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Characterization of EDFA by using different measurement methods

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ABSTRACT Different methods for conventional erbium-doped fiber amplifier (EDFA) evaluation, namely Interpolation Method and Time-Domain Extinction (TDE) or Pulsed Method are compared. Principles of both measurement methods are also addressed. The data showed that discrepancies in signal gain and noise figure rose from different ways in the determination of the amplified spontaneous emission (ASE) level.

ABSTRAK Cara-cara pengukuran untuk pembesar gentian berdop erbium (EDFA), Cara Interpolasi dan Cara Pembezaan Julat Masa (TDE) atau Denyutan telah dibandingkan. Prinsip-prinsip cara pengukuran juga diterangkan. Data menunjkkan perbezaan dalam gandaan dan kebisingan isyarat timbul daripada cara penentuan yang berlainan untuk aras pancaran spontan terganda (ASE).

(interpolation method, time-domain extinction method, erbium-doped fiber amplifiers, amplified spontaneous emission)

INTRODUCTION

EDFAs are an enabling technology for WDM optical networks. Their ability to simultaneously amplify multiple wavelengths provides significant performance and cost advantages over electronic regeneration. EDFAs are used in networks to boost transmitted power (booster amplifier), amplify signals in transit to compensate for losses sustained in the fiber (in-line amplifier), or amplify signals before a receiver (preamplifier).

The optical amplifier's gain and noise characteristics greatly affect the signal-to-noise ratio (SNR) of the transmitted signals. In the case of the wavelength division multiplexing (WDM) system, the characteristics of the optical fiber amplifiers are very important. Therefore, it is important to be able to gather accurate information about basic characteristics such as the gain and the noise figure characteristics of the optical fiber amplifier when designing optical transmission systems using these optical fiber amplifiers.

PRINCIPLES OF MEASUREMENT

Interpolation Method

EDFAs can be characterized with a stable laser source used as an input signal and an Optical Spectrum Analyzer (OSA) for the spectral measurements. Spectral measurement of the laser source and the EDFA output are required to determine the EDFA parameters. The spectrum of the input signal shows that there is spontaneous emission coming from the laser source. This must be measured and accounted for in the calculation of the EDFA parameters.

The gain of the EDFA can be easily calculated as the difference between the input and output peak power of the signal as shown in (Figure 1). The input and output power levels are actually the sum of the signal power and the small amount of spontaneous emission power at the signal wavelength. It is negligible for low spontaneous emission levels. If the spontaneous emission level is high, it should be subtracted from each of the power measurement. In this case, the signal gain is determined by the following equation [1]:

$$G=\frac{P_{out} - P_{ASE}}{P_{in}} \qquad (1)$$

where P_{out} = output signal power, P_{ASE} = spontaneous emission level at the signal wavelength, and P_{in} = input signal power.

The P_{ASE} is an important parameter in determining the noise figure which is given by [1]:

$$NF = \frac{P_{ASE}}{Gh\nu\Delta\nu} + \frac{1}{G} \qquad (2)$$

where $h\nu$ = photon energy for the input signal, and $\Delta\nu$ = bandwidth at P_{ASE} measurement. Ideally, an EDFA would amplify the input signal by its gain and produce no additional output. However, the EDFA also produces ASE, which adds to the spontaneous emission produced by the source. In order to accurately determinate the noise figure, the P_{ASE} must be determined at the signal wavelength. However, it cannot be measured directly since the signal is superimposed on the spectrum of the ASE. Therefore, an approximate curve generated by *interpolation* is generally used to find the P_{ASE} as shown in (Figure 2). In the OSA (ANDO AQ6317B), various ways of fitting an interpolation curve are available such as Gaussian approximation, Lorenzian approximation, etc [2]. It is important to select the most appropriate interpolation curve depending on the waveform.

Principles of Time-Domain-Extinction (TDE) Method

The TDE method (Pulsed Method) takes advantage of the fact that the metastable energy level of the erbium ion has a lifetime of ~10 ms. Immediately after the input signal is turned off, the ASE power remains at the same level it was in the presence of the input signal. Then it starts to rise in an exponential fashion until it reaches the level of an undriven condition [3].

In this study, an ANDO AQ8423Z Optical Amplifier Analyzer (OAA) was used to automatically control the measurement process. It utilizes 1 MHz modulation frequency, which is high enough to suppress a rise of ASE level during off signal. The OAA modulates signals from external light source with an acousto-optic modulator, AOM 1, and another modulator, AOM 2, selects the timing to measure signal or ASE level. When AOM 2 is set for ASE measurement, it eliminates the source signal and source spontaneous emission (SSE) without affecting the ASE level. Therefore, the OAA can measure the ASE at a signal wavelength very accurately. In this method, a signal whose intensity has been modulated by the AOM 1 is input to the EDFA. The modulation frequency, 1 MHz, is a value sufficiently smaller than the lifetime of an Er^{3+} ion in the amplifier. Since the EDFA output signals are phase-isolated into the signal and the ASE light by switching ON/OFF of the AOM 1, it is possible to measure the signal, P_{out} and the ASE level independently by setting the phase of AOM 2 to each phase of the output signal as shown in (Figure 3).

The equations (1) and (2) are still applicable in calculating the signal gain and noise figure. Obviously, the difference between these two measurement methods is the way to determine the parameter of ASE level, P_{ASE}. In the TDE method, however, the isolation of the AOM 2 is not infinite. Consequently, if the input to the EDFA exceeds certain level, a leaked signal may appear on the measured waveform in the ASE measurement and causes errors in the signal gain and noise figure measurement.

