RSOA based WDM-PON delivering 10-Gbps Downstream/5-Gbps Upstream Data

Amit Shetkar
P. G. Department
M.B.E.S. College of Engineering,
Ambajogai, India

S.K. Sudhansu
P. G. Department
M.B.E.S. College of Engineering,
Ambajogai, India

ABSTRACT
We demonstrate bidirectional wavelength division multiplexing passive optical network (WDM-PON) based on soliton pulse using two channels. The system uses 1550 nm and 1550.04 nm wavelength for each channel, which is capable of delivering 5-Gbps downstream data over 203 km and 2.5-Gbps upstream data over 153 km optical fiber with 0.2dB/km attenuation loss. The optical source for downstream transmission is sech pulse generator at central office and refractive semiconductor optical amplifier at each optical network unit for upstream transmission. The maximum optical to signal noise ratio for upstream and downstream transmission is obtained at input power 7.56dBm. We investigate backscattered optical power, quality factor and bit error rate (BER). The BER performance shows that our proposed scheme is a practical solution to meet the data rate and cost-efficient of the optical links simultaneously in tomorrow's WDM-PON access networks.

Keywords
Wavelength division multiplexing passive optical network (WDM-PON), soliton pulse, reflective semiconductor optical amplifier, erbium doped fiber amplifier (EDFA), single mode fiber, photo detector.

1. INTRODUCTION
There have been substantial growth and devolvement in implementing Fiber–to-the-home (FTTH) networks for various multimedia services, internet protocol telephony [1]. These services require high speed access network which provide bandwidth of above 50 Mbps. Wavelength divisions multiplexing passive optical network, (WDM-PON) is good candidate to meet these high speed data rate for above services. WDM-PON is considered as a promising solution for the next-generation of Fiber-to-the-x (FTTx) because of its larger bandwidth, security, and protocol transparency [2]. In terms of cost, passive optical network (PON) is very attractive, since there are no active components in transmission line and use of reflective semiconductor optical amplifiers (RSOA) at optical network unit. Also optical system uses optical sources such as light emitting diodes (LEDs) and the amplified spontaneous emission (ASE) of erbium doped fibre amplifiers (EDFAs), benefit from simple implementation or low cost. WDM-PON system typically consists of optical line terminal in central office (CO), a remote node (RN), and optical network units (ONUs). A light source is deployed at each central office (CO) for each downstream wavelength channel [2, 3].

In long haul optical communication non-linearity induced due to self phase modulation (SPM) and dispersion, to reduce nonlinearity soliton pulse is used. Soliton pulse by nature exhibit many desirable properties making them suitable for use in long-haul optical communication systems, since it has ability to retain their shape after certain periodic amplification and capable of maintaining their shapes over large distances [4].

In this article we demonstrate WDM-PON for two wavelength channel delivering downstream and upstream data on soliton pulse. The 5-Gbps downstream data at central office will be transmitted using soliton pulse and same soliton pulse is remodulated for upstream transmission with 2.5-Gbps data using refractive semiconductor optical amplifier at optical network unit (ONUs). These modulated channels will be multiplexed using WDM-MUX and transmitted over single 203 km single mode fiber (SMF) for downstream transmission and 153km SMF for upstream transmission. To utilize optical fiber, we adopt transmission of downstream and upstream data on single SMF for two channels. Performance of proposed scheme evaluated for two wavelength channels with channel spacing 0.04 nm by transmitting 5-Gbps downstream and 2.5-Gbps upstream data on each channel. At the end we infer that total transmission speed for downstream is 10-Gbps & for upstream it is 5-Gbps.

