# OSA: Optical Amplifier (EDFA) Measurement Guide

**Applicable model: AQ6380/AQ6370 series/AQ6360, except AQ6373 family**

## 1. Outline of Optical amplifier measurement

With the increase in communication traffic, the importance of optical amplifiers such as EDFAs (erbium-doped fiber amplifiers) that can directly amplify optical signals without converting them into electrical signals has been widely deployed in traditional backbone optical transmission networks. This proven amplification technique has expanded to a next generation application to boost free space communication laser signals for orbiting satellite communication networks.

Optical amplifiers are primarily evaluated by GAIN and NF (noise figure). The Yokogawa OSAs offers a built-in EDFA-NF analysis function to easily measure these characteristics. Simply measure the spectra of input and output of the optical amplifier, using Trace A and Trace B respectively, and execute the analysis function.

Figure 1 shows the basic configuration of an optical amplifier measurement. A polarization scrambler can be added before the OSA to reduce the effects of the OSA's polarization dependence.

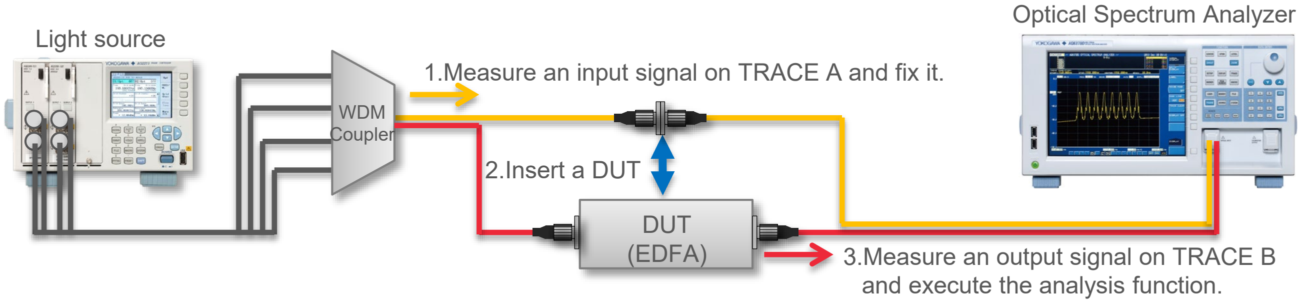


Fig. 1 Typical setup of EDFA measurement

## 2. EDFA-NF analysis function

The applicable models are equipped with an optical amplifier analysis function (EDF A-NF) that automatically calculates the gain and noise figure (NF) of the optical ampl ifier from the input and output optical spectrum of the optical amplifier.
This function can obtain accurate gain and noise figure by excluding the spontaneou s emission light (SSE) of the light source amplified by the optical amplifier.

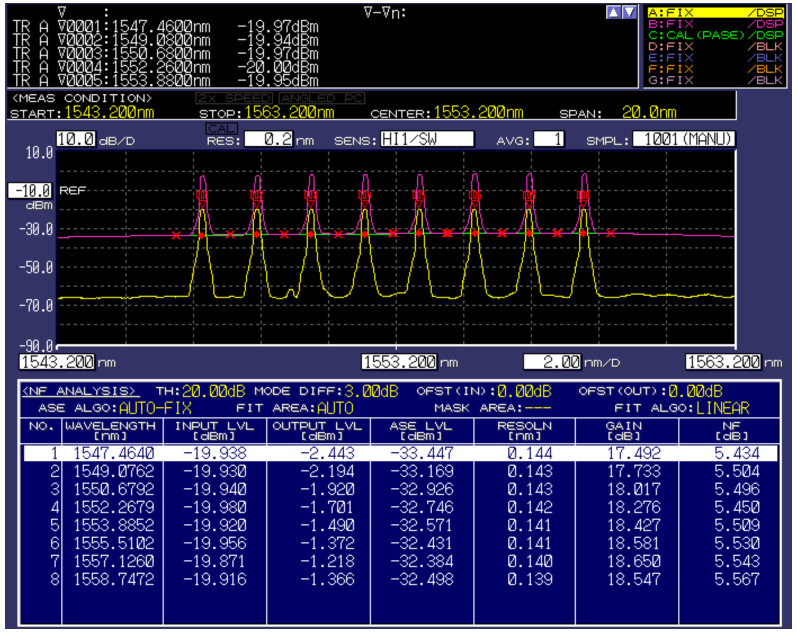


Fig. 2 EDFA-NF analysis results

- Calculate the gain and NF for each channel of the input optical signal. (Compatible with DWDM signals.)
- Analysis results such as wavelength, gain, and NF are displayed in a list or graph for each channel.
- Possible to set analysis parameters such as channel detection and ASE level detection

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## 3. Perform before measurement

In order to accurately measure the characteristics of an optical amplifier, it is necessary to calibrate the optical spectrum analyzer and correct the offset of the optical power value due to external loss before making the measurement.