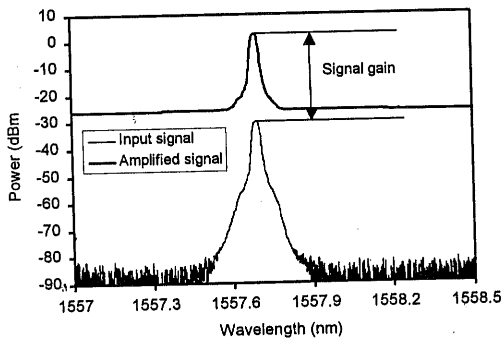

Figure 1. Signal gain determined by difference between the input and output peak power of the signal.

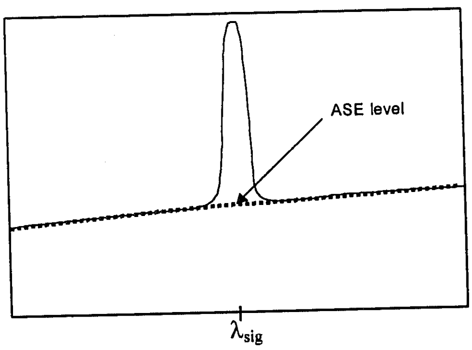

Figure 2. Interpolation method using curve fitting to determine the ASE level at signal wavelength.

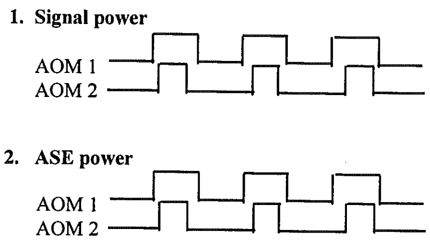

Figure 3. Timing diagram of the TDE

RESULTS AND DISCUSSION

Experimental comparison between the Interpolation Method and the TDE Method is done. The data is shown in (Figure 4). The input signal power was P_{in} = −31.2 dBm at the wavelength λ_{sig} = 1550 nm. The discrepancy of the signal gain between both measurement methods is fairly consistent with the interpolation method achieves the gain 0.4 dB higher than that obtained by the TDE method. For the noise figure the deviation is relatively large with the TDE method exhibits the noise figure ~0.7 dB higher for the entire pumping range.

Figure 5 shows the signal gain and noise figure as a function of the input signal power at the pump power P_p = 43.4 mW and the signal wavelength λ_{sig} = 1550 nm. In the unsaturated regime, there is ~1 dB gain difference between both methods. However, the signal gains are found to be nearly identical in the saturated regime. The deviation is relatively large for noise figure with the TDE method achieves noise figure ~0.9 dB higher than that of the interpolation method. The results show that the interpolation method exhibits a high signal gain and a lower noise figure than that obtained using TDE method. The deviation is mostly arising from the difference in the ASE level obtained using different measurement methods. In the interpolation method, the ASE level is measured at the wavelengths just above and just below the signal using an appropriate curve fitting. While the TDE method measures the ASE level by utilizing 1 MHz modulation frequency, which is high enough to suppress a rise of ASE level during the signal OFF phase. Obviously, the TDE method measures the ASE level when the signal is OFF. Consequently, the ASE level measured using the latter method is higher, resulting in a lower signal gain and higher noise figure according to the Eqs. (1) and (2).

CONCLUSIONS

Evaluation of the conventional EDFA using different measurement methods has been presented. Deviation in the signal gain and noise figure was due to different ways in determining the ASE level. The Interpolation Method was found to give a higher signal gain and a lower noise figure as compared with that obtained from the Time-Domain Extinction Method.

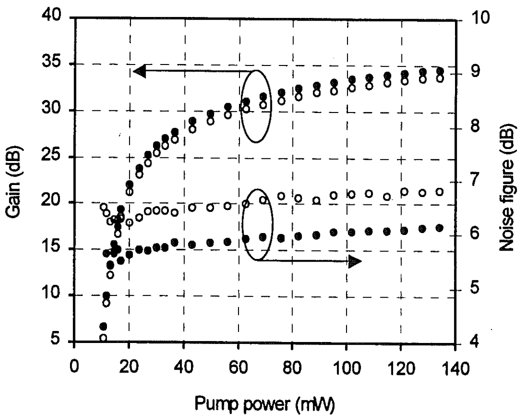

Figure 4. Signal gain and noise figure as a function of the pump power obtained from Interpolation Method and TDE Method. (o: TDE Method; •: Interpolation Method).

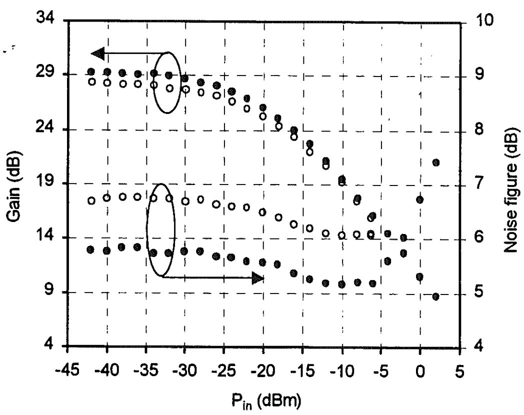

Figure 5. Signal gain and noise figure as a function of the input signal power at the pump power P_p = 43.4 mW and the signal wavelength λ_{sig} = 1550 nm. (o: TDE Method; •: Interpolation Method).

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