IEC 61300-3-53

Edition 2.0 2020-12
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Fibre optic interconnecting devices and passive components – Basic test and measurement procedures
Part 3-53: Examinations and measurements – Encircled angular flux (EAF) measurement method based on two-dimensional far field data from ~~step index~~ multimode waveguide (including fibre)

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Part 3-53: Examinations and measurements – Encircled angular flux (EAF) measurement method based on two-dimensional far field data from ~~step index~~ multimode waveguide (including fibre)

FOREWORD

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International Standard IEC 61300-3-53 has been prepared by subcommittee 86B: Fibre optic interconnecting devices and passive components, of IEC technical committee 86:Fibre optics.

This second edition cancels and replaces the first edition in 2015. This edition constitutes a technical revision.

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

a) the scope of the applicable wave guides, and graded index multimode optical wave guide and fibre have been included;
b) the structure of 5.3 has been rearranged;
c) Annex C and Annex D have been added.

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

FDIS	Report on voting
86B/4343/FDIS	86B/4373/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 61300, published under the general title *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures*, 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- withdrawn,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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FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – BASIC TEST AND MEASUREMENT PROCEDURES

Part 3-53: Examinations and measurements – Encircled angular flux (EAF) measurement method based on two-dimensional far field data from step index multimode waveguide (including fibre)

1 Scope

This part of IEC 61300 is intended to characterize defines the encircled angular flux of measurement step index of multimode waveguide light sources, in which most of the transverse modes are excited. The term "waveguide" is understood to include both channel waveguides and optical fibres but not slab waveguides in this standard.

Encircled angular flux (EAF) is the fraction of the total optical power radiating from a step index multimode waveguide's core within a certain solid angle. The EAF is measured as a function of the numerical aperture full angle. The basic approach is to collect, for every measurement, two dimensional far field data using a calibrated camera and to convert them mathematically into encircled angular flux.

The applicable fibre types are the followings:

- A1 specified in IEC 60793-2-10;
- A3 specified in IEC 60793-2-30;
- A4 specified in IEC 60793-2-40.

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 60793-2-10, *Optical fibres – Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres*

IEC 60793-2-30, *Optical fibres – Part 2-30: Product specifications – Sectional specification for category A3 multimode fibres*

IEC 60793-2-40, *Optical fibres – Part 2-40: Product specifications – Sectional specification for category A4 multimode fibres*

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

IEC 61300-1:2016, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 1: General and guidance*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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
encircled angular flux
EAF
fraction of the total optical power radiating from a ~~step index~~ multimode waveguide's core within a certain solid angle

3.2
Fraunhofer far field
far field which occurs when

$$L \gg D^2/\lambda$$

where

L is the distance of the detection plane from the waveguide end facet;

D is the diameter of the multimode waveguide core or strictly mode field diameter;

λ is the wavelength.

3.3
$f\theta$ lens
lens converting the angle of incidence of the input beam, θ, into the output beam height, h

Note 1 to entry: The relationship between them is $h = f\theta$, where f is the focal length of the lens.

3.4
mode power distribution
MPD
relative mode power in each of the mode groups of a multimode fibre

[SOURCE: IEC 62614-2:2015, 3.5, modified – The words "often shown graphically" have been deleted.]

3.5
numerical aperture
NA
sine of the vertex half-angle of the largest cone of meridional rays that can enter or leave the core of an optical waveguide, multiplied by the refractive index of the medium in which the cone is located

3.6
far field pattern
FFP
angular distribution of light radiating from a waveguide's core, which corresponds to the optical power distribution on a plane normal to the waveguide axis some distance from its end facet

Note 1 to entry: The distance depends on the largest waveguide cross section, a, the wavelength, ~~lambda~~ λ, and the angle, φ, to the optical axis. ~~It is abbreviated to FFP.~~ In the far field region, the shape of the distribution does not change as the distance from the waveguide end facet increases; the distribution only scales in size with distance, L.

$$L >> \frac{2a^2(\cos\varphi)^2}{\lambda}$$

3.7
far field image
far field pattern formed on an imaging device

~~**3.6**~~
~~**centroid**~~
~~optical centre of the far field image~~

3.8
neutral density filter
ND filter
filter that attenuates light of all colours equally

4 ~~Standard atmospheric~~ Measurement conditions

Optical fibres which are applied to this measurement are specified in IEC 60793-2-10, IEC 60793-2-30 and IEC 60793-2-40. The measurement ambient condition shall be the standard atmospheric conditions ~~are~~ specified in IEC 61300-1.

5 Apparatus

5.1 General

The optical source multimode waveguide shall be long enough to ensure that all cladding modes are stripped by passage through the waveguide. Often, the fibre coating or tight buffer is sufficient to perform this function. Alternatively, a cladding mode stripper shall be used in the source launch ~~optical~~ multimode optical fibre. An example of a typical cladding mode stripper which would be suitable for optical fibre is sufficient windings of the fibre around a mandrel of an appropriate diameter. The windings also have a more important essential effect to fully fill the transverse modes across the maximum mode field diameter. It should be checked that all of the transverse modes of the fibre are sufficiently well excited. See Annex D. This can be done by comparing the FFPs for different lengths of the launch fibre or different light sources. Once the FFP no longer changes in form as the launch fibre length is increased, there is no need to increase the length further.

5.2 Measurement method 1: $f\theta$ lens imaging

5.2.1 General

In theory, this measurement method, which is effectively a coherent optical method to Fourier transform the near field to the far field using a lens, does not operate well using very wideband optical sources. Experimentally, it has been shown to operate sufficiently well for sources up to 30 nm bandwidth, which are most commonly used.

Figure 1 below shows the apparatus configuration. The measurement system consists of a micro-positioner, a far field broadband optical system, an imaging device (e.g. camera) and computer (~~beam analysis module~~ EAF analyser module). An appropriate type of camera (~~detector~~ imaging device) ~~should~~ shall be chosen to suit the wavelength under test.

