Chapter 1

Introduction

1.1 Review of gain-control erbium-doped fiber amplifiers

Optical fibers are the medium of choice for telecommunications systems. They were first deployed by long-distance carriers for long-haul systems and are replacing copper and coaxial cable in local telephone networks. However, the major limitation is to recover the optical signal as it undergoes fiber loss and passive component attenuation in a fiber transmission link. Besides, the wavelength division multiplexing (WDM) is the main technique of increasing the transmission capacity, multiplexing signals of different wavelengths. The separated electronic repeaters for each channel in WDM system were expensive and impracticable. With the advent of erbium-doped fiber amplifiers (EDFA), it became feasible to amplify multiple signals simultaneously.

In WDM networks, the number of transmitted channels may vary due to optical add drop multiplexers (OADM) or failure of a channel. Gain cross saturation in EDFA will induce power transients in the surviving channels which can cause service impairment not known in electronically switched networks. The steady state and the transient channel addition/removal response must be minimized to avoid error bursts in the surviving channels. The solution to the above problems is automatic gain control (AGC). AGC maintains the EDFA gain at a fixed level during transient signal perturbations or changes in system loss. Several control techniques have been proposed and can be divided into electronic and all-optical schemes.

The electronic approaches are mainly applied on pump-controlled and signal-controlled AGCs. Pump-controlled AGCs suppress gain saturation by pump increase [1.1]-[1.8]; signal-controlled AGCs maintain constant the degree of EDFA saturation [1.9],[1.10]. The AGCs have three elementary functions: (1) the detection of signal power variations with respect to some reference level; (2) the generation of an error signal; and (3) the restoration of initial conditions corresponding to zero error.

These functions can be implemented optoelectronically in either feedforward or feedback loops. In either case, the error signal can be used to control the pump power, or to control the power of an auxiliary saturating signal. Both types produce EDFA gain linearization, i.e., the relation $P_s^{out} / P_s^{in} = G = const.$ holds for any input signal power falling in a given dynamic range.

The electronic feedfworward and feedback compensations with the control of pump power were first proposed and analyzed theoretically and experimentally by Giles et. al [1-1] and K. Motoshima et. al [1-6], respectively, which experimental setups are shown in Fig. 1.1 and Fig. 1.2. The pump power is automatically adjusted in response to the total power, resulting in a constant amplifier gain.

The first investigation for signal-controlled AGC using the electronic feedback loop is achieved by E. Desurvire et. al [1-9], as shown in Fig. 1.3. In this experiment, dynamic compensation of low-frequency ($f < 1$ kHz) gain fluctuations in saturated erbium-doped fiber amplifiers is demonstrated. This control methodology requires only a few microwatts of compensating signal power, compared to 10-20 mW pump power change for $\Delta G \sim 3$dB in the case of pump-controlled AGC. However, the signal-controlled requires an auxiliary (monochromatic) signal source, rendering this control methodology less attractive.

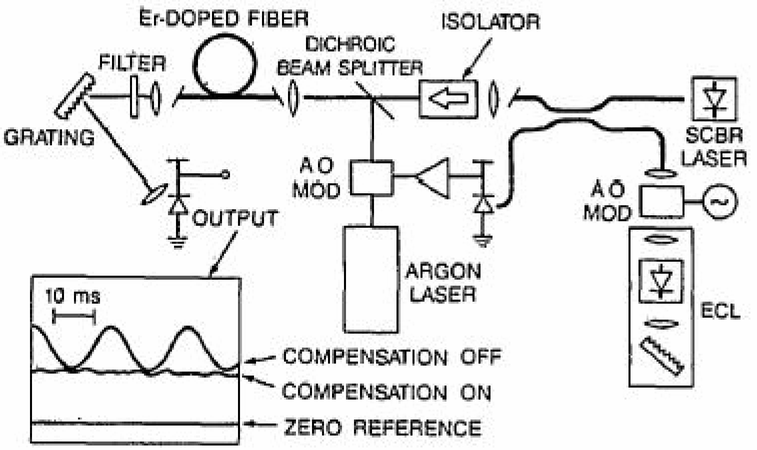

Fig. 1.1 Experimental setup for feedforward compensation of saturation-induced cross talk in the fiber amplifier. The control loop adjusts the pump power in order to maintain constant gain in the fiber amplifier with varying input signal power. AO MOD's, acousto-optic modulators.

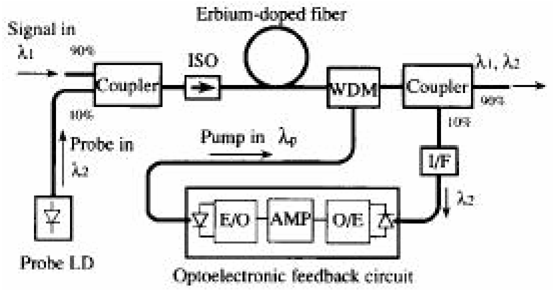

Fig. 1.2 Erbium-doped fiber amplifier with pump feedback control. ISO: optical isolator. O/E: optical-to-electrical converter. E/O: electrical-to-optical converter. AMP: error amplifier.

