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Optical Multicarrier Frequency Generator Based Ultra Dense Passive Optical Network using Different Cascaded Modulators Configurations

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A B S T R A C T

Passive optical network (PON) is prominent technology to serve multiple users with high speed and fulfill the ever-increasing demands. Comb generation or multicarrier generation is a popular approach to make the device cost-effective since it removes the need for multiple lasers in multiplexing-based systems for wavelength division. In this work, ultra dense PON is presented using optical multicarrier technique which provides 700 Gbps capacity, high tone-to-noise ratio (TNR) and lower difference in amplitude between different carriers. Three modulators are taken into account in various configurations, such as the Mach-zehnder modulator, the amplitude modulator and the phase modulator, in order to generate multicarrier. With the proposed technique (Amplitude Modulator + Mach-zehnder Modulator + Amplitude Modulator), <0.8 dB amplitude difference among 70 multicarrier and TNR of 53 is achieved. Downstream and upstream transmission of proposed PON system is analyzed at different distance in terms of Q factor, BER and received power. Results revealed that system in both direction works for 30 km link distance within acceptable range of BER (10^{-9}).

Keywords: PON, TNR, MZM, AM, PM, Comb Generation

1. Introduction

Propelling internet services now imposes stress on optical networks and pushes them to expand bandwidth by adding more and more channels. Multiplexing of the wavelengths is attracting attention because of ever-increasing capacity demand of users [1]. For deployment of access networks, operators are encouraged to invest on a PON infrastructure. Incorporation of PON offers a good solution to multi-users ever increasing data hunger because its user handling capacity and longer transmission distances. Wavelength division multiplexing (WDM) PON are getting attention of researcher because of flexibility, transparency and high capacity. But wavelength division multiplexing (WDM) system has limitation of high cost due to requirement of laser sources equal to channels [2]. In order to reduce the cost of WDM systems and to generate multiple carries with single laser, Optical multi carrier generation (OMCG) is required [3]. Researchers and scientist accentuated on OMCG because it can enhance the speed, capacity and performance of the system. In the past, many studies are reported in the context of OMCG and most of them concentrated on the more generation of carriers, low amplitude difference, and high TNR [4] [5]. From the reported works, three major issues are encountered such as (1) Low TNR (2) High amplitude difference among generated carriers (3) Short reach of OMCG carriers in PON systems. After the extensive study of literature, it is perceived that there are three major OMCG generation techniques such as re-circulating frequency shifting loop (RFS) using different modulators and filters, and cascading of modulators [6] [7] [8]. In [9], a novel optical multicarrier generation system with cascaded modulators such as amplitude modulator and two mach-zehnder modulators was presented which offered TNR of 40 dB with the amplitude difference of 1 dB. Total 61 multi-carriers were generated and OMGC technique was employed in PON having capacity of 570 Gbps over 25 km with 10^{-9} BER. DPSK was used in upstream and downstream and frequency spacing of 30 GHz was taken at 10 Gbps.

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In this work, WDM-PON using 70 carriers at ultra dense (10 MHz) frequency spacing using optical multi carrier module is proposed. Total capacity of system is 700 Gbps because 10 Gbps data speed is given to each wavelength. Proposal of economical and high TNR carriers is good area of research and therefore in this work different arrangement of three modulator such as Mach-Zehnder Modulator (MZM), Amplitude modulator (AM) and Phase modulator (PM) is demonstrated at 10 Gbps.

2. System Setup

For the realization of OMCG in PON system using different cascaded modulators, Optiwave optisystem software is used. Proposed work is divided into two sections such that (1) generation of OMCG (2) deployment of OMCG in PON.