2. OPERATIONAL PRINCIPLE
The operational principle and simulation setup of proposed scheme is presented in figure 1, which consists of a pseudorandom sequence generator. The downstream signal transmitted over soliton pulse that is mode-locked laser, generating a single pulse of sech shape with specified power and width. Here, sech pulse generator is nothing but mode-locked laser which generate soliton pulse [5]. The shape of soliton pulse can be maintained by increasing soliton peak power and reducing pulse width [6]. It is possible to generate soliton pulse for different wavelengths with specified peak power level. Two soliton pulses at 1550nm and 1550.04nm were multiplexed using WDM MUX-1 and launched into single mode fiber (SMF) through optical circulator. At circulator-1 backscattered optical power is measured using optical power meter and spectrum analyzer. At ONU these signal wavelength demultiplexed by WDM-DEMUX-1 and send to corresponding ONU. Received optical power of demultiplexed optical signal for each wavelength channel splitted by splitter, half of received optical power used to detect downstream data and other half of received optical power remodulated by refractive semiconductor optical amplifier (RSOA) with upstream data. Half of received power of both wavelength channels is remodulated using RSOA for upstream transmission and multiplexed at WDM MUX-2. The multiplexed upstream data transmitted over single mode optical through circulaor-2 to CO. Backscattered optical power is measured using optical power meter and spectrum analyzer at circulator-2. Upstream data at CO will be detected by photo detector (PD) [12].

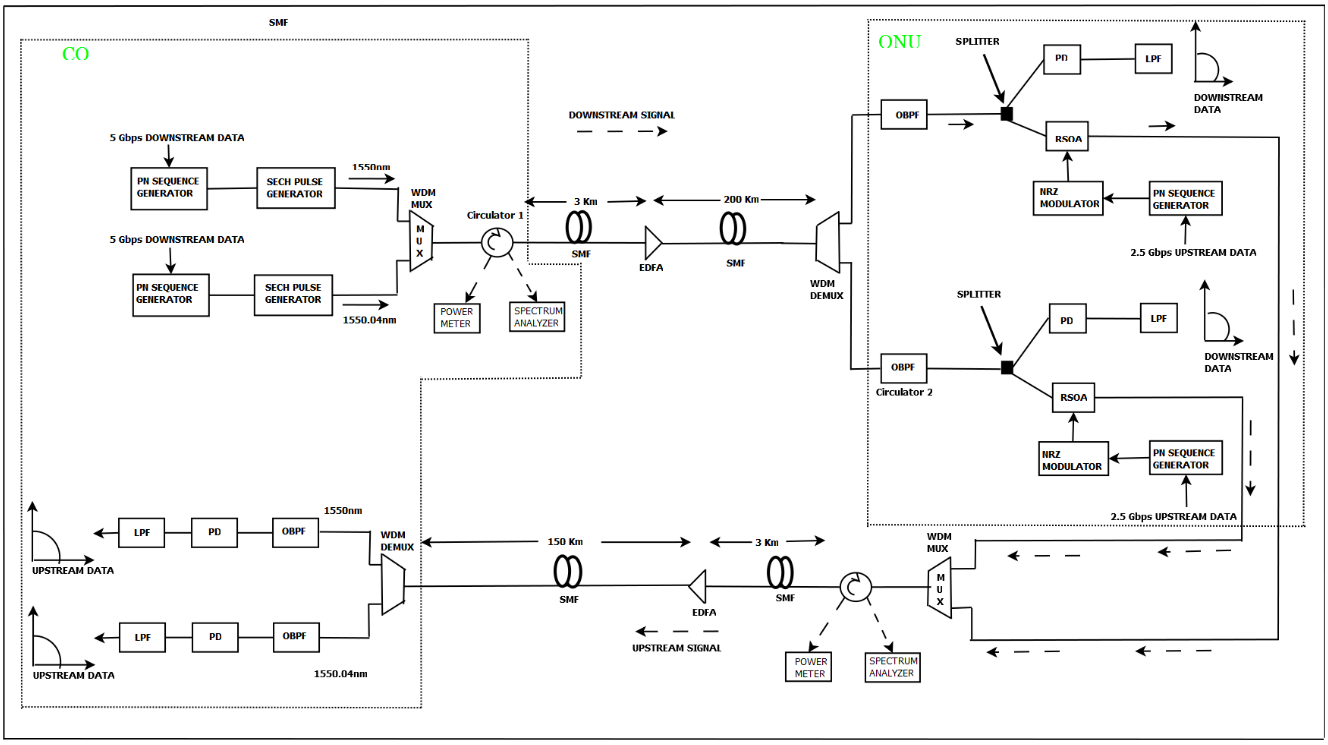

Fig 1: The schematic diagram of the proposed WDM-PON

3. SIMULATION SET-UP

Figure 1 shows simulation set-up for proposed scheme. We present two wavelengths these are 1550 nm and 1550.04 nm transmission in this article for sake of simplicity. Soliton was modulated at downstream data 5Gbps with pseudorandom bit sequence with length of 2^{31}-1. At 5-Gbps, initial pulse width is 14.18 ps [12].