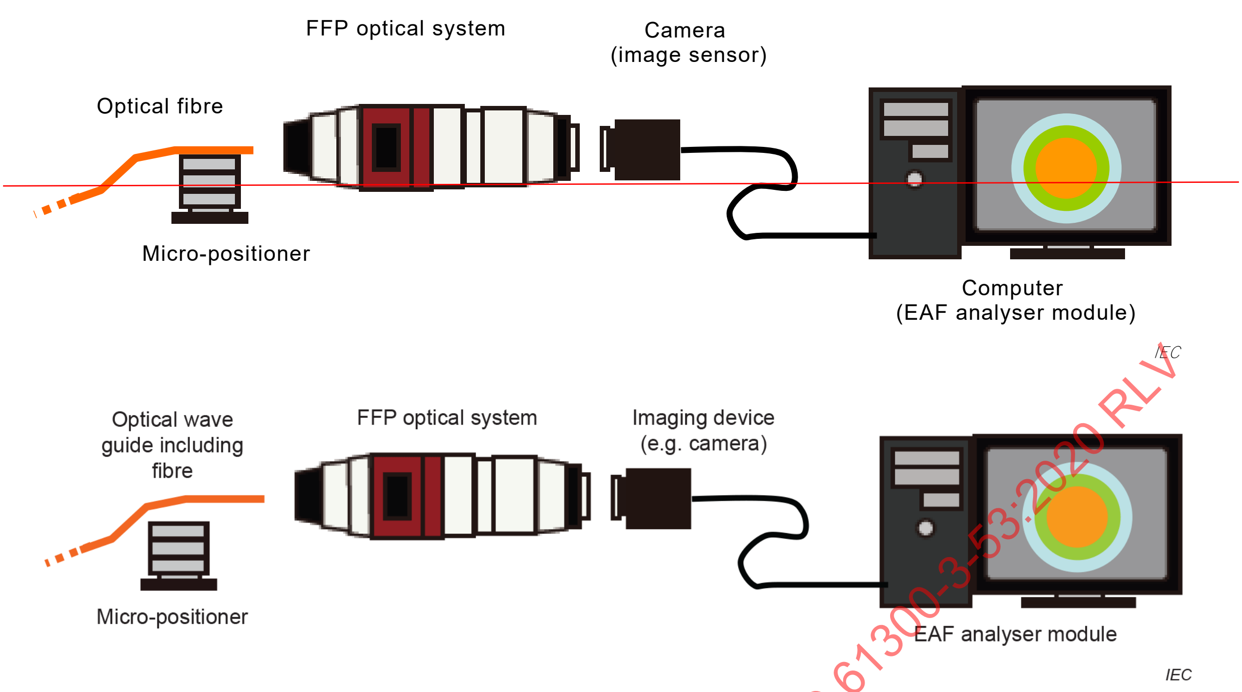


Figure 1 – Apparatus configuration of measurement method 1: $f\theta$ lens imaging

5.2.2 Micro-positioner

~~The micro-positioner shall have a function of fixing an optical waveguide and moving in three directions (X, Y, Z). In addition yaw and pitch controls are recommended.~~

The micro-positioner shall hold the optical source (including the waveguide) and be able to move in three directions (X, Y, Z). Angular movement for the optical system is recommended.

5.2.3 FFP optical system

As shown in Figure 2~~, basically,~~ an $f\theta$ lens can directly convert ~~input~~ the light from the multimode waveguide to a far field image; however, scaling the far field image in order to fit the image sensor in the ~~camera~~ imaging device and adjustment of the light intensity in order to prevent saturation ~~may be~~ is required. The FFP optical system ~~shall be~~ is chosen to operate at the measurement wavelength across the required measurement bandwidth to match that of the detection system. See Annex A for more information.

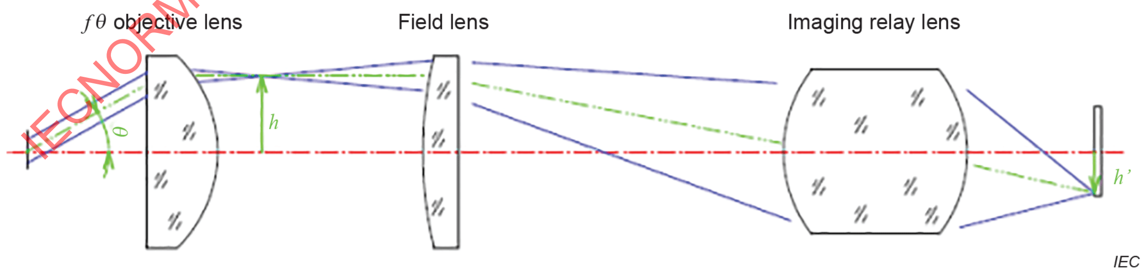


Figure 2 – Far field optical system diagram

5.2.4 ~~Camera~~ Imaging device

Imaging device includes a camera, CCD, CMOS, etc. that can detect images. ~~Although~~ The detector is typically a charge coupled device (CCD) or a complementary metal oxide semiconductor (CMOS) camera~~, other types of array cameras may be considered~~. The type of ~~image sensor~~ imaging device shall be chosen by the measurement wavelength. Absolute ~~radiometric~~ intensity measurement ~~of flux (optical power flow)~~ is not required.

5.2.5 Computer (EAF analyser module)

Since the acquired image contains many thousands of pixels, and the image conversion into encircled angular flux requires substantial computation, a computer is required. The computer ~~will usually~~ shall be connected to the ~~image sensor~~ imaging device through an image acquisition board (or with an embedded image acquisition circuit), and ~~installed~~ beam analysis software which enables the computer as a EAF analyser shall be installed.

