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Impact of Hybrid Optical Amplifiers in High Speed Networks

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ABSTRACT–It is observed that All Optical Networks (AONs) exploiting Dense Wavelength Division Multiplexing Systems (DWDMs) have emerged through implementation of optical amplifiers. DWDM systems require optical amplifiers for enhanced performance. In this paper several optical amplifiers have been discussed with their applications that are suitable for the low-cost, high performance applications of DWDM systems. The different amplifiers, such as Erbium Doped Fiber Amplifiers (EDFA), Distributed Raman amplifiers (DRA) and Semiconductor Optical Amplifier (SOA), have distinct properties that make them suitable for a variety of applications. Their advantages can be integrated to improve the performance of an optical communication system. Present study shows that hybrid optical amplifiers are useful to combine the benefits and compensate for the drawbacks of different optical amplifiers for enhancement of optical networks.

Key-words: Optical communication system, SOA, EDFA, DRA, hybrid amplifiers, DWDM.

1.INTRODUCTION:

In order to transmit signals over long distances (>100km) it is necessary to compensate the attenuation losses within the fiber [1]. Earlier this was accomplished with an OE (Opto-Electronic) module consisting of an optical transmitter, regeneration system, equalization system, and an opticalreceiver. Although functional, the given arrangement is limited by the optical to electrical and electrical to optical conversions. Optical amplifiers have eliminated the need of EO (Electronic to Optical) and OE conversions.

To counter attenuation and dispersion effects, optical fiber amplifiers OFA's are used. Introducing OFA's into the system causes additional problems, for instance, amplified spontaneous emission ASEnoise, which accumulates as the number of OFA's in the signal path increases. The bandwidth ofoptical fibers is really great if the all the bands: S-band (short 1460-1530 nm), C-band (central 1530-1565 nm), and L-band (long 1565-1625 nm) are utilized efficiently. Hence optical amplifiersmust be designed to amplify the signal along the fiber. The more the gain of an amplifier, the more span distance between them, as long as the signal is not distorted due to high optical power.

Optical amplifiers have found many applications ranging from ultra-long undersea linksto short links in access networks. These applications involve:
In-line amplifier:This is used as a repeater along the link at intermediate points between two ends. It can be used to compensate for transmission losses and increase the span distance between regenerative repeaters.
Pre-amplifier:This is used before the photo detector at the receiver end in order to strengthenthe weak received signal. This increases the sensitivity of the receiver very efficiently.
Post-amplifier:This is used at the transmitting end after the source to increase its power. The power launched into the fiber is enhanced so therepeater span becomes large. This serves to increase the transmission distance by greater value depending on the amplifier gain and fiber loss.

2.OPTICAL AMPLIFIERS

The optical amplifiers that find widespread use in optical systems can beclassified into three main categories:-

- Fiber Raman Amplifier (FRA)
- Erbium Doped Fiber Amplifier (EDFA)
- Semiconductor Optical Amplifier (SOA).

Fiber Raman Amplifier (FRA) and Erbium Doped Fiber Amplifier(EDFA) can be coupled to the transmission fiber efficiently and classified as optical fiber amplifiers OFAs.

2.1. Raman Amplifier

Raman amplifiers are based on Stimulated Raman scattering (SRS). A small signal gain arises due to the energy transfer from a powerful pumping optical beam to the amplified signal. In fibers, the peak amplifications correspond to the signal frequency that is ~ 13.2 THz (100 nm) lower than the pumping one; this frequency difference is called the Stokes shift. Such downshift is due to the energy of optical phonons which represent the vibration mode of medium [9].

The main advantage of Raman amplifier is that its gain spectrum is very broad, and its shape can be changed by varying the number of pumps and their wavelengths. It also has relatively low noise figure making it more efficient. These two aspectsmake Raman amplifiers the main component of optical networks, as they can be used to enhance the gain of a particular amplifier by broadening and equalizing the gain spectrum, with addition of very little noise to the amplified signal. The main disadvantages of Raman amplifiers are the poor pumping efficiency at lower signal power, and the use of expensive high power lasers capable of delivering great powers into single-mode fibers. Raman amplifiers are also preferable due to negligible coupling loss, negligible noise and inter-channel cross talk making it more efficient for DWDM [25].

