Performance Analysis of Different Configurations of Dispersion-Supported Equalization in 100 Gbps TWDM PON

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Abstract: *Symmetrical 4×25-Gb/s time-wavelength-division-multiplexed passive optical network (TWDM-PON) system based on non-return-to-zero on-off-keying (NRZ-OOK) format is proposed over 20 km in O-band. Bidirectional communication TWDM PON system using directly modulated lasers (DMLs) and Dispersion-Supported Equalizations (DSE) is investigated. Use of digital signal processing (DSP) was used in many PON systems but it increase complexity and cost of the system. By employing a spool of dispersion-shifted fiber (DSF) in optical line terminal (OLT), a single device can be used to simultaneously equalize the frequency response of multiple downstream and upstream channels. Three different configurations of DSEs are investigation such as pre, post and symmetrical DSE in O-band. It is observed that symmetrical DSE provide best performance in terms of Q factor and BER.*

Keywords: **TWDM, PON, DML, DSP, DSE**

1. INTRODUCTION

The bandwidth demand in the optical access network has increased dramatically in recent years, powered by broadband applications such as cloud services, HD, and virtual video [1]. Recently the studies for next generation PON focus on the symmetric capacity of 100-Gb/s with 25-Gb/s per wavelength in both upstream and downstream link and the 100G-EPON standardization is currently in progress with the IEEE 802.3ca task force [2]. Since low-cost is one of the most remarkable features in the access network, low-cost 10 G class optics off-the-shelf are reused to bring costs down to a minimum. A number of experimental demonstrations of 25-Gb / s data rate transmission based on 10G-class optical devices were recorded for discussion previously. Duobinary formats [3], Pulse amplitude modulation (PAM) [4], electrical duobinary (EDB) [5], are combined with DSP for performance improvements. But real time burst mode receiver in EDB, PAM-4 are not commercialized so far. Non return to zero (NRZ) linecoding is deployed in many research works due to its simple operation and low cost but addition of DSP increase system cost and complexity [6]. In [7], frequency equalization is performed with optical delay interferometer (DI) and DSP. But addition of DI is unsuitable for upstream because of wavelength drifts. To our knowledge, as the low-cost 25-Gb / s upstream approach is more difficult there have been no symmetric real-time 100G-PON demonstrations yet. Furthermore, all of the above examples are based on a wavelength plan of the C-band. In IEEE 802.3ca the 100G-EPON wavelength plan is still under investigation. There are currently four main wavelength proposals under consideration in the pro 802.3ca [8]. O-band wavelength plan is particularly favoured in upstream because it has low dispersion properties and we can exploit high volume data centre O-band DMLs and external modulated lasers (EMLs). In addition, due to the small form factor and fast carrier dynamics, SOA is an acceptable option as an optical amplifier for improving the loss budget in O-band. In [9], demonstration of symmetric 100G-PON using NRZ-OOK format for equalisation in O-band without DSP is reported. In OLT a DSF spool with a dispersion of about -150 ps / nm at 1310 nm is used to compress the pulse width of directly modulated signals and to equalise the frequency response for both downstream and upstream channels. Addition to the negative dispersion produced by DSF at 1260 nm and 1360 nm is -200 ps / nm and -100 ps / nm respectively within the tolerance range of the DSE technique, the DSE technique based on DSF is therefore almost wavelength-insensitive and therefore supports uncooled lasers with wide wavelength drift which is the real case for most lasers commonly used in O-band. Both users share the expense of DSF, so it can be ignored, ensuring it outperforms other DSP dependent equalisation techniques. Simultaneously, a bit-error rate tester (BERT) with an embedded CDR chip is used for real-time BER measurement so no pre-FEC DSP is required. DSF introduced insertion losses in the system and for the performance improvements; optimization is performed by adjusting DML operating current. Further semiconductor optical amplifier (SOA) for the attenuation compensation is used in 100 Gbps TWDM PON and utmost concern is to reduce the cost and to improve performance with pre DSE. However, author investigate only pre-DSE configuration in TWDM PON, but other DSE configurations can also be explored to investigate optimal configuration. In this research article, Symmetrical 4×25-Gb/s TWDM-PON system based on NRZ format is proposed over 20 km in O-band. Bidirectional communication TWDM PON employing DMLs and DSE is investigated. Three different configurations of DSEs are investigation such as pre, post and symmetrical DSE in O-band.

