Optik 125 (2014) 5450–5453

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Design and implementation of fuzzy logic based automatic gain controller for EDFAs

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ARTICLE INFO

Article history:
Received 11 October 2013
Accepted 27 May 2014

Keywords:
Automatic gain controller
Electronic control card
EDFA
Fuzzy logic

ABSTRACT

In this study, the design and implementation of a fuzzy logic (FL) based automatic gain controller card (AGC) is performed in order to control the pump laser current with respect to signal power and signal wavelength. The FL-AGC card consists of an amplifier, an analogue to digital converter (ADC), a digital to analogue converter (DAC), and a FL based software that is embedded to a microcontroller. With this configuration, gain flattening at the output of the erbium doped fibre amplifier (EDFA) along C band is achieved. In this way, ergonomically designed FL-AGC card can be easily matched with EDFAs and can be applicable to optical system applications.

1. Introduction

The wavelength division multiplexing systems (WDM) with erbium doped fibre amplifiers (EDFA) are commonly used in long distance optical communication systems due to their attractiveness, high capacity, and high speed [1]. In addition to that, gain spectrum and add/drop process of the channels are the two important parameters used in these systems. Flattened gain is very important in long haul optical communication systems because of inherent wavelength dependence of the gain, causing performance degradation of optical signal power among the WDM channels in cascade EDFA chains of optically amplified transmission systems and networks [2–10]. Furthermore, the number of present channels in EDFA can be different due to network reconfiguration or channel failures. This leads to cross-gain saturation in fibre amplifiers resulting power transients in the remaining channels which is another source of degradation [11]. Because of these reasons, quick gain control of EDFAs becomes an important issue for WDM optical network applications. For the compensation of these negative effects, it is critical to keep a fixed optical signal level for each channel and EDFA gain must be controlled at high speeds [12]. In the literature many AGC schemes are proposed to keep the output gain fixed and the decrease the transients in EDFAs [12–18]. The AGC schemes are generally classified as electronic [12,15,19], all-optical [11,13,17], or combination of both [20,21]. In all-optical control (OC) methods, EDFA gain clamping is accomplished by controlling the saturation level by means of an additional control channel inside the amplifier's gain bandwidth. The achieved settling times for these control methods are around 10 microseconds [13]. Electronic control (EC) methods are based on setting the pump laser current for fixed gain level with a stabilizing time of 1 μs. The main disadvantage of EC is the relatively complicated implementation as compared to OC methods [13].

In this study, previously proposed FL-AGC [4] is experimentally performed. The FL approach and other artificial intelligence methods are commonly used for estimation, prediction, and control of the electronic and photonic implementations/applications [22–53]. The FL approach keeps away the designer from more complex mathematical equations using expert knowledge and experience by fuzzy rules. The main difference between classical data sets and Fuzzy sets is the usage of syntactic statements instead of numerical values [33,34]. The FL has very simple linguistic rules, and it is easy to apply to a system that will be controlled [12]. The FL-AGC card consists of an amplifier stage in order to boost the weak electrical signal at the output of optical photo detector, an analogue to digital converter (ADC), and a digital to analogue converter (DAC).

The paper is organized as follows. In Section 2 the background about fuzzy logic is recalled and the choice of the structure of the FL-AGC card is given. Section 3 shows the experimental FL and simulation results obtained by applying the performed the FL-AGC for EDFAs. Finally, Section 4 reports the conclusions.

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http://dx.doi.org/10.1016/j.ijleo.2014.07.003

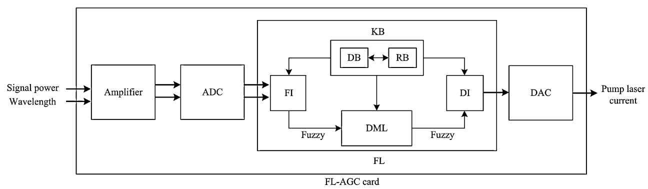

Fig. 1. The structure of the designed FL-AGC card.

2. Structure of the FL-AGC card

The FL algorithm is very useful in many fields to avoid rigorous complicated mathematical equations using expert knowledge and experience by fuzzy rules that enable FL control techniques to be easily applied for engineering applications [12,33]. The structure of the proposed and designed FL-AGC card is shown in Fig. 1. The input variables are signal power and wavelength, and the output variable is current of the pump laser. The measured values of the signal power and the wavelength are fed into the amplifier unit. Then the amplified signals are applied to the ADC. Afterwards, these input values are converted digital form from analogue form in the ADC unit. Finally, digital signals are applied to the FL unit.

