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Investigating a Simulated Model of 2.5 GHz 64 Channel 140 kmDWDM System Using EDFAand Raman Amplifier Considering Self-Phase Modulation

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Abstract: *In this paper a 2.5 GHz 64 channel DWDM fiber optic transmission system is investigated with 140km of fiber length.For comparative analysis, both EDFA and Raman areused for amplification purposes but in consideration with self-phase modulation. The model of DWDM grid frequency ranged from193.1 THz to 199.4 THz (1552.52 nm to 1503.47 nm in wavelength) and with 100GHz (0.8nm) of channel spacing. This range covers most of the C-band and a portion of the S-band.The simulationresults show that the system with Raman Amplifiers yieldedahighest gain of 12.36 dB whereas the system withEDFA produced ahighest gain of 13.01dBat C band region and it was further reduced to 5dB entering S band region. It isalso shown thatRaman Amplifier networks are less prone to crosstalk and inter symbol interference than EDFA networks.*
Keywords:*DWDM, EDFA, Raman Amplifiers, Self-Phase Modulation (SPM), C-band, S-band.*

I. Introduction

With the increase in demand on the load of fiber optical networks, Dense Wavelength Division Multiplexing (DWDM) flexible grid spectrums are getting wider with narrow channel spacing. As the systems are prevalently used for long distance communication, optical amplifiers are critical in compensation for the attenuation. Two of the more popular optical amplifiers are Erbium Doped Fiber Amplifiers (EDFA) and Raman Amplifiers. Raman Amplifiers exhibit different characteristics for different parameter change. Research shows that Raman Amplifier's gain is directly proportional to temperature and Noise Figure [1]. In Case of EDFA, the gain sharply changes with the input pump power and also with the orientation of pump or pump propagation scheme such as Counter Propagation and Co-Propagation. Fiber nonlinearity is often ignored in simulated models of such optical amplifier systems. This parameter increases with bit rate, wavelength, number of channels, pump power, etc. and obviously is worth considering in complex systems where extensive lengths of fiber optic cables arebeing deployed. In fiber optic systems, prominently observed nonlinearities are Stimulated Brillouin scattering (SBS), Stimulated Raman Scattering (SRS), Four Wave Mixing (FWM), Self-Phase Modulation (SPM), Cross-Phase Modulation (XPM), and InterModulation. SPM occurs due to the interaction of light matter in optical media and optical Kerr effectwhen an ultra-short light pulse travelling through the media induces varying optical refractive index and causes a nonlinear phase delay. SPM affects quality factor of the transmission as well. In this paper the effect of this nonlinearity is investigated over different fiber lengths and also using two different types of optical amplifiers- EDFA and Raman. The simulated model includesa 64-channel DWDM system with a frequency range between 193.1 THz to 199.4 THz (1552.52 nm to 1503.47 nm in wavelength) and with 100GHz (0.8nm) of channel spacing. This range covers most of C-band and a portion of S-band. Optisystem-7.0 is used as the simulation tool for gathering the analyzed data.

II. Theory

Raman optical amplifiers follow the principle of Raman scattering. In 1928 C. V. Raman *et al*. published a paper about the scattering phenomena of incident light in liquids and after that in the same year,G.S. Landsberg*et al*. found similar optical scattering in quartz. Their observation was that frequency of scattered light is less than frequency of incident light. In 1971 Stolen *et al*. experimentally observed the stimulated Raman emission in a single mode optical fiber. Since then Raman amplifierswere developed and further evolved in three steps over three decades.However, during the 90s, EDFA took over all the attention since it yielded a much higher gain around the 1.5μm region[2].The first commercially viable EDFA wasdeveloped by researchers of SouthamptonUniversity and AT&T Bell Laboratory in 1987[3]. It then started a new era of fiber transmission systemwith the transmission window centred at 1.55μm wavelength.

Raman amplifiers' dependence on its parameters help explain why it failed to compete against EDFAs. The gain of Raman amplifiers can be shown using the expression below:

$$G_R = \exp(\frac{g_R P_P L_{eff}}{A_{eff}\, k}) \qquad (1)[4]$$

Where , $L_{eff}$is the Effective Length, A_{eff} is Effective Area , k is Numerical Factor (Polarization Dependence), $Pp$is the Pump Power, $r_{eff}$is Effective Core Radius, $\alpha_p$is Transmission Loss, and $g_R$is the Power Raman Gain Coefficient.

