PDG CHARACTERIZATION OF AN EDFA DEVELOPED FOR CATV APPLICATION

Meire C. Fugihara, Hypolito J. Kalinowski, Márcia Müller, José L. Fabris and Walter Arellano

Abstract - Results for the Polarization Dependent Gain (PDG) of an Erbium-Doped Fiber Amplifier, aimed to cable television distribution networks (CATV), are described. PDG measurements are done by switching the state of polarization of the launched signal between two orthogonal states, for several wavelengths and signal input powers. The obtained results show that the amplifier has very low PDG, $0.0279 \pm 0.0012\,\mathrm{dB}$.

Keywords: Erbium-Doped Fiber Amplifier, Optical Amplifier, Polarization, PDG, PHB.

Resumo - Descrevem-se resultados para o Ganho Dependente da Polarização (PDG) de um Amplificador a Fibra Dopada com Érbio (EDFA) destinado a redes de distribuição de TV a cabo (CATV). A medida do PDG foi realizada mediante chaveamento da polarização do sinal de entrada entre dois estados ortogonais, para vários comprimentos de onda e diversas potências naquele sinal. Os resultados obtidos mostram que o amplificador tem um PDG bastante reduzido, $0.0279 \pm 0.0012\,\mathrm{dB}$

Palavras-chave: Amplificador a Fibra Dopada com Érbio, Amplificador Ótico, Polarização, Ganho Dependente da Polarização (PDG), PHB.

1. INTRODUCTION

After the Erbium-Doped Fiber Amplifier (EDFA) [1], long haul optical communication systems evolved considerably in the power budget management as well as in the transmitted rate, due in large part to the use of Wavelength Division Multiplexing (WDM) techniques. Such evolution spread also to other fiber applications, like optical data networks or distribution networks with high transmission rate demand. However, some problems that were not significant for an isolated device now must be taken in account due to amplifier's cascading along the optical link. One of such problems is related to amplifier's gain dependence with the state of polarization (SOP) of the pump or signal fields.

Ideally, in the weakly guiding approximation used to solve the propagation equation, the fundamental mode in single mode optical fibers shall not show dependence with polarization, due to the guide symmetry. The SOP of the light should be maintained along the fiber. However, it has been seen that this does not occur and the guided light SOP evolves along the fiber [2], as the fiber presents local fluctuations in their material properties. Thermo-mechanical processes during the fiber drawing result in a non perfect homogeneous material, and they induce regions with different densities (refractive index) that lead to interfaces between microscopic material clusters in the glass. As those regions are randomly distributed, light suffers partial scattering and polarization changes during propagation [3, 4]. Geometry and dimension fluctuations, as well as bends or devices inserted along the link, also contribute to change the SOP.

Studies on the polarization effects in optical communication systems using EDFA started by the end of the 80's [5–9]. Such effects are due to Polarization Dependent Loss (PDL) [6–8], Polarization Dependent Gain (PDG) [6–9] and Polarization Hole Burning (PHB) [10–13]. PDL is due to the polarization of the pump signal, and it leads to degradation of the signal to noise ratio at the receiver end of the amplified optical system. PDG has two components, one results from the polarization selective excitation of the dopant ions (Er^{3+}) by the pump light, while the other (PHB) originates from the polarization selective de-excitation of the dopant ions by the saturating signal field. Pump dependent PDG, as well as PDL, are stochastically accumulated along the optical link [14, 15], as the principal birefringence axes for each domain are independent and randomly oriented. On the other hand, PHB effects, due to signal polarization, are deterministic, since the gain is maximum when the polarization is orthogonal and minimum when it is parallel to pump polarization.

Several authors studied the dependence of the EDFA performance with the SOP in optical communication systems [5–8], [15–17]; one of first reports gave, for an optical link of 3100 km length with 69 amplifiers, polarization dependent losses of $\approx 0.07\,\mathrm{dB}$ [7]. Other authors also found performance degradation for optically amplified systems due to PDG and PDL [8,16,17], and they studied techniques to avoid or compensate that degradation [18]. The use of EDFA in optical communication systems increased the number and variety of optical components along the link. As example, in a transoceanic system the signal goes through tens of optical amplifiers, each one with several components (splices, fibers, isolators, WDM, couplers, and others). Polarization effects, previously small, now might become considerable due to the cascading of each amplifier module, leading to the degradation of signal to noise ratio in the output end. A similar process occurs in distribution optical networks, e.g., cable television (CATV), where the number of amplifiers can be large to compensate signal branching and distribution losses. Optical components in the network nodes also contribute to increase the polarization scattering, with a consequent decrease in the

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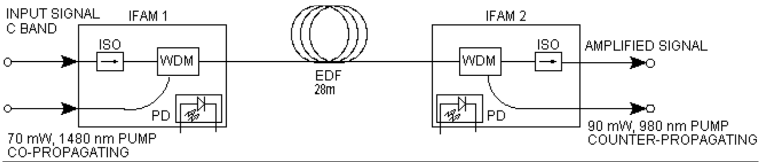

Figure 1. Schematics of the used EDFA, after [19].