The FL unit consists of four subunits. At the first unit, the fuzzification interface (FI) obtains fuzzified data by using fuzzy sets which are represented by membership functions (MFs). The optimized MFs are shown in Fig. 2. The selection of the number of MFs and their initial values are based on the experimental knowledge and experience. In this study, the triangular-shaped MFs is used since, it gives quite accurate results and fastest calculation time among other MFs used in the analysis [12,33,34]. The Mamdani-type [22] and if-then rule structures are used in the FL unit. Secondly, the knowledge base (KB) unit consists of database (DB) and rule base (RB) units. The DB unit contains the experimental data for the essential explanations. It is used to explain linguistic control rules (LCRs). The RB describes all control strategy of the experts by the way of a set of LCRs. Thirdly, the decision-making logic (DML) unit checks the KB to find the suitable output value for the several input values symbolized by the MFs. The RB unit includes a series of fuzzy rules, which defines the relation between signal power, wavelength and current of the pump laser variables that is shown in Table 1. In this table, the linguistic variables mf1 and mf13 correspond to smallest and biggest MFs, respectively. These rules are used in max–min fuzzy method. Finally, the defuzzification interface (DI) unit converts the fuzzy set to real time number that performs the reverse process of the fuzzification block. In this study, the centroid defuzzification method is used in the designed FL-AGC [12,33,34].

3. Experimental fuzzy logic and simulation results

Fig. 3 shows configuration of FL based C-band AGC-EDFA. In order to reach the best flattened gain, 980 nm pump laser diode

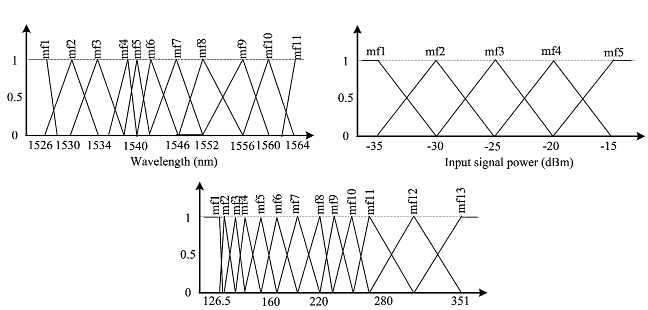

Fig. 2. The membership functions of the input variables and output variable.

Table 1
Rule base of the FL-AGC.

Input variables → ↓	Input signal power (dBm)				
Wavelength (nm)	mf1	mf2	mf3	mf4	mf5
mf1	mf10	mf10	mf8	mf11	mf13
mf2	mf2	mf2	mf2	mf4	mf8
mf3	mf1	mf2	mf1	mf4	mf8
mf4	mf5	mf5	mf5	mf6	mf10
mf5	mf5	mf5	mf5	mf7	mf11
mf6	mf4	mf5	mf4	mf6	mf10
mf7	mf3	mf4	mf3	mf5	mf9
mf8	mf3	mf3	mf3	mf5	mf9
mf9	mf2	mf3	mf3	mf5	mf9
mf10	mf3	mf3	mf3	mf5	mf9
mf11	mf7	mf8	mf6	mf8	mf12

Output variable
Current of the pump laser (mA)

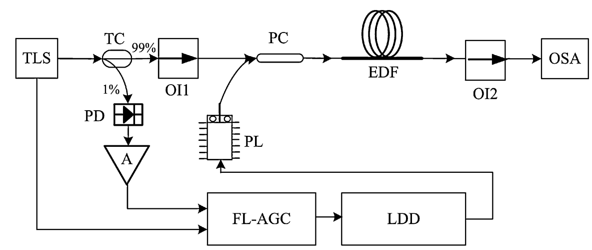

Fig. 3. The C-band AGC-EDFA based on FL.

(PLD) is utilized as a co-pumping source in the configuration. An EDF having the length about 13.5 m (the properties of the EMP980 EDF are shown in Table 2) serves as the gain medium. In the scheme, the C band signals (range from 1526 nm to 1564 nm) are launched to system from tunable laser source (TLS). The single-mode tap coupler (TC-1% coupling) separates the signal into two parts; 1% of the signal used to FL-AGC block via an amplifier. The remaining part of the input signal is then applied to the pump coupler (PC) through the optical isolator (OI1). Both pump (PL) and input signals are merged inside the PC and the combined signal are applied to erbium doped fibre (EDF). After then it passes through the second optical isolator (OI2) and reaches to optical spectrum analyser (OSA). The 1% of the input signal is detected by an InGaAs PIN photo diode (PD) which converts optical signal to electrical signal which is amplified by the amplifier (A) and directly inputted to FL-AGC. Finally, the signal wavelength is read from TLS.

The inputs, which are signal power that is obtained from PD and signal wavelength that is retrieved from TLS, are converted to digital using 24-bit delta-sigma ADC in FL-AGC. Output of ADC is retrieved by 48 MHz 32-bit ARM microprocessor. ADC and microprocessor is interfaced through an SPI serial link. Digitized data is then fed into the fuzzy algorithm. Output of the fuzzy algorithm is directly applied to pump laser current driver. This value is converted to the desired 0–10 V voltage output needed by the laser diode driver (LDD) in the microprocessor by using 16-bit DAC. DAC is also connected to the microprocessor using the same SPI serial link. Finally, it is shown that the current value of the LDD is quickly tuned (approximately 1 μs) to hold within band of 25 dB and 0.1 dB

Table 2
The properties of the EMP980 EDF.

Parameters	Values
Fibre length	13.5 m
Erbium concentration	227 ppm
Erbium radius	1.68 μm
Core radius	1.77 μm
Numerical aperture (NA)	0.19
Life time	10 ms