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Cost Effective Long Reach Hybrid WDM-TDM Passive Optical Network Using Bidirectional EDFA

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Abstract— Both the low cost and high capacity has become an increasingly significant aspect of network design. So this tutorial paper demonstrates a long reach hybrid WDM (wavelength division multiplexing)/TDM (time division multiplexing) PON (Passive optical network) system with dual pumped bidirectional Erbium doped fiber amplifier (EDFA). This architecture has a total reach of 115Km and EDFA provides a gain of ~23db.

Index Terms— access network, long-reach passive optical network, time division multiplexing, wavelength division multiplexing, erbium doped fiber amplifier.

1 INTRODUCTION

IN order to increase the ever increasing bandwidth demand from end users it is mandatory to introduce FTTH (fiber to the home) in the broadband access network also known as last mile network (connects central office to each end user) [1]. PON came in to existence in the year 1980.The potential of PON to deliver high BW (bandwidth) to users in access network and their advantages over current access technologies have been widely recognized. PON minimizes the no. of optical transceivers to N+1 (where N is the no. of end users), CO terminations and fiber deployment [2].

PON can be categorized in two types based on data multiplexing schemes: TDM and WDM. Traditional TDM is considered as a cost-effective scheme in terms of installation and operation but it reduces the data rate because BW is shared by no. of subscribers usually 32 or 64 [3-4]. Usually optical amplifiers are used to increase both the reach and split-ratio of the network. On the other hand WDM-PON has been considered as a powerful mean to support more subscribers by introducing multiple wavelengths without sacrificing bandwidth [5]. WDM-PON has many advantages over TDM-PON in terms of bandwidth, security, low channel splitting loss but they are not cost effective. One way to reduce the cost is to use the concept of LR-PON (long reach passive optical network) which has the coverage of more than 20-25km by exploiting optical amplifiers [6-9]. And the other way is to introduce hybrid PON. So in this paper we combine the LR-PON with hybrid PON to exploit the advantages of TDM, WDM and inline amplifiers (EDFA) to achieve high per subscriber bandwidth and low cost.

This paper is organized as follows: Section II introduces proposed bidirectional EDFA. Section III introduces the proposed system architecture. Section IV demonstrates the simulation parameters and the discussion on the result and finally this paper is summarized in section V.

2 BIDIRECTIONAL EDFA

Commonly used mid-span amplifiers are SOAs (semiconductor optical amplifiers) [10], distributed Raman amplifier [11] and Erbium Doped Fiber Amplifier [12]. As we are proposing a bidirectional system in which both downstream and upstream signals use different wavelengths it is mandatory to introduce bidirectional amplifier ie. Capable of separating downstream and upstream signals and amplifying them individually. Here we propose an EDFA that has a doping concentration of $6e^{25}$and have bidirectional pumping scheme.

A two-level system approximation is used in this model. Under the assumption of the normalized population densities N_1 and N_2 at the ground and metastable energy level, ${}^4I_{\frac{15}{2}}$ and ${}^4I_{\frac{13}{2}}$ populations are calculated by numerically solving the rate and propagation equations as given below.

$$\frac{\partial N_2(z,t)}{\partial t} = -\frac{N_2(z,t)}{\tau} - \frac{1}{Aeff}\sum_{n=1}^{N}\{\Gamma_n$$

$$-[(\sigma_n^e + \sigma_n^a N_2(z,t) - \sigma_n^a]\}[P_n^+(z,t) + P_n^-(z,t)] \quad (1)$$

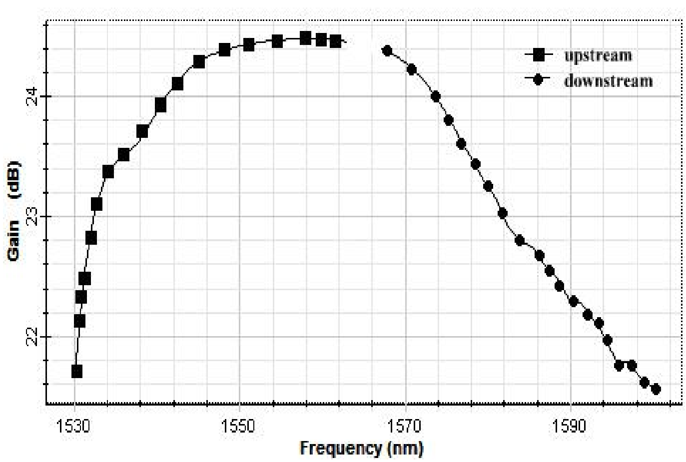
$$N_2 + N_1 = 1 \quad (2)$$

$$\frac{\partial P_n^{\pm}(z,t)}{\partial z} = \mu_n\{\rho\Gamma_n[(\sigma_n^e + \sigma_n^a)N_2(z,t) - \sigma_n^a - \alpha]$$

