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Optical monitoring technique based on scanning the gain profiles of erbium-doped fiber amplifiers for WDM networks

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Abstract

We have proposed and demonstrated a new optical monitoring technique based on scanning the gain (or loss) profiles of the erbium-doped fiber amplifiers for WDM networks. The maximum measured error of $\leqslant 0.31$ dB, the sensitivity of -50 dBm, and the dynamic range of 34 dB have been achieved experimentally for a 4-channel demonstration.

Keywords: Erbium-doped fiber amplifier; Gain-clamped; Optical monitoring; Wavelength division multiplexing networks

1. Introduction

Wavelength division multiplexing (WDM) technique has been widely applied on optical networks to improve transport capacity. This progress also bring new essential for optical surveillance of each channel characterization and system performance. Conventionally, optical monitoring can be achieved by spectrometers, wavemeters or tunable fiber Fabry–Perot filters. Recently, several new techniques, such as to add the pilot tones for channel identification and power monitoring [1,2], the detection of the transparent point of semiconductor optical amplifier or semiconductor laser diode [3], to combine a concatenated fiber Bragg gratings (FBGs) with the optical sampling method [4], and the data correlation detection [5,6], have been studied for optical monitoring in WDM systems. In this paper, we propose and demonstrate a new technique based on the scanning of the gain or loss profiles of erbium-doped fiber amplifiers (EDFAs) to monitor the powers of WDM signals. Compared with the past reports [1–6], this proposed technique have simple structure and lower cost to

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monitor channel power for WDM networks. As a result, this new technique can be integrated with EDFA modules and provide optical monitoring function in WDM systems.

2. Operation principle and simulation

Fig. 1 shows the proposed configuration to monitor the powers of input WDM signals. As shown in Fig. 1, a measurement unit, which is composed of a distributed feedback (DFB) laser for the saturated tone, a few meter long erbium-doped fiber (EDF), a optical circulator (OC), a 980/1550 nm WDM coupler and a 980 nm pump laser, is used to detect the powers of input WDM signals. The powers of real input WDM signals are observed at the "A" position.

The operation principle of the proposed method will be introduced as follows. If the operating wavelength range is divided into N equal sections, the optical powers in the section "n" can be indicated as $P_{\mathrm{in},n}$ ($1 \leqslant n \leqslant N$) for the input WDM signals before entering the EDFA module. Since the pump power, P_{pump}, will determine the gain profile of the EDFA, the transfer function between the input and output powers of the EDFA can be described by $g_{m,n}(P_{\mathrm{pump},\ m})$, where m is the level number of pump power. If the output power for each pump level is indicated by $P_{\mathrm{out},m}$, the relationship between input and output powers in each wavelength section can be represented by

$$P_{\mathrm{out},m} = \sum_{n=1}^{N} g_{\mathrm{m},n}(P_{\mathrm{pump},m}) \cdot P_{\mathrm{in},n} \quad \text{for } 1 \leqslant m \leqslant M. \tag{1}$$

If $M = N$, then the input power in each wavelength section can be governed by

$$\begin{bmatrix} P_{\mathrm{in},1} \\ P_{\mathrm{in},2} \\ \vdots \\ P_{\mathrm{in},N} \end{bmatrix} = \begin{bmatrix} g_{1,1} & g_{1,2} & \cdots & g_{1,N} \\ g_{2,1} & g_{2,2} & \cdots & g_{2,N} \\ \vdots & \vdots & \vdots & \vdots \\ g_{N,1} & g_{N,2} & \cdots & g_{N,N} \end{bmatrix}^{-1} \begin{bmatrix} P_{\mathrm{out},1} \\ \vdots \\ P_{\mathrm{out},2} \end{bmatrix}. \tag{2}$$

Therefore, this method can measure the input WDM signals if the gain profiles of the EDFA are only dependent on the pump power and irrelevant to the input power. We employ a backward-injection saturated tone to achieve this gain-clamped requirement. As a result, any input WDM signal can be retrieved by this gain (or loss) profile scanning method.

