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Lukashchuk, A.; Neskorniuk, V. A.; Lyubopytov, Vladimir; Gabitov, I. R.; Malekizandi, M.; Chipouline, A.; Küppers, F.

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# Optical Rectification of Phase Modulated Signal Based on Injection Locking

A Lukashchuk<sup>1,2</sup>, V A Neskorniuk<sup>1,2</sup>, V S Lyubopytov<sup>3,4</sup>, I R Gabitov<sup>1,5</sup>, M Malekizandi<sup>6</sup>, A Chipouline<sup>6</sup> and F Küppers<sup>6</sup>

<sup>1</sup> Skolkovo Institute of Science and Technology, Skolkovo 143025, Russia

<sup>2</sup> Moscow Institute of Physics and Technology, Dolgoprudny 141700, Russia

<sup>3</sup> Telecommunication Systems Dept., Ufa State Aviation Technical University, Ufa 450000, Russia

<sup>4</sup> Department of Photonics Engineering, Technical University of Denmark (DTU), Ørstedes Plads 343, 2800 Kgs. Lyngby, Denmark

<sup>5</sup> Department of Mathematics, University of Arizona, Tucson 85721-0089, USA

<sup>6</sup> Institute for Microwave Engineering and Photonics, TU Darmstadt, 64283 Darmstadt, Germany

**Abstract.** We experimentally demonstrate feasibility of simultaneous use of Differential Phase Shift Keying (DPSK) and Amplitude Shift Keying (ASK) formats (orthogonal modulation) using injection-locked semiconductor laser. Experimental study shows significant improvement of the bit-error-rate (BER) and doubling of the system capacity.

## 1. Introduction

Fiber-optic communication lines is a back bone for data transmission. Present and future demand on high bandwidth Internet services leads to the requirement of increase of channel's capacity at all the stages of network. Here we investigate an efficient and cheap technique to double the capacity of metro-level networks or inter data centre communications based on optical injection locking.

Phase locking of a laser with an external seeding signal has been investigated in details [1], and stable locking conditions have been determined [2]. It has been found, that the laser under certain parameters can follow the phase of the external seeding, while keeping its own output amplitude, almost independent from the amplitude of the input seeding signal. Semiconductor edge-emitting lasers locked by phase-modulated external signal have been also tested as phase preserving amplitude limiters [4].

In this work we show how a distributed feed-back (DFB) laser under special injection-locking conditions can be used in fiber optic communication systems for the suppressing of an amplitude modulation. To distinguish DPSK and ASK signals DFB laser is utilized to extract the phase information before receiver. This method is simple, requires only relatively small modification in the infrastructure of communication systems, and hence is supposed to be cost effective.

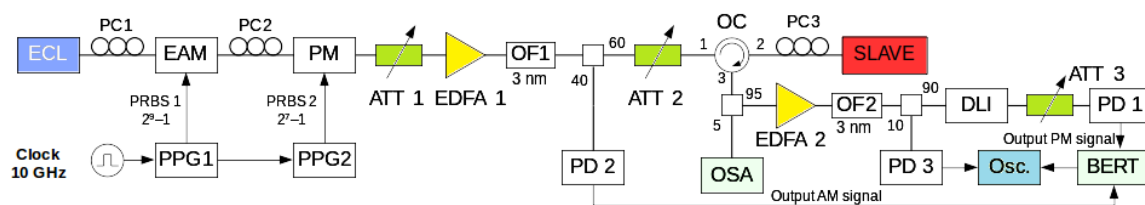
Fragkos et al. have already demonstrated an experimental possibility of successful orthogonal modulation. In contrast to the previously published data [5], we show that the relation between BER and amplitude modulation Extinction Ratio (ER) depends critically on the correlation between ASK and DPSK bit sequences.



## 2. Operation principle and experimental setup

CW light from a tunable external cavity laser (ECL), used as a master laser, is consecutively and independently modulated by amplitude and phase with 10 Gbit/s rate using two pseudorandom binary sequences of lengths  $2^9-1$  and  $2^7-1$  bits. Pulse pattern generators (PPG) are synchronized in such a way that the modulated amplitude and phase symbols in optical signal coincide in time. Afterwards signal is divided into two parts. One goes directly to the photodiode to decode ASK component. Second part is directed to the Slave laser to rectify phase. The DFB laser, used as slave one, is pumped up to 15.5mA, while its lasing threshold is near 8.7mA. The output signal of DFB laser after the circulator is detected by a differential phase-shift keying (DPSK) receiver. Analysis of the detected bit sequences is performed by bit error rate tester (BERT). For capturing eye diagrams and measuring extinction ratios (ER) before and after DFB laser, digitizing oscilloscope is used.

The desirable regime of injection locking can be obtained when the detuning between master and slave lasers approaches zero (from the shorter wavelengths). Depending on both DFB laser current and resulting detuning, an optimal injection power was empirically adjusted in order to minimize BER in the demodulated signal after DPSK receiver.