2.1 Generation of OMCG

For the generation of ONCG, three different configurations of modulators are investigated such as AM+MZM+AM, AM+MZM+PM and AM+MZM+MZM. Detailed discussion is as follows:

2.1.1 AM+MZM+AM

There are two amplitude modulators at first and third position and Mach-zehnder modulator is between them. A radio frequency signal is generated from sine generator in the simulation and biased at 35 GHz having amplitude of 2 a.u., bias of 3 a.u. and nil phase. A laser with 15 dBm input power is selected having narrow linewidth of 0.1 MHz. Frequency of carrier is 192.15 THz with zero initial phase. A 1x3 fork is incorporated in the system to generate three mirror images of incoming RF signal. One arm of fork is given to amplitude modulator which is having modulation index 1. An optical spectrum analyzer to check carriers is employed after amplitude modulator. Amplitude modulator is followed by mach-zehnder modulator and also getting drive of RF signal from fork. MZM modulator has two arms such that one arm gets drive RF signal and other gets amplified RF signal with the help of electrical gain amplifier. Parameters of MZM are given in Table 1. Optical spectrum analyzer (OSA) is placed after MZM to visualize increase of decrease in carriers. After MZM, in this arrangement amplitude modulator is chosen and gets drive from RF signal.

Table 1 Parameters of MZM modulator

Parameters	Values
Extinction Ratio	40 dB
Switching Bias Voltage	0.1 V
Switching RF Voltage	0.1 V
Bias Voltage 1	20 V
Bias Voltage 2	20 V
Modulation Voltage 1	4.5 V
Modulation Voltage 1	4.5 V

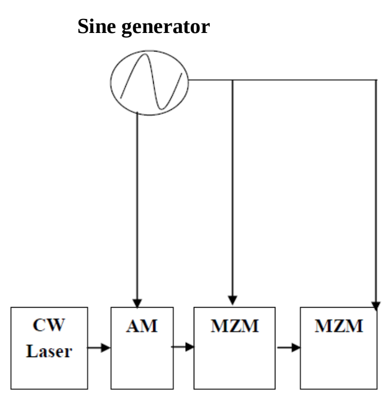


Figure 1 Simulation setup of AM+MZM+AM arrangement

Modulation index is 1 and OSA is employed which is followed by erbium doped fiber amplifier of gain 5 dB. Tone to noise ratio and amplitude difference of carriers can be seen from WDM analyzer after amplifier. Figure 1 represents the simulation diagram of AM+MZM+AM modulator arrangement.

2.1.2 AM + MZM + PM

Further in second case, all the modulators are different from aforementioned case such as Amplitude Modulator + Mach-zehnder Modulator + Phase Modulator as shown in Figure 2. First modulator is amplitude modulator which is followed by MZM modulator and last is phase modulator. A radio frequency signal is generated from sine generator in the simulation and biased at 35 GHz having amplitude of 2 a.u., bias of 3 a.u. and nil phase as discussed in first case. A laser with 15 dBm input power is selected having narrow linewidth of 0.1 MHz. Frequency of carrier is 192.15 THz with zero initial phase. A 1x3 fork is incorporated in the system to generate three mirror images of incoming RF signal. One arm of fork is given to amplitude modulator which is having modulation index 1. An optical spectrum analyzer to check carriers is employed after amplitude modulator. Amplitude modulator is followed by mach-zehnder modulator and also getting drive of RF signal from fork. MZM modulator has two arms such that one arm gets drive RF signal and other gets amplified RF signal with the help of electrical gain amplifier. Parameters of modulators are given in Table 2. Optical spectrum analyzer (OSA) is placed after MZM to visualize increase of decrease in carriers. After MZM, in this arrangement phase modulator is chosen and gets drive from RF signal. Phase deviation of phase modulator is 90 degree and OSA is employed which is followed by erbium doped fiber amplifier of gain 5 dB. Figure 2 depicts the simulation diagram of AM+MZM+PM modulator arrangement.

Table 2 Parameters of AM + MZM + PM

Parameters	Values
MZM Extinction Ratio	40 dB
MZM Switching Bias Voltage	0.1 V
MZM Switching RF Voltage	0.1 V
MZM Bias Voltage 1	20 V
MZM Bias Voltage 2	20 V
MZM Modulation Voltage 1	4.5 V
MZM Modulation Voltage 1	4.5 V
Amplitude modulator modulation index	1
Phase modulator phase deviation	90 degree

