Performance of Various Types of Amplifiers in DWDM Technology

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Abstract: The Optical Amplifier plays a vital role for optical communication systems amplifies the without converting to electrical signal. Their performance improves the signal communication through fiber, reduces the noise and improves signal to noise ratio and hence improves the efficiency of the system. There is a variety of optical amplifiers amongst which Doped fiber amplifier (EDFA), Semiconductor optical amplifier (SOA) and Fiber Raman amplifier (FRA) and hybrid amplifiers using combination of various types are few of the important technologies. They have significantly improved the fiber optic communication. In this paper comparative performance of these amplifiers is discussed.

Keywords: EDFA, RAMAN, SOA, OSNR

I. INTRODUCTION

For long distance communication, fiber optic communication plays a vital role and the signal travels without attenuation. Optical fibre amplifiers provide in-line amplification of optical signals by effecting stimulated emission of photons by rare earth ions implanted in the core of the optical fibre. Traditional Configuration of WDM Systems. A typical configuration of a point-to-point WDM system is shown in Fig.1. It consists of number of optical transmitters, optical multiplexer, spans of optical transmission fiber like standard single-mode fiber (SSMF), optical amplifiers, usually erbium-doped fiber amplifiers (EDFAs), dispersion compensating devices, like spans of dispersion compensating fiber (DCF), optical de multiplexer and optical receivers .

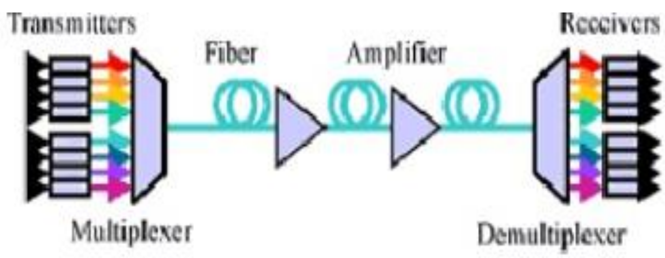

Fig. 1 Layout of WDM Transmission System

II. VARIOUS TYPES OF AMPLIFIERS

A. *Erbium Doped Fiber Amplifier (EDFA):*

Erbium is the preferred rare earth for this purpose though amplifiers using Praseodymium are also in use. EDFAs are used to provide amplification in long distance optical communication with fibre loss less than0.2 dB/km by providing amplification in the long wavelength window near 1550 nm. The principle of rare earth doped fibre amplifier is the same as that of lasers excepting that such amplifiers do not require a cavity whereas a cavity is required for laser oscillation. Advantages of EDFA are that it provides in-line amplification of signal without requiring electronics i.e., the signal does not need to be converted to electrical signal before amplification, the amplification is entirely optical. It provides high power transfer efficiency from pump to signal power. The amplification is independent of data rate. The gain is relatively flat so that they can be cascaded for long distance use. On the debit side, the devices are large, there is gain saturation and there is also presence of amplified spontaneous emission (ASE).

i) Composition of Rare Earth Doped Fiber :

The fiber core makes use of SiO and GeO along with Er and Pr doping. The cladding is made up of SiO. As a material for laser host, glass has several advantages over other solid state material, e.g., transparency, glassy structure, high optical damage threshold, optical quality etc. Oxides, such as SiO, GeO, SbO etc. ZBLAN glass known as flurozirconate (ZrF) is a substitute to oxide glass. The major glass forming components of ZBLAN glass are AL (which along with ZR, acts as a glass former), LA (intermediate), BA and NA (network modifiers).

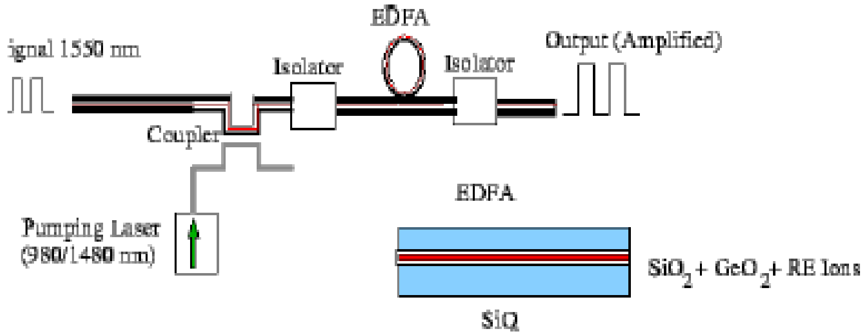

Fig. 2 Communication System using EDFA

The communication system using EDFA is shown in Figure 2. The optical output is first passed through an optical isolator which prevents reflection, i.e. allows light to move from left to right. The pump input is fed into the fiber through coupler with minimal loss.

ii) Principle of EDFA:

Energy levels of ER doped system is shown in the Fig.3. It may be noted that the energy levels form three groups of energy levels marked with their spectroscopic notations. In the absence of any radiation, the ions are in their ground states . The ions get excited to higher levels if appropriate frequency light beam is incident to the system and is called as **pump radiation** , if chosen at 980 nm, will excite the ions to the level .

