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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Calibration of tuneable laser sources

Étalonnage des sources laser accordables

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CALIBRATION OF TUNEABLE LASER SOURCES

FOREWORD

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The text of this standard is based on the following documents:

CDV	Report on voting
86/443/CDV	86/459/RVC

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Wavelength-division multiplexing (WDM) transmission systems have been deployed in optical trunk lines. ITU-T Recommendations in the G.694 series describe the frequency and wavelength grids for WDM applications. For example, the frequency grid of G.694.1 supports a variety of channel spacing ranging from 12,5 GHz to 100 GHz and wider. WDM devices, such as arrayed waveguide grating (AWG), thin film filter or grating based multiplexers (MUX) and demultiplexers (DMUX) with narrow channel spacing are incorporated in the WDM transmission systems. When measuring the characteristics of such devices, wavelength tuneable laser sources are commonly used and are required to have well-calibrated performances; wavelength uncertainty, wavelength tuning repeatability, wavelength stability and output optical power stability are important parameters.

The tuneable laser source (TLS) is generally equipped with the following features:

a) the output wavelength is continuously tuneable in a wavelength range starting at 1 260 nm or higher and ending at less than 1 675 nm (the output should excite only the fundamental LP01 fibre mode);
b) an output port for optical fibre connectors.

The envelope of the spectrum is a single longitudinal mode with a FWHM of at most 0,1 nm. Any adjacent modes are at least 20 dB lower than the main spectral mode (for example, a distributed feedback laser diode (DFB-LD), external cavity laser, etc.)

CALIBRATION OF TUNEABLE LASER SOURCES

1 Scope

This International Standard provides a stable and reproducible procedure to calibrate the wavelength and power output of a tuneable laser against reference instrumentation such as optical power meters and optical wavelength meters (including optical frequency meters) that have been previously traceably calibrated.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60793-2-50, *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*

IEC 62129-2, *Calibration of wavelength/optical frequency measurement instruments – Part 2: Michelson interferometer single wavelength meters*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99:2007, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

3 Terms, definitions and abbreviations

For the purposes of this document, the following terms, definitions and abbreviations apply.

3.1 Terms and definitions

3.1.1
accredited calibration laboratory
calibration laboratory authorized by an appropriate national organization to issue calibration certificates that demonstrates traceability to national standards

3.1.2
adjustment
set of operations carried out on an instrument in order that it provides given indications corresponding to given values of the measurand

[SOURCE: IEC 60050-300:2001, 311-03-16, modified – minor editorial change, omission of the NOTE]

[See also ISO/IEC Guide 99:2007, 3.11, modified – 3 NOTES omitted].

3.1.3
calibration
set of operations that establish, under specified conditions, the relationship between the values of quantities indicated by a measuring instrument and the corresponding values realized by standards

Note 1 to entry: The results of a calibration permit either the assignment of measurand values to the indications or the determination of corrections with respect to the indications.

Note 2 to entry: A calibration may also determine other metrological properties such as the effects of influence quantities.

Note 3 to entry: The result of a calibration may be recorded in a document, called a calibration certificate or a calibration report.

[SOURCE: ISO/IEC Guide 99:2007, 2.39, modified – shortened; the two NOTES replaced by 3 new NOTES].

3.1.4
calibration conditions
conditions of measurement in which the calibration is performed

3.1.5
calibration at reference conditions
calibration which includes the evaluation of the uncertainty at reference conditions of the light source under calibration

3.1.6
calibration at operating conditions
calibration which includes the evaluation of the uncertainty at operating conditions of the light source under calibration

3.1.7
level of confidence
estimated probability that the true value of a measured parameter lies in the given range

3.1.8
coverage factor
k
used to calculate the expanded uncertainty U from the standard uncertainty, u

3.1.9
decibels
dB, dBm
sub-multiple of the Bel, B, unit used to express values of optical power on a logarithmic scale

Note 1 to entry: The power level is always relative to a reference power P_0

$$L_{P/P_0} = 10 \times \log_{10}\left(\frac{P}{P_0}\right)$$

where P and P_0 are expressed in the same linear units.

