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DSP-FREE REAL-TIME 25 GBPS QUASICOHERENT RECEIVER WITH ELECTRICAL SSB FILTERING FOR C-BAND LINKS UP TO 40 KM SSMF

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Abstract

We have experimentally demonstrated a real-time 25 Gbps transmission for C-Band up to 40 km SSMF without optical or digital chromatic dispersion compensation by using a single sideband quasicoherent receiver with sensitivity of -20 dBm (pre-FEC BER = $5\cdot10^{-5}$) and 40 km dispersion penalty below 6.3 dB.

1 Introduction

The data traffic increment over optical networks requires a migration from the current 10 Gbps based networks to 25 Gbps based networks. The current 10 Gbps based networks usually operate in C-band in order to transmit several channels in the same fibre by using dense wavelength division multiplexing (DWDM) over distances longer than 20 km. The natural step on this migration to 25 Gbps would be to directly upgrade from 10 Gbps transceivers to 25 Gbps transceivers. However, the chromatic dispersion in the C-band limits transmission distances to 10-15 km.

Current 25 Gbps transceivers can barely transmit over distances longer than 10 - 15 km in C-band [1]. The short reach provided by these transceivers would require a new deployment of the network with shorter transmitted distances or with optical dispersion compensation modules. This new network deployment is unacceptable in terms of cost for the network operators.

An alternative approach is the migration to O-band, where the chromatic dispersion is negligible. Recent advances have led to 25 Gbps O-band transceivers with long reach and high sensitivities [2], but they are neither compatible with C-band DWDM MUX/DEMUX or with DWDM channel spacing requirements. In addition, pay-as-you-grow channel by channel capacity upgrades of C-band networks are not possible. Therefore, the migration to O-band for DWDM networks is not a viable option in practice.

Upgrading to digital signal processing (DSP) enabled coherent receivers cannot be justified due to the cost of these transceivers and due to their power consumption and heat dissipation. Similarly, the so-called Kramers-Kronig (KK) receiver, which is able to reconstruct the phase information of the signal and thereby completely compensate for chromatic dispersion [3, 4] are not suitable for these cost-sensitive networks as they require DSP as well as specialized transmitters which are typically based on Mach-Zehnder or IQ types of external modulators.

What is needed is a technology that allows for pay-as-you grow upgrades for 10 Gbps to 25 Gbps at a small cost increment over direct detection while increasing reach to beyond 20 km (ideally towards 40 km). At the same time, it should work with standard EML based 25 Gbps NRZ-OOK transmitters.

The single sideband quasicoherent (SSB-QC) receiver presented in this paper delivers just that. It allows to perform the single sideband filtering in the electrical domain at the receiver, avoiding the frequency fading caused by chromatic dispersion. The SSB QC receiver has experimentally demonstrated the feasibility of transmissions up to 40 km over SSMF in the C-band with -13.7 dBm sensitivity at the Ethernet pre-FEC BER of $5\cdot10^{-5}$.

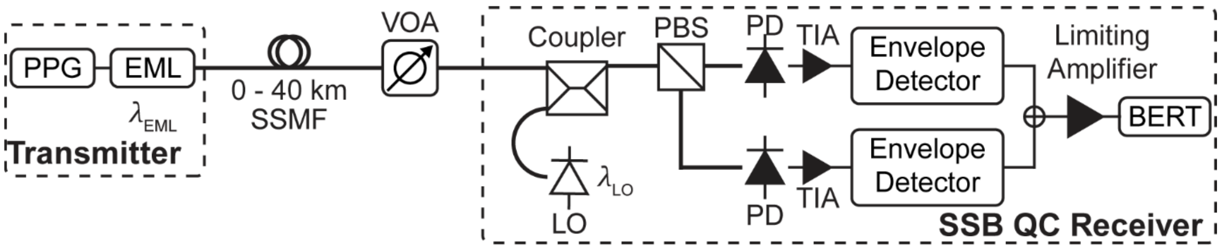

Fig. 1 Experimental setup and SSB QC receiver schematic.

