IEC 62129-3

Edition 1.0 2019-05

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Calibration of wavelength / optical frequency measurement instruments – Part 3: Optical frequency meters internally referenced to a frequency comb

Étalonnage des appareils de mesure de longueur d'onde / appareil de mesure de la fréquence optique – Partie 3: Fréquencemètres optiques faisant référence en interne à un peigne de fréquence

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FOREWORD

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International Standard IEC 62129-3 has been prepared by IEC technical committee 86: Fibre optics.

This first edition cancels and replaces IEC TS 62129-3, published in 2014.

This edition includes the following significant technical changes with respect to the previous edition:

a) text has been added to 5.2.3 about calibration at a second optical frequency;
b) Annex D is now normative;
c) Subclause 4.2 has been improved;
d) measurement method of frequency has been moved to Annex B;
e) example of optical frequency comb has been moved to Annex C;
f) frequency-dependence uncertainty has been moved to Annex D.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
86/551/FDIS	86/554/RVD

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

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

A list of all parts in the IEC 62129 series, published under the general title *Calibration of wavelength/optical frequency measurement instruments*, can be found on the IEC website.

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

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- withdrawn,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

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INTRODUCTION

It is essential for realizing fibre optic systems that optical channels are defined in the optical frequency domain, not the wavelength domain. One example: the anchor frequency of the ITU-T grid is 193,1 THz, and the channel spacings of the ITU-T grid are 12,5 GHz, 25 GHz, 50 GHz, and 100 GHz [1][1].

ITU-T has also discussed λ-interface systems such as "black link" [2]. "Black link" includes WDM MUX/DEMUX and a transmission fibre, and provides λ-interfaces. Especially in DWDM systems (channel spacing < 100 GHz), the uncertainty in specifying optical frequency needs to be minimized.

To implement future telecom systems, it is expected that optical frequency measurements will need to be extremely precise. For example, to achieve the channel spacing of 25 GHz, signal optical frequency uncertainty (Uf_{sig}) and required measurement uncertainty (Uf_{meas}) need to be 2 GHz to 200 MHz ($Uf_{\mathrm{sig}} / f = 10^{-5}$ to 10^{-6}) and 200 MHz to 2 MHz ($Uf_{\mathrm{meas}} / f = 10^{-6}$ to 10^{-8}), respectively. Unfortunately, conventional wavelength meters have measurement uncertainties of 10^{-6} to 10^{-7}. The solution is to use optical frequency measurements since measurement uncertainties can be as small as 10^{-9}, which satisfies the above telecom requirement ($Uf_{\mathrm{meas}} / f = 10^{-6}$ to 10^{-8}). Therefore, an optical frequency measurement scheme is necessary for the calibration of future telecom systems.

The frequency meter to calibrate with the procedure described in this document is the measurement equipment internally utilizing the optical frequency comb. In Annex A, the mathematical basis for the uncertainty of measurement is described. The measurement procedure of the frequency with the frequency meter utilizing the optical frequency comb is shown in Annex B and the example of the optical frequency comb sources are shown in Annex C. Additionally, the uncertainty depending on the frequency is shown in Annex D.

This document defines all the steps involved in the calibration process of the frequency measuring with the optical frequency meter internally utilizing an optical frequency comb: establishing the calibration conditions, carrying out the calibration, calculating the uncertainty, and reporting the uncertainty, the calibration conditions and the traceability.

[1] Numbers in square brackets refer to the Bibliography.

CALIBRATION OF WAVELENGTH / OPTICAL FREQUENCY MEASUREMENT INSTRUMENTS –

Part 3: Optical frequency meters internally referenced to a frequency comb

1 Scope

This part of IEC 62129 describes the calibration of optical frequency meters using an optical frequency comb as an internal reference. It is applicable to instruments measuring the optical frequency emitted from sources that are typical for the fibre-optic communications industry. It is assumed that the optical radiation will be coupled to the optical frequency meter by a single-mode optical fibre. This document is part of the IEC 62129 series on the calibration of wavelength/optical frequency measurement instruments. Refer to IEC 62129-1 [3] for the calibration of optical spectrum analyzers, and refer to IEC 62129-2 [4] for calibration of Michelson interferometer single wavelength meters.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. 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 TR 61931, *Fibre optic – Terminology*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TR 61931, and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
accredited calibration laboratory
calibration laboratory authorized by the appropriate national organization to issue calibration certificates with a minimum specified uncertainty, which demonstrate traceability to national measurement standards (3.3)

3.2
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 measurement standards

Note 1 to entry: The result of a calibration permits either the assignment of values of measurands to the indications or the determination of corrections with respect to indications.

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

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

[SOURCE: ISO/IEC Guide 99:2007 [5], 2.39, modified – Only the first part of the definition has been used and the notes to entry have been modified.]