Figure 1 illustrates the optical spectrum of a forward-pumped Raman optical amplifier. The pump laser is injected at thetransmitter end rather than the receiver end.The pump signal has a wavelength of 1535nm; the amplitude is much larger than the data signals. Figure 1 shows example of Transmitted Spectrum of Raman Amplifier and Figure 2 shows example ofReceived Spectrum of Raman Amplifier

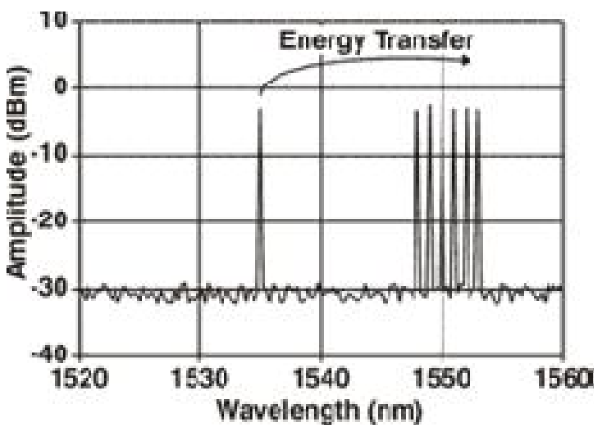

Figure 1: Transmitted Spectrum (6 channel DWDM System) in 1550nm [19]

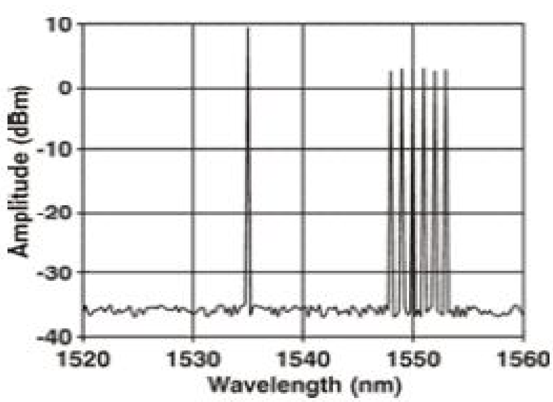

Figure 2: Received Spectrum after SRS [19]

Raman amplifiers have a wide gain bandwidth (up to 10 nm).They can use any transmissionoptical fiber [17]-[18]. Hence, they reduce the effective span loss to improve noise performance by boosting the optical signal transmitted. They can be combined with EDFAs to expand optical gain flattened bandwidth.

2.2. Erbium Doped Fiber Amplifier (EDFA)

The EDFA is the most deployed fiber amplifier since its amplification window coincides with the third transmission window of optical fiber.

The gain spectrum of EDFA is strictly wavelength-dependent. The main disadvantage of EDFA is that its wavelength-dependent gain spectrum bandwidth is only about 30-40 nm; besides, it is not flat. On the other hand, it determines amplification of individual channels and avoids cross-gain saturation in WDM systems. Due to a relatively long spontaneous carrier lifetime in silica fibers, this allows achieving high gain for a weak signal with low noise figure, which represents the difference in signal-noise ratio at the input and output of the device under consideration [24]. This is the main reason why the EDFAs are most frequently used for optical amplification.

Fiber amplifiers are also insensitive to polarization and have negligible noise for inter channel cross talk. It has minimum coupling losses with requirement of lesser pump power. It has wide operating bandwidth suitable for DWDM. EDFA provided new technologies that allow high bit rate transmission over long distances. It has a narrow high gain peak at 1532nm and a broad peak with a lower centered at 1550nm. Owing to their versatility, useful gain bandwidth, high pumping efficiency and low intrinsic noise, EDFAs are the choice for most of the optical network applications. The gain is provided through stimulated emission. The energy level diagram of Er3+ is shown in figure 3[2].

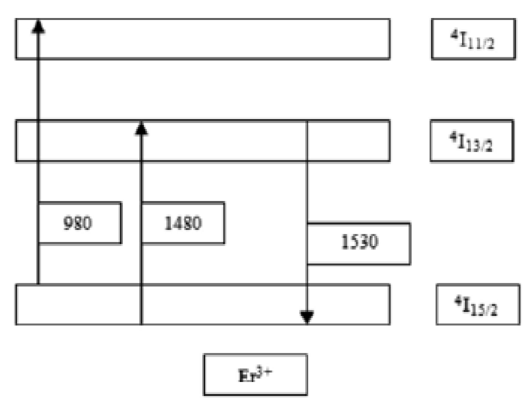

Figure 3: Energy Level Diagram of Er3+ [2]

2.3. Semiconductor Optical Amplifiers (SOA)

SOAs are essentially laser diodes without end mirrors having fiber attached to both theends. They amplify an optical signal that comes from either fiber end and transmit an amplified version of the signal out of theother fiber end. SOAs are typicallyconstructed in a small package, and theywork for 1310 nm and 1550 nm systems. Additionally, they transmit bi-directionally, making the reduced size of the device anadvantage over regenerators or EDFAs

[20].However, the drawbacks of SOAs includehigh-coupling loss, polarizationdependence, and a higher noise figure.