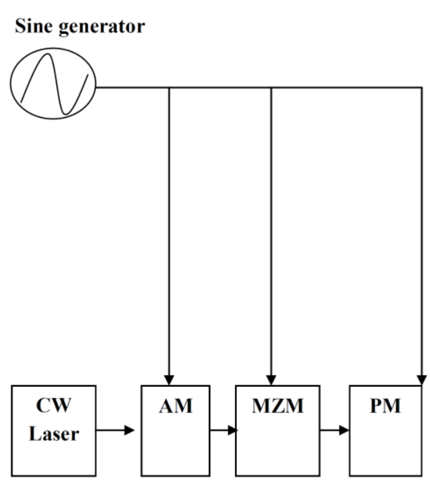


Figure 2 Simulation setup of AM+MZM+PM arrangement

2.1.3 AM + MZM + MZM

Similarly, in this case also, first modulator is amplitude modulator which is followed by two MZM modulators. A radio frequency signal is generated from sine generator in the simulation and biased at 35 GHz having amplitude of 2 a.u., bias of 3 a.u. and nil phase as discussed in second case. A laser with 15 dBm input power is selected having narrow linewidth of 0.1 MHz. Frequency of carrier is 192.15 THz with zero initial phase. A 1x3 fork is incorporated in the system to generate three mirror images of incoming RF signal. One arm of fork is given to amplitude modulator which is having modulation index 1. An optical spectrum analyzer to check carriers is employed after amplitude modulator. Amplitude modulator is followed by mach-zehnder modulator and also getting drive of RF signal from fork. Output of MZM 1 is then fed to MZM 2 which is also getting drive from same RF signal. Parameters of modulators are given in Table 3. Optical spectrum analyzer (OSA) is placed after MZMs to visualize increase of decrease in carriers. OSA is followed by erbium doped fiber amplifier of gain 5 dB. Figure 3 represents the simulation diagram of AM+MZM+PM modulator arrangement.

Table 3 Parameters of modulators AM + MZM + MZM

Parameters	Values
MZM Extinction Ratio	40 dB
MZM Switching Bias Voltage	0.1 V
MZM Switching RF Voltage	0.1 V
MZM Bias Voltage 1	20 V
MZM Bias Voltage 2	20 V
MZM Modulation Voltage 1	4.5 V
MZM Modulation Voltage 1	4.5 V
Amplitude modulator modulation index	1

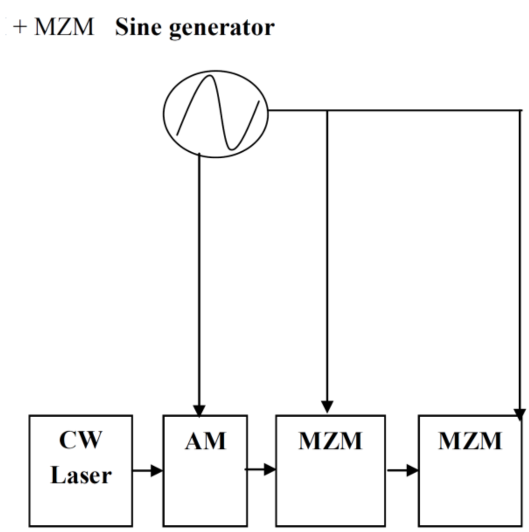


Figure 3 Simulation setup of AM+MZM+PM arrangement

2.2 Deployment of OMCG in PON

Wavelength division passive optical network is proposed with OMCG as shown in Figure 4. A data tributary of 10 Gbps is operated at each pseudo random bit sequence generator. PRBS is used to generate logic level of 1's and 0's. This binary data stream is coded with differential phase shift keying modulation (DPSK). A single laser source with 192.15 THz frequency at 0.1 MHz linewidth is employed in the OMCG unit to generate multiple carriers from single laser. Laser signal then passed through AM + MZM + AM. A radio frequency signal is generated from sine generator in the simulation and biased at 35 GHz having amplitude of 2 a.u., bias of 3 a.u. and nil phase. A 1x3 fork is incorporated in the system to generate three mirror images of incoming RF signal and these frequencies are given to each modulator. Optical spectrum analyzers are placed after each modulator to check the carriers. An EDFA with 5 dB gain is used after cascaded modulator and WDM analyzer is place after that to check the final carriers, TNR and amplitude difference. A de-multiplexer starting from frequency 191.83 THZ is incorporated after OMCG module to differ the carriers 10 MHz apart. De-multiplexer is succeeded by multiplexer to convert 70 signals into one which is further fed to optical bi-circulator. Here work of circulator is to provide isolation between downstream and upstream signals. Bi-directional single mode fiber is getting signal from optical circulator and having length 30 km. Attenuation of optical fiber is 0.2 dB/km and pulse broadening value is 17 ps/nm/km. De-multiplexer separates the wavelengths after SMF and here each wavelength is divided into two equal parts by passive splitter. DPSK receiver gets half of the signal and other half reserved for upstream wavelength reuse. For upstream, DPSK modulation is also employed because it has better bandwidth efficiency and lower dispersion effects. Simulation parameters of the proposed work are shown in Table 4. All 70 reused wavelengths are multiplexed and sent to same optical fiber and de-multiplexed through de-mux followed by DPSK receiver which consisting of mach-zehnder interferometer, photodetectors, low pass filter, 3-R regenerator and BER analyzer.