The unit symbol dBm is used to indicate power level relative to 1 mW:

$$L_{P/1\text{mW}} = 10 \times \log_{10}\left(\frac{P}{1\text{mW}}\right)$$

The linear ratio, R_{lin}, of two radiant powers, P_1 and P_2, can alternatively be expressed as an power level difference in decibels (dB):

$$\Delta L_P = 10 \times \log_{10}(R_{\text{lin}}) = 10 \times \log_{10}\left(\frac{P_1}{P_2}\right) = 10 \times \log_{10}(P_1) - 10 \times \log_{10}(P_2)$$

Similarly, relative uncertainties, U_{lin}, or relative deviations, can be alternatively expressed in decibels:

$$U_{\text{dB}} = \left|10 \times \log_{10}\left|(1 - U_{\text{lin}})\right|\right|$$

Note 2 to entry: For mathematical treatment all measurement results should be expressed in linear units (e.g. watts) and all uncertainties should be expressed in linear form. This is recommended because the accumulation of uncertainties in logarithmic units is mathematically difficult. The final statement of an uncertainty may be either in the linear or in the dB form.

Note 3 to entry: ISO 80000-3 and IEC 60027-3 should be consulted for further details. The rules of IEC 60027-3 do not permit attachments to unit symbols. However the unit symbol dBm is accepted in this standard because it is widely used and accepted by users of fibre optic instrumentation.

3.1.10
optical power deviation
D_{P}
difference between the set power of the light source under calibration, P_{TLS}, and the corresponding reference power P_{meas}, measured by the reference power meter

$$D_{\text{P}} = \frac{P_{\text{TLS}} - P_{meas}}{P_{meas}}$$

3.1.11
operating conditions
appropriate set of specified ranges of values with influence quantities usually wider than the reference conditions for which the uncertainties of a measuring instrument are specified

Note 1 to entry: Operating conditions and the uncertainty at operating conditions are usually specified by the manufacturer for the convenience of the user.

3.1.12
reference conditions
conditions used for testing the performance of a measuring instrument or for the intercomparison of the measurement results

Note 1 to entry: Reference conditions generally include reference values or reference ranges for the quantities influencing and affecting the measuring instrument.

3.1.13
side-mode suppression ratio
SMSR
peak power ratio between the main mode spectrum and the largest side mode spectrum in a single-mode laser diode such as a DFB-LD

Note 1 to entry: Side-mode suppression ratio is usually expressed in dB.

3.1.14
wavelength
wavelength (in a vacuum) of a light source

3.1.15
wavelength deviation
D_λ
difference between the target wavelength, set on the light source under calibration, λ_{TLS}, and the measured wavelength, λ_{meas}, in nm or µm

$$D_\lambda = \lambda_{\text{TLS}} - \lambda_{meas}$$

3.2 Abbreviations

APC	Angled physical contact
DFB-LD	Distributed feedback laser diode
FWHM	Full-width/half-maximum
OSA	Optical spectrum analyser
SMSR	Side-mode suppression ration
TLS	Tuneable laser source
WDM	Wavelength-division multiplexing

4 Preparation for calibration

4.1 Organization

The calibration laboratory should satisfy requirements of ISO/IEC 17025.

There shall be a documented measurement procedure for each type of calibration performed, giving step-by-step operating instructions and equipment to be used.

4.2 Traceability

The requirements of ISO/IEC 17025 should be met.

All standards used in the calibration process shall be calibrated according to a documented program with traceability to national standards laboratories or to accredited calibration laboratories.

It is advisable to maintain more than one standard on each hierarchical level, so that the performance of the standard can be verified by comparisons on the same level. Make sure that any other calibration equipment which have a significant influence on the calibration results are calibrated.

4.3 Preparation

The environmental conditions shall be commensurate with the level of uncertainty that is required for calibration:

a) calibrations shall be carried out in a clean environment;
b) temperature monitoring and control is required;
c) all laser sources shall be safely operated (refer to IEC 60825-1 and IEC 60825-2);
d) the output of the tuneable laser source should be examined with an optical spectrum analyser (OSA) to check for single mode operation.

The recommended temperature is 23 °C (for example, 23 °C ± 2 °C). Give the calibration equipment a minimum of 2 h prior to testing to reach equilibrium within its environment. Allow the tuneable laser source a warm-up period in accordance to the manufacturer’s instructions.