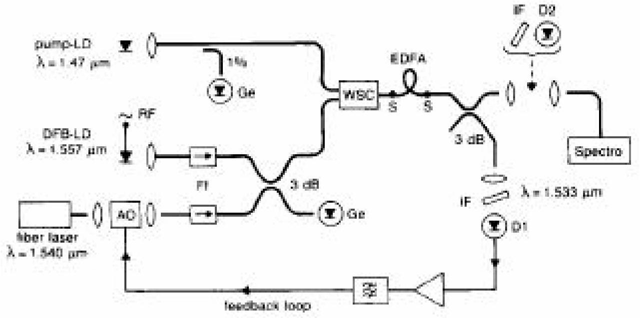

Fig. 1.3 Experimental setup for feedback signal control. AO: acoustooptic modulator, Fl: faraday isolator, Ge,D1,D2: germanium detector, WSC: wavelength-selective coupler, IF: interference filter.

In contrast to electronic AGC scheme, all-optical AGC has the advantage of no complex electronic hardware, and furthermore, it can be implemented using exclusively all-fiber components. M. Zirngibl devised the first all-optical feedback signal-controlled AGC in 1991, as shown in Fig. 1-4 [1-11]. All-optical AGC feeds back a fraction of output ASE into the EDFA. The EDFA operates as an amplifier for the signal wavelength λ_S and as a ring laser oscillating at wavelength λ_F. Any input signal increase results in a decreased laser feedback, and conversely, any signal decrease results in increased laser feedback. As a result, the single-pass signal gain is clamped by the effect of laser oscillation. The clamping level is controlled by the intracavity attenuator. Moreover, the other feedback gain control by placing fiber gratings at input and output ends of the amplifier was developed. Examples for this technique have been presented in publications by E. Delevaque et. al. [1-12], J. F. Massicott et. al. [1-13], and S. Y. Ko et. al. [1-14]. This typical configuration is shown in Fig. 1.5.

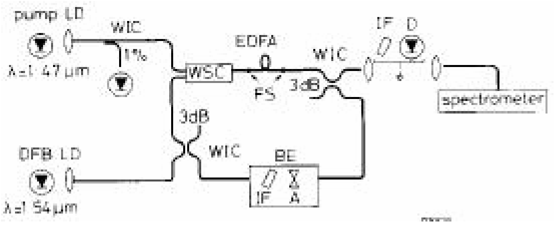

Fig. 1.4 Optical feedback scheme.

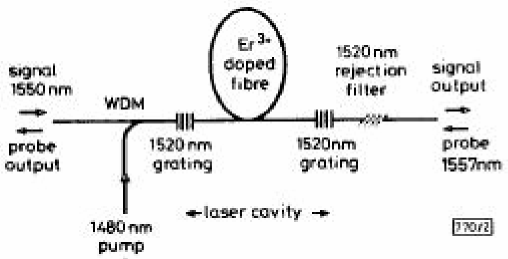

Fig. 1.5 Optical gain control scheme with fiber Bragg gratings [1-13].

For the transients of the all-optical gain-clamped EDFAs, many dynamic models have been proposed, demonstrated, and analyzed in theoretically and experimentally [1-15]-[1-23]. These investigations showing how to reduce the dynamic excursion of the surviving channel will be very useful for EDFA designs. M. Cai et. al. proposed a simplified method to estimate the noise figure of the optically gain-clamped EDFAs, and reported the noise-optimum configuration corresponding to the co-pump scheme [1-24]. The relaxation oscillations and spectral hoe burning effects in all-optical stabilization relative to the choice of feedback lasing wavelength were studied by G. Luo et. al [1-25]. The experimental results show that there is a tradeoff in selecting the lasing control wavelength to minimize impairments from SHB and relaxation oscillations. In order to deal with the dynamic instabilities and the steady-state power offset, the novel gain control methods, i.e., optical feedback plus electronic pump feedforward, are proposed by H. S. Chung et. al. and S. V. Sergeyev et. al., respectively [1-26]-[1-28].

1.2 Organization of this dissertation

This dissertation is organized into six chapters. The present chapter, being the first, is the prolegomenon for the researches that follow. The second chapter introduces the fundamental properties of EDFAs, and the gain transient effects including static power excursion and relaxation oscillation in all-optical gain-clamped EDFA. These statements are useful to comprehend the following studies. The third chapter gives a detailed account of the proposed L-band gain-stabilized EDFA with the simplified ring laser configuration. The coupler and optical filter in the typical ring laser structure are replaced with one C/L-band WDM. The fourth chapter presents a novel gain-controlled method adopted for the serial broadband (1530-1600 nm) EDFA. We use the sole ring laser cavity to achieve the broadband gain-clamping. The fifth chapter brings a new approach to suppress the static power excursion and relaxation oscillation in ring laser. This technique is to apply an extra channel in EDFA with the internal optical feedback loop. Finally, a brief conclusion for these researches is given in the sixth chapter.

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