

ALL OPTICAL PACKET ROUTING TWDM PON SYSTEM ARCHITECTURE USING 2.5GBPS WDM TO 10GBPS OTDM XGM TO SUPPORT COEXISTENCE GPON AND XG-PON NETWORK

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Abstract—A new architecture of TWDM PON system using all optical packet routing (AOPR) in OLT design is proposed in this paper. This architecture is designed using cross gain modulation (XGM) none –return- to-zero (NRZ) 2.5Gbps WDM to return-to-zero (RZ) 10Gbps OTDM multiplexing technique using Semiconductor Optical Amplifier (SOA) component. This study shown that without implementing 10Gbps OLT card in the system, four 2.5Gbps WDM downstream signals could be multiplexed to carry 10Gbps OTDM signal by utilizing the existing E/GPON network infrastructure. This paper is concluded with an analysis and discussion on the gain saturation effect in SOA components affecting the BER and quality of the signal in the proposed system. The result shown that both 2.5Gbps and 10Gbps can coexist to support maximum up to 30dB loss margin with minimum 1x64 splitting ratio. In addition, this architecture also shows that it could be deployed as an open platform of hybrid solution of TWDM PON for 10Gbps and ready for 40Gbps or 100Gbps platform in the future.

I. INTRODUCTION

IEEE and ITU-T have proposed a roadmap to define standard for future requirement of supporting more bandwidth while maintaining most of the network design in order to utilised network infrastructure that have been invested by Telecommunication service provider. ITU-T under FSAN group defines 2.5GPON [1], 10GPON [2] and IEEE define GEPON [3], 10GEPON [4]. The objective of 10GEPON is to support subscriber access networks using point to multipoint topologies on optical fiber with 10 Gbps downstream/ 1 Gbps upstream and split ratios of 1:16 and 1:32, with distances up to 20 km [4]. For 10GPON, Next Generation Passive Optical Network (NG-PON) Task Group under Full service access network (FSAN) aims to provide carrier class solutions, with the capability of smooth migration between system generations and reuse of the “legacy” fiber plant. The first specification is to have a capacity of 10Gbps downstream and 2.5Gbps upstream; featuring a cost competitive component. Meanwhile,

ITU-T under Full Service Access Network (FSAN) group is focusing on the additional features and tools for extending the capability of the XG-PON technology [5]. Under the generic term of “NG-PON2”, the working group has started an investigation on upcoming technologies with higher bandwidth utilization and able to solve the issues encountered in the “1G” and “10G” PON technology deployments. Furthermore, vendors and telecommunication service providers have proposed a number of technologies in support of this initiative. One of the possible candidates is WDM PON [6] or WDM/TDM PON [7]. Consequently, in order to migrate from pure TDM PON to WDM PON system in brown field network, the operator should find alternative solution to minimized cost of deployment at the same time to offer very minimal disruption to the network and to the user. In order to accommodate high demand of bandwidth at the access network in the future, hybrid WDM/TDM PON system architecture has been proposed. This architecture was designed to increase bandwidth per user using multiplexing multiple channel of PON port in a downstream direction while maintaining single wavelength in an upstream direction; while at the same time to maintain the conventional and coexistence system configuration using TDM PON between GPON and XG-PON. The paper is organized as follows: Section 2 discusses the WDM PON system architecture design. In this section we introduce the proposed AOPR architecture design and principle of WDM to OTDM trans-multiplexer design in PON system. Section 3 introduces the simulation setup using commercial VPI software. Results and discussion are presented in Section 4. Finally, the paper is concluded in Section 5.

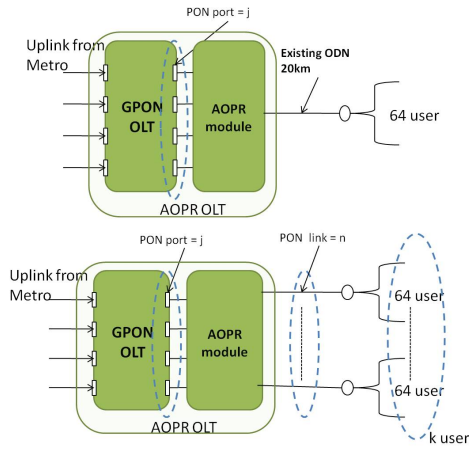


Fig. 1. Proposed AOPR WDM/TDM PON system architecture (a) AOPR TWDM PON with single PON link, (b) AOPR TWDM PON with multiple PON link