### ■ Optical Alignment and Wavelength Calibration [SYSTEM]

- Execute <OPTICAL ALIGNMENT> in [SYSTEM] which performs both Optical Alignment adjustment and Wavelength calibration using the internal calibration light source.
- The output of calibration light source needs to be connected to the Optical input port using a single mode fiber before the execution.
- For models that do not have the internal calibration light source, calibrate using a single wavelength light source with stable output, such as a DFB-LD.
- For details, refer to the user manual. (For AQ6370D, Chapter 3.6)

### ■ Resolution Calibration [SYSTEM]

- The resolution calibration function calibrates the resolution bandwidth of the OSA to the equivalent noise bandwidth (Fig. 3), using an external light source.
- The IEC standards require the Equivalent Noise bandwidth for the optical amplifier measurement.
- The resolution calibration is recommended because the filter response of an optical spectrum analyzer is not rectangular typically, and thus the Resolution bandwidth defined as FWHM (Fig. 4) differs slightly from the equivalent noise bandwidth.
- This function is effective especially when the wavelength resolution is 0.05 nm or less for example as the difference becomes prominent.
- As for an external light source, use a stabilized single-mode laser light source with an output power of -20 dBm or more, a level stability of 0.1 dBp-p or less, and an output line width of 5 MHz or less.
- For details, refer to the user manual. (For AQ6370D, Chapter 3.8)

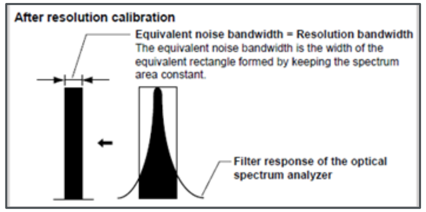

Fig. 3 Equivalent Noise bandwidth

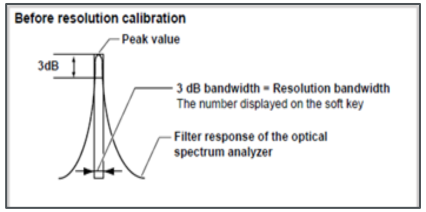

Fig. 4 Resolution bandwidth (FWHM)

### ■ Absolute Power Calibration with Optical Power Meter

- The absolute power reading of the OSA must be calibrated before measurement.
- As for the measurement light source, use a single-wavelength light source with stable output, such as DFB-LD.
- The power correction factor (PCF) is calculated by the following formula.

  PCF (dB) = P_OPM (dBm) - P_OSA (dBm).

  P-OPM: The optical power value on the optical power meter (dBm)

  P-OSA: The spectral peak power value on the OSA (dBm)
- To correct the OSA reading, enter the above PCF value to <LEVEL SHIFT> in [SYSTEM].

### ■ Optical Power Correction (Power Offset)

- EDFA analysis requires the correct input and output power of the EDFA. Therefore, if optical connectors, optical splitters, optical switches, etc. are inserted between the light source and the EDFA input or between the EDFA output and the OSA, it is necessary to compensate for those losses.
- After calibrating the absolute power using an optical power meter, make sure there is an extra loss that causes an error in the absolute power reading.
- Determine an additional losses in both the input and output paths of EDFA and set correction values to OFFSET (IN) and (OUT) respectively in <Parameter setting> Interpolation setting.

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## 4. Tips for Setting the Analysis Parameters (1/2)

The EDFA analysis function has a selection of various analysis parameters to meet the analysis needs of customers. This section provides a description of the main analysis parameters and some commonly used settings. The title of each parameter is described according to the analysis parameter of the product.