~~5.2.6 Calibration light source~~

~~Calibration light source is used when calibrating the apparatus in Clause 7. The calibration source is assumed to be broadband and incoherent so that speckle is not a problem, and to have a sufficiently symmetrical far field distribution so that the calculated centroid of the far field indicates the location of the optical centre axis of the waveguide with sufficient accuracy for the purposes of this standard.~~

5.3 Measurement method 2: direct imaging

5.3.1 General

~~There are three alternative methods to detect the far field. One uses a detector, one uses a single-mode fibre and the other uses a camera.~~

In this method, far field images are acquired directly by an imaging device without any optical system. The distance between the optical waveguide source under test and the imaging device shall be long enough to achieve Fraunhofer far field.

NOTE A CCD device generally consist of CCD semiconductor tip and micro lens array to get higher sensitivity practically, then the structure generates shading effect which is incident angle dependent sensitivity consequently. For more information, see Annex C and Figure 3.

See detail information of imaging device setup in Annex B.

When the far field image is larger than the area of the imaging device, multiple images shall be taken and stitched together to configure a complete far field image.

5.3.2 Micro-positioner

Both the input ~~step index~~ multimode waveguide source and the photo detector (PD) shall be mounted on ~~high precision~~ motorized translation Astages. The motorized translation stages shall operate for both coarse alignment with tenths millimetres step movement for wide position and accurate alignment with sub-micron step adjustment to maximize the light through the waveguide.

~~5.3.3 Optical power~~

~~The output from the multimode waveguide shall be set to a power level of 0 dBm.~~

~~5.3.4 Alignment~~

~~Firstly, the input waveguide and detector shall be properly aligned to obtain the maximum output power.~~

~~5.3.5 Detector~~

~~An integrating sphere PD preceded by a pinhole shall be placed sufficiently far from the optical source launch multimode waveguide facet so as to be in the Fraunhofer or far field. The Fraunhofer far field occurs when $L >> D^2/\lambda$ where L is the distance of the detection plane from the waveguide end facet, D is the diameter of the multimode waveguide core or strictly mode field diameter and λ is the wavelength. For example, a large area integrating sphere PD preceded by a pinhole, shown in Figure 3, shall be used to measure the integrated output optical~~

power so avoiding inconsistencies due to laser speckle and spatial variation of efficiency across the photodiode detector. In this method the integrating sphere and its pinhole are moved in X and Y to sample the far field. This has the advantage that a very large area can be sampled. Moreover, it can also be moved in an arc on a goniometer so that its input facet always faces the centre of the core of the multimode waveguide output. This goniometric method can also be used to calibrate the far field in the $f\theta$ imaging method as the far field is measured directly as a function of angle. If the detector aperture is instead moved across an XY plane then the lateral position from the optical axis shall be converted to an angle of divergence from the optical axis. The angle is the arctangent of the ratio of the lateral X or Y position to the distance L. Therefore, considerable care needs to be taken to accurately measure L.

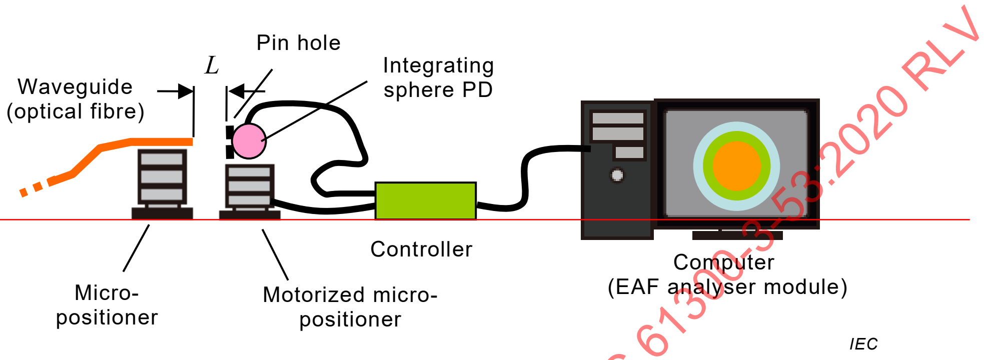


Figure 3 – Apparatus configuration: measurement method 2 – Direct imaging using an integrating sphere

5.3.6 Single-mode fibre

The single-mode optical fibre shall be placed sufficiently far from the optical source launch multimode waveguide facet so as to be in the Fraunhofer or far field. The Fraunhofer far field occurs when $L >> D^2/\lambda$ where L is the distance of the detection plane from the waveguide end facet, D is the diameter of the multimode waveguide core or strictly mode field diameter and λ is the wavelength. For example, a single-mode fibre attached to a detector, shown in Figure 4, shall be placed in the far field and moved in X and Y to sample the far field. This has the advantage that a very large area can be sampled. Moreover, it can also be moved in an arc on a goniometer so that its input facet always faces the centre of the core of the multimode waveguide output. This goniometric method can also be used to calibrate the far field in the $f\theta$ imaging method as the far field is measured directly as a function of angle. If the single-mode fibre core is instead moved across an XY plane then the lateral position from the optical axis shall be converted to an angle of divergence from the optical axis. The angle is the arctangent of the ratio of the lateral X or Y position to the distance L. Therefore, considerable care needs to be taken to accurately measure L.