II. WDM PON SYSTEM ARCHITECTURE DESIGN

A. Proposed AOPR TWDM PON Architecture

Figure 1 shows the two generic AOPR TWDM PON system architecture design [8], [9]. The first AOPR TWDM PON was designed to support a single link TWDM PON and the second architecture was designed to support multiple PON link TWDM PON architecture. Under the same existing fiber plant (same ODN and fiber network), each PON port can route their packet to any PON destination link whether single or multiple PON links. In this design each PON port could handle up to $N \times 64$ customers using single PON port to support WDM multicasting and $K \times$ PON port into a single PON link for 64 customers to support WDM multiplexing. The downstream signal from each PON link transmits a different wavelength in TDM mode and broadcasts to 64 customers in a single PON link using optical splitter. The upstream signal will utilize the standard E/GPON 1310nm wavelength and also operating in normal PON TDM mode.

Figure 2 depicts the system components of AOPR OLT module. The module consists of sub components such as multiple port of PON chips, wavelength converter using SOA (XGM module), tuneable multi wavelength pump pulse probe signal (PPPS), array waveguide grating (AWG), fiber delay line (FDL), optical coupler and controller. A processor (or controller) will control the multiple PON ports chipsets as well as other components in the module. Figure 2(a) shows the OLT module supporting single PON link and Figure 2(b) shows the OLT module to support Multiple PON links. AOPR OLT module was designed to integrate OLT system with AOPR transmitter module. All of this module will controlled via OLT PON chipset that control tuning wavelength of PPPS according to their allocation time and also tuneable optical delay line to ensure the synchronization between PPPS signal and OLT downstream transmit signal.

Figure 3 show the PPPS module design that consist of multiple tuneable wavelength Pulse probe signal at 10Gbps.

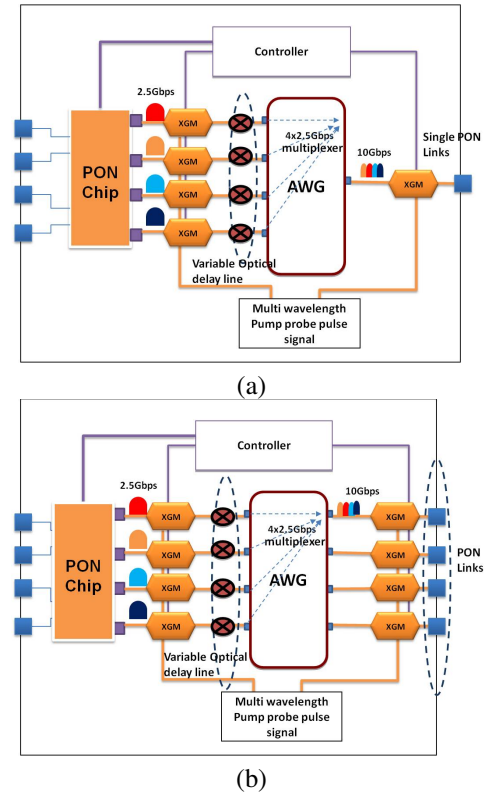


Fig. 2. Proposed integrated AOPR OLT module design (a) OLT module with single PON link and (b) OLT module with Multiple PON link

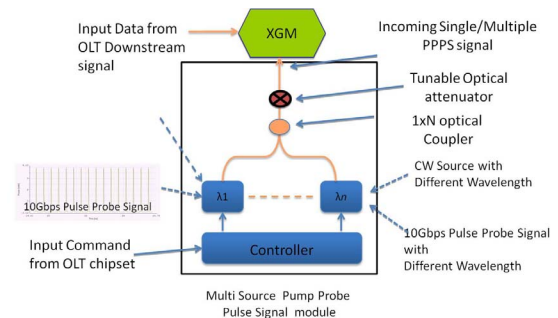


Fig. 3. Pump pulse probe signal module in XGM module.

This laser controlled by electronic controller that gets the interrupt message from OLT chipset. Using 1xN optical couple all Pulse signal at different wavelength will pump into XGM module to generate XGM effect. Optical tuneable attenuator will be placed between optical coupler and XGM module to controlled power level of incoming PPPS to achieve the best performance of the system.

