideally components in the system would be polarization maintaining. The light goes into the MRR input port and comes out from the drop port. Before the laser light feedback to the laser cavity, a second PC combined with a polarization beam splitter (PBS) was used to align the polarization to the free-running laser.

In the coherent communications testbed (Fig. 2 right, red dashed box), the locked lasers were first amplified and then modulated. The signals were noise loaded to test system performance against optical signal to noise ratio (OSNR). Before the coherent receiver, a channel filter with 20 GHz passband bandwidth to select a specific channel. As a benchmark, we compared the performance between the locked DFB lasers and the state-of-the-art external cavity lasers (ECL), with the ECLs carefully set to the same spacing as the locked DFBs.

3. Results

The locking bandwidth (see Fig.1b) can show where the laser gets locked and reveal the system's durability to the temperature changes in practical applications. After conversion, where the temperature tuning coefficient is -12.5 GHz/°C, the ∼10 GHz locking bandwidth (e.g. Fig. 1b) corresponds to around ±0.4 °C change on laser chip temperature [11]. The generation frequency results show less than ∼100 MHz change when the laser gets locked. Without self-injection locking, the laser will detune by 100 MHz after a laser cavity temperature change of only 0.008 °C (i.e. ±0.004 °C). The effective 0.4 °C tolerance then represents a factor of 100 improvement in thermal stability. This locking range corresponds to a ∼ ±3 °C ring resonator temperature change, indicating that it is less difficult to lock the MRR frequency against thermal environmental changes than individual lasers. We also see the linewidth reduction after the locking, similar to [8–10]. By taking the delayed self-heterodyne measurement, the locked laser's linewidth is <6.5 kHz (down from a datasheet value of 1 MHz [11]).

Two locked lasers were used as the carriers to build up a wavelength division multiplexing channel. The first laser was locked at 193.1196 THz and the second laser was locked at 193.1392 THz. The frequency distance between two locked lasers is 19.6 GHz which is the free spectral range (FSR) of the MRR.

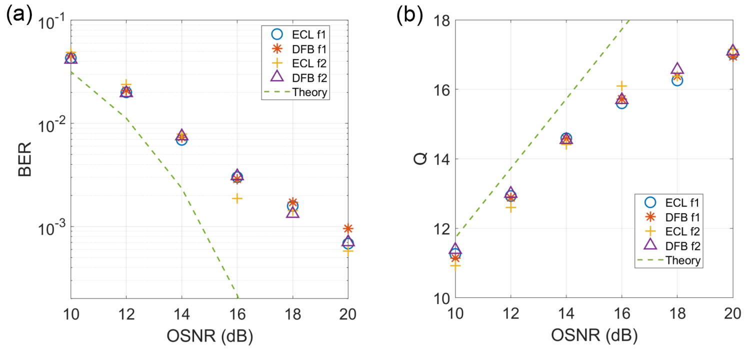

Fig. 3. BER and Q results for ECLs and self-injection locked DFB lasers at different OSNR levels. The green dashed lines in each figure are theoretical results respectively.

The carriers are modulated with a 1.5% roll-off RRC shaped, 18.6 Gbd dual-polarization 16-QAM signal. Since the FSR of the ring is 19.6 GHz, this leaves <1 GHz guard-band between the channels, allowing a fair comparison with the ECLs, by enabling the ECL separation to be slightly off the set 19.6 GHz spacing.

The quality factor (Q) and pre-feedforward error correction code (pre-FEC) bit error rate (BER) results for this back-to-back communication testbed show that both locked lasers achieved a similar performance to a commercial ECL for all OSNR levels investigated. With reference to pre-FEC BERs below the threshold for 400-ZR ($\sim 1.25 \times 10^{-2}$) [12] as an example, for OSNRs of 14 dB or above, error free operation can be achieved, as seen in Fig. 3a.

4. Conclusion

We demonstrated the locking stability of a self-injection locking DFB laser through an external moderate Q MRR over a wide locking range. The self-injection setup shows enhanced locking stability in the presence of temperature variations while ensuring precise laser locking to a frequency grid. The test-bed results prove that self-injection locking to a MRR can help build a precision multiwavelength source from low precision lasers, which can be used in high-speed transmission technologies.

Self-injection locking to MRRs may reduce the need for laser temperature controlling circuits, leading to potential energy savings on a per laser basis. The scalable design of the self-injection locking to MRR setup would seem to be compatible with integrated photonic circuit transceiver designs using multiple wavelength carriers. This technology provides a way of employing low-precision lasers in demanding WDM systems in future high capacity optical communication systems.

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