Real-time 400 Gb/s CDWM-4 DMT Directly Modulated Transmission over 10 km

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Abstract We demonstrate the first real-time 400 Gb/s CDWM-4 DMT transmission over 10 km using a 16 nm CMOS ASIC operating at 71 GS/s and commercial 25 GHz-class directly modulated lasers.

Introduction

To support the ever-increasing connectivity demand, network operators have already started to deploy 400 GbE optics. For datacenter and other short-reach networks such as edge-cloud, inter-campus and 5G mobile-fronthaul, 400 Gbs CWDM-4 intensity modulation – direct detection (IM/DD) in the O-band is the prefered option due to its low-cost, low power consumption and low footprint. Today comercial 400 Gb/s CDWM-4 modules for 2 km (FR) and 10 km (LR) in QSFP-DD form factor use externally modulated laser (EML) as the light-source with PAM-4 [1].

Compared to EML, directly-modulated laser (DML) can provide a significantly lower power consumption, footprint, and production cost [2]. As a result, high-speed DML which are capable of supporting 100 Gb/s per lane over FR and LR distances are of great demand.

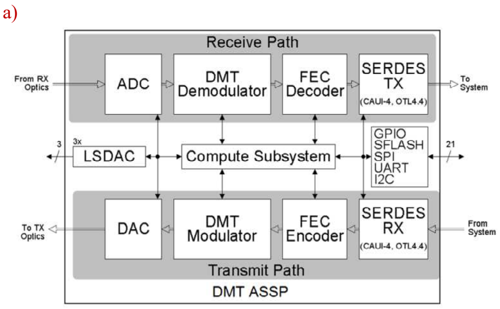
One critical difference between EML and DML is that the chirp for DML is a mixture of transient and adiabatic chirp compared to only transient chirp of EML. Unlike the transient chirp, which should be suppressed, adiabatic chirp can be greatly benefical in increasing the reach [2]. As a result, by carefully tailoring the DML chirp characteristics, DML can provide a comparable or even better tolerance to chromatic dispersion (CD) compared to EML. One additional benefit of DML is its high output optical power (several dB higher than EML) which directly increases the overall system power budget.

Another approach for increasing the reach of IM/DD systems is to employ a dispersion-tolerant modulation format such as Discrete Multitone (DMT). Due to the long symbol duration and the capability of bit and power loading which can adapt to the power-fading characteristics of the IM/DD channel, DMT can provide higher capacity and longer reach compared to the PAM-4 format [3]. In light of that, a combination of DML and DMT is an attrative solution for cost-optimized and power-optimized 400 Gb/s CWDM-4 optics.

In this paper, we present the first real-time demonstration of 400 Gb/s CWDM-4 DMT transmission using a 16 nm CMOS ASIC and a 25 GHz-class DML over 10 km. The achieved sensitivity was -5 dBm, which indicates a record system link power budget of ~ 14 dB. The commercial availability of both the CMOS DMT ASIC and DML indicates that the demonstrated 400 Gb/s CDWM-4 solution can be commercialized to meet the market demand.

100 G DMT ASIC and 25 GHz DML

The 100 G DMT ASIC used in this experiment was designed by Socionext and is commercially available [4]. It can operate at various data rates, from 25 Gb/s to 100 Gb/s and has been tested in several configurations reported in recent publications [5-6]. The simplified block diagram of the DMT ASIC is depicted in Fig. 1a. It incorporates a complete single channel DMT transmission PHY for up to 100 Gb/s data rates over short reach optical fibre. It includes an 8-bit



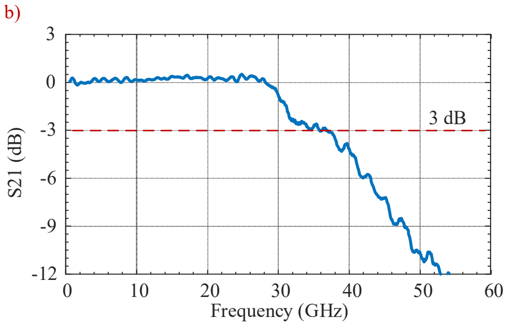


Fig. 1a) – Basic block diagram of the 16 nm CMOS DMT ASIC; b) – Small signal response of the DFB at 20 C showing a 3dB bandwidth of ~ 34 GHz

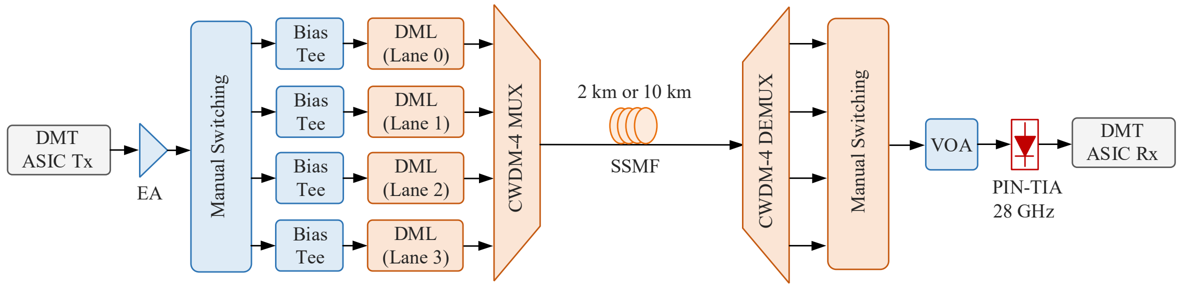


Fig. 2. Experimental setup for real-time 400 Gb/s CWMD-4 DMT transmission over 2 km and 10 km; EA – Electrical amplifier