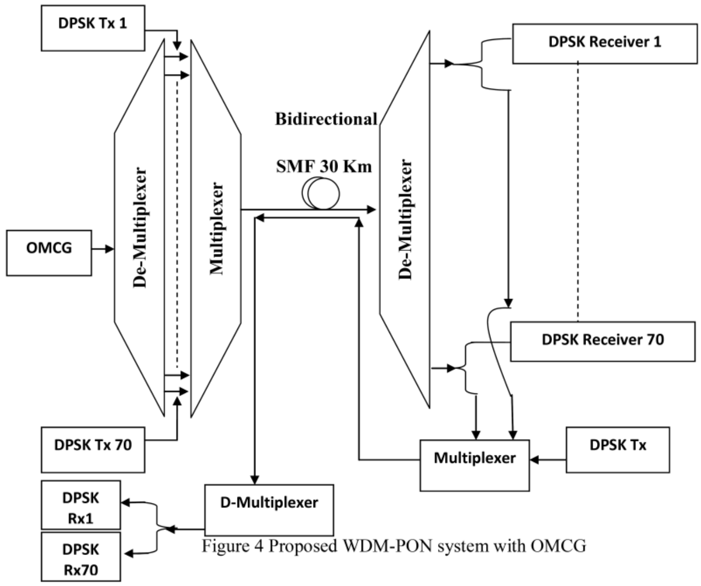


Figure 4 Proposed WDM-PON system with OMCG

Table 4 Simulation parameters of WDM-PON system

Parameter	Values
Data Rate	10 Gbps
Channels	70
Distance	30 Km
Modulation (downstream/upstream)	DPSK
Photodetector	PIN
Wavelength reuse	Yes
Amplifier	EDFA

3. Results and Discussions

OMCG is utmost concern in this work due to its cost effective advantages. First and foremost, in this work, optimal parameters are selected by varying values of sine generator, and modulators. In order to check the optimal value, first of all, a laser along with RF generator and amplitude modulator are placed. Frequency of sine generator is varied from 10 GHz to 40 GHz with difference of 5 GHz. As shown in Figure 5, TNR varies with the RF frequency change and highest TNR comes at three frequencies such as 25 GHz, 35 GHz and 40 GHz. However, in this case, two parameters are important (1) TNR and (2) Number of carriers. At 25 GHz, TNR is high but it has 60 number of carriers and at 35 GHz, number of carriers are 70 with high TNR. Also at 40 GHz RF frequency, TNR is high but numbers of carriers are least. Therefore, optimal value is 35 GHz of RF frequency for proposed OMCG module.

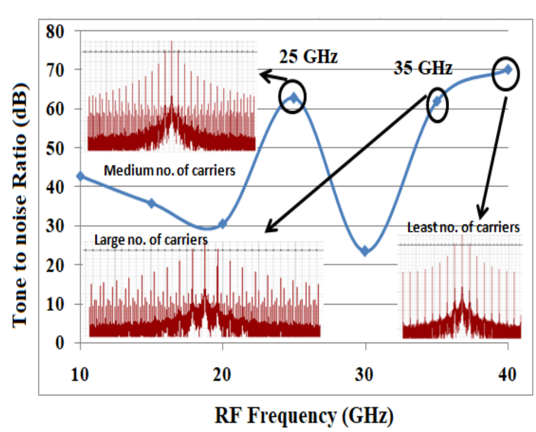


Figure 5 Variation of TNR with RF frequency and number of carriers generated

Figure 6 represents the column graph of different cascaded modulator in terms of amplitude difference. Amplitude difference is difference between least power carrier and highest power carrier and for the optimal communication, amplitude difference should be least. Results revealed that least amplitude difference obtained is less than 0.8 dB in case arrangement AM+MZM+AM.