4.4 Reference calibration conditions

The reference calibration conditions usually include the following parameters and, if necessary, their tolerance bands: date, temperature, relative humidity, atmospheric pressure, displayed optical power, displayed wavelength, fibre, connector-adapter combination, (spectral) bandwidth and resolution bandwidth (spectral resolution) set. Unless otherwise specified, use a single-mode optical fibre category B1.1 or B1.3 pigtail as prescribed by IEC 60793-2-50, having a length of at least 2 m. It is desirable to perform all the calibration in a situation where back-reflections are negligible. Thus, angled connectors and isolators should be used wherever the situation permits.

Operate the tuneable laser source in accordance with the manufacturer’s specifications and operating procedures. Where practical, select a range of calibration conditions and parameters that emulate the actual field operating conditions of the tuneable laser source under calibration. Choose these parameters so as to optimize the tuneable laser source’s accuracy, as specified by the manufacturer’s operating procedures.

Document the conditions as specified in Clause 7.

NOTE The calibration results only apply to the set of calibration conditions used in the calibration process.

5 Wavelength calibration

5.1 Overview

The factors making up the uncertainty in the wavelength of the light source under calibration consist of

a) the intrinsic uncertainty of the light source under calibration as found in the calibration at reference conditions including temperature and time dependences for these tight conditions, and

b) the uncertainties due to dependences on optical power, temperature and time as found in the calibrations at broader operating conditions.

The wavelength calibration at reference conditions, for discrete wavelengths, as described in 5.2 is mandatory. The calibration at operating conditions, described in 5.3, is optional.

5.2 Wavelength calibration at reference conditions

5.2.1 Set-up

Figure 1 shows a system for wavelength calibration. The calibration is performed under the given reference conditions.

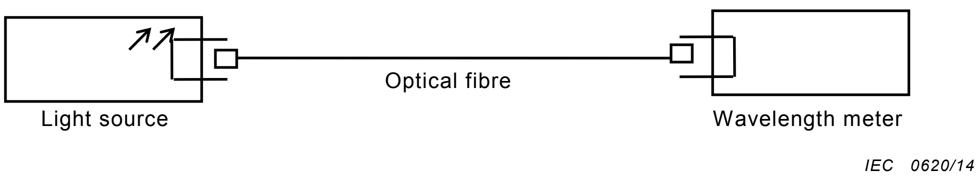

Figure 1 – Measurement set-up for wavelength calibration

5.2.2 Calibration equipment

A wavelength meter shall be used for the calibration. The wavelength meter should be calibrated using IEC 62129-2.

5.2.3 Procedure for wavelength calibration

The calibration procedure is as follows:

a) Regarding the calibration system shown in Figure 1, the set wavelength of the light source is given by $\lambda_{\mathrm{TLS}\ j}$ and the measured values are given by $\lambda_{meas\ i,j}$. The uncertainty of the wavelength measurement takes into account the tuning repeatability and hysteresis of the tuneable laser source (TLS). Hysteresis is defined as the deviation resulting from tuning the desired wavelength from both the shorter and the longer wavelengths.

b) Repeat the wavelength measurement $\lambda_{meas\ i,j}$ at least 10 times. Ensure that the TLS is tuned to $\lambda_{\mathrm{TLS}\ j}$ prior to each measurement. The target wavelength (j) should be approached in such a way that tuning occurs from both longer and shorter wavelengths.

c) Calculate the average measured wavelength: $\bar{\lambda}_{meas\ j}$

$$\bar{\lambda}_{meas,\ j} = \frac{1}{m}\sum_{i=1}^{m}\lambda_{meas\ i,j} \tag{1}$$

where m is the number of measurements performed. Each $\lambda_{meas\ i,j}$ is suggested to be an averaged value from the wavelength meter. Calculate the wavelength deviation: D_{λ_j}

$$D_{\lambda_j} = \lambda_{\mathrm{TLS}\ j} - \bar{\lambda}_{meas\ j} \tag{2}$$

where $\lambda_{\mathrm{TLS}\ j}$ is the tuned wavelength of the TLS.

