Dynamic adjustment for gain-clamping erbium-doped fiber amplifier using a backward-injection light

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1 Introduction

Erbium-doped fiber amplifiers (EDFAs) have been intensively studied for wavelength-division-multiplexing (WDM) communication systems. The stabilization of the amplifier gain against the input signal-power variation is one of the key issues for WDM networks. The gain-stabilizing technique using a passive optical feedback device, such as a bandpass filter or a fiber Bragg grating, has been reported.[1–6] The gain medium, in conjunction with the passive feedback device acting as a cavity mirror, can provide a lasing light for gain saturation. Therefore, the gain profile of the EDFA in a WDM system is stable against the input signals added or dropped. This method is simple and effective for gain stabilization. However, because the lasing light propagates in the same direction as the input signal, the input signal cannot be close to the lasing wavelength determined by the passive feedback component. Furthermore, the additional lasing light would degrade the EDF noise figure, because it depletes the population inversion during the lasing mechanism.

We experimentally demonstrate a simple gain-stabilizing technique for an EDFA in WDM systems. A backward-injected Fabry-Perot laser diode (FP-LD) is adopted as an optical feedback device instead of a passive optical filter for a gain-clamped EDFA. By using this proposed scheme, we not only can stabilize the gain value but also can dynamically control the gain profile by adjusting the bias current of the FP-LD. To solve the problem of noise figure degradation, we propose a configuration of a preamplification stage with a short erbium-doped fiber (EDF). This preamplification EDF locates at the front of the entire gain-clamped EDFA system, and the backward-injected FP-LD cannot affect the gain of this preamplification stage. Consequently, the dynamic gain-clamped profile is retrieved and the degradation of the noise figure is improved.

2 Experimental Setup

The basic configuration for a dynamic gain-clamped EDFA module by using a backward-injected FP-LD is shown in Fig. 1(a). The EDFA is constructed by a 12-m EDF (HighWave 741) pumped by a 1480-nm LD via a 1480/1550-nm WDM coupler. The pumping power of the 1480-nm LD is 140 mW. A distributed feedback laser diode (DFB-LD) is used to act as a saturation tone for simulating the multiwavelength input signals in a WDM system. Because of the homogeneously broadened characteristic of the EDF, such an arrangement is reasonable as long as the power of the saturation tone is equal to the aggregated power of the multiwavelength input signals.[7] The gain profile in a WDM system can be measured by a tunable laser source (TLS) as a probe light. This probe light and the saturation tone are fed into the EDFA through a 1×2 (50:50) coupler (C) and an optical isolator (OIS). To stabilize the gain profile in such simulated WDM systems, we use a FP-LD as an optical feedback element for gain clamping. The central wavelength of the FP-LD is 1533.5 nm at its threshold current of 14 mA. This FP-LD is backward injected into the EDFA through an optical circulator (OC). In contrast with the passive feedback element for gain clamping, the EDFA gain profile can be dynamically controlled by adjusting the bias current of the FD-LD. However, this basic gain-stabilizing configuration would result in the degradation of noise figure because the injection of the FD-LD depletes the population inversion of the EDF. To overcome this problem,[8] we develop another architecture on the basis of a