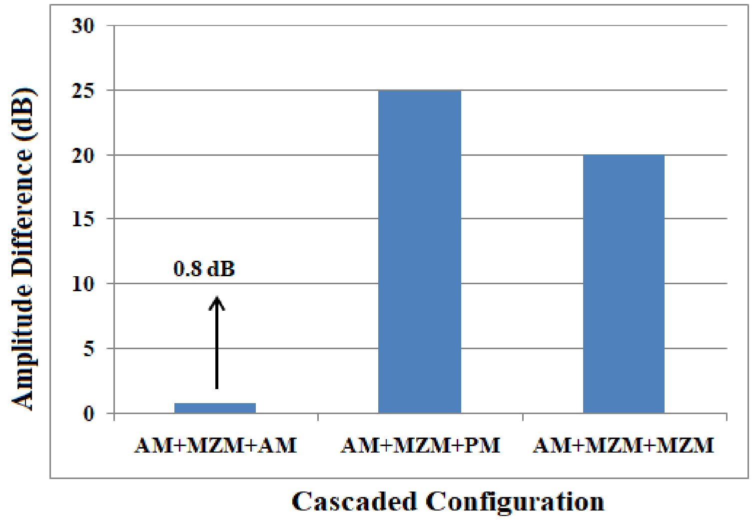


Figure 6 Amplitude difference in different cascaded arrangements of modulators

Figure 7 represents the optical spectrums of different cascaded configurations of modulators. Optical spectrum analyzer basically depicts the carriers with their centred frequency and power at each carrier. Figure 7 (a) represents the optical spectrum of AM+MZM+MZM arrangement and Figure 7(b) shows optical spectrum of AM-MZM+PM configuration. Figure 7 (c) depicts the carriers of AM+MZM+AM configuration. It is observed that carriers with minimum amplitude difference is obtained in case of AM+MZM+AM (0.8 dB) with 70 carriers. Number of carriers in AM-MZM+PM and AM+MZM+MZM are almost similar (60) however amplitude difference is 25 dB and 20 dB respectively. Therefore optimal configuration using mentioned parameters is AM+MZM+AM because it has highest number of carriers, highest TNR and minimum amplitude difference.