Soliton pulse generated using mode-locked laser at power 7.56dBm and wavelength λ_1 = 1550 nm λ_2 = 1550.04 nm. Soliton at each wavelength that is λ_1 and λ_2 was modulated at downstream data 5-Gbps. Downstream signal is multiplexed at WDM-MUX-1 and signal passes through single mode fiber of length 203 km. Soliton can maintain their shape by preamplifying fiber link, erbium doped fiber amplifier is used at distance 3 km from CO for downstream link. The Downstream signal is given to erbium doped fiber amplifier after 3 km to amplify the weak signal and then passed over 200 km fiber, we design system by considering 0.2 dB/km loss of SMF, hence system will be practical solution. The analysis of backscattered signal for downstream

data signal is done at circulator 1 by calculating optical power of backscattered signal. At the end of link, signal are demultiplexed using DEMUX-1, after demultiplexing channel will be separated, these separated channels will pass over two different optical band pass Bessel filter, which is having bandwidth = 4 * bit rate for downstream signal is used. Optical signal is splitted by splitter, half of optical signal is detected by PD for reception of downstream data signal and output of PD given to low pass Bessel filter which having cut off frequency 0.75 * bit rate to get better signal to noise ratio. The other half of optical signal is injected by RSOA for remodulation of RSOA with the upstream baseband data 2.5-Gbps simulation parameters for RSOA are shown in Table1. After remodulation of RSOA with the upstream baseband data 2.5-Gbps upstream signal having optical power -41dBm at output of RSOA. This upstream signal is passed via circulator-2. The analysis of backscattered signal for upstream data signal is done at circulator-2 by calculating optical power of backscattered signal. Single mode fiber of total length 153 km with erbium doped fiber amplifier at 3 km from ONU on upstream link. The upstream signal is given to erbium doped fiber amplifier after 3 km to amplify the weak signal and passed over 150 km fiber. The analysis of backscattered signal for upstream data signal is done at circulator-2 by calculating optical power of backscattered signal. At the end of link, optical band pass Bessel filter is used which having the bandwidth = 4 * bit rate for upstream signal. Upstream optical signal is detected by PD for reception of upstream data signal and output of PD given to low pass Bessel filter which having the cut off frequency 0.75 * bit rate for upstream data to get better signal to noise ratio. Finally, BER performance of downstream data and upstream data signal was measured.

Table 1. Simulation parameter

RSOA Parameters	
Input facet reflectivity	$5e^{-5}$
Output facet reflectivity	$5e^{-5}$
Active length	$700e^{-6}$ m
Taper length	$700e^{-6}$ m
Width	$0.4e^{-6}$ m
Height	$0.4e^{-6}$ m
Optical confinement factor	0.45
Nonlinear gain parameter	$1.2e^{-22}$ m^3

4. RESULTS AND DISCUSSION

The result have been obtained for various performance measures viz. Backscattered optical power, OSNR, input optical power, BER, received optical power, Q-factor. Figure 2(a) and figure 2(b) shows the input power spectrum that is spectrum sech pulse generator observed using optical power spectrum. Most of the optical power of that channel from sech pulse generator output was -6.943 dBm that was large, which did satisfy the RSOA to work under the gain saturation condition. In this condition, the output optical power of RSOA-1 and RAOA-2 is about -34.262 dBm and -35.239 dBm respectively. In this analysis we assessed Rayleigh scattering effect that reflects back to source. The scheme depicted in Figure 1 was utilized to study the influence of backscattered power in the downstream and upstream data transmission simultaneously backscattered power in this design is very negligible.