3.3
national measurement standard
standard recognized by a national decision to serve, in a country, as the basis for assigning values to other standards for the quantity concerned

[ISO/IEC Guide 99:2007, 5.3, modified – Some terms have been replaced with similar meaning.]

3.4
reference standard
standard, generally having the highest metrological quality available at a given location or in a given organization, from which measurements made therein are derived

Note 1 to entry: The general definition of this term is described in ISO/IEC Guide 99:2007, 5.6.

3.5
traceability
property of the result of a measurement or the value of a measurement standard whereby it can be related to stated references, usually national or international measurement standards, through an unbroken chain of comparisons all having stated uncertainties

Note 1 to entry: The general definition of this term is described in ISO/IEC Guide 99:2007, 2.41.

3.6
traceability chain
unbroken chain of comparison

Note 1 to entry: The general definition of this term is described in ISO/IEC Guide 99:2007, 2.42.

3.7
working standard
measurement standard that is used routinely to calibrate or check measuring instruments

Note 1 to entry: A working standard is usually calibrated against a reference standard.

Note 2 to entry: The general definition of this term is described in ISO/IEC Guide 99:2007, 5.7.

4 Calibration test requirements

4.1 Organization

The calibration laboratory should ensure that suitable requirements for calibration are followed.

NOTE Guidance about good practices for calibration can be found in ISO/IEC 17025 [6].

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 calibration laboratory should ensure that suitable requirements for traceability are followed.

NOTE Guidance about good practices for traceability can be found in ISO/IEC 17025.

Make sure that any test equipment which has a significant influence on the calibration results is calibrated. Upon request, specify this test equipment and its calibration chain(s). The recalibration period(s) shall be defined and documented.

4.3 Preparation

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

a) the environment shall be clean;
b) temperature monitoring and control is required;
c) all laser sources shall be safely operated (refer to IEC 60825-1 and to IEC 60825-2).

4.4 Reference calibration conditions

The reference calibration conditions usually include the following parameters and, if necessary, their tolerance bands: date, temperature, relative humidity, displayed power level, displayed optical frequency, fibre, (spectral) bandwidth and resolution bandwidth (spectral resolution) set. Unless otherwise specified, use a single-mode optical fibre input pigtail as specified in IEC 60793-2-50, having a length of at least 2 m.

The calibration should be made in a temperature-controlled environment. The recommended temperature is 23 °C. Depending on the desired uncertainty, the temperature, atmospheric pressure and humidity may need to be monitored during the measurement.

Operate the optical frequency meter in accordance with the manufacturer's specifications and operating procedures. Where practical, select a range of test conditions and parameters which emulate the actual field operating conditions of the optical frequency meter under test. Choose these parameters so as to optimize the optical frequency meter's uncertainties, as specified by the manufacturer's operating procedures.

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

5 Optical frequency calibration

5.1 Establishing the calibration conditions

Establishing and maintaining the calibration conditions is an important part of the calibration, because any change of these conditions is capable of producing erroneous measurement results. The calibration conditions should be a close approximation to the intended operating conditions. This ensures that the (additional) uncertainty in the operating environment is as small as possible. The calibration conditions should be specified in the form of nominal values with uncertainties when applicable. In order to meet the requirements of this document, the calibration conditions shall at least consist of:

a) date of calibration;

b) ambient temperature, for example 23 °C. The temperature may need to be monitored continuously to ensure that it remains within the requisite limits;

c) ambient relative humidity, for example 30 % to 70 %. The ambient relative humidity may need to be monitored continuously to ensure that it remains within the requisite limits. A relative humidity below the condensation point is assumed by default;

d) input optical power (that has to fall within the allowable specification for the optical frequency meters);

e) if a transition locked source is used, then the quality of the lock shall be continuously monitored during the measurements; a lock indicator can be sufficient.

The above conditions may not be exhaustive. There might be other parameters that have a significant influence on the calibration uncertainty.

5.2 Calibration procedure

5.2.1 General

The main steps of the calibration procedure are as follows:

a) establish and record the appropriate calibration conditions (see 5.1). Switch on all instrumentation and wait until it stabilizes;

b) set up the reference source in accordance with condition 5.1 d);

c) set up the instrument state of the test optical frequency meter according to the instruction manual. Select appropriate units;

d) record the instrument states of the optical frequency meter.

5.2.2 Measurement configuration

Two possible configurations can be used for calibration. One uses a stabilized laser as shown in Figure 1, and the other uses a reference frequency meter as shown in Figure 2.

Figure 1 shows the configuration using the reference source.

