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A Survey on EDFA Amplifier for DWDM System

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Abstract: The goal of this review paper is to get the analysis of an erbium doped fiber amplifier (EDFA) for dense wavelength division multiplexing (DWDM) system. They analyzed that the output peak power is increased many times and optimized by using EDFA. The performance of single & hybrid optical amplifiers using the output power, BER, eye height and Q factor. The system is simulated using Opt system software to achieve gain flatness, BER (Bit error rate), and noise figure of EDFA through optimized fiber analyzed separately. The simulation results showing length and pump power. The system is simulated using Opt system software to achieve gain flatness, noise figure of EDFA. An efficient flat gain characteristic is demonstrated using a two stage DRA-EDFA configuration. The performance of the DWDM system using both hybrid fiber amplifier configurations has been quality factor (Q), eye diagrams, signal strengths and BER at various receivers for BER of 10^{-9} at 1479 nm to 1555 nm bandwidth. The performance of a 64 channel DWDM system for different modulation formats, channel spacing, line widths of optical sources and different fiber lengths has been observed. They analyzed the EDFA adaptive gain control effect over a cascade amplifier in a DWDM system & the performance of optical cross connect in DWDM system under the influence of intra-band crosstalk.

Keywords: Erbium Doped Fiber Amplifier (EDFA), Erbium Doped Fiber (EDF), Dense Wavelength Division Multiplexing (DWDM), Doped Fiber Amplifiers (DFAs), Gain Flatness (GF), Noise Figure (NF), Adaptive Gain Control (AdGC), Multi Core-EDFA (MC-EDFA).

I. INTRODUCTION

The tremendous growth of the high speed internet and data traffic has created an enormous demand for transmission bandwidth of dense wavelength division multiplexed (DWDM) optical communication systems. The conventional optical amplifiers, such as the erbium doped fiber amplifier (EDFA) and Raman amplifier, are the vital components for DWDM system [4].

Doped fiber amplifiers (DFAs) are optical amplifiers that are used by doped optical fiber as a gain medium to amplify an optical signal. They are related to fiber lasers. The signal to be amplified and a pump laser are multiplexed into the doped fiber, and the signal is amplified through interaction with the doping ions. The most common example is the Erbium Doped Fiber Amplifier (EDFA), where the core of a silica fiber is doped with trivalent erbium ions and can be efficiently pumped with a laser at a wavelength of 980 nm or 1,480 nm and exhibits gain in the 1,550 nm regions. An erbium doped fiber amplifier (EDFA) is an optical amplifier which is used to boost an optical signal [14].

EDFA is an optical amplifier that uses a doped optical fiber as a gain medium to amplify an optical signal. EDFA also have large gain bandwidth, high output power, and low noise figure. EDFAs are very much reliable for long distance transmission using single and multi-wavelength sources because of their wide bandwidth and optimum Bit Error Rate (BER) [1].

WDM is the technology in which multiple wavelengths of light are launched into single optical fiber with the advantage of no additional fiber link has to be installed. Dense Wavelength Division Multiplexing (DWDM) is a denser version of WDM resulting from advances made in the tuning of lasers and wavelength filtering combine different wavelength channels to increase the capacity of the existing optical network, each carrying an optical data signal [14].

A brief description of the state of the art of Erbium Doped Fiber Amplifier (EDFA) and Dense Division Multiplexing (DWDM) is given in section II. A literature survey is described in section III. In section IV, a OptiSystem software has been described. Section V has been used for the conclusion.

II. THE STATE OF THE ART

A. Erbium Doped Fiber Amplifier (EDFA)

The erbium doped fiber amplifier (EDFA) is a device that plays a key role in optical networks responsible for regenerating the signal power. On the other hand, it is an important source of system noise. Moreover, other impairment that comes from the EDFA is that the gain depends on wavelength, thus leading a non-flat gain. The noise level added, associated to the Noise Figure (NF), and the Gain Flatness (GF) depends on the operating point of the amplifier, which can be adjusted by its set point gain.

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In essence, the EDFA set point gain can be automatically adjusted to provide optima NF and GF [8]. Erbium Doped Fiber Amplifiers (EDFA) made by doping the silica fiber with erbium ions can operate in a broad range within the 1550 nm window at which the attenuation of silica fiber is minimum therefore it is ideal for the optical fiber communication systems operating at this wavelength range. Pumping of erbium doped fiber at 980 nm or 1480 nm is the most efficient way [15]. High gain, large bandwidth, high output power and low noise figure can be obtained using an erbium doped fiber amplifier optimized for 1.55 μm range. The amplification that could previously be made within C band (1525-1565 nm) has now extended to L band (1570-1620 nm) [15].

1) Basic Principle of EDFA

The basic principle of EDFA is Stimulated Emission. Fig. 1 shows block diagram of EDFA. It is a conventional silica fiber doped with the Erbium. When erbium is stimulated with some suitable wavelength (980nm or 1480nm pump source) light energy, erbium ions are excited to some high energy metastable state. After some time these ions decay back to ground state, by giving up their energy in the form of light. If during decay process some light energy already exist within the fiber then this decay process is stimulated. So, the name is stimulated emission [1].

