Real-time 100 Gb/s IM/DD DMT with Chirp Managed Laser Supporting 400 Gb/ CWDM-4 over 20 km

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Abstract: We demonstrate the first real-time 100 Gb/s IM/DD DMT transmission with a chirp managed laser over - 65.6 ps/nm to + 48.6 ps/nm of dispersion which is sufficient to support 400 Gb/s CWDM-4 transmission over 20 km.

OCIS codes: (060.2330) Fiber optics communications; (060.1660) Coherent communications.

1. Introduction

Network operators have already started to deploy 400 GbE optics to support the ever-increasing connectivity demand. 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 preferred option due to its low-cost, low power consumption and low footprint. Today commercial 400 Gb/s CDWM-4 modules for 2 km (FR) and 10 km (LR) in QSFP-DD form factor use an externally modulated laser (EML) as the light-source with PAM-4 [1].

Compared to EMLs, directly modulated lasers (DMLs) can provide significantly lower power consumption, footprint, and production cost [2, 3]. In addition, the chirp for DMLs is a mixture of transient and adiabatic chirp compared to only transient chirp of EMLs. It has been shown that adiabatic chirp can be greatly beneficial in increasing the reach [2]. By carefully tailoring the DML chirp characteristics, a DML can provide a comparable or even better tolerance to chromatic dispersion (CD) compared to an EML.

Recently, by using 4 DMLs with carefully engineered chirp characteristics, a real-time 400 Gb/s CWDM-4 transmission over 10 km (with a dispersion range from ~ -31 ps/nm to + 20 ps/nm) using discrete multitone (DMT) format has been reported [4, 5]. In that experiment, the bit-error-rate (BER) floor of the 1330 nm channel at 10 km was close to the Forward Error Correction (FEC) limit, which prevented further reach extension.

For addressing this problem, the concept of a chirp managed laser (CML) was proposed [6, 7]. A CML is formed by passing the output of a DML through an optical filter (OF) for FM discrimination [6]. Despite the simplicity of CMLs, the interaction between the chirp of DMLs and the OF produces a rich variety of effects such as FM-AM conversion, the suppression of transient chirp, the optical duobinary (ODB) effect, the dispersion supported transmission (DST) effect, minimum shift keying (MSK) format generation and vestigial sideband (VSB) effects. These effects can significantly extend the reach of DML-based transmission systems. In [7], 250 km of reach in C-band for 10 Gb/s NRZ transmission was achieved, which is ~ 3 times of the reach of EML.

In this work, using a CML formed by a 25-GHz class DML and a commercially available AWG filter, we demonstrate a real-time 100 Gb/s DMT transmission over wide dispersion range from - 65.6 ps/nm to + 48.6 ps/nm which is sufficient to support 400 Gb/s CWDM-4 transmission over 20 km.

2. Experimental setup

The experimental setup for 100 Gb/s IM/DD DMT transmission using a CML and a real-time DMT ASIC is shown in Fig. 1a. At the transmitter, 100G traffic at 4×25.78125 Gb/s (IEEE CAUI-4 compliant) was emulated,

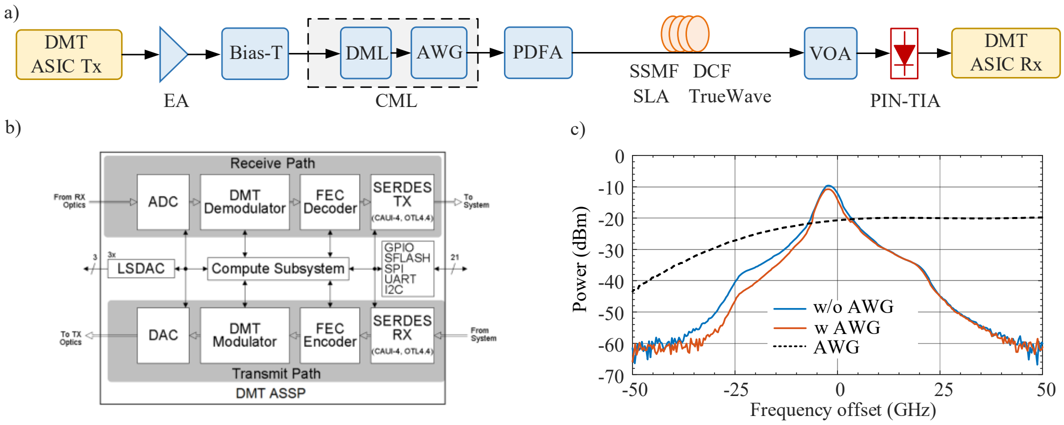

Fig. 1a) Experimental setup; b) – Basic block diagram of the 100 Gb/s DMT ASIC; c) – Optical spectra of modulated DMT signals with and without the AWG; The center wavelength is 1312.9 nm. DSP – digital signal processing; EA – electrical amplifier; VOA – variable optical attenuator; PDFA – O-band optical amplifier

