Journal of the Optical Society of Korea, Vol. 10, No. 4, December 2006, pp. 174-177

A Novel Technique to Minimize Gain-Transient Time of WDM signals in EDFA

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(Received December 4, 2006 : revised December 14, 2006)

We propose a new technique to minimize gain-transient time of wavelength-division-multiplexing (WDM) signals in erbium-doped fiber amplifiers (EDFA) in channel add/drop networks. We have dramatically reduced the gain-transient time to less than 3 μsec by applying, for the first time to our knowledge, a disturbance observer with a proportional/integral/differential (PID) controller to the control of EDFA gain. The 3 μsec gain-transient time is the fastest one ever reported and it is approximately less than 1.5% of 200 μsec gain-transient time of commercially available EDFAs for WDM networks. We have demonstrated the superiority of the new technique by performing the simulation with a numerical modeling software package such as the Optsim™.

OCIS codes : 060.2320

I. INTRODUCTION

In a wavelength-division-multiplexing (WDM) network with erbium-doped fiber amplifiers (EDFAs), the signal level of each WDM signal fluctuates after EDFA as the number of WDM signals to EDFA changes due to channel add/drops or active rearrangement of WDM networks. Therefore, it is quite indispensible to keep the signal levels unchanged after EDFAs so that the receiver to detect the arrived signal lacks gain-related errors.

When the number of signals to EDFA varies, the amplifier gain for each signal also changes due to cross gain saturation effect in the EDFA [1]. So, our goal for an EDFA gain control in a WDM network is to find a novel method of maintaining the signal level not to be affected by the change of number of WDM signals to EDFA. Several methods have been reported to solve signal level fluctuation problem in EDFA. Basically, there are two methods: an all-optical method and an electrical method. The former uses EDFA output as a feedback signal in an optical feedback control loop [2]. It seems to be an ideal method since it involves no electrical signal which may degrade the speed of the whole system, however, for this method to operate properly, the frequency of channel add/drop should be less than that of the relaxation oscillation of the EDFA, which leaves not much room for system specifications. The other one controls the pump laser output electrically according to the EDFA output signal level [3]. This is a generally accepted method in industry since it is simpler, cheaper and more robusr. However, the main drawback of this scheme is that it generates big dips & spikes in gain in the process of gain recovery or gain flattening. The faster the control proceeds, the less the intensity of dips & spikes becomes. Therefore, one of the main focus in developing gain controllable EDFA for WDM networks is on how fast the control can be accomplished. The fastest time of gain control, i.e. the shortest gain-transient time in commercially available EDFA in these days is more or less 200 μsec. In this paper, we propose a novel technique which minimizes the gain-transient time to less than 3 μsec.

In our method, we employ a novel control scheme generally accepted in the field of control but not so much familiar in the field of optical communication.

We apply, for the first time to our knowledge, a disturbance observer technique [4,5] with a proportional/integral/differntial (PID) controller to the control of EDFA gain in WDM add/drop networks. To prove the opration and the superiority of the new scheme, we first have made an EDFA gain control module by modeling EDFA and disturbance observer. The module was implemented by MATLAB. Next, we applied this gain control module to a numerical optical communication software package such as the Optsim[TM] 4.0.2 to get more accurate simulation results. We have set up not only various parameters of disturbance observer and PID controller for optimum operation but also many characteristic parameters in Optsim[TM] to make the experimental environment as close as possible to the real situation.

II. PRINCIPLE OF OPERATION

The schematic diagram of the system is shown in Fig. 1. To minimize the transient-timed, we have derived 3-level EDFA model. We consider the random add/drop process as a disturbance ($d(t)$ in Fig. 1), and make the pump laser be prepared to this disturbance ($d(t)$ in Fig. 1) in advance so that the dips & spikes become minimized when the actual control takes place. The $d(t)$ is defined by Eq. (1).

$$d(t) \equiv -e^{G_0(t)} P_0^{in}(t) + \sum_{k=1}^{N} P_k^{in}[1 - e^{G_k(t)}] \quad (1)$$

Where P_0^{in} and P_k^{in} are pump power and channel power, respectively, G_0 and G_k are gain.