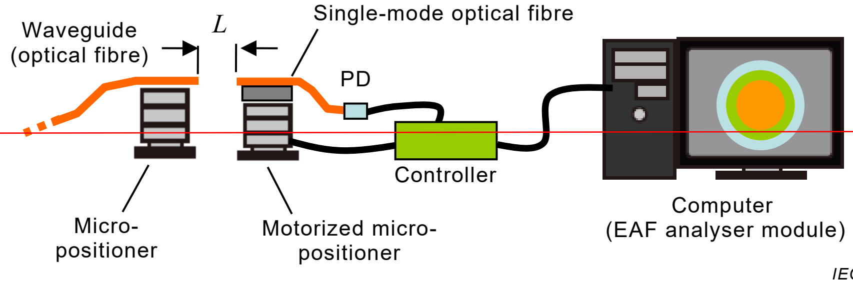
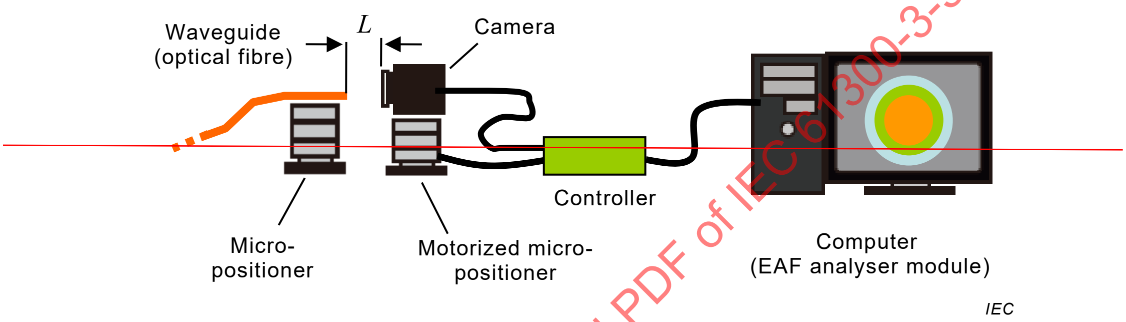


Figure 4 – Apparatus configuration: measurement method 2 – Direct imaging using a single-mode fibre

~~5.3.7 Imaging device~~

~~An imaging device plane without any lens system shall be placed sufficiently far from the optical source launch multimode waveguide facet so as to be in the Fraunhofer or far field. The Fraunhofer far field occurs when $L >> D^2/\lambda$ where L is the distance of the detection plane from the waveguide end facet, D is the diameter of the multimode waveguide core or strictly mode field diameter and λ is the wavelength. For example, an imaging device, shown in Figure 5, shall be placed L away from the exit facet of the multimode waveguide. The distance L between the imaging device and the waveguide end facet is much larger than the core size of the waveguide, so the field captured is the far field distribution. The imaging device may for example, be a CCD camera with its lens removed so that the light distribution falls directly on the CCD chip. The lateral position from the optical axis in the far field shall be converted to an angle of divergence from the optical axis. The angle is the arctangent of the ratio of the lateral X or Y position to the distance L. Therefore, considerable care needs to be taken to accurately measure L.~~



~~**Figure 5 – Apparatus configuration: measurement method 2 – Direct imaging using an imaging device**~~

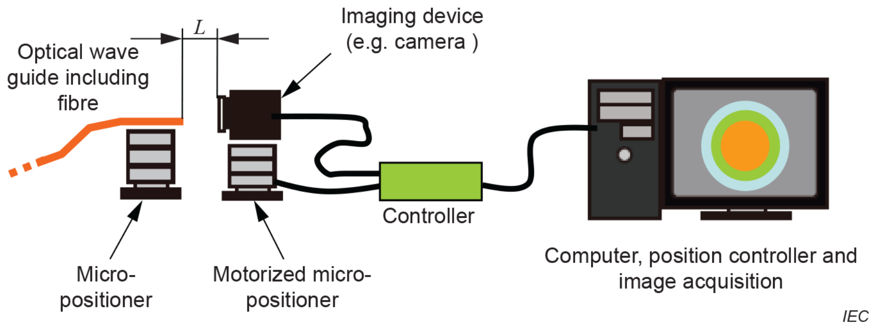
5.3.3 Imaging device

An imaging device includes a camera, CCD, CMOS, etc. that can detect images. An imaging device plane without any lens system shall be placed sufficiently far from the optical source launch multimode waveguide facet so as to be in the Fraunhofer far field.

The imaging device may, for example, be a CCD camera with its lens removed so that the light distribution falls directly on the CCD chip. The lateral position from the optical axis in the far field shall be converted to an angle of divergence from the optical axis. The angle is the arctangent of the ratio of the lateral X or Y position to the distance L. Therefore, considerable care shall be taken to accurately measure L.

5.3.4 Computer, position controller and image acquisition

The computer controls the position of the imaging device (camera) so that the proper image(s) is(are) acquired. If the far field image is too large to shoot an single image, the computerized controller moves the imaging device to the several different positions to acquire multiple images which are finally combined and become one far field image.



NOTE A CCD device generally consist of CCD semiconductor tip and micro lens array to get higher sensitivity practically, then the structure generates shading effect which is incident angle dependent sensitivity consequently. For more information, see Annex C.

Figure 3 – Apparatus configuration of measurement method 2: direct imaging

6 Sampling and specimens

~~Light sources to be tested shall be chosen and prepared by the user of this standard, who shall document the sampling and preparation procedures used. The only requirements on the light sources under test are that they have an operating wavelength compatible with the detector and fθ lens, and have optical connectors or splices compatible with the input port of the apparatus. The construction details of the light sources are otherwise unspecified.~~

The sampling and preparation procedures for the light sources which launch light into multimode waveguides to be tested shall be documented. The light sources under test shall have an operating wavelength compatible with the detector and $f\theta$ lens, and have optical connectors or splices compatible with the input port of the apparatus. The construction details of the light sources are not otherwise specified.

7 Geometric calibration

7.1 General

Calibration of the apparatus is critical to the accuracy of this measurement procedure. Calibration shall be performed periodically. If the calibration is known to drift significantly during a measurement interval, the drift of the source(s) shall be identified and eliminated. If the apparatus is disassembled or its components in or affecting the optical path are otherwise manipulated, calibration shall be performed before measurements are made.

The purpose of geometric calibration is to obtain the measurement data needed to compute the conversion factor. The factor ~~will~~ shall be used to convert camera coordinates to light launching angle relative to the optical axis of optical waveguide.