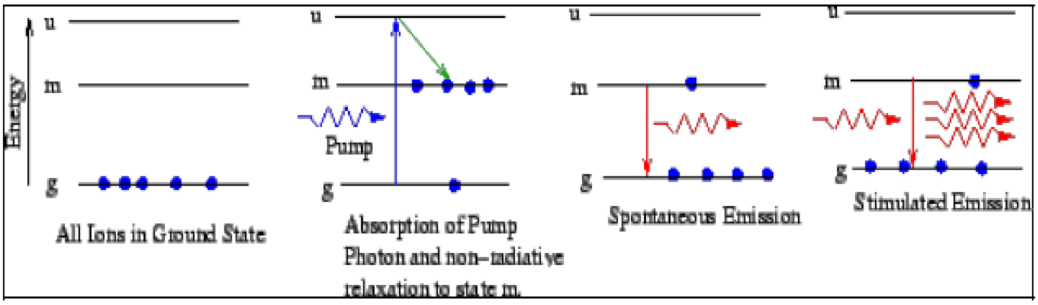

Fig. 3 Energy levels of ER doped System

Pump can also work directly at 1480 nm to excite the ions directly to the metastable level. If the laser action takes place from lowest sublevels then rapid relaxation occurs. Though pumping with 1480 nm is used and has an optical power conversion efficiency which is higher than that for 980 nm pumping, the latter is preferred because of the following advantages it has over 1480 nm pumping. It provides a wider separation between the laser wavelength and pump wavelength. 980 nm pumping gives less noise. Unlike 1480 nm pumping, 980 nm pumping cannot stimulate back transition to the ground state. The excited ions make transition to the ground state, either by Spontaneous Emission or Stimulated Emission.

EDFA can be used to amplify signal in two bands of wavelengths in the third transmission window. The wavelength range 1525 nm to 1565 nm is known as the C-band or the conventional band and the second band from 1568 nm to 1610 nm is known as the L band or the long band. The name long band is given because the doped section used for this band is longer.

B. Fiber Raman amplifier (FRA):

Fiber Raman Amplifier (FRA) is mature optical amplifier. In a FRA, the optical signal is amplified due to stimulated Raman scattering (SRS). FRA can is classified as lumped type called LRA and distributed type called DRA. The fiber gain media of the former is generally within 10 km. In addition, it requires on higher pump power, generally in a few to a dozen watts that can produce 40 dB or even over gains. It is mainly used to amplify the optical signal band of which EDFA cannot satisfy. The fiber gain media of DRA is usually longer than LRA, generally for dozens of kilometers while pump source power is down to hundreds of megawatts. It is mainly used in DWDM communication system, auxiliarying EDFA to improve the performance of the system, inhibiting nonlinear effect, reducing the incidence of signal power, improving the signal to noise ratio and amplifying online.

FRA works on Stimulated Raman Scattering (SRS) effect. The gain medium is undoped optical fiber. Electron is excited to the virtual state using incident photon and the stimulated emission occurs when the electron de-excites down to the vibrational state of glass molecule. The Stokes shift corresponding to the eigen-energy of a phonon is approximately 13.2 THz for all optical fibers. Typical RA Design in WDM systems is shown in Fig. 4.

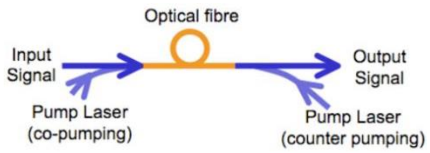

Fig. 4 Typical RA Design in WDM Systems

C. Hybrid EDF/Raman amplifier

Fig. 10 shows a possible design of a hybrid EDF/Raman amplifier. The doped fiber is pumped remotely via the transmission fiber where Raman amplification occurs

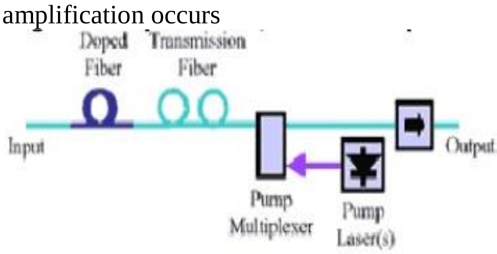

Fig. 10 Hybrid EDF/RA

The transversal power distribution of the signal over an amplified fiber span is strongly dependent on the applied amplification scheme and can be controlled by the Raman pump power and pump direction.

