UGC Approved Journal
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ISSN : 2348 - 5612 | Volume : 05 , Issue : 01 | January – March 2018

Maximizing the Efficiency of Hybrid Optical Amplifiers in Dense Wavelength Division Multiplexing Networks

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Abstract: In this study, we explore how to use amplification methods to enhance the DWDM system's transmission qualities. Changing the kind of optical amplifier used or modifying the specifications of the optical amplifiers might affect the parameter values. Optimization is a synopsis of the relevant information about the hardware and software in use. A series of simulations are run to test these hypotheses, and the resulting numerical values are compared to those reported in the cited papers. Over very great distances, the suggested design using many EDFA amplifiers has been shown to outperform those using only one. The suggested technique also outperforms other methods developed for the same goal in terms of transmission characteristics.

Keywords: "DWDM; EDFA; optical network; OptiSystem; ROA; SOA"

I. Introduction

In order to keep up with consumers' ever-increasing demands for bandwidth, networking have had to upgrade their infrastructure, and recent advancements in optical components, subsystems, structures, and connections have made this possible. In continuous 40-80 channel optical correspondence architectures working at 10 Gb/s, it may be challenging to create high-limit transmission topologies. With the use of cutting-edge optical correspondence structures, data speeds of 40-100 Gb/s per channel may be sent across very long distances [1].

Data transmission is expected to rise in the future as a result of the widespread use of high-speed electronic connections and web technologies like insanely high television (UHDTV), skype, etc. Thanks to this model, advancements in broadband network connectivity may continue to improve client speeds, tipping point, and range.

The International Telecommunication Union's Telecommunications Middleware Group (ITU-T) [2] established standards for the commercialisation of DWDM (Thick Recurrent Division Multiplexing) architectures, which are increasingly important for telecommunications networks. OTN (Optical Vehicle Connection) customers may choose to have up to the entire rehash [3] because of this, and relationships can be maintained utilising various frequencies of light when supplied across comparable optical strands.

It has also been upgraded so that it can carry the massive amounts of data used by several existing and future business organisations and applications. To speed up the process of upgrading the communication method from copper to optical fibre, the DWDM technology was implemented in the early 2000s. All financial dealings and data administration in this revolutionary period of DWDM architectures were executed digitally, with the visible light sent through the optical fibre being transformed to an electrical current at each of the network's nodes. The research of optical connection networks advanced greatly in the waning decade of the 1990s and the early years of both the new century. Since the constraints of security and recovery were relocated to the optical component of the connection, this was mostly due to the fundamental relationship towards a new DWDM design and other advancements, which we call the "second age of optical connection" [1].

Increased communication is a key factor in the remarkable strengthening of bonds. Fully optical interactions, in which the transmitted sign is transferred unmodified by opto electronic methods, may be the future of interesting communication networks. There have been significant advancements in optical connections that have allowed for the development of unique DWDM upgrades that allow for the data communication of multiple carriage optical waves over a single optical fibre. With their low transmit debilitating difficulties, C-band and L-band are often agree upon for employment in the DWDM system [4].

Network orchestration and subsequent improvement evaluation and enhancement both benefit from the arrangement methods. Today, it's crucial that the service provider convey its partnership with a certain amount of enormous value. The Q factor, often known as BER, is the most widely used dynamic indicator. Picking these bounds should, in general, be done using operational models. The association service provider then decides whether the network's foundational services are up to par [5]. It is necessary to integrate DWDM networks into existing optical backbones. Because of the aforementioned, it places an excessive burden on the transmission infrastructure while the strands stay unaltered. As a result, DWDM improvement is being consistently used nowadays.

The next stage is to establish an incredibly clear optical link, since this offers the greatest strategy it terms of data rate, signalling plan, and projection [6]. A regular DWDM design and interconnection may cover the whole association region, including the development's own affinities, access, and urban, large distance, and particularly significant distance party affiliation. These connections may span anything from some few feet in the case of local connections to long distances in the instance of global ones.

