DIFFERENT TRANSMISSION SCHEMES AND OPTIMAL FIBER LENGTHS FOR A HIGH PERFORMANCE FLATBAND HYBRID AMPLIFIER BASED ALL OPTICAL COMMUNICATION SYSTEM

1RASNA K. B. DAS, 2SATHEESH KUMAR J, 3ABEL JERRY, 4MAHIJITH K
1M.Tech Student, Model Engineering College, Thirakkakara, Kerala, India
2M.Tech Student, Model Engineering College, Thirakkakara, Kerala, India
3B.Tech Student, MGCET, Pampakuda, Kerala, India
4B.Tech Student, MGCET, Pampakuda, Kerala, India
E-mail: www.jackzmail@gmail.com

Abstract -
Fiber optic systems are important telecommunication infrastructure for world- wide broadband networks. Wide bandwidth signal transmission with low delay is a key requirement in present day applications. Optical fibers provide enormous and unsurpassed transmission bandwidth with negligible latency, and are now the transmission medium of choice for long distance and high data rate transmission in telecommunication networks. One of the primary limitations in optical communication is attenuation, which will affect the transmission distance of the optical signal. This is overcome by using all-optical amplifiers. A novel approach of designing a hybrid amplifier with a combination of a single mode (SM) erbium ytterbium co-doped fibre amplifier (EYDFA) and a discrete Raman amplifier (RA) is analyzed to flatten its gain over the optical spectrum of the C and L bands. The amplifier with 40 Gb signals as the input and with different transmission methods are simulated using Optisystem simulation software. Different combinations of input is simulated and analysed for BER, OSNR, and Eye diagrams. The simulation is performed with five optimized pumping signals spaced semi-unequally are applied in forward, backward and both forward and backward directions. The performance of the amplifier in forward, backward, and both forward and backward schemes are analysed for maximum gain, noise figure and OSNR. This communication system finds use in cable television or community antenna television (CATV) and telecommunication networks, satisfy the increased number of user demands in the local area network (LAN) and offer uniform amplification to the cable TV or fiber to the home DWDM optical communication signals over the L and C bands.

Keywords - Single Mode (SM), Erbium ytterbium Co-doped Fibre Amplifier (EYDFA), Community Antenna Television (CATV).

I. INTRODUCTION

The world’s largest communication system is fiber optic-based. A communication system transmits information from one place to another, whether separated by a few kilometers or by transoceanic distances. As the number of users is increasing every year, the demand of data traffic also increases. Optical communication, due to its enormous bandwidth and low attenuation loss, caters to the demand of future communication. It provides a very low attenuation loss of 0.2 dB km⁻¹ and offers flexibility whereby the number of users and their bit rates can be upgraded. Thus, it serves as the best mode of communication for higher bandwidth and data rate requirements. In the early stages of optical communication, the attenuated signal was reconstructed with the optical-electrical-optical (O/E/O) method. But this O/E/O concept was a lossy and complicated process. Moreover, it was also not upgradable, and hence it was only used for single wavelength operation. Also, the optical-electrical-optical (OEO) method used to reconstruct the transmitted data results in added latency on the network and thus is a limitation to achieving very high data rates [2]. The method is also complex and expensive. The limitations of OEO conversion and the attenuation in optical fibers can be overcome by all optical amplifiers [4]. This report analyses different transmission schemes for an all optical communication system with flat band hybrid amplifier designed by cascading an EYDFA and Raman amplifier proposed in [1].

II. ALL OPTICAL COMMUNICATION SYSTEM

Block diagram

This is the basic block diagram of an optical communication system. Fiber optic systems are important telecommunication infrastructure for world- wide broadband networks. Wide bandwidth signal transmission with low delay is a key requirement in present day applications. In an optical communication system, over a broad range of...
spectrum, the gain of the amplifier must be flattened in order to increase the bandwidth utilization of the network. The amplifier used in such a system must flatten its gain over the entire optical spectrum of the C and L bands, which is about 90 nm of spectral width where C band extends from 1530 nm to 1565 nm and L band from 1565 nm to 1625 nm. In these, signals suffer lowest attenuation and are compatible with fiber amplifiers.

OPTICAL AMPLIFIERS

Rare-Earth -Element Doped Fiber Amplifiers

These amplifiers use rare-earth-elements such as erbium, thulium, praseodymium and ytterbium. The most usable element is erbium, because it allows optical amplifiers to operate in the C-band, (that is from 1530 to 1565 nm). Thus the amplifier is called Erbium Doped Fiber amplifier (EDFA). Further, to open up the available band in optical fiber, other types of rare earth elements were also used as dopants with silica fibers in a specific concentration to amplify the signals in a specific wavelength region. But these rare-earth doped elements are band restricted [3] and do not provide uniform gain over the utilized band of operation of optical fiber.