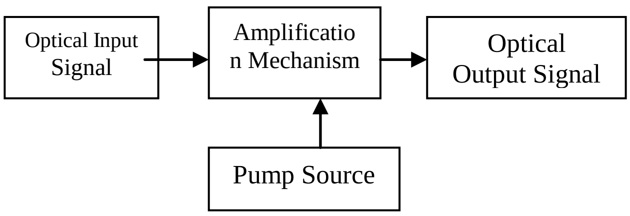

Figure.1. Block Diagram of an EDFA

The two main parameters which have a direct impact on the performance of EDFA are Gain and Noise figure. The length of EDFA also has an impact on gain and noise figure. Main issue while using EDFA is selection of Pump source Wavelength.

2) Energy Levels

EDFA consist of optical fiber of which the core has been doped with erbium ions. The electrons of EDF can be excited to higher energy levels by pumping with a shorter wavelength light. The amplification takes place in both the C band (1530 nm – 1560 nm) as well as L band (1570 nm – 1610 nm). Pump wavelengths of 980 nm or 1480 nm are usually used to excite erbium's quantum levels [22]. The pump supplies energy to the electrons in an active medium, raising them to a higher energy level. An EMF may excite an atom's electrons, which are in the ground state, to higher energy levels [23].

These higher energy levels are unstable and the electrons will tend to fall back down to the ground state. If the time it takes for the electrons to fall back to the ground state from certain energy level is very long compared to the lifetime of the previous states that led to this level, a metastable band is formed. Electrons will thus accumulate on this energy level [16]. If the number of electrons in the metastable band exceeds the number of electrons in the ground state, population inversion has occurred. This is necessary for amplification to take place [16].

In Spontaneous emission, if an atom is in an excited state, it may spontaneously decay into a lower energy level after some time, releasing energy in the form of a photon, which is emitted in a random direction.

In Stimulated emission, photon of the same frequency interacts with electron in excited state which drops to lower state - the emitted photon is coherent with the incoming photon [22]. The parameters of EDFA are Gain, Noise figure and large bandwidth.

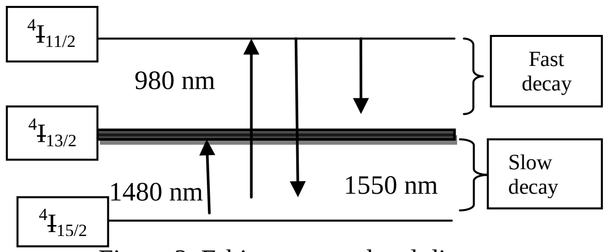

Figure.2. Erbium energy level diagram

B. Dense Wavelength Division Multiplexing (DWDM)

DWDM is a fiber optic transmission technique that employs light wavelengths to transmit data parallel-by-bit or serial-by-character. DWDM, an optical technology used to increase Band width over existing fiber optic backbones. Dense wavelength division multiplexing systems allow many discrete transports channels by combining and transmitting multiple signals simultaneously at different wavelengths on the same fiber. In effect, one fiber is transformed into multiple virtual fibers [20].

A key advantage to DWDM is that it's protocol and bit-rate independent. DWDM-based networks can transmit data in IP, ATM, SONET, SDH and Ethernet. Therefore, DWDM-based networks can carry different types of traffic at different speeds over an optical channel. Voice transmission, e-mail, video and multimedia data are just some examples of services which can be simultaneously transmitted in DWDM systems [20].

DWDM is a core technology in an optical transport network. The schematic is for four channels. Each optical channel occupies its own wavelength. In DWDM system, lasers with precise, stable wavelength are on the transmitter side & optical fiber that exhibits low loss and transmission performance in the relevant wavelength spectra, in addition to flat-gain optical amplifiers to boost the signal on longer spans are on the link. Photodetectors and optical demultiplexers using thin film filters or diffracting elements are on the receiver side & Optical add/drop multiplexers and optical cross-connect components are also used. The source, a solid-state laser, must provide stable light within a specific, narrow bandwidth that carries digital data modulated as an analog signal. Modern DWDM systems employ multiplexers to combine the signals. There is some inherent loss associated with multiplexing and demultiplexing. This loss is dependent on the number of channels but can be

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mitigated with optical amplifiers, which boost all the wavelengths at once without electrical conversion. The effects of crosstalk and optical signal degradation or loss must be considered in fiber-optic transmission.

Transmitters
Receivers

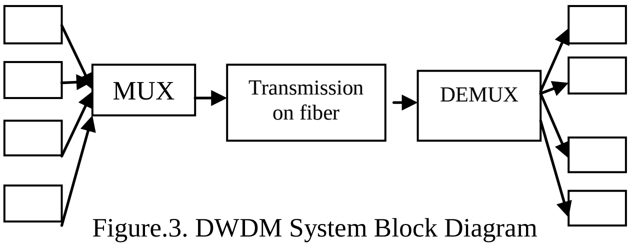

Figure.3. DWDM System Block Diagram

Controlling variables such as channel spacing, wavelength tolerance, and laser power levels can minimize these effects. The signal might need to be optically amplified over a transmission link. At the receiving end, the multiplexed signals must be separated out. The demultiplexed signal is received by a photodetector [21].