### A. Interpolation setting
### ASE Algorithm (ASE ALGO)

- Select the ASE power calculation algorithm and define the range of ASE data used for the interpolation method.
- In general, the "AUTO-FIX" setting is often used.

| | | |
|---|---|---|
| ✓ | ***AUTO-FIX*** | ***FIT ALGO: LINEAR (fixed)***<br>*FIT AREA:  AUTO (Point)*<br>*- Single channel: at λ ± a preset value (nm)*<br>*- Multi channels: at λ ± Channel spacing/2 (Minimum value among channels)*<br>*MASK AREA: Disabled* |
| | *AUTO-CTR* | ***FIT ALGO: LINEAR (fixed)***<br>*FIT AREA:  Between CH (Point)*<br>*- Single channel: at λ ± a preset value (nm)*<br>*- Multi channel: at λi ± Channel spacing/2*<br>*MASK AREA: Disabled* |
| | *MANUAL-CTR* | ***FIT ALGO: All settings***<br>*FIT AREA: Between CH  (Area or point)*<br>*- Single channel: at λ ± a preset value (nm)*<br>*- Multi channel: at λi ± Channel spacing/2*<br>***MASK AREA: **.** nm*** *(Disabled when FIT ALGO is LINEAR)* |
| | *MANUAL-FIX* | ***FIT ALGO: All settings***<br>***FIT AREA: **.** nm*** *(Area or point)*<br>***MASK AREA: **.** nm***  *(Disabled when FIT ALGO is LINEAR)* |

### B. Interpolation setting
### Fitting Algorithm (FITTING ALGO)

- Select the best fitting algorithm for the ASE spectrum from the following.
  LINEAR, GAUSS, LORENZ, 3RD POLY, 4TH POLY, 5TH POLY
- We recommend "LINEAR" setting. which is IEC standard compliant
- When the ASE calculation algorithm is set to "AUTO-FIX" or "AUTO-FIX", the Fitting Algorithm is automatically set to "LINEAR".

| | | |
|---|---|---|
| ✓ | ***LINEAR*** | ***IEC standard compliant***<br>*This mode uses only two points on the left and right of the channel for the interpolation.* |

### C. NF calculation setting
### Resolution Bandwidth (RES BW)

- Select the definition of the resolution bandwidth (RB) for the EDFA analysis function.
- It is recommended to use the resolution calibration function and the CAL DATA setting together. It complies IEC standard.

| | | |
|---|---|---|
| ✓ | ***CAL DATA*** | ***<u>With Resolution Calibration</u>***<br>***IEC standard compliant***<br>*It uses the resolution bandwidth stored by the Resolution Calibration*<br>*RB = Equivalent Resolution Bandwidth*<br>*Recommend especially when the wavelength resolution is  0.05 nm or less for example.* |
| | ***CAL DATA*** | ***<u>Without Resolution Calibration</u>***<br>*It uses factory calibrated resolution bandwidth stored in the internal memory (FWHM)*<br>*BB = FWHM (Factory-calibrated)*<br>*Recommend especially when the wavelength resolution is  0.05 nm or less for example.* |
| | ***MEASURED*** | *It determines a FWHM from the actual spectrum on TRACE B and set to RB.*<br>*RB = FWHM of the actual spectrum (Traditional method)* |

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## 4. Tips for Setting the Analysis Parameters (2/2)

### D. Other setting

#### SIGNAL POWER

- Select how to obtain the optical signal power.
- The "PEAK" setting is typically used because a continuous wave (CW) laser light source is used for the EDFA measurements.

| | | |
|---|---|---|
| ✓ | ***PEAK*** | *The signal power is defined as the spectral peak power.*<br>*Select when the spectral width of the signal is smaller than the wavelength resolution of OSA, such as with a CW laser light source.* |
| | *INTEGRAL* | *The signal power is defined as the integrated power of the center wavelength ± **INTEGRAL RANGE** (GHz).*<br>*Select when the spectral width of the signal is greater than the wavelength resolution of the OSA, such as a modulated laser source.* |

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## 5. Algorithm of EDFA-NF analysis (1/4)

The analysis algorithm of the EDFA analysis function is shown in comparison with the IEC standard.

IEC 61290-10-4:2007 Optical amplifiers - Test methods - Part 10-4: Multichannel parameters - Interpolated source subtraction method using an optical spectrum analyzer

Yokogawa's OSA uses formulas that use the optical power (W), optical wavelength (m), and wavelength resolution (m) that are directly obtained from the OSA measurement results, while IEC calculation formula uses optical power (dBm), optical frequency (Hz), and frequency resolution (Hz). However, the result is the same for both formulas.

