Application Note

Optical Amplifier (EDFA) Characteristics Evaluation

Optical Amplifier NF/Gain Measurements with MS9740A Optical Spectrum Analyzer

MS9740A
Optical Spectrum Analyzer

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4. Summary

1. Introduction

The development of erbium-doped fiber amplifiers (EDFA) in the latter half of the 1990s supported amplification of signals using wavelength-division multiplexing (WDM) and permitted the spread of long-distance, large-capacity communications, such as optical submarine cables and optical subscriber systems. Evaluation of EDFA characteristics as key devices in long-distance, large-capacity transfers described in IEC61290 and JISC6122 specifies the importance of gain and noise figure (NF) measurement items. This application note describes the measurement methods, advantages and precautions using the Anritsu MS9740A Optical Spectrum Analyzer to measure EDFA parameters.

2. NF/Gain Measurement Outline

Measurement of EDFA gain using an optical spectrum analyzer (OSA), can be performed simply by comparing the EDFA optical input and output levels. Measurement of NF requires accurate measurement of the EDFA amplified spontaneous emission (ASE) level. However, direct measurement is difficult because the actual ASE is buried within the amplified signal. There are three recommended methods for measuring the ASE level as described below.

(1) Level interpolation method (Direct interpolation method)
(2) Polarization nulling method
(3) Pulse method

In the level interpolation method, the ASE level at the optical signal wavelength is estimated by interpolation from the ASE level near the optical signal wavelength. Measurement using this method is comparatively simple and when the ASE near the measurement point is flat, the measurement reproducibility is high.

In the polarization nulling method, since ASE output from the EDFA is non-polarized, the ASE is measured directly by inputting a polarized optical signal to the EDFA and nulling the optical output (amplified optical signal component—polarized part, or 50% of the ASE components) from the EDFA using a detector. This method requires adjustment of the polarization state, but it is effective when the interpolation method is difficult to use.

In the pulse method, since the metastable erbium ions in the EDFA require a relatively long time to recover the ground state, if the on/off switching cycle of the optical input to the EDFA is sufficiently shorter than the recovery time, the ASE can be measured directly by measuring the output of the EDFA while the optical signal is off. This method requires a lot of ancillary peripheral equipment, but it does also support multiplexed signals (WDM).

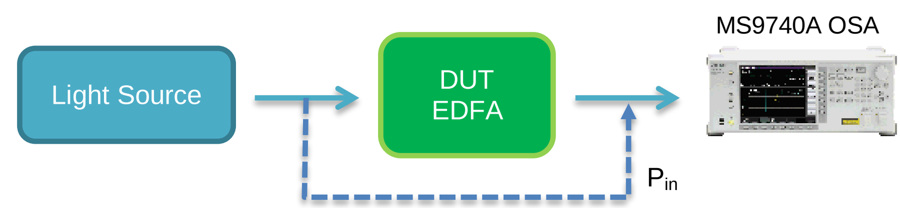
The MS9740A standard application software supports all the above three measurement methods. A concrete example of each measurement is explained below along with precautions at measurement.

3. Measurement Examples

3-1. Level Interpolation Method (Direct Interpolation Method)

A) Figure 1 shows NF/Gain measurement using the Level interpolation method.

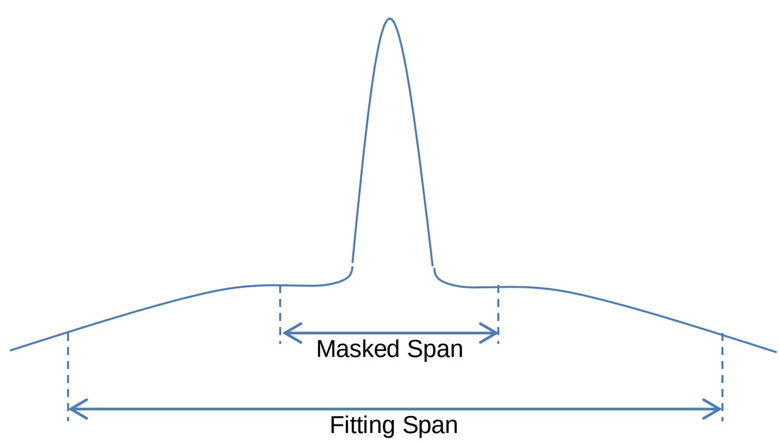
Figure 1: Level interpolation method measurement system using