However, contemporary optical correspondent techniques may operate at rates of 40-100 Gb/s. Because of the ever-increasing demand for media, DWDM designs must evolve to satisfy industry standards. To help constrain DWDM links, it is essential to assess the medium's characteristics and to foreground any system limits [7]. The optical route is typically most affected by the sign shape, dispersive characteristics, and linear character of the transceiver. Transmission at high speeds across a limited number of transmission rates is very hazardous. These contaminating effects are more harmful at greater data rates in multiple channels optical transmission when nonlinearities are present. Thus, we want the building-to-building data transmission with the lowest un-sign degradation [8].

There is a pressing need to enhance our DWDM bandwidth in addition to creating cutting-edge transmission techniques. In addition, our technique should allow for better BER constraints when sending a larger number of mission-critical EDFA enhancements in a DWDM plot. We see no benefit in arranging DWDM plans with SOA enhancers due to the paucity of illuminating details on this strategy.

II. Experimental Setup

When designing DWDM systems, selecting the appropriate optical amplifier is crucial. A DWDM state's range being severely limited by the magnitude of the signal intensity associated with the optical fibre, which has a profound effect on the emergence of phenomena. We go through some of the most important design considerations for EDFA, SOA, and ROA optical amplifiers. Finally, we compare the bit error rates (BER) achieved by using different kinds of optical amplifiers in our DWDM test rig. Our research was performed using the Uni programme.

As an optical communication system simulator, Optiwave's OptiSystem is a good choice. Optical connections and systems, from purely analogue to completely digital, may be designed, tested, and optimised. Also, the software isn't perfect; we couldn't find the measurement blocks we needed to conduct

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the parameter determination work, for example. To evaluate the effectiveness of the solutions we offer, we employ just the most fundamental metrics.

All of the optical amplifiers were modelled using the methods with fixed parameters presented in (Table 1).

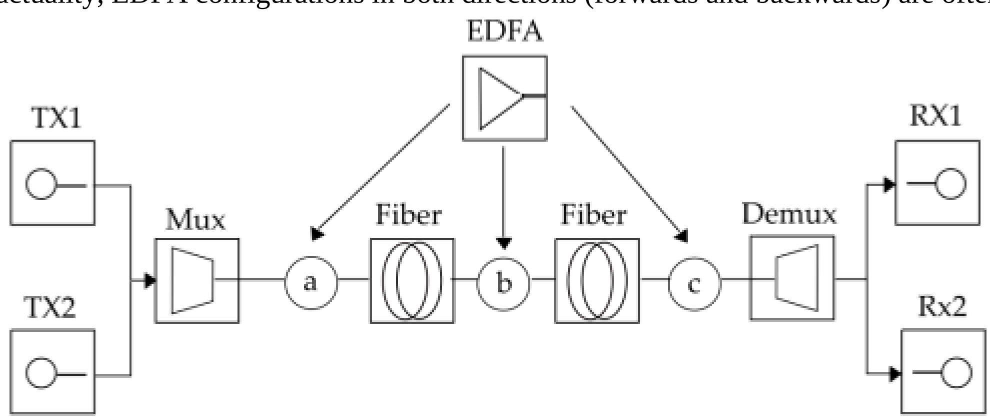
"Table 1: Stable parameters for all optical schemes."

Parameters	System Design
Bit rate	40 Gb/s
Number of channels	32
Channel spacing	100 GHz
Initial frequency	193.1 THz
Modulation type	NRZ
SMF chromatic dispersion	17 ps/nm/km
Attenuation	0.2 dB/km
Dispersion—β_2	-20 ps^2/km
Polarizing dispersion—PMD	0.2 ps/km
Effective area of fiber Ae	80 μm^2
Nonlinear refractive index n_2	2.6×10^{-20} m^2/W
DCF length	10 km
DCF chromatic dispersion	-85 ps/nm/km

Erbium Doped Fiber

Typically, the EDFA boost per mile is 20-30 dB while operating at a depth of 10 metres utilising Erbium Liquored Fiber (EDF). Nonetheless, the pumping, the fibre, and the fiber's length all place limits on how much horsepower an amp can deliver.

"Since a continuous wave laser (CW Laser) may be used as the light source for near 1550 nm pumps, and the pump is then paired with an information signal using a wavelength division multiplexer (WDM), the EDF length can be up to 30 m, depending on the EDFA setup. The effectiveness of EDFA is heavily influenced by the light source used. In the real world, we use 1550 nm forward-mode light sources (Figure 2). With forwards pumping, the pump wavelength travels in the same direction as the signal (Figure 2). In actuality, EDFA configurations in both directions (forwards and backwards) are often used".