Raman Amplifiers [4]

In order to overcome this problem, in the later years discrete and distributed RAs were used along with rare earth-element-doped fiber amplifiers. RAs can be utilized in any band by properly choosing the pump signals. RAs reduce the nonlinear penalty and improve the signal-to-noise ratio (SNR) of the signal amplified compared to the rare earth elements[5,10,11]. Sometimes the SNR of the amplified signals of the RAs is also affected by double Rayleigh scattering and other noises such as relative intensity noise (RIN) and amplified spontaneous emission (ASE) noise [14].

Semiconductor Optical Amplifiers

A semiconductor optical amplifier (SOA) is a semiconductor laser with reduced facet reflectivity. However, a SOA is not very useful due to its coupling loss, polarization sensitivity, and inter-channel crosstalk. Also, it generates more phase noise and nonlinear effects through which it reduces the SNR of the amplified signal compared to the other two amplifying methods [2, 3, 12].

HYBRID AMPLIFIERS

In order to satisfy the increased number of user demands in the local area network (LAN) and for cable television or community antenna television (CATV) applications, high power amplification is needed in the optical communication receiver’s distribution end. And also this high gain should be uniform and flat over the whole band of operation of a long haul communication such as the DWDM case [5, 13, 14]. The different amplifiers have several individual benefits and drawbacks. To compensate the drawbacks and combine the benefits of different amplifiers, these can be used together forming a hybrid amplifier [2]. Different approaches have been attempted so far to obtain the high power flattened response optical amplifiers. Some of them are rare earth elements like erbium and ytterbium co-doped fibers for high power wideband amplification and hybrid amplifiers. Hybrid amplifier refers to a combination of two or more dissimilar or similar amplifiers connected in series or in parallel. A great variety of such combinations can be used in modern transmission systems. They provide high power amplification at the receiver and provide a high gain with flat and uniform response [3]. The combined system gives enhanced performance compared to the constituent amplifiers.

Combinations

- A hybrid amplifier can be made with different combinations such as:
- Same or different rare-earth-element-doped fiber
- Rare-earth-element-doped fiber and discrete Raman amplifier
- Rare-earth element doped fiber and SOA
- SOA and RA

Hybrid amplifiers consisting of all rare-earth-doped fiber amplifiers are easy to utilize. These are simple gain spectra control. Hybrid doped fiber amplifiers with different gain bandwidths have attracted a large interest for increasing the transmission capacity of long haul wavelength multiplexed optical communication.

System in C-band and in L-band. Hybrid amplifier’s important parameters are maximum gain, gain ripple, noise figure, OSNR, bandwidth, number of channels, and maximum transmission capacity [6]. A hybrid amplifier allows wide and flattened bandwidth of amplification compared to other cases.

Second option from the above list has been considered in this report i.e., a combination of a rare-earth element-co-doped fiber amplifier and its complementary discrete RA to form the hybrid amplifier. Such a hybrid amplifier is constructed by cascading a Single Mode Erbium Ytterbium co-Doped Fiber (SM EYDFA) and a Standard Single Mode Fiber (SSMF) which in turn act as a Raman Amplifier (RA).

SM EYDFA-RA Hybrid amplifier

The gain spectrum of RAs can be tailored by adjusting the pump powers and pump wavelengths. So this property is used to increase the amplification bandwidth of EDFA. This combination provides less distortion of the amplified signals.

Features

- Enlarged transmission capacity of a broadband system
- Broadened and flattened amplification over a wide bandwidth [6,7,8,15]
- Ability to multiplex more wavelengths
Different Transmission Schemes and Optimal Fiber Lengths for a High Performance Flatband Hybrid Amplifier based All Optical Communication System

- Flexibility in amplification since the gain is tailored by RA pump wavelengths.
- Improves noise figure
- Improves OSNR

**Advantages of SM EYDFA**
- This gives a very low noise figure with very good gain.
- The length of the SM EYDFA and pump signal powers are chosen to minimize the gain ripple at the SMEYDFA output.
- Short length, single mode operation of EYDFA with core pumping enables easy splicing in the existing optical network.

### III. SIMULATION PARAMETERS

#### Block Diagram

![Block diagram of the communication system with hybrid amplifier](image)

#### Transmitter

The performance of a flat gain all optical communication system is analyzed in this report by the following different combinations:
- NRZ
- RZ
- UDBS
- DWDM
- PRBS

And analyzed for the Q factor and Min BER, Eye Height, Threshold, Decision etc.