Introduction about TWDM-PON and DSE is given in Section 1, simulation model is discussed in Section 2, results and discussions are covered in Section 3 and conclusion is written in Section 4.

2. SYSTEM SETUP

Simulation setup of the 100-Gb/s TWDM-PON is investigated in Optisystem software. The total data rate of symmetric 100-Gb/s is achieved by using four pairs of wavelengths in both upstream and downstream directions. In the optical line terminal side, the 25 Gb/s NRZ-OOK signal is generated by pseudo random binary sequence (PRBS) pattern. NRZ linecoder for directly modulated laser is employed and four DMLs are considered such as 1270 nm, 1290 nm, 1310 nm and 1330 nm. These wavelengths combined through multiplexer with 20 nm channel spacing. Difference in downstream and upstream wavelengths is at 1.6 nm difference for interference reduction among neighboring channels. Table 1 shows the parameters of the proposed work. Semiconductor optical amplifier (SOA) after DSE is placed to amplify the signal. Channels are de-multiplexed and received with avalanche photodiode, low pass filter and BER analyzer. Upstream four channels 1271.6 nm, 1291.6 nm, 1311.6 nm and 1331.6 nm are multiplexed and sent over same fiber and DSE configurations. Channels in upstream are also de-multiplexed and received with APD, LPF and BER analyzer. Figure 1 shows the performance of different configurations of DSE in proposed work. Multiplexed signals are send to different configurations of DSE and the over single mode fiber.

Table 1 Simulation parameters of proposed TWDM PON

Parameter	Values
Data rate	25 Gbps/channel
Total channels	4
Laser used and power	DML and 10 dBm
Fiber distance	20 km
DSE configurations analyzed	Pre, post, symmetrical
Amplifier	SOA
Photo detector	APD

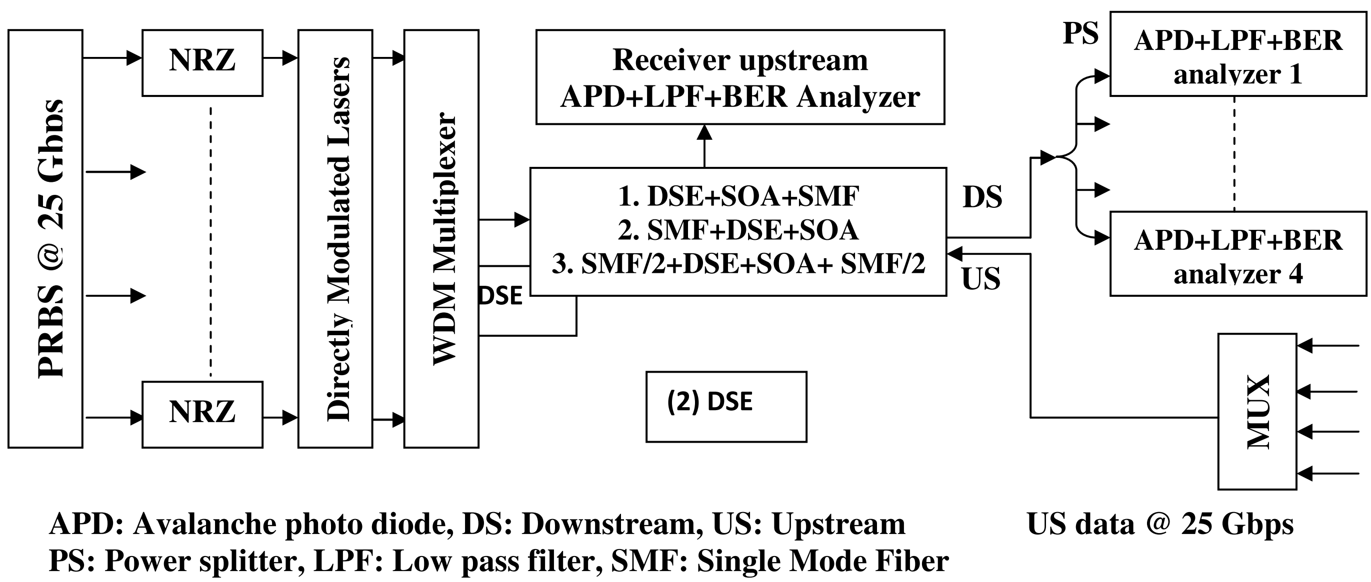
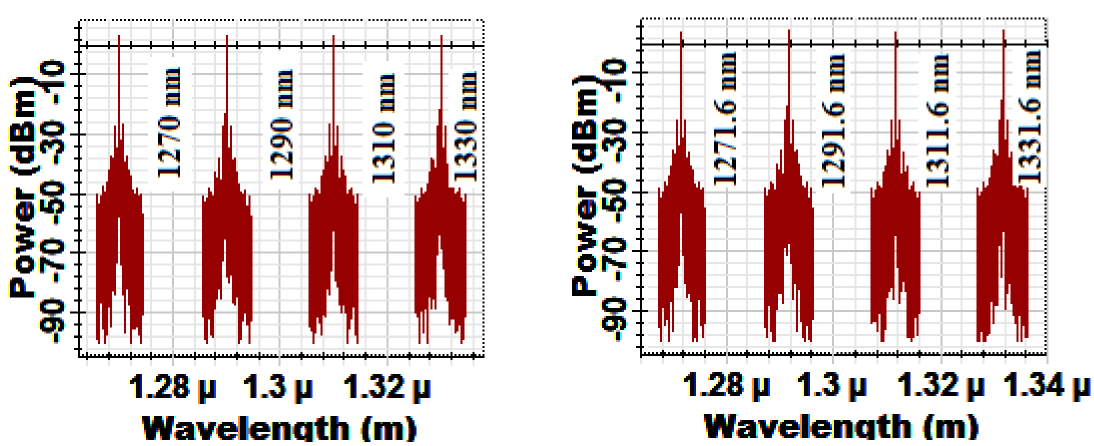