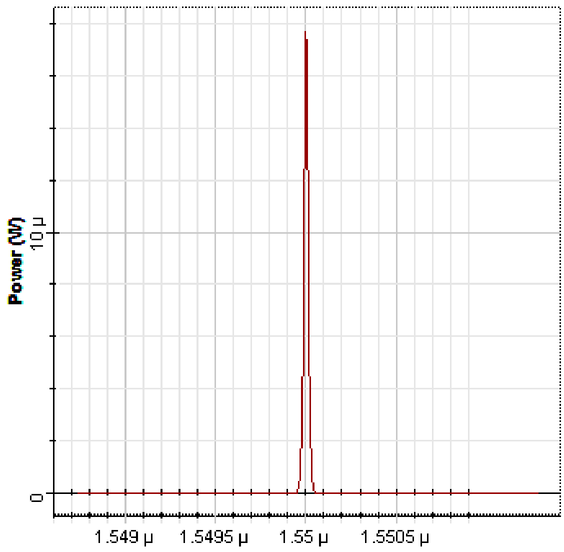

Fig 2: (a) Optical spectrum at output of sech pulse generator for 1550nm

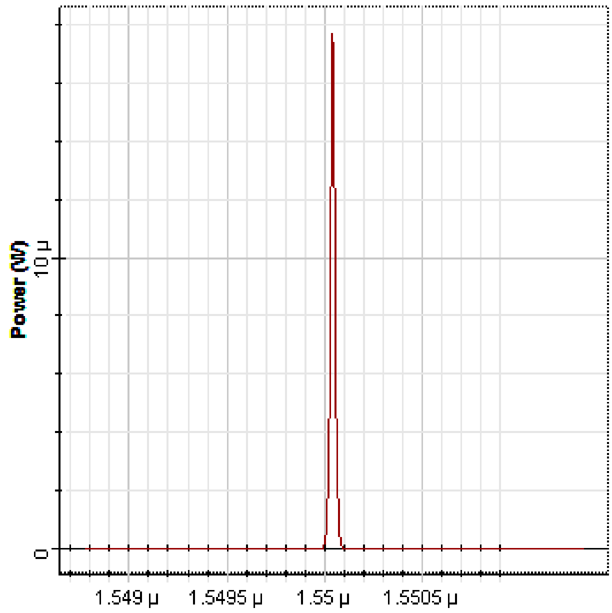

Fig 2: (b) Optical spectrum at output of sech pulse generator for 1550.04nm

The downstream and upstream data transmission simultaneously is shown in figure 3. At input power that is -7.56 dBm, backscattered optical power for downstream and upstream transmission is -91 dBm and -95 dBm respectively. From simulation of design, it observed that, as input optical power increases the backscattered signal power increases, it is also observed that the backscattered signal power is large in case of downstream data signal transmission as compare to upstream data signal transmission. There is too much reduction in backscattered signal power for our proposed scheme.

In this analysis, only BER curve for both downstream and upstream data of channel 1550 nm were measured as shown in Figure 3(a) and 3 (b) respectively. Obviously, the downstream and upstream performances increase with increase in received optical power. From these results, we compared the performance of downstream and upstream data for wavelength channel 1550 nm and 1550.04 nm, the performance of downstream is better than upstream. In Figure 4(a) and 4(b), simulated Q-factor for downstream and upstream data signal is shown. Obviously, the Q-factor for downstream and upstream data increases with increase in input optical power. From the above result, it is observed that BER for downstream data signal is same for input optical powers 7.56 and 7.5 dBm, and also it is true about Q-factor of downstream data signal.

