Wavelength-Tunable Receiver Channel Selection and Filtering Using SG-DBR Laser injection-Locking

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Abstract: An injection-locked SGDBR laser is used for wavelength-tunable receiver channel selection and filtering. Successful phase tracking of a 2Gbps DPSK modulated signal at 10 GHz channel spacing was achieved.

OCIS codes: (060.1660) Coherent communications; (060.5060) Phase modulation; (140.3600) Lasers, tunable; (140.3520) Lasers, injection-locked.

1. Introduction

Coherent techniques and systems for optical communications have traditionally been considered due to increased receiver sensitivity, compared to conventional intensity modulation -direct detection (IMDD) optical transmission. With the introduction of the erbium-doped fiber amplifier (EDFA), most interest for coherent optical transmission consequently waned, as nearly all optical transmission needs could now be satisfied using IMDD links. However, during the recent years there has been a renewed interest in coherent techniques, mainly driven by the improved fiber transmission properties of high bit rate phase modulated coding schemes, e.g. DPSK, QPSK and related. Another area where coherent coding schemes can be of benefit is increased spectral efficiency, where using multilevel modulation formats can either increase channel bit rate, or lead to closer channel spacing.

Even considering recent interest in coherent modulation techniques, further benefits, and greater challenges arises when an optical communications system fully taking advantage of coherent techniques is considered. Drawing a parallel with aspects of the development of radio and wireless systems; optical communications have much to catch up with in order to reach a comparable functionality in terms such as efficient use of spectral resources, frequency agility, multiple access, efficient multiservice usage and secure transmission. These are aspects that will be relevant for applications like multifunctional optical systems, sharing analog/digital communication, sensing applications and other functions. Particular areas where coherent techniques can contribute are exact wavelength and band-limited channel forming, agile and high precision channel selection and filtering and wavelength conversion of phase or frequency modulated signals, all operating in a highly dynamic optical environment. One interesting note is that the originally most interesting aspect using coherent techniques; receiver sensitivity is still offset by the availability of optical amplification, most recently SOA-preamplified receivers.

In this paper, a channel selection scheme is proposed and demonstrated where optical injection locking of a widely tunable laser can be used to pick out a phase-modulated signal in a closely-spaced WDM environment. Although not investigated in this paper, this technique, combined with ns wavelength switching [1], can be used in a fast frequency-hopping optical communications scheme where secure communications are of importance.

2. Channel selection scheme

In the proposed channel selection scheme, an optical signal, consisting of several closely-spaced wavelength components, is injected into a semiconductor laser, illustrated by the schematic in Fig. 1. The laser will track the frequency and phase of any signal falling within the injection locking-range of the laser, and reject any signal falling outside. By using a widely tunable sampled-grating (SG) DBR laser, the laser will be able to pick out any wavelength window within typically a 40nm wavelength tuning range. Using this channel selection scheme, the out-of-channel rejection ratio has been theoretically and experimentally investigated for CW multiline injection [2]. It is found that only closely-spaced wavelength channels will cause significant channel crosstalk.

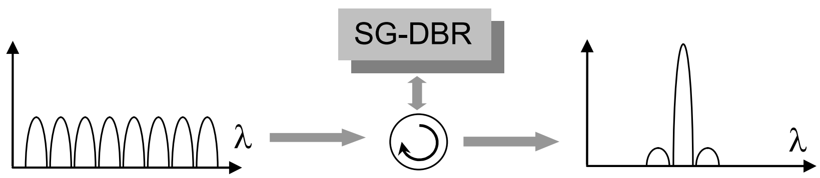

Fig. 1: Schematic of channel selection and filtering scheme.

If the injected signal is being phase or frequency modulated, the injection locked-laser will track any modulation falling within a bandwidth determined by the injection locking range. A more precise expression for the phase-tracking capabilities of an injection-locked laser is given in [3].

Further, by using injection-locking for wavelength stabilization, an SG-DBR laser has been used to demonstrate switching times in the ns-range [1]. Combined with the above capabilities, a multifunctional device is obtained that simultaneously can track, filter and amplify a channel-hopping optical signal with moderate bandwidth phase or frequency encoding. For this vision to be realized, careful control of the laser free-running wavelength and injection ratio need to be implemented as indicated by the results presented below. One technique to stabilize the free-running wavelength would be combining optical injection-locking and an optical phase-lock loop, as described in [3].

3. Experimental verification

To verify the principle, an SGDBR laser with a tuning range exceeding 40 nm, integrated to an optical amplifier and electroabsorption modulator, is used for injection-locking. More details about the device are found in [4]. Figure 2a shows the CW injection locking characteristics of the SGDBR laser, including locking range and areas within the locking range where chaotic or resonant behavior is observed. In these following experiments, the injection ratio with the widest stable locking range is used; between -25 dB to -20 dB.

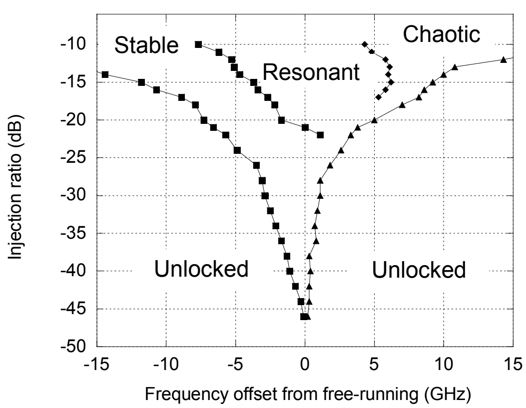

Fig. 2a: SGDBR laser injection locking characteristics.