Figure 1 Proposed system with different DSE configurations

3. RESULTS AND DISCUSSIONS



(a) (b)

Figure 2 Optical carriers showing wavelengths of (a) downstream (b) upstream

Optical carriers are used in upstream as well as in downstream and total 8 carriers are considered, four in each direction transmission. Figure 2 represents the optical carriers in downstream and upstream which represents the power at each carrier with respect to the wavelength. In order to avoid wavelength interference inside SMF, downstream and upstream wavelengths are 1.6 nm apart. Figure 3 shows the performance of different configurations of DSE in proposed system at different distances in terms of Q factor. Pre DSE, Pose DSE and Symmetrical DSE configurations are investigated and it is observed that with the increase in distance of the SMF, Q factor of the all three configurations decreases due to attenuation, dispersion and scattering.

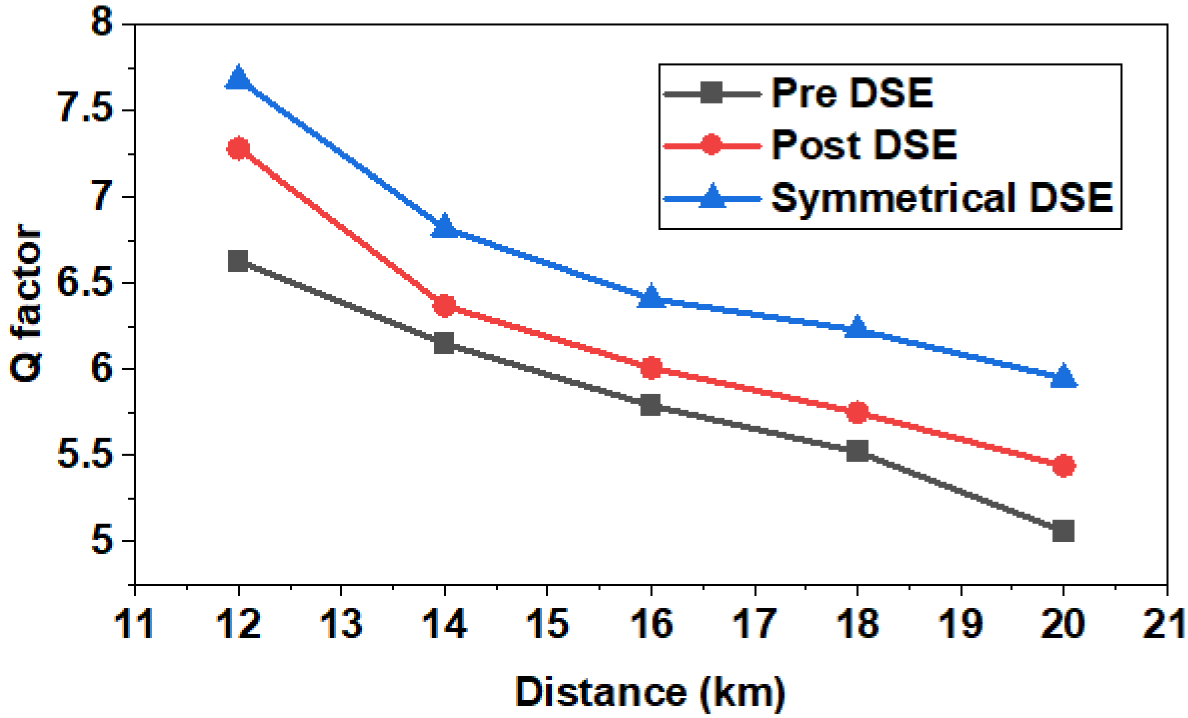


Figure 3 Performance comparisons of pre, post and symmetrical DSEs in terms of Q factor in downstream

Table 2 Values of pre, post and symmetrical configurations 100 Gbps TWDM PON system in downstream

Distance (km)	Pre DSE	Post DSE	Symmetrical DSE
12	6.63	7.28	7.68
14	6.15	6.37	6.82
16	5.79	6.01	6.41
18	5.52	5.75	6.23
20	5.06	5.44	5.95

Performance of symmetrical DSE is highest because fiber is divided into two half of 10 km-10 km and because length is half, noise are also lesser than other configurations. Performance of post configurations is followed by pre DSE. Values of Q factor at different distances are shown in Table 2. Figure 4 shows the performance of different configurations of DSE in proposed system at different distances in terms of log BER. With the increase in distance of the fiber, log BER of the all three configurations increases due to losses, noises and nonlinear effects. Log BER of symmetrical DSE is least because of high effectiveness of DSE in to equal halves.