"Figure 1: EDFA amplifier scheme with options for placement in the optical system (a—power amplifier, b-in-line amplifier, c-preamplifier)"

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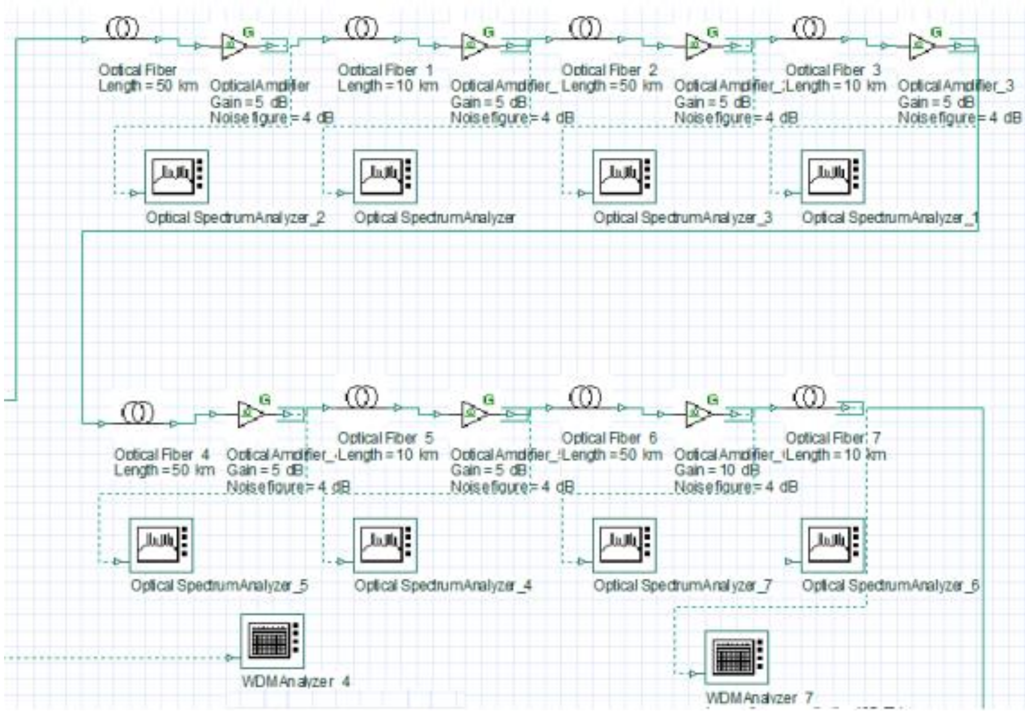

"Figure 2: EDFA model in our DWDM system."

According to our plan (Table 2), we will use both ten-kilometer-long DCF fibres and fifty-kilometer-long optical separate fibres (ITU-T.G.652 [27]). The length of optical fibre utilised amounts to 240 kilometres. The setup depicted in Figure 3 employs seven EDFA amplifiers, six of which have a gain of 5 dB and a noise figure of 4 dB, and the remaining two of which have gains of 10 dB and 4 dB, respectively. Amplification equipment is installed in the spaces in between fiber optic. In the receiving area, you'll find 32 optical receivers together with BER analyzers. We achieved a bit error rate (BER) of 4.229 x 1014 on the first channel and 3.609 x 103 on the twentieth. Results are given in Table 3.

"Table 2: Parameters of the designed model EDFA"

Parameters	System Design
Laser power (dBm)	10
Gain (dBm)	5 or 10
Saturation power (dB)	10
Noise figure (dB)	4
Polarization filter	none
Noise bandwidth (THz)	13
Total fiber length (km)	240

"Table 3: Results of 32-channel EDFA DWDM system"

