



A Novel Technique to minimize Gain-Transient Time of cascaded EDFA using Fuzzy Logic-Controller

Nimisha Bhardwaj, Dr. Neena Gupta
Department of Electronics and Electrical Communication
PEC University of Technology
Sector-12, Chandigarh
INDIA

Abstract: In this paper we propose a new method to minimize Gain-Transient time of WDM signals in cascaded Erbium-Doped fiber amplifier (EDFA) in channel add/drop networks. For the suppression of transients we employ electronic feedback gain control using Fuzzy-Logic controller. Gain-Transients can be drastically reduced using this technique. The new technique is demonstrated using Simulink in MATLAB. The simulations are performed for various fiber parameters.

Keywords: Erbium-doped fiber amplifier (EDFA); Fuzzy Logic Controller; gain transients; Pump power; wavelength-division-multiplexing (WDM).

I. Introduction

The Optical signal power fluctuations at the input of erbium doped fiber amplifiers (EDFAs) can result in amplifier gain variations, especially in saturated amplifiers. In WDM networks, these fluctuations can be severe as the number of channels may vary with time, making the gain dependent on the transmitted channel number. Keeping the signal powers to a constant value is more important when the signals are amplified through EDFAs. At the EDFA, the change of the number of signals causes the change of the amplifier gain of each signal due to the cross gain saturation effect [1,2]. Therefore, there are fluctuations of power level in each channel which results in the gain-related error at the receivers. The main goal of research these days in this area is to study, design, characterize, and propose different approaches for automatic gain control in EDFAs, based on either all-optical, electronic or hybrid techniques.

The all-optical method seems to be an ideal method because there is no need of conversion of optical signal to electrical signal and vice-versa for the amplification purpose. But this method has a disadvantage that the frequency of channel add/drop should be less than that of the relaxation oscillation frequency of EDFA, which is several hundred Hz. The electronic method controls the pump laser output electrically according to EDFA output signal level [3]. This method is generally used in the industry due to its simple, cheap and robust design. The drawback of this scheme is generation of big dips and spikes in the process of gain recovery. Therefore to minimize these dips and spikes the gain control process should be very fast. In this paper we propose a design to minimize gain-transients using Fuzzy-logic controller. With this design the gain-transients are reduced to a great extent.

II. Working Principle

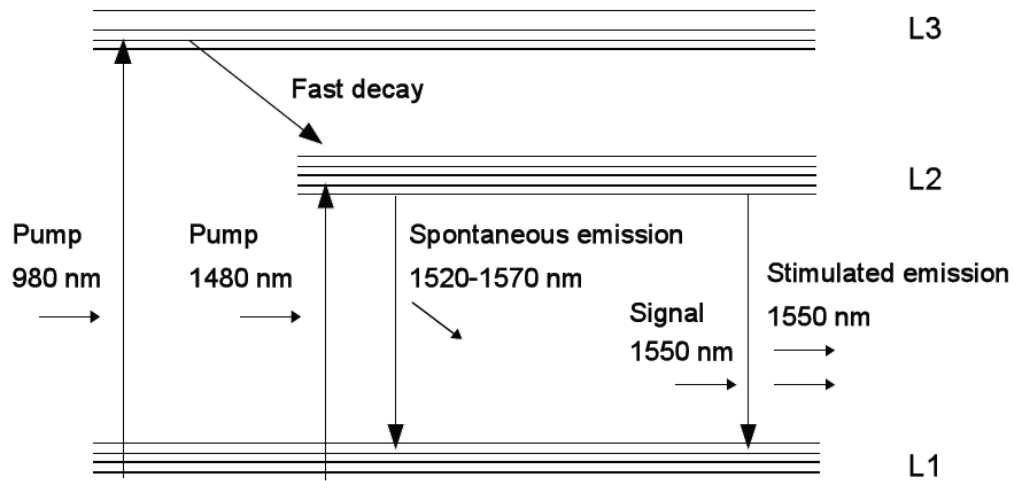
In order to design the EDFA gain controller to minimize the gain-transient time, three level model of EDFA is used [4]. In order to excite the Erbium-ions, we send a beam of light, which we call the *pump*, into the fiber. If the pump is at wavelength 980 nm, Erbium will rise from the ground state L1 to the higher L3, as illustrated in Figure 1. However, the ions will rapidly decay to energy level L2 without producing photons. The lifetime in L3 is approximately 1 μ s. Pumping with 1480 nm light will excite the ions directly to state L2. Relaxation from L2 to L1 will occur after approximately 10 ms, producing photons in the wavelength band 1520-1570 nm. This is called *spontaneous emission*. If we send a data signal with a wavelength between 1520 and 1570 nm into the fiber, there are three possible outcomes for the signal photon:

1. It can excite an Erbium ion from state L1 to a higher state and become annihilated in the process. The result is spontaneous emission when the ion subsequently decays to the ground state.
2. It can stimulate an ion at state L2 to decay to L1, producing another photon at the same wavelength and with the same direction of propagation as the signal photon. The new photon can in turn stimulate more L2-L1 transitions along the fiber. Thus, the signal is amplified.
3. It can propagate unaffected through the fiber.

Spontaneous emission has no correlation with the signal, but is distributed over the entire bandwidth of the L2-L1 transition and can travel in backward as well as forward propagation direction. Hence, it is noise. Obviously, outcome 2 is the desired behaviour of an amplifier and can be achieved by pumping the fiber until *population*

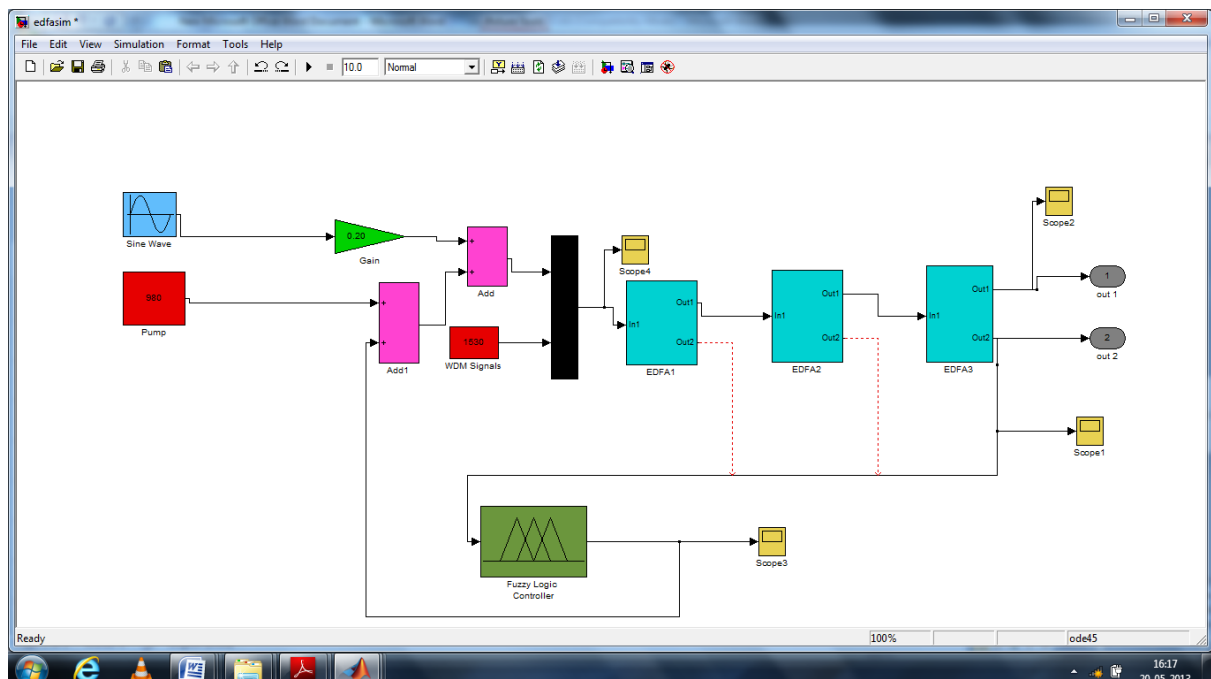
inversion occurs: when the number of ions in state L2 exceeds the number of ions in the ground state, the probability of outcome 2 is higher than that of 1 and 3 [5].