In Fig. 1, transfer function $P(s)$ represents nominal EDFA plant model with no disturbance and $Q(s)$ is a filter which makes the characterisitics of transfer function of whole disturbance observer the same as low-pass filter. $G_k(t)$ is the gain with a disturbance, i.e. the channel variation, $\hat{G}_k(t)$ is the gain without any disturbance. Eq. (2-5) describe the functions $P(s)$, $Q(s)$, $G_k(s)$. In this paper, we do not explain the paramters of the equations and do not derive the equations because these are well-known in the EDFA and the control theory.

$$P(s) \equiv \frac{G_k(s)}{\{P_0^{in}(s) + d(s)\}} = \frac{B_k}{s + 1/\tau} \quad (2)$$

$$Q(s) = \frac{\omega_n^2 (s + 1/\tau)}{B_k (s^2 + 2\zeta\omega_n s + \omega_n^2)} \quad (3)$$

$$G_k(s) = \frac{B_k (P_0^{in}(s) + d(s))}{s + 1/\tau} \quad (4)$$

The disturbance observer obtains the difference between $G_k(t)$ and $\hat{G}_k(t)$, and the filter $Q(s)$ produces $\hat{d}(t)$ from the difference and $\hat{d}(t)$ information is added to the pump laser driver so that EDFA becomes able to eliminate the effect of disturbance on the gain. PID controller is used together with the disturbance observer to control the gain far more accurately and to speed up the control process. The major gain control due to input channel variations is performed at the disturbance observer first, and the fine tuning of gain control is accomplished at the PID controller. If we perform the gain control with PID controller only specially under the situation of large amount of gain change, it takes a lot of time to get the optimum result since PID control process requires tremendous number of feedback loopings. Since the disturbance observer eliminates most of the gain variation in advance, PID controller just needs to do some kind of final touching to get the exact result. $\bar{G}_k(t)$ in Fig. 1 represents the desired gain.

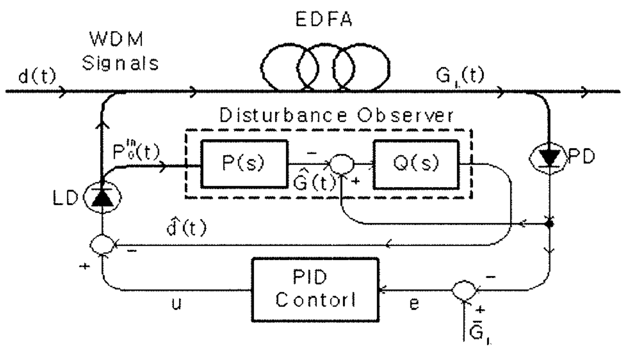


FIG. 1. Disturbance observer with PID controller for EDFA gain control. Thick-line: optical signal, thin-line: electrical signal.

III. SIMULATIONS AND RESULTS

We have proved the operation principle of the proposed system by using the well-known commercially available numerical simulator, Optsim[TM]. Fig. 2 shows the experimental setup for two channel WDM system.

EDFA pump-power control- module in the setup was implemented by MATLAB according to three-level EDFA modeling scheme. We have solved the interfacing problems between EDFA pump-power control-module made by MATLAB and the simulator Optsim[TM]. The major parameter values we have used in the experiment are shown in Table 1.

We have performed several experiments by changing the power of laser diodes (LDs). Fig 3 (a) and (b) show the power fluctuations when channel add/drop occurs when the powers of laser are 0.3 mW and 3.0 mW, respectively. Fig. 3 (c) shows the result of gain-transient

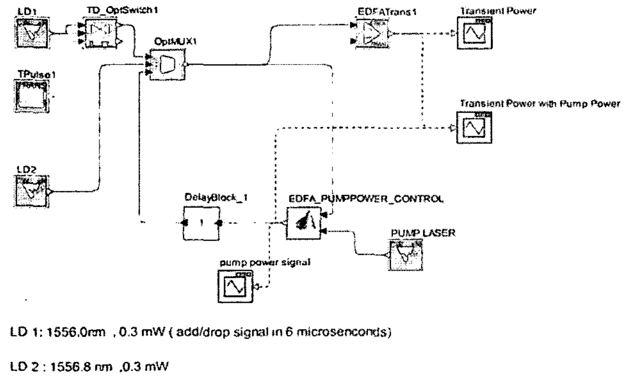


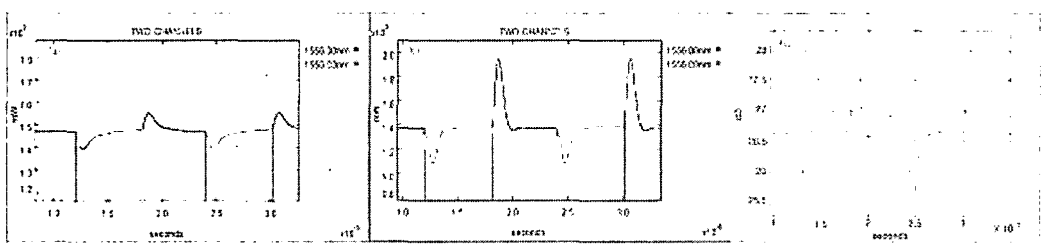
FIG. 2. Experimental setup for gain control of EDFA in two channel WDM system by Optsim^{TM}. EDFA_PUMPPOWER_CONTROL module has successfully been interfaced with Optsim^{TM}.