B) Measurement Procedure

(1) Directly input the output of the light source to the OSA and measure the Pin input signal to the EDFA.
(2) Switch the OSA measurement trace to Pout. Input the light source to the EDFA and input the EDFA output light to the OSA to measure Pout.
(3) Set the Fitting Span to perform a data interpolation and the Masked Span to remove data from the interpolation calculation. Fitting Span is the wavelength span excluding other optical signals in that range and Masked Span is the wavelength span that is affected by the optical signal (Fig. 2).
(4) Set the fitting method as follows:
・Gauss Fit (Gaussian approximation)
・Mean (Linear approximation)

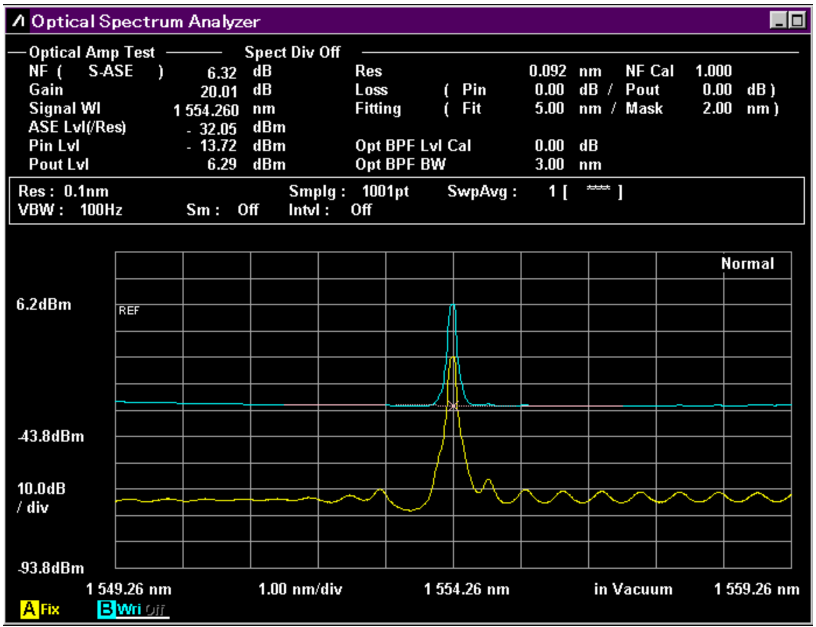
Figure 2: Fitting/Masked Span setting



C) Measurement Results

Figure 3 shows the measurement results. The ASE level was determined from these measurements by Gaussian fitting. The set Fitting Span was 5 nm and the Masked Span was 2 nm. Measurement was repeated 20 times and the repeatability of the NF measurement was better than 0.1 dB.

Figure 3: NF/Gain measurement using level interpolation

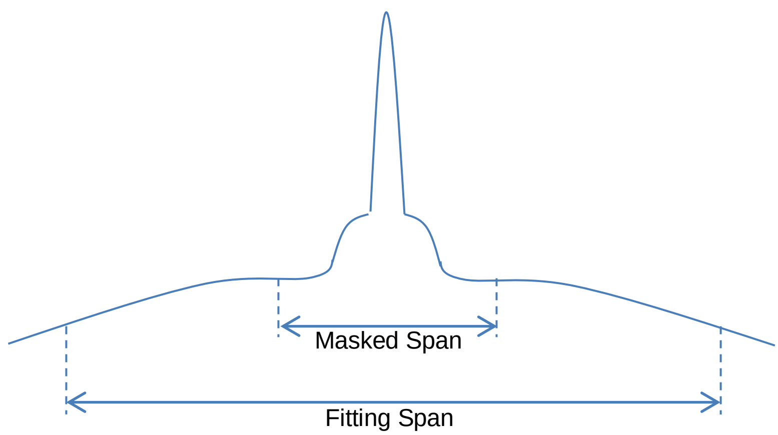


D) Measurements when optical band pass filter (OBPF) inserted at EDFA output

The measurement is broadly the same as measurement procedure (2) above but when measurement is started, the OBPF characteristics and data for level interpolation are input as parameters. (See section 5.5 in the instruction manual.)

Moreover, the Masked Span at this time must be set to a larger value than the OBPF pass band. (See Figure 4.)

