Comparison Study of Hybrid Optical Amplifier

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ABSTRACT
DWDM have emerged in today’s optical networks due to usage of Hybrid Optical Amplifier. The performance of DWDM system is enhanced through Hybrid Optical Amplifier. In this review paper several hybrid optical amplifiers have been discussed that are suitable for the low-cost, high performance applications of DWDM systems. Their advantages can be integrated to improve the performance of all optical networks. Different combination of Hybrid optical amplifiers (HOAs) can be exploited to provide the benefits as well as reduction of existing drawbacks of individual amplifier.

Keywords – DWDM, EDFA, Hybrid Amplifiers, SOA, RA.

1. INTRODUCTION
To increase the transmission capacity of a single fiber, DWDM is used. DWDM is a technology, which combines large number of independent information carrying wavelengths onto the same fiber. In DWDM, each optical channel is allocated its own wavelength, a range of wavelengths. A typical optical channel spacing might be 1 nm wide or less. 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.

There 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[1].

In parallel configuration, the DWDM signals are first demultiplexed into several wavelength-band groups with a coupler, then they are amplified by amplifiers that have gains in the corresponding wavelength band and then they are multiplexed again with a coupler. The parallel configuration is very simple and applicable to all amplifiers. However, it has disadvantages also e.g. 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 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.

2. HYBRID OPTICAL AMPLIFIERS
2.1 EDFA and DRA
The gain spectrum of DRA can be vary by adjusting the pump powers and pump wavelengths. So this property is used to increase the amplification bandwidth of EDFA. The noise figure of Raman amplifiers is much lower than that of EDFA. So 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).

Two stage DRA-EDFA configuration with flat gain characteristics. This HOA has been investigated as a DWDM system with 25 GHz channel spacing. It is observed that as we increase the input power, the gain variation over the bandwidth increases. With an input signal power of 3 mW, a flat gain of >10 dB is obtained for the frequency region 187 to 190.975 THz with a gain variation of less than 4.5 dB[2].

Optimal configuration of hybrid Raman/EDFA yielding a closed form analysis. In order to compare different system configurations, impact of fiber nonlinearities has been introduced[3].
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[4].

32*10 Gbps and 64*10 Gbps over SMF of 650 km and 530 km respectively by using RAMAN-EDFA HOA as inline and pre-amplifier and defined the parameter Q-factor and BER on the standard acceptable value such that the HOA is acceptable for long haul transmission[5].

2.2 EDFA and SOA

Hybrid SOA-EDFAs can be used to widen the gain spectrum of an EDFA. But it generates greater amount of ASE than in the EDFA-DRA or SOA-DRA. This affects the total performance of the system 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[6].

Hybrid three stage L-band fiber amplifier configured by a SOA and two EDFA over gain-bandwidth of 1540 to 1600 nm[7].

16 channel WDM systems at 10 Gb/s for the various optical amplifiers and hybrid optical amplifiers and the performance had been compared on the basis of transmission distance and dispersion. The amplifiers EDFA and SOA had been investigated independently and further compared with hybrid optical amplifiers like RAMAN-EDFA and RAMAN-SOA. It was observed that hybrid optical amplifier RAMAN-EDFA provides the highest output power (12.017 and 12.088 dBm) and least bit error rate (10–40 and 9.08 ×10–18) at 100km for dispersion 2 ps/nm/km and 4 ps/nm/km respectively[8].

2.3 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 and distributed Raman amplifiers (DRA) provide broad amplification spectrum, less amplified signal distortions, even negative noise figure values. 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[9].

SOA-Raman hybrid amplifier using 4-channels and 200-km for CWDM systems using 60 nm bandwidth in which the Raman amplifier increases overall system gain and reduces SOA gain tilt[10].

Hybrid SOA-Raman amplifiers with broad gain bandwidth (> 80 nm) and can be designed to operate in any wavelength region compatible with single-mode optical fiber[11].

Hybrid semiconductor optical amplifier-Raman hybrid amplifiers which provided nearly flat gain over 70 nm. A coarse-wavelength-division multiplexing transmission system consisting of three spans of 80 km and 1dB power penalty. Performance was observed over the entire band with no more than a 1dB power penalty after 240 km[12].