d) Calculate the standard deviation for λ_j from the (m) wavelength measurement results: $\lambda_{meas\ i,j}$

$$s_{\lambda\ j} = \left[\frac{1}{m-1}\sum_{i=1}^{m}(\lambda_{meas\ i,j} - \bar{\lambda}_{meas\ j})^2\right]^{\frac{1}{2}} \tag{3}$$

e) Calculate the wavelength tuning repeatability: $S_{\mathrm{rep},\lambda_j}$

$$S_{\mathrm{rep},\lambda_j} = 2 \times s_{\lambda_j} \tag{4}$$

This calibration procedure shall be performed for each calibration wavelength. A minimum of 10 discrete wavelengths or every 10 nm, including the first, the central and the last wavelength of the range shall be measured.

5.2.4 Dependence on conditions

5.2.4.1 Temperature dependence (optional if known)

5.2.4.1.1 Set-up

Figure 2 shows a calibration system for temperature dependence. This calibration is performed under the reference calibration conditions with the exception of temperature.

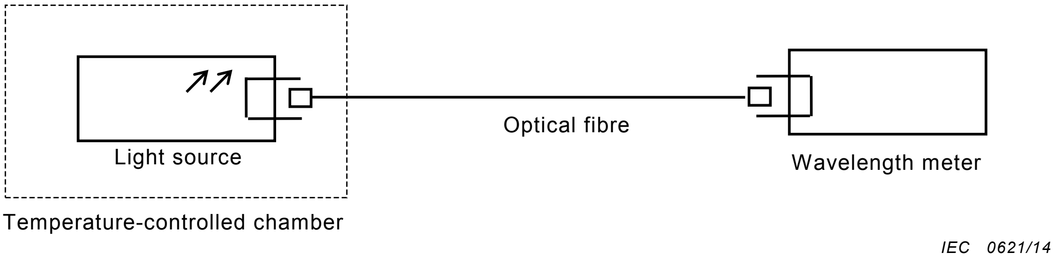

Figure 2 – Measurement set-up for temperature dependence

5.2.4.1.2 Calibration equipment

The calibration equipment is as follows:

a) A wavelength meter capable of detecting wavelength fluctuations at least ten times smaller than the wavelength stability of the TLS.

b) Temperature-controlled chamber: make sure that the measurement results are immune to the inner temperature distribution.

5.2.4.1.3 Calibration procedure for determining temperature dependence

The calibration procedure is as follows:

a) Regarding the calibration system of Figure 2, measure the nominal wavelength (j) of the TLS at optical power $P_{\mathrm{TLS}j}$ at reference conditions: $\lambda_{j,\mathrm{ref}}$. The wavelength used should possess the maximum response to temperature variations. Otherwise characterization of several output wavelengths should be performed.

b) Measure the wavelength of the TLS at temperature (i): λ_{j,Θ_i}. Wavelength readings corresponding to each temperature setting should be averaged to determine λ_{j,Θ_i}.

c) Calculate the relative wavelength deviation:

$$D_{\lambda_{j,\Theta_i}} = \lambda_{j,\Theta_i} - \lambda_{j,\mathrm{ref}} \qquad (5)$$

d) Repeat steps 2 and 3 with (m) different temperature settings Θ_i ensuring that the instrument is allowed the necessary time to eliminate sufficiently any thermal gradients.

e) Calculate the maximum $\max\left(D_{\lambda_{j,\Theta_i}}\right)\Big|_{i=1}^{i=m}$ and minimum $\min\left(D_{\lambda_{j,\Theta_i}}\right)\Big|_{i=1}^{i=m}$ wavelength deviations.

f) The standard uncertainty for wavelength temperature dependence $u_{\lambda_{j,\Delta\Theta}}$ at the calibration wavelength (j) using a rectangular distribution model is

$$u_{\lambda_{j,\Delta\Theta}} = \frac{1}{2\sqrt{3}}\left[\max\left(D_{\lambda_{j,\Theta_i}}\right)\Big|_{i=1}^{i=m} - \min\left(D_{\lambda_{j,\Theta_i}}\right)\Big|_{i=1}^{i=m}\right] \qquad (6)$$

where $\Delta\Theta$ is the temperature variation.

It is recommended that a wavelength acquisition be performed with the optical wavelength meter for the duration of this calibration.