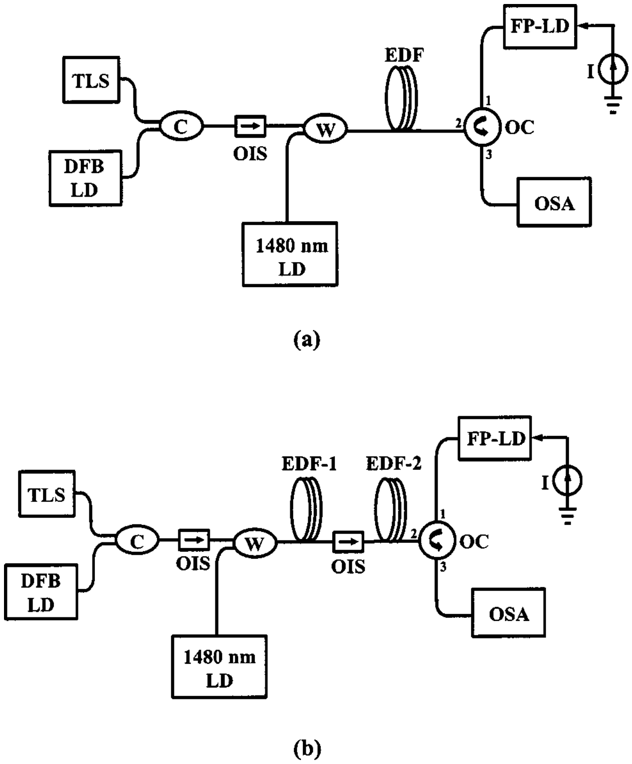


Fig. 1 The proposed and experimental setup for the dynamic gain-clamped EDFA module with backward injection of a Fabry-Perot laser light. (a) Basic configuration and (b) new configuration with a preamplification stage.

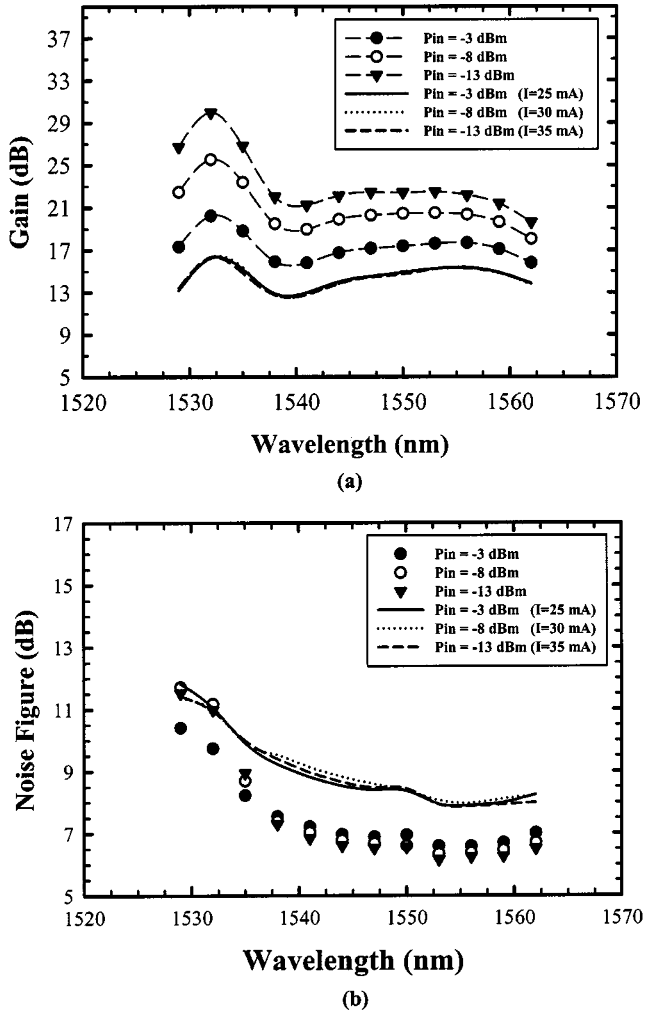


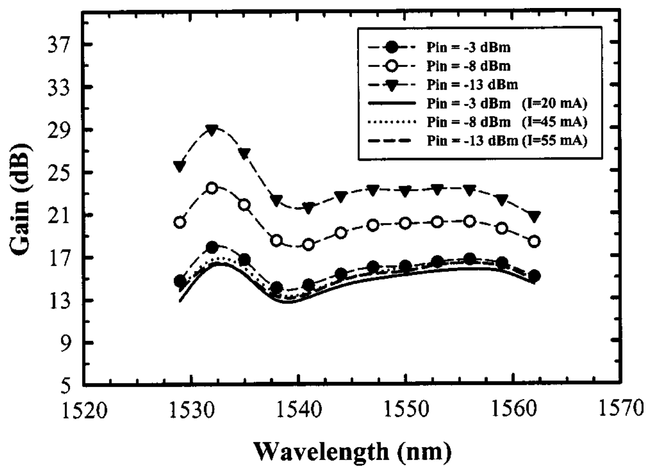
Fig. 2 (a) Measured gain spectra and (b) noise figure degradation of the basic configuration shown in Fig. 1(a). Without the backward-injected FP-LD, the data marked by the solid circles, the hollow circles, and the solid triangles show the gain profiles when pin=−3, −8, and −13 dBm, respectively. The gain stabilization against the DWDM input signals simulated at pin=−3, −8, and −13 dBm was improved when we added the backward-injected FP-LD and adjusted its bias currents at $I=25$ mA (solid line), $I=30$ mA (dotted line), and $I=35$ mA (dashed line), respectively. However, the noise figures were degraded for the wavelength longer than 1532 nm.