Figure 4: Fitting/Masked Span setting when OBPF inserted



E) Measurement with spectrum division method

The EDFA output includes the noise level of the amplified optical signal as well as the ASE. As a result, the following type of correction is required to find the ASE more accurately.

$$ASE = ASE' - G \times P_{in\_noise} \qquad \cdots\cdots\cdots (1)$$

ASE': Measured ASE level, G: EDFA gain, Pin_noise: Noise of input signal

Performing level interpolation for the corrected ASE spectrum enables accurate determination of the ASE level.

The MS9740A can perform measurement with the spectrum division method set to either on or off (Spectrum Div. ON/OFF function). Figure 5 shows the NF/gain measurement results using the spectrum division method, and Figure 6 shows the EDFA measurement results without using the spectrum division method under the same conditions. A difference of about 0.1 dB is observed for both NF measurements. When using an optical source with side modes in addition to the optical signal, such as a DFB-LD, the effect of side modes can be suppressed by using the spectrum division method.

Figure 5: Measurement with spectrum division method

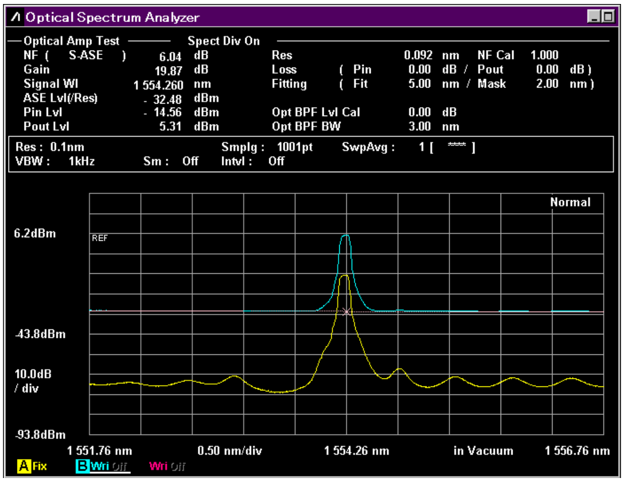
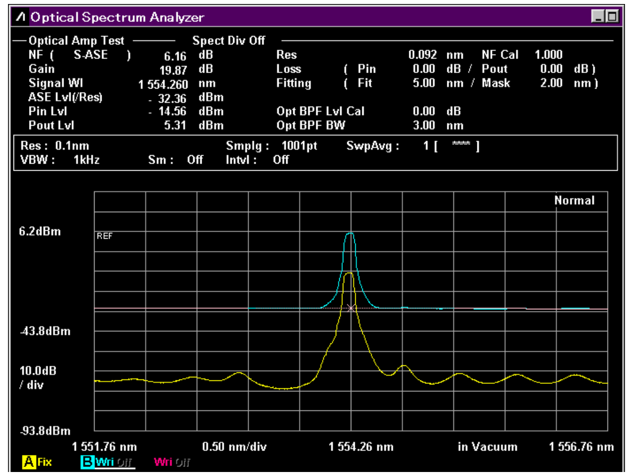


Figure 6: Measurement without spectrum division method



The following example shows the results when an ASE light source (optical noise) is added to a DFB-LD. Figure 7 and 8 show the measurement results with and without the spectrum division method, respectively. Even in this case, the measurement results clearly show that using the spectrum division method suppresses the effect of optical input noise components.

Figure 7: Measurement with spectrum division method

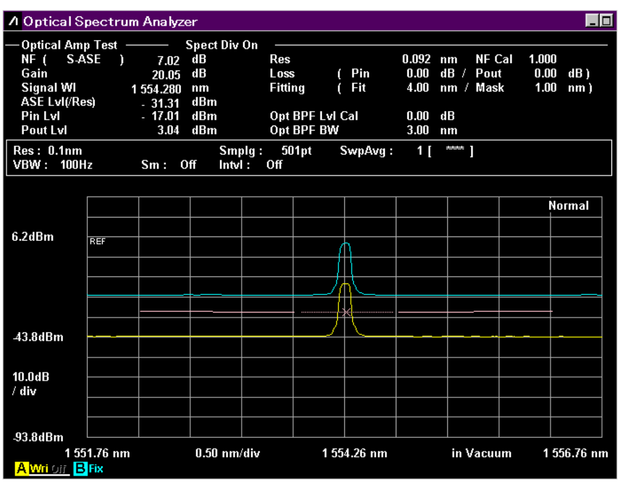
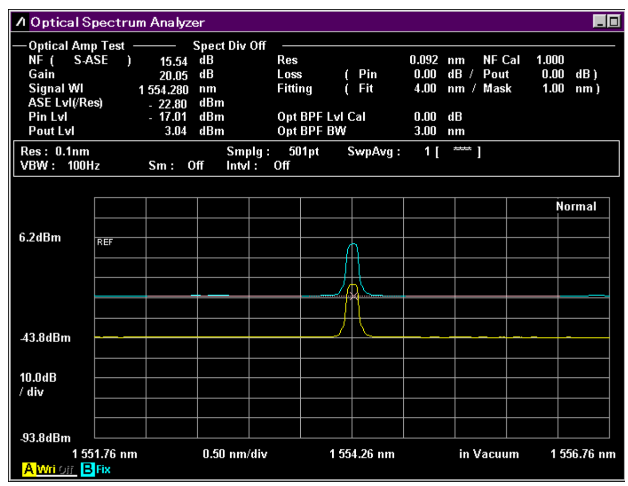