B. WDM to OTDM Tran-multiplexer design using SOA cross gain modulation in AOPR TWDM PON system

Figure 4 shows the concept of XGM modulation using PPPS. The PPPS is generated by pulse code at quarter of the 2.5Gbps original pulse width. By dividing the signal into 4 time cluster, additional 3 time slot is created for other

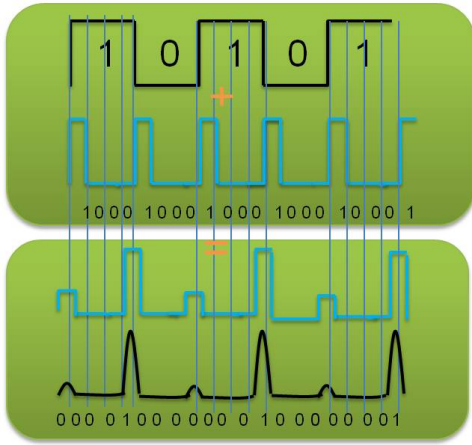


Fig. 4. Bundling 2.5Gbps signal into 10Gbps multiplexing signal

signal to be multiplexed into this signal. From the above figure explained that by using (1 0 0 0) code word of 10Gbps signal, this combination of PPPS with original 2.5Gbps OLT downstream signal will be injected into SOA at high saturation gain region to create XGM effect. The effect copies the original signal onto the PPPS in an inverted order. By applying this concept additional 3 new PPPS signal is generated but carry the original OLT downstream data at different PON port. Each of these new signals will be delayed according to their time slot to bundle this signal into single 10gbps downstream signal.

The AOPR OLT module that will integrate OLT transmitter with SOA and AWG module; where the SOA is used to multiplex four PON ports of 2.5Gbps OLT downstream signal into a single PON link WDM format data and then to the OTDM format data at 10Gbps by using 10Gbps PPPS. It will duplicate original wavelength into a new wavelength carried by optical probe pulse by modulating NRZ 2.5Gbps signal data into 10Gbps RZ data as an output signal using XGM technique. Apparently, RZ signal has better tolerance to the ISI that caused by modulation of TLS [10]. Next, each PON port will demultiplex 2.5Gbps signal into 10Gbps signal and aggregated into a single PON link at the output port of AWG. Using fixed optical delay line or queuing mechanism at OLT chipset, each data will then be aggregated at the output port of AWG. The chosen of SOA in this architecture because it can perform XGM for wavelength conversion to each packet and also has multicasting capability in the TWDM PON system proposed in this design. The NxN AWG router is a passive device used to route packet from N input AWG port to N output AWG port and vice versa. Using frequency spectral range (FSR) characteristic, wavelength cycle could be defined in order to enable multiple wavelengths to pass through a single input or output port. Hence, this characteristic is used to provide different wavelength for upstream and downstream packet and could be routed by this AWG.

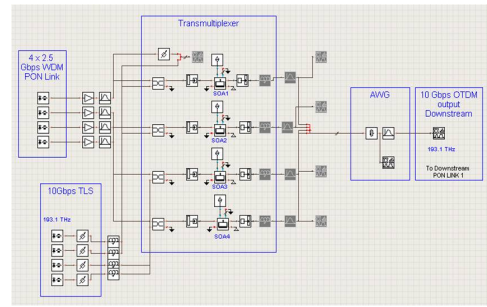


Fig. 5. Simulation Schematic of TWDM AOPS PON system configuration

TABLE I
PON LINK TRANSMITTER (OOK TRANSMITTER MODULE)

Label	Value
Sample Rate	8*10e9 Hz
Bit Rate	2.5e9 bps
Emission Frequency	193.1e12+1.5*100e9 Hz
Laser Power	0.5e-3
Modulation Type	NRZ
Channel Label	Ch1
Line width	1.2e7
PRBS_Type	PRBS
Code Word	1 1 1 0
Random Seed PRBS	10
Duty Cycle_NRZ	1.0
Duty Cycle_RZ	0.5
Constant Pulse Width	Yes
OutputLevel_0	0
OutputLevel_1	1

III. SIMULATION SETUP

A gain of pre-amp SOA (OLT AOPR module) in four channel of transmitting signal and gain of post-amp SOA (OLT AOPR module) is investigated in this simulation setup (Figure 5). To investigate the saturation cross gain effect of the SOA, the system has been simulated by the fixed parameter of a few components such as SOA design parameter, 2.5Gbps OOK transmitter, 10Gbps pulse probe signal, optical receiver and clock recovery module design. The parameter of each module is set as per table below (Table 1,2 and 3).