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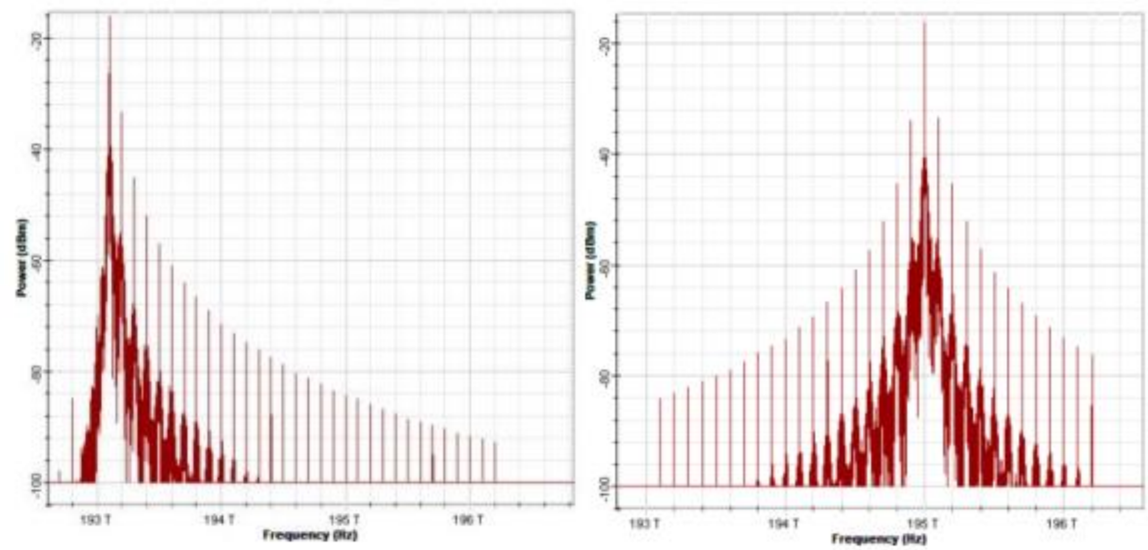
Parameters	Max Q Factor	Min BER	Eye Height	OSNR (dB)
CH 01	7.460	4.229×10^{-14}	3.086×10^{-5}	27.107
CH 05	6.668	1.284×10^{-11}	2.729×10^{-5}	27.173
CH 10	6.452	5.462×10^{-11}	2.595×10^{-5}	26.980
CH 15	6.998	1.265×10^{-12}	2.851×10^{-5}	27.024
CH 20	5.327	4.906×10^{-8}	2.023×10^{-5}	27.009
CH 25	3.780	7.355×10^{-5}	9.017×10^{-6}	26.863
CH 30	3.653	1.218×10^{-4}	7.209×10^{-6}	26.714

Our approach, using an EDFA amplifier, improves upon the outcomes of across greater fibre optic lengths as compared to. For both tested channels, their system managed a BER of 1109. We were able to do this with a BER of 4.229 x 1014 on the first channel and 3.6 x 103 on the twentieth channel. An increase in bit error rate (BER) is seen on the primary channel. The system is optimised for longer distance transmissions. Figure 4's optical spectrum illustrates the frequencies and received strength of the distinct channels.



“Figure 3: Optical spectrums for the first and twentieth channels EDFA”

Raman Optical Amplifier

The Raman emphasis has been placed (ROA) is activated when light waves are emitted from molecules (i.e. to high power areas as a result of Rayleigh scattering, which occurs when positive ions of the laser intensity socialise with protons and nuclei from either the reflection coefficient intermediate and with spectral and pivoting states of something like the optical drives format. This emission is triggered by light striking the optical media; it does not occur spontaneously. The useful range of ROA is between 1300 and 1600 nm, where the gain generally exceeds 15 dB. There is a 48 nm bandwidth for ROA that may be put to good use. Both ROA and EDFA are widely employed in DWDM systems today, with ROA being particularly well-liked for long-distance transmissions. The ease with which it may be integrated into preexisting systems is a major benefit. Since the amplification takes place inside the transmission fibre itself, a doped fibre is unnecessary. A distributed optical amplifier is another name for ROA. There are two distinct setups that may be used for ROA: the forwards pump source configuration shown in Figure 5 and the reverse pump source configuration shown in Figure 6. The increase in return on average (ROA) does