Figure 8: Measurement without spectrum division method



F) Precautions at level interpolation measurement

When there is sufficient data for interpolation at level interpolation measurement, NF can be measured with quite good accuracy. However, when measuring the NF of multiplexed signals, the settable Fitting Span is limited by the WDM Channel interval. When measuring the NF of this type of WDM signal, it is necessary to use the pulse method described below.

When measuring using the spectrum division method, accurate measurement is not possible if the value of Pin_noise in Eq. (1) is uncertain. For example, this may occur when the optical noise components of the input signal are buried by OSA noise at the range where fitting is performed. An example of this is shown below. In this measurement result, we can see that the NF measurement result is clearly wrong when the spectrum division method is set to on (Figs. 9 and 10).

To prevent this type of measurement error, it is necessary to set the OSA VBW so that the optical noise component is sufficiently larger than the OSA noise level. (See Appendix E in the instruction manual for the relationship between the VBW and optical reception sensitivity.)

Figure 9: Measurement with spectrum division method

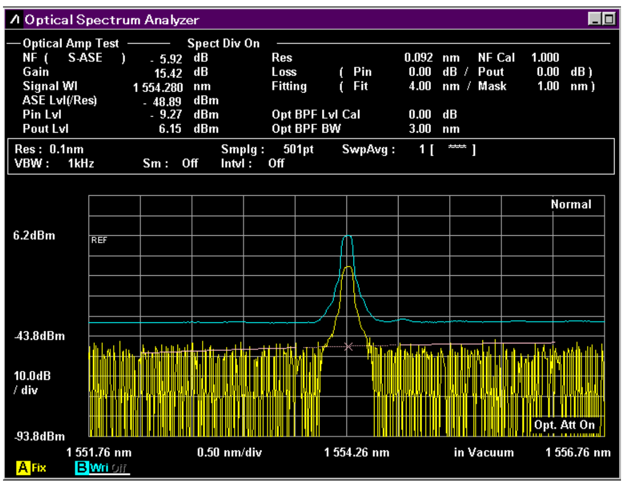
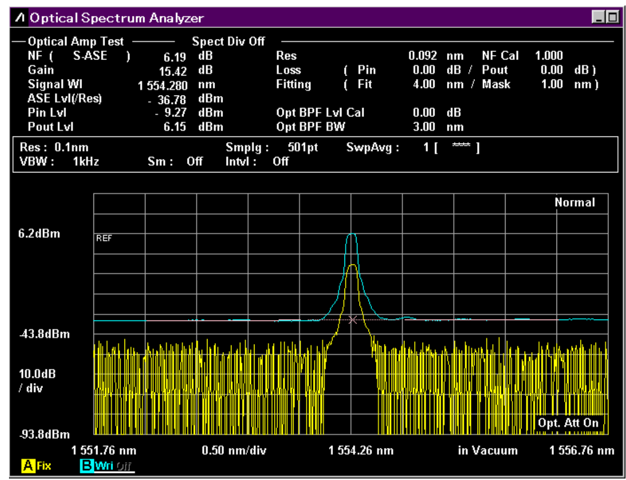