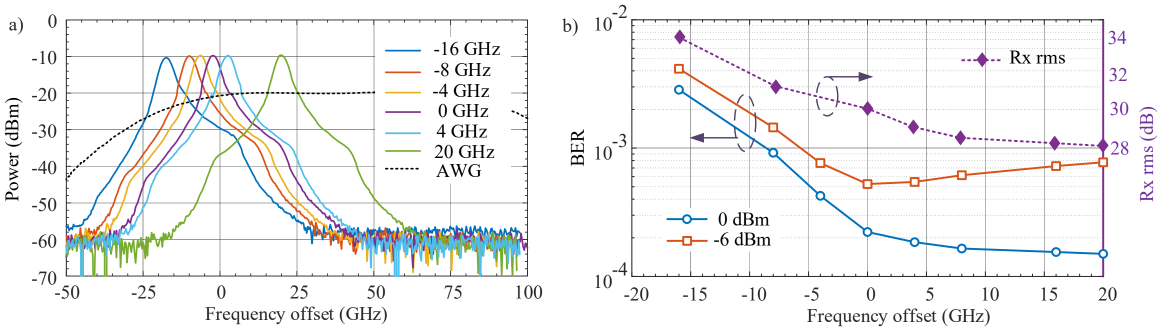

Fig. 2a) Optical spectra of 100 Gb/s DMT signal after AWG with various values of frequency offset related to the optimum DML frequency: b) – BER and Rx signal rms as the function of frequency offset (relative to the optimum DML frequency) in the B2B case

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. The DMT ASIC (Fig. 1b) includes 8-bits DAC and ADC with sampling rates up to 71 GS/s, 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 [5]. 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 were amplified using a 25-GHz RF driver before bias-adding for directly driving a 25-GHz class DML. The DML was biased at ~ 70 mA and stabilized by a thermal electric cooler (TEC) and its output is passed through a fiber-pigtailed athermal AWG (NTT Electronics) with ~ 125 GHz of passband bandwidth and an insertion loss of ~ 6 dB to form a CML. The optical spectra of the DMT signals with and without AWG where the DML emitted at ~ 1312.9 nm are shown in Fig. 1c. One can note the impact of the AWG on the signal spectrum, where the edge of left sideband was suppressed by ~ 7 dB.

To emulate the impact of fiber dispersion, combinations of SSMF (0.51 ps/nm/km), UltraWave SLA (2.83 ps/nm/km), TrueWave (-11.39 ps/nm/km) and dispersion-shifted fiber (DCF, 65.67 ps/nm/km) were used. In order to compensate for the fiber loss, a PDFA with a gain up to 30 dB was used. At the receiver, the signal was passed through a variable optical attenuator (VOA) which controlled the Rx signal power and then the signal was received by a PIN-TIA with a variable gain up to 3000 V/W. After that, the detected electrical signal was 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).

3. Experimental transmission results and discussions

First, we optimized the frequency offset between the DML and AWG by thermally tuning the DML. The impact of the frequency tuning on the optical spectra together with the spectral shape of the AWG are shown in Fig. 2a. Herein, 0 GHz offset represents the optimum configuration (~ 1312.9 nm) which provides the best transmission performance, which will be discussed later. The dependency of BER on the frequency offset in the B2B case is shown in Fig. 2b, where one can note that for a signal power value close to the Rx sensitivity (e.g. -6 dBm), there is an optimum frequency offset between the DML and AWG. When the Rx signal power is high (e.g. 0 dBm, at which the system performance is limited by the Tx rather than the Rx), increasing the frequency offset (reducing the filtering slope) improves the performance. When the modulated spectrum is located at the center of the AWG filter (BW ~ 90 GHz), there is no performance degradation or improvement. The dependency of Rx signal rms (or extinction ratio (ER) tracked by the DMT ASIC) on the frequency offset is depicted in Fig. 2b. Herein, both the Rx optical signal power and the TIA gain are fixed, so the impact of VSB filtering on the

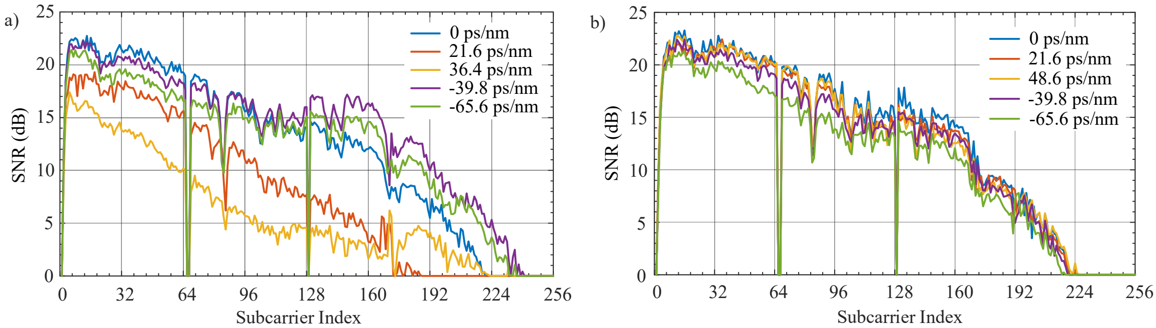

Fig. 3a) Measured SNR versus subcarrier index for 100 Gb/s DMT transmissions with conventional DML (w/o AWG); b) – Measured SNR versus subcarrier index for 100 Gb/s DMT transmissions with CML (with AWG)