In order to simulate this system according to the hybrid TDM WDM PON system architecture, 4 transmitters OOK

TABLE II
SOA MODULE

Label	Value
Active Region Type	MQW
Device Section Length	600.0e-06
Active Region Width	2.5e-6
Active Region Thickness	SCH 210e-9
Current Injection Efficiency	1.0
Nominal Wavelength	1.5525246e-6
Gain Bandwidth	10e12
Carrier Density Ref Gain Shape	-1.0e-26
Differential Index MQW	-1.0e-26
Differential Index SCH	-1.50e-26
Carrier Density Ref Index	2.0e+24

TABLE III
DELAY LINE MODULE

PON Link	Delay Line
Link 1	0
Link 2	100e-12
Link 3	200e-12
Link 4	300e-12

was designed to represent four PON link in a single processing module. Delay line was replaced by queuing data in buffer chipset in the real PON implementation, Optical Filter will be replace by AWG as a routing and filter device, 10Gbps OTDM receiver is represent customer that request 10Gbps signal and 2.5Gbps single channel receiver is representing normal customer that received 2.5Gbps GPON signal.

IV. RESULTS AND DISCUSSION

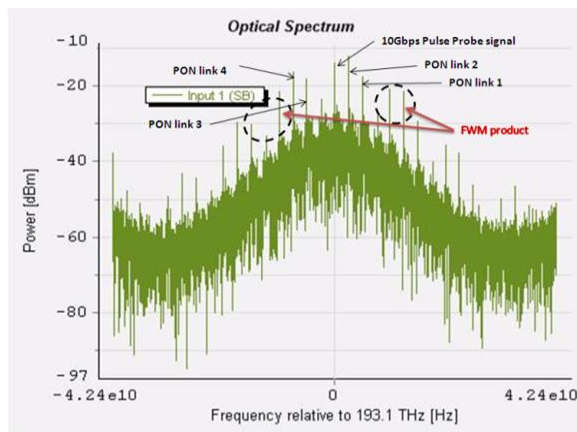


Fig. 6. Multiple source of Output signal before filtered by AWG

Figure 6 shows the performance of aggregation of multiple wavelengths from four sources of PON link. Based on the graph, the output signal shows the SOA non linearity effect FWM [11] by introducing multiple extra wavelengths that can cause interference with other original signal and induce intraband cross talk. Since the wavelength of FWM can be predicted, by carefully design and plan the wavelength can eliminated this issue. In this system by using AWG as a passive routing device, it will automatically filter unwanted signal pass through the system.

In order to analyze the system performance in detail, we adopted a multiplexing WDM to OTDM and wavelength conversion scheme based on an RZ configuration. The SOA has a bias current $I = 0.350$ mA and is connected to a receiver composed of a Bessel optical filter centred on, a photo-detector PIN, a low pass Bessel filter and a Bit Error-Rate (BER) analyzer. The default order of the Bessel optical filter was set to. By varying the input power using Amplifier gain that was set as an input data signal, the maximum value for the Q-factor, the minimum value for the BER, and the eye opening factor are shown in Figure 7, Figure 8 and Figure 9. From the figure 7 (a), the result of 10Gbps OTDM signal combining 4 channel

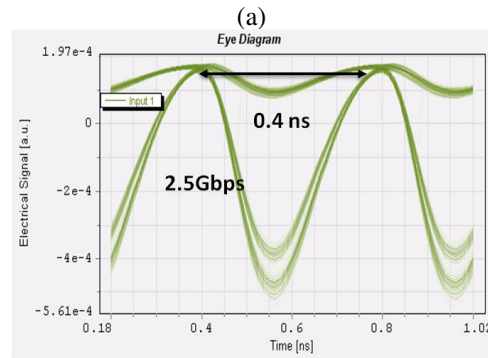
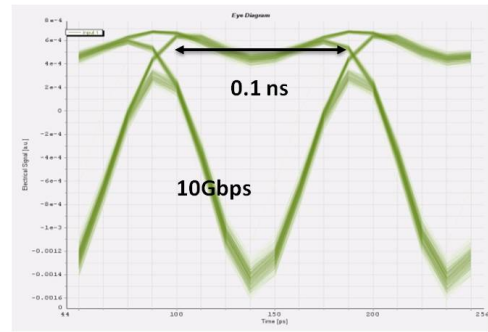