Figure 10: Measurement without spectrum division method



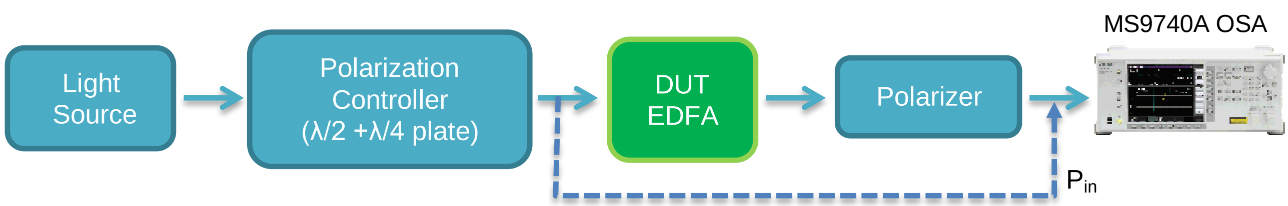
Furthermore, when using the spectrum division method, it is necessary to pay attention when the values of ASE’ and G x Pin_noise in Eq. (1) are extremely close. In other words, when the optical output ASE is sufficiently larger than the noise of the gain-multiplied optical input, the problem is small and can be ignored, but when the optical output ASE is very much smaller, the difference between the gain-multiplied optical input noise, the G×Pin_noise and the Pin_noise can have a large impact on the measurement results.

As an example, consider the situation when the measurement error of optical input level is 1 µW, the ASE optical output level is 1 mW and the gain is 20 dB. In this case, since the measurement error of optical input level is 100µW ., measurement using the spectrum division method includes error of 10% (≒0.45 dB).

3-2. Polarization Nulling Method

A) Figure 11 shows the NF/gain measurement system using the polarization nulling method.

Figure 11: Polarization nulling method measurement system using MS9740A



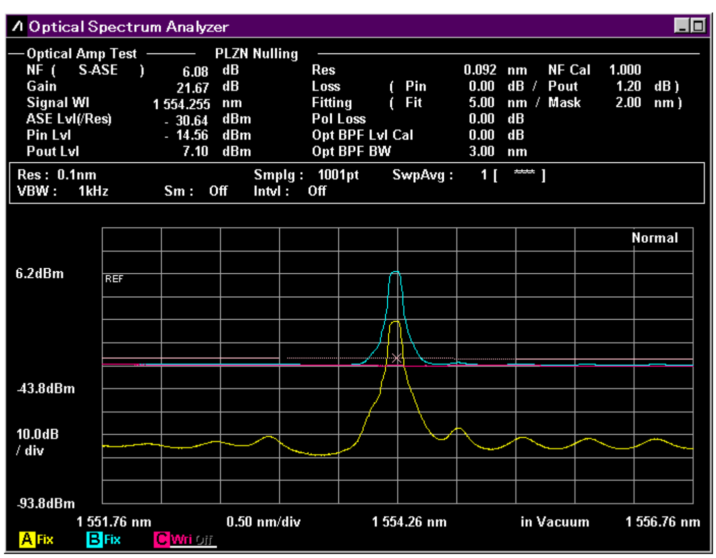
B) Measurement Procedure

(1) Measure the insertion loss of the polarizer and input it to the Pout loss parameter.
(2) Directly input the output of the polarization controller to the OSA and measure the input signal Pin to the EDFA.
(3) Connect as shown in Figure 11 to switch the OSA measurement to Pase. Adjust the polarization controller and detector so that the level of the signal observed by the OSA becomes minimum and stop the OSA sweeping with the level at the minimum and capture the ASE spectrum. Polarization adjustment is simplified by setting the OSA VBW to the maximum bandwidth at which ASE can be accurately observed.
(4) Switch the OSA measurement to Pout and adjust the polarization controller and analyzer to maximize the monitoring signal level. Stop the OSA sweep at the maximum level and capture the Pout spectrum.
(5) Set the Fitting Span and Masked Span for the captured ASE spectrum for level interpolation. For details, see section 3.1 Level Interpolation Method.

C) Measurement Results

Figure 12 shows the NF/gain measurement results using the MS9740A polarization nulling method.

Figure 12: NF/gain measurement example using polarization nulling method



D) Precautions at Polarization Nulling Measurement

In this method, the polarization controller and detector must always be adjusted according to the polarization state of the measured optical signal. If the DOP (degree of polarization) of optical input and the extinction ratio of the polarizer are inadequate, the optical signal cannot be fully controlled/nulled, causing measurement error. In addition, since the polarization controller and detector insertion loss and polarization dependency (PDL) have a direct impact on measurement accuracy, it is necessary to use devices with small PDL.