#### Hybrid amplifier

The hybrid amplifier is a combination of 1m long single mode (SM) EYDFA and 13.5km long standard single mode fiber (SSMF) which acts as an RA. The core radius of SM EYDFA is 2μm, numerical aperture is 0.15 and the doping concentrations of Yb and Er are \(700 \times 10^{24}\) and \(51.4 \times 10^{24}\) with a lifetime of 10ms and 1.5ms respectively. EYDFA is pumped with 980nm sources in forward and backward directions with pump powers 150mW and 50mW respectively. The length of the SM EYDFA and pump signal powers are chosen to minimize the gain ripple at the SMEYDFA output. Short length, single mode operation of EYDFA with core pumping enables easy splicing in the existing optical network.

The multiple pump signals are multiplexed and coupled with the help of a pump coupler. This RA with a reduced length will reduce the double Rayleigh scattering (DRS), signal-ASE beat noise, phonon stimulated optical noise, noise figure and improves OSNR. Splice loss in this case also will be very low. Due to Raman amplification in the SSMF, this fiber can be directly utilized in the existing optical network with a suitable pump arrangement. This reduced length of the Raman fiber amplifier with very low nonlinear coefficient also reduces the nonlinear penalty of the fiber and increases the capacity of fiber-optic networks to higher bit rates [14]. No gain flattening filter (GFF) is required – hence cost effective. RA gives a complementary gain response with that of the SM EYDFA to flatten the gain over a broad spectrum [6].

#### Rectangular filter

When the input signal passes through the EYDFA, noise may be added to the signals outside the assigned frequency range of the signals due to the amplifier. When this signal is sent to the RA, the signal along with the noise is amplified leading to deteriorated performance. To remove the undesired noise outside the frequency band considered, a rectangular filter is placed after the EYDFA amplifier.

![Output of EYDFA before placing rectangular filter](image)

### Table 1: Pump signal and frequency spacing of RA.

<table>
<thead>
<tr>
<th>Pump Power (mW)</th>
<th>Semi-unequal Frequency Spacing (THz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1=1185</td>
<td>209.88</td>
</tr>
<tr>
<td>P2=420</td>
<td>205.137</td>
</tr>
<tr>
<td>P3=450</td>
<td>203</td>
</tr>
<tr>
<td>P4=504</td>
<td>200.5</td>
</tr>
<tr>
<td>P5=204</td>
<td>198</td>
</tr>
</tbody>
</table>

The diagram and table are placeholders for graphical representations of the system's performance before and after the EYDFA with a rectangular filter.
Isolators
Isolators placed at every stage will safeguard and avoid unwanted interaction of residual pump signals and the Brillouin scattered signal with the hybrid amplifier as well as the source.

Receiver
The final amplified signal with the maximum gain and flat gain response is given to the receiver section and the filtered output is given to the optical receiver and the bit error rate (BER) analyzer in order to measure the signal quality parameters such as Q factor and Min BER, Eye Height, Threshold, Decision inst. etc.

IV. SIMULATION RESULTS

Simulation Layout

The analysis of different transmission schemes for such a communication system using hybrid amplifier is performed with the help of Optisystem™ simulation software. The simulation is done for forward, backward and dual directional pumping schemes for RA with semi unequal frequency spacing of pump signals for different transmission methods viz.

- DWDM
- DWDM with reduced fiber length
- Optical Transmitter with NRZ Modulation
- Optical Transmitter with RZ modulation
- Optical Transmitter with NRZ Modulation with reduced fiber length
- User Defined Bit Sequence Generator with Mach-Zehnder Modulator
- User Defined Bit Sequence Generator with Mach-Zehnder Modulator with reduced fiber length
- Pseudo Random Bit Sequence Generator with Mach-Zehnder Modulator
- Pseudo Random Bit Sequence Generator with Mach-Zehnder Modulator with reduced fiber length