preamplification stage with a short EDF, as shown in Fig. 1(b). The original EDF now is divided into EDF-1 3 m long and EDF-2 9 m long. This new amplifier module is also pumped by the 1480-nm LD with 140-mW pumping power, which is connected at the front of the preamplification stage. The insertion loss of the isolator is ~1.9 dB near 1480 nm. Under the configuration, the pump power of the 1480-nm pump laser is about 110 mW after passing through the second isolator, due to the losses of the isolator and the splicing points between a single mode fiber (SMF) and EDF, as shown in Fig. 1(b). If the isolator is S- plus C-band one, it would maintain the pump power level of a 1480-nm pump laser. Using this preamplification scheme with a backward-injected FP-LD, we experimentally show the improvement of the noise figure for a gain-clamped EDFA in WDM systems.

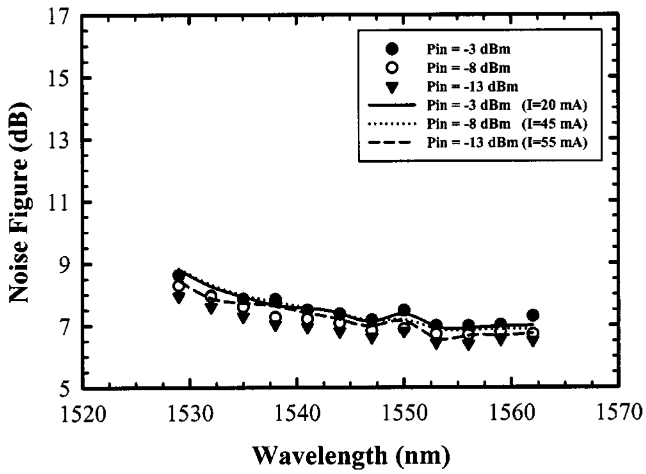
3 Results and Discussion

In general, gain-clamping amplifier modules use all optical feedback methods,[1–6] producing a saturated tone to clamp the gain profiles. In this proposed scheme, a Fabry-Perot laser diode acts as a saturated tone to clamp gain profiles by properly adjusting the different current level of a FP-LD. When the current level of the LD is increased, then the output power should increase and the output central wavelength of the LD will slightly shift to a longer wavelength.[9] Therefore, the gain will be clamped dynamically by controlling the current level of the FP-LD.

We first examined the performance of the basic gain-clamped configuration, as shown in Fig. 1(a). The WDM input signals were simulated by the DFB-LD with three input power levels: pin=−3, −8, and −13 dBm. Without the backward-injected FP-LD, the data in Fig. 2(a), marked by the solid circles, the hollow circles, and the solid triangles, show the gain profiles when pin=−3, −8, and −13 dBm. Clearly, the EDF gain profile varied with different input power without the gain-stabilizing mechanism. The gain stabilization against the DWDM input signals simulated at pin=−3, −8, and −13 dBm was improved when we added the backward-injected FP-LD and adjusted its bias currents at $I=25$ mA (solid line), $I=30$ mA (dotted line), and $I=35$ mA (dashed line), respectively. Over the operating wavelength range from 1526 to 1562 nm, the gain variation for a 10-dB input power-level change (from



(a)



(b)

Fig. 3 (a) Measured gain spectra and (b) noise figure of the preamplification scheme as shown in Fig. 1(b). The gain-stabilizing performance of this preamplification scheme was slightly degraded in contrast with that of the basic configuration shown in Fig. 2(a). Nevertheless, Fig. 3(b) presents the better performance of the noise figure than that of the previous experimental setup when the FP-LD was added.