3-3. Pulse Method (WDM method)

When using the MS9740A with the pulse method, either the "Pulse Method" can be selected when using a single light source for measurement, or the "WDM Method" can be selected for WDM signals. When a WDM signal is amplified by the EDFA, the NF characteristics are different from when measuring a single signal using the same EDFA.

The purpose of the WDM Method is to measure the NF and gain of amplified signals more accurately by measuring one of the WDM signals using the Pulse Method.

A) Figures 13-1 and 13-2 show the NF/gain measurement system using pulse method.

Figure 13-1: Pulse method measurement system using MS9740A

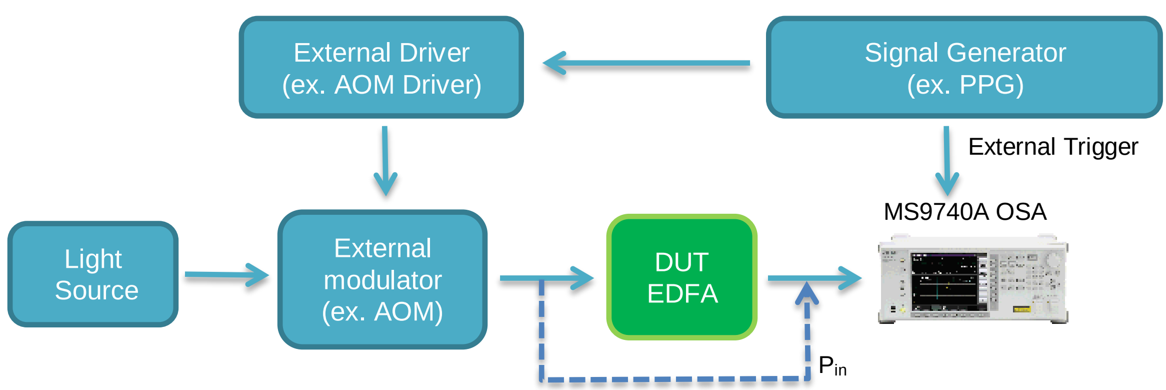
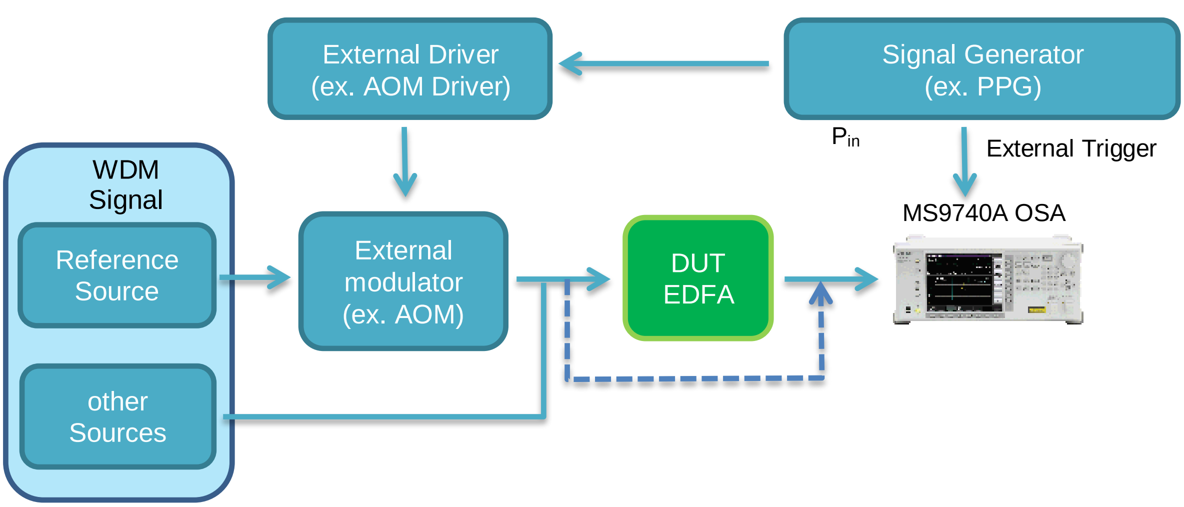