Different HOA(RAMAN-EDFA, RAMAN-SOA, SOA-EDFA, EDFA-RAMAN-EDFA) using different channels(16, 32 and 64 channels) at speed of 10 Gbps with different parameters such as quality factor, BER[13].

2.4 EDFA-EYCDFA

Disadvantage of EDFA is different gain for different wavelength due to doping concentrarion and EYCDFA supresses concentration quenching effect resulting in higher gain with flatness under certain pump power[14].

Hybrid EDFA (Erbium Doped Fiber amplifier) and EYCDFA (Erbium Ytterbium Co-Doped Fiber Amplifier) provides flat gain of 36dB with Noise Figure of 4.0 to 4.2dB for length of 14m and pumped at 980 nm wavelength[14].

2.5 EYDWA and SOA

EYDWA provides high and flat gain due to high doping and SOA provides large output power or gain with lesser variation. So HOA EYDWA-SOA with higher gain and less gain variation to address typical requirements in metropolitan networks[15].

Hybrid amplifiers Er-Yb co-doped waveguide amplifier (EYDWA) and a semiconductor optical amplifier (SOA) for 100x10Gbps dense wavelength division multiplexed system with interval of 0.2nm provides flat gain of >14 dB with gain variation of ~0.75dB without using any gain flattening techniques[15].
2.6 EDFA and TDFA

Today’s need is broad gain spectrum and less noise figure in doped amplifiers. The focus is to improve doped amplifiers with broad and flat gain spectrum, so as to accommodate more number of channels in DWDM system. Erbium and Thulium are the main rare earth dopants for doped fiber amplifiers. The EDFA provides sufficient gain flattening but gain spectrum is narrow, therefore DWDM channels get lesser. So, there is a necessity to improve the amplification bandwidth of EDFA. TDFA is a highly viable alternative to meet out the limitations of EDFA[16].

Hybrid TDFA-EDFA and EDFA-TDFA configurations for 96 DWDM channels spaced at 0.8 nm in the wavelength range of 1479nm to 1555nm in terms of Parameters Quality factor(Q), eye diagram, signal strength and BER[16].

Hybrid TDFA-EDFA in terms of gain characteristics and shows that the hybrid amplifiers have gain of over 20 dB and low noise figure (NF) below 7 dB was obtained in 1460–1540 nm with the bandwidth of more than 80 nm[17].

2.7 TDFA and FRA

Combining FRA with TDFA is very effective approach, because FRA can provide any gain bandwidth by selecting the appropriate pump wavelengths. However, a drawback with FRAs is that double Rayleigh scattering (DRS) degrades the amplified signals. The operating wavelength of this amplifier covers the bandwidth of entire short wavelength band (S-band) region by combining the gain spectrum of TDFA and FRA[19].

Wide-band hybrid amplifier series configuration of TDFA and FRA, which using the similar type of pump laser. The theoretical gain varies from 20 to 24 dB within a wavelength region from 1460 to 1525 nm[19].

3. CONCLUSION

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.

### TABLE 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Gain and NF</th>
<th>Gain Flattess</th>
<th>Number of channels/ channel spacing</th>
<th>Gain Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDFA+EYCDFA[14]</td>
<td>Gain ~36 dB</td>
<td>Flat</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EYDWA+SOA[15]</td>
<td>Gain=14 dB</td>
<td>~0.75dB</td>
<td>Channels:100 Spacing: 0.2nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>HA+DRA-EDFA[15]</td>
<td>Gain &gt;24 dB</td>
<td>~1.15dB</td>
<td>Channels:100 Spacing: 0.2nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>EDFA+TDFA[17]</td>
<td>Gain &gt;20 dB</td>
<td>gain variation ratio &lt; 0.4</td>
<td>-</td>
<td>80 nm</td>
</tr>
<tr>
<td>L-Band RAMAN+EDFA HOA[18]</td>
<td>Gain &gt;12 dB</td>
<td>~1.2 dB</td>
<td>Channels:35 Spacing: 1nm</td>
<td>23.5 nm</td>
</tr>
</tbody>
</table>

REFERENCES