7.2 Light source

The calibration light source shall be broadband and incoherent, in order to avoid speckle noise issues, and shall have a sufficiently symmetrical far field distribution so that the calculated centroid of the far field indicates the location of the optical centre axis of the waveguide with sufficient accuracy for the purposes of this document.

7.3 Procedure

Calibration ~~is~~ shall be performed to measure the conversion factor that relates the light launching angle to the pixel of the detector corresponding to this angle. The factor has a unit of degree per pixel and ~~will~~ shall be used to convert ~~camera~~ imaging device coordinates to far field angle coordinates. The collimated light source for geometric calibration, shown in Figure 4, shall have a spectral power distribution similar to that of the measurement light source and the central wavelength within 30 nm around the nominal wavelength of the measurement light source.

~~An example of~~ The calibration procedure is stated below:

Step 1: set a collimated light source whose incident angle relative to the optic axis of the far field optical system can be precisely controlled; and

NOTE An example of the calibration apparatus is shown in Figure 4.

Step 2: measure the conversion factors from the whole range of angles to be measured with an interval small enough (e.g. 1°) to enable accurate interpolation.

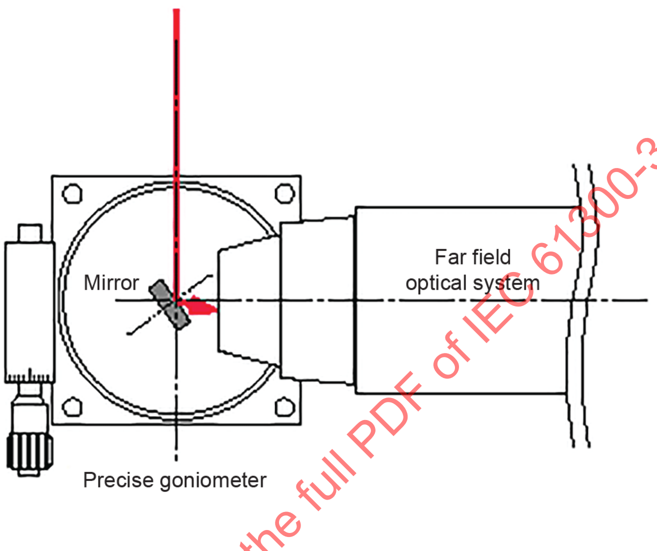


Figure 4 – Calibration apparatus example

~~Alternatively the direct imaging methods described in Clause 5 may be used for calibration.~~

8 Measurement procedure

8.1 Safety

All procedures in which a light emitting diode (LED) or a laser source is used as the optical source shall be carried out using safety precautions in accordance with IEC 60825-1.

8.2 Far field image acquisition

8.2.1 General

Acquiring an image is central to the measurement of encircled angular flux. The approach to image acquisition depends on the general characteristics of the light source being measured.

8.2.2 Waveguide end-face alignment

A waveguide end-face ~~is~~ shall be placed at the front focal point of the FFP optical system. The live far field image acquired on the computer display ~~is~~ shall be adjusted to be in the centre of the display using the X and Y axes of the micro-positioner, and to a minimum diameter and in focus using the Z axis of the micro-positioner in 5.2.2.

8.2.3 Light source image acquisition

Measurement light sources ~~are~~ shall be sufficiently incoherent and ~~are~~ shall be sufficiently intense to easily get good dynamic range, although attenuation may be required using neutral density (ND) filter(s). The acquired image ~~should~~ shall be shown in the PC display as in Figure 5. The picture may be displayed with false colour in Figure 6.

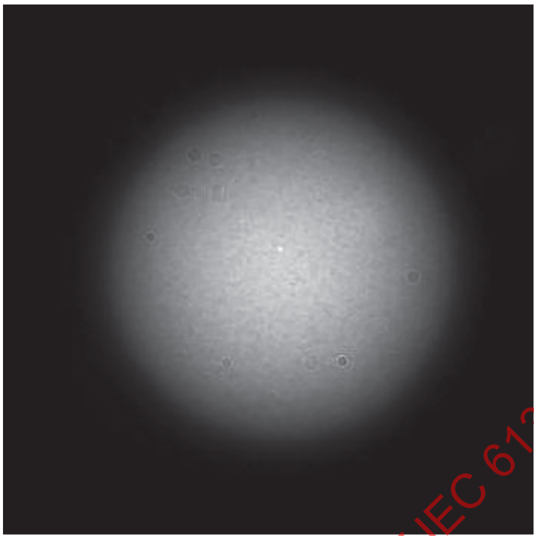


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Figure 5 – Acquired far field image

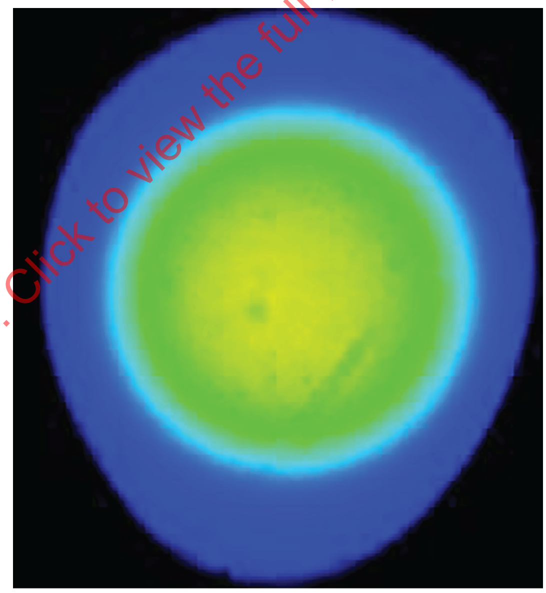

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Figure 6 – Acquired far field image with false colour

8.3 Removal of background noise

The dark current of the camera which is acquired by obscuring the input light beforehand shall be removed from the acquired image, or 0,5 % intensity of the peak power in the acquired image shall be set as a ~~threshold~~ background level ~~to keep the parts of the image above this threshold~~.