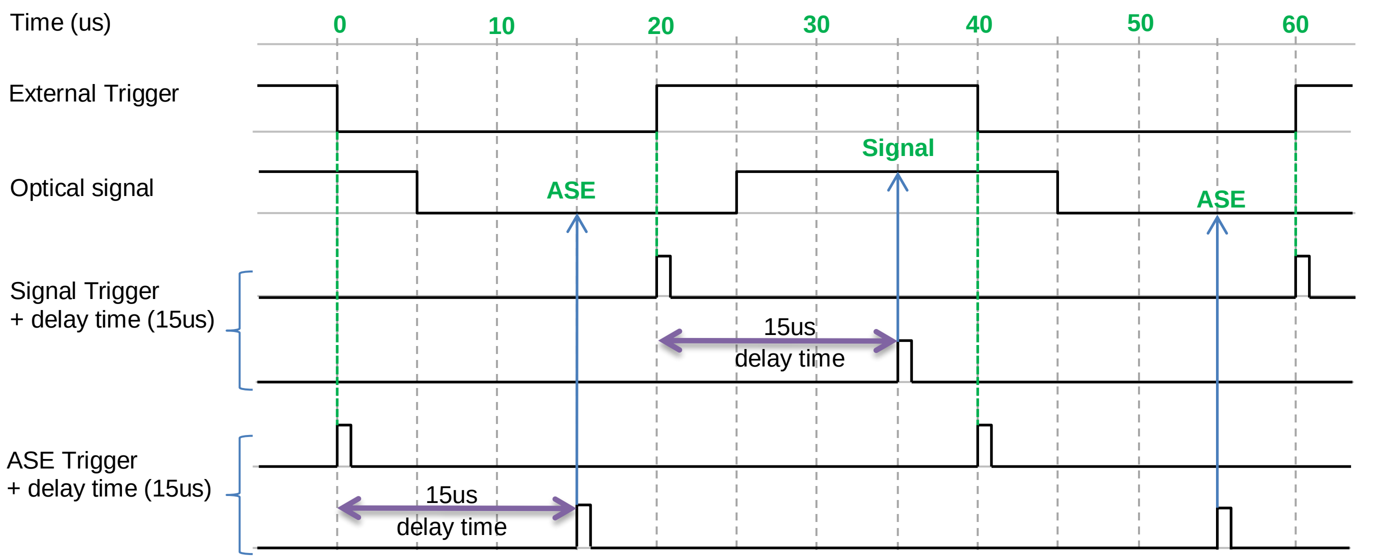
Figure 13-2: WDM method measurement system



B) Measurement Timing Chart

Figure 14 shows the pulse method timing chart using the MS9740A. In this measurement, the amplified signal is measured from the rising edge of the external trigger input to the OSA until the point when the delay time has elapsed; the ASE is measured at the point after the delay time from the trigger falling edge.

Fig. 14: Pulse method measurement time timing chart (delay time = 15 µs)



C) Measurement Procedure

(1) Set the OSA measurement mode to the external trigger mode and the VBW to a wider bandwidth than the trigger signal frequency (1 MHz or 100 kHz preferred). Input the synchronizing clock from the signal generator to the external trigger terminal on the back panel of the OSA.

(2) Directly input the AOM output to the OSA and adjust the delay time so the measurement level is maximum. Measure the input level Pin at the maximum level.

(3) Connect the EDFA as shown in Figures 13-1 or 13-2 and switch the OSA measurement memory to Pout. Adjust the delay time to the maximum measurement level and measure the EDFA output Pout at the maximum level. The ASE is measured automatically at each measurement point in chronological order. (See the timing chart.)

D) Measurement Results

Figure 15 shows an NF/gain measurement example using the MS9740A pulse method. An AOM with an extinction ratio of 40 dB is used as an external modulator for this measurement.

There is slight distortion in the ASE level but this is error caused by the AOM extinction ratio. The error due to the extinction ratio is explained in item E)-a)

Figure 16 shows the measurement result for a multiplexed signal using the WDM Method. Although this measurement uses the same EDFA, since the ratio of the signal level and ASE level is about 30 dB, it is clear that measurement is possible without ASE level distortion.

