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Pulsed laser-based optical frequency comb generator for high capacity wavelength division multiplexed passive optical network supporting 1.2 Tbps

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Abstract. An architecture for flattened and broad spectrum multicarriers is presented by generating 60 comb lines from pulsed laser driven by user-defined bit stream in cascade with three modulators. The proposed scheme is a cost-effective architecture for optical line terminal (OLT) in wavelength division multiplexed passive optical network (WDM-PON) system. The optical frequency comb generator consists of a pulsed laser in cascade with a phase modulator and two Mach-Zehnder modulators driven by an RF source incorporating no phase shifter, filter, or electrical amplifier. Optical frequency comb generation is deployed in the simulation environment at OLT in WDM-PON system supports 1.2-Tbps data rate. With 10-GHz frequency spacing, each frequency tone carries data signal of 20 Gbps-based differential quadrature phase shift keying (DQPSK) in downlink transmission. We adopt DQPSK-based modulation technique in the downlink transmission because it supports 2 bits per symbol, which increases the data rate in WDM-PON system. Furthermore, DQPSK format is tolerant to different types of dispersions and has a high spectral efficiency with less complex configurations. Part of the downlink power is utilized in the uplink transmission; the uplink transmission is based on intensity modulated on-off keying. Minimum power penalties have been observed with excellent eye diagrams and other transmission performances at specified bit error rates. © The Authors. Published by SPIE under a Creative Commons Attribution 3.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI. [DOI: [10.1117/1.OE.55.9.096106](https://doi.org/10.1117/1.OE.55.9.096106)]

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1 Introduction

The ongoing exponential growth and ever-increasing demand for broadband and triple play applications calls for optical frequency comb generation (OFCG) or optical multicarriers. Optical frequency locked and coherent multicarriers were studied in the past decade for their numerous applications such as reconfigurable optical pulse generator,¹ wavelength division multiplexing,²⁻⁵ and optical signal processing.⁶ Optical frequency comb (OFC) is deployed in numerous super channel systems due to its supportive property in optical transmissions supporting high data rates in long-distance systems.⁷ The very distinguished methods are coherent dense wavelength division multiplexing⁸⁻¹² and coherent optical orthogonal frequency division multiplexing.¹³⁻¹⁷ Due to the properties of fixed frequency spacing and phase relation between the generated comb lines of OFC, the OFCG can be called frequency locked.¹⁸ The method based on a mode locked laser does not offer free spectral range tunability and also suffers from cavity complexity.¹⁹ Several methods have been reported for optical frequency

locked multicarrier generation incorporating modulators in cascade²⁰⁻²⁵ and using recirculating frequency shifting (RFS) loop²⁶⁻³⁵ for frequency locked multicarrier generation. All the modulators used in cascade and RFS loops are driven by amplified RF clocks along with phase shifters and optical filters. The referred techniques used multisidebands, single-sidebands (SSB), or double-sidebands modulators in the RFS loops driven by a high powered electrical amplifier (EA). With high tone-to-noise ratio (TNR), SSB modulation techniques produced more multicarriers,^{27-30,36,37} which could be affected by the noise called amplified spontaneous emission (ASE).^{8,14,15} The ASE noise is suppressed by using optical filters in RFS loop³³ and in cascade configurations.³⁸ With the same fashion, in cascade configurations, the OFC is generated using phase modulator with dual-drive Mach-Zehnder modulator (DD-MZM)²⁰ with Mach-Zehnder modulator (MZM),²¹⁻²² and phase modulator (PM)²³⁻²⁵ only. DD-MZM based OFC is generated with hybrid interferometer modulator.³⁹ An OFC is generated with one electroabsorption modulated laser in cascade with a PM, which is driven by various amplified RF clocks with costly setup and limited number of comb lines.⁴⁰ Yet, the referred techniques have the major issues of extra costly components (high

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powered EA, phase shifter, and optical filter), more than one RF clock, a minimum number of comb lines, and greater amplitude excursions between comb lines.

On the other hand, due to striking demand of high bandwidth communication, optical access networks are highly desired due to provision of high bandwidth. TDM-PON was initially deployed, but that had the problem of limited bandwidth for each user and was not suitable for such revolutionary bandwidth-hungry applications. Therefore, the most suitable optical access network for next generation access network is wavelength division multiplexed passive optical network (WDM-PON). Entirely new network infrastructure is adopted in the WDM-PON network, thereby providing a separate wavelength domain for each user in the downlink and uplink transmissions.⁴¹ Due to allotment of separate bandwidth, it can provide enough bandwidth to all the future demands. However, for high capacity WDM-PON, numerous numbers of laser sources would be needed at the optical line terminal (OLT) side and due to the large number of laser sources, size and costs of the transmitter would be increased. Therefore, taking advantage of OFC due to its small size and low costs, OFC can be used as an optical source at OLT, replacing conventional setup in WDM-PON.