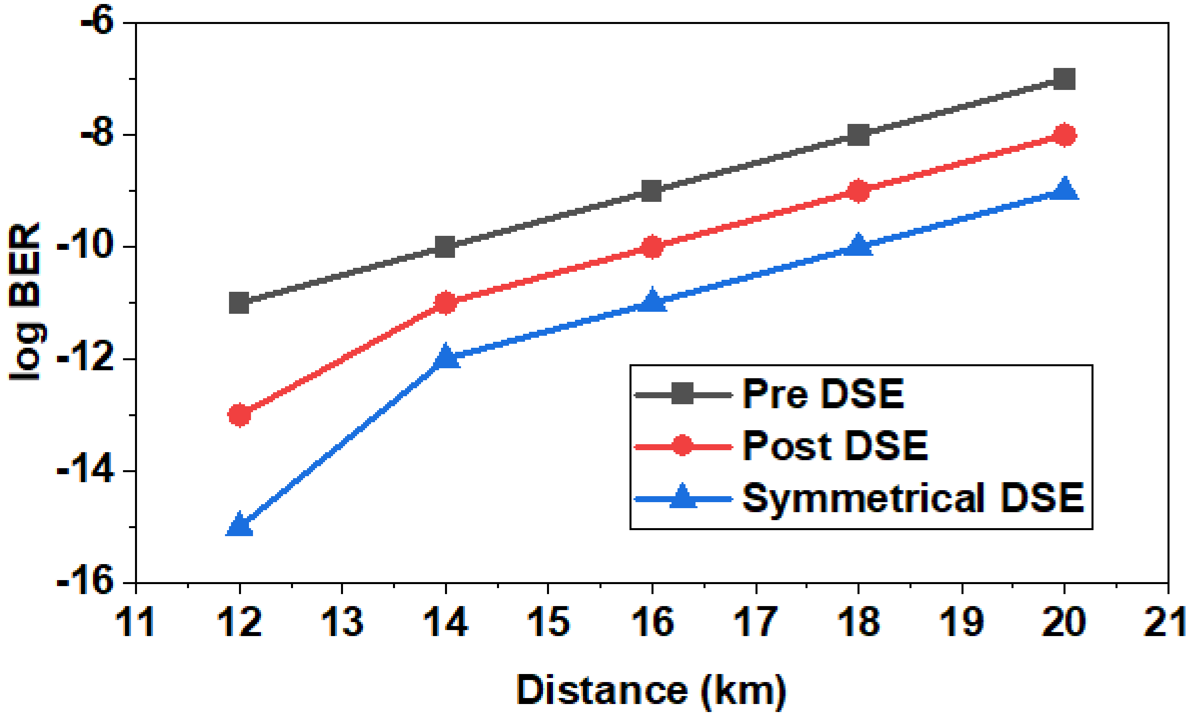


Figure 4 Performance comparisons of different DSEs in terms of log BER in downstream

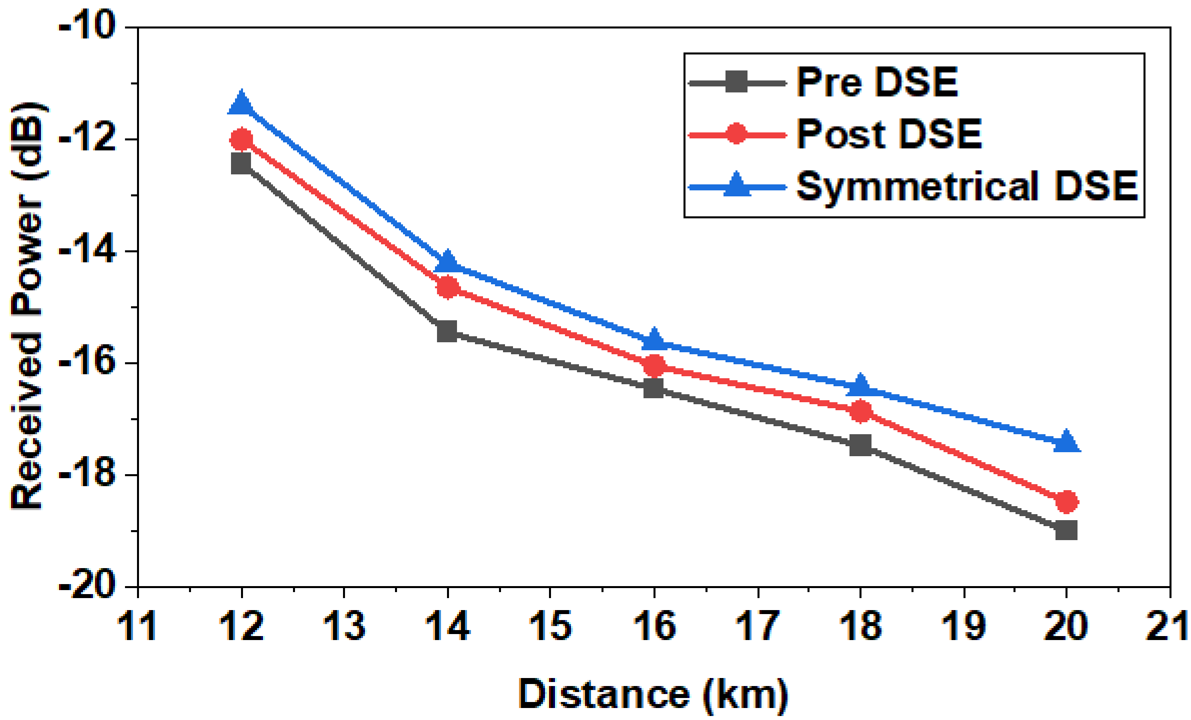


Figure 5 Effect of distance on received power of the three configurations in downstream

Dispersion, and spectrum broadening copped up by using DSE in symmetrical positions and in this way management of dispersion and spectral distortion is better. Values of log BER and received power at varied distances for proposed DSE configurations are shown in Table 3.