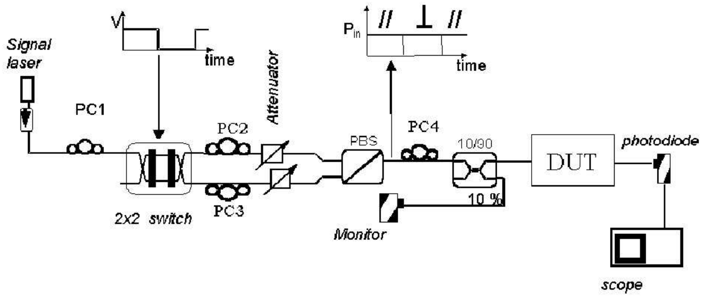

Figure 2. Schematic of the experimental setup used to characterize the PDG of an optical amplifier, from [21].

signal to noise ratio.

In this work we present results for the PDG characterization of an optical amplifier, previously developed for CATV applications [19, 20]. Simulations and measurements of the spectral gain, saturation [19], as well as simulations for the carrier to noise ratio (CNR) and composite second order (CSO) distortion in a typical NTSC CATV link [20] were already published. The schematic of the amplifier can be seen in Fig. 1. It can have counter propagating pumping by a 980 nm laser or bidirectional pumping employing the previous device added by a secondary 1480 nm pump laser. Integrated Fiber Amplifier Modules (IFAM) are used to couple the pump laser's light to the Erbium-Doped fiber and to isolate the lasers from reflections or spurious signals. The IFAM modules also have integrated photodetectors to measure the signal. The results presented in the next sections are for the EDFA with counter propagating pump at 980 nm.

2. MEASUREMENTS AND DISCUSSION

Measurements were made by using an experimental setup, shown in Fig. 2, developed at the 'Gleb Wataghin' Physics Institute (State University of Campinas - UNICAMP) by the group of Fragnito [21]. The setup allows to launch into the device under test a laser signal with two alternating orthogonal polarization states, with the same optical power.

An electro-optic, 2x2, switch is used to divide the laser beam in two independent signals, which are complementary and show an step function amplitude modulation. Polarization controllers (PC1, PC2 and PC3, see Fig.2) are used to set the SOP at the input of the polarization beam splitter (PBS), while optical attenuators serve to adjust the optical power in each arm to the same value. PC4 serves to control the SOP of both beams after they are recombined in the same fiber. In this way the signal at the output of the PBS has a polarization alternating periodically between two orthogonal states, as shown in the detail graph on that Figure. A $10/90$ optical coupler is used to remove a control signal, in order to compensate for signal changes due to thermal and vibrational variations during the measurement. The main output power is directed to the device under test (DUT) and, after passing through it, is detected and displayed in an oscilloscope. In this way it is possible to observe and record directly the changes in the amplifier's gain when the signal polarization alternates.

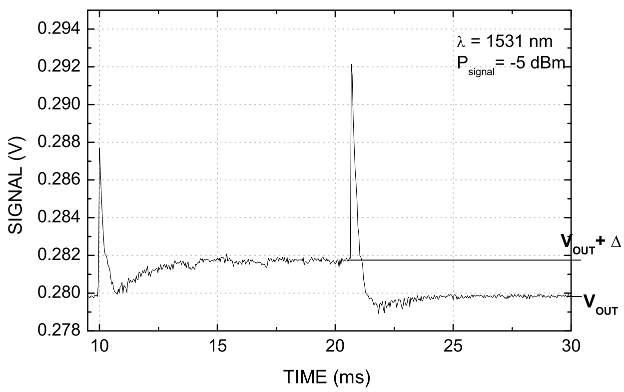

Figure 3. Experimental signal recorded over one polarization switching period during the determination of the PDG.