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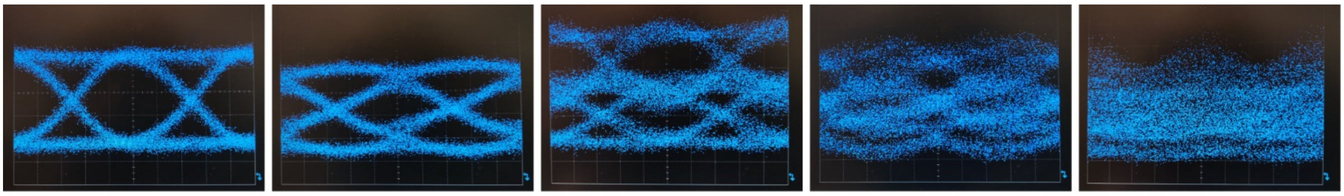


(a) BTB (b) 10 km SSMF (c) 20 km SSMF (d) 30 km SSMF (e) 40 km SSMF

Fig. 2 Optical eye diagrams, i.e. DD eye diagrams with a P_{RX} = -5 dBm: BTB (a), 10 km SSMF (b), 20 km SSMF (c), 30 km SSMF (d) and 40 km SSMF (e).

2. Experimental setup

Fig. 1 shows the experimental setup schematic used to test the SSB QC receiver. Additional measurements have been made with a direct detection (DD) in order to obtain a reference value for comparison.

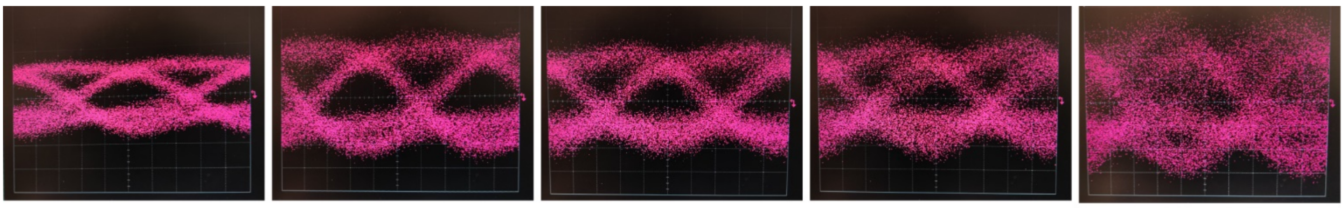
The transmitter part is common for both receivers and it is based on a 30 GHz bandwidth EML with a wavelength of 1554.8 nm and an emitted power of +1.87 dBm. The EML consists of a DFB laser section followed by an electro-absorption modulator (EAM) section and is modulated with a 25 Gbps non-return to zero (NRZ) signal, obtaining an intensity modulated (IM) signal with an extinction ratio of 5.5 dB. The EML was selected with enough electrical bandwidth to prevent any possible distortion in the transmitted NRZ.

The NRZ-IM signal is transmitted through a standard single mode fibre (SSMF). Five different cases have been tested: back-to-back (BTB) and transmission through 10 km, 20 km, 30 km and 40 km SSMF.

