Coherent Detection for 1550 nm, 5 Gbit/s VCSEL Based 40 km Bidirectional PON Transmission

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Abstract: Coherent detection of directly modulated 1550nm VCSELs in 5Gbit/s bidirectional 40km SSMF PON-links is presented. Receiver sensitivity of –37.3dBm after transmission is achieved with 30dB system margin, corresponding to 1:1024 passive power-splitting.

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1. Introduction

In next generation passive optical networks (PONs) for fiber to the home deployment (FTTH), bidirectional transmission of symmetric uplink/downlink data capacity will be increasingly important due to the growth of intrinsically bidirectional services such as on-line gaming and peer-to-peer networks. Moreover, for point-to-multipoint PONs, there is a desire to increase the reach as well as the amount of users serviceable from a single central office. Indeed, a passive splitting ratio of 1000 has been proposed for future PONs [1], a number unreachable by present PON technology without the introduction of e.g erbium doped fiber amplifiers (EDFAs) and dispersion compensating fiber (DCF) in the field; a solution which would be problematic in the access networks due to complexity and power consumption issues. Moreover, an EDFA/DCF based architecture does not lend itself well to single-fiber bidirectional transmission.

An alternative solution is to introduce coherent detection in access networks. By employing coherent detection, the receiver sensitivity can be significantly increased [2], dispersion compensation can be performed in the digital domain [3], and support for advanced modulation formats can be provided [4]. Moreover, as the current PON architecture based on passive optical transmission and splitting can be maintained, graceful migration can be performed by upgrading terminal equipment only with no changes in the optical fiber transmission path. Due to the cost sensitivity of optical access system, however, present day coherent technologies based on external modulation needs to be simplified.

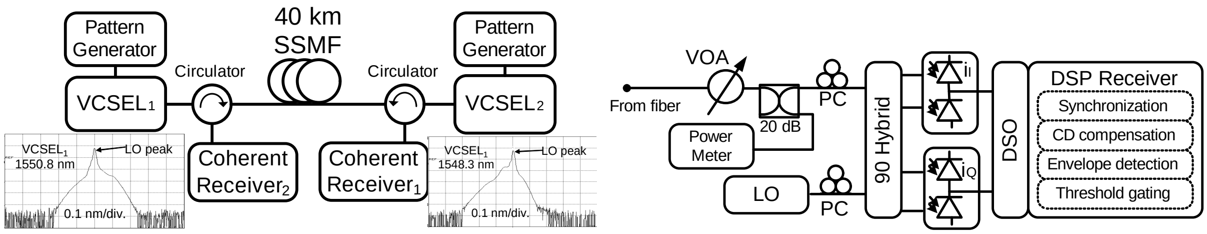
In recent years, a number of breakthroughs within the area of long wavelength vertical cavity surface emitting lasers (VCSELs) have resulted in the emerge of 1550 nm VCSELs [5]. Due the cost-effectiveness and low drive voltage, these are attractive candidates for future PONs. Coherent detection of VCSEL based signals have been presented [6], albeit only with the employment external I/Q modulators; a solution which to some degree counteracts the cost and energy efficiency of VCSELs.

We present what is, to the best of our knowledge, the world's first demonstration of a bidirectional coherent detection PON link employing directly modulated (DM) VCSELs operating at 1550 nm wavelength as transmitters. Our system operates at 5 Gbit/s in both directions, and transmission is over a single, un-amplified 40 km standard single mode fiber (SSMF) link with no use of optical dispersion compensation. Receiver sensitivity at the 2×10^{-3} limit for forward error correction (FEC) was better than –37 dBm, corresponding to an improvement of more than 17 dB over direct detection using the same DM-VCSEL transmitter.

2. Experimental Setup

A block diagram of the bidirectional transmission system and optical spectra (a) and of the coherent/digital signal processing (DSP) reciver (b) is shown in Fig. 1.

A pulse pattern generator directly modulates two uncooled VCSELs ($VCSEL_1$ at 1550.8 nm center wavelength for downstream and $VCSEL_2$ at 1548.3 nm center wavelength for upstream) with a 5 Gbit/s pseudo random binary sequence (PRBS) with a word length of $2^{15}-1$. Driving voltage is 1 V peak-peak, and bias current of the VCSELs is set to 12.4 mA for $VCSEL_1$ and 15.6 mA for $VCSEL_2$. Adjustment of bias current and drive voltage is optimized by maximizing the extinction ratio while minimizing the overshoot. The extinction ratio of the VCSELs at the transmitter



(a) Setup (b) Coherent Receiver

Fig. 1. Experimental setup of the bidirectional system (a) and the coherent/DSP receiver (b). VOA is a variable optical attenuator, DSO is a digital storage oscilloscope with a samplig rate of 40 GSamples/s, LO is the local oscillator laser, and PC is polarization controllers.

is 6.8 dB measured with an oscilloscope. The different center wavelength of the two VCSELs is due to bias current dependence of a VCSELs emission wavelength. As the two VCSELs were not completely identical, and the bias current was optimized for identical extinction ration and overshoot for the two VCSELs, it was not possible to achieve exactly identical optical spectrum and center wavelength for the two VCSELs. The optical power spectra of the two VCSELs combined with the local oscillator (LO) laser are shown as inserts in Fig. 1 (a).

The two VCSELs are connected to opposite ends of a 40 km SSMF transmission span via optical circulators so that the received signal from $VCSEL_1$ can be received at the site of $VCSEL_2$ and vise versa, while the two signals are simultaneously counter-propagating in the fiber. Launch power into the fiber is 0.6 dBm in both directions; fiber attenuation is 7.7 dB; and total chromatic dispersion is 640 ps/nm.