First of all, a 6-m long EDF (MP980) and a 15 dBm DFB laser at 1540 nm are employed. The op-

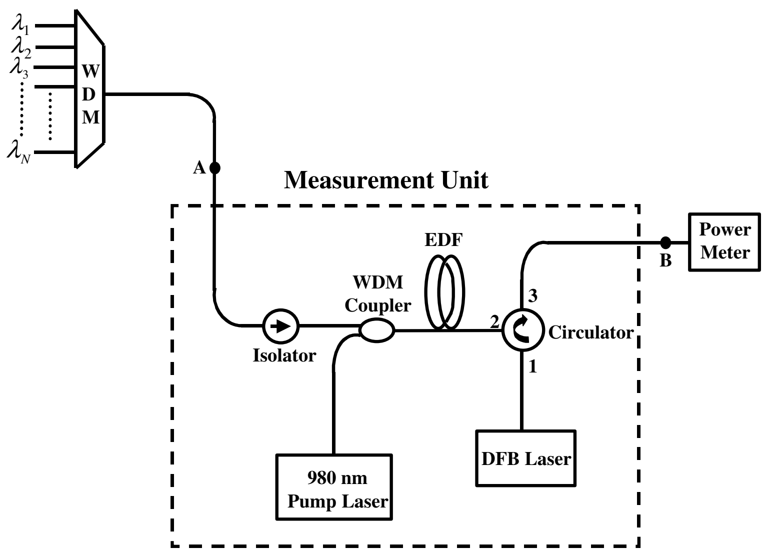
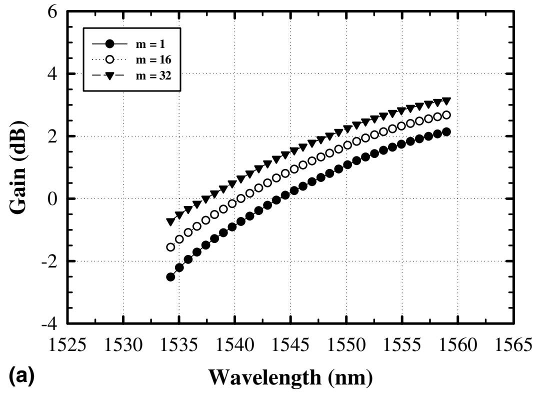


Fig. 1. The proposed configuration to monitor optical channel powers of WDM signals.

erating wavelength range from 1534.25 to 1558.98 nm is divided into 32 sections with 0.8 nm spacing (i.e., $N = 32$). The pump powers of 980 nm pump laser from 6 to 37 mW are utilized to generate 32 pump power levels (i.e., $M = 32$). Fig. 2(a) shows different gain profiles versus pump power levels of $m = 1$, 16 and 32 while the input power = −25 dBm per channel for the 32-channel WDM signals. To investigate the feasibility of this gain (or loss) profiles scanning method, we used commercial software with the related parameters as above to execute the simulation. To realize the performance of gain clamping, 37 mW pump laser and 15 dBm saturated tone are used with the 32-channel WDM signals. Fig. 2(b) shows the gain spectra when input powers = 0, −10 and −25 dBm, respectively. If the gain profile will be clamped, the optical power difference of the saturated tone and the all measured WDM signals should be larger than 10 dB, as shown in Fig. 2(b). And then, the reverse transfer matrix in Eq. (2) is obtained by injecting a −25 dBm probe light with a single tone from 1534.25 to 1558.98 nm with 0.8 nm spacing. Next, the spectral components of input WDM signals are measured according to Eq. (2). To determine the measurement error and dynamic range, three 32-channel WDM signals with powers of −10, −25 and −60 dBm per channel are used as the testing signals, and measured at the "B" position. Therefore, Fig. 3 indicates the comparison between the original and simulated optical powers of the 32-channel WDM signals while the input powers = −10, −25 and −60 dBm per channel, and the maximum measured error is less than 0.14 dB with different pump power levels. As a result, the dynamic range of input power can reach 50 dB for the maximum measured error is less than 0.12 dB.