The QC receiver [5, 6] consists of an optical coupler combining the LO and the signal, followed by a polarization beam splitter (PBS). After the PBS, the signal and the LO of each polarization are detected with a PD and transimpedance amplifier (TIA) with a combined electrical bandwidth of 39 GHz. After the TIAs, the original NRZ signal is reconstructed from the LO-signal beating term centred at the intermediate frequency between them by rectification in an ultra-wide band Schottky envelope detector (ED) with an electrical output bandwidth of 18 GHz. The intermediate frequency is equal to the offset between signal and LO- In this experiment, 44 GHz is used. Finally, the tributaries from the two polarizations are added and amplified with a limiting amplifier, which contains a built-in continuous time linear equalization (CTLE) module. The CTLE value is adjusted to the specific transmission distance and receiver input power for optimum performance. The LO used in this test is a tuneable laser source with a 10 kHz linewidth and an emitted power of +15 dBm. A tuneable laser has been selected in the experiment reported here for the ease and repeatability of precise tuning. Previous studies [5,7] have demonstrated the QC receiver to be highly tolerant to laser line width and phase noise - real time operation with VCSEL transmitters and LO has even been shown. This is a consequence of the use of envelope detection which removes the phase information thereby increasing tolerance to phase noise. The tolerance towards variations in intermediate frequency (i.e. the requirement of a stable frequency relation between signal and LO) for a QC receiver generally depends on the electrical bandwidth of the PD/TIA - as long as the IF signal is within the PD/TIA bandwidth, the signal can be detected. For the SSB-QC receiver, the requirements are stricter since the principle relies on accurately removing (most of) the upper sideband. In the experiment, the transmitter used simple thermal tuning without a wavelength locker. This was sufficient to secure short term stable operation but required LO re-tuning in general once or twice per hour. The addition of a conventional wavelength locker with +/- 2 GHz stability is believed to be sufficient, but further studies are required to quantify this precisely.

3 Results

The optical eye diagrams before and after transmission are shown in Fig. 2(a-e). The BTB eye diagram in Fig. 2(a) has a perfect NRZ signal. Already after 10 km transmission, the chromatic dispersion distorts the eye as seen in Fig. 2(b). In this case, the signal is still recoverable with conventional direct detection. After 20 km SSMF shown in Fig. 2(c), the signal is so heavily distorted by inter-symbol interference (ISI) that it has taken on a duobinary-like shape where the 2 levels of the original NRZ signal have completely disappeared, and after 30 km and 40 km (Fig. 2(d-e)), the distortion gets progressively worse.



(a) BTB (b) 10 km SSMF (c) 20 km SSMF (d) 30 km SSMF (e) 40 km SSMF

Fig. 3 Electrical eye diagrams after SSB QC receiver with a P_{RX} = -12 dBm: BTB (a), 10 km SSMF (b), 20 km SSMF (c), 30 km SSMF (d) and 40 km SSMF (e).

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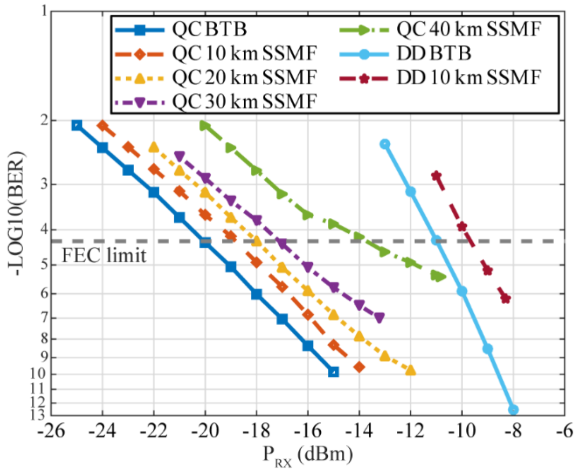

Fig. 4 BER vs received power for 25 Gbps IM signal received with SSB QC receiver and with direct detection (DD) for BTB and 10 km, 20 km, 30 km and 40 km SSMF transmission.

The degradation of the signals after the SSMF transmission is mainly due to the chromatic dispersion induced selective frequency fading in the transmitted signal [8]. In frequency domain, CD introduces a linearly varying group delay across the signal. When the PD in direct detection squares the signal (folds it around the optical carrier), corresponding frequency components of the upper and lower sideband will interfere with each other. When the group delay between upper and lower sideband at a given frequency component is exactly 180 degrees, this frequency component will cancel leading to severe signal degradation. The first frequency fading will occur at 13.1 GHz after 20 km SSMF, at 10.7 GHz after 30 km SSMF and at 9.3 GHz after 40 km SSMF.