The gain of EDFA depends upon the contribution of the N slices of its total length. If the length of the amplifier is L, then$G = \exp(\int_0^L g(z)dz)$ (2)

The gain of a slice $g(z)$ can be determine by : $g(z) = \Gamma_s[\sigma_{e,s}N_2(z) - \sigma_{a,s}N_1(z)]$ (3) [5]

The overlap factor can be calculated by: $\Gamma = \left(1 - e^{-\frac{R^2}{\omega^2}}\right)$ (4)

Where $\Gamma_s$is the overlap factor, **N** is population density, **σ** is cross section (***e*** – Emission, ***a*** - Absorption), R is thedistribution radius of Erbium ion, and ω represents the spot size.

It should be noted thatequations (1) and (2) both have length of the fiber *L*asone of the key parameters.Inthis paperthe length of EDFA and Raman is set to 5m and 10km respectively.For selecting those lengths of the amplifiers a single channel optical transmission systems of 200km fiber length is simulated.The results are shown in the figures below.EDFA provides around 30dB at 5m of length and Raman provides around 15dB of gain with 26.38 ofQ-factor.

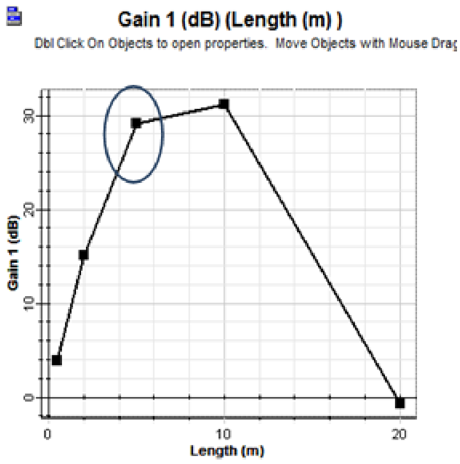

Figure 1: Gain Vs. Length curve of EDFA at 200 kmof fiber length.

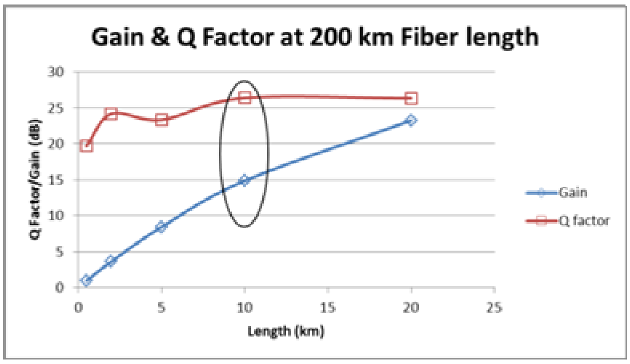

Figure 2: Gain and Q Factor vs. Length curve of Raman at 200km of fiber length.

With the increment of channels in DWDM systems, the effect of non-linear phenomena increases. Due to SPM, the modulated optical signal induces a modulation in the fiber's refractive index and thisleads to the spectral broadening of the propagating pulses [6]. Basically when an optical pulse is travelling through a medium due Kerr effect it causes a time dependent phase shift in accordance with the time dependent pulse intensity thus a temporal frequency variation occurs. For a Gaussian beam having beam radius w in a medium of length L then the phase shift per unit optical power can be described by proportionality constant:

$$\gamma_{SPM} = \frac{2\pi}{\lambda} n_2 L \left(\frac{\pi}{2} w^2\right)^{-1} = \frac{4n_2 L}{\lambda w^2} \quad (5)$$

Where n_2 is the nonlinear refractive index [7].

Raman pump power was set to 1W for the simulation of a single channel of 100km fiber length.Results show that 1W pump provides aQ-factor of 55.43 where 800mWpump and 2W pump provides a Q-factor of 54.69 and 53.07 respectively. For EDFA a pump power of 100mW was chosen, asfig.3clearly shows thatat 100mW pump power the EDFA provides the maximum Q-factor.
Selecting the spectrum bands is essential for implementing DWDM systems with amplifiers. As EDFAsare centered at 1552nm,they give better performance at C-band (1525-1565 nm) and L-band (1565-1620 nm) [8]. Raman amplifiers have a flat gain over S(1460-1530 nm), C, and L-bands [4].
The Raman frequency shift is about 440cm^{-1} so the pump wavelengthfor the highest gain was found to be 1433.5nm for a 1530nm signal wavelength.EDFA works best with apump wavelength of980nm and 1480nm[4].