### Example of measurement parameters and analysis results

**YOKOGAWA**

| | | | |
|---|---|---|---|
| λ | 1550.00 | nm | Signal wavelength |
| RB | 0.10 | nm | Resolution bandwidth of OSA **(Equivalent Noise Bandwidth)** |
| c | 299792458 | m/s | Velocity of light in vacuum |
| h | 6.62608E-34 | Js | Planck's constant |

*Sample data*

| | | | |
|---|---|---|---|
| $L_{IN}'$ | 1.00E-04 | W | **OSA reading** $L' = 10^{\frac{P-30}{10}}$ (Convert each dBm value in the IEC table on the right to a linear value.) |
| $L_{OUT}'$ | 3.16E-02 | W | |
| $L_{ASE}'$ | 1.26E-06 | W | |
| $L_{SSE}'$ | 1.00E-10 | W | |
| Gain | 25.00 | dB | G= 10log ($L_{OUT\_SIG}$ / $L_{IN}$) |
| NF | 3.85 | dB | $NF = 10log(\frac{1}{hc^2} \times \frac{\lambda^3}{RB} \times \frac{L_{ASE\_AMP}}{G'})$ |

**IEC 61290-10-4:2007**

| | | | |
|---|---|---|---|
| λ | 1550.00 | nm | Signal wavelength |
| $\Delta\lambda_{BW}$ | 0.10 | nm | Resolution bandwidth of OSA **(Equivalent Noise Bandwidth)** |
| c | 299792458 | m/s | Velocity of light in vacuum |
| h | 6.62608E-34 | Js | Planck's constant |
| v | 1.93E+14 | Hz | Signal Frequency $v = C/\lambda$ |
| $B_0$ | 1.25E+10 | Hz | Frequency resolution bandwidth $B_0 = c[(\lambda - \Delta\lambda_{BW}/2)^{-1} - (\lambda + \Delta\lambda_{BW}/2)^{-1}]$ |

*Sample data*

| | | | |
|---|---|---|---|
| $P_{IN\_OSA}$ | -10.00 | dBm | **OSA reading** |
| $P_{OUT\_OSA}$ | +15.00 | dBm | |
| $P_{ASE\_OSA}$ | -29.00 | dBm | |
| $P_{SSE\_OSA}$ | -70.00 | dBm | |
| Gain | 25.00 | dB | G = $P_{OUT\_SIG}$ - $P_{IN}$ |
| NF | 3.85 | dB | $NF = P_{ASE\_AMP} - G - 10log[hvB_0]$ |

# OSA: Optical Amplifier (EDFA) Measurement Guide

## 5. Algorithm of EDFA-NF analysis (2/4)

**YOKOGAWA (in Watt)**

| | Parameters | Data | | Descriptions |
|---|---|---|---|---|
| 1 | **Optical power correction** | | | |
| | PCF | | | The absolute power correction factor (vs OPM)<br>It affects to both Gain and NF values.<br>**Not used. Because it must be corrected prior to OSA measurements using <LEVEL SHIFT> of [SYSTEM].** |
| | **$OFFSET_{IN}$** | See "Optical Power Correction" on page 2. +0.00 | dB | Offset for an additional loss for EDFA input path<br>Set OFFSET (IN) in <Parameter setting> Interpolation setting |
| | **$OFFSET_{OUT}$** | +0.00 | dB | Offset for an additional loss for EDFA output path<br>Set OFFSET (OUT) in <Parameter setting> Interpolation setting |
| 2 | **Input signal power ($L_{IN}$)** | | | |
| | $L_{IN}'$ | 1.00E-04 | W | **Obtained on Trace A (EDFA input)** |
| | PCF | | | Not used. It must be corrected prior to OSA measurements. |
| | $OFFSET_{IN}'$ | 1.00 | | $OFFSET_{IN}' = 10^{\frac{OFFSET_{IN}}{10}}$ |
| | $L_{IN}$ | 1.00E-04 | W | $L_{IN} = L_{IN}' \times OFFSET_{IN}'$ |
| 3 | **Output signal power ($L_{OUT}$)** | | | |
| | $L_{OUT}'$ | 3.16E-02 | W | **Obtained on Trace B (EDFA output)** |
| | PCF | | | Not used. It must be corrected prior to OSA measurements. |
| | $OFFSET_{OUT}'$ | 1.00 | | $OFFSET_{OUT}' = 10^{\frac{OFFSET_{OUT}}{10}}$ |
| | $L_{OUT}$ | 3.16E-02 | W | $L_{OUT} = L_{OUT}' \times OFFSET_{OUT}'$ |