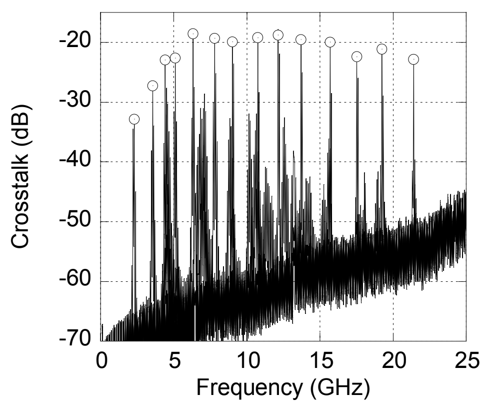

Fig. 2b: Channel crosstalk values at different channel spacing.

The neighboring channel-rejection ratio is experimentally investigated by injecting two CW optical wavelengths with equal power corresponding to -23dB injection ratio each into the SG-DBR laser. The laser output is then detected and the beat between the main locked line and interfering line is displayed using a spectrum analyzer. The channel-rejection ratio is defined as the resulting power ratio between the selected channel and the rejected channel and is calculated based on the power of the detected beat-signal and the optical received power. The result is shown in Fig. 2b, where the crosstalk, calculated from multiple spectrum analyzer traces, is shown. With closer channel spacing, a weak trend of increasing values of crosstalk is observed down to the laser resonance frequency, 7 GHz, below which the crosstalk is dropping rapidly, more rapidly than predicted compared to the analysis in [2]. The difference can be partly attributed to increased instability and appearance of harmonics at these lower frequencies. The spurious, unmarked peaks seen in the overlapped spectra are harmonics that appears when the channel spacing is lower than the resonance frequency of the laser.

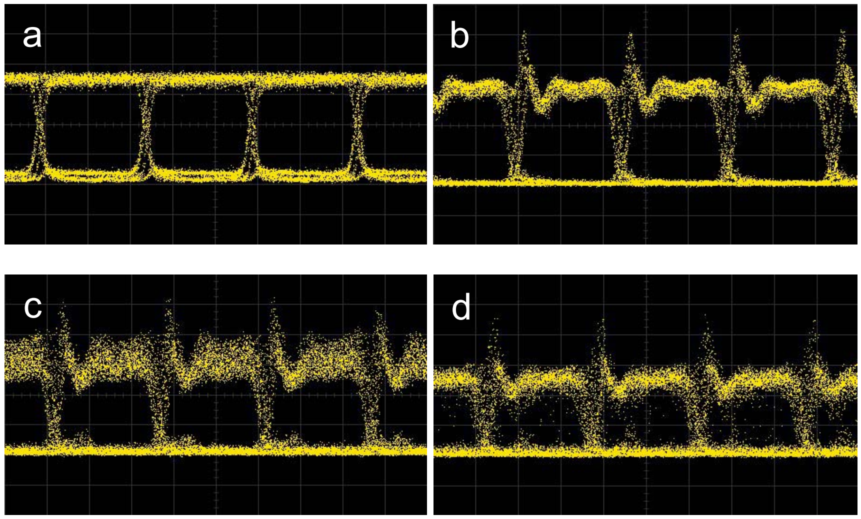

Fig. 3: Captured demodulated eye diagrams for a: back-to-back, b: single channel injection, c: dual channel injection, 10 GHz spacing and d: dual channel injection, 5 GHz spacing

In order to investigate the viability using the channel-selection scheme to select a modulated input, a 2Gbps DPSK modulated signal was generated using push-pull modulation of a Mach-Zehnder modulator. The bit-rate was selected to match the fiber-delay line DPSK demodulator used. Figure 3a shows the back-to-back demodulated eye diagram. Injecting the modulated signal into the SG-DBR laser, the phase of the injection-locked laser will track that of the injected signal, as evident by the recovered eye after injection, shown in Fig. 3b. The resonance in the demodulated eye matches that of the laser. Figure 3c and 3d shows demodulated eyes when an interfering channel is added just above resonance, at 10GHz offset, and just below resonance frequency, at 5GHz offset. A slight degradation in SNR, mainly due to more critical stable locking range, can be seen in the eye at 10 GHz channel spacing, though not sufficient to prevent error-free operation. At 5 GHz spacing, further degradation of the eye is observed, both in terms of added SNR and increased distortion, as expected by the increased distortion below resonance frequency seen in Fig. 2b.

Viewed from a tunable optical filter perspective, the injection-locked laser has the advantage of having adjustable filter bandwidth in the form of varying locking-range with injection ratio, such that varying channel spacing can be dynamically adjusted for by regulating injection ratio and laser bias point, for optimum resonance frequency. In combination with the potential for faster wavelength switching than most optical filters, this results in a highly flexible tool for optical channel selection. One limitation is the inability to track amplitude modulation, which will interfere with successful phase tracking. A second limiting factor is the high degree of required control that the high degree of flexibility brings. Free-running wavelength, injection ratio and laser bias must be adjusted for optimal phase tracking. In these experiments, BER testing was not possible due to a combination of master and slave laser wavelength wandering and demodulator drift. By using optical injection in combination with a simple optical phase-lock loop [3], and using a more stable commercial demodulator the system stability should improve.

4. Conclusion

We successfully used optical injection locking of an SG-DBR laser to select and track a 2 Gbps DPSK modulated optical signal. Open eye diagrams were obtained both for single injected optical channel and dual injected channels at 10 GHz offset. Based on obtained data, one interesting prospect would be the selection and tracking of a well-filtered 10 Gbps DPSK modulated signal at 10 GHz channel spacing. A second promising prospect is the application in a rapidly frequency hopping secure communications scenario, using fast wavelength switching techniques.

5. References

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