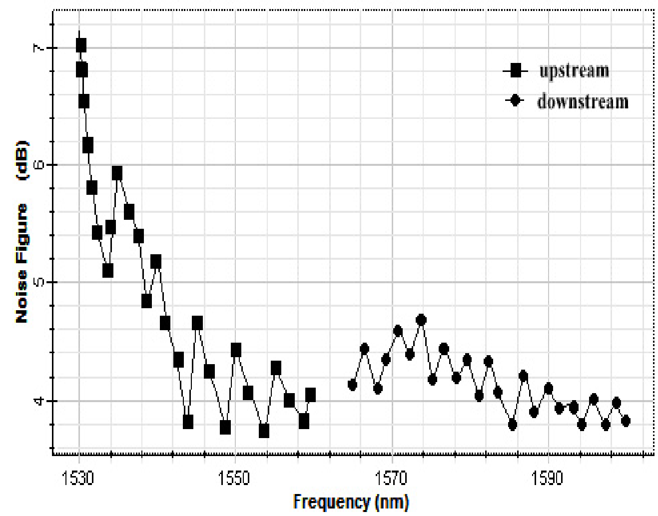
- $\}P_n^{\pm}(z,t) + 2\rho\Delta\vartheta N_2\Gamma_n\sigma_n^e$ (3)

where the optical powers are expressed in units of number of photons per unit time, τ is the metastable spontaneous emission lifetime, N is the number of channels taken into account in the simulation, ϱ is the number density of the active erbium ions, is the attenuation coefficient (which takes into account the background loss of the fiber), $\Delta\vartheta$ is the frequency step used in the simulation to resolve the amplified spontaneous emission spectrum, and A_{eff} is the effective doped area given by , $\pi \times b^2$ where b is the Er doping radius (it is considered a uniform distribution of erbium ions in the area given by the Er doping radius region). The *n*th channel of wavelength λ_n has optical power $P_n(z,t)$ at location z and time t, with emission and absorption cross-section σ_n^e and σ_n^a respectively, and confinement factor Γ_n. The superscript symbols + and – are used to indicate channels traveling in forward (from 0 to L) and backward (from L to 0) directions, respectively. For beams traveling in the forward direction $u_n = 1$ and for beams in the opposite direction $u_n = -1$.

We used two pump beams of 980nm and 1480nm having pump powers of both 100mW where 980nm pump power is co-propagating and 1480nm is counter propagating. We used L-band for downstream signals and C-band for upstream signals. This amplifier is characterized in terms of signal gain and noise figure as shown in fig 1. The signal gain and noise figure are measured by sweeping the CW laser (continuous wave) frequency in L and C-band.



(a)



(b)

Fig 1. (a) Gain for different values of frequency and (b) Noise figure for different values of frequency.

From fig. 1(a) it is clearly visible that the approximate gain of the bidirectional amplifier is ~23db. Fig 1(b) shows the variation of noise figure with frequency. It is observed that noise figure is less than 6db in C-band and less than 5db in L-band.

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3 LR- HYBRID WDM/TDM PON ARCHITECTURE

The configuration of the proposed LR-hybrid WDM/TDM PON with bidirectional pumped EDFA is shown in Fig 2.

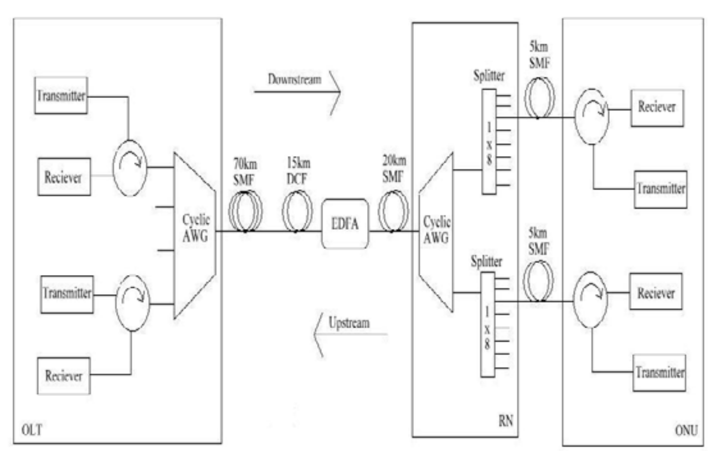

Fig 2. Architecture of LR- Hybrid WDM/TDM PON

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Different wavelength lasers are used for both upstream and downstream transmission. In each channel non return to zero(NRZ) signal modulates the continuous wave laser using Mach-Zehnder modulator at 10Gb/s PRBS ($2^{31}-1$). For multiplexing and de-multiplexing we used cyclic AWG which has periodic wavelength passband responses. The multiplexed signal is passed through a 70km long single mode fiber followed by a 15km DCF (dispersion compensation fiber). The SMF (single mode fiber) and DCF are shared by both upstream and downstream wavelengths. After DCF we used our proposed amplifier to increase the signal gain and signal to noise ratio (SNR). Further a 25km feeder fiber is used whose one end is connected to bidirectional EDFA amplifier and is other at RN (Remote Node). At RN AWG and 1x8 coupler is used to support 8 TDM ONU's (optical network units) per single wavelength channel. Each ONU at subscriber end is connected to RN through a 5km distribution fiber. Using 1x8 coupler data rate reduces to 1.25Gb/s at each subscriber unit. The receiver consists of variable optical attenuator and a PIN diode.