TABLE 1. Summary of optical parameters for experiment.

Parameter	Value
LD1 frequency	1556.0 nm
LD1 Power	3 mW or 0.3 mW
LD2 frequency	1556.8 nm
LD2 Power	3 mW or 0.3 mW
TPulse	0.16 kHz
EDFA length	35 m
metastable_lifetime	10.5 ms
Pump power frequency	980.0 nm

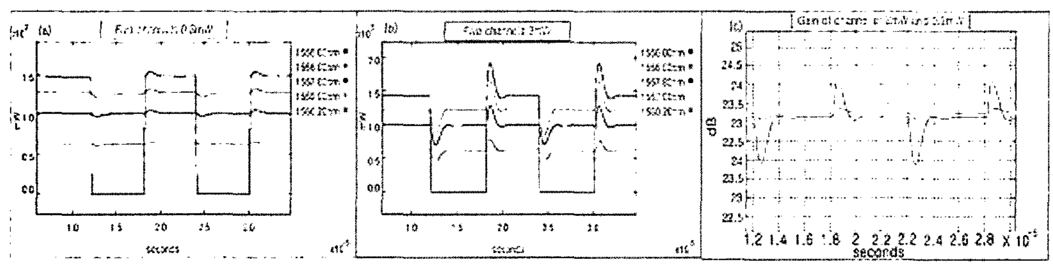
process of one channel (λ = 1556.0 nm) when the other channel (λ = 1556.8 nm) is being added or dropped in every 6 μsec. For the low LD-power, the dips and spikes in gain are small and less than 3 μsec gain-transient time has been obtained. For the high LD-power case, even if the dips and spikes are much bigger than for the low LD-power case, the gain of EDFA also has been recovered to its original value within 3 μsec. We have performed various kinds of experiments by not only changing the number of WDM channels to EDFA but also varying the number of add/drop channels.

Fig. 4 shows the results when the number of WDM channels are five and the number of add/drop channel is one. The time for gain recovery in this case also is less than 3 μsec. For low LD-power case, when four channels out of five are added or droped, it is observed the amount of gain-transient time was less than 3 μsec, however, for high LD-power (3 mW) case, the gain-transient time has been increased to 15 μsec. It is because when the total amount of power variation becomes too big, the degree of accuracy of disturbance observer reaches to the limit, and as a result of that, PID controller has to do more job, which leads to more gain-transient time. However, fortunately, high LD-power situation never happens in real EDFA-installed WDM system. In general, the amount of optical signal power to EDFA in the system is much less than -5 dBm. We just applied 3 mW LD-power to EDFA to



(a) (b) (c)

FIG. 3. Power fluctuations of WDM channels due to channel add/drops (a) when the power of laser diode is 0.3 mW, and (b) when the power of laser diode is 3.0 mW. (c) Less than 3 μsec gain-transient time was obtained for both cases of (a) and (b).



(a) (b) (c)

FIG. 4. Power fluctuations of WDM channels due to channel add/drops (a) when the power of laser diode is 0.3 mW, and (b) when the power of laser diode is 3.0 mW. (c) Less than 3 μsec gain-transient time was obtained for both cases of (a) and (b).

verify system peformance and to check its limt. Even under extreme situation, the system works very well with reasonable gain recovery time.

IV. CONCLUSION

In this paper, we have introduced a novel technique to minimize gain-transient time of WDM signals in EDFA in channel add/drop networks. The newly proposed gain controller is composed of a disturbance observer and a PID controller. We have applied a disturbance observer to detect and compensate the gain variation due to channel add/drops. While the major compensation of gain is performed by the disturbance observer, the fine control process for exact gain recovery is done by PID controller. The proposed gain control algorithm for EDFA was implemented by MATLAB and the performance has been verified by various kinds of experiments based on commercially available numerical simulator Optsim^{TM}. Simulation results show that the new technique decreases the amount of gain-transient time up to less than 3 μsec in most of the cases. This is the fastest transient time ever reported so far.

ACKNOWLEDGMENT

This work was supported by grant No. R01-2006-000-10277-0 from the Basic Research Program of the Korea Science & Engineering Foundation.

This research was supported by Hallym University Research Fund.

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