To ensure the performance of the proposed configuration under the different channel numbers and powers of input WDM signals, thus the 32-, 8- and 4-channel WDM signals are used in this proposed configuration. The power difference of each channel reaches 50 dB between −10 and −60 dBm.



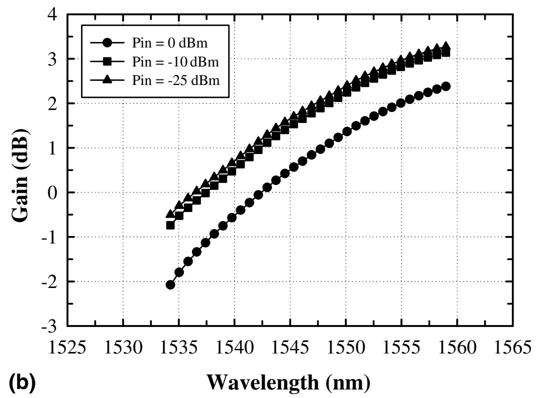


Fig. 2. (a) The simulated gain spectra of the measurement unit in Fig. 1 versus pump power levels of $m = 1$, 16 and 32 with the channel power of −25 dBm per channel and the 32-channel WDM signals ranging from 1534.25 to 1558.98 nm with 0.8 nm spacing, and (b) the gain spectra with 15 dBm saturated tone and 37 mW pump power when the input power are 0, −10 and −25 dBm per channel, respectively.

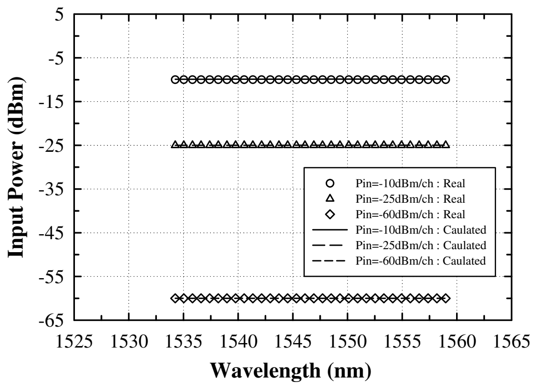
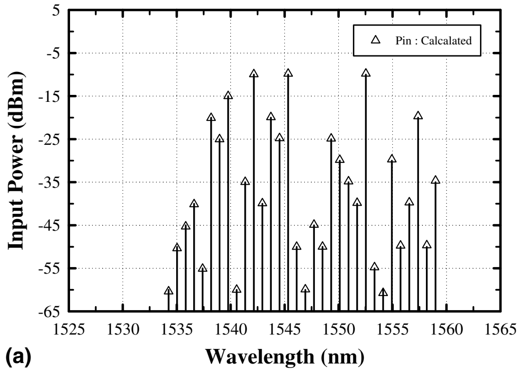
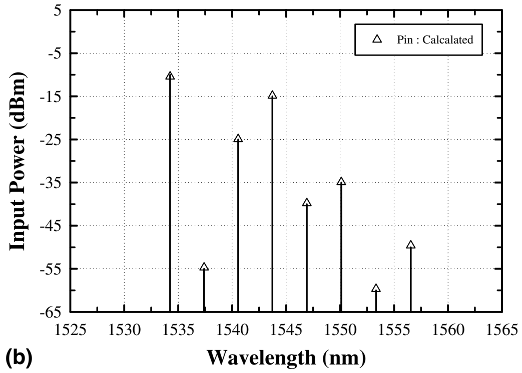


Fig. 3. Comparison of measured error between the real and calculated input optical powers of 32-channel WDM signals while the input powers = −10, −25 and −60 dBm per channel, respectively.