8.4 Centre determination

8.4.1 General

One of the two methods ~~needs to~~ shall be used.

8.4.2 Method A: Optical centre determination

The encircled angular flux is computed with respect to the optical centroid of the FFP distribution. As shown in Figure 7, the centroid of the acquired image shall be determined with the use of Formula (1).

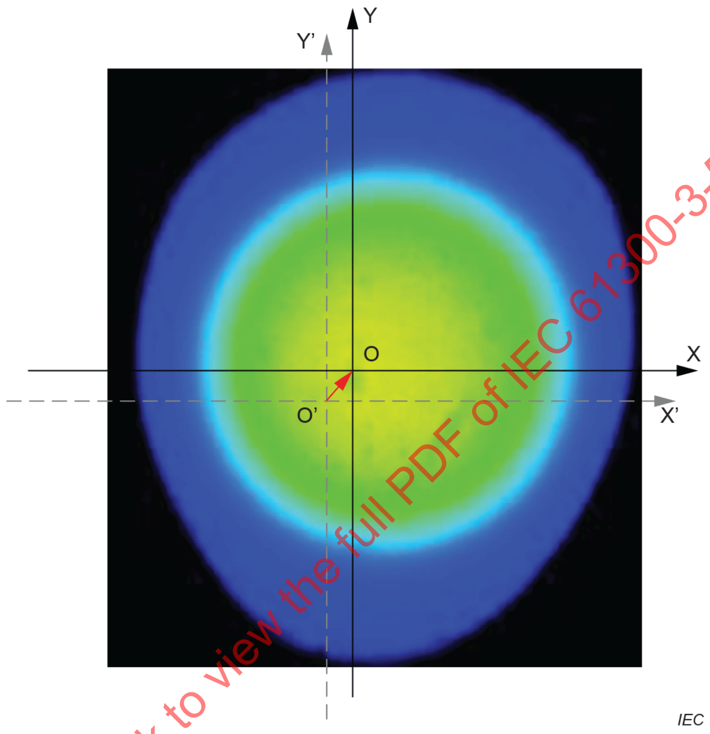


Figure 7 – Optical centre determination

$$O(x=0,\ y=0)=O'(x'=0,\ y'=0)-\left(\frac{\sum_{x'} x' \sum_{y'} I(x',y')}{\sum_{x'}\sum_{y'} I(x',y')},\ \frac{\sum_{x'} y' \sum_{y'} I(x',y')}{\sum_{x'}\sum_{y'} I(x',y')}\right) \qquad (1)$$

where

O' is the origin of FFP optical system;

O is the calculated centroid of the acquired image;

(x', y') is the x-y coordinates based on the FFP optical system origin;

$I(x', y')$ is the light intensity at coordinate (x', y').

8.4.3 Method B: Mechanical centre determination

The encircled angular flux is computed with respect to the optical central axis of the measurement optics. The optical central axis of the measurement optics, O_m, shall be determined by measuring the far field pattern of a reference waveguide. The reference waveguide shall be a single-mode fibre, and the end-face of the fibre should be perpendicular to the optical axis.

$$O_m\left(x_m=0,\ y_m=0\right)=O'_m\left(x'_m=0,\ y'_m=0\right)-\left(\frac{\sum_{x'}x'_m\sum_{y'}I\left(x'_m,y'_m\right)}{\sum_{x'}\sum_{y'}I\left(x'_m,y'_m\right)},\ \frac{\sum_{x'}y'_m\sum_{y'}I\left(x'_m,y'_m\right)}{\sum_{x'}\sum_{y'}I\left(x'_m,y'_m\right)}\right) \quad (2)$$

where

O'_m is the origin of direct imaging;

O_m is the calculated centroid of the acquired image;

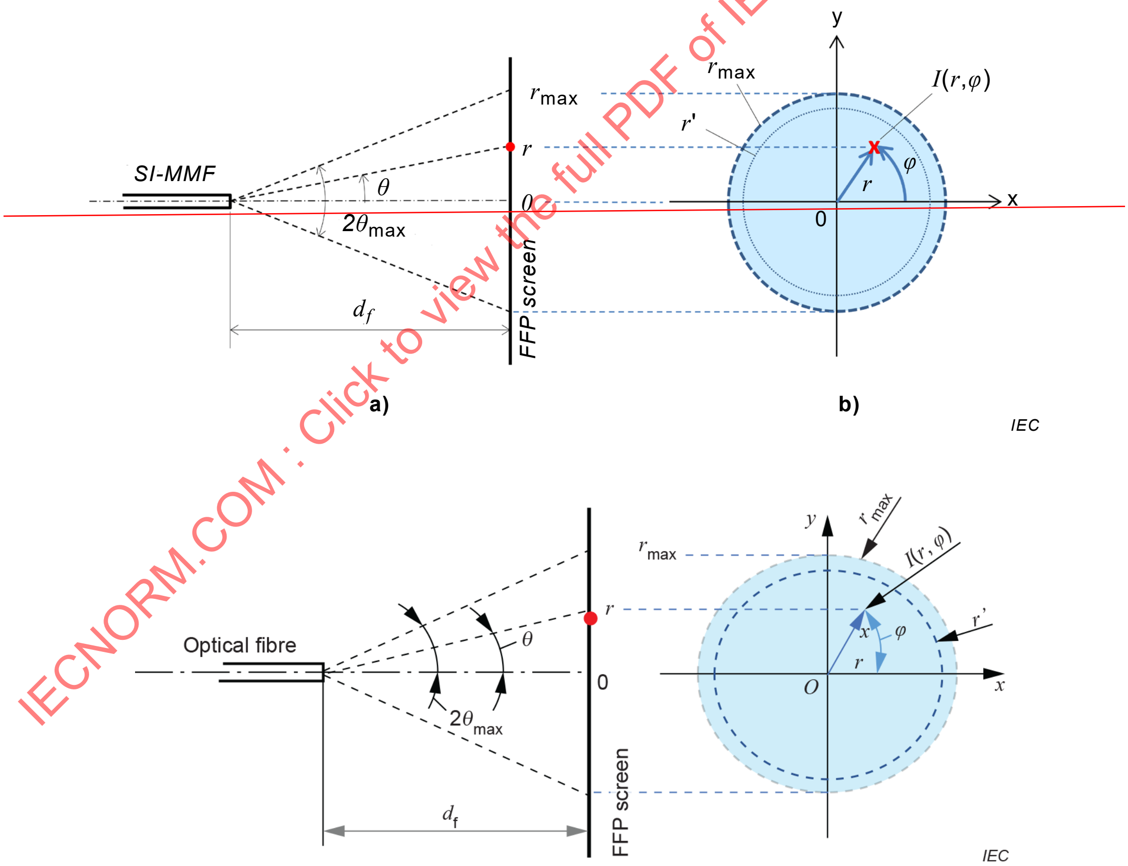
(x'_m, y'_m) is the x-y coordinates based on the direct imaging origin.