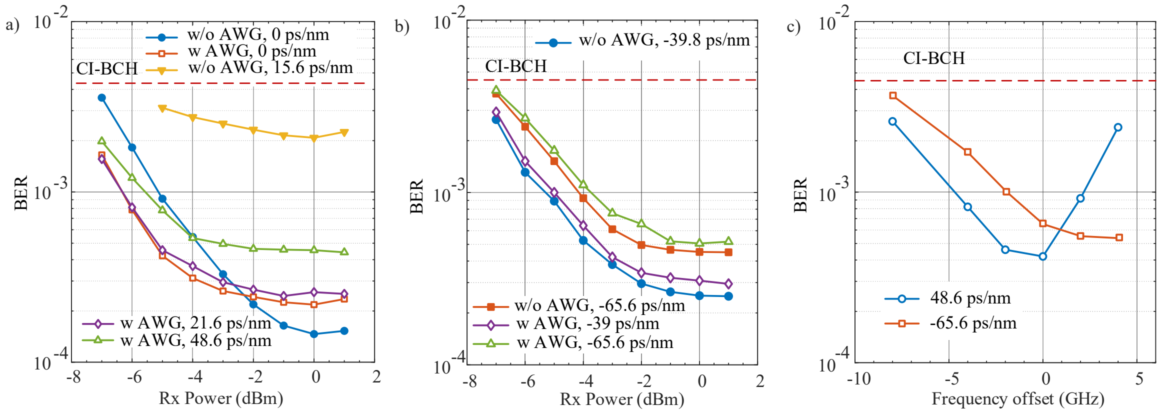

Fig. 4a) Sensitivity measurements for 100 Gb/s DMT transmissions with DML and CML in positive dispersion regime ; b) – Sensitivity measurements for 100 Gb/s DMT transmissions with DML and CML in negative dispersion regime; c) – Frequency offset tolerance for CML-based transmission at 0 dBm of Rx optical power

detected electrical signal power can be accurately observed. One can note that increasing the filtering slope (reducing the frequency offset) improves the received signal power and thus, the Rx SNR. However, this does not always improve the system's performance as shown in Fig. 2b.

To study the impact of CD on DMT transmissions, the measured SNR distributions among DMT subcarriers for systems with conventional DML and CML are depicted in Fig. 3. In Fig. 3a, one can note that positive dispersion has a strong impact on systems with conventional DML. At +21.6 ps/nm of dispersion, the averaged SNR per subcarrier reduces by ~ 4 dB and error free 100 Gb/s transmission could not be achieved. On the other hand, for CML transmission, even + 48.6 ps/nm of dispersion does not have a significant impact on the subcarriers' SNR, which clearly indicates an excellent dispersion tolerance. One can also note in Fig. 3a that negative dispersion has a moderate impact on the DML-based transmissions. In fact, up to -65.6 ps/nm, the negative dispersion even enhances the SNR of subcarriers from 128 to 256. This, however, is not the case for CML-based transmissions, which indicates that CML is less effective in the negative dispersion regime compared to the positive dispersion regime.

The sensitivity measurements for 100 Gb/s DMT transmissions with DML and CML in positive dispersion and negative regimes are depicted in Fig. 4a - 4b, respectively. In the B2B case, CML enhances the performance in the Rx noise limited regime due to the enhancement of the ER. However, as expected, there is a small penalty in the BER floor. For DML transmission, at + 15.6 ps/nm of dispersion the BER floor is already close to the CI-BCH limit. On the other hand, for CML transmission, excellent performance still can be achieved at +48.6 ps/nm. The sensitivity penalty at + 48.6 ps/nm for CML transmission is within 1 dB. For negative dispersion regime, DML shows better performance than CML for both -39.8 ps/nm and -65.6 ps/nm. Nevertheless, -65.6 ps/nm could be achieved with CML.

In Fig. 4c, the impact of frequency offset on CML transmissions at +48.6 ps/nm and -65.6 ps/nm is depicted. At +48.6 ps/nm, small performance variation is observed within ~ 6 GHz of frequency offset range (from -4 GHz to 2 GHz). This frequency offset tolerance indicates a TEC stabilization requirement of ~ 0.3°C for DML-AWG frequency locking, which can be comfortably achieved in practical implementations.

4. Conclusion

We have shown that CML can significantly improve the performance of 100 Gb/s DMT transmissions in the positive dispersion regime. Using a CML formed by a 25-GHz class DML and a commercial AWG, real-time 100 Gb/s DMT transmissions over -65.6 ps/nm to +48.6 ps/nm of dispersion has been demonstrated. This dispersion range is sufficient to support 400 Gb/s CWDM-4 transmission over 20 km.

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