DAC and ADC with sampling rates up to 71 GS/s, a DMT core engine, an on-chip digital RX timing recovery, a low-jitter RX clock generation and high coding gain FECs to ensure error free data is passed to the client interface. The DMT core engine uses 512pt FFT/iFFT to encode data onto 256 subcarriers with adaptive quadrature amplitude modulation (QAM) modulation formats with 0-8 bits per subcarrier. For best transmission, the QAM modulation is determined by measuring the signal-to-noise ratio (SNR) of the channel at each subcarrier frequency. A water-filling algorithm then computes the bit and power loading for each subcarrier and an adaptive background equalization guarantees optimum adaptation to any variations in the channel. The DMT ASIC also includes configurable cyclic prefix for total bitrate optimization and frequency domain equalization. The DFB lasers used in this experiment are commercially available lasers at II-VI Inc. The DFB lasers employ the buried-hetero (BH) structure with proven reliability verified over 198 billion DFB device hours in the field since reported at OFC 2015 [7]. In the DFB laser design, the separate confinement layer, doping profile, and numbers of wells in the MQW structure were carefully tailored to enhance the adiabatic chirp and suppress the transient chirp. The 3-dB bandwidth (BW) of the DFB laser is 24 GHz, 29 GHz, and 34 GHz, at 70°C, 50°C, and 20°C (Fig. 1b), respectively.

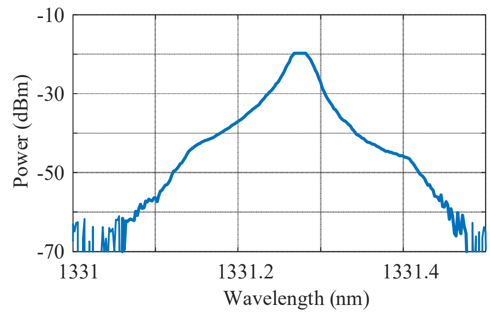


Fig. 3. Optical spectrum of line 3 centered at ~ 1331 nm

Experimental transmission setup

The experimental transmission setup is shown in Fig. 2. At the transmitter, 100G traffic at 4×25.78125 Gb/s (IEEE CAUI-4 compliant) was emulated, which was then mapped onto 256 subcarriers (after FEC-encoding) by the DMT core engine through bit and power mapping based on the channel condition measured during the initialization stage. During operation, the channel condition is automatically tracked and updated by the DMT core engine after each predefined (adjustable) time interval. The modulated DMT signals of the ASIC were amplified using a 25-GHz RF driver before bias-adding for directly driving a DML (1270 nm (lane 0) to 1330 nm (lane 3)) through manual switching. The DML was biased at ~ 80 mA which provides an average output power of ~ 9 dBm. The EA's gain was optimized for achieving the best

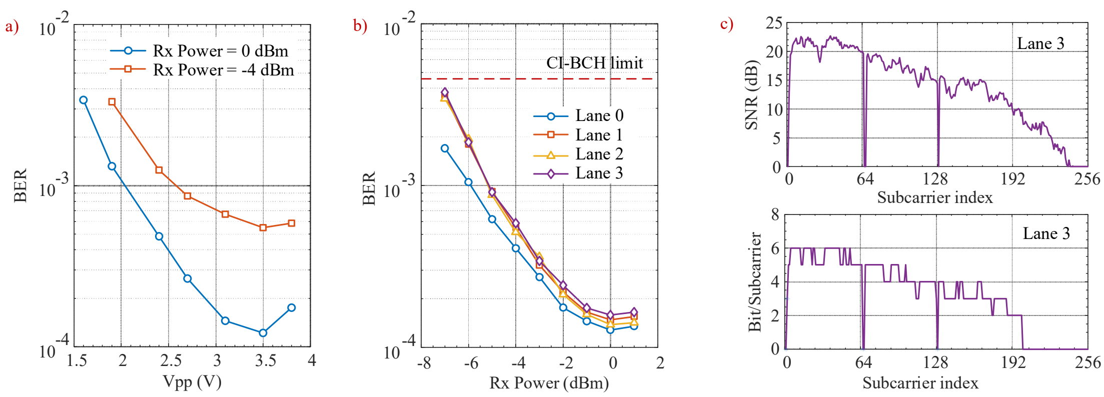


Fig. 4a) – Optimizing the Vpp of the DMT-modulated signal for the lane 3; b) – Sensitivity measurement in B2B for all 4 CWDM-4 lanes; c) – Measured SNR and DMT bit-loading for lane 3 at a Rx power of 0 dBm