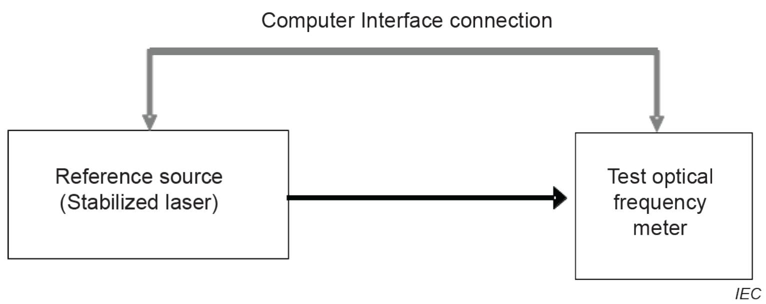

Figure 1 – Optical frequency meter measurement using a reference source

Figure 2 shows the configuration using a reference optical frequency meter.

It is necessary that the measurements be performed simultaneously on both the reference and the test optical frequency meters.

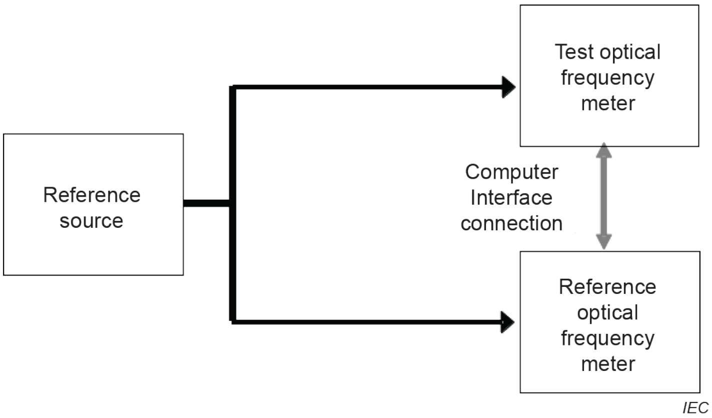

Figure 2 – Optical frequency meter measurement using a reference optical frequency meter

5.2.3 Detailed procedure

The measurement process is as follows:

a) allow the equipment to reach equilibrium;
b) configure the data acquisition software;
c) ensure that the optical source is operating correctly;
d) run the data acquisition software.

The correction factor (CF) is determined from the difference between the reference optical frequency and the mean values from each measurement:

$$CF = f_{\text{ref}} - \frac{1}{n}\sum_{i=1}^{n} f_{\text{test}_i} \quad (1)$$

where

f_{ref} is the reference optical frequency, which is the frequency of the reference stabilized laser in calibration of Figure 1 and the frequency of the reference frequency meter in calibration of Figure 2, and

f_{test} is the optical frequency measured by the test optical frequency meter.

In order to obtain the statistical stability of the measurement, it is desirable to take 50 samples (n), for example, per measurement.

It is recommended to repeat the measurement at a second reference optical frequency in case there is an error in the comb spacing frequency. This is described in Annex D.

NOTE The number of measurements averaged per reading affects the size of the results file, the rejection of data by the measurement routine, and the frequency stability of the reference source. A large number of samples per measurement will increase the size of the data set used to check that the extreme data points are valid, and uncertainty of the reference source frequency and the n can be determined with the method of statistical rejection of outlying points described in Annex B of IEC 62129-2:2011.

5.3 Calibration uncertainty

The mathematical basis, Annex A, should be used to calculate and state the uncertainty. Note that the following list may not be complete; additional contributions may have to be taken into account, depending on the measurement setup and procedure:

a) stability measurement (drift of equipment during measurements taken over a long period of time);

b) "on/off repeatability" measurement (uncertainty of measured value in repeat of on and off of electric power supply);

c) frequency dependence measurement (difference in uncertainty due to measured frequency);

d) uncertainty of the reference frequency meter;

e) reference source uncertainty (how well the source is stabilized to the natural standard, for example to a molecular absorption line);

f) display resolution of the test frequency meter (difference between the measured value and displayed value that might be degraded due to resolution);

g) temperature and relative humidity (uncertainty of performance of components embedded in the equipment due to environmental conditions).

5.4 Reporting the results

Suitable requirements for reporting the results of each calibration should be followed.

NOTE Guidance about good practices for reporting the results of calibration can be found in ISO/IEC 17025.

Calibration certificates referring to this document shall, at a minimum, include the following information:

a) all calibration conditions of the calibration process as described in 5.1;

b) the test meter's correction factor(s) or deviation(s), if the test meter was not adjusted;

c) on receipt, correction factors or deviations and, after adjustment, correction factors or deviations in the case that an adjustment was carried out;

d) the calibration uncertainty in the form of an expanded uncertainty as described in 5.3 and Annex A;

e) the configuration of the test meter during the calibration;

f) evidence that the measurements are traceable (see ISO/IEC 17025).

6 Absolute power calibration

Currently, the frequency meter does not have the function to measure the optical power at a specific optical frequency due to its measurement principle. If the frequency meter has a power measurement capability in the future, then it shall be calibrated using the power meter calibration procedure (IEC 61315 [7]).