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SIMULATION OF PHOTONIC DEVICES – L-BAND AMPLIFIER

I. Bibac

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The two-directional characteristic feature for an L – band amplifier at 1590 nm produced by NORTEL NETWORKS is described, based on a very powerful software simulator tool - PTDS - produced by Virtual Photonics. With the help of PTDS tool it is demonstrated the advantage of using L – band amplifiers especially for long – haul terrestrial or submarine DWDM systems in which thousands of amplifiers might be needed in a single transmission link. This is due to the exceptionally feature that permit in a cascade configuration a very flat gain. It is show that L –band amplifier doesn't require a gain-flattening filter (GFF) compared to C –band amplifiers.

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1. Introduction

An optical transport network based on dense wavelength – division multiplexing DWDM technology is the next logical step in the evolution of Internet network [1]. An Optical Internet network [2] is defined as any Internet network where the network link layer connection are "dedicated" wavelengths on an Wave Division Multiplexed optical fibre directly connected to a high performance network router. The high performance network router replaces traditional ATM and SONET/SDH switching and multiplexing equipment, the essential statistical multiplexing device that controls wavelength access, switching, routing and protection. The optical amplifier is the key element that contributes to design an Optical Internet network. The design of an optical component and in particular an optical amplifier can directly and significantly affect the performance of an optical system.

To overcome the attenuation in the fibre, amplifiers are required. Only a few years ago electrical amplification was the only technology available. However optical amplification using special material such as EDF called Erbium Doped fibre Amplifier (EDFA) is now quite common on long haul systems.

In wavelength – division multiplexing (WDM) system, channels are laid one against another [3]. Due to the limited 30 –nm bandwidth of the EDFA and the desire to simultaneously transports as many channels as possible, the distance between each channel is very small and the consequence is the interchannel cross-talk, which results from a transfer of power from one channel to another. As a result, the actual DWDM system's capacity is inherently limited by the EDFA bandwidth.

EDFA bandwidth must be extended and what we need is an amplifier that dramatically increases bandwidth and allows the control – if not elimination – of crosstalk problems.

To solve this problem, Nortel Networks is developing fiber optic components for the L-band window (1560 – 1610 nm). This enables system manufacturers to more than double the bandwidth capacity of high-speed optical communications network.

2. Theory

The erbium-doped fibre amplifier contains several meters of silica glass fibre that has been doped with ions of erbium, a rare-earth metal [4]. Illuminating the fibre amplifier with a pump laser operating at a wavelength of 0.98 μm or 1.48 μm excites the erbium ions to a higher energy level.

But the new state is meta-stable and the ions spontaneously decay back to the ground state in a matter of milliseconds, meanwhile emitting photons in random directions and at random phases. This incoherent radiation constitutes additive amplifier spontaneous emission noise.

If, however, a meta-stable erbium ion is stimulated by a signal photon, it will cascade back down to the ground state, emitting a photon in precisely the same direction, phase, and wavelength as the incoming signal photon. All these coherent photons constitute gain.

The EDFA has the following advantages over optoelectronic regenerators.

- The amplifier wavelength interval corresponds to a bandwidth of about 3 THz – meaning that the fibre amplifiers can boost tens of different- wavelength signals simultaneously
- The gain of erbium-doped fibre amplifiers is very high – commercial unit at 20-30 dB
- The gain is only slightly dependent on the polarised direction of the electromagnetic wave of the incoming signal
- Erbium-doped fibre amplifiers are a very low noise. External noise figure varies from 4.5 of pre-amplifier to 5.5 of booster.

In order to extend the EDFA bandwidth the researchers at Bell Laboratories (Murray Hill, NJ) and Nippon Telegraph &Telephone (NTT-Tokyo) have constructed the standard silica erbium fibre-based dual-band fibre amplifier (DBFA) – based on two sub-band amplifiers with silica erbium fibre. The first commercial high-efficiency 1528 to 1610 nm DBFA was introduced only recently at OFC'98.