As the simulatedDWDM grid stats from 1500nm range,980nm was chosen for pump wavelengthof the EDFA to avoid unwanted noise insertion.

The total length of the fiber (140km) was selected as beyond this length the output of 64 channel transmission system with EDFA amplifier considering SPM gets distorted. The output is shown below in fig.4.

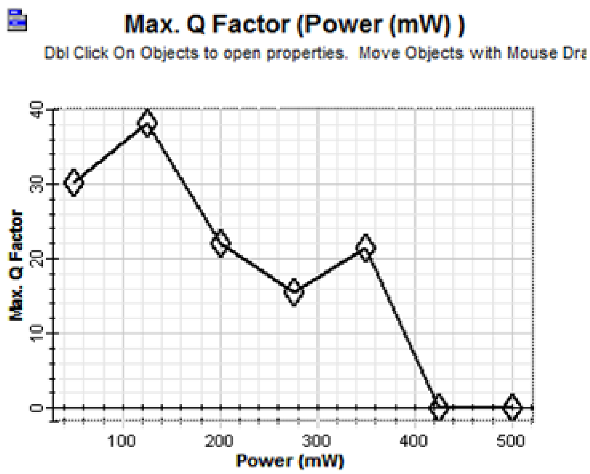

Figure 3: Q factor Vs. Pump power curve for EDFA at 100km fiber length.

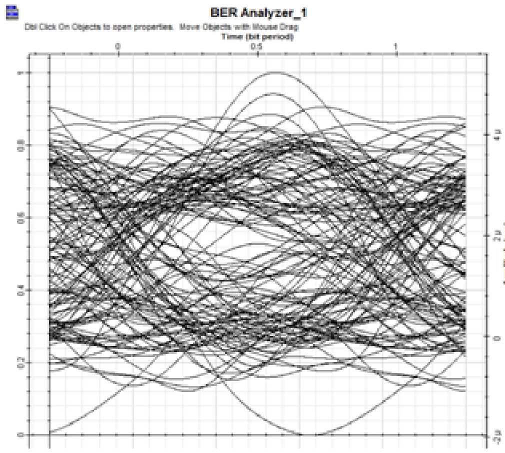

Figure 4: Eye Diagram of 64th channel output of 64- channel DWDM system with 140km of fiber length.