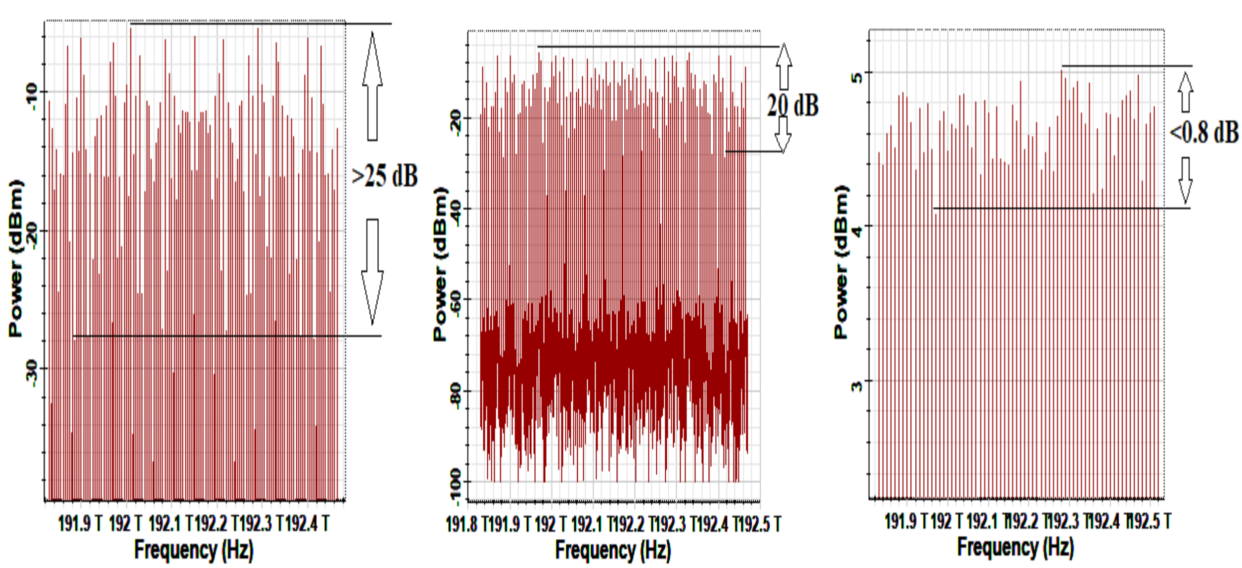


Figure 7 Optical spectrum of different cascaded configurations (a) AM+MZM+PM (b) AM+MZM+MZM (c) AM+MZM+AM with amplitude difference

Figure 8 represents the optical spectrum of single channel differential phase shift keying modulation. Optical spectrum of differential phase shift keying modulation is centred at 191.83 THz because this is frequency of first channel of optical multicarrier generator. Power of optical carrier is less than -20 dBm because of insertion loses of different modulators and other optical components. Generally optical modulator causes 3 dB insertion losses. There are three modulators in OMCG module and after that two modulators are in DPSK transmitter.

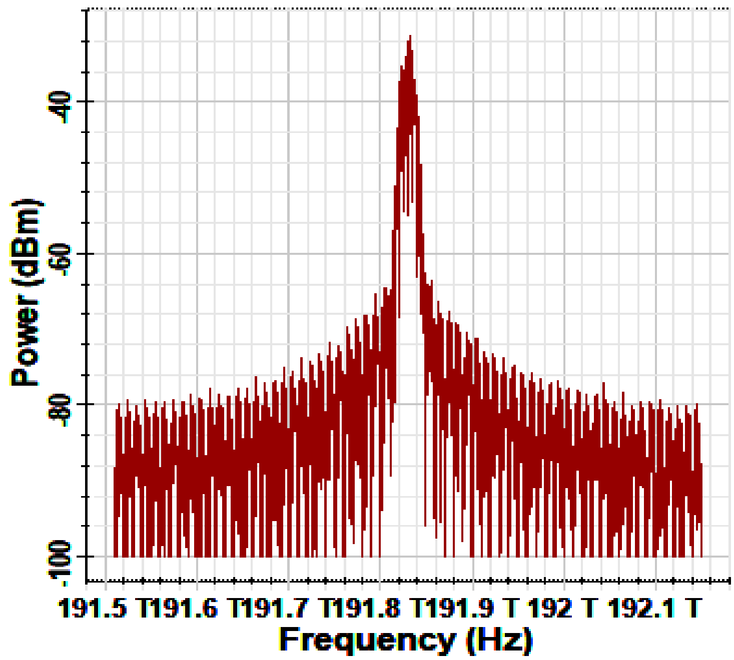
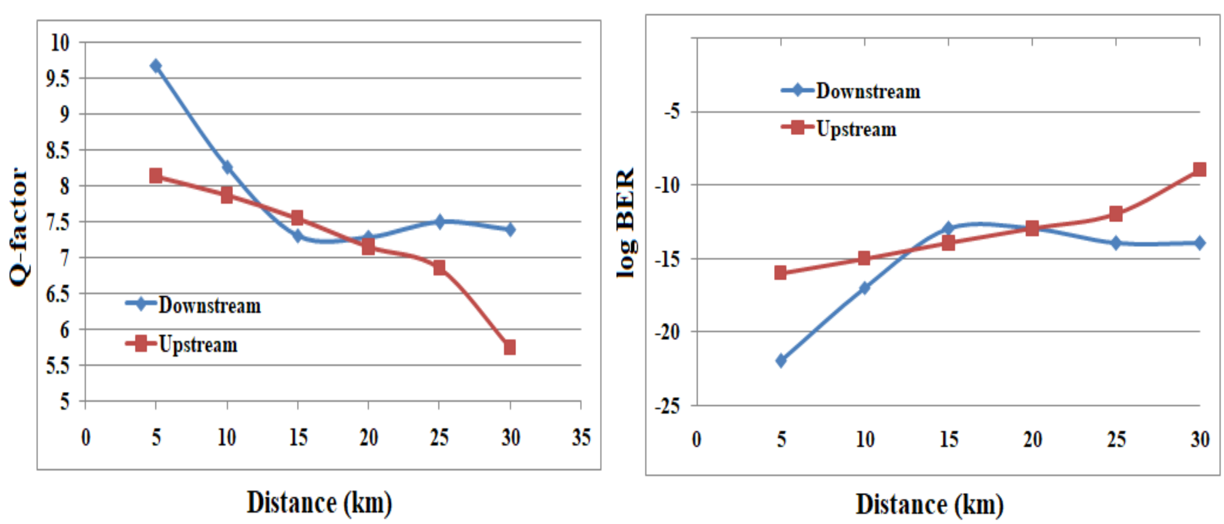