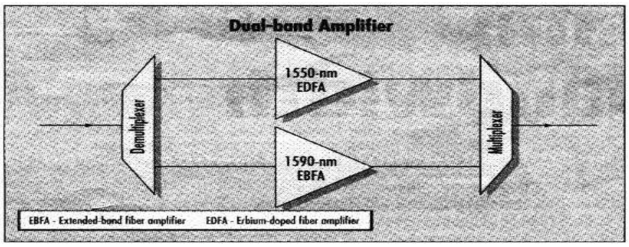

Fig. 1. The 75-nm dual-band amplifier combines a 1550 nm EDFA and 1590 nm EBFA in parallel to provide wider bandwidth.

DBFA - Dual band fibre amplifier – consist of two separate sub-band amplifiers [3]:

- C-Band Amplifier - the conventional 1550 nm *EDFA* which has an operating wavelength from 1530 nm to 1560 nm and
- L-Band Amplifier - the 1590 nm extended band fibre amplifier *EBFA* - which has an operating wavelength from 1570 nm to 1605 nm.

When the 1550 nm EDFA and 1590 nm EBFA are multiplexed/demultiplexed in a parallel circuit, they can offer a total of more than 75 nm of bandwidth – Fig. 1.

Compared with the conventional C – band amplifiers, the L-Band Amplifier features several attractive aspects:

- Flat gain as an inline amplifier

A C-band amplifier has a gain peak at 1532 nm and a dip around at 1558 nm. When cascaded C-band amplifiers for long - haul point – to - point transmission systems, the accumulated gain is much higher at 1558 nm. This will require gain - flattening techniques and the most common is passive gain flattening by filters.

In contrast, L – band amplifiers exhibit a very flat gain over more than 35 nm of bandwidth, with a better dynamic range to resist input - level variation.

- High-gain and low-noise figure

The typical noise figure over 35 nm of bandwidth is below 5.5 dB This number satisfy the pre – amplifier requirements and make L – band amplifier suitable for receiver applications.

- Slow saturation

The L-band amplifier achieves deep saturation once the input signal exceeds about –5 dBm. That means the output will remain almost constant, even though the input level is still increasing.

3. Experimental setup

3.1 Signal representations for interconecting models – L – band amplifier

The simulations [4] was done based on the PTDS (Photonic Transmission Design Suite) – software simulator produced by Virtual Photonics Inc (www.virtualphotonics.com).

Two modes of simulation exist in PDTS***: sample mode and block mode***. *Sample Mode* is used for bi-directional simulation of closely coupled components. *Block Mode* passed data as arrays of the complex envelope of the optical field, restricting bidirectionality to components spaced by more than a block length, such as optical switches separated by fibres [5].

Sample mode has a single signal representation, covering all simulated optical frequencies and assuming a single polarisation.

Block mode has both sampled and statistical signals, containing polarisation information and centre frequency, allowing a simulation to be portioned spectrally into appropriate signal representations as follows.

- A single frequency band **(SFB)** can be used to cover all data channels, or individually using multiple frequency bands **(MFB's),** each with a centre frequency and each covering one ore more channels.
- Noise Bins **(NB's)** represent broad noise spectra efficiently as a mean power spectral density within a defined frequency range. NB's are effective for the amplified spontaneous **(ASE)** in an optical amplifier.

The experimental arrangement that permit to demonstrate the two-directional propagation capability feature for a L – band amplifier at 1590 nm and also to show the spatial mapping of signal representations onto a system simulation is schematically done in Fig. 2 [6]. The transmitters produce SFB's, each with a distinct carrier frequency. When multiplexed together, the SFB's become an MFB. The pump laser adds a parameterised signal (PS), which feeds into a length of doped fibre. This produces wideband ASE in the form of NB. Noise within the sampled bands can be added to the bands or propagated separately.

Fig. 3 represent the output spectrum for an L –band amplifier where the noise bins (bars) are used to represent the ASE noise and the parameterised signals (arrows) represent the mean channel powers.