Fig. 7. Downstream RZ eye diagram (a) 2.5Gbps signal and (b) 10Gbps signal

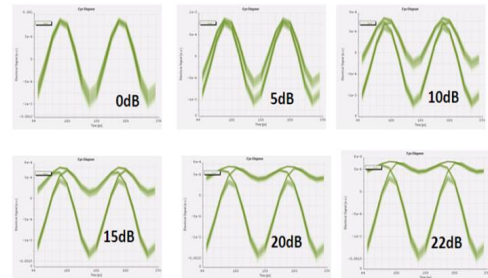


Fig. 8. Eye diagram of RZ downstream signal at different level of Gain power transmitting data signal

2.5Gbps of data stream was obtained. Eye diagram and BER was measured at $5.79e-17$ with Q factor of 8.29.. Using four different delay lines (refer to Delay line module table) in simulation setup each channel was multiplexed to generate 10Gbps downstream signal. This result showed the system of OLT by using single processing module can generate multiple 2.5Gbps signal and transmitting the data using queuing method in PON chipset before transmitting each packet to SOA..

The eye diagram of the optical signal generated by the SOA is displayed in Figure 8. The effect of amplifier can be observed by varying the gain parameter of optical amplifier. It can be observed that BER and eye opening is decreasing when increased the gain of amplifier. This result can be examined in Figure 16, whereby both signals for 10Gbps OTDM and 2.5Gbps single channel source, the BER value decreasing when the gain of incoming data signal has certain gain to

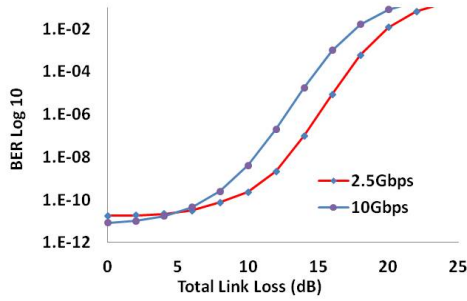
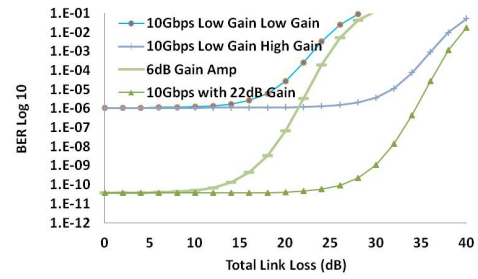


Fig. 9. BER performance of the system at 2.5Gbps and 10Gbps downstream signal using single high gain pre-amp OLT SOA (22dB)

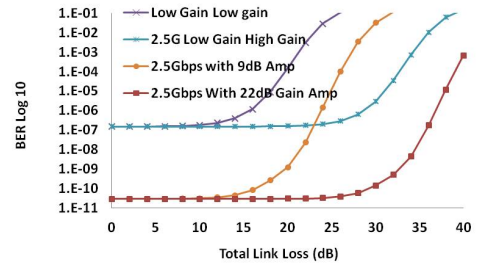
activate XGM effect between this two signal. In order to achieve the best BER, the incoming data signal needs to achieve high saturation gain in order to press pulse probe signal or seeding signal to modulate with input data signal in inverted format but until certain level BER drop after too much power input injecting into the SOA and this pattern can be seen in figures below when we measure detail correlation between OLT transmit signal with different SOA pre amplifier Gain and also post Amplifier SOA gain.

Figure 9 shows the BER performance of the 2.5Gbps signal and multiplexing of 4x2.5Gbps signal to become 10Gbps signal with the total link loss in the system (between OLT to ONU) using pre-amps SOA only. This result shows both of 2.5Gbps and 10Gbps signals only able to support below 10dB loss margin in order to maintain BER below $1e-9$. This value of margin cannot comply even with max class A ODN GPON system class of optical path loss that require min 5dB to max 20dB loss margin which is the lowest class of optical path loss margin that specified by ITU G.984.2.