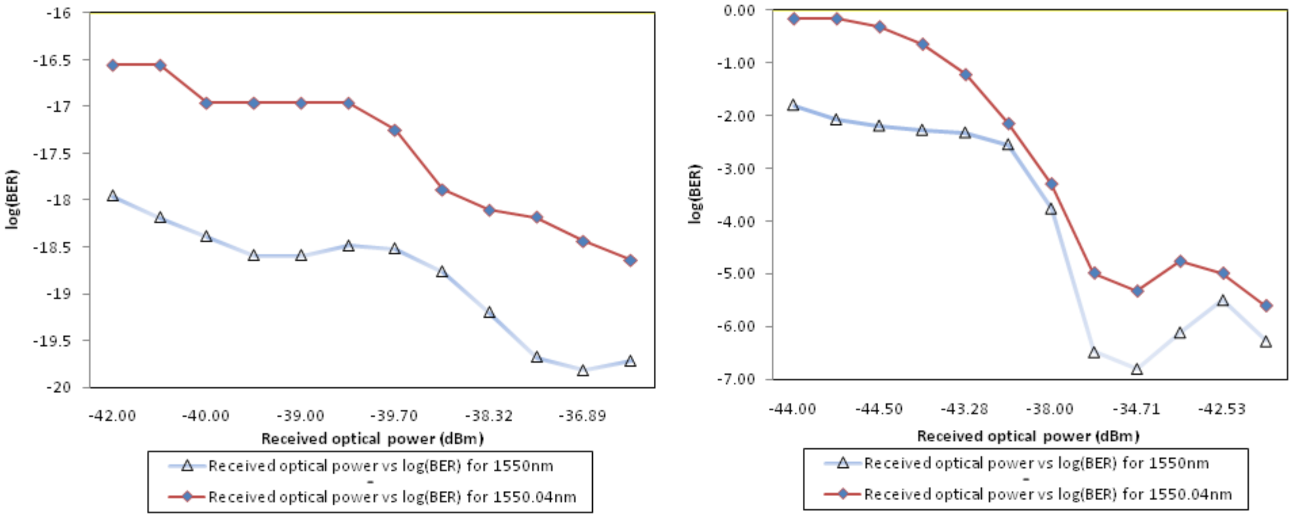

Fig 3: (a) transmission performance of downstream data (b) transmission performance of upstream data

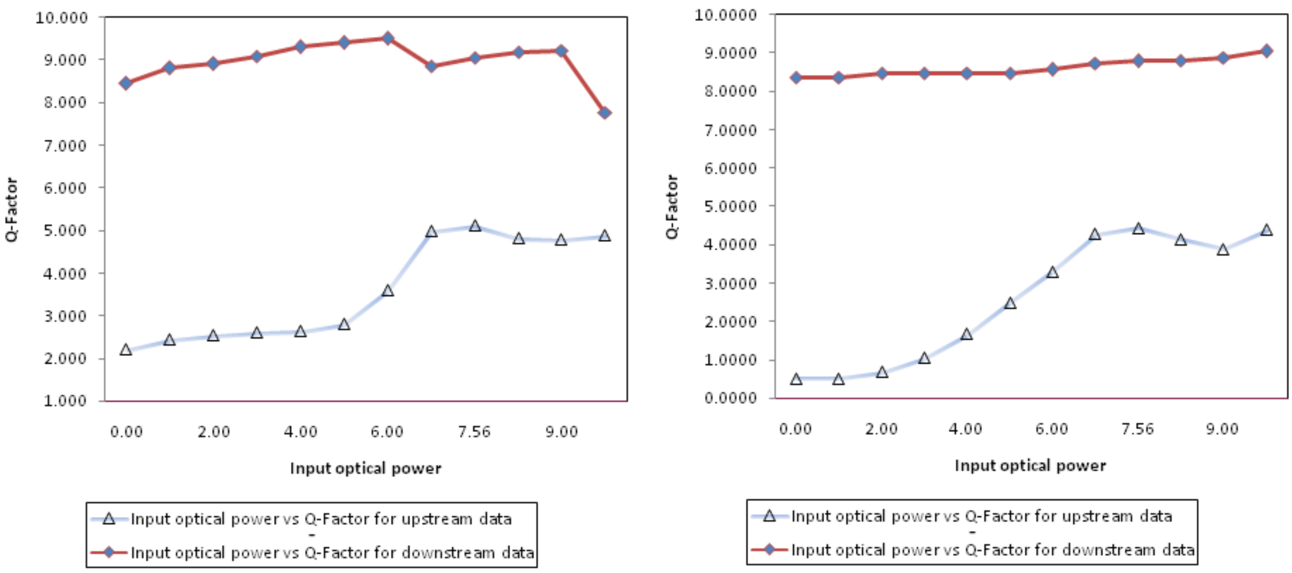

Fig 4: (a) simulated Q-factor for downstream data for 1550nm (b) simulated Q-factor for upstream data for 1550.04nm.