$I(x'_m, y'_m)$ is the light intensity at coordinate (x'_m, y'_m).

For method B, O'_m shall be fixed during a series of measurements.

8.5 Computation of encircled angular flux

Before computation of encircled angular flux, the x-y coordinates are converted to polar coordinates using r and φ as shown in Figure 8 (b). Figure 8 (a) shows the side view of the fibre and the emitted beam. Applying r and φ to encircled flux equation, light intensity distribution on an FFP screen is described in Formula (3).



a) Side view b) Image sensor plane

Figure 8 – ~~Coordinate conversion~~ Transformation of x-y to polar coordinates on the image sensor plane

$$EF(r') = \frac{\int_0^{2\pi}\int_0^{r'} I(r,\varphi)\cdot r\cdot dr\cdot d\varphi}{\int_0^{2\pi}\int_0^{r_{max}} I(r,\varphi)\cdot r\cdot dr\cdot d\varphi} \quad (3)$$

~~Equation (4) is a simple equation that shows the relationship between r, θ and d_f, and its differential form (5):~~

$$r = d_f \cdot tan(\theta) \quad (4)$$

$$r \cdot dr = d^2 \cdot sin(\theta) \cdot cos^{-3}(\theta) \cdot d\theta \quad (5)$$

~~Replacing r with θ using Equation (4) and (5), Equation (6) is obtained. This shows encircled angular flux EAF(θ').~~

$$EAF(\theta') = \frac{\int_0^{2\pi}\int_0^{\theta'} I(r,\varphi)\cdot\frac{sin(\theta)}{cos^3(\theta)}\cdot d\theta d\varphi}{\int_0^{2\pi}\int_0^{\theta_{max}} I(r,\varphi)\cdot\frac{sin(\theta)}{cos^3(\theta)}\cdot d\theta d\varphi} \quad (6)$$

$$EF(r') = \frac{\int_0^{2\pi}\int_0^{r'} I(r,\varphi)\cdot r\cdot dr\cdot d\varphi}{\int_0^{2\pi}\int_0^{r_{max}} I(r,\varphi)\cdot r\cdot dr\cdot d\varphi} \quad (3)$$

Here is a simple Formula (4) to show the relationship between r, θ and d_f, and its differential form, Formula (5):

$$r = d_f \cdot \tan(\theta) \quad (4)$$

$$r \cdot d_r = d_f^2 \cdot \sin(\theta)\cdot \cos^{-3}(\theta)\cdot d\theta \quad (5)$$

Replacing r with θ using Formula (4) and Formula (5), Formula (6) is obtained. This shows EAF value $E(\theta')$.

$$E(\theta') = \frac{\int_0^{2\pi}\int_0^{\theta'} I(r,\varphi)\cdot\frac{\sin(\theta)}{\cos^3(\theta)}\cdot d\theta d\varphi}{\int_0^{2\pi}\int_0^{\theta_{max}} I(r,\varphi)\cdot\frac{\sin(\theta)}{\cos^3(\theta)}\cdot d\theta d\varphi} \quad (6)$$

where

r is the radial distance from the origin corresponding to an angle between one ray emitted from the multimode waveguide and the optical axis of the multimode waveguide;

r_{max} is the radial distance from the origin corresponding to the maximum ray angle, which is approximately 30° for category A3 multimode fibre for example;

φ is a circular angle in polar coordinates;

θ is an angle between one ray emitted from the multimode waveguide and the optical axis;

θ_{max} is the maximum ray angle, which is approximately 30° for category A3 multimode fibre for example;

d_f is the distance between the end of multimode optical waveguide and FFP screen;

O and O_m are the calculated centroids discussed in 8.4.

An example of EAF is shown in Figure 9.

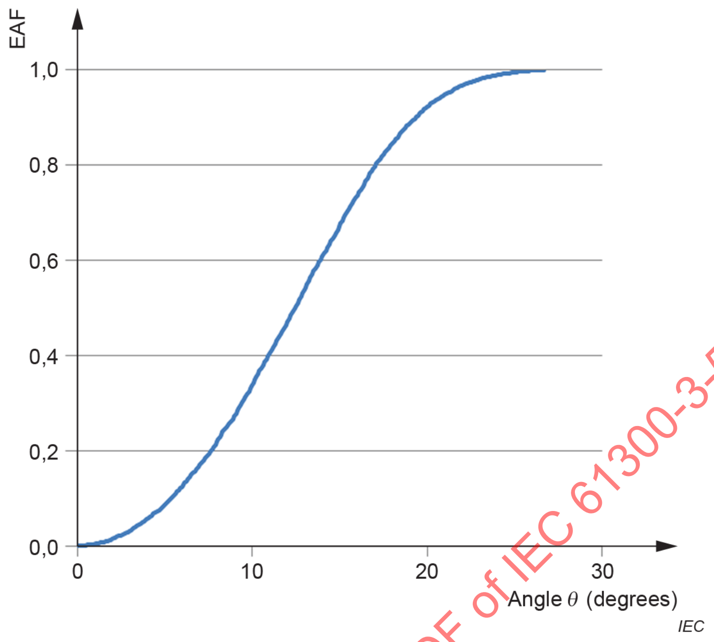


Figure 9 – ~~Standard~~ Typical encircled angular flux chart

9 Results

9.1 Information available with each measurement

Report the following with each measurement:

- date and time of measurement;
- identification of source;
- nominal wavelength of source;
- method of centre determination;
- the encircled angular flux at each angle shall be reported after a series of measurements is completed;
- EAF as a graph as a function of angle θ (Figure 9), including any specified template limits.