**IEC 61290-10-4:2007 (in dBm)**

| | Parameters | Data | | Descriptions |
|---|---|---|---|---|
| 1 | **Optical power correction** | | | |
| | PCF | | dB | The absolute power correction factor (vs OPM)<br>PCF = P_PM - P_OSA |
| | | | | Not used. It is considered as a part of uncertainty |
| | | | | Not used. It is considered as a part of uncertainty |
| 2 | **Input signal power ($P_{IN}$)** | | | |
| | $P_{IN\_OSA}$ | -10.00 | dBm | **OSA reading (EDFA input)** |
| | PCF | +0.00 | dB | The absolute power correction factor (vs OPM) |
| | | | | Not used. It is considered as a part of uncertainty. |
| | $P_{IN}$ | -10.00 | dBm | $P_{IN} = P_{IN\_OSA} + PCF$ |
| 3 | **Output signal power ($P_{OUT}$)** | | | |
| | $P_{OUT\_OSA}$ | +15.00 | dBm | **OSA reading (EDFA output)** |
| | PCF | +0.00 | dB | The absolute power correction factor (vs OPM) |
| | | | | Not used. It is considered as a part of uncertainty. |
| | $P_{OUT}$ | +15.00 | dBm | $P_{OUT} = P_{OUT\_OSA} + PCF$ |

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## 5. Algorithm of EDFA-NF analysis (3/4)

| | YOKOGAWA (in Watt) | | | |
|---|---|---|---|---|
| 4 | **Output ASE power ($L_{ASE}$)** | | | |
| | $L_{ASE}'$ | 1.26E-06 | W | **Obtained on Trace B (EDFA output)** |
| | PCF | | | Not used. It must be corrected prior to OSA measurements. |
| | $OFFSET_{OUT}'$ | 1.00 | | $OFFSET_{OUT}' = 10^{\frac{OFFSET_{OUT}}{10}}$ |
| | $L_{ASE}$ | 1.26E-06 | W | $L_{ASE}=L_{ASE}' \times OFFSET_{OUT}'$ |
| | **$P_{ASE}$** | **-29.00** | **dBm** | $P_{ASE} = 10\log(L_{ASE} \times 1000)$ |
| 5 | **Actual output signal power ($L_{OUT\_SIG}$)** | | | |
| | $L_{OUT\_SIG}$ | 3.16E-02 | W | $L_{OUT\_SIG}=L_{OUT} - L_{ASE}$ |
| 6 | **Gain (G)** | | | |
| | $G'$ | 316.22 | | $G' = L_{OUT\_SIG} / L_{IN}$ |
| | **G** | **25.00** | **dB** | **Analysis result** $G = 10\log(G')$ |
| 7 | **Input SSE power ($L_{SSE}$)** | | | |
| | $L_{SSE}'$ | 1.00E-10 | W | Obtained on Trace A (EDFA input)<br>This process is actually done<br>in the actual ASE power calculation. |
| | PCF | | | Not used. It must be corrected prior to OSA measurements. |
| | $OFFSET_{IN}'$ | 1.00 | | $OFFSET_{IN}' = 10^{\frac{OFFSET_{IN}}{10}}$ |
| | **$L_{SSE}$** | **1.00E-10** | **W** | $L_{SSE}=L_{SSE\_OSA} \times OFFSET_{IN}'$ |