Table 3 Log BER and received power values at different distance in downstream

Distance (km)	BER of Pre DSE	BER of Post DSE	BER of Symmetrical DSE	Received power of Pre DSE	Received power of Post DSE	Received power of Symmetrical DSE
12	-11	-13	-15	-12.43	-12	-11.39
14	-10	-11	-12	-15.45	-14.64	-14.22
16	-9	-10	-11	-16.46	-16.05	-15.63
18	-8	-9	-10	-17.48	-16.86	-16.44
20	-7	-8	-9	-19	-18.48	-17.45

Received power at BER is total received power and it is combination of signal power and noise power. Higher power may increase the performance of the system because in order to eliminate noises, low pass filters are also used in the receiver. Moreover, in this, negligible thermal effects of APD are considered and therefore, symmetrical DSE is getting highest power levels at receiver. System experiences loss in power due to insertion losses, attenuations of components and scattering. From the Figure 5, it is clear that maximum power is received in symmetrical DSE and it is followed by post DSE. Received power has significant on bit error rate of the optical communication system and in WDM systems, received power gets affected by attenuation, scattering, nonlinear effects such as four wave mixing, cross phase modulation and gain modulations etc.

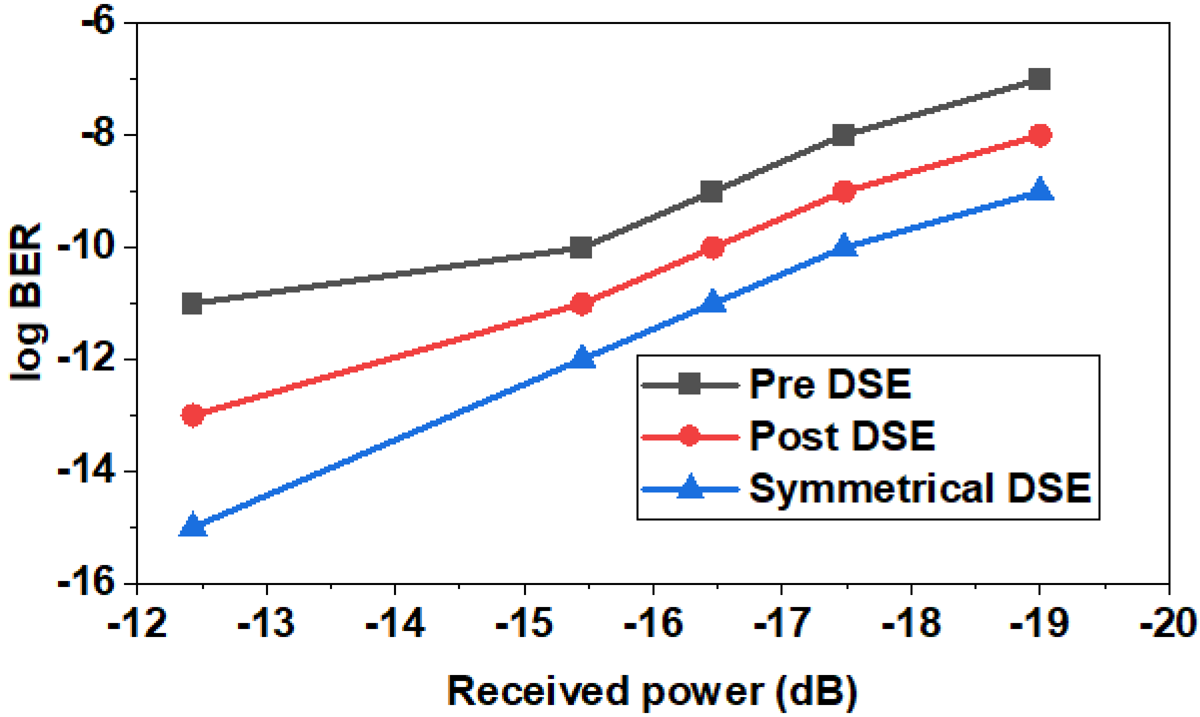


Figure 6 Received power versus log BER in downstream

Sensitivity of BER towards received power is such that, there is reduction bit errors when high power receives on receiver. Figure 6 shows that symmetrical DSE exhibits least errors and receive maximum power. Figure 7 represents the performance comparison of downstream and upstream transmission in proposed system at varied distances. Distances are varied from 12 km to 20 km and results are taken using symmetrical DSE because it is highest performing among all the configurations. Q factors in downstream are better than upstream because of lesser losses and ideal environment in the central office. However, upstream transmitters are at user premises and therefore bit higher degradations are there. Results revealed that proposed system can cover 20 km in both directions i.e. downstream and upstream within acceptable BER range.