−3 to −13 dBm) was suppressed from 9.7 to 0.1 dB; and the maximal gain flatness was reduced from 10.4 to 3.5 dB. However, the injected light from the FP-LD degraded the EDFA noise figure, as shown in Fig. 2(b). Without the injected FP-LD, the data marked by the solid circles, the hollow circles, and the solid triangles show the noise figures at pin=−3, −8, and −13 dBm. The noise figures were degraded for the wavelength longer than 1532 nm when a backward-injected FP-LD was added at the same operation conditions.

To overcome the degradation of the noise figure, we subsequently examined the performance of the new gain-clamped configuration with a preamplification stage, shown in Fig. 1(b). For comparison, in Fig. 3(a) we still show the gain profiles without the backward-injected FP-LD. The data in Fig. 3(a), marked by the solid circles, the hollow circles, and the solid triangles, show the gain profiles when the WDM signal power was simulated at pin=−3, −8, and −13 dBm. The gain stabilization at these input power levels was improved when we added the FP-LD under its bias currents at $I=20\,\text{mA}$ (solid line), $I=45\,\text{mA}$ (dotted line), and $I=55\,\text{mA}$ (dashed line), respectively. Over the operating wavelength range, the gain variation for a 10-dB input power-level change (from −3 to −13 dBm) was suppressed from 11.1 to 0.5 dB; and the maximal gain flatness was reduced from 8.5 to 3.5 dB. The gain-stabilizing performance of this new developed scheme was slightly downgraded in contrast with that of the basic configuration shown in Fig. 2(a). Nevertheless, Fig. 3(b) presents a better performance of the noise figure than that of the previous experimental setup when the FP-LD was added. The better noise figure results from the short EDF-1 acting as a preamplifier in the entire EDFA system. Figure 4 shows the gain spectra of EDF-1 pumped by a 1480-nm LD with 140-mW pumping power. Obviously, over the operating windows (from 1526 to 1562 nm), the lower gain level due to the short EDF length could avoid the gain saturation for preamplification. The gain variation was less than 0.8 dB for the 10-dB input power-level change (from −3 to −13 dBm). Moreover, the backward-injected light from the FP-LD was isolated by the optical isolator between the FP-LD and EDF-1. Therefore, our proposed scheme can achieve a dynamic gain-clamped profile for an EDFA and maintain its performance of noise figure against the injected light for gain stabilizing. This setup is simple and would be useful for a practical EDFA system in WDM networks.

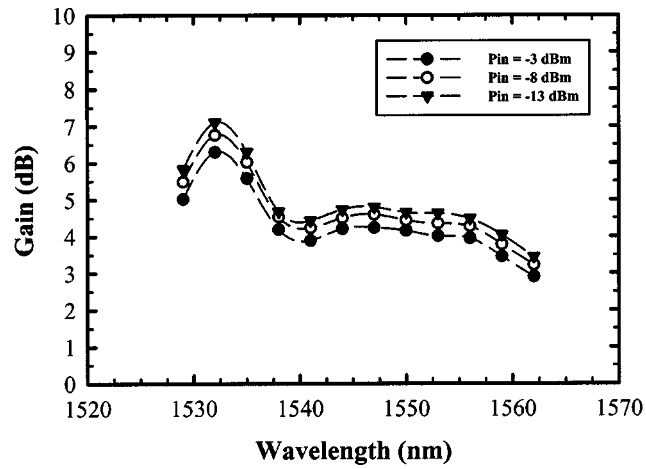


Fig. 4 Gain spectra of EDF-1 pumped by a 1480-nm LD with 140-mW pumping power. The data marked by the solid circles, the hollow circles, and the solid triangles correspond to the gain profiles when pin=−3, −8, and −13 dBm, respectively.

4 Conclusion

A gain-stabilizing technique for EDFAs using a backward-injected FP-LD is proposed and experimentally demonstrated. By using the proposed scheme, we not only can stabilize the EDF gain but also can dynamically control the gain profile by adjusting the bias current of the FP-LD. To overcome the problem of noise figure degradation, we propose a configuration of preamplification stage with a short

EDF. The experimental results show that our configuration can achieve a dynamic gain-clamped profile for an EDFA and improve the performance of noise figure against the injected light for gain stabilization.

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