In this paper, we performed two main contributions. First, a new cost-effective technique is introduced for tightly spaced OFC, which is deployed at OLT side for high capacity colorless next generation WDM-PON system. Second, pulsed laser (PL) is designed for producing the maximum number of multicarriers in the given configurations where each comb line could carry 20-Gbps data rate in downstream/upstream transmissions. PL is connected in cascade with the PM and two MZMs. All the modulators are driven by RF clock without incorporating the phase shifter, EA, or some optical filter. Differential quadrature phase shift keying (DQPSK)-based transmitter is used across each carrier, supporting 20 Gbps. In the proposed technique, 60 comb lines are generated by using PL with one PM and two MZMs in cascade, which are driven by RF clock. In this way, the overall system capacity is 1.2 Tbps to 1200 Gbps. In OFCG, PL is used for the first time, where pseudorandom code is given at the input of laser for generating maximum number of comb lines. The frequency spacing between the generated comb lines is 10 GHz with least spectral power difference and high TNR of 40 dB. We deployed the generated OFC in WDM-PON system supporting high data rate both in downlink and uplink transmissions with good results in terms of specified bit error ratio, minimum power losses, and good eye diagrams. At network terminal, each carrier is filtered out by using Gaussian filters tuned at fixed frequency. DQPSK modulated data of 20 Gbps is transmitted through each carrier; DQPSK-based modulation can transmit 2 bits per symbol. QPSK can also transmit 2 bits per symbol but with a complex system. Conversely, DQPSK can provide a promising alternative but with a less complex system. Furthermore, it is preferable to use DQPSK modulation due to its tolerant behavior toward chromatic and polarization mode dispersion. All the data of 1.2 Tbps are multiplexed from 60 carriers and transmitted through single-mode fiber of 25 km span. At colorless optical network unit (ONU) side, each carrier is filtered out using optical filters along with 3-dB optical half power optical splitter, which is utilized for splitting the received signal into two halves.

Half of the signal is demodulated while half power is utilized for the uplink transmission at ONU side. As no dedicated light source is used at ONU side for uplink transmission, we successfully achieve a colorless transmission. Intensity modulated on-off-keying (IM-OOK) is used in the uplink transmission. Power penalties, eye diagrams, and bit error rates (BER) are the parameters, which are used for the analysis of the system.

2 Procedure for Pulsed Laser-Based Optical Frequency Comb Generation

2.1 Theoretical Presentation

The PL-based OFC generator is shown in Fig. 1. The PL source was designed by connecting optical Gaussian pulse generator (OGPG)^{42,43} with user-defined bit sequence generator (UDBSG).⁴⁴ Fixed numbers of bits with certain bits pattern were carefully generated before applying to the input of OGPG.

The sequence length of the UDBSG can be given as⁴⁴

$$N = T_w B_r, \quad (1)$$

where T_w is the global parameter called time window and B_r shows the bit rate. If the sequence of bits is shorter than N , the sequence will be repeated till it becomes equal to N . The OGPG creates an optical pulse modulated by UDBSG. For each bit at the input, the output optical power of OGPG can be given as⁴⁴

$$P(t) = B \cdot \left[A_p \cdot e^{-\frac{1}{2} \left(\frac{t-k}{T_{FWMN}} \right)^{2N}} + A_{\text{bias}} \right]. \quad (2)$$

In Eq. (2), B is the bit value, A_p is the peak to peak power, A_{bias} is the biasing parameter, k is the fitting coefficient, which is determined numerically for generating pulses with exact values of width T_{FWMN} of the signal while N is the order of Gaussian pulses ($N = 1$). The PL was connected with PM in cascade with two MZMs, where all the modulators are driven by microwave signal using no EA or phase shifter, therefore, making it cost effective. Using PL, we achieved 60 numbers of multicarrier signal, also called OFC, with large TNR and least excursions in the comb lines of the generated multicarrier proposing greater capacity in a typical WDM-PON system.

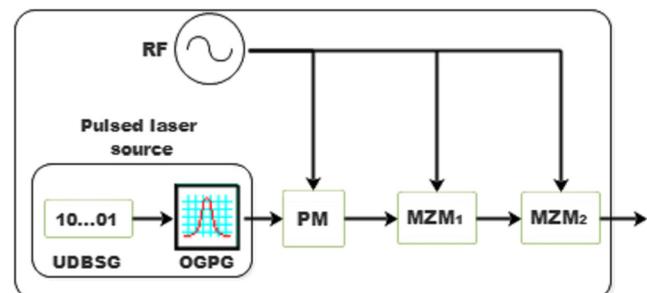


Fig. 1 Schematic presentation of the proposed OFC generator. (OFC, optical frequency comb). UDBSG, user-defined bit sequence generator; OGPG, optical Gaussian pulse generator; RF, radio frequency source; PM, phase modulator; MZM₁, Mach-Zehnder modulator-1; MZM₂, Mach-Zehnder modulator-2.

By assuming the output signal of GPG as $E_i[E_i = E_o \exp(j2\pi f_c t)]$ and the signal generated by RF source as $f_s(t) = TP_\pi \sin(2\pi f_s t)$, the output of PM can be given as

$$E_{\text{pout}} = E_o \exp(j2\pi f_c t) \exp(j\pi T \sin 2\pi f_s t). \quad (3)$$

After applying the Jacobi–Anger theorem in Eq. (3), the resultant expression can be given as

$$E_{\text{pout}} = E_o \sum_{n=-\infty}^{n=+\infty} J_n(\pi T) [\exp[j2\pi(f_c + n f_s)t]]. \quad (4)$$

The output of PM is connected with the following two MZMs, where the biasing voltages of the modulators are V_{bias1} and V_{bias2} of the two MZMs. The RF signals provided at the input of two MZMs can be given as $T_1 P_\pi \sin(2\pi f_s t)$ and $T_2 P_\pi \sin(2\pi f_s t + \Delta\varphi)$, respectively. The output of MZM₁ can be given as⁴⁵

$$E_{M_1\text{-out}}(t) = \frac{\sqrt{2}}{2} E_o \sum_{n=-\infty}^{\infty} \left[J_n\left(-\frac{\pi T_1}{M_{\pi 1}}\right) \cdot \exp\left(j\frac{\pi V_{\text{bias1}}}{M_{\pi 1}}\right) + J_n\left(\frac{\pi T_1}{M_{\pi 1}}\right) \right] \cdot \exp[j2\pi(f_c + n f_s)t]. \quad (5)$$