D. Semiconductor optical amplifier (SOA):

Semiconductor optical amplifier is one type of optical amplifier which uses a semiconductor to provide the gain medium. They have a similar structure to Fabry–Perot laser diodes but with anti-reflection design elements at the end faces. Unlike other optical amplifiers SOAs are pumped electronically (i.e. directly via an applied current), and a separate pump laser is not required. Typical construction SOA is depicted in Fig. 13.

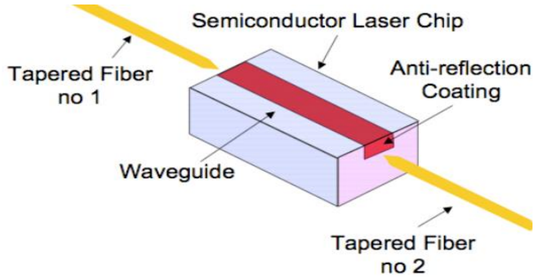

Fig.13 Construction of SOA

SOA works on the principle of stimulated emission in the active region of semiconductor and injects current to pump electrons at the conduction band. Here the transition of electrons down to the valence bond is being stimulated by input signal. It is shown in Fig. 14 .SOA has the major advantages such as small size and electrically pumped, runs with low power laser, less expensive than EDFA, all nonlinear operations such as cross gain and phase modulation, four wave mixing can be easily done. The performance of SOA is still not comparable with the EDFA. The SOA has higher noise, lower gain, moderate polarization dependence and high nonlinearity with fast transient time.

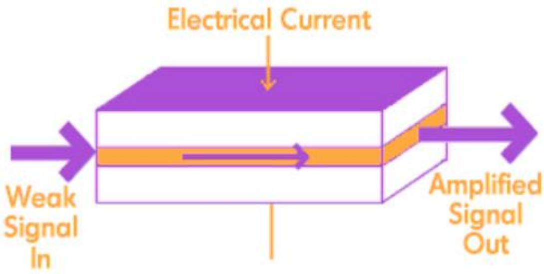

Fig. 14 Working principle of SOA

III. PERFORMANCE OF VARIOUS AMPLIFIERS

A. RA in Wideband WDM Transmission:

The dramatically increasing service demand driven by the rapid growth of the Internet generates new challenges for WDM system designers. Future systems must comply with upgraded performance criteria, such as Transmission of higher total data capacities through increased channel bit rates and number of wavelength-multiplexed channels, cost-reduction by allowing longer amplifier spacing, reduction of signal distortion to allow transmission over longer all-optical transmission links,New transmission windows in wavelength domain , new types of optical amplifiers covering a very high signal bandwidth to increase data capacity, bidirectional WDM transmission allowing suppression of nonlinear fiber interactions. Signal amplification is achieved using silica fiber in Raman amplifier.and hence that the intrinsic attenuation of data signals transmitted over the fiber can be combated within the fiber. Distributed Raman amplifier (DRA) is based on SRS. This occurs when a sufficiently large pump wave is co-launched at a lower wavelength than the signal to be amplified. The Raman gain depends strongly on the pump power and the frequency offset between pump and signal. Amplification occurs when the pump photon gives up its energy to create a new photon at the signal wavelength, plus some residual energy, which is absorbed as phonons (vibrational energy) as shown in Fig.5

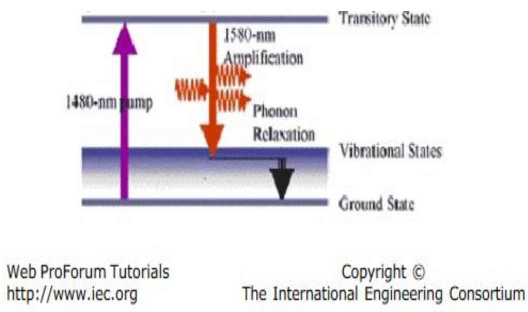

Fig. 5 Energy states during SRS

As there is a wide range of vibrational states above the ground state, a broad range of possible transitions are providing gain shown by means of the shaded region. Generally, Raman gain increases almost linearly with wavelength offset between signal and pump peaking at about 100 nm and then dropping rapidly with increased offset. Raman gain curve v/s wavelength offset is shown in Fig.6. The usable gain bandwidth is about 48 nm.