The L-band amplifier produced by NORTEL NETWORKS used has the following characteristic [4]:

- Reference frequency: 189.1 THz – correspond to 1585 nm
- Core radius: 1.8 μm
- Numerical Aperture: 0.26
- Internal Losses: 0.01 dB/m
- Dopant Density: 6×10^{24} 1/m^3
- Fluorescent Time: 10 ms
- Noise Bandwidth: -40 dB
- Noise Center Frequency: 1585 nm
- Noise Bin Spacing: 0.25THz
- Noise Dynamic: 1 dB

- Noise Threshold: -40 dB
- OSA Noise Bandwidth: 0.1nm
- Fibre length: 8m
- Pump - Laser average power: 2 mW at 1480 nm

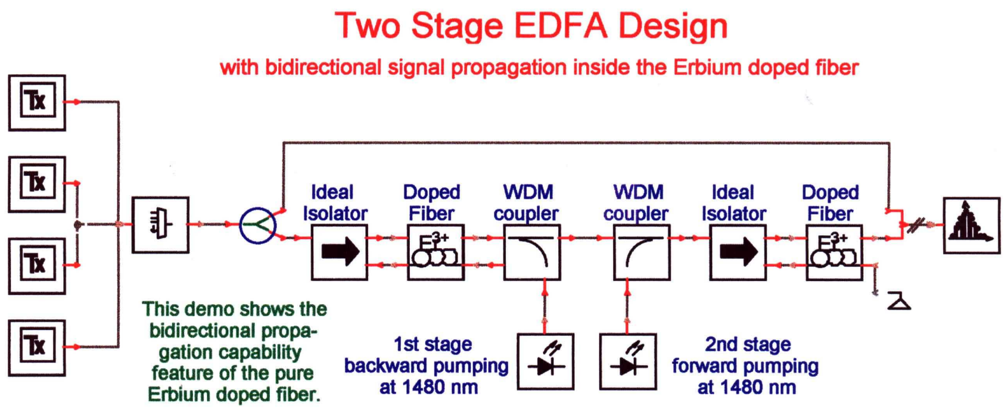

Fig. 2. The experimental arrangement to show the bi-directional propagation capability feature of the pure Erbium doped fibre (C-band Amplifier or L-Band Amplifier).

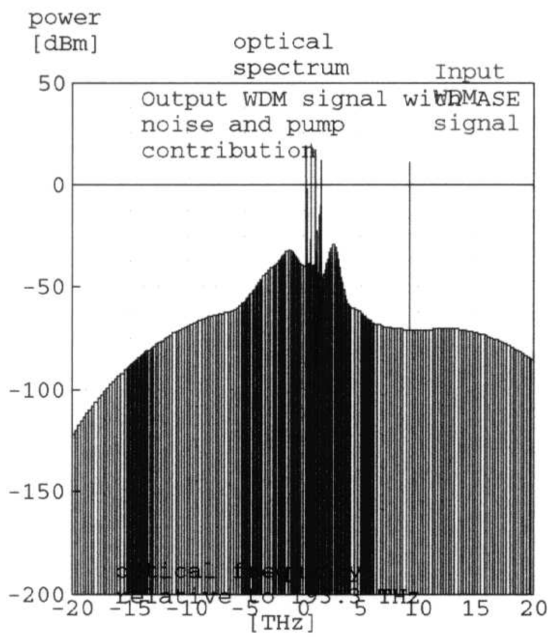

Fig. 3. Output spectrum into an L-band amplifier. The noise bins (bars) are used to represent the ASE noise, whereas parameterised signal (arrows) represent the mean channel powers.

3.2 Modelling a 100- channel WDM system using a stationary system analysis

To model optical communication systems, which are typically, point – to - point links we distinguish to type of system analysis: stationary and transient systems.

The long-term dynamics of optical systems caused by the dynamic effects (reshaping of signals in fibres and filters) should be analysed using a simulation technique that allows for a transient behaviour. An example of the transient systems analysis's the transient behaviour of an EDFA in the burst mode.

Stationary system analysis is commonly used for simulation of signal propagation in optical fibres and allows easy and exact interchange between the time and frequency domains.

An example of a stationary system analysis is a point – to – point WDM system transmits 100 channels over 10 fibre spans and EDFA's. The signal is generated in the laser array and no transients of EDFA's or other elements are considered.

Fig. 4 represent a 100 channel with 2.5 Gbps per channel, 100 GHz channel spacing 10 loops, 50 Km SMF per loop.