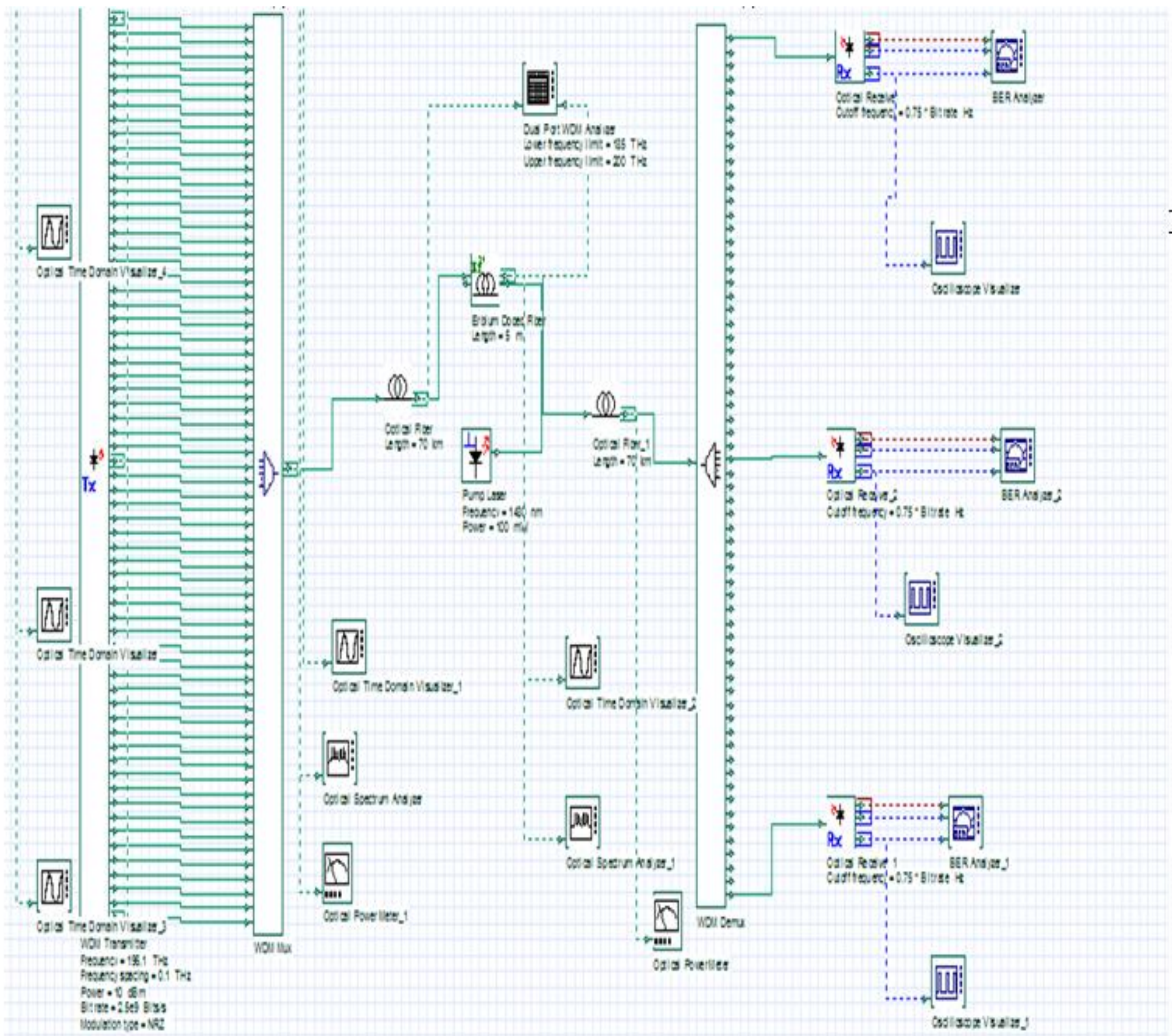

Figure 5: Simulation Layout

III. Simulation Setup

Simulation setup for the 64-DWDM channels is shown infig.5. A WDM transmitter with 2.5 Gb/s bit rate, frequency spacing 100GHz, 10dBm power is transmitting a signal through a WDM mux to a Single-Mode Optical Fiber (SMF). The output terminal of WDM MUX is connected with a SMF channel with a Raman Amplifier just at the mid span of the channel which divides the channel fiber length equally. Here the length of the Raman Amplifier is 10 km. The length of the channel is varied by 60km, 100km and 140km. Considering the length of the fiber amplifier, the total length of the link is 70km, 110km and 150km. The pump laser is connected in counter propagating orientation. Here Continuous Wave (CW) LASER is used as pump, the pump signal frequency is 209.65 THz (1430nm in wavelength) and the pump power is 2W. Similarly for the simulations with EDFA, the fiber amplifier device is connected at the mid span and length of the optical fiber channel is varied. The length of the EDFA is selected to be 5m. Here also CW LASER is used as the pump LASER witha signal frequency of 202.56 THz (980nm in wavelength)and 100mW of power.

IV. Figures And Results

The gain of the optical transmission system in fig.5is compared for each amplifier along with Noise Figure, Q-factor, EYE diagram and EYE width.At a length of 140km for the system with EDFA, the highest gain of 13.01dBwas obtained at channel-1 (1552.52 nm in wavelength). For Raman, the highest gain of 12.36 dB was obtained at channel-32 (1527.21 nm in wavelength). The Q-factors obtained at output channel-32 were 11.07 and 14.86 for EDFA and Raman respectively. The Noise Figure of the system with Raman amplifier was around 7.2 but for the EDFA systemit was around 13dB over most of the S-band region, and entering the C-band region its came down to 10dB gradually. In between 1550nm to 1540nm it crossed 8dB and continued decreasing. According to the EYE diagram and EYE width simulation results it is seen that the EYE pattern and EYE width results are almost similar at the output channel-32 but at channel-64 (1503nm)EDFA provides completely distorted output where Raman provides outputs with Q-factor of 14.53.

