

Nordtest method project 1634-03

High Power Fibre Optic Calibration

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Scope

This NORDTEST procedure describes a method for calibration of fibre optic power meters at power levels from 1 mW-200 mW. A fibre optic power meter is here defined as an electrical device, which is used to measure optical power that exits an optical fibre. The calibrated property is power responsivity.

The test method takes into consideration the general aspects of fibre optic power measurements, such as fibre coupling and measurement geometry. Also the aspects of producing and measuring high power levels (>10 mW) are considered.

1. Field of application

The method is applicable to fibre optic power meters equipped with standard fibre connectors, operating at the common optical communications wavelength window around 1550 nm. Calibrations can be done in the power range 1 mW-200 mW.

2. References

1. *ISO Guide to the expression of uncertainty in measurement*, International Organization for Standardization, Geneva, 1995, 110 p.
2. ISO/IEC FDIS 17025:1999(E), *General requirements for the competence of testing and calibration laboratories*, International Organization for Standardization, Geneva, 1999, 26 p.
3. IEC 61281-1 Fibre optic communication subsystems – Part 1: Generic specification.
4. IEC 61315 Calibration of fibre-optic power meters.
5. IEC 61292-4 Technical report-Part 4: Maximum permissible optical power for safe and damage-free use of optical amplifiers.
6. S.R.G Hall, T.C.E Jones, and A.G. Roddie, “Traceability For High Power Fibre Optic Measurements,” OFMC proceedings 2001.

7. P. Corredera, M.L. Hernánz, J. Campos, J.L. Fontecha, A. Pons, and A. Corróns, “Application of an addition method to obtain the non-linearity of optical fibre instrumentation,” OFMC proceedings 1997.

3. Definitions

3.1. Optical power

The rate of flow of optical (electromagnetic) energy. Unit: [J/s] = [W].

3.2. Fibre optic power

Optical power radiated from the end of an optical fibre.

3.3. Fibre optic power meter (FOPM)

An electrical device used to measure fibre optic power. A fibre optic power meter is thus an optical power meter that is equipped with an adaptor for connection of optical fibres.

3.4. Power responsivity

The electrical signal (amps or volts) given by the FOPM, divided by the corresponding optical power. Unit: [A/W] or [V/W].

4. Sampling

Not applicable to calibration method.

5. Test method

5.1. Principle

The power responsivity of an FOPM is measured using a laser source and by comparing the signal of the test meter with that of a reference meter. The calibration of the reference meter and the measured wavelength of the laser used in the calibration must be traceable to SI units.

5.2. Equipment

5.2.1. *Laser*

A fibre coupled laser source is used as the light source in the calibration. The wavelength of the laser should be in the 1550 nm window used in optical telecommunications.

5.2.2. *Optical spectrum analyser / Wavelength meter*

The wavelength of the laser must be measured with an optical spectrum analyser or a wavelength meter, traceable to SI units. The optical spectrum analyser is also used to measure the ground noise level of the Erbium Doped Fibre Amplifier (EDFA) (see 5.4.2). If the wavelength of the laser is known (for example gas lasers) then the wavelength does not have to be measured.

5.2.3. *EDFA*

An erbium doped fibre amplifier is used to produce fibre optic power levels up to 200 mW that is needed for high power calibrations.

5.2.4. *Low power reference*

A reference standard for optical power measurements is needed for calibration of the power responsivity of the high power transfer standard. The calibration of the high power transfer standard is performed at the 1 mW level. A reliable power meter of any type that operates in 1550 nm wavelength region can be used as the low power reference. The calibration of the low power reference must be traceable to SI units, e.g. via a national standards laboratory or an accredited calibration laboratory. The low power reference meter must have a fibre connector similar to that of the high power transfer standard. Alternatively, the calibration can be done with an open collimated beam, if practical.

5.2.5. *High power transfer standard*

A high power transfer standard (HTS) is used as the reference detector in the high power calibration of a test detector. The power responsivity of HTS must be linear

over the power range 1 mW-200 mW. The high power levels may affect the aging properties of the HTS and must be known (see 5.4.5 and 5.4.6). Examples of suitable HTS's are those that were used in the comparison measurements at high fibre optic power levels between Helsinki University of Technology (HUT, Finland), Swedish National Testing and Research Institute (SP, Sweden) and Danish Institute of Fundamental Metrology (DFM, Denmark). They are described below.

5.2.5.1. Integrating sphere detector (HUT)

HUT uses a Spectralon coated integrating sphere detector (\varnothing 50.8 mm) as HTS. The sphere has been custom made by Labsphere Inc. The sphere has two input ports (\varnothing 5 mm) located at the equator of the sphere. The angle between the input ports is 90° . At the north pole of the sphere there is an exit port (\varnothing 4 mm). An InGaAs photodiode (GAP 5007, Germanium Power Devices Inc.) is attached at the output port. The active area of the photodiode is circular and its diameter is 5 mm, thus the active area is underfilled during measurements. One of the input ports (Port 1) is equipped with a removable FC/PC connector (Anritsu MP92B) while the other input port (Port 2) is just a free hole. Port 2 can either be open or covered with a Spectralon plug.