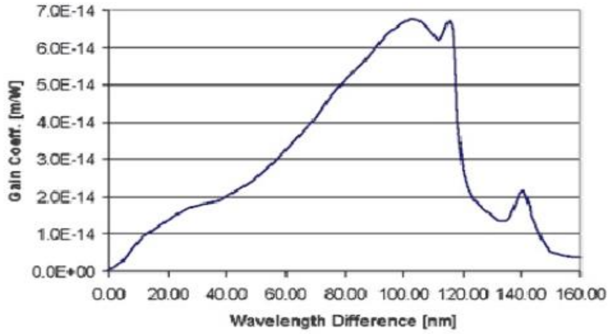

Fig. 6 Raman gain curve v/s wavelength offset

The example demonstrates the design of a distributed Raman amplifier for ultra- wideband WDM transmission, using multiple pumps to achieve a gain flatness over an 80-nm signal bandwidth as designed after the work of Kidorf et al. As mentioned earlier, a very wideband flat amplification can be achieved by selecting launched powers and emission wavelengths of the Raman pumps properly. Fig. 7 shows the general design setup for Wideband RA Evaluation.

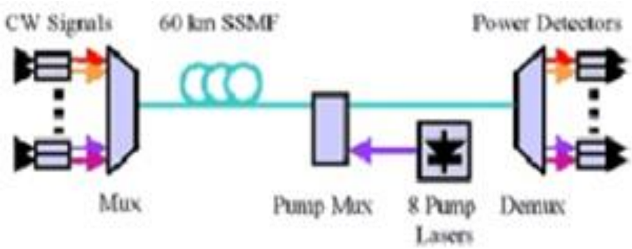

Fig. 7 Design Setup for Wideband RA Evaluation

Figure 8 shows the optical spectrum at the receiver. The gain ripple is less than 2 dB over 81 nm. Note that there is still enough power margin to introduce a gain-flattening filter at the output of the fiber span to achieve a total gain ripple of less than 0.5 dB.

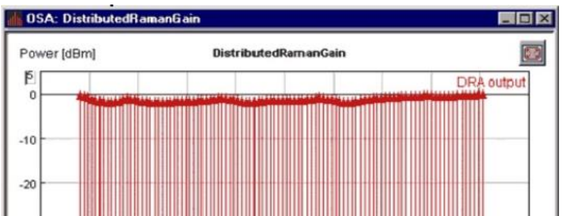

Fig. 8 Optical Output Spectrum after propagation 60km SSMF applying Backword Raman Amplification using 8 Raman Pumps.

Second, there are strong pump-to-pump interactions, as the Raman pumps are spaced over 86 nm for which the Raman efficiency is already very large. Pumps emitted at the very low wavelengths amplify the WDM signal band as well as the pumps at the higher wavelengths.

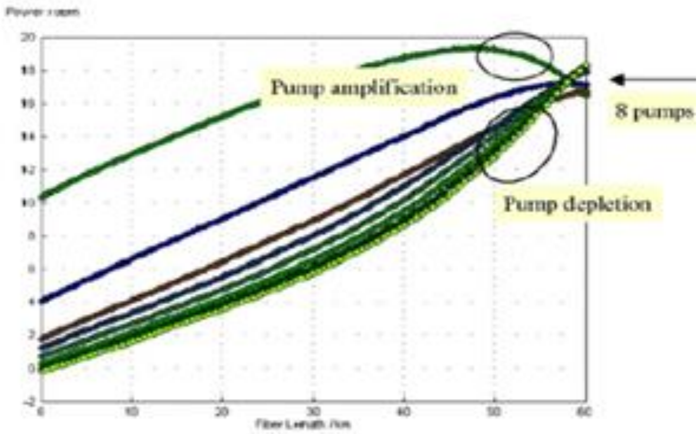

Fig. 9 Propagation of the 8 Raman overPumps over the Fiber

Fig. 9 shows the pumps' power profile along the fiber. Starting with almost equal pump powers at the far end of the fiber, the pumps at the higher wavelengths are first amplified by the pumps at the lower wavelengths. Further down the fiber, when the power of the low-wavelength pumps is reduced due to energy transfer to high wavelengths and fiber attenuation, the effect of pump-to-pump amplification is reduced. As can be concluded from

B. Raman Amplification to Build Bidirectional WDM Systems

This example demonstrates the bidirectional WDM signal transmission and Raman pumping to compensate attenuation in the transmission fiber. Figure 11 shows the design.