With the same fashion, the output of second modulator can be expressed as

$$E_{M_2\text{-out}}(t) = \sum_{n=-\infty}^{\infty} E_{n,k}(T_1, T_2, V_{\text{bias1}}, V_{\text{bias2}}, \Delta\varphi) \cdot \exp[j2\pi(f_c + n f_s)t]. \quad (6)$$

Finally, the spectrum at the output of MZM₂ can be written as

$$P_{M_2\text{-out}}(t) = \sum_{n=-\infty}^{\infty} |E_{n,k}(T_1, T_2, V_{\text{bias1}}, V_{\text{bias2}}, \Delta\varphi)|^2 \cdot \delta[f - (f_c + n f_s)t]. \quad (7)$$

In the above equations, $J_n(\dots)$ is the Bessel function of n 'th order. T shows the modulation index, which shows the rate of amplitude of RF signal to the half-wave voltage of the modulators used in the system, such as: $P_\pi, M_{\pi 1}, M_{\pi 2}$. Here P represents the PM while M shows MZM.

Equation (3) shows that the power of the carriers drops sharply, which becomes flattened by providing biasing voltages and RF signals. The flattened optical spectrum is shown

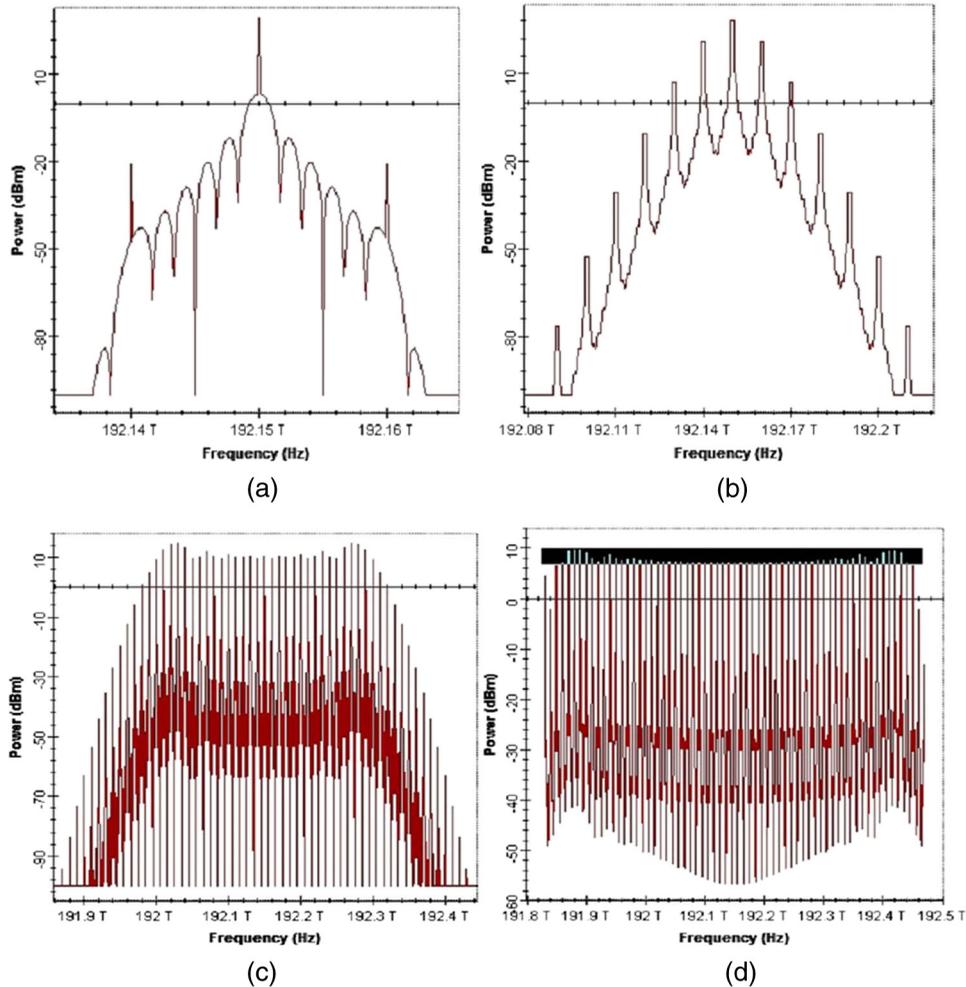


Fig. 2 Pulsed laser-based OFC generation. (a) Output of PL, (b) output of PM, (c) output of first Mach–Zehnder modulator, and (d) output of second Mach–Zehnder modulator.

in Eq. (7), where $E_{n,k}(T_1, T_2, V_{bias1}, V_{bias2}, \Delta\varphi)$ is the n 'th order variable for $T_1, T_2, V_{bias1}, V_{bias2}$, and $\Delta\varphi$. The frequency tones at the sidebands can be suppressed by the following mathematical condition:

$$E_{n,k}(T_1, T_2, V_{bias1}, V_{bias2}, \Delta\varphi) = \begin{cases} C(C \neq 0) & n = -30:30 \\ 0 & \text{others} \end{cases} \quad (8)$$

In Eq. (8), various results can be obtained by adjusting different values of $T_1, T_2, V_{bias1}, V_{bias2}$, and $\Delta\varphi$.

2.2 Simulation Results of the Proposed Optical Frequency Comb Generator

PL is designed by connecting UDBSG and optical GPG. The length of the bit stream is carefully selected for generating maximum number of comb lines (carriers). The bit rate of UDBSG is recorded/kept as $1e+010$. The frequency of the OGPG is kept at 192.15 THz with its power equal to 18 dBm. The chirp factor and sample rate of OGPG is 0 rad/s and $6.4e+011$, respectively. Frequency of the RF source is fixed at 10 GHz with same sample rate as in OGPG. The iteration of RF source and PL is 1. The half-wave voltage, bias voltage, extinction ratios, and symmetry factor of the modulators are carefully selected.