| | IEC 61290-10-4:2007 (in dBm) | | | |
|---|---|---|---|---|
| 4 | **Output ASE power ($P_{ASE}$)** | | | |
| | $P_{ASE\_OSA}$ | -29.00 | dBm | **OSA reading (EDFA output)** |
| | PCF | +0.00 | dB | The absolute power correction factor (vs OPM) |
| | | | | Not used. It is considered as a part of uncertainty. |
| | | | | Not used. |
| | **$P_{ASE}$** | **-29.00** | **dBm** | $P_{ASE}=P_{ASE\_OSA} + PCF$ |
| 5 | **Actual output signal power ($P_{OUT\_SIG}$)** | | | |
| | $P_{OUT\_SIG}$ | +15.00 | dBm | $P_{OUT\_SIG} = 10log_{10}\left[10^{\frac{P_{OUT}}{10}} - 10^{\frac{P_{ASE}}{10}}\right]$ |
| 6 | **Gain (G)** | | | |
| | $G'$ | 316.22 | | Not used.<br>Convert (dB) to a linear value for the NF formula (a). |
| | **G (dB)** | **25.00** | **dB** | **Analysis result** $G(dB) = P_{OUT\_SIG} - P_{IN}$ |
| 7 | **Input SSE power ($P_{SSE}$)** | | | |
| | $P_{SSE\_OSA}$ | -70.00 | dBm | **OSA reading (EDFA input)** |
| | PCF | +0.00 | dB | The absolute power correction factor (vs OPM) |
| | | | | Not used. It is described as a part of uncertainty. |
| | **$P_{SSE}$** | **-70.00** | **dBm** | $P_{SSE} = P_{SSE\_OSA} + PCF$ |

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## 5. Algorithm of EDFA-NF analysis (4/4)

| YOKOGAWA (in Watt) | | | | |
|---|---|---|---|---|
| 8 | ***Actual ASE power ($L_{ASE\_AMP}$)*** | | | |
| | $L_{ASE\_AMP}$ | **1.23E-06** | **W** | *Interpolated source subtraction (ISS)*<br>***Calculated on Trace C***<br>*by using the curve fitting and interpolation techniques*<br>$L_{ASE\_AMP} = L_{ASE} - G' \times L_{SSE}$ |
| 9 | ***Noise figure (NF)*** | | | |
| | ***NF*** | ***3.85*** | ***dB*** | ***Analysis result***<br>$NF(dB) = 10log(\frac{1}{hc^2} \times \frac{\lambda^3}{RB} \times \frac{L_{ASE\_AMP}}{G'})$<br>*$L_{ASE\_AMP}$ (W), G' (linear), λ (m), RB (m), h (Js)*<br>*Yokogawa OSA calculates the NF using wavelength data such as λ and RB. The power is in W.* |
| | *NF w/shot noise* | *3.86* | *dB* | *NF formula (a) with Shot noise (for reference)*<br>$NF(dB) = 10log(\frac{1}{hc^2} \times \frac{\lambda^3}{RB} \times \frac{L_{ASE\_AMP}}{G'} + \frac{1}{G'})$<br>*It is provided to maintain compatibility with data acquired in the past.* |

| IEC 61290-10-4:2007 (in dBm) | | | | |
|---|---|---|---|---|
| 8 | ***Actual ASE power ($P_{ASE\_AMP}$)*** | | | |
| | $P_{ASE\_AMP}$ | ***-29.11*** | ***dBm*** | *Interpolated source subtraction (ISS)*<br>$P_{ASE\_AMP} = 10log_{10}[10^{\frac{P_{ASE}}{10}} - 10^{\frac{G+P_{SSE}}{10}}]$ |
| | $L_{ASE\_AMP}$ | *1.23E-06* | *W* | *Not used.*<br>*Convert (dBm) to (W) for the NF formula (a)*<br>$L_{ASE\_AMP} = 10log[10^{\frac{P_{ASE\_AMP}}{10}}]$ |
| 9 | ***Noise figure (NF)*** | | | |
| | ***NF*** | ***3.85*** | ***dB*** | ***Analysis result***<br>$NF(dB) = P_{ASE\_AMP} - G - 10log[h\nu B_0]$<br>*$P_{ASE\_AMP}$ (dBm), G (dB), ν (Hz), $B_0$ (Hz), h (mJs)*<br>*Planck's constant is set to (mJs) according to $P_{ASE\_AMP}$ (dBm).* |
| | *NF (a)* | *3.85* | *dB* | *NF formula (a) (for reference)*<br>$NF(dB) = 10log(\frac{L_{ASE\_AMP}}{h\nu B_0 G'})$ |
| | *NF (a) w/shot noise* | *3.86* | *dB* | *NF formula (a) with Shot noise (for reference)*<br>$NF(dB) = 10log(\frac{L_{ASE\_AMP}}{h\nu B_0 G'} + \frac{1}{G'})$<br>*The current IEC/JIS standards do not require the shot noise.* |

# Revision note

| Rev # | Descriptions |
|---|---|
| 0 | • First edition |