The gain of an SOA is influenced by the input signal power and the internal noise generated by the amplification process. As the output signal power increases the gain decreases as shown in Figure 4. This gain saturation can cause significant signal distortion [21]. It can also limit the gain achievable when SOAs are used as multichannel amplifiers in wavelength division multiplexed (WDM) systems, which is a major drawback of SOA.

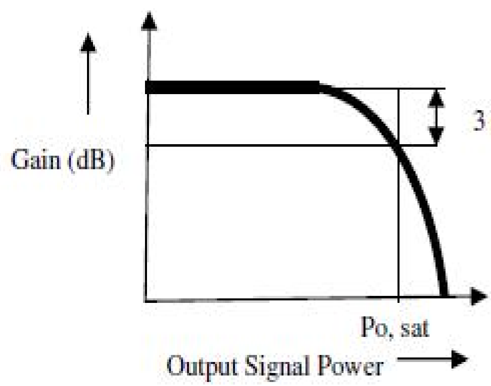

Figure 4: Typical SOA gain versus outputsignal power [1]

SOA accepts a wide range of input power and delivers constant output power because it has short carrier lifetime of about several tenths to several hundreds of picoseconds compared to several hundred microseconds to several milliseconds in EDFA's, this means SOA has fast gain dynamics. This dynamic gain can cause signal distortion in SOA, which becomes more severe as the modulated signal bandwidth increases. These effects are even more pronounced in multichannel systems where the dynamic gain leads to inter-channel crosstalk [22].

3. OPTICAL AMPLIFIERS IN DWDM SYSTEMS

In CWDM wide separation of wavelengths is used whereas in Dense WDM (DWDM), each optical channel is allocated its own wavelength **-** or a range of wavelengths. A typical optical channel might be 1 nm wide or less [5]. This channel is a wavelength range within which the signal must stay. The key component of DWDM system is optical amplifier. In DWDM system, it is desirable to set a very narrow grid of optical carriers in order to allow more channels in the same optical bandwidth. This demands an optical amplifier with high gain and very broad and flat gain profile to ensure a nearly identical amplification factor in every channel of the system. DWDM systems involve high capacity long haul transmission. Hybrid Amplifiers (HA) are an enabling and promising technology for future DWDM multi-terabit systems as it has been shown in recent experimental results [6]**.** Besides the bandwidth and noise level issues, HAs are designed in order to maximize the fiber span and/or to minimize the impairments of fiber non-linearities. Hence, the design of the optimal HA is a complex problem with several degrees of freedom.

This is the method of utilizing amplifiers for optimum utilization of available fiber bandwidth i.e. by way of using various combinations of optical amplifiers in different wavelength ranges. The amplifiers can be connected either in parallel or in series and this configuration is termed as Hybrid Amplifier. In parallel configuration, the DWDM signals are first de-multiplexed into several wavelength-band groups and then amplified by amplifiers that have gains in the corresponding wavelength band and then are again multiplexed. The parallel configuration is simple and applicable to all amplifiers. However, it has disadvantages that an unusable wavelength region exists between each gain band originated from the guard band of the coupler. Also, the noise figure degrades due to the loss of the coupler, used for multiplexing, located in front of each amplifier. On the contrary, the amplifiers connected in series have relatively wide gain band, because they do not require couplers and without any bandwidth loss.

Hybrid configurations can be made by combination of the following:

3.1 EDFA and DRA

It has been observed that the gain spectrum of DRAs can be tailored by adjusting the pump powers and pump wavelengths. So this property is used to increase the amplification bandwidth of EDFA. Our previous studies show that the noise figure of Raman amplifiers is much lower than that of EDFA. So the best way to achieve a higher gain with lower noise figure or a wider amplification band is to use an EDFA in combination with a distributed Raman amplifier (DRA).