Figure 2(a) shows the output of the PL, which is obtained by connecting UDBSG and OGPG. As mentioned, the OGPG produced some pulses depending on the UDBS. The central frequency of the OGPG have many weaker sidebands having power less than -20 dBm, which are a bit energized and amplified by passing it through PM, where RF is also provided as the driving signal. Figure 2(b) shows the output of PM. Two MZMs were used to make a flattened optical comb with least amplitude difference. The first MZM

gave some flattened comb lines and the amplitude difference is still high, yet there remain many weak sidebands with less power, as shown in Fig. 2(c). By connecting second MZM in cascade with the first MZM, the output becomes flattened with least amplitude excursions in the final spectrum and high TNR as shown in Fig. 2(d). The amplitude difference is 0.7 dB and TNR is found to be ~ 40 dB. The frequency spacing for generating the OFC is 10 GHz. The OFCG ranges from 191.84 to 191.82 THz with frequency spacing equal to 10 GHz, providing a bandwidth around 0.5 THz.

3 Operational Analysis of Optical Frequency Comb in High Capacity Access Network-Based WDM

In this article, new arrangements are presented for cost-effective OLT in typical WDM-PON system. The proposed OLT is based on OFC, which is generated by deploying PL in cascade with PM and two MZMs, where all the modulators are driven by RF clock of 10 GHz. After deploying the proposed OFC in WDM-PON system, resulted WDM-PON setup supports data rate of 1.2 Tbps. In conventional WDM-PON system, laser sources/laser array were required in providing such a high capacity system, which was very expensive. By deploying PL in generating the multicarrier scheme, we received a large number of carriers ~ 60 with minimum fluctuation difference ~ 0.7 dB and high TNR (~ 40 dB). With 10-GHz frequency spacing, each carrier in the generated OFC can support DQPSK-based modulated signal of 20 Gbps. In this way, we achieved very high capacity data rate of 1.2 Tbps (~ 1200 Gbps) in WDM-PON system with a single laser source (PL). Figure 3 shows the schematic presentation of the proposed high capacity WDM-PON system. PL-based OFC can entertain 60 users in a full duplex transmission, where each user's data is 20 Gbps. The results of the proposed architecture are in good agreement with the theoretical analysis, thus showing the applicability

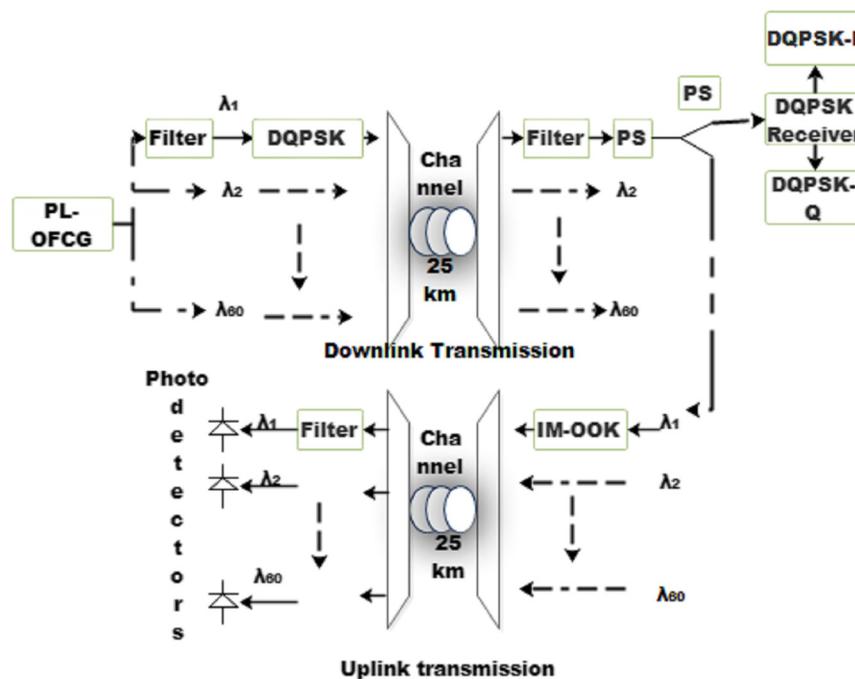


Fig. 3 Schematic presentation of high capacity full duplex WDM-PON system. PL-OFCG, PL-based OFC generator; DQPSK, differential quadrature phase shift keying; PS, power splitter; IM-OOK, intensity-modulated on-off keying.

of the proposed model in WDM-PON system. After generating PL-based OFC, erbium-doped amplifier is used to amplify the comb lines to some extent. Each carrier is filtered at certain frequency with the help of optical filter at OLT side. The frequency spacing between each adjacent carrier is equal to 10 GHz. DQPSK-based modulated data are carried by each carrier frequency and the multiplexed data from all the carriers is transmitted over single-mode fiber span of 25 km. After receiving the specified data at ONU, optical filters are used to detach every user's data for demodulation. As shown in Fig. 3, half power splitters of 3 dB are used to split the received signal into two halves.

