# Frequency Chirp Reducing of a Colorless Laser Diode for 40-Gbit/s 256-QAM OFDM Transmission

**Cheng-Ting Tsai, Yu-Chieh Chi, and Gong-Ru Lin***
*Graduate Institute of Photonics and Optoelectronics, and Department of Electrical Engineering, National Taiwan University*
*No. 1, Roosevelt Rd, Sect. 4, Taipei 10617, Taiwan ROC*
**grlin@ntu.edu.tw*

**Abstract:** A wavelength controlled and frequency chirp reduced colorless laser diode is directly modulated by 256-QAM-OFDM data to achieve a high spectral efficiency of 8 bit/sec/Hz at 40 Gbit/s with an optimized BER of $3.7\times10^{-3}$.

**OCIS codes:** (320.1590) Chirping; (140.3518) Lasers, frequency modulated; (140.2020) Laser diode; (060.2330) Fiber optics communication; (140.3520) Lasers, injection-locked

## 1. Introduction

The directly modulated colorless laser diode (DMCL) with wavelength control is a cost-effective transmitter to implement dense wavelength-division-multiplexed passive optical network (DWDM-PON) due to its simple and compact structures [1]. By using the orthogonal frequency division multiplex (OFDM) data format with high spectral-usage efficiency, the DMCL can provide high data rate transmission in the DWDM-PON. However, the DMCL induced large frequency chirp could degrades the OFDM transmission performance. Although the frequency chirp can be effectively suppressed by biasing the DMCL at high level in view of previous works, the strong cavity effect in typical laser diode inevitably reduces the injection-locking efficiency during wavelength control. To release the cavity effect of the DMCL, a colorless laser diode with reduced front-facet reflectance has to be considered.

In this work, a directly modulated colorless laser diode with reduced frequency chirp is employed to carry the 256-QAM OFDM transmission at 40 Gbit/s. The frequency chirp reduction and the signal-to-noise ratio (SNR) enhancement of the wavelength controlled colorless laser diode are achieved by changing its DC-bias. The bit error rate (BER) contour plot of the received 256-QAM OFDM data is introduced to show the tolerance on the bias and the injection power. The spectral pre-leveling on the OFDM subcarrier amplitude further improves the SNR performance of the 25-km single-mode-fiber (SMF) transmitted 256-QAM OFDM data.

## 2. Experimental Setup

The testing architecture of the wavelength controlled and directly-modulated colorless laser diode for delivering 256-QAM OFDM transmission at 40 Gbit/s is shown in Fig. 1(a). The electrical 256-QAM OFDM data with 214 subcarriers and 5-GHz bandwidth was exported by an arbitrary waveform generator with a sampling rate of 12 GS/s, which was employed to directly modulate the colorless laser diode after passing through a linear pre-amplifier with 26-dB gain. To stabilize the wavelength, the colorless laser diode with a central wavelength of 1562 nm was operated at a temperature of 22°C. Such a colorless laser diode was injection-locked by a coherent master light source to perform the wavelength selection. After transmitting through a 25-km SMF, the injection-locked colorless laser diode carried 256-QAM OFDM data was received by a photodetector and amplified by a post-amplifier with power gain of 18 dB. Finally, the 256-QAM OFDM data was re-sampled by a digital signal oscilloscope at a sampling rate of 100 GS/s. The BER, the SNR and the error vector magnitude (EVM) of the received 256-QAM OFDM data were analyzed with a homemade demodulation program written by MATLAB.

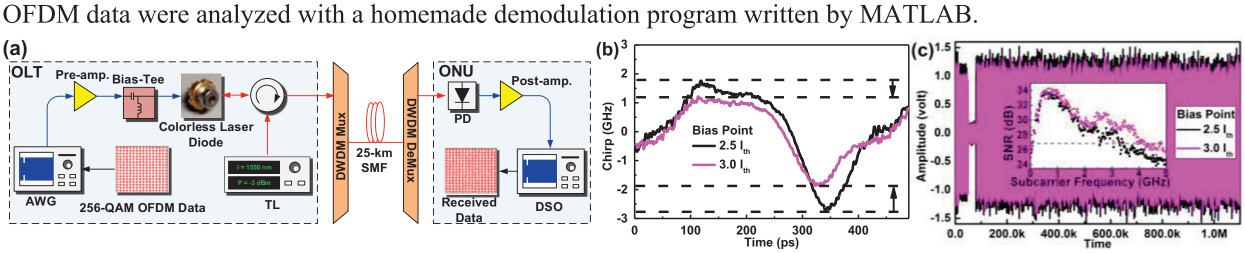


Fig. 1. (a) The testing architecture of the injection-locked and directly-modulated colorless laser diode for 256-QAM OFDM transmission; (b) The frequency chirp induced by the injection-locked colorless laser diode at different bias points; (c) The time-waveform and the SNR of the back-to-back transmitted 256-QAM OFDM data

## 3. Results and Discussions

As shown in Fig. 1 (b), the negative chirp is observed for the wavelength controlled colorless laser diode, which the peak-to-peak frequency chirp can be diminished from 4.5 to 3.1 GHz by raising the DC-bias from $2.5I_{th}$ to $3.0I_{th}$

(52 to 63 mA) at an injection power of 0 dBm. With increasing the DC-bias to $3.0I_{th}$, the frequency chirp induced amplitude fluctuation on the temporal waveform of the back-to-back transmitted 256-QAM OFDM data can be effectively suppressed, which concurrently improves the total SNR of the 256-QAM OFDM data from 27.3 to 28.7 dB, as shown in Fig. 1(c). In our case, the deep modulation depth at high DC-bias dominates the transmission performance of the wavelength controlled colorless laser diode carried 256-QAM OFDM data. The BER contour plot of the back-to-back transmitted 256-QAM OFDM data versus different bias currents and injection powers of the injection-locked colorless laser diode is shown in Fig. 2(a). By pre-amplifying the $V_{pp}$ of the OFDM data from 2.5 to 2.7 volts, the tolerant range of the bias current for obtaining the optimized BER of $<1.5\text{x}10^{-3}$ up-shifts from 49-56 to 65-70 mA, and the allowable injection power also enlarges from -3±2 to 0.5±2 dBm (see the arrow in Fig. 2(a)).