The low power calibration of the sphere is done with an open collimated beam via Port 1. The fibre connector is removed to allow an open beam to enter the sphere. Port 2 can be used to examine the effect of removing the fibre adapter during calibration to the responsivity of the sphere. This is done by measuring the responsivity of the sphere via Port 2 when Port 1 is either open or covered with the fibre adapter. The angular and spatial non-uniformities of the sphere are measured in order to allow for calculation of a correction due to the change in measurement geometry between low power and high power calibrations (collimated beam versus power spreading from the fibre end).

The linearity of the sphere detector was measured to be better than 1 % over the power range 1 mW-200 mW. The angular non-uniformity is better than 0.1 % over the angle covered by the power emitted from the fibre. The aging properties of the detector were examined by exposing the sphere for high optical power (100 mW-

300 mW) for total of 20 hours. During this test the power responsivity of the detector remained the same within measurement uncertainty of 0.15 % ($k=1$). The detector was found suitable for measurements of high fibre optic power with a measurement uncertainty of 1.5 % ($k=2$).

5.2.5.2. SP detector

As HTS, SP uses a thermopile detector equipped with a removable FC/PC fibre optic coupler. The detector is an OPHIR laser star with 3A-P-CAL measuring head. SP HTS showed linear behaviour within 1 % for powers from 2 mW to 200 mW. The aging properties of the detector were not examined. The results at HUT are taken into account and initially the HTS will be calibrated regularly in order to determine any effect. The detector was found suitable for measurements of high fibre optic power with a measurement uncertainty of 2,9 % ($k=2$).

For powers between 1 mW and 8 mW an electrical substitution detector could alternatively be used. The detector is of type, Laser Probe RS-5900 with RsP-590 pyroelectric measuring head. The detector was found suitable for measurements of powers from 1 mW to 8 mW with a measurement uncertainty of 2 % ($k=2$).

5.2.5.3. DFM detector

DFM uses a Spectralon coated integrating sphere detector (\varnothing 101.6 mm) as the HTS. The sphere is a product by Labsphere Inc. The sphere has one input port (\varnothing 25,4 mm) and one output port (\varnothing 12,5 mm). The angle between the two ports is 90°. A Ge photodiode (Judson JS16) is attached at the output port. The active area of the photodiode is circular and its diameter is 5 mm. The input port is equipped with a removable FC/PC connector (Anritsu MP92B).

The low power calibration of the sphere is done using optical fibres in turn connected to the low power reference and the high power transfer standard. The power responsivity of the sphere detector was determined at the 1 mW level. The linearity was measured to be better than 1 % over the power range 1 mW-200 mW. The aging properties of the detector were not examined. The results at HUT are taken into account and initially the HTS will be calibrated regularly in order to determine any

effect. The detector was found suitable for measurements of high fibre optic power with a measurement uncertainty of 1.3 %.

5.3. Testing environment

The calibrations can be done in ordinary room conditions (ambient temperature $T_A = 23 \pm 3$ °C, relative humidity $R.H. = 45 \pm 20$ %). The values should be recorded during the calibration and stated in the calibration certificate [1]. Effect of environmental conditions must be taken into account in the uncertainty evaluation.

5.4. Pre-conditioning and testing of equipment

5.4.1. Cleaning of connectors

If the fibre connectors of the detectors to be calibrated are dirty, they should be cleaned, if the customer agrees.

5.4.2. Measurement of the noise level of the EDFA

The ground noise level of the EDFA must be measured. This gives the fundamental limit to the noise to signal ratio of the measurement, which must be taken into account in the uncertainty analysis of the calibration. This measurement is done by measuring the output spectrum of the EDFA with an optical spectrum analyser. The spectrum should contain a peak at the wavelength of the laser and continuous background at other wavelengths. The total noise is calculated as the integral of the signal over the spectrum outside the laser wavelength. The noise to signal ratio is calculated by dividing the total noise by the peak power at the laser wavelength. The noise to signal ratio is added to the uncertainty budget of the calibration.

5.4.3. Measurement of the wavelength of the laser

The wavelength of the laser is measured with an optical spectrum analyser or a wavelength meter, traceable to SI units. If the wavelength of the laser is otherwise known, it does not need to be measured.

5.4.4. *Calibration of the HTS*

The power responsivity of the HTS is measured at the 1 mW level using a low power reference detector. The measurement can be done either with fibre adapters attached or with an open beam, depending on the structure of the detectors. The measurement must be repeated at least five times, and the arithmetic mean of the measured values is taken as the responsivity of HTS. The relative standard deviation of the measured values is added to the uncertainty budget of the calibration.