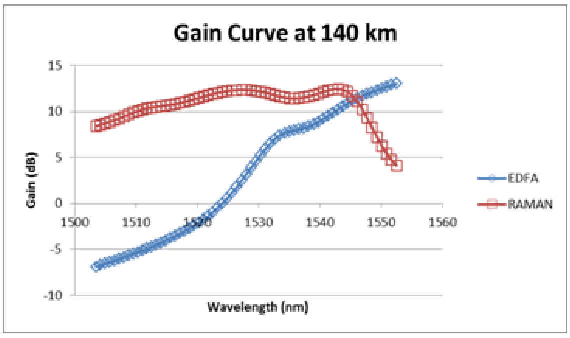

Figure 6: Gain vs. wavelength curve of EDFA and Raman at 140km length system

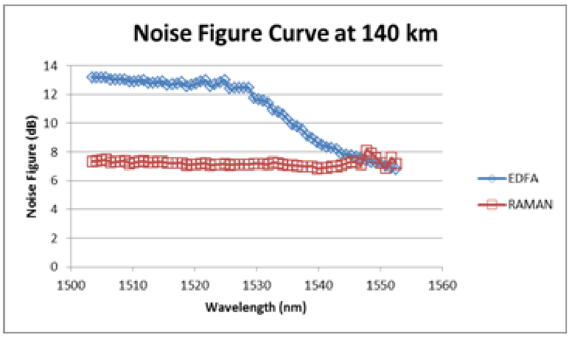

Figure 7: Noise Figure vs. wavelength curve of EDFA and Raman at 140km length system

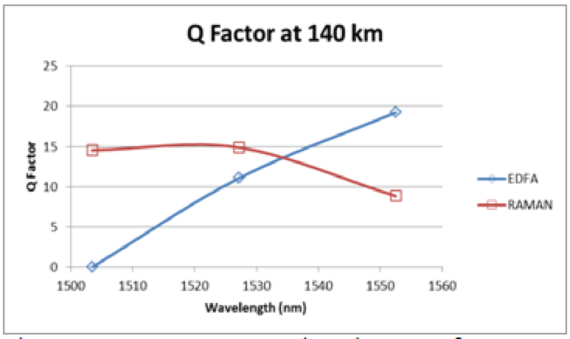

Figure 8: Q Factor vs. wavelength curve of EDFA and Raman at 140km length system

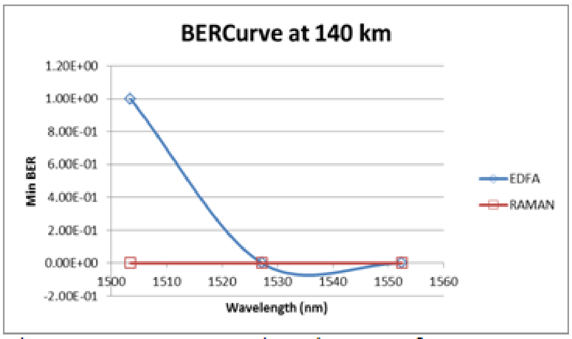

Figure 9: BER vs. wavelength curve of EDFA and Raman at 140km length system

V. Conclusion

In this paper a comparative analysis of the performance of EDFA and Raman are separately investigated in 64-Channel DWDM system with bit rate of 2.5 GHz, 0.8nm of channel spacing and 140 km of channel length system considering the non-linearity effect – SPM. From the results and figures, it is evident that EDFA performs better than Raman in C-band region. The Raman amplifier provides 11dB of gainoverall considering SPM where the channel dispersion was 16.5 ps/nm/km and group delay was 0.2ps/km. For Raman, 1W and for EDFA, 100mW pump laserswereused in counter propagation scheme. These results shows that for flexibleDWDM grid of 64 channels, the EDFA system has higher gain with less power consumption but employing Raman a flat gain over a wide spectrum can be achieved, overcoming nonlinear effect of SPM. According to the EYEdiagram, the EDFA system ismore prone to crosstalk and jitter than the Raman Amplifier system. It can be concluded thatinter symbol interference occurs more in EDFA basedDWDM networks than Raman Amplifier basedDWDM networks.

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