The system above described is used to characterize the EDFA, and a typical result is displayed in the graph on Fig. 3, with the signal wavelength set to 1531 nm and input power of -5 dBm. That result shows as the gain changes as the input signal polarization alternates; the resulting voltage on the scope screen is clearly seen to jump between high and low figures as the number of periods increase. The limits and dispersion of the signal plateau at the end of each alternating half cycle show that the EDFA has good gain stability, even after several successive changes of the polarization. This stability is a good indication that the developed amplifier can be used to CATV without too much degradation due to polarization fluctuations if a single polarization control can be applied.

Calculations of the PDG are done using the limits of the signal plateau recorded in detail from the oscilloscope, see Fig. 3, for each of the polarization alternating half period. Being V_{out} the signal output level for one of the input polarization states and $V_{\text{out}} + \Delta$ the corresponding output for the other state, the polarization dependent gain, ζ, is given by [21]

$$\zeta = 10 \log \frac{V_{\text{out}} + \Delta}{V_{\text{out}}}. \quad (1)$$

As long term stability of the observed signal is very good, three periods of alternating polarization for the input signal are chosen to determine the PDG, beginning at the time of 10 ms, 30 ms and 50 ms, respectively. The graph of Fig. 4 shows in detail the sampled voltage at the end of the first plateau presented in Fig. 3. The PDG is directly obtained from the recorded signal voltage on the scope, so that the dispersion of PDG measurements is also related to the dispersion of the sampled signal voltage. The average value for this signal is $< V >= 0.28172$ V, with standard deviation $< \delta V^2 >^{1/2}= 0.00010$ V in the interval from 10 ms to 20 ms. Table 1 sumarizes the data also for the other two intervals. The standard deviation figures are very small when compared with the mean values and they warrant that the PDG results will have enough accuracy to characterize the amplifier, irrespective of the adopted mean value (chosen plateau) used in the calculation. Averaging the voltage signal over the three mentioned intervals and calculating the corresponding standard error results in $< V >= 0.28170 \pm 0.00001$ V. The corresponding low signal mean values for each period are presented in Table 2, with an average value of $< V >= 0.27982 \pm 0.00001$ V.

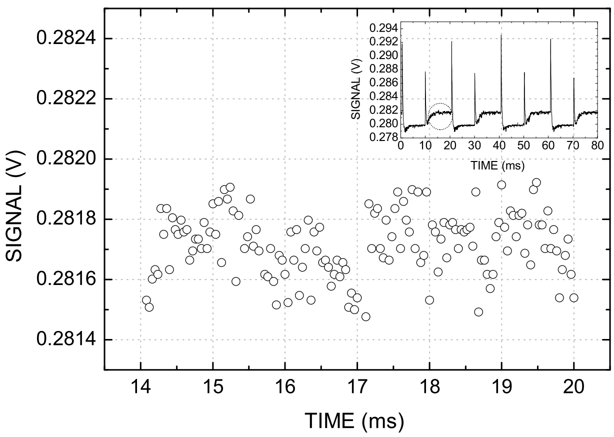

Figure 4. Experimental sampling for one of the plateau shown in Fig. 3, the insert shows the observed signal, with the circle marking the sampled data interval, from 10 ms to 20 ms.

t (ms)	$< V >$ (V)	$< V^2 >^{1/2}$ (V)
$10 - 20$	0.28172	0.00010
$30 - 40$	0.28170	0.00012
$50 - 60$	0.28170	0.00013

Table 1. Mean values and standard deviation for the sampled "high" signal.

t (ms)	$< V >$ (V)	$< V^2 >^{1/2}$ (V)
$0 - 10$	0.27980	0.00011
$20 - 30$	0.27982	0.00008
$40 - 50$	0.27982	0.00009
$60 - 70$	0.27982	0.00009

Table 2. Mean values and standard deviation for the sampled "low" signal.

Fig. 3 shows one of the gain cycles of the amplifier, for a signal wave with specific wavelength and input power. Equation (1) is used to calculate the PDG with the obtained average values of the sampled voltage, for each wavelength in the experimental range (1531 nm to 1562 nm) and each launched power (-16 dBm to -2 dBm). The experiments were carried changing independently each of those parameters. For the first set of measurements the power was kept constant at -5 dBm while the wavelength changed. During the second set of measurements the wavelength was fixed at 1532 nm and the power changed by 2 dB steps. Figures 5 and 6 show the results obtained in such measurements. The details in the insert on each graphs help to show the low dispersion of the calculated PDG values for the amplifier under test.