Most of the optical power of that channel from sech pulse generator output was -6.943 dBm which was large, which did satisfy the requirement of injected optical power of RSOA to work under the gain saturation condition. In this condition, the output optical power of RSOA is about -36.733 dBm and spectrum at the output of RSOA as presented in Figure 3(b). First, we assessed Rayleigh scattering effect that reflects back to source. In this condition, the output optical power of RSOA is about -36.733 dBm and spectrum at the output of RSOA as presented in Figure 3(b). First, we assessed Rayleigh scattering effect that reflects back to source. The scheme depicted in Figure 2 was utilized to study the influence of backscattered power in the downstream and upstream data transmission simultaneously. In Figure 4(a), detected total backscattered optical power in the downstream and upstream data transmission simultaneously is shown. As input optical power increases the backscattered signal power increases. In Figure 4(a), it is observed that the backscattered signal power is large in case of downstream data signal transmission as compare to upstream data signal transmission. There is too much reduction in backscattered signal power for our proposed scheme. In this article, only BER curve for both downstream and upstream data of channel 1550 nm and 1550.04 were measured as shown in Figures 3(a) and 3(b) respectively. Obviously, the downstream and upstream performances increase with increase in received optical power. From these results, we compared the performance of downstream and upstream data. Obviously, the performance of downstream is better than upstream. In Figure 4(a) and Figure 4(b), simulated Q-factor for downstream and upstream data signal is shown. Obviously, the Q-factor for downstream and upstream data increases with increase in input optical power. Figure 5(a) and 5(b) presents eye diagram for both wavelength at end of upstream transmission.

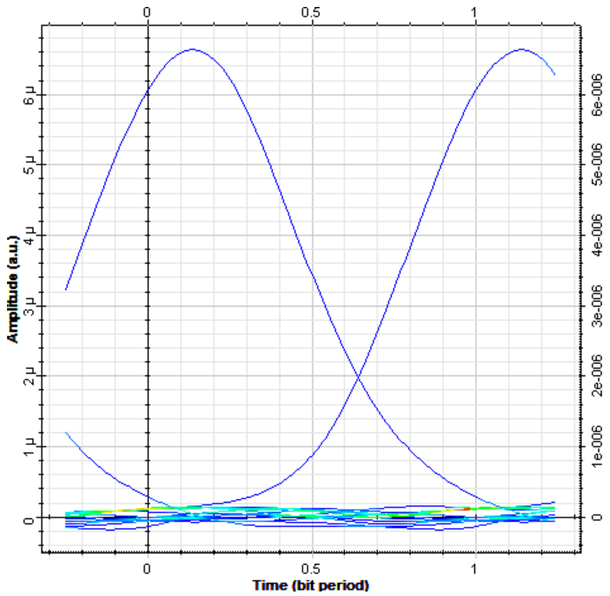

Fig 5: (a) Eye diagram at end of upstream transmission for 1550 nm

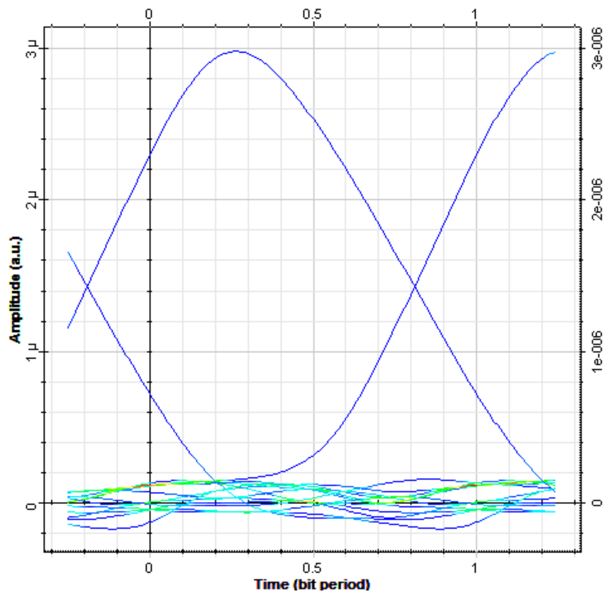

Fig 5: (b) Eye diagram at end of upstream transmission for 1550.04 nm

From these results, we compared the performance of downstream and upstream data then obviously the performance of downstream is better than upstream data signal. From the above result, it is observed that BER for downstream data signal is same for input optical powers 7.56 and 7.5 dBm, and also it is true about Q-factor of downstream data signal.