Fig. 4 shows the measured power versus the real power with the different input channel numbers and powers. The data marked by the vertical lines and the hollow triangle indicates the original input WDM signals and the calculated WDM signal powers, respectively. Therefore, Figs. 4(a)–(c) shows the measured errors are less than 0.21, 0.28 and 0.25 dB while the input signals are 4-, 8- and 32-channels, respectively. According to theses simulation results, the maximum measured error of $\leqslant 0.28$ dB with 50 dB power difference of each channel has been achieved when the different channel numbers and powers are applied for the proposed configuration and method.





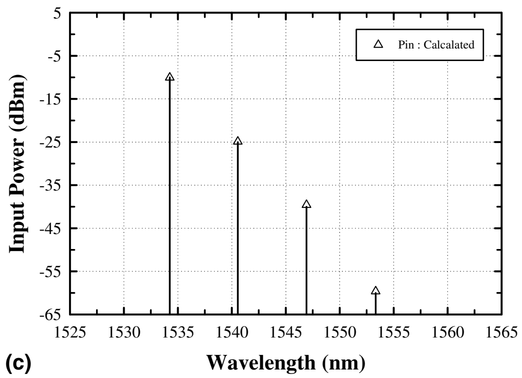


Fig. 4. The measured error of 0.38, 0.41 and 0.42 dB while (a) the 32-, (b) 8- and (c) 4-channel WDM signals are used, and per channel with different optical power and 50 dB power variations between −10 and −60 dBm (the vertical lines are channel powers of real input WDM signals, and the data marked by the hollow triangle indicates the measured and calculated WDM signal powers per channel).

3. Experimental results

To demonstrate this proposed method experimentally, a 0 dBm saturated tone at 1540 nm produced by a backward-injected DFB laser, a 10-m long EDF and a 980 nm pump laser are used in the measurement unit, as seen in Fig. 1. The input WDM signals with four operating wavelengths at 1534.23, 1539.35, 1546.11, and 1552.50 nm (λ_1–λ_4) are employed as the testing signals, respectively. Fig. 5 shows the gain spectra at 19 mW pump power when the input signal power $P_{in} = -6$, -16 and -50 dBm per channel, respectively. If the gain profile will be clamped, the optical power difference of the saturated tone and the all measured WDM signals should be

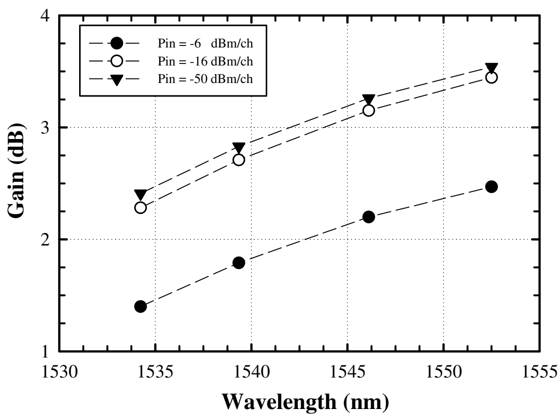


Fig. 5. The gain spectra with 19 mW pump power with 4-channel WDM signals when $P_{in} = -6$, -25 and -50 dBm per channel, respectively.

larger than 10 dB according to the Fig. 5. The reverse transfer matrix in Eq. (2) is determined by injecting a −25 dBm probe light with four WDM signals into the measurement, and then, Fig. 6 shows the gain tilts for the four probe lights when the P_{pump} = 10, 13, 16 and 19 mW, respectively. To determine the calculated error and the dynamic range, 4-channel WDM signals with −16, −30 and −50 dBm per channel, respectively, are used as the testing signals. The channel powers are measured at the "B" position as seen in Fig. 1. Therefore, after measuring and calculating, the real and retrieved input powers per channel for the four WDM signals are shown in Fig. 7 when the different input power levels are applied. The errors at each channel are [0.12, 0.22, 0.29, 0.12 dB], [−0.25, 0.2, 0.02, −0.02 dB] and [−0.13, 0.31, 0.28, 0.19 dB] while the input signal power = −16, −30 and −50 dBm per channel, respectively. As a result, the dynamic range of 34 dB and the maximum error less than 0.31 dB have also been achieved experimentally. To realize the behavior for the various power levels of input WDM signals, thereby the different input power at each channel is used. The input powers of the 4-channel signals are −8, −50, −28 and −16 dBm, respectively. After measuring and calculating, the error of [0.12, 0.21, −0.24, −0.21 dB] for each channel is shown in Fig. 8.