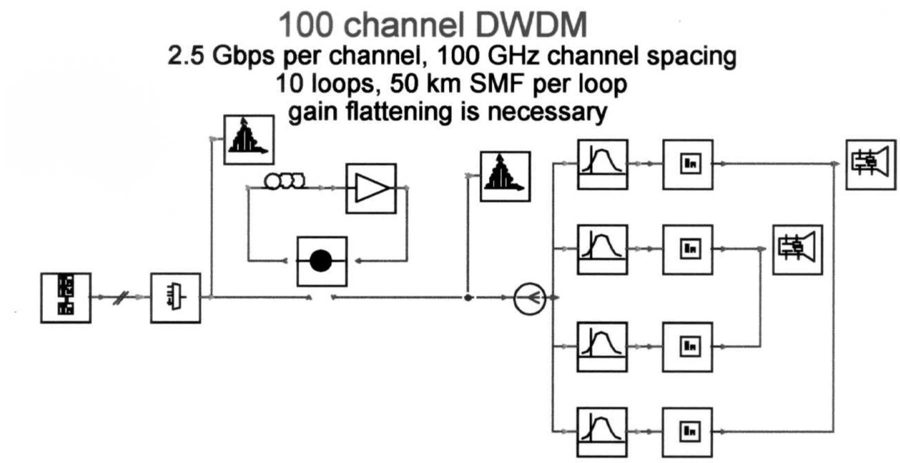

Fig. 4. 100 channel with 2.5 Gbps per channel, 100 GHz channel spacing 10 loops, 50 Km SMF per loop.

In the first case we use like amplifier a conventional C – band amplifier produced by NORTEL NETWORKS that have the following characteristics:

- Reference frequency: 193.1 THz
- Fibre length: 6 m
- Core radius: 1.5 μm
- Numerical Aperture: 0.29
- Internal Losses: 0.01 dB/m
- Dopant Density: 2×10^{24} m^{-3}
- Fluorescent Time: 10 ms
- Noise Bandwidth: -40 dB
- Noise Center Frequency: 1585 nm
- Noise Bin Spacing: 0.25 THz
- Noise Dynamic: 1 dB
- Noise Threshold: -40 dB
- OSA Noise Bandwidth: 0.1 nm
- Pump - Laser average power: 1 mW at 1480 nm

The eye diagrams – Figs. 5 and 6 for the inner channels are much better than for outer ones, thus demonstrating a necessity of gain equalisation.

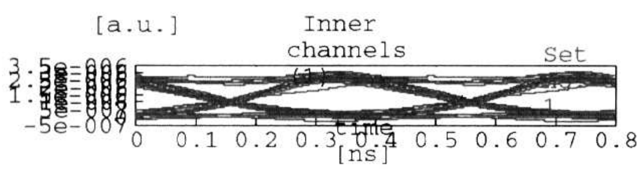

Fig. 5. Inner channels – C – band amplifier.

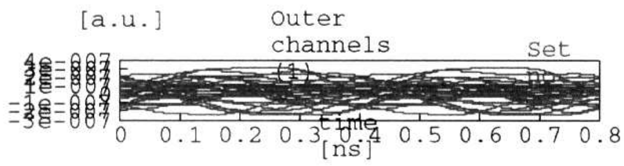

Fig. 6. Outer channels – C –band amplifier.

In the second case we use like amplifier a conventional L – band amplifier produced by NORTEL NETWORKS that have the following characteristics:

- Reference frequency: 189.1×10^{12} Hz
- Fibre length: 8m
- Core radius: 1.8 μm
- Numerical Aperture: 0.26
- Internal Losses: 0.01 dB/m
- Dopant Density: 6×10^{24} $1/m^3$
- Fluorescent Time: 10 ms
- Noise Bandwidth: -40 dB
- Noise Center Frequency: 1585 nm
- Noise Bin Spacing: 0.25×10^{12} Hz
- Noise Dynamic: 1 dB
- Noise Threshold: -40 dB
- OSA Noise Bandwidth: 0.1×10^{-9} m
- Pump - Laser average power: 2 mW at 1480 nm

The laser is a InGaAsP/InP MQW-DFB laser diode modules designed for fibre optic communication systems at 2.5 Gb/s and has the following technical characteristics:

- Optical output power 2 mW
- Operating voltage: 1.7 V
- Typical peak wavelength: 1590 nm
- Extinction ratio 10 dB
- Rise time: 0.05 ns
- Fall time: 0.10 ns

The laser diode module is produce by Sumitomo Electric Industries, Ltd.