Figure 8 Optical spectrum of DPSK transmitter for single channel

Figure 9 (a) represents the performance of proposed WDM-PON system with wavelength reuse in downstream and upstream at different distances. Distance is varied from 5 km to 30 km and results are checked in terms Q factor. With the distance increase, Q factor of the system decrease because attenuation, and dispersion increases.



(a) (b)

Figure 9 Performance of WDM-PON system in downstream and upstream (a) Q factor (b) log BER versus distance

Out of downstream and upstream transmission, performance of downstream is better than upstream at most of the distances. After 30 km, Q factor of the system goes below acceptable range and therefore system works for 30 km. Figure 9 (b) shows the log BER of the system at varied distances in downstream and upstream in proposed work. Distance is varied from 5 km to 30 km and results are checked in terms log BER. With the distance increase, log BER of the system increases because of attenuation, and dispersion increases. Out of downstream and upstream transmission, performance of downstream is better than upstream. After 30 km, log BER of the system goes more than acceptable range and therefore system works for 30 km at 10-9. Figure 10 shows the received power variation with the distance increase at 10 Gbps and 20 Gbps to check the effect of increase in data rate. Data rate increase cause decrease in signal power because of the more interferences at high bit rates. Time slot of bits at 20 Gbps is half of the 10 Gbps which cause more errors. Received power has impact on signal to noise ratio, Q factor and log BER.

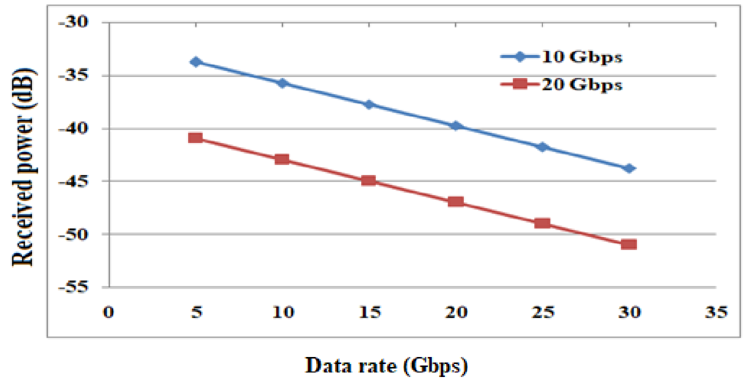
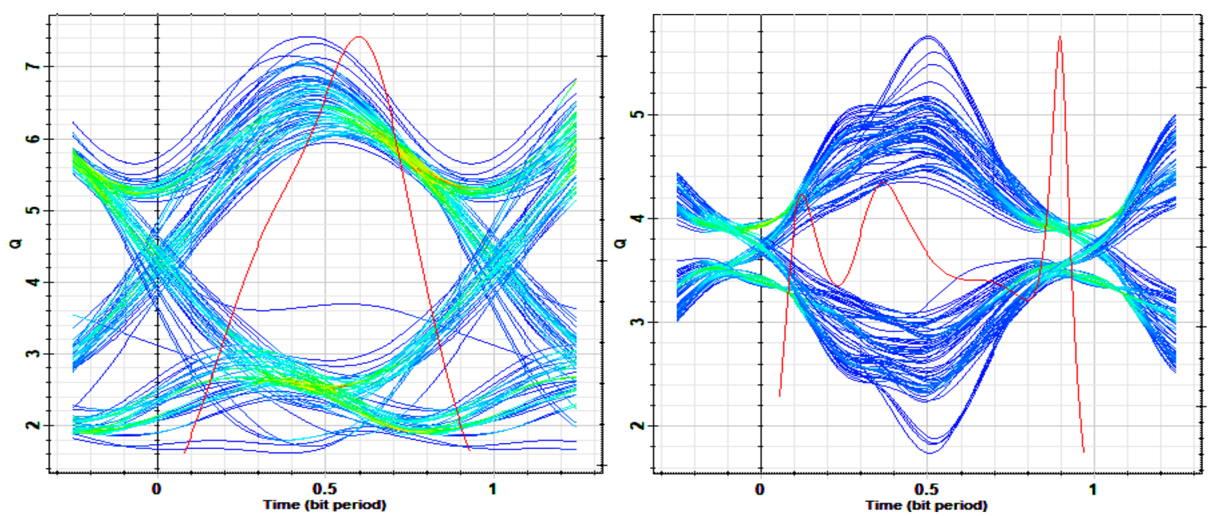