<table>
<thead>
<tr>
<th>Pumping Method</th>
<th>Transmission Scheme</th>
<th>Length of RA</th>
<th>G - Factor</th>
<th>Min. BER</th>
<th>Eye Height</th>
<th>Threshold</th>
<th>Decision instant</th>
<th>Simulation inst.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward Pumping</td>
<td>DWDM</td>
<td>5.5 km</td>
<td>2.452 e+05</td>
<td>6.00054955</td>
<td>7.1872e+05</td>
<td>0.0000119</td>
<td>0.0119</td>
<td>0.0219</td>
</tr>
<tr>
<td>Forward Pumping</td>
<td>DWDM</td>
<td>5.5 km</td>
<td>2.452 e+05</td>
<td>6.00054955</td>
<td>7.1872e+05</td>
<td>0.0000119</td>
<td>0.0119</td>
<td>0.0219</td>
</tr>
<tr>
<td>Backward Pumping</td>
<td>DWDM</td>
<td>5.5 km</td>
<td>2.452 e+05</td>
<td>6.00054955</td>
<td>7.1872e+05</td>
<td>0.0000119</td>
<td>0.0119</td>
<td>0.0219</td>
</tr>
<tr>
<td>Dual Pumping</td>
<td>DWDM</td>
<td>5.5 km</td>
<td>2.452 e+05</td>
<td>6.00054955</td>
<td>7.1872e+05</td>
<td>0.0000119</td>
<td>0.0119</td>
<td>0.0219</td>
</tr>
</tbody>
</table>

Table 2: Simulation results with forward pumping.

Table 3: Simulation results with forward and backward pumping.

Table 4: Simulation results with backward pumping.
Optimal fiber lengths
The length of the Raman Amplifier is varied from meters to several hundreds of kilometers to find the optimal length of different transmission schemes using the three different pumping methods forward, forward backward and backward pumping.

The optimal fiber length for a BER of $10^{-12}$ and a corresponding Q-factor of 6 is obtained at 1 km but the 110 *40 Gb s NRZ DWDM transmitter with forward semi-unequal pumping provides reliable transmission up to 100 km. Moreover, it provides a maximum gain of 19.93 dB, maximum noise figure of 4.58 dB, and maximum OSNR of 83.09 dB at an input power of −17 dBm.

It is inferred that this scheme offers a poor transmission and hence not preferred.

Table 5: Forward Pumping DWDM Transmitter

<table>
<thead>
<tr>
<th>Pumping Method</th>
<th>Transmission Scheme</th>
<th>Length of A (m)</th>
<th>Q-Factor</th>
<th>Min. BER</th>
<th>Eye Height</th>
<th>Threshold</th>
<th>Error vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward</td>
<td>Optical Transmitter</td>
<td>5 m</td>
<td>1.17</td>
<td>0</td>
<td>6.15</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Backward</td>
<td>Optical Transmitter</td>
<td>50 m</td>
<td>4.09</td>
<td>0</td>
<td>5.21</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Forward</td>
<td>Optical Transmitter</td>
<td>100 m</td>
<td>4.09</td>
<td>0</td>
<td>5.21</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Forward</td>
<td>Optical Transmitter</td>
<td>150 m</td>
<td>4.09</td>
<td>0</td>
<td>5.21</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Forward</td>
<td>Optical Transmitter</td>
<td>200 m</td>
<td>4.09</td>
<td>0</td>
<td>5.21</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Backward</td>
<td>Optical Transmitter</td>
<td>50 m</td>
<td>4.04</td>
<td>0</td>
<td>5.26</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Forward</td>
<td>Optical Transmitter</td>
<td>100 m</td>
<td>4.04</td>
<td>0</td>
<td>5.26</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Forward</td>
<td>Optical Transmitter</td>
<td>150 m</td>
<td>4.04</td>
<td>0</td>
<td>5.26</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Forward</td>
<td>Optical Transmitter</td>
<td>200 m</td>
<td>4.04</td>
<td>0</td>
<td>5.26</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

Table 6: Optical Transmitter with NRZ modulation

This scheme has got a Q-factor of nearly 4.5 with a BER of the order of $10^{-7}$ between 25 - 50 km and offers transmission maximum up to 125 km.

Even though this scheme offers a transmission distance up to 175 km, the signal quality parameter is only 4 with an unacceptably low BER.

Table 7: Optical Transmitter with RZ modulation

Table 8: PRBS with Mach-Zehnder Modulator

This is only a test transmission scheme.

Table 9: UDBS with Mach-Zehnder Modulator

Table 10: Forward - Backward Pumping DWDM Transmitter

This shows an exactly similar result that of a forward pumping method.
Different Transmission Schemes and Optimal Fiber Lengths for a High Performance Flatband Hybrid Amplifier based All Optical Communication System

The communication distance obtained for this is up to 125km but with a very low Q-factor of 3 and the BER is also too low.