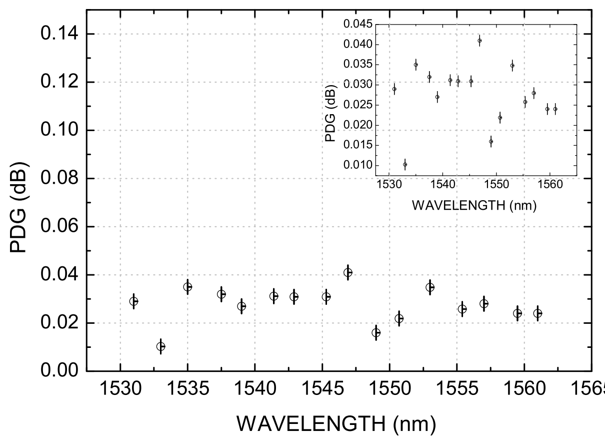

Figure 5. Obtained values for the PDG of the EDFA under study, as a function of the input signal wavelength. Input power -5 dBm. The insert shows the low standard deviation.

The mean PDG value, $< \zeta >$, is calculated for each one of the above mentioned set of experiments. For the experiments in which the power was kept constant and the wavelength scanned, $< \zeta >= 0.0287$ dB with standard deviation $<\delta\zeta^2>^{1/2}= 0.0061$ dB and standard error of $\pm 0.0016\,(dB)$. When the power was changed, the average points to $<\zeta> =$

$0.0270\,\text{dB}$ with standard deviation $< \delta\zeta^2 >^{1/2} = 0.0044\,\text{dB}$ (standard error $\pm 0.0017\,(dB)$. Those data show that the PDG of the tested amplifier is stable over a large excursion of the launched power or signal wavelength. The range of each of those last two parameters is adequate to the intended commercial use of that EDFA. The stability of the PDG also implies that the apparatus can have a simplified gain control mechanism to account effects of the signal polarization, as the signal SOP is the only parameter that has to be controlled at the amplifier's input.

3. CONCLUSION

The results obtained in this work show that the developed EDFA has, for a broad range of wavelength or input power, a small polarization dependent gain of only $\zeta = 0.0279 \pm 0.0012\,\text{dB}$, which is considered a low PDG for optical amplifiers [21]. As the pump parameters (pump laser polarization, wavelength, pump power) are not changed during the experiment, the PDL had a constant value, and it is possible to state that the variation in the measured PDG shall be assigned to PHB effects, being dependent on the signal characteristics.

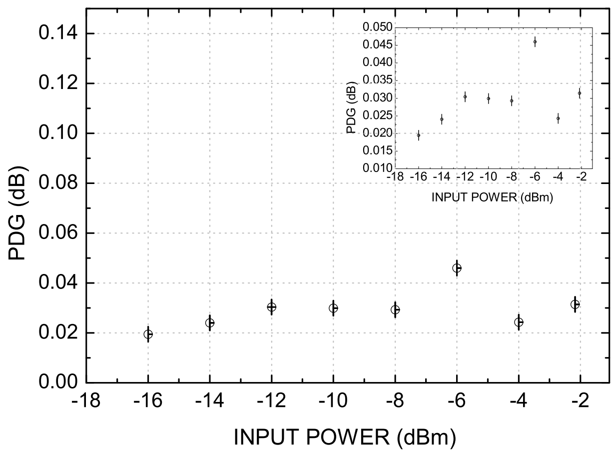

Figure 6. Measured PDG dependence with the input signal power, $\lambda_{\text{signal}} = 1532\,\text{nm}$. The insert highlights the low dispersion observed.

However, it is not possible to separate the PDL values from the measured PDG because there are also PDL effects due to components in the optical link, and because PDG also has contributions originated from the pump laser power. Even if it is not possible to separately identify each component in the total PDG, the mean obtained value is low enough to guarantee that the studied EDFA can be used in optical systems without significant degradation due to signal polarization. That value is, in fact, well below published results obtained for other EDFA [22].

It is also possible to state, from the results shown in Figs. 3 and 4, that the deterministic component of the PDG is constant. This statement originates from observing the stability on the average recorded signal at each plateau, after several changes in the polarization. Such observation is compatible with a stable PHB. The low dispersion in the sampled signal, for each plateau, also implies that the stochastic component of the sampled signal is very low, as the changes in the significant figures only occurs after the fifth digit. This allows the assignment of well behaved stochastic PDG components both to signal and pump, without severe influence in the signal polarization PDG.

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