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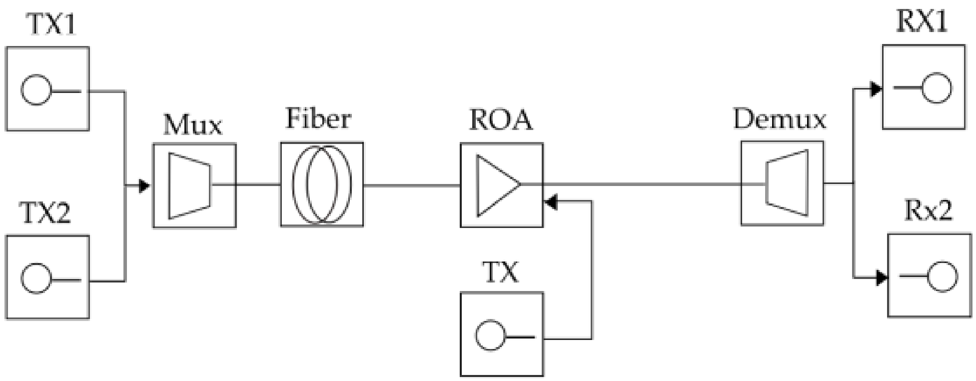
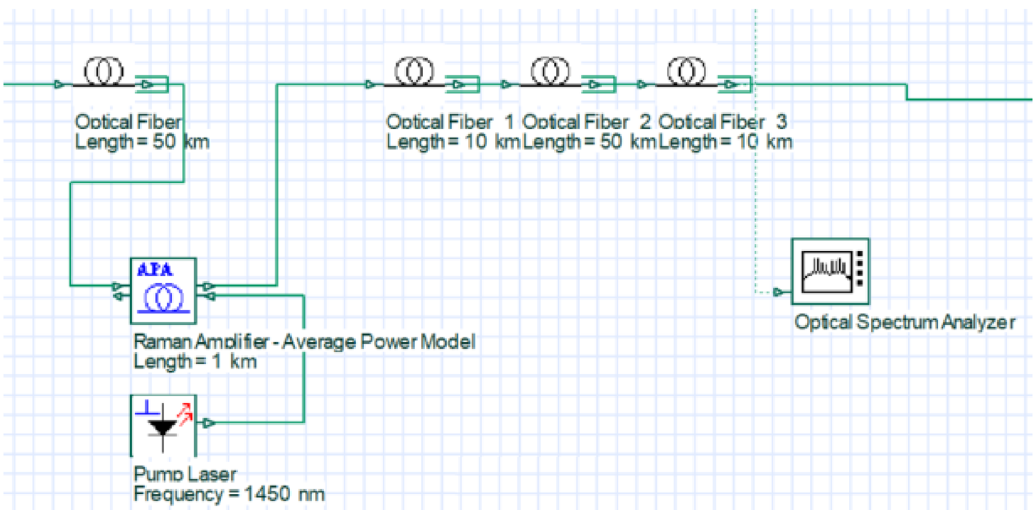
not change based on where the pump comes from. The light output of the pump source may fluctuate, which is a drawback of ROA. In a wavelength division multiplexing (WDM) system, this may lead to changes in the amplitude and jitter of the amplified signal due to unequal amplification while transmitting numerous wavelengths.



“Figure 4: ROA amplifier scheme in optical system”

Figure 5 depicts our set up, which makes use of a 32-channel photonic array linked by both 50-km OM1 and 10-km DCF fibres. The total length of the optic line is 120 kilometres. The proposed solution makes use of a single, 1-kilometer-long ROA amplifier. Amplification equipment is installed in the spaces between the optical fibres. In the receiving area, you'll find 32 optical receivers together with BER analyzers. On channel 1, we saw a BER of 5.166 x 1011, whereas on channel 20 we saw a BER of 5.676 x 10108. Data collected are summarised in Table 10.



“Figure 5: ROA model in our DWDM system”

“Table 4: Results of 32-channel ROA DWDM system”