Table 11: Optical Transmitter with NRZ modulation

<table>
<thead>
<tr>
<th>Pumping Method</th>
<th>Transmission Scheme</th>
<th>Length of RA (m)</th>
<th>Q Factor</th>
<th>BER</th>
<th>Threshold</th>
<th>Deviation in BER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward pump</td>
<td>Optical Transmitter</td>
<td>100</td>
<td>0.000008</td>
<td>0</td>
<td>0.000008</td>
<td>0.000008</td>
</tr>
<tr>
<td>Forward pump</td>
<td>Optical Transmitter</td>
<td>150</td>
<td>0.000007</td>
<td>0</td>
<td>0.000007</td>
<td>0.000007</td>
</tr>
<tr>
<td>Forward pump</td>
<td>Optical Transmitter</td>
<td>200</td>
<td>0.000006</td>
<td>0</td>
<td>0.000006</td>
<td>0.000006</td>
</tr>
<tr>
<td>Forward pump</td>
<td>Optical Transmitter</td>
<td>250</td>
<td>0.000005</td>
<td>0</td>
<td>0.000005</td>
<td>0.000005</td>
</tr>
</tbody>
</table>

Table 12: Optical Transmitter with RZ modulation

As in the above case RZ scheme offers a poor performance.

Table 13: PRBS with Mach-Zehnder Modulator

The results show that forward pumping for this scheme is more efficient than forward- backward method.

Table 14: UDBS with Mach-Zehnder Modulator

These cannot be used for 10 to 100kms but for 100 kms these show a Q-factor of nearly 4.5 but has got undesired gain characteristics.
None of these show an acceptable Q or BER but can transmit up to 175km.

This provides communication only up to 75km with a Q-factor of nearly 3.5.

RESULTS

Q factor measures the quality of a transmission in terms of its signal-to-noise ratio (SNR). As such, it takes into account physical impairments to the signal (for example, noise, chromatic dispersion and any polarization or non-linear effects) which can degrade the signal and ultimately cause bit errors. The higher the value of Q factor the better the SNR and therefore the lower the probability of bit errors. Associated raw BER of a Q of 6 is 10⁻⁹. The required BER for a high speed optical communication system is in the range of 10⁻¹³ to 10⁻¹⁵, the typical value being 10⁻¹⁶. Specifically, Q-Factor represents the quality of the SNR in the “eye” of a digital signal, which indicates transmission system performance.

Here the DWDM transmitter showed the exact results when the fiber length is reduced. RA with a reduced length will reduce the double Rayleigh scattering (DRS), signal-ASE beat noise, phonon stimulated optical noise, noise figure and improve OSNR. For some cases, when the length of the fiber (RA) is reduced, Q factor becomes extremely high and BER became unacceptably low. From which an optimal fiber length is found out which will give an acceptable BER. For all the transmission methods the bit rate was kept 40 GBPS but for UDBS the bit sequence chosen was 1111 0000 and PRBS can only be used as a test transmission system. In all cases, NRZ transmission method showed higher Q than RZ method. RZ method does not work well with Forward and backward pumping schemes. Spatial Modulator was not used as a transmission method in this experimental set up because in optical communication between Transmitter and Receiver requires a line-of-sight. So, spatial modulation cannot be used. However, we can use it along with an FSO link for transmission.

CONCLUSION

In this paper the core pumped SM EYDFA allows a wide range of gain bandwidth spectrum and ensures very low noise figure to the next stage. The following RA has a complementary gain response to that of the SM-EYDFA by which it can improve the performance of the hybrid amplifier. For 40 GB/s transmission signals, RA with Forward, Forward Backward and Backward Pumping showed somewhat similar results. But for 110*40 GB/s NRZ DWDM signals with standard telecommunication input power of −17 dBm and semi-unequal pumping scheme in the RA, a maximum gain of 19.93 dB, maximum noise figure of 4.58 dB, and maximum OSNR of 83.09 dB (which is greater than the requirement of 32 dB for the best signal detection) are obtained in the hybrid amplifier using forward pumping scheme. It also provides a reliable communication up to 100kms. Other methods use only single channel and multiplexing of more wavelengths is not possible. Obviously, the DWDM Transmission method is the best candidate to offer uniform amplification over the L and C bands for applications like cable TV or fiber to the home DWDM, CATV, LAN etc.

REFERENCE

[5] P. F. Wysocki, N. Park, and D. DiGiovanni, “Dual-stage erbium-doped, erbium ytterbium-codoped fiber amplifier with up to +26 dBm output power, and a 17-nm flat spectrum”,

Table 18: PRBS with Mach-Zehnder Modulator

Table 19: UDBS with Mach-Zehnder Modulator