5.4.5. *Measurement of linearity of the HTS*

The linearity of the high power transfer standard must be known. Because the calibration of the HTS is done at the 1 mW level and the calibration of the test detector is done at power levels up to 200 mW, the linearity of the HTS must be known over this region. This measurement can be done using the flux addition method in open air or a purely fibre based system using an optical switch. Alternatively, a detector, which is known to be linear, such as a high power thermopile, can be used as reference. Also, a method using a splitter consisting of one high power fibre output and one fibre output with attenuation can be applied. The power level from the attenuated output should be low enough so that a low power detector with known linearity can be used.

5.4.6. *Testing of aging properties of the HTS*

At high power levels certain detector types may experience aging. The aging properties of the HTS must therefore be examined. The acceptable amount of aging for the HTS depends on how often the detector is calibrated. If the calibration of the HTS is done, for example, once a year, then the total exposure of the HTS to high power levels during the one year calibration period must be estimated. In the test of aging properties, the HTS must be exposed to highest measurable power for this estimated time of exposure, and the power responsivity of HTS is measured before and after the exposure. Possible aging noted is accounted for in the uncertainty budget. Alternatively, the calibration interval of the HTS can be kept sufficiently short to minimise the aging effect.

5.4.7. Geometrical aspects

If the low power calibration of the HTS is done with an open beam, the change in measurement geometry between low power calibration and high power calibration must be accounted for. In the high power calibration, where the fibre adapters are used, the power spreads to a wide solid angle from the fibre end. This leads to a systematic calibration error when compared to the calibration that is done with a collimated beam. To compensate for this error, the spatial and angular non-uniformities of the HTS must be measured. Also, the angular distribution of the optical power spreading from the fibre end must be known or estimated.

The angular non-uniformity of the HTS and the angular power distribution of the fibre are used to calculate a correction due to the geometrical error in the calibration. The correction C is given by

$$C = \frac{\int P(\varphi)R(\varphi)d\varphi}{\int P(\varphi)d\varphi}, \quad (1)$$

where φ is the angle of incidence, $P(\varphi)$ is the relative power distribution and $R(\varphi)$ is the relative angular non-uniformity of HTS. The integrals are taken over the angle where most (~99.9 %) of the power exiting the fibre exists. The responsivity of HTS for fibre optic power is obtained by dividing the responsivity measured with a collimated beam with the correction factor C .

5.5. Test procedure

After performing of the pre-tests mentioned above, the power responsivity of the test detector is calibrated against the HTS. The laser source and the EDFA are used to produce the desired power level. Optionally, an attenuator can be used to adjust the power. The output power remains more stable if an attenuator is used instead of changing the settings of the EDFA. The output fibre of EDFA is interchanged between the test detector and the HTS and their readings are recorded. This measurement is repeated at least five times, and the standard deviation is included in the uncertainty budget. The power responsivity or the correction factor of the test

detector can then be calculated as the ratio of its signal and the power (in watts) measured with HTS.

To avoid any damage to the EDFA, it is recommended that the output fibre is not directly connected to the detectors during high power calibrations, but an additional fibre is used between the output fibre and the detectors. This prevents the output fibre from burning when interchanging between detectors; when the fibre is removed/attached, hazardous inter-reflections may occur between the fibre and the detector and thus the fibre end may be damaged.

5.6. Applicability

The applicability of this NORDTEST method was verified with a comparison between three laboratories: HUT, SP and DFM. The comparison at power levels up to 200 mW showed that the results of the three laboratories agreed within 1,4 %. The measurement uncertainties ($k=2$) for the three laboratories are 1.5 % (HUT), < 2,9 % (SP) and 1,3 % (DFM). It is recommended that laboratories test the applicability of their setups by performing comparisons with other laboratories.

5.7. Uncertainty

The uncertainty of the calibration is calculated according to [1]. The components of uncertainty should include at least:

- Noise to signal ratio of the output of the EDFA,
- Repeatability when interchanging the fibre between detectors,
- Uncertainty of the low power calibration of the HTS,
- Linearity of the HTS,
- Ageing of the HTS, if needed,
- Effects of environmental conditions.

The following components of uncertainty must be included when calculating the uncertainty of the low power calibration of the HTS:

- Uncertainty of the calibration of low power standard,
- Repeatability of the measurements,
- Spatial/angular non-uniformity of HTS, if needed,
- Linearity of the HTS at 1 mW level, if needed.

According to the tests carried out so far, an overall uncertainty better than 1,5 % ($k=2$) is achievable. The uncertainties of HUT, DFM and SP range between 1,3 % and 2,9 %. The differences are mainly due to the transfer detectors providing the traceability to the primary standard.

5.8. Calibration certificate

The certificate of calibration must be written according to the requirements of [2]. At least, the following parameters should be stated:

- The measured responsivities or correction factors,
- The power levels and wavelengths used,
- Number of repetitions,
- Environmental conditions (room temperature and relative humidity),
- Uncertainty,
- Traceability of results.

5.9. Acceptance or rejectance of the results

Not applicable to calibration method.