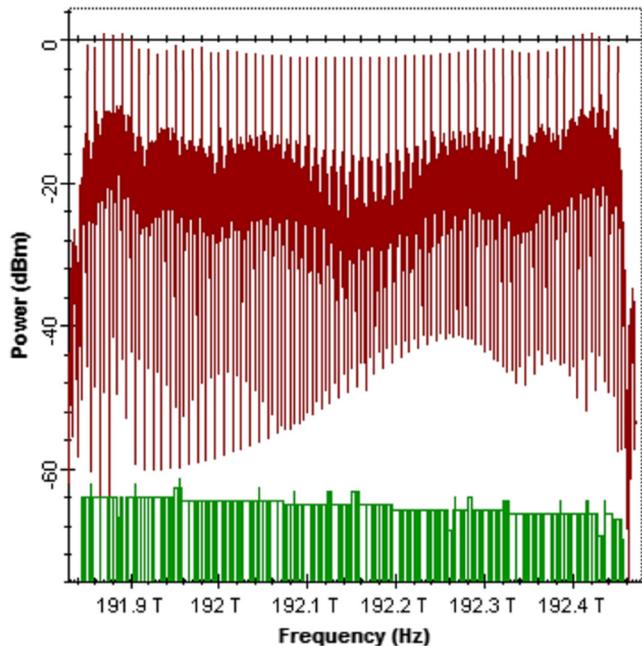


Fig. 4 Multiplexed signal of 1.2 Tbps before injecting into the fiber with the lowest noise figure.

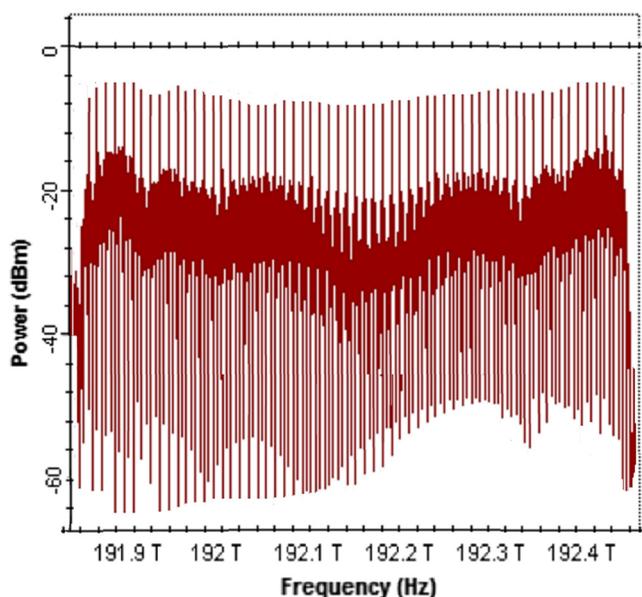


Fig. 5 Received multiplexed optical signal at ONU side with minimum loss.

First half power of the signal is used in the DQPSK-based demodulation while the second is used as a light source for uplink transmission using IM-OOK. DQPSK is applied at OLT side for increasing the capacity of the proposed WDM-PON system.

In optical communications, duobinary and DPSK-based modulation techniques are used, which can transmit 1 bit per symbol only. On the other hand, QPSK can transmit 2 bits per symbol, decreasing the symbol rate to the half of bit rate and requiring bandwidth equal to one-fourth of the bit rate.^{46,47} In QPSK, the major issues are the increase in system complexity and requirement of high SNR. DQPSK provides the same promising performance as QPSK does but with reduced system complexity. DQPSK provides better performance and is tolerant to nonlinear effects such as polarization mode dispersion and chromatic dispersion; also, it can provide high data rate, spectral efficient, and multilevel transmission. Because of these above stated properties, it can be used in long-distance optical communication. DQPSK

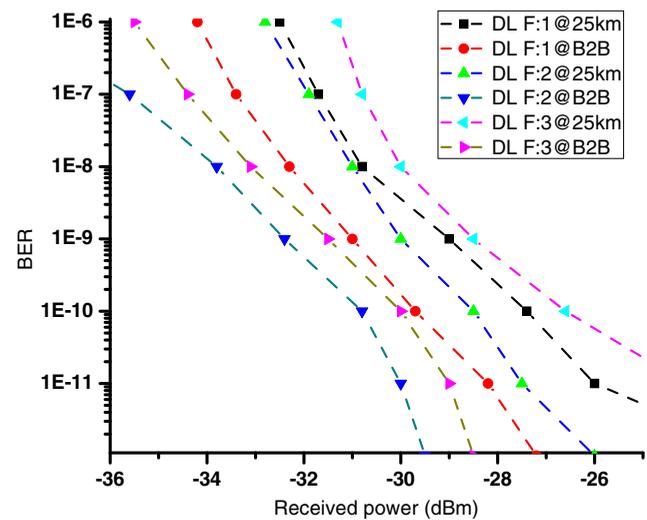


Fig. 6 Received optical power versus different BER for downlink transmission (@DQPSK-I).

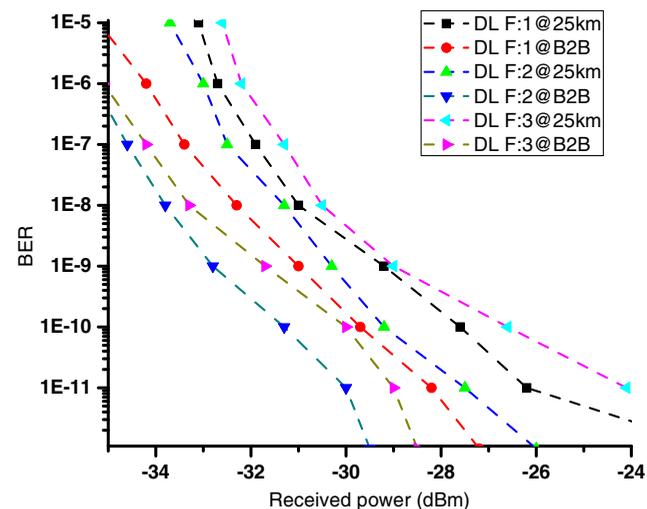


Fig. 7 Received optical power versus different BER for downlink transmission (@DQPSK-Q).

