24 Gbit/s Synthesis of BPSK signals via Direct Modulation of Fabry-Perot Lasers under Injection Locking

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Abstract

BPSK modulation tunable over 30 nm is obtained, highlighting the practicality of a recently-demonstrated new scheme for direct synthesis of phase and amplitude modulated signals. Experiments are carried out at 12 and 24 Gbit/s.

I. Introduction

Phase shift keying (PSK) allows for better resilience to transmission-related linear and nonlinear impairments (e.g., using binary phase shift keying, BPSK). However, for PSK, direct modulation of the signaling laser is generally not possible due to the high chirp associated with such a modulation approach. Instead, an external amplitude modulator is typically used, made from materials such as $LiNbO_3$ or InP. The $LiNbO_3$ modulator is the industry standard today, but has a large footprint, is difficult to integrate, and is thus expensive. As for InP, impressive results are being reported [1], but most implementations to date have been for differential (e.g., differential BPSK, DPSK or differential quadruple phase shift keying (DQPSK)) rather than fully coherent modulation formats. We suspect that residual chirp on the modulated waveform currently compromises the use of InP modulators for fully coherent systems. Another issue, relevant mainly to InP modulators, is the insertion loss which is typically 5-8 dB per modulator [1].

Recently, we suggested a new approach to coherent data signal generation based on the use of ultralow-chirp, direct modulation of injection-locked (IL) semiconductor lasers, followed by coherent superposition and coherent carrier suppression of their outputs [2]. We showed experimental results for BPSK and QPSK modulation and suggested how the scheme might be extended to 16 QAM and higher modulation formats [2]. The main drawback of our demonstration was the limited wavelength tunability, which was restricted to several nanometers due to the use of narrow linewidth discrete-mode lasers. Moreover, we presented results at 10 Gbit/s only.

Here, we demonstrate how a larger tunability (over 30 nm in the experiment shown) can be achieved for our new scheme. This is achieved by using simple, lower-cost Fabry-Perot semiconductor lasers injection-locked to a tunable semiconductor laser. Experiments dealing with BPSK generation are carried out at significantly higher data rates than our previous demonstration (up to 24 Gbit/s). Our future work will concentrate on synthesis of QPSK and 16QAM modulation formats.

II. Principle of Operation

Fig. 1 shows the operating principle [2]. We first injection-lock a directly modulated laser: feeding a component of CW light from a master laser into a current-modulated slave laser. If both free running lasers emit at the same wavelength, they become phase locked, meaning that the slave frequency follows that of the master, even in the presence of modulation of the slave laser current. This is an established method to suppress the chirp of directly-modulated lasers [3], enabling low-chirp amplitude modulation of the slave laser. Moreover, as the slave laser output is phase-locked to the master, stable interference between the master laser and the modulated slave is possible. Consequently, the carrier of the amplitude modulated slave laser can be eliminated by interfering it destructively with an appropriate portion of the CW master laser light, as shown in Fig. 1. This produces BPSK modulation.

The key features of this technique are (i) the slave produces ultralow-chirp amplitude modulation, and (ii) the slave is phase locked to the CW master thereby allowing for carrier removal. This method can be straightforwardly scaled further – e.g. to QPSK and 16 QAM (more details are in [3]).

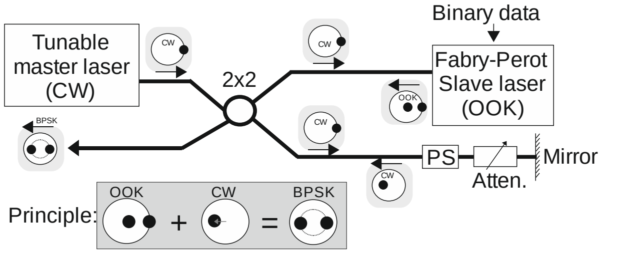

Fig. 1. Set-up. The slave laser is injection-locked producing low-chirp OOK. The carrier is subsequently removed via destructive interference with the master laser generating BPSK.