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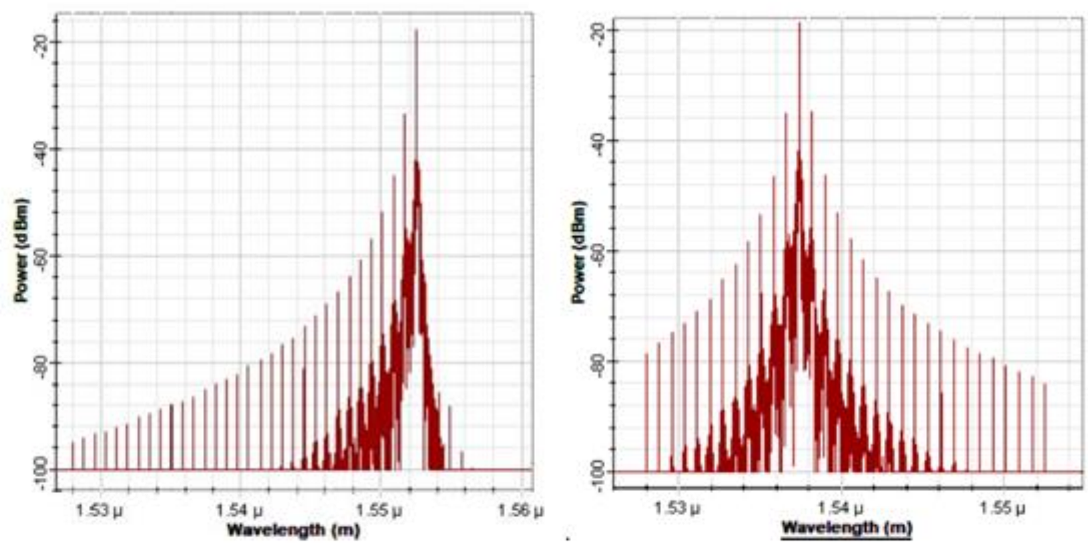
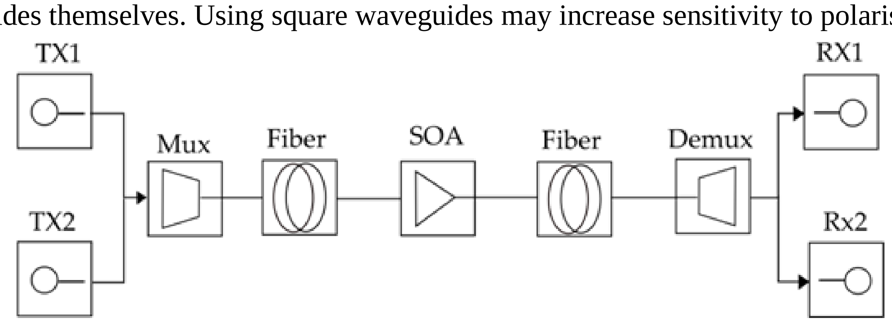
Parameters	Max Q Factor	Min BER	Eye Height	OSNR (dB)
CH 01	6.462	5.166×10^{-11}	1.954×10^{-5}	38.543
CH 05	7.038	9.641×10^{-13}	2.144×10^{-5}	38.742
CH 10	5.485	2.0513×10^{-8}	1.542×10^{-5}	38.541
CH 15	5.194	1.021×10^{-7}	1.278×10^{-5}	38.498
CH 20	5.303	5.676×10^{-8}	5.425×10^{-6}	38.456
CH 25	4.618	1.933×10^{-6}	9.018×10^{-6}	38.413
CH 30	3.851	5.876×10^{-5}	5.024×10^{-6}	38.576

Figure 7 depicts the optical spectra of the channels with the ROA amplifier. The first circuit has a power level of 16 dBm and operates at a range of 1.552 m. Power is 17 mhz and bond length is 1.539 m at the 20th position.



"Figure 5: Optical spectrums for the first and twentieth channels ROA"

Powering the SOA amplifier (shown in Figure 6) is electrical. Through stimulated emission, the device's active region amplifies the input signal. There is noise on the signal at the output. As a byproduct of amplification, we get this new kind of background noise known as amplified spontaneous emission (ASE). SOAs are very polarization-sensitive. Many things are at play here, including the design and composition of the waveguides themselves. Using square waveguides may increase sensitivity to polarisation.



"Figure 6: SOA amplifier scheme in optical system"

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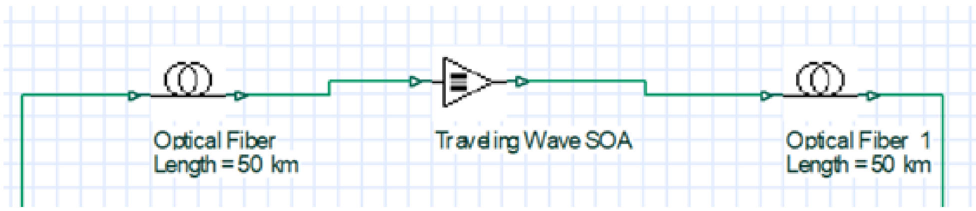
Gain in SOA is sensitive to the strength of the signal being amplified as well as the noise introduced by the amplification process itself. There is an inverse relationship between input signal strength and gain. Intense signal distortion may result from gain saturation. The gain potential of WDM systems using SOAs as multichannel amplifiers is similarly constrained.