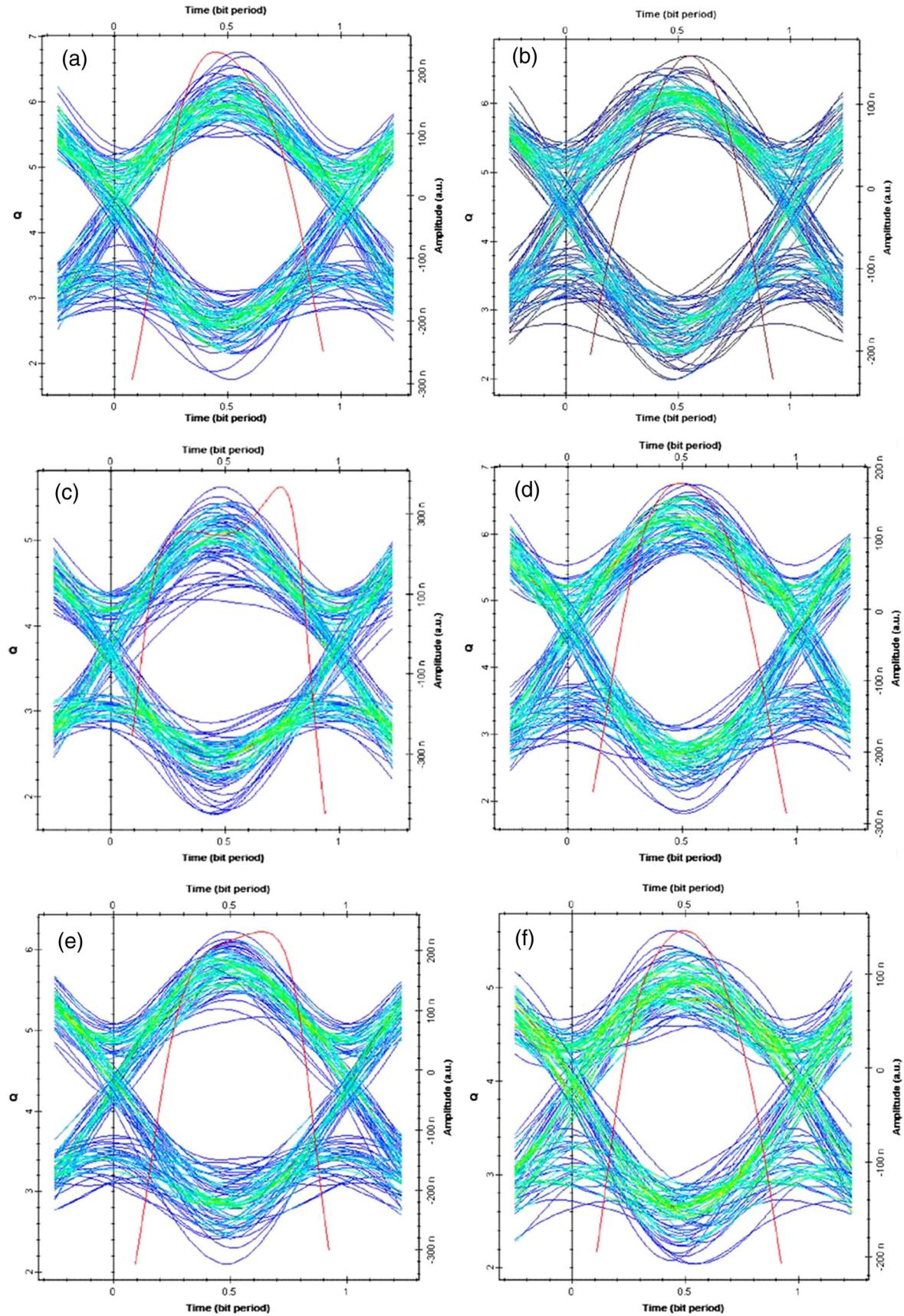


Fig. 8 Eye diagrams for downlink transmission (with good openings) shows high transmission performance of the selected frequencies. (a) Eye diagram for frequency-1 (DQPSK-I), (b) eye diagram for frequency-1 (DQPSK-Q), (c) eye diagram for frequency-2 (DQPSK-I), (d) eye diagram for frequency-2 (DQPSK-Q), (e) eye diagram for frequency-3 (DQPSK-I), and (f) eye diagram for frequency-3 (DQPSK-Q).

requires half spectral occupancy as compared to DPSK. A 20-Gbps DQPSK-based signal is generated by using pseudorandom binary sequence, and precoder is used for serial to parallel conversion. Precoder divides the signal into two 10-Gbps sequences for generating in (I-phase) and quadrature (Q-phase) phases of DQPSK signal.

3.1 Downlink and Uplink Transmission Performance and Results

In the proposed technique, the PL-based generated carriers are deployed in the WDM-PON system. Optical filters are used to isolate the carriers of specific tones before modulating with users' data. Modulated data from 60 DQPSK based transmitters are multiplexed before transmitting through 25-km single-mode fiber span. Figure 4 shows the multiplexed signal of 1.2 Tbps with the minimum noise figure at the bottom in green. Finally, the overall 1.2-Tbps data from 60 users is transmitted through the mentioned fiber span. The transfer function of the filter used at transmitter's side can be given as

$$H(f) = \begin{cases} \alpha, & f_c - B/2 \leq f \leq f_c + B/2 \\ d, & \text{otherwise} \end{cases} \quad (9)$$

$H(f)$ shows the transfer function of the optical filter, α is the parameter for insertion loss, d is the depth of the filter, f_c is the central frequency, and B is the bandwidth of the filter. Once the carriers are separated by means of the filters, each carrier is passed through DQPSK transmitter. The frequency range of the generated carriers is from 191.85 to 192.45 THz. The frequency spacing between all the carriers is 10 GHz, where the 60 comb lines have least excursions in its comb lines ~ 0.7 dB and high TNR ~ 40 dB.