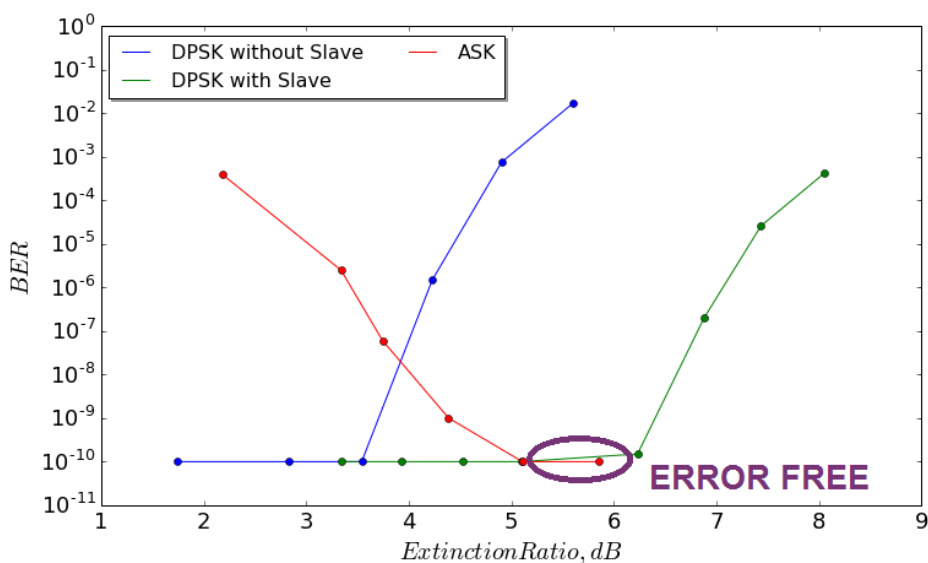


**Figure 1.** Scheme of the experimental setup (ECL - external cavity laser; PC – circular polarizer; EAM - Mach Zehnder amplitude modulator; PM - phase modulator; PPG - pulse pattern generator; ATT - variable attenuator; EDFA - erbium doped fiber amplifier; OF - optical filter; OC - optical circulator; PD - p-i-n photodiode; DLI – delay line interferometer; OSA – optical spectrum analyser; Osc. – digitizing oscilloscope; BERT – bit error tester; DFB – distributed feedback laser; ).

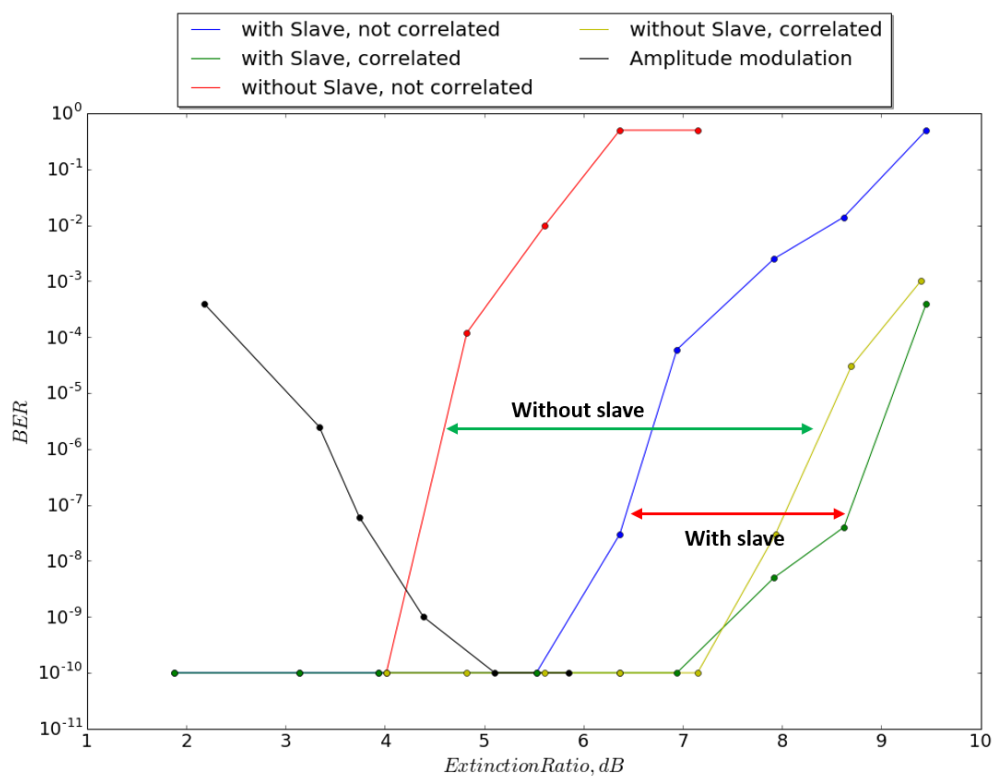
## 3. Experiment results and discussion

Figure 2 shows BER vs. AM (amplitude modulation) ER dependences. As follows from these curves, injection-locked DFB laser provides significant improvement of the transmission reliability for the DPSK signal component, and great BER improvement can be achieved. Furthermore, amplitude and advanced phase modulations can be both recognized error free. This way we can double the capacity of transmission lines.

Figure 3 demonstrates dependence of correlation between ASK and DPSK signals. In non-correlated case Pseudo Random Bit Sequence of  $2^7-1$  bits to generate DPSK signal and  $2^9-1$  for ASK were used. In correlated –  $2^{31}-1$  for both. It is worth noting that using same data streams for ASK and DPSK modulators is not reliable. In this case, it is possible to vary the level of correlation between two bit sequences from non-correlated to fully correlated simply by changing the length of SMA cables connecting PPGs and modulators or by switching PPGs at different times.



**Figure 2.** BER vs. Amplitude modulation ER for cases without Slave laser and with Slave laser.



**Figure 3.** BER vs Amplitude modulation ER for correlated and non-correlated bit sequences.

**4. Conclusion**

We have found that the special operation mode of the externally seeded DFB laser can be used for effective suppression of the amplitude modulation in a phase modulated optical signals. Based on this effect, we have successfully demonstrated BER improvement of the phase modulated signal by several

orders of magnitude. It leads to effective decoding of ASK/DPSK modulated channel and increasing its capacity. In contrast to the previous publications, it was found that the system performance depends critically on the bit correlation of both orthogonal channels.

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