Figure 1 Energy levels of EDFA.



The SIMULINK model of the system is shown in Fig. 2. For our purpose we are using 980nm pump. Number of WDM signals used is two in this case. The out1 represents EDFA loss and out2 represents the Gain of EDFA. Here we are using cascaded stages of EDFAs. The Gain transients of EDFA is controlled with the help of a Fuzzy Logic Controller.

Figure 2 Experimental setup for EDFA gain control using Fuzzy Logic Controller in SIMULINK



III. Fuzzy Logic Controller

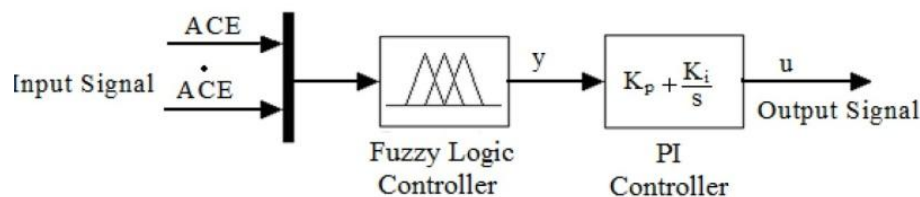
The inherent characteristics of the channel add/drop , complexity and multi-variable conditions of the EDFA system limits the conventional control methods giving satisfactory solutions. Artificial intelligence based gain

scheduling is an alternative technique that can be used in designing controllers for EDFA based systems. Fuzzy system transforms a human knowledge into mathematical formula. Fuzzy set theory and fuzzy logic establish the rules of a nonlinear mapping. Fuzzy control is based on a logical system called fuzzy logic which is much closer in spirit to human thinking and natural language than classical logical systems. Nowadays fuzzy logic is used in almost all sectors of industry and science. One of them is automatic generation control. The main goal of AGC is to protect the balance between production and consumption. Control algorithms based on fuzzy logic have been implemented in many processes[6][8]. The application of such control techniques has been motivated by the following reasons[7]:

- 1) Improved robustness over the conventional linear control algorithms;
- 2) Simplified control design for difficult system models;
- 3) simplified implementation

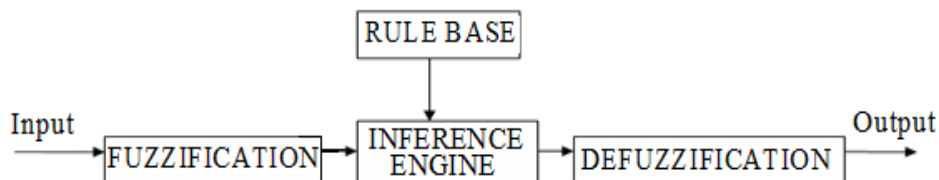
The application of fuzzy logic control techniques appears to be most suitable one whenever a well-defined control objective cannot be specified, the system to be controlled is a complex one, or its exact mathematical model is not available. Recent research indicates that more emphasis has been placed on the combined usage of fuzzy systems and neural networks [6]-[10]. The fuzzy logic controller designed can be of the form shown in Fig. 6[6].

Figure 3 Fuzzy Logic Controller



The fuzzy logic controller is comprised of four main components [6]: the fuzzification, the inference engine, the rule base, and the defuzzification, as shown in Fig. 4.