In the QC receiver, due to the high 44 GHz LO-signal offset, the electrical bandwidth of the PD+TIA removes the upper sideband of the intermediate frequency signal obtained after the PD+TIA, thereby converting it to an SSB signal. Since there is now only a single sideband, the dispersion induced frequency fading and the distortion that comes along with it has been eliminated. The signal is now much more tolerant to chromatic dispersion than in the direct detection case. It should be noted that SSB filtering only eliminates the RF fading – it does not completely remove dispersion induced signal degradation. Even the retained sideband suffers from CD induced pulse broadening which ultimately will result in unrecoverable ISI. For very long links, other means of CD management must be used, e.g. dispersion compensating fibre, KK receivers or DSP enabled coherent detection. The electrical eye diagrams after reception by the SSB-QC receiver (but before the CTLE) is shown in Fig. 3(a-e). Up to and including 30 km SSMF, the signal is recovered well, but after 40 km, degradation due to the CD induced pulse broadening is visible. This signal, however, could still be recovered with a BER well below the Ethernet FEC limit of $5{\cdot}10^{-5}$.

Fig. 4 shows the BER vs. received power (P_{RX}) curves for the SSB QC receiver BTB and after 10km, 20 km, 30 km and 40 km SSMF transmission. Also included is the direct detection BER BTB and after 10 km (longer distances could

Table 1 Receiver sensitivities at BER = 5e-5 for SSB-QC and DD BTB and after 10 km, 20 km, 30 km and 40 km SSMF transmission.

	BTB [dBm]	10 km [dBm]	20 km [dBm]	30 km [dBm]	40 km [dBm]
DD	-11.0	-9.7	NA	NA	NA
SSB-QC	-20.0	-18.8	-18	-17.1	-13.7

not be recovered using direct detection). The DD measurements was obtained using the same PD, TIA and CDR with built-in CTLE as for the SSB-QC measurements. The obtained receiver sensitivities at the Ethernet pre-FEC requirement limit (BER = $5{\cdot}10^{-5}$) for the different cases are included in Table 1.

Back-to-back and after 10 km, the SSB-QC receiver displays an improvement of minimum 9 dB in sensitivity over PIN based direct detection, corresponding to a power penalty of 1.2 dB for SSB-QC and 2.3 dB for DD. For 20 km, 30 km and 40 km, the penalty for the SSB-QC receiver is 2 dB, 2.9 dB and 6.3 dB, respectively. The increased penalty after 40 km reflects the ISI that can be seen in the eye diagram in Fig. 3(e). The lowest measured BER after 40 km is $4.1{\cdot}10^{-6}$ at -10.8 dBm. At this point the VOA is at its lowest setting, so higher powers cannot be measured in the system used in these experiments.

4 Conclusion

The proposed SSB QC receiver allows to successfully receive 25 Gbps IM signals in C-band with transmission distance up to 40 km over SSMF without any type of optical or digital chromatic dispersion compensation. This is possible thanks to the electrical filtering of the upper sideband of the received signal at the intermediate frequency, which avoids the frequency fadings caused by chromatic dispersion.

The quasicoherent receiver provides a sensitivity of -20 dBm (BER = $5{\cdot}10^{-5}$) with a dispersion penalty below 1.2 dB, 2 dB, 2.9 dB and 6.3 dB for 10 km, 20 km, 30 km and 40 km SSMF transmission, respectively.

Currently available C-band 25 Gbps transceivers (e.g. [1]) only allow to reach 15 km with BTB sensitivities of -14.5 dBm and dispersion penalties of 3.5 dB after 15 km SSMF. Therefore, our SSB QC receiver allows to increase the transmission reach up to 40 km SSMF with a BTB sensitivity of -20 dBm and a lower dispersion penalty (2 dB for 20 km of SSMF transmission).

In conclusion, the SSB QC receiver shows significant merits as a candidate for upgrading the networks to the next generation data rate of 25 Gbps.

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