III. Results

First, we measured eye diagrams at the output of the

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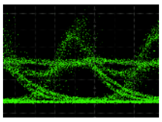
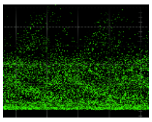
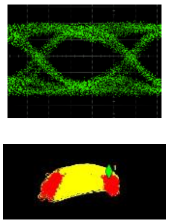
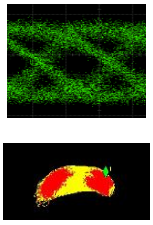
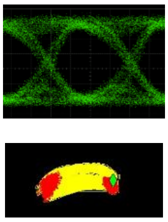
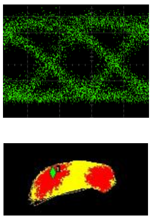
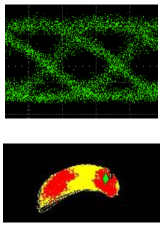
slave laser, as well as the constellation at the output. We carried out the characterization at three different wavelengths spanning from 1530 to 1560 nm and two data rates of 12 and 24 Gbit/s. These results are shown in Table 1. Without IL, the eye is distorted (12 GHz) and fully closed (24 GHz), respectively. The magnitude, phase and Error Vector Magnitude (EVM) errors are almost constant over the 1530-1560 nm band being below 10%, 9 deg and 18% (12 Gbit/s) respectively and 22%, 15 deg, and 32% (24 Gbit/s), respectively.

TABLE I Eye diagrams captured at the slave laser output and constellation diagrams captured at the output of our BPSK synthesizer.

	12 GHz	24 GHz
Free running		
1530 nm		
1543 nm		
1560 nm		

Spectra are shown in Fig. 2 and 3. In Fig 2 we can appreciate that the spectral width of the slave laser is narrowed down in the presence of the injection locking (showing reduction of the chirp) and the spectral shape becomes symmetric. We can also appreciate, Fig. 2, how the carrier is suppressed via destructive interference of the slave signal with the master laser.

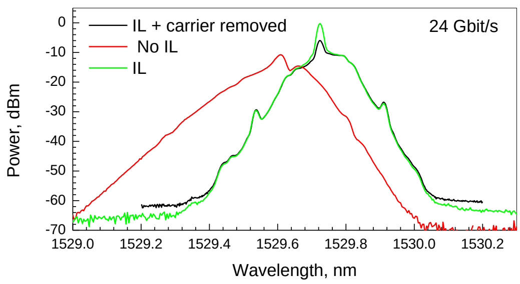


Fig. 2. Spectral characteristics under different operating conditions.

Fig. 3 shows how injection locking suppresses the non-injection-locked Fabry-Perot modes (>50 dB). The central wavelength of the free running slave was tuned via temperature (between 10 and 50 deg). Comparing Fig. 3a and b we can also appreciate that the power in the IL mode is about 8 dB higher than in the free-running slave, showing that IL not only suppresses the other modes, but also re-distributes gain into the IL mode.

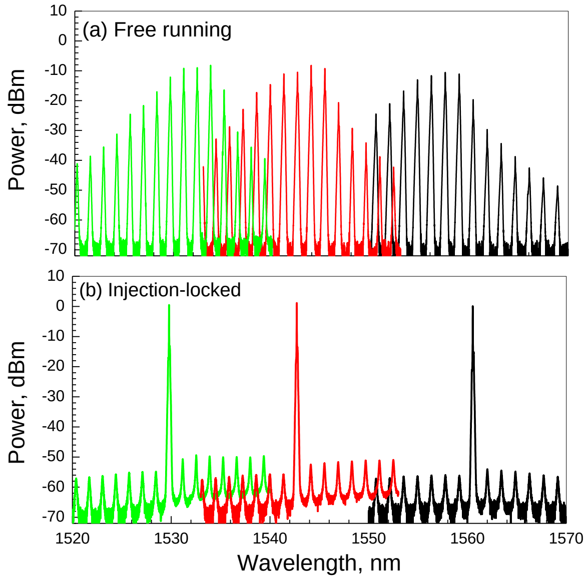


Fig. 3. Spectral characteristics of the free running (a) and injection-locked (b) slave laser measured over 20 nm set for operation at 1530, 1543 and 1560 nm.

IV. Conclusions

We demonstrate tunable (over 30 nm) generation of 12 to 24 Gbit/s BPSK data streams with an EVM of 18% at 12 Gbit/s. The scheme is extendable to higher modulation formats (QPSK, 16 QAM, etc.) by coherent combination of more lasers, each of them carrying one bit [3]. When integrated on a single chip, this represents a low-cost and low-noise (due to noise rejection during injection-locking process) alternative to IQ modulators.

References

[1] K. Prosyk et al, “Tunable InP-based Optical IQ Modulator for 160 Gb/s,” ECOC, paper Th13A.5, Geneva, Switzerland, Sept. 2011.

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[3] S. Mohrdiek, H. Burkhard, and H. Walter, "Chirp Reduction of Directly Modulated Semiconductor Lasers at 10 Gb/s by Strong CW Light Injection," *J. Lightwave Technol.* 12, 418 (1994).