Simple and Low Cost 10 Gb/s Coherent Transmission for Long Reach PON

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Abstract: 131 km transmission (typical LR-PON distance) at 10Gb/s over G.652 fiber is demonstrated exploiting a direct modulated (DM) DFB laser, coherent receiver and electrical filtering obtaining an innovative chirp managed approach. No dispersion compensation (optical or DSP) is exploited.

Introduction

In order to support the future bandwidth growth over existing Optical Distribution Networks (ODN), the ITU-T and the IEEE with the Full Services Access Network (FSAN) group, have defined their respective 10 Gb/s solution, namely ITU-T XG-PON and IEEE Std. 802.3av 10GE-PON.

At the same time long reach passive optical network (LR-PON), with reach exceeding 100 km and up to 130 km are being considered. LR-PONs are attractive because they would enable network operators and service providers to reach a vast number of users and simultaneously consolidate their network simplifying its management [1,2]. A 10 Gb/S LR-PON needs to exploit dispersion compensation, external modulation and optical amplification in order to overcome the dispersion and the losses (including the high splitting ratio) of the ODN [3].

In the last years interest has grown in applying coherent detection and digital signal processing (DSP) in the access segment to extend the system reach and to support high user density [4]. Yet, all the appealing features offered by present coherent receiver technology, based on high-resolution A/D converters and advanced digital signal processing (DSP) techniques, can be hardly suitable (or required) for access networks where receivers are expected to be low-cost, simple and robust [5].

Recently, a cost-effective coherent envelope detection scheme has been demonstrated to enable the use of directly modulated (DM) lasers with adiabatic chirp in WDM PON access networks at 1.25 or 2.5 Gb/s [6]. We showed that electrical filtering implemented by bandwidth-limited photodiodes is equivalent to the optical filtering in direct-detection receivers, avoiding the extra insertion losses of the optical filters. In this way the Optical Network Unit (ONU) is kept at a low-complexity level and colorless.

Here we extend this approach to 10 Gb/s DM-DFB lasers and we experimentally demonstrate that coherent homodyne receiver with proper electrical filtering work similarly to the optical filtering as implemented in [7] obtaining an effect similar to chirp management. Thanks to this effect we demonstrate 131 km, 10 Gb/s transmission over G.652 fiber using a DM-DFB laser as a transmitter and an electrically filtered homodyne receiver without any optical nor DSP based dispersion compensation.

As the technique is based on low cost DM-DFB transmitters and cost-effective electrically filtered homodyne receivers, it offers an interesting solution towards the realization of a 10 Gb/s LR-PON where the use of expensive components (external modulators, optical filters, dispersion compensation modules) and DSP must be avoided.

Experiment and results

The experimental setup is shown in Fig. 1. A DFB laser (DFB-1) was DM at 10 Gb/s by a non-return-to-zero (NRZ) pseudorandom bit sequence (2^7-1). The laser was emitting at 1540.55 nm and had a line-width of about 10 MHz.

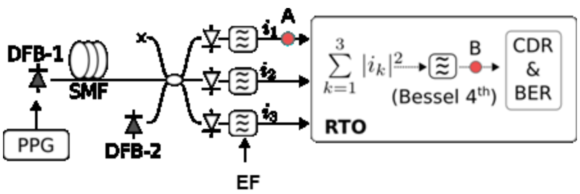

Fig. 1:Experimental set-up. PPG: pulse pattern generator; DFB: distributed feedback laser; SMF: single-mode fiber; RTO: real-time oscilloscope; CDR: clock and data recovery EF: electrical filters. A and B indicate measurement points