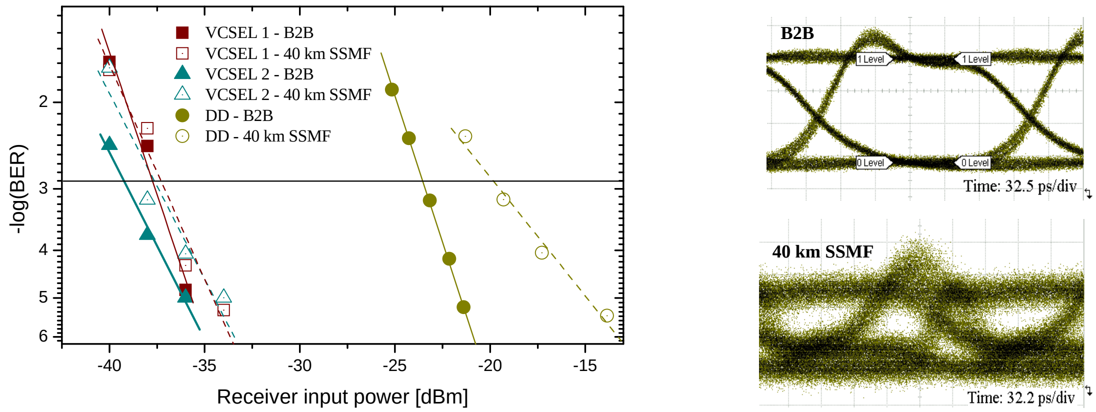
At the receiver input, the signal is attenuated, and the receiver input power is measured with a calibrated optical power meter through a –20 dB directional coupler. After the coupler, the signal is mixed with light from a free running external cavity laser (ECL) local oscillator (LO) in a 90° optical hybrid, and detected by two sets of balanced photodetectors. The received I_I and I_Q components of the signal are stored by a digital storage oscilloscope with a sampling rate of 40 Gsamples/s.

The coherent detection is performed using intra-dyne detection, where the LO laser has a small frequency offset with respect to the transmitter laser center frequency. The narrow linewidth LO laser can be identified within the broader VCSEL spectra in Fig. 1 (a).

Demodulation of the data is performed by off-line digital signal processing (DSP), consisting of synchronization of the received bits, chromatic dispersion (CD) compensation, envelope detection by squaring and low pas filtering, and decision gating. Due to the chirp induced by the direct modulation of the VCSEL, optimum performance is achieved by over-compensating by 425 ps/nm. This residual chirp-compensation is independent of fiber length (the same value was used back to back and after transmission), and is therefore not expected to be a problem in system installations. The effect of random frequency offset between the VCSELs and LO laser does not effect the performance, as the DSP perform envelope detection of the in-phase and quadrature components of the received field.

3. Results

The measured BER of the coherently detected signals before (B2B) and after bidirectional transmission over 40 km SSMF is plotted in Fig. 2 (a) together with the measured BER after direct detection of $VCSEL_1$ with no counter propagating signal. Back to back receiver sensitivity at the FEC limit of 10^{-3} for the coherent detection case is -37.7 dBm for $VCSEL_1$ and –39.3 dBm $VCSEL_2$. After 40 km transmission with the counterpropagating signal, the receiver sensitivity is –37.3 dBm and –37.7 dB for $VCSEL_1$ and $VCSEL_2$ correponding to transmission penalties of 0.4 dB and 1.6 dB. In order to benchmark these results against conventional direct detection unidirectional systems, the BER of $VCSEL_1$ is measured in this manner. The receiver sensitivities for $VCSEL_1$ employing direct detection are –23.6 dBm B2B and –19.8 dBm after transmission, corresponding to a transmission penalty of 3.8 dB. The increased transmission penalty using direct detection is due to chromatic dispersion, which for the coherent detection case was compensated by DSP. This is confirmed by inspection of the direct detection eye diagrams in Fig. 2 (b) which show severe waveform distortion after transmission. The low transmission penalty of the coherently detected signals shows that the chromatic dispersion has been successfully compensated in the DSP. The improvement in receiver sensitivity due to coherent detection for $VCSEL_1$ is 13.1 dB B2B and 17.5 dB after 40 km SSMF.



(a) BER (b) Eye diagrams

Fig. 2. Measured BER back to back (B2B) and after 40 km SSMF bidirectional transmission. Direct detection (DD) direction, single transmission using $VCSEL_1$ is included for reference.

As the launch power is 0.6 dBm, and total fiber loss is 7.7 dB, the presented bidirectional coherent system provides a system margin above 30 dB, corresponding to a passive spitting ratio of 1024. This is a dramatic improvement over the direct detection margin of 12.7 dB corresponding to a passive splitting ratio of 18. Alternatively, as chromatic dispersion is compensated using DSP, the improved system margin could be utilized to extend the reach to e.g. 80 km. Assuming an 80 km link loss of 15.4 dB, the residual margin of 22.3 dB would be able to accommodate the loss of a 1:128 power splitter.

4. Conclusion

We have presented experimental results from what we believe to be the worlds first demonstration of bidirectional 40 km SSMF link employing coherent detection with free running local oscillators and un-cooled directly modulated VCSEL transmitters. Through the use of digital signal processing for demodulation and dispersion compensation, receiver sensitivities of –37.3 dBm downstream and –37.7 dBm upstream was achieved with no use of optical amplifiers or optical dispersion compensation. At a launch power of 0.6 dBm and 7.7 dB fiber loss, a system margin of 30 dB was achieved, corresponding to the loss of a record passive splitting ratio of 1024.

The reported experiments demonstrate the potential for coherent detection in bidirectional access links employing directly modulated VCSEL transmitters. Future work include the investigation of the feasibility of using low-cost solutions for LO lasers, and upgrade to 10 Gbit/s bit rate.

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