Figure 4 Components of Fuzzy Logic Controller [11]



The fuzzifier transforms the numeric/crisp value into fuzzy sets; therefore this operation is called fuzzification. The main component of the fuzzy logic controller is the inference engine, which performs all logic manipulations in a fuzzy logic controller. The rule base consists of membership functions and control rules. Lastly, the results of the inference process is an output represented by a fuzzy set, however, the output of the fuzzy logic controller should be a numeric/crisp value. Therefore, fuzzy set is transformed into a numeric value by using the defuzzifier. This operation is called defuzzification. The control signal is given by[6][8]

$$u(t) = -K_p y + K_i \int y \, dt \quad \dots\dots\dots(i)$$

K_p and K_i are the proportional and the integral gains respectively and taken equal to one.

IV. Simulations and Results

We have proved the operation principle of the proposed system by using well-known commercially available numerical simulator, SIMULINK. Fig. 2 shows the experimental setup for two channel WDM system. The major EDFA parameter values we have used in the experiment are shown in Table I.

Table I Shows the Summary of EDFA parameters used for experiment

Symbol	Description	Value	Dimension
N_2	Total erbium ions in excited state	Variable	
T	Spontaneous emission	10.5	ms
L	Length of erbium-doped fiber	Variable (15 here)	m
R	Radius of fiber core	1.2×10^{-6}	m
A	Area of fiber core	πr^2	m^2
P	Density of erbium ions	6.3×10^{24}	m^{-3}
α_p	Pump absorption coefficient	3.31	dB/m
β_p	Pump emission coefficient	0	dB/m
α_s	Signal absorption coefficient	Varies with λ	dB/m
β_s	Signal emission coefficient	Varies with λ	dB/m
λ_p	Pump wavelength	980	nm
λ_s	Signal wavelength	1520-1570	nm

We have performed experiments initially without using Fuzzy Logic Controller and after that with using Fuzzy Logic Controller. Fig 5 shows the power fluctuations when channel add/drop occurs and also the noise when the power of laser is 18dBm. 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. Here we are using cascaded EDFAs in the system. Fig. 6 shows the results when the Fuzzy Logic Controller is used in the system. The simulation results shows that the transients in gain and noise are removed completely.

Figure 5 Power fluctuations of WDM channels due to channel add/drops without Fuzzy Logic Controller