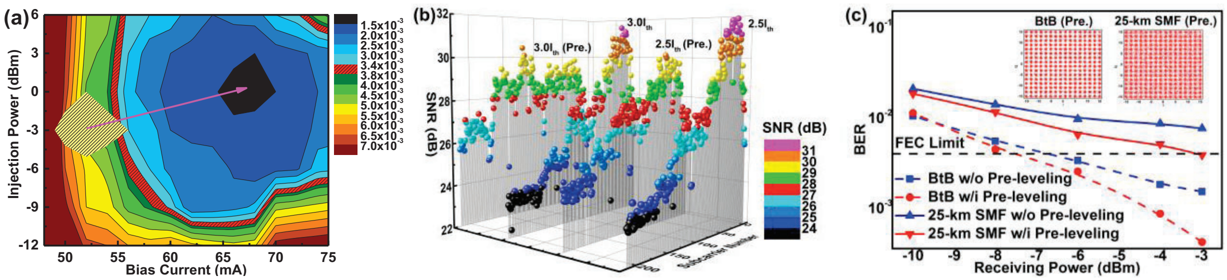


Fig. 2. (a) The BER contour plot of the back-to-back transmitted 256-QAM OFDM data versus different bias currents and injection powers; (b) The SNR versus different bias points of the 25-km transmitted 256-QAM OFDM data without and with pre-leveling; (c) The constellation plots and the BERs of the 256-QAM OFDM data before and after transmitting through the 25-km SMF.

The increased DC-bias of the colorless laser diode not only suppresses the waveform clipping of the pre-amplified 256-QAM OFDM data but also reduces the strong injection induced roll-off effect on the frequency response at low frequency region to enlarge the injection power range. Note that the BER of the back-to-back transmitted 256-QAM OFDM data can easily achieve the FEC criterion of $3.8\times10^{-3}$ when setting the DC-bias ranged between 55 and >75 mA and the injection power ranged between -10.6 and >+6 dBm. As shown in Fig. 2(b), when biasing the colorless laser diode at $2.5I_{th}$ under 0-dBm injection-locking, the total SNR of the 25-km SMF transmitted 256-QAM OFDM data is improved from 26.1 to 26.4 dB with OFDM subcarrier pre-leveling; however, it is failed to meet the FEC criterion defined SNR of 26.9 dB. That is, the output power of the injection-locked colorless laser diode at $2.5I_{th}$ DC-bias is insufficient to compensate the degradation of the OFDM subcarrier at high frequency region even using the pre-leveling technique. With increasing the DC-bias from $2.5I_{th}$ to $3.0I_{th}$, the total SNR of the pre-leveled 256-QAM OFDM data can further be improved from 26.4 to 27.4 dB. The constellation plots of the 256-QAM OFDM data before and after 25-km SMF transmission are shown in the inset of Fig. 2(c). After pre-leveling, the EVMs of the 256-QAM OFDM data at back-to-back and 25-km SMF transmission conditions are suppressed from 3.9% to 3.5% and from 5.1% to 4.5%, respectively. As shown in Fig. 2(c), the BER of the 256-QAM OFDM data before and after 25-km SMF transmission at a receiving power of -3 dBm can also be optimized to $4.1\times10^{-4}$ and to $3.7\times10^{-3}$ by the pre-leveling, respectively, and the power penalty can thus be suppressed to 4.5 dB.

## 4. Conclusion

The directly modulated 256-QAM OFDM transmission at 40 Gbit/s is demonstrated by the colorless laser diode with reduced frequency chirp and controlled wavelength. The negative peak-to-peak frequency chirp of the colorless laser diode can be diminished to 3.1 GHz by increasing its DC-bias to $3.0I_{th}$, which effectively suppresses the waveform distortion and the intensity fluctuation added on the modulated 256-QAM OFDM data. After reducing the frequency chirp, the total SNR of the back-to-back transmitted 256-QAM OFDM data carried by the single-mode controlled colorless laser diode is optimized from 27.3 to 28.7 dB. The $V_{pp}$ of the 256-QAM OFDM data is amplified to 2.7 volts so as to enhance the modulation depth after increasing the DC-bias of the colorless laser diode, and the DC-bias for optimized BER of $<1.5\text{x}10^{-3}$ extends from 49-57 to 65-70 mA with a tolerance of 5-mA under the requested injection power of 0.5±2 dBm. In addition to enlarge the DC-bias of the injection-locked colorless laser diode up to $3.0I_{th}$, the pre-leveling of the OFDM subcarrier amplitude is also performed to further improve the total SNR of the 256-QAM OFDM data up to 27.4 dB after 25-km SMF transmission. The BER and EVM can be optimized to $3.7\times10^{-3}$ and 4.5% for the 25-km transmitted 256-QAM OFDM data with pre-leveling, and the receiving power penalty is suppressed from >6.5 to 4.5 dB between back-to-back and 25-km transmission.

## 5. References

[1] M.-C. Cheng, Y.-C. Chi, Y.-C. Li, C.-T. Tsai, and G.-R. Lin, “Suppressing the relaxation oscillation noise of injection-locked WRC-FPLD for directly modulated OFDM transmission,” Opt. Express, **22,** 15724-15736 (2014).