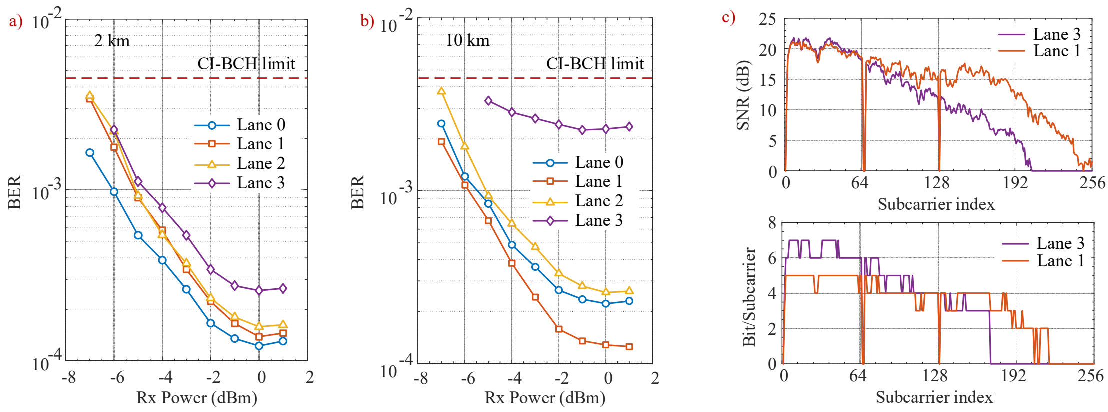


Fig. 5a) – Sensitivity measurements at 2 km for all lanes; b) – Sensitivity measurements at 10 km for all lanes; c) – Measured SNR and DMT bit-loading for lane 3 and lane 1 after 10 km at a Rx power of 0 dBm

performance. The 4 optical signals (three un-modulated and one modulated) are combined using a CDWM-4 MUX before being launched to either a 2 km or a 10 km span of SSMF. The optical spectrum of the modulated line 3 is shown in Fig. 3. The fibre has a zero dispersion at ~ 1307.6 nm and a dispersion slope of ~ 0.0897 ps/nm^2/km (at 1307.6 nm). The fibre's insertion loss in the O-band is below 0.4 dB/km. At the receiver, the optical signal was fed to a CDMW-4 DEMUX. The combined insertion loss of the CWDM-4 MUX and DEMUX was ~ 3 dB. After the DEMUX, the modulated channel was put through a variable optical attenuator (VOA) for varying the received signal power. This channel was then detected by a 28-GHz PIN-TIA before being fed back to the ASIC for real-time signal processing and decoding. Herein, we report the transmission performance in terms of pre-FEC bit-error-rate (BER). All the reported pre-FEC BER values below the CI-BCH threshold of 4.5e-3 indicate an error-free transmission (post-FEC BER < 1e-15).

Transmission results and discussions

First, we optimize the EA's gain and plot the BER versus peak-to-peak voltage of the modulated DMT signal for the lane 3 (1330 nm) in Fig. 4a. One can note that the optimized Vpp should be around 3.5 V. We then fix the EA's gain and measured the B2B sensitivities as depicted in Fig. 4b, showing that a sensitivity of -7 dBm was achieved for all lanes. Lane 0 (1270 nm) shows the best performance, especially at a low Rx signal power. This is due the fact that lane 0 provides a better modulation efficiency compared to other lanes. Lanes 1, 2, and 3 show very similar performances. The measured SNR and bit loading for lane 3 at 0 dBm of Rx signal power is shown in Fig. 4c.

The sensitivity measurements for 2 km (FR) is shown in Fig. 5a. Herein, the impact of dispersion can already be noticed, especially for lane 3. However, the sensitivity is unchanged over 2 km of transmission which indicates the excellent tolerance to dispersion of the considered solution with DMT and DML. The transmission performance over 10 km is shown in Fig. 5b. One can note that the dispersion of ~ 16 ps/nm (at 1330 nm) has a strong impact on the BER floor of lane 3, which is the worst-performing lane. Herein, due to the impact of dispersion, lane 1 becomes the best-performing lane instead of lane 0 compared to the B2B case. The impact of dispersion can also be clearly observed in the measured SNR of lane 3 as shown in Fig. 5c. Because of the significant power-fading, high-frequency subcarriers (e. g. from subcarrier 170) could not be used for carrying data. Because of that, to maintain 100 Gb/s, low-frequency subcarriers were loaded with 128-QAM (7 bit/symbol) instead of 64-QAM compared to the case of lane 1. This flexibility is a big advantage of DMT format over the PAM-4. Overall, all lanes were decoded error free at -5 dBm of power, showing a power margin of ~ 7 dBm which confirms the reliability of the demonstrated real-time transmission system.

Conclusions

We have demonstrated a real-time 400 Gb/s CWDM-4 transmission over 10 km using a commercial CMOS DMT ASIC and 25 GHz-class DMLs. This result indicates that a combination of DMT and DML is a promising solution for low-cost CWDM-4 transceivers over FR and LR distances.

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