3.2 EDFA and SOA

Hybrid SOA-EDFAs can be used in the cases where it is necessary to widen the gain spectrum of an EDFA [7]. However, such a combination generates a greater amount of ASE than in the cases of EDFA-DRA or SOA-DRA. This significantly affects the total system performance in the case of a nonlinearity-sensitive transmission system, where, due to the limitations on signal amplification caused by nonlinearity, the received optical power penalty plays a great role as it affects the receiver’s sensitivity needed for achieving a definite bit error rate (BER). Therefore, normally it is not applied in long haul DWDM systems.

3.3 DRA AND SOA

DRA suppress the nonlinear effects produced by SOA. SOA benefits include compactness and the ability to facilitate additional functionalities such as wavelength conversion and all-optical regeneration [1] and distributed Raman amplifiers (DRA) provide broad amplification spectrum, less amplified signal distortions, even negative noise figure values[9]. But this type of amplifiers requires powerful pumping sources. So it is used to achieve higher gain with low noise figure or a wider amplification bandwidth. However multiple SOAs are generally not preferred due to large signal distortions produced by it.

Therefore, it is not clear which combinations would provide better system performance in the case where the impact of fiber nonlinearity is strong. Our main goal is therefore to find out which of these combinations can ensure good enough signal amplification with less distortion and without loss in the operational quality of a nonlinearity-sensitive transmission system.

4. LITERATURE SURVEY

Hari et al. [10] investigated the different optical amplifiers for less number of channels with large channel spacing using eye pattern, BER and Q factor and get optimized transmission distance to transmit the signal.

Lee et al. [11] compared the performance of three single pumps, Raman/EDFA hybrid amplifier recycling residual Raman pump in a cascaded EDF section located after and prior to DCF and Raman assisted EDFA with respect to gain, noise figure and BER.

Cheng et al. [12] demonstrated a bismuth-based erbium-doped fiber amplifier (Bi-EDFA) that operates in both the C- and L-band regions with an intermediate broadband fiber Bragg grating sensor to improve flat gain characteristics and to reduce the noise figure.

Masuda et al. [13] proposed a wide band and gain flattened discrete hybrid optical amplifier for long-distance wavelength-division-multiplexed (WDM) optical communication systems.

Simranjit Singh et al. [14] presented a HOA model using two stages DRA-EDFA dense wavelength division multiplexing system to minimize the gain variation without using any gain flattening technique.

A Carena et al. [15] investigated on the optimal configuration of hybrid Raman/EDFA yielding a closed formanalysis. In order to compare different system configurations,impact of fiber non linearties has been introduced.

Chieng Hung Yeh et al. [16] demonstrated a new hybridthree stage L-band fiber amplifier module composed of asemiconductor optical amplifier and two EDFA over gain-bandwidth of 1540 to 1600 nm. Therefore, this amplifier is useful in application to WDM networks.

5. RESULTS AND DISCUSSIONS

The results show the improvement in characteristics of amplifiers when combining the individual effects in a hybrid amplifier. This can be proved by comparing the results as shown in table 1.

Table 1: Features of Hybrid OA [1,7,23,24]

Features	**DRA-EDFA**	**DRA-SOA**	**SOA-EDFA**
ADVANTAGES	Low noise figure, Higher equalized gain, Wide bandwidth, High output power	Low noise figure, High equalized gain, Wider bandwidth,	Wider gain spectrum, Cost-effective
DRAWBACKS	Expensive	High Amplified Spontaneous Emission(ASE)	High Amplified Spontaneous Emission(ASE), Low output power
APPLICATIONS	Ultra long haul high capacity optical transmission, WDM networks	Long haul optical transmission	Long haul optical transmission

6. CONCLUSION AND FUTURE SCOPE:

Hybrid amplifiers have proven effective in DWDM systems to increase long haul transmission distances with improvement of bandwidth along with suppressed impairments and nonlinear effects. The biggest challenge with hybrid amplifier is to maintain and offer high bandwidth in case of higher number of channels.Hybrid Amplifiers will be modeled for DWDM systems using Optical Communication software in which various combinations of optical amplifiers will be combined in series to make use of their advantages in DWDM systems. Modeling of different parameters e.g. gain, amplified spontaneous emission, BER, length of fiber and variation of output power can be performed for proposed hybrid amplifier.

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