DQPSK-based modulation technique is used to modulate 20-Gbps user data. DQPSK transmitter includes PRBS generator, a precoder, and two MZM modulator drivers. DQPSK-based signal is generated by using PRBS with bit rate ~ 20 Gbps while a precoder is used as a serial to parallel converter divide the signal into two 10-Gbps sequences with four different binary states. Each 10-Gbps sequence is passed through an MZM (both connected in cascade) for generating the in-phase and quadrature-phase (I, Q) of the DQPSK signals. I and Q phases correspond to four phases ($0, \pi/2, \pi, 3\pi/2$) with four given binary patterns (00, 01, 10, 11). Precoder is required here because it is reducing hardware complexity, avoiding iterative decoding, and bringing accuracy at ONU side for detection. In DQPSK, the phase change shows the encoded symbol information from one period to the other instead of absolute phase. The receiver detects the change in the phase rather than the absolute value of the phase. Encoding of the symbols avoids the essential condition of synchronized local carrier.

The multiplexed signal of 1.2 Tbps is transmitted through single-mode fiber of 25 km. In our simulations, the dispersion of fiber is kept at 16.75 ps/nm/km. Effective core area and differential group delay are selected as $80 \mu\text{m}^2$ and 0.2 ps/km and dispersion slope is kept at 0.075 ps/nm²/km. The responsivity of photodetector and dark current is set as 1 A/W and 10 nA, respectively, while attenuation of the fiber is 0.2 dB/km. Figure 5 shows the received signal on ONU side with minimum channel losses. On ONU side, fork is used with the splitting ratio of 1:60 to provide the received signal at each user end.

Following the fork, optical Gaussian filters are used of specific band to recover the data of each user sent at OLT side. The transfer function of the filter can be given as

$$H(f) = \alpha e^{-\ln \sqrt{2} \left(\frac{2(f-f_c)^2}{B} \right)} \quad (10)$$

In Eq. (10), $H(f)$ represents the transfer function of the filter with insertion loss equal to α , f_c is the central frequency, and B is the bandwidth. The order of the filter is represented by N whereas f represents the frequency. After introducing filters, power splitters (of 3 dB) are used with each filter to tap off the downlink signal into two halves, where first half of the downlink signal is received by DQPSK-based receiver. DQPSK receiver consists of two Mach-Zehnder delay interferometers (MZDI) and two phase shifters. MZDIs are used for coherence and signals cancellation with a delay T equal to $2/B$ for producing the phases at I and Q branches, while the phase shifts are $\pi/4$ and $-\pi/4$ and B shows the transmission bit rate. Two well-adjusted detectors are applied separately for the phase difference at I and Q arms of the DQPSK receiver. A low pass filter is used at the output of both arms for these I and Q phases. We selected three random channels for our observations during the experiments. The frequencies of the selected tones were 191.9, 192.05, and 192.2 THz. The results were observed with the help of optical received powers at ONU side, power penalties and eye diagrams at specified bit error ratios; the power penalties across the said channels are calculated at 10^{-9} BER. The power penalties both at I and Q arms of DQPSK can be found by comparing the results for the received powers by calculating them using fiber (single-mode fiber ~ 25 km) and in back to back (B2B) configuration (without fiber). The noted power penalties of I branch at DQPSK receiver for the mentioned channels are calculated to be 2, 2.4, and 3 dB. Figure 6 provides the graphical representation of the optical received powers versus different BERs. Similarly, for the Q branch, the calculated power penalties are found to be 1.8, 2.5, and 2.7 dB. Figure 7 shows the graphical relation between BER and different power penalties. Such minimum power penalties, both for I and Q phases of DQPSK receiver demonstrate

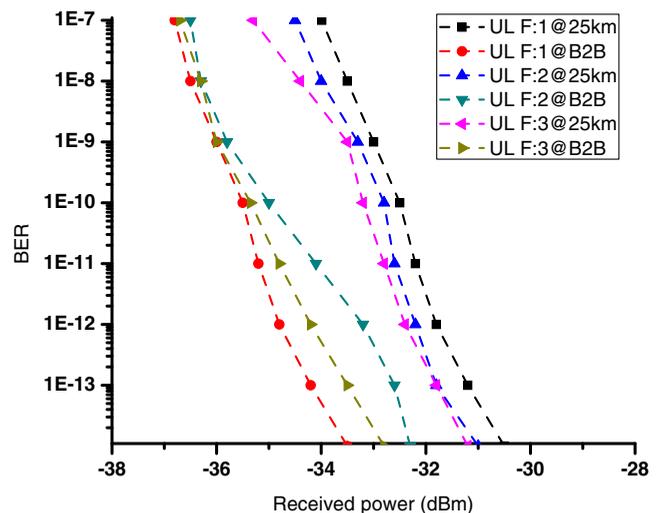


Fig. 9 Received optical power versus different BER for uplink transmission using IM-OOK.