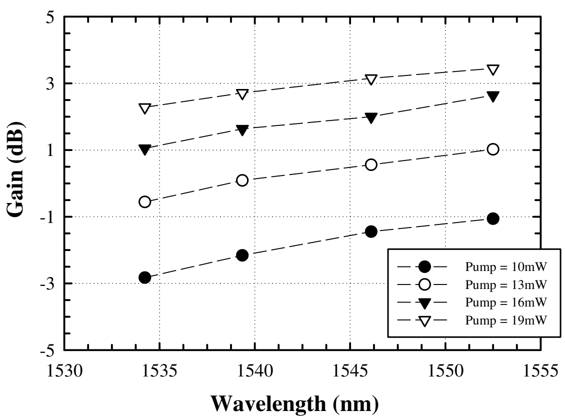


Fig. 6. The gain tilts for the 4-channel WDM signals with −25 dBm input power per channel when the P_{pump} = 10, 13, 16 and 19 mW, respectively.

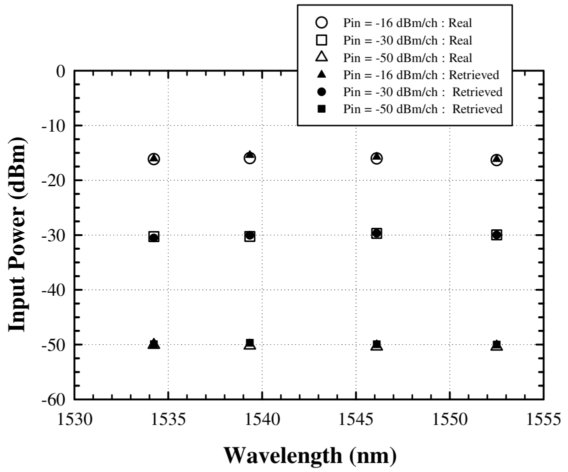


Fig. 7. The real and retrieved input signal powers for the testing 4-channel WDM signals while the real input powers = −16, −30 and −50 dBm per channel, respectively.

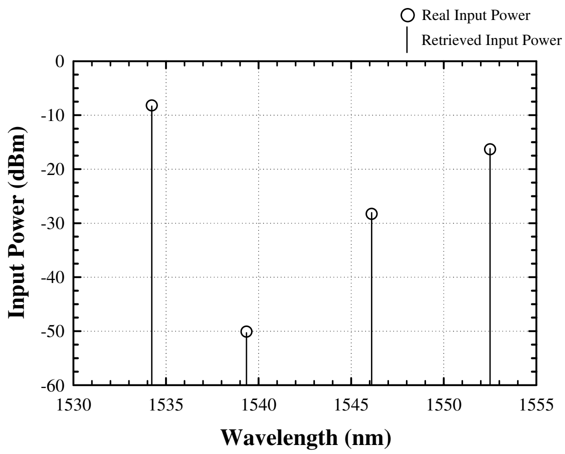


Fig. 8. The real and retrieved input signal powers for the testing 4-channel WDM signals while the input powers of the 4-channel signals are −8, −50, −28 and −16 dBm, respectively.

4. Conclusion

A new optical monitoring technique based on the scanning of the gain profiles of EDFAs for WDM networks has been proposed and demonstrated. The optical power at each channel can be retrieved after scanning the gain (or loss) profiles of the EDFA and calculating the corresponding aggregated output powers. For a demonstration of 4-channel WDM signals, the maximum calculated error of $\leqslant 0.31$ dB, the sensitivity of -50 dBm and the dynamic range of 34 dB have been achieved experimentally. This new technique can be integrated with an EDFA modules and provide optical monitoring function for WDM networks.

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