The **SMF fibre** optic has the following technical characteristics:

- Attenuation: 0.2×10^{-3} dB/m
- Dispersion 16×10^{-6} s/m^2
- Dispersion slope: 0.08×10^{3} s/m^3
- Non-linear index: 2.6×10^{-20} m^2/W
- Core area: 80×10^{-12} m^2
- Length: 25 Km

The **photodiode - PIN** has the following technical characteristics:

- Responsivity: 1 A/W
- Thermal Noise: 3×10^{-12} $A/Hz^{-1/2}$
- Dark Current: 0 A

The eye diagrams – Figs. 7 and 8 shown that in contrast with C – band amplifier the L – band amplifier exhibit a very flat gain over more than 35 nm of bandwidth, with a better dynamic range to resist input – level variation.

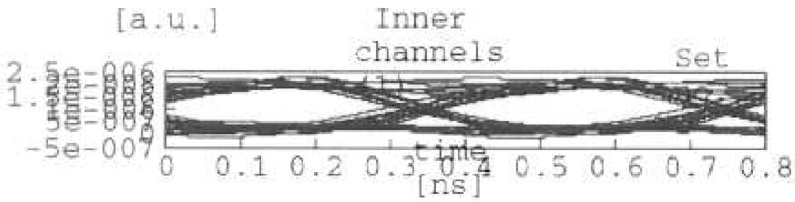

Fig. 7. Inner channels – L – band amplifier.

Fig. 8. Outer channels – L – band amplifier.

This characteristic is very attractive, especially for long haul terrestrial or submarine DWDM systems in which thousands of amplifiers might be needed in a single transmission link.

In order to obtain the same gain in case of using a L - band amplifier without using the gain flattening filters we need to do the following:

- Increase the length of the EDF fibre with 35% of in case of using C – band amplifier
- Increase of the laser average power for the wavepump laser to simple to double
- Decrease the length of SMF fibre

4. Conclusions

The advantages of the new 1590 nm L – band amplifiers are therefore obvious. Employing only standard silica fibre components and regular pump lasers, while sharing the same circuit and packaging of conventional C – band amplifier, the 1590 nm L – band amplifier is fully compatible with DWDM equipment

Due to the very flat gain over more that 35 nm of bandwidth, with a better dynamic range to resist input – level variation make possible to use L – band amplifier in the long – haul terrestrial or submarine DWDM systems.

Slow saturation provides a great opportunity to use the high – power laser transmitters that are already commercially available.

In the 1590 nm region the dispersion increases slightly – 3 ps/(km-nm) at 1590 nm, instead of 0.05 ps/(km-nm) at 1550 nm. The disadvantage that appears is very small because the dispersion is small enough to support high data rates and large enough to efficiently decrease four wave mixing.

Therefore, the L – band amplifier represents a major step in order to meet the demands of high – capacity fibre – optic transmission systems to carry voice and data traffic and support Internet activities.

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References

[1] B. Allen, J. Rouse – Cambrian Systems Corp. – Optical networking and WDM – Lightwave – pp. 47-52, August 1998.

[2] T. Wo Chung, J. Coulter, J. Fitchett, S. Mokbel, Bill St. Arnaud - Architectural and Engineering Issues for Building an Optical Internet – www.canet3.net.

[3] D. Yang – Chief scientist at AFC technologies inc, Hull, QC, Canada – Amplifiers at 1590 nm double the DWDM bandwidth – Lightwave, pp. 71-73, September 1998.

[4] A. Eli Willner – University of Southern California – Mining the optical bandwidth for a terabit per second - IEEE Spectrum, pp. 32-41, April 1997.

[5] A. Lowery, O. Lenzmann, I. Koltcanov, R. Moosburger, R. Freud, A. Richter, S. Georgi, D. Breuer, H. Hamster – "Multiple signal representation simulation of photonic devices, systems and networks" - Virtual Photonics Inc (www.virtualphotonics.com) – JSTQE Special Issue on Modeling of High Data Rate Fiber Communications Systems, Vol. 6, no. 2, March/April 2000.

[6] Photonic Transmission Design Suite – System Designer User's Manual - Virtual Photonics Inc (www.virtualphotonics.com).

[7] O. Lenzmann, I. Koltchanov, A. Lowery, D. Breuer, A. Richter – Photonic Multi-Domain Simulator – White Paper, OFC'99, San Diego, 1999.