In order to achieve higher optical path loss margin to support GPON Class A, B+ and C, as well implementing pre-amp in OLT module, we proposed additional amplifier called post-amp OLT inside the AOPR OLT module. Figure 10(a) shows the relationship BER performance of 2.5Gbps signal using low gain SOA and High Gain SOA at pre-amp SOA OLT and post-amp SOA OLT. This graph show the BER line for system using low gain pre-amp SOA 6dB and low gain post-amp SOA 6dBm gives maximum BER value maintained at $1e-6$ and loss margin reach up to 18db, using the same low gain SOA at pre-amp SOA, the maximum loss margin can extend their reach up 30db by using High Gain as a post-amp SOA, nevertheless the BER performance value still maintained at maximum $1e-6$. However by using both pre-amp and post-amp high Gain SOA at 22dB, we can see the maximum BER value reach up to $1e-11$ and maximum loss power margin can reach up to 30dB at BER $1e-10$. The same trends occur at 10Gbps multiplexing signal as shown in Figure 10(b), but 10Gbps multiplexing signal just slightly drop their BER performance at BER line using low gain pre-amp SOA. From this two graphs we can conclude that in order to support class A ODN optical path loss with good performance of BER, the system must be fixed



(a)



(b)

Fig. 10. BER performance of the system (a) 2.5Gbps and (b) 10Gbps downstream signal by comparing performance of both High Gain and Low Gain of SOA in Pre amp OLT and post amp OLT

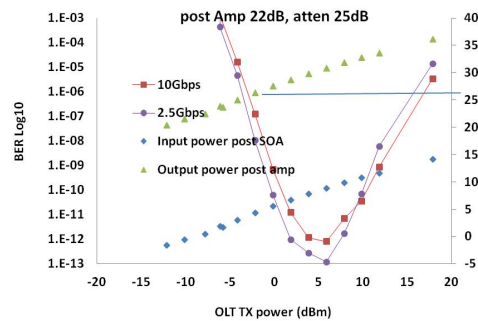


Fig. 11. BER performance of the system at different transmitting power into the XGM SOA and the correlation with input power and output power of post-amp SOA

with high gain pre-amp SOA and low gain post-amp, but to achieved maximum reach to support Class B+ and C optical path Loss the system must used both high gain for pre-amp SOA and post-amp SOA in AOPR OLT module system design.

Figure 11 shows the BER performance of the system with downstream input signal transmit power of XGM SOA. Pump pulse probe signal fixed at +6dBm and we vary all the 4 input transmit powers from -5dBm to +20dBm and at the same time we measure input power and output power of high gain post-amp SOA that fixed at 22dB. We set the system at 20km fiber with 1x64 optical splitter. The result shows the system performance below than BER $1e-9$ at downstream signal power -2dBm to 13dBm gives the range of input power of post-amp SOA at +5dBm to +15dBm; and range of the output post-amp SOA power at +25dBm to +35dBm, respectively. The different

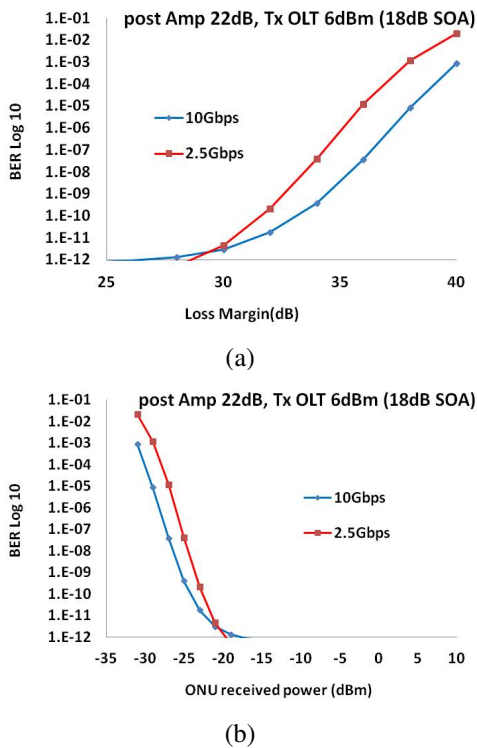


Fig. 12. (a) Total Loss margin and (b) ONU received sensitivity margin with BER performance of the proposed system using 18dB pre-amp SOA and 22dB post-amp SOA at AOPR OLT module

between input and output post-amp SOA is around 20dB.