4 SIMULATION PARAMETERS AND DISCUSSION

Simulation parameters used are summarized in the table below.

Table 1
PARAMETER VALUES

PARAMETER	VALUE
AWG loss	6.6dB
Bi-EDF length	2.3m
DCF loss	0.5 dB/km
SMF loss	0.2 dB/km
1x8 splitter loss	10dB
Circulator loss	0.5dB
CW laser power	0dB

We used four different wavelengths for both downstream and upstream transmission. Downstream wavelengths are 1575nm, 1580nm, 1585nm, 1590nm and upstream wavelengths are 1545nm, 1550nm, 1555nm and 1560nm. The total signal transmission loss from OLT transmitter to ONU receiver is ~42dB.

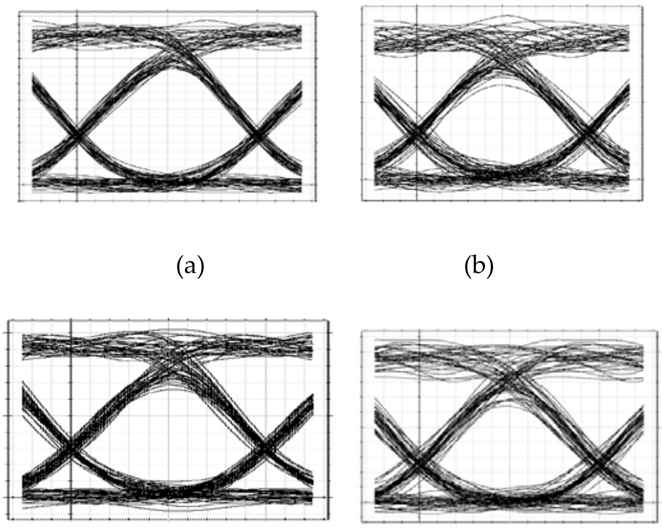
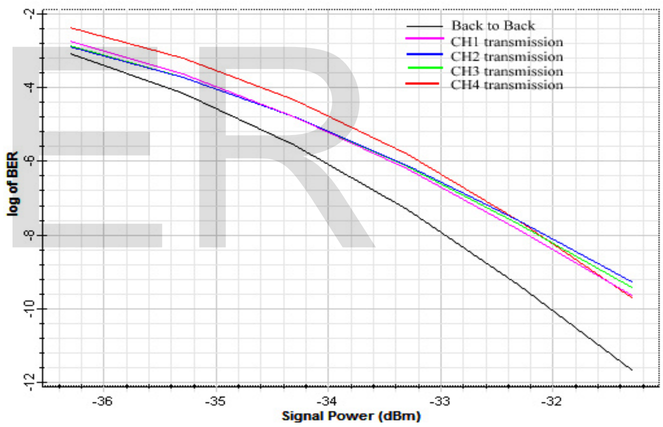
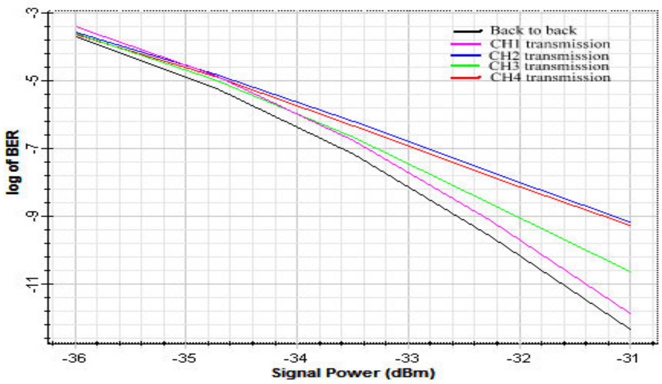

(a) (b)
(c) (d)

Fig 3. Optical eye diagram of (a) downstream back to back (b) downstream transmission (c) upstream back to back (d) upstream transmission



(a)



(b)

Fig 4. (a) BER for downstream (b) BER for upstream

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To investigate the performance of our proposed architecture we measure the eye diagram and BER values for both downstream and upstream signals at back-to-back and after 115 km transmission using EDFA. Error free operations (at 10^{-9}) are observed with ~1.2dB power penalty. It is also observed from our BER graphs that downstream receivers need to have higher sensitivity than upstream receivers.

4 CONCLUSION

We have successfully proposed an EDFA based LR-hybrid WDM/TDM PON. This architecture not only increases the no. of subscribers and provide security due to WDM but also reduces the cost by inducing inline amplifiers and TDM PON. A further reduction in cost can be done by implementing colorless Optical network units [13]. Best utilization of bandwidth can be done by proper network planning where TDM signals are shared based on user behaviors [14].

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