For method B, specify the single-mode fibre and multimode fibre connectors and their lateral and angular tolerances, if the measurements are referenced to the connector.

9.2 Information available upon request

The following information shall be available upon request:

- date of most recent calibration of equipment;
- method of calibration of equipment;
- the integration limit parameters (larger than the angle corresponding to the NA of ~~DUT~~ the specimen and less than the field of view);
- the original images used in the computations;

- the derived centre, and if different, the centroid image;
- the angular data functions computed in 8.5.

10 Details to be specified

The following details, as applicable, shall be stated in the relevant specification:

- type of source to be measured;
- sampling requirements, if any;
- criteria to be met by sources;
- any deviations to the procedure that may apply;
- angle θ at which the EAF is to be reported;
- the EAF template used to report results;
- measurement uncertainty.

Annex A
(informative)

System ~~requirements~~ recommendations – Measurement method 1: far field optical system

A.1 General

An $f\theta$ lens can directly convert the distribution of intensity as a function of input light angle to the distribution of intensity as a function of radius in the far field. However, scaling the far field image in order to fit the image sensor in the camera may be required. In addition, adjustment of the input light intensity in order to prevent the saturation of the image sensor may also be required using an ND filter(s). Accordingly, the far field optical system consists of $f\theta$ (telecentric) optical system and imaging optical system (relay lens). An ND filter may be placed at the filter port. Figure A.1 shows an example of an optical system using $f\theta$ lens.

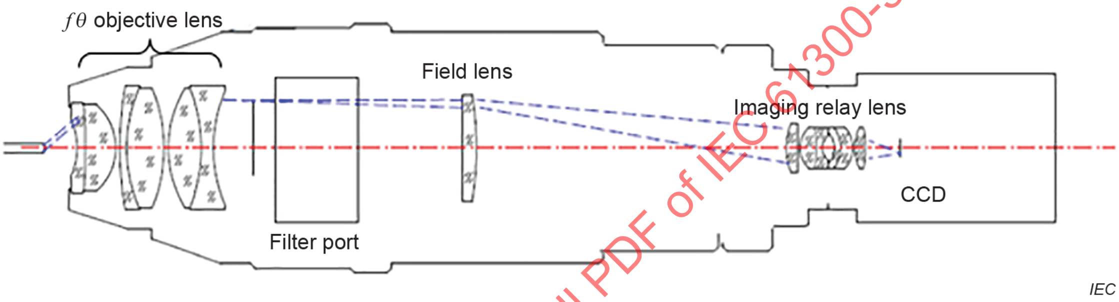


Figure A.1 – An example of an optical system using an $f\theta$ lens

A.2 ~~Requirements~~ Recommendations

~~Requirements~~ Recommended specifications of the far field optical system are ~~as follows~~:

Main lens system: $f\theta$ objective lens

Range of measurement angle to the optical axes: ±40° (NA = 0,64)

Resolution of measurement angle: 0,1° or less

Annex B
(informative)

System ~~requirements~~ recommendations – Measurement method 2: direct imaging

B.1 General

The principle of this measurement method is that light diverges from the step index multimode waveguide connected to the light source and this light is allowed to diverge in free space without passing through any lenses, prisms, apertures or other optical elements before it impinges on the photodiode or CCD or CMOS detector apart from the case of the integrating sphere where multiple internal reflections are permitted.

B.2 ~~Requirements~~ Recommendations

~~An imaging device plane without any lens system shall be placed sufficiently far from the optical source launch multimode waveguide facet so as to be in the Fraunhofer or far field. The Fraunhofer far field occurs when $L >> D^2/\lambda$ where L is the distance of the detection plane from the waveguide end facet, D is the diameter of the multimode waveguide core (or strictly mode field diameter) and λ is the wavelength.~~ The distance L between the imaging device and the waveguide end facet is much larger than the core size of the waveguide, so the field captured is the far field distribution. It ~~shall~~ should be confirmed that all of the light distribution is detected by the CCD camera, which may require the camera to be moved closer to the light source or alternatively multiple images may be stitched together.

Recommended setup specifications are:

Distance of detection surface from waveguide end facet:	$L \gg D^2/\lambda$
Range of measurement angle to the optical axes:	±40° (NA = 0,64)
Resolution of measurement angle:	0,1° or less

Annex C
(informative)

Shading effect of CCD devices: incident ray angular sensitivity

C.1 General

It is generally known that a CCD device consist of a CCD semiconductor tip and a micro lens array. The purpose of the lens array is to maximize the CCD sensitivity. At the same time, the structure causes the incident angle dependent sensitivity. When FFP image is gotten with use of direct imaging method with CCD camera, the higher angle image data may be affected by the shading effect. The shading effect is strongly dependent upon the actual CCD product structure and the tester should consult the CCD camera manufacturer shading characteristics, then adjust the measurement result using the data, although self-correction function may be included in some CCD devices.

C.2 Scheme of shading and example of the characteristics

Figure C.1 shows a scheme of shading effect of a CCD device.

Figure C.2