The DM-DFB-1 produced a modulated signal with an output power of +1.8 dBm. A combination of G.652 fiber spools allowed for a transmission up to 131 km. The signal was detected by a coherent receiver that implements a 3 × 3 homodyne envelope detector [8] where the local oscillator (LO) was a free running DFB laser (DFB-2, 6 MHz line-width). Homodyne operation was achieved by tuning the DFB-2 operating temperature and bias current, i.e. without any automatic frequency control to match DFB-1 and DFB-2 wavelengths. Three identical photodiodes (PD) having a 15 GHz bandwidth, followed by integrated trans impedance amplifiers (TIAs) were used. As will be clarified later, such a high PD speed is not functional to the final result. The PD output currents were processed by a real-time oscilloscope (13 GHz analogue bandwidth, 20 GSa/s), where squaring and summing of the three photocurrents was performed via software to recover the signal envelope (as shown in Fig. 1). The bit error ratio (BER) was computed by comparing bit-by-bit the received sequence against the transmitted one. As reported in [7] the frequency modulation of a DM-DFB laser is the result of gain compression in the laser, which generates an adiabatic chirp proportional to the output intensity ("1"s bits are blue shifted relative to the "0"s bits). In [7] FM-AM conversion is obtained by using an optical spectrum re-shaper (OSR) filter placed in front of the DM-DFB, which passes the blue shifted "1"s and attenuates the red shifted "0"s, increasing the extinction ratio at the output of the filter by more than 10 dB.

Here we replace the OSR in the transmitter by an electrical filter (EF in Fig.1) in each of the three branches of the coherent receiver, placed between the PIN+TIA and the envelope detection stage. The LO was tuned to match the wavelength of the "1"s, thus the low pass EF lets "1"s through and attenuates the red shifted "0"s. The frequency chirp needed to obtain the dispersion managing effect is half the bit rate (5 GHz for 10 Gb/s) [7], thus we set DFB-1 modulation amplitude to obtain 5 GHz adiabatic chirp between "1"s and "0"s. The reshaping EF were implemented by a built-in low pass filter function in the oscilloscope (Gaussian amplitude shape, linear phase) before the data elaboration.

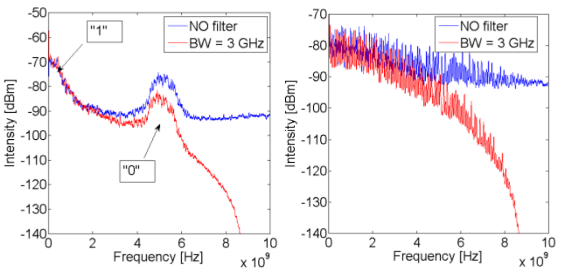

Fig. 2: DFB modulation spectra for 1 Gb/s (left) and 10 Gb/s (right) measured in point A

The -3 dB width was 3 GHz, which is almost equivalent to the band-pass OSR characteristics (7.1 GHz FWHM) used in [7]. Fig. 2 shows the electrical spectrum measured at point A in Fig. 1, for 1 Gb/s (left) and for 10 Gb/s (right) modulation speed in case of full bandwidth and 3 GHz bandwidth of the EF. The 5 GHz frequency shift between "1s" and "0s is clearly seen in the plot on the left.

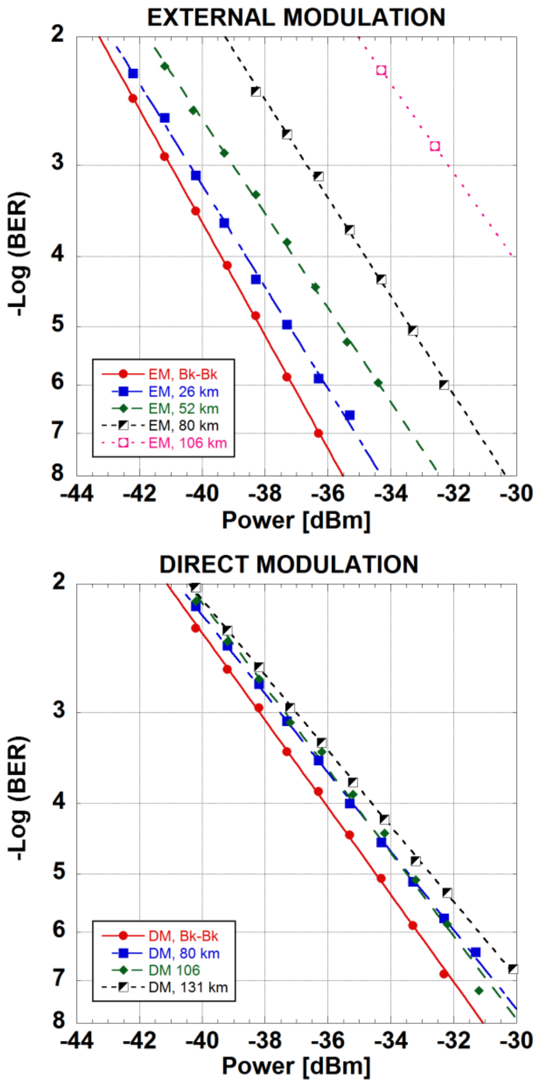

Fig. 3: External and direct modulation performance in back-to-back and in propagation.