In our configuration (shown in Figure 7), we use two 50 km optical single- mode fibres to connect a 32-channel laser array. A hundred kilometres' worth of the optical cable's length. An SOA amplifier of length 0.0003 m.s. is used in the scheme. The amplification components are sandwiched among the optical fibres. We achieved BER values as low as 3.651 x 103 on the first channel and as high as 5.565 x 103 on the twentieth. Table 5 displays the whole of the findings.

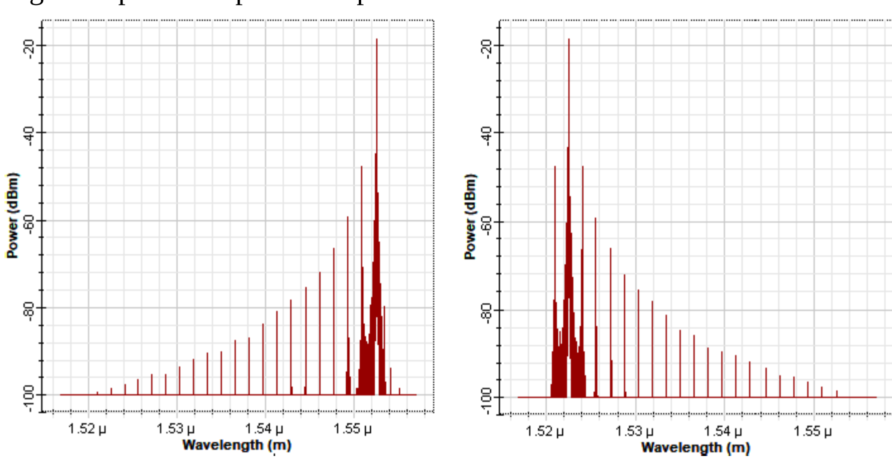


“Figure 7: SOA model in our DWDM”

“Table 5: Results of 32-channel SOA DWDM system”

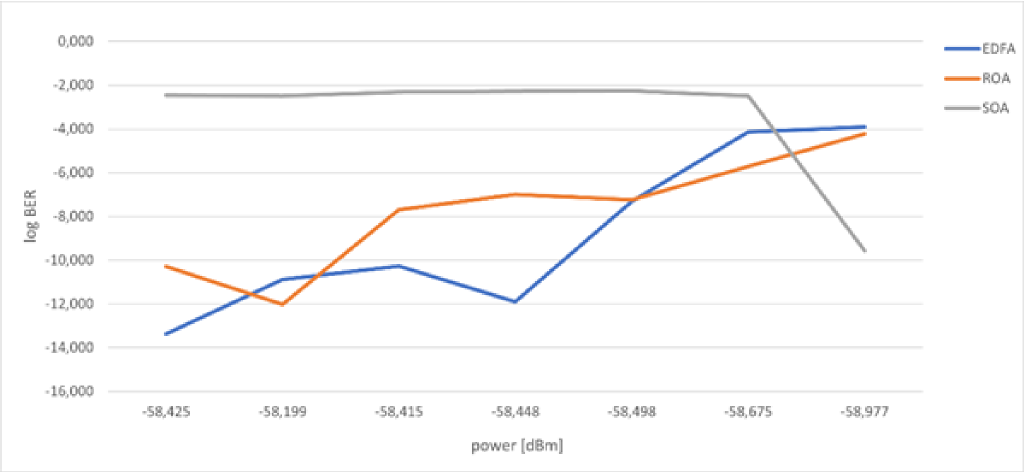
Parameters	Max Q Factor	Min BER	Eye Height	OSNR (dB)
CH 01	2.675	3.522×10^{-3}	3.522×10^{-6}	36.561
CH 05	2.717	3.195×10^{-3}	3.004×10^{-6}	35.659
CH 10	2.573	4.875×10^{-3}	4.452×10^{-6}	34.941
CH 15	2.547	5.183×10^{-3}	5.096×10^{-6}	35.793
CH 20	2.521	5.565×10^{-3}	5.366×10^{-6}	34.679
CH 25	2.719	3.212×10^{-3}	2.863×10^{-6}	35.414
CH 30	6.206	2.713×10^{-10}	1.368×10^{-5}	36.295