5. CONCLUSIONS

We have proposed and successfully demonstrated cost-effective WDM-PON system delivering downstream 10-Gbps data over 203 km SMF and upstream 5-Gbps data over 153 km SMF on two different wavelength using pulse source that is mode-locked laser generating a single pulse of sech shape for each wavelength with specified power and width, that is, soliton pulse. The transmission distance of the proposed WDM-PON system can be expanded, while the performance is maintained. We have successfully demonstrated the propagation of soliton pulse in optical fiber, so our scheme will be a practical solution, since we designed system by considering 0.2 dB/km loss of SMF that is 40.6 dB and 30.6 dB loss of downstream and upstream SMF respectively. So this technique is very useful where high data rate speed is required.

7. REFERENCES

[1] S.J. Park, C.H. Lee, K.T. Jeong, H.J. Park, J.G. Ahn, and K.H. Song, "Fiber to the home services based on wavelength division multiplexing passive optical network", *J Lightw Technol* 22 (2004), 2582–2591.

[2] H. Shinohara, "Broadband access in Japan: Rapidly growing FTTH market", IEEE Commun Mag 43 (2005), 72–78.

[3] J.J. Yoo, H.H. Yun, T.Y. Kim, K.B. Lee, M.Y. Park, B.W. Kim, and B.R. Kim, "A WDM-ethernet hybrid passive optical network architecture", *In: Proc. ICACT*, 2006, Vol.3, nos. 20–22, pp. 1754–1757.

[4] G. Maier, M. Martinelli, A. Pattavina, and E. Avadori, "Design and cost performance of the multistage WDM-PON access networks", *J Lightw Technol* 18 (2000), 125–139.

[5] C.H. Lee, W.V. Sorin, and B.Y. Kim, "Fiber to the home using a PON infrastructure", *J Lightw Technol* 24 (2006), 4568–4583.

[6] S.J. Park, G.Y. Kim, and T.S. Park, "WDM-PON system based on the laser light injected reflective semiconductor optical amplifier", *Opt Fiber Technol* 12 (2006), 162–169.

[7] F. Payoux, P. Chanclou, T. Soret, N. Genay, and R. Brenot, "Demonstration of a RSOA-based wavelength remodulation scheme in 1.25 git/s,bidirectional hybrid WDM-TDM PON", *In: Proc. OFC*, 2006, TuC4.

[8] J.-H. Moon, K.M. Choi, and C.H. Lee, "Overlay of broadcasting signal in a WDM-PON", *In: Proceedings of the Optical Fiber Communication and Conference*, 2006, Paper OThK8.

[9] G.P. Agrawal, "optical pulse propagation in doped fiber amplifier", Phys Rev A 44 (1991), 7493–7501.

[10] G.P. Agrawal, "Nonlinear fiber optics", 3rd ed., Academic Press, Orlando, FL, 2001.

[11] L Tawade and S Deosarkar "cost-effective wavelength division multiplexing passive optical Network delivering upstream/downstream data on a single wavelength using soliton pulse", *microwave and optical technology letters*, vol.54,No.2,February2012

[12] Balaji Raobawale, S. K. Sudhansu, "WDM-PON delivering 5-Gbps downstream/ 2.5-Gbps upstream data", International Journal of computer applications, vol. 72, no. 4, pp. 23-27, 2013.

[13] Balaji Raobawale, "RSOA based WDM-PON delivering upstream/ downstream data on Soliton pulse", Elsevier Science & Techonology, vol. 3,vol. 54, pp. 321-326, 3rd International conference ICRTET-2014