Figure 12(a) and Figure 12(b) show the BER performance of the system using pre-amp and post-amp in AOPR OLT module at 18dB and 22dB SOA gain respectively. By varying the attenuation level using variable optical attenuator, we measure optical ODN path loss margin between OLT to ONU to calculate the maximum total loss margin and ONU received sensitivity in the system. Figure 17 shows the both signal 2.5G and 10Gbps multiplexing signal achieve maximum up to 32dB loss margin and ONU received sensitivity measured at -23dBm at BER performance below than 1e-9. This result show that the proposed system able to support both single channel 2.5Gbps and 10Gbps multiplexing channel at Class A, Class B+ and Class C GPON optical path loss as specified in ITU-T G.984.2 standard [1].

V. CONCLUSION

This paper provides study of new architecture AOPR TWDM PON system. The objective of this system architecture is to provide more flexibility of data delivery for each PON port with more bandwidth to each subscriber up to 10Gbps downstream and ready for 40Gbps PON transmission rate. This paper proves the capability of the system to aggregate four 2.5Gbps WDM PON links to 10Gbps OTDM with the BER value at 1e-9 with maximum loss margin up to 32dB for both 2.5Gbps and 10Gbps signal and ONU received sensitivity at -25dBm. This paper also study the effect of system quality

by varying the input data gain using pre-amp and post-amp SOA in the proposed design. This study also provide the alternative solution of hybrid WDM TDM PON system to increase performance of bit rate to support higher bandwidth demand to a specific user with coexistence between 10Gbps ONU with 2.5Gbps ONU. Based on this finding, we target to extend the research using by replicate this simulation to experimental setup and compare both results.

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REFERENCES

- [1] "G.984.1 : Gigabit-capable passive optical networks (gpon): General characteristics," 2008.
- [2] "G.987.1 : 10-gigabit-capable passive optical networks (xg-pon): General requirements," 2010.
- [3] "802.3ah carrier sense multiple access with collision detection (csma/cd) access method and physical layer specifications-amendment: Media access control parameters, physical layers, and management parameters for subscriber access networks," 2004.
- [4] "802.3av carrier sense multiple access with collision detection (csma/cd) access method and physical layer specifications-amendment: Physical layers specifications and management parameters for 10 gb/s passive optical networks," 2009.
- [5] F. Effenberger, H. Mukai, J.-i. Kani, and M. Rasztoivits-Wiech, "Next-generation pon-part iii: System specifications for xp-pon," *Communications Magazine, IEEE*, vol. 47, no. 11, pp. 58–64, 2009.
- [6] E. C. Marco Presi, "Stable self-seeding of reflective-soas for wdm-pons," March 2011.
- [7] H. Nakamura, S. Tamaki, K. Hara, S. Kimura, and H. Hadama, "40gbit/s λ -tunable stacked-wdm/tadm-pon using dynamic wavelength and bandwidth allocation," in *Optical Fiber Communication Conference*, p. OThT4, Optical Society of America, 2011.
- [8] M. Salleh, Z. A. Manaf, K. Khairi, Z. A. Kadir, Z. Yusof, A. Supa'at, and S. M. Idrus, "Simulation design for aopr wdm/tadm pon system architecture using wdm to otdm xgm," in *Communications (APCC), 2012 18th Asia-Pacific Conference on*, pp. 366–371, IEEE, 2012.
- [9] M. Salleh, Z. A. Manaf, Z. A. Kadir, Z. M. Yusof, A. S. M. Supa'at, S. M. Idrus, and K. Khairi, "Simulation on physical performance of twdm pon system architecture using multicasting xgm," in *Photonics (ICP), 2012 IEEE 3rd International Conference on*, pp. 46–50, IEEE, 2012.
- [10] K. Y. Cho and Y. C. Chung, "10-gb/s operation of rsoa for wdm pon using return to zero modulation format," in *OFC/NFOEC*, 2011.
- [11] S. Kumar and A. E. Willner, "Simultaneous four-wave mixing and cross-gain modulation for implementing an all-optical xor logic gate using a single soa," *Optics express*, vol. 14, no. 12, pp. 5092–5097, 2006.