Then we measured the BER value at different transmission distances up to 131 km of G.652 fiber and compared the performance of the proposed solution with that of a chirp free external modulator (EM). In this case the optimum value for the EF bandwidth was 10 GHz. The obtained BER curves are shown in Fig. 3. As can be seen, our solution (lower plot) has a back-to-back penalty of 3 dB with respect to EM (upper plot). This can be partially explained looking at Fig.4. The eye diagram at 0 km for the direct modulation case shows slow wave front, because we used a DFB laser normally operated at 2.5 Gb/s. However at

80 km it out-performs the EM transmitter by about 1 dB. Moreover at 106 km the reduced output power of the EM limits received power to -32.3 dBm with a BER of $1.4e^{-3}$. On the contrary, by exploiting the proposed solution, a span length of 131 km can be reached with only 1 dB of power penalty with respect to the back to back. In Fig. 4 eye diagrams, (recorded at point B in Fig. 1), for both EM and DM at back-to-back and at maximum distance (106 km for EM and 131 km for DM and electrical filtering) are reported. In the case of EM, the eye diagram is strongly degraded after 106 km, while the DM and electrical filtering approach allows to obtained a clear open eye diagram even at 131 km.

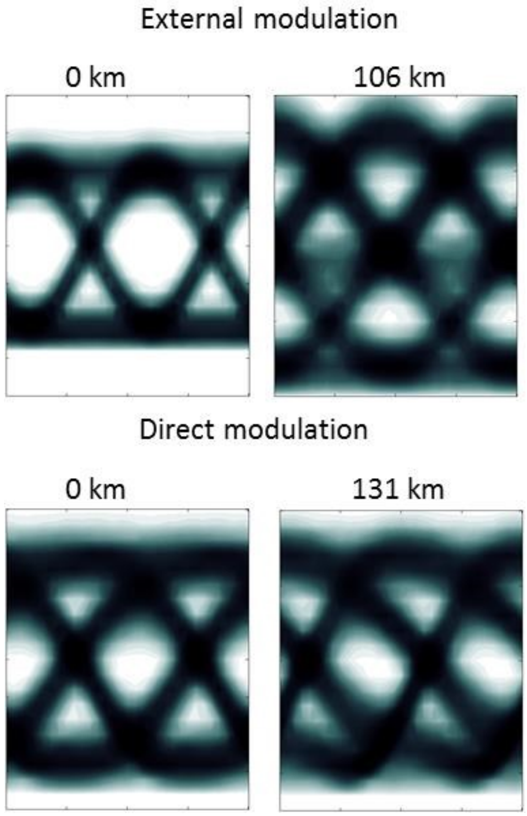

Fig. 4: Eye diagrams

Conclusions

We exploited homodyne coherent detection of a directly-modulated low cost DFB laser to obtain and equivalent chirp managed approach. To this aim ad-hoc electrical filtering must be implemented, with the advantage of not inserting "colored" optical elements either at TX or at RX. The proposed approach performs better than a chirp-free EM for 10 Gb/s transmission and propagation longer than 80 km. At 10 Gb/s, 131 km transmission with only 1 dB penalty using a simple DM-DFB laser was demonstrated. The use of DM-DFB lasers is particularly appealing for LR-PON with target span of 130 km as it saves the losses associated with external modulators (5-6 dB) and significantly reduces the transmitter costs. Electrical filtering is equivalent to the OSR in direct-detection receivers: it effectively performs the FM-AM conversion while keeping the system at a low-complexity level and colorless. Moreover no optical or DSP based dispersion compensation is required simplifying the system even further.

Acknowledgements

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