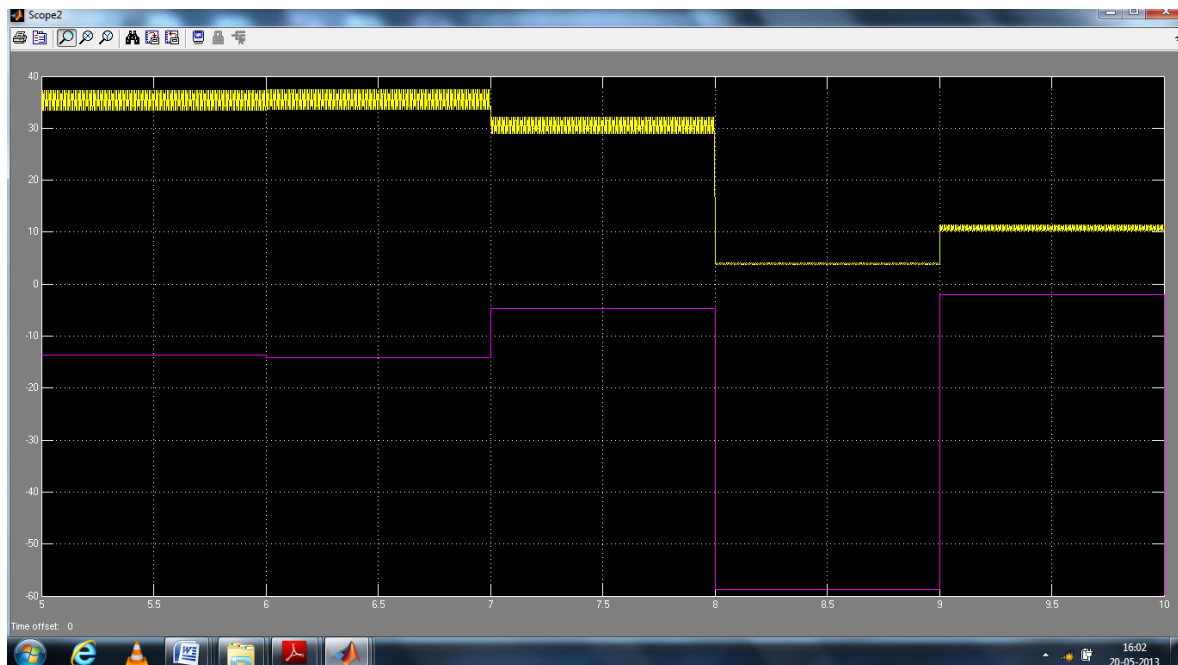
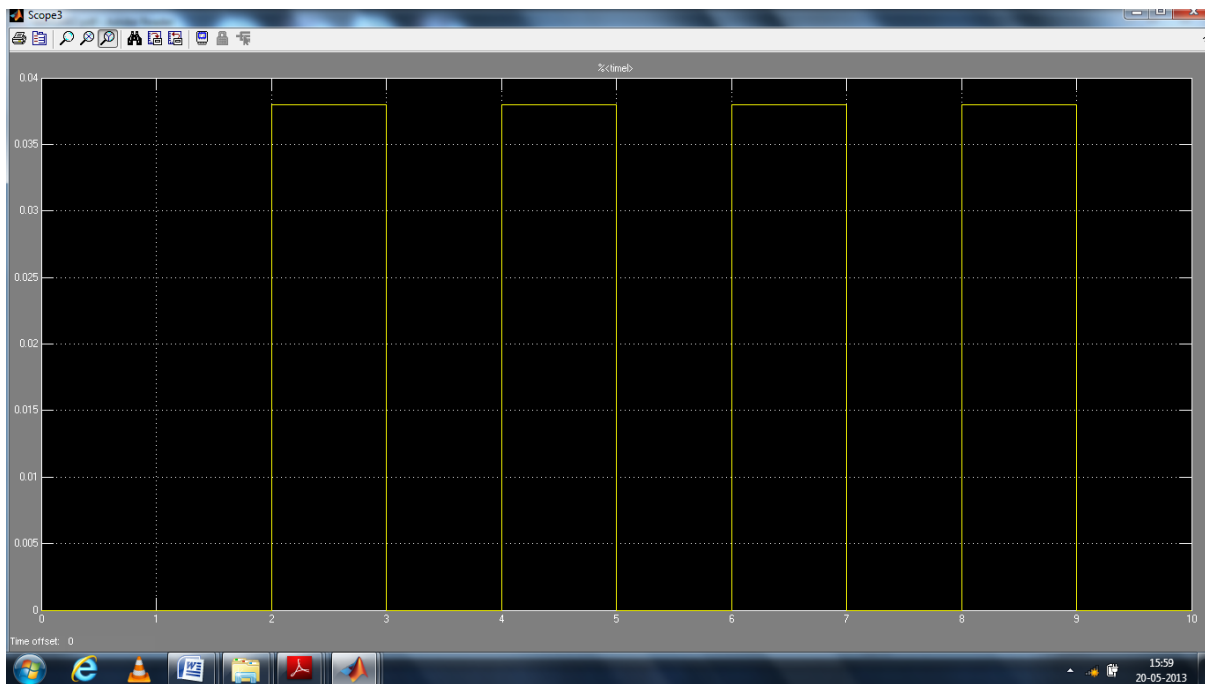


Figure 6 Removal of gain-transients and noise in EDFA using Fuzzy Logic Controller



V. Conclusion

In this paper we proposed a novel technique to minimize gain-transients in cascaded EDFAs using a Fuzzy Logic Controller in the feedback loop.

VI. References

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