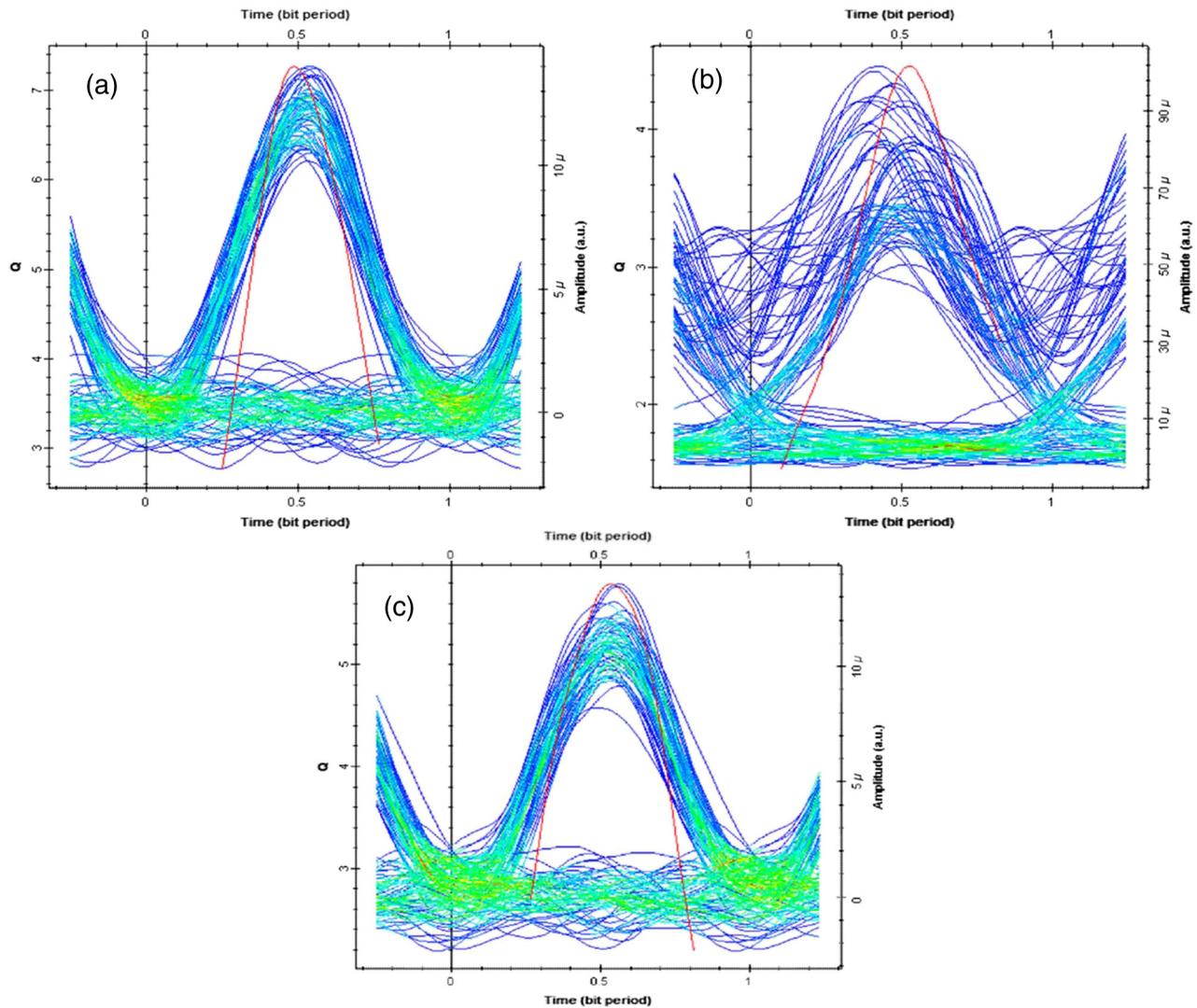


Fig. 10 Eye diagrams during uplink transmission (with good openings) shows the transmission performance. (a) Eye diagram for frequency-1 during uplink transmission, (b) eye diagram for frequency-2 during uplink transmission, and (c) eye diagram for frequency-3 during uplink transmission.

the applicability of the proposed PL-based OFC in supporting a high capacity WDM-PON system. Figure 8 shows the eye diagrams of the selected channels for I and Q branches at receiver side shows the excellent performance of the system [Figs. 8(a)–8(f)].

The optical power splitters are used at ONU side for tapping the incoming signal into two halves. Figure 5 shows the signal received at ONU side with minimum power loss during the channel. As discussed earlier, first half of the signal is demodulated by the DQPSK receiver while the second half is used in the uplink transmission using IM-OOK. In the uplink transmission, at ONU side, the data of 1.2 Tbps from 60 users are collected and transmitted across the fiber span of 25 km, having the same specifications used in the downlink transmission; colorless transmission is achieved as no extra dedicated light source is used at ONU side. The results have been investigated for downlink transmission in terms of received optical powers, eye diagrams, power penalties, and BER of the given four channels. The power penalties across the selected channels are found at BER of 10^{-9} with the help of numerous tests conducted against B2B and 25-km fiber.

The power penalties across the selected three channels were found to be 3, 2.5, and 2.8 dB. Figure 9 shows the graph of received optical power versus BER in the uplink transmission. Figure 10 shows the eye diagrams of the aforementioned selected channels.

4 Conclusion

In the current study, a new OLT arrangement-based OFC with a decreased deployment cost has been proposed in comparison with state-of-the-art techniques. With high bandwidth of around 0.5 THz, the generated OFCG was successfully deployed in achieving high capacity WDM-PON system of 1.2 Tbps. PL source was used for the first time in generating the OFC. One PM and two MZM were connected in cascade mode with PL driven by RF signal of 10 GHz. With 10-GHz frequency spacing, the 60 generated OFC lines have the least power spectral difference of 0.7 dB and high TNR ~ 40 dB. At OLT side, each carrier was successfully deployed in transmitting 20-Gbps data by using DQPSK-based transmitter. DQPSK has been utilized due to its spectral efficiency with least system complexity as

compared to QPSK. Similarly, it can carry 2 bits per symbol as compared to DPSK, which has the capacity of 1 bit per symbol as obvious from the previous techniques. Multiplexed signal of overall 1.2 Tbps was transmitted across single-mode fiber of 25 km, which was received on ONU side. Half power splitters are used for splitting the signal into two. Part of the power in downlink signal was utilized for uplink transmission, using IM-OOK using fiber span of 25 km. In the future, we can deploy the same OFC in a long reach WDM-PON system in single feeder fiber setup.

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