From these results, it is clear that the suggested EDFA 32-channel system performs better than our method, which uses a semiconductors amplifier for each 100 kilometres of optical line. It is 3.522 x 103 for a single-output, single-channel (SOA) system, and 4.229 x 1014 for a dual-output, dual-channel (EDFA) system. Figur8 depicts the spectral response.



“Figure 8: Optical spectrums for the first and twentieth channels SOA”

The nonlinear impact known as SRS is taken into account in another simulation designed to acquire the relationship between electrical output or log of BER (Figure 9). (Simulated Raman Scattering). A steady amount of electricity was fed in (0 dBm at 193.1 THz).



"Figure 9: Amplifier comparison output power vs. log of BER."

III. Discussion

Traditional DWDM amplifiers are used in simulations to transmit 40 Gb/s across the networks specified in Section 4. An SMF link of 240 miles in length and seven optical amplifiers are used in this EDFA simulator example's individual channels. The various tables display the results of several modelled channels. An median of 10 iterations of the same experiment yields the results shown for channels 1 and 20.

For a 40 Gb/s system across 70 kilometer of fibre, we used a refund (ROA) amplifier. The averaged of the outcomes from ten separate simulations was calculated. Finally, we ran a simulation of a SOA amplifier that was 100 km in length. Results are listed in Table 9. The results of our simulations consistently outperformed those of our contemporaries.

In our designs, the EDFA amplifier get the best results, with BERs of the magnitude of 1 x 1014. The lowest BER value currently observed on Channel 5 is 1.284 x 1011. Channel 5 is ideal for using the ROA strategy (with a BER of 9.641e-10). The SOA amplifiers does not fare better than the other two in our setup, however. Lower bounds for BER SOA are within the order of 1 x 103. More SOA optimizations should lead to improved results.

We believe that the EDFA system may be optimised to improve BER values under fixed circumstances by tuning the number of amplifier components and their output power. The findings validate the proper treatment of higher bit rate and lower BER DWDM systems. Numerous SOA-based DWDM methods have been deployed and evaluated. As a result, this paper does not provide a comparison of SOA to any other methods. Furthermore, our established method of comparing SOA amplifiers may be utilised to make future comparisons using the information presented in this paper.

In order to evaluate the effectiveness of the amplifiers we offer, we turn to this paper. There has been no progress towards the end aim of creating a system for eventual deployment in the real world. As a result of our studies, we developed a system with more amplifiers, which improved BER but came at a cost from a financial perspective. Although there are now no plans to use the system, many academics will find it useful when designing DWDM networks in the future.

IV. Conclusions

Finally, a unique design for combining several EDFA optical amplifiers into a single signal path is shown. Several DWDM optoelectronic amplifiers are compared and contrasted. The role of amplifiers in DWDM networks was also discussed. We investigated the impact of EDFA, ROA, and SOA on transmission quality in a 32-channel dense wavelength division multiplexing (DWDM) system. After briefly discussing the field and various associated approaches in Section 3, a novel system is proposed in Section 4. Our state-of-the-art knowledge on DWDM systems and their characteristics is compiled here. Approximating DWDM and optical amplifiers in optical networks was of great interest to us. Section 3 is devoted to discussing the related literature that helped put our results in perspective. At the end of the paper, we compared the three types of amplifiers in terms of their output power and log of BER.

We can further improve transmission speed with reduced BER by comparing several kinds of amplifiers in our DWDM systems.

Our long-term goal is to improve the BER of high-capacity DWDM systems by optimising their use of optical amplifiers. Our goal is to improve transmission speed by increasing the number of channels to 64 or more. We want to achieve rates of 100 Gb/s or higher, which is far faster than the typical 40 Gb/s used today.

Our final goal is to determine BER values and create eye diagrams for a respect to the horizontal 100 Gb/s DWDM system operating over extended distances. The outcomes of these simulations will then be included into the design of these systems.

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