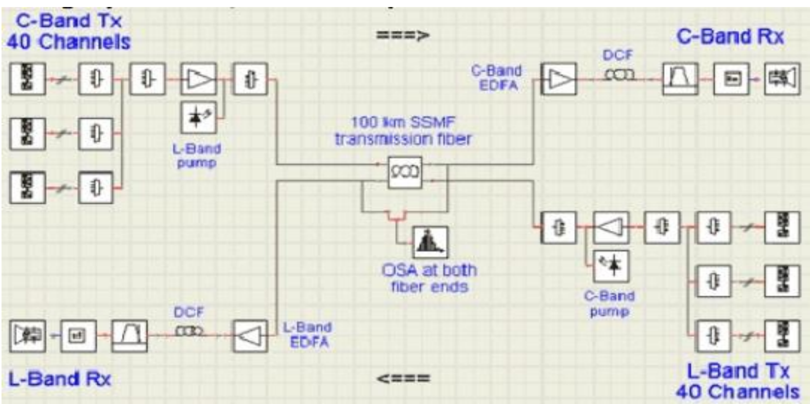

Fig. 11 Bidirectional DWDM system Exploiting C and L Bands Using Hybrid EDF/ RA

In this system configuration, the C band is employed for signal transmission in one direction and the L band to propagate signals in the opposite direction. The fiber attenuation is partly compensated by the distributed Raman amplifier. Accordingly, applying the backward pumping scheme for each band requires the L-band pump to be placed at the same fiber end as the C-band transmitter and vice versa. Obviously, this configuration implies the bidirectional pumping. When modeling such systems, it is crucial that the power exchange between the co- and counter-propagating signals and pumps (pump-to-pump, pump-to-signal, and signal-to-signal) is accurately considered. Therefore, simplified approaches neglecting, for example, pump depletion are not suitable. Accurate modeling is only possible if all bidirectional interactions are modeled.
Typical signal and pump spectra are shown in Fig. 12. The non flatness of the signal spectrum is due to the Raman gain shape. It can be overcome with gain flattening filters placed right after the EDFAs.

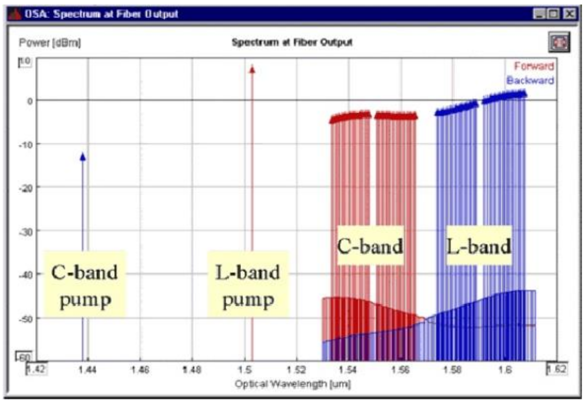

Fig.12 Spectrum at the output ofTransmission Fiber

Table 1 gives an overview of important technical terms related to RA, EDFA and SOA amplifiers. Hybrid amplification using these amplifiers can be designed to take their advantage.

Table 1: Different Technical Terms Related to RAMAN Amplifier (RA) and Dopped Fiber Amplifier (DFA) and Semiconductor Optical Amplifier (SOA)

Sr. No.	Technical term	RA	EDFA	SOA
1	**Amplification Bandwidth**	48nm or more	20nm or more	60nm
2	**Amplifier Gain**	4 to 11 dB or more depending upon effective fiber length and pump intensity	20dB or more	30dB or more
3	**Amplifier Saturation Power**	Same as power of pump wave	Depends on gain and different constants of the material chosen	Depends on semiconductor
4	**Amplifier Pump Wavelength**	100nm less than signal wavelength at peak gain	980nm or 1480nm for EDFA	1280 to 1650nm
5	**Max. Saturation(dBm)**	0.75 multiple of no. of pumps	22dBm	18dBm
6	**Amplifier Noise Figure(dB)**	5	5	8
7	**Pump power**	More than 30dBm	25dBm	Less than 400mA
8	**Time constant**	10-15 s	10-2 s	2*10-9
9	**Size**	Bulk Module	Rack mounted	Compact
10	**Switchable**	No	No	Yes
11	**Cost Factor**	High	Medium	Low

IV. CONCLUSIONS

The paper describes how Raman amplification could be helpful when designing future fiber-optical communication systems requiring throughput of large capacity. Then, a general introduction of the Raman effect was presented, and advantages of certain amplifier topologies were discussed. With the help of application examples, general problems arising from the design of systems considering Raman amplification were presented. Then the performance EDFA, SOA and hybrid EDF/ RA is explained in this paper. From the Table no. 1 it has been observed that the Semiconductor Optical Amplifier is found to be most effective as compared to the EDFA and Raman Amplifier.

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