Figure 10 Performance analysis of WDM-PON in terms of received power at different data rates



(a) (b)

Figure 11 Eye diagram at (a) 30 km for downstream and at (b) 30 km for upstream

Eye diagram is decision component in the communication systems which let us know the Q factor, log BER, jitter and eye opening. More the opening of the eye, more is the Q factor and lesser are errors. Figure 11 shows eye diagrams of system at 30 km in downstream are better than upstream. Results revealed that eye opening is more in downstream due to ideal environment in central office and signal strength.

4. Comparison of Proposed Work with Reference Work

In proposed work, we have accomplished two tasks such as generation of OMCG from single laser and proposed a WDM passive optical network with high capacity. In order to perform simulation on OMCG, different cascaded modulator cases are taken such as AM+MZM+AM, AM+MZM+PM and AM+MZM+MZM. In our case, AM+MZM+AM is found out to be optimal with 53.97 TNR and 0.8 dB amplitude difference. Total carriers generated are 70 and percentage improvement is given in Table 5.

Table 5 Comparison of proposed work with reference work with percentage improvement

Parameters	Reference work [9]	Proposed work	% Improvement
Data rate	10 Gbps	10 Gbps	-
Carriers generated	61	70	14.75%
Cascaded modulators arrangement	AM+MZM+MZM	AM+MZM+AM	-
TNR	44 dB	53.97	31.75%
Amplitude difference	1 dB	0.8 dB	20%
PON Total capacity	570 Gbps	700 Gbps	35.08%
Distance achieved	25 km	30 km	20%
BER at 25 km	10^{-9}	10^{-16}	77.8%

5. Conclusion

In this work, two different contributions are made such as generation of OMCG and its use in PON. Three different cascaded arrangements of modulators are investigated such as (1) AM+MZM+AM (2) AM+MZM+PM (3) AM+MZM+MZM. In order to select optimal parameters of RF generator and modulators, amplitude difference and total number carriers are analyzed in all the three configurations. RF frequency is selected 35 GHz, and MZM bias voltage 1 and 2 are fixed to 20 V. Results revealed that AM+MZM+AM provides best results in terms of number of carriers (70), TNR (53.97) and amplitude difference (0.1 dB). However, other two configurations have less number of carriers (60) and very high amplitude difference (25 dB). Total carriers are spaced at 10 GHz and this spacing is ultra dense for high capacity systems to make system bandwidth system. Further, an ultra dense (10 GHz) passive optical network with 70 wavelengths and 700 Gbps capacity has been investigated. DPSK is serving the high speed data in downstream as well as in upstream over 30 km bidirectional single mode fiber. System is investigated for different distance, and data rates and it is observed that system works for 30 km within acceptable range of BER (10^{-16} in this case) and data rate has significant effect on the system such that results degraded in case of 20 Gbps as compared to 10 Gbps. Proposed system is economical, flexible and performance enhanced. In future, OMCG can be used in Inter-satellite optical wireless systems, free space optical systems and in hybrid WDM-TDM PONs.

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