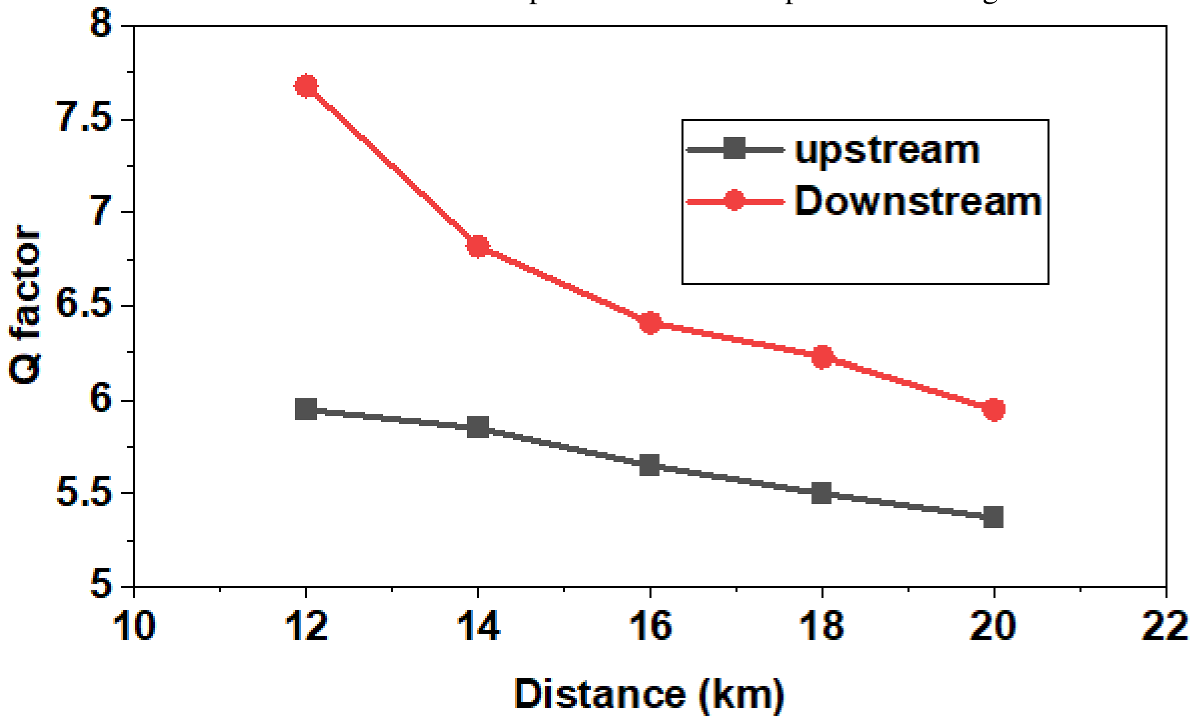


Figure 7 Performance comparison of upstream and downstream in proposed TWDM PON

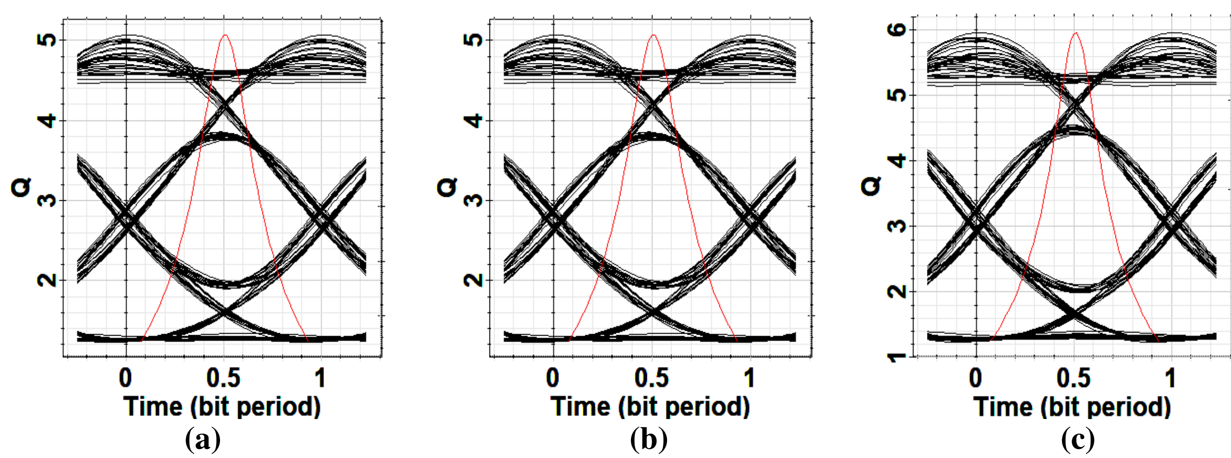
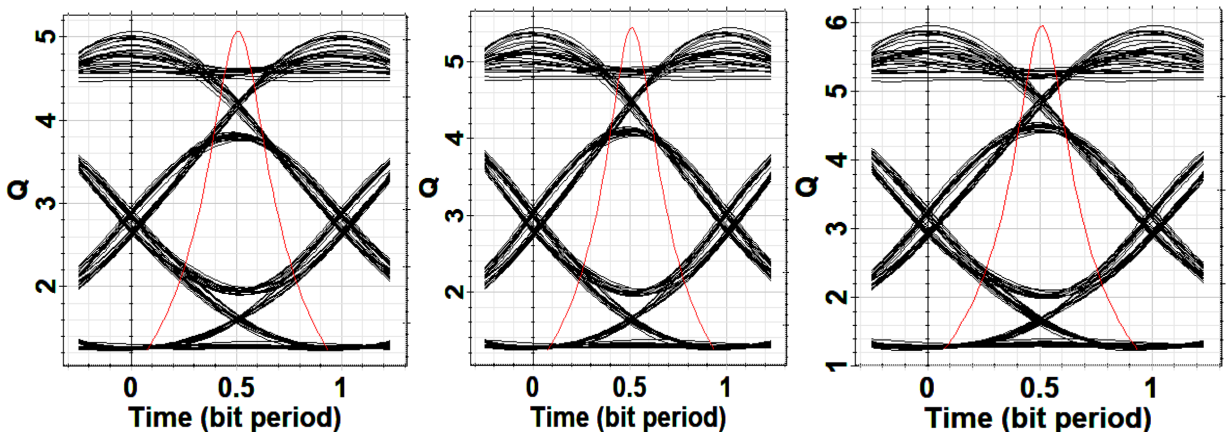


Figure 8 Eye diagrams at 20 km SMF for (a) pre (b) post (c) symmetrical DSE in downstream



(a) (b) (c)

Figure 9 Eye diagrams at 20 km SMF for (a) pre (b) post (c) symmetrical DSE in upstream

Figure 8 and Figure 9 shows the eye diagrams in downstream and upstream respectively at 20 km link distance. Downstream and upstream eye diagrams represents that symmetrical DSE diagram has maximum eye openings. But downstream has little wider eye diagram than upstream communication. Pre and post DSE eye diagrams have approximately similar eye opening in both directions.

4. CONCLUSIONS

In this work, symmetric 100-Gb / s TWDM-PON with a range of 4 to 25-Gb/s on both downstream and upstream directions running in O-band using NRZ-OOK format is demonstrated. A DSF spool in OLT is used to equalise the transceiver frequency response, thus allowing 25-Gb/s NRZ-OOK to be sensed directly using 10Gbps DMLs and APDs without DSP. Since the DSF is wavelength-insensitive and can be shared by all users, the proposed DSE technique will be a realistic and cost-effective solution for 100G-PON symmetry. Use of digital signal processing (DSP) was used in many PON systems but it increase complexity and cost of the system and therefore not used. Three different configurations of DSEs are investigation such as pre, post and symmetrical DSE in O-band and results revealed that Q factor at 20 km for pre, post and symm. DSE are 5.06, 5.44, 5.95 in same order. Better performance is observed in sym. DSE because of better dispersion, attenuation and frequency spectrum management compensation after SMF/2 length which attracts lesser noises in the system. Therefore, it is recommended to use symmetrical DSE in O-band TWDM high speed PONs.

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