Figure 15: Pulse Method measurement

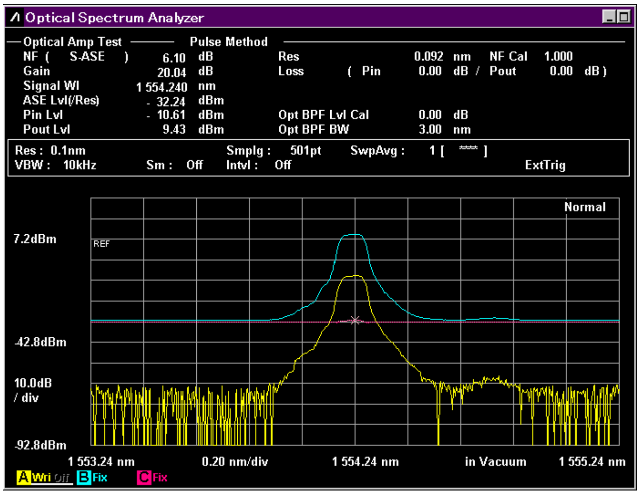
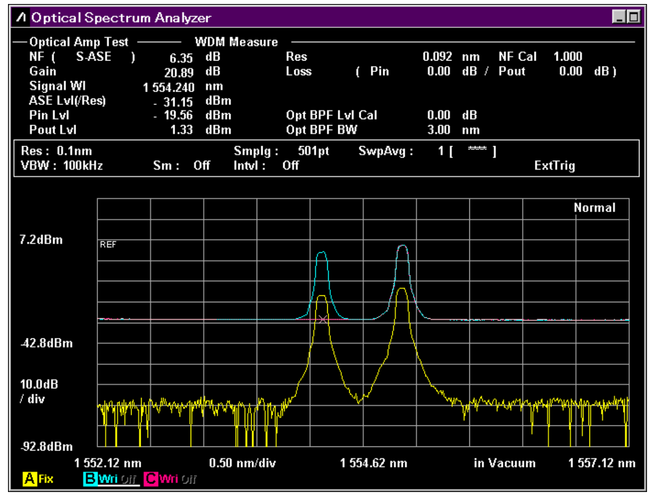


Figure 16: WDM Method measurement



E) Precautions for Pulse Method

a). Measurement error and delay time relation

An erbium-ion doped EDFA requires several ms to recover from the metastable state. As a result, during the period for several ms immediately after the optical signal goes off, the ASE level can be considered as almost equal to the state with an optical signal present. On the other hand, when measuring ASE, the OSA optical receiver may be completely saturated immediately after the signal goes off and some short time may be required to recover from this saturation state. This time depends on the level difference between the amplified optical signal and the ASE; it is about 10 µs when the level difference is 30 dB. If an inadequate delay time is set, precautions will be required to prevent measurement error.

In addition, if the EDFA itself has a built-in output control function such as ALC (Auto Level Control), precautions such as pre-adjustment of the ALC feedback period and optimum trigger frequency are required because changes in the optical output when the optical input goes off are controlled automatically.

b). Measurement error caused by optical source on/off extinction ratio

The optical signals must be off when measuring the ASE level. For example, if the extinction ratio of the modulated light input to the EDFA is inadequate, the optical signal level will leak into the ASE level, causing the same error as in item a). For example, when the level difference between the amplified optical signal and ASE is about 35 dB, measurement with an error of less than 0.1 dB requires an optical source with an on/off extinction ratio of more than 55 dB.

c). Trigger frequency and VBW setting

Since the VBW must be set to a sufficiently higher frequency than the trigger frequency, when the DUT has a high S/N ratio, the ASE may be buried in the noise of the OSA itself, preventing accurate measurement.

Based on the above precautions, although the Pulse Method is very effective for measuring WDM signals, at measurement, it is necessary to make adjustments to the measurement system starting from the DUT EDFA properties and pulse driver switching characteristics.

In addition, care is required because if the pulse repetition frequency is slower than required, a much larger power than the EDFA Q switch oscillation may be output, possibly causing damage to peripheral equipment, including measuring instruments. (IEC recommends a repetition frequency of 10 kHz or more.)

4. Summary

This document summarizes EDFA NF and gain measurements using Anritsu's MS9740A OSA. If future EDFA evaluations will require more accurate measurements, Anritsu will investigate further work to develop measurement systems offering better data collection and even more precise measurements.

Note: Patent-related Issues

EDFA measurement using the pulse method is covered by NTT US Patent No. 5, 521, 751 and Agilent Technologies Inc. US Patent No. 5, 340, 979. Consequently, there are potential patent-related issues when using the measurement method described in section 3.3 of this document with an optical spectrum analyzer. In this case, customers using an optical spectrum analyzer for measurement may have problems other than the optical spectrum analyzer. As a result, it is the responsibility of the customer to choose a measurement method, considering countermeasures to the above patent issues.

Anritsu

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