III. LITERATURE SURVEY

In [1], WDM system with four channels have been proposed and simulated with and without using EDFA. The various results were analyzed and the analysis of simulation results shows that output peak power is increased many times and optimized by using EDFA.

In paper [2], to optimize the optical amplifiers for different transmission distance and study the nonlinearities effect. The performance of single and hybrid optical amplifiers was evaluated using the output power, BER, eye height and Q factor.

In [3], EDFA each stage's pump power and mid-stage attenuation were controlled according to the power variations of the input signal channels and the optical supervisory channel, respectively. The different pump power can affect the output power base on their length of fiber.

In [4], A Hybrid Optical Amplifier with flat gain characteristics is proposed using a two stage Distributed Raman Amplifier-EDFA configuration.

In [5], the simulation results showing eye diagrams, signal strengths, BER and Q-factor at various receivers clearly demonstrate that both the configurations work satisfactorily for BER of 10-9 at 1479 nm to 1555 nm bandwidth spectrum.

In paper [6], authors introduced the performance of a 64 channel DWDM system for different modulation formats; channel Spacing; line widths of optical sources and different fiber lengths has been analyzed.

In this paper [7], a simulation of an EDFA has been studied to characterize Gain, Noise Figure of a forward pumped EDFA operating in C band as functions of Er^{+3} fiber length, injected pump power, signal input power and Er^{+3} doping density.

In this paper [8], with no Adaptive Gain Control, all the four measured channels were not able to be detected due to their high BER values. When Adaptive Gain Control is applied, half of measured channels remain undetected in terms of BER values.

The paper [9], demonstrate the 7-core Multi Core-EDFA (MC-EDFA) with low crosstalk between cores, while the further investigation into the crosstalk in Multi Core-EDFA may be required because of the complexity.

In paper [10], authors presents performance under the influence of intra-band crosstalk has been analyzed and found that the BER rate increases with the increase in the number of channels and with number of hobs.

In this paper [11], authors concluded that increase in the amplifier length results in an increase of its gain when there is a suitable pumping power in accordance with the increase of the length.

IV. THE OPTISYSTEM SOFTWARE

Based on the findings in the existing papers studied, OptiSystem software is being used that is an innovative optical communication system simulation package for the design, testing and optimization of virtually any type of optical link in the physical layer of a broad spectrum of optical networks, from analog video broadcasting systems to intercontinental backbones [13]. It offers transmission layer optical communication system design and planning from component to system level, and visually presents analysis and scenarios. Its integration with other Optiwave products and design tools of industry leading electronic design automation software all contribute to OptiSystem speeding your product to market and reducing the payback period.

A comprehensive Graphical User Interface (GUI) controls the optical component layout and net list, component models, and presentation graphics. OptiSystem allows for the design automation of virtually any type of optical link in the physical layer, and the analysis of a broad spectrum of optical networks, from Long-Haul Networks, Metropolitan Area Networks (MANs) and Local Area Networks (LANs). It includes an extensive library of sample optical design (.osd) files that can be used as templates for optical design projects or for learning and demonstration purposes. OptiSystem capabilities can be extended with the addition of user components, and can be seamlessly interact with a wide range of tools.

It represents an optical communication system as an interconnected set of blocks. Each block is simulated independently using the parameters specified by the user for that block and the signal information passed into it from other blocks. As physical signal are passed between components in a real-world communication system, "signal" data is passed between components models in the simulation. These blocks are graphically represented as icons in OptiSystem [13].

V. CONCLUSION

In this paper, a very comprehensive review of the conventional approaches and software used in the analysis of erbium doped fiber amplifier for dense wavelength division multiplexing system. The survey has been carried out related to both EDFA and DWDM that ensures that output peak power is increased many times and optimized

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by using EDFA. The performance of single and hybrid optical amplifiers was Evaluated using the output power, BER, eye height and Q factor. The different pump power can affect the output power base on their length of fiber.

It is observed that as they increase the input power, the gain variation over the bandwidth increases and a minor degradation in BER and Q factor has been observed with increase in wavelength. They analyzed the performance of 64 channel DWDM systems for different channel spacing, modulation formats and line width.

EDFA AdGC effects on an amplifier cascade performance in a DWDM optical system with a full C-band load are favorable when we just monitor OSNR, NF and GF. To improve the noise figure and the crosstalk properties in MC-EDFA, optimization of fan-in/out devices is essential as well as the optimization of the MC-EDF. The performance of optical cross connect in DWDM system under the influence of intra-band crosstalk has been analyzed & as amplifier length increases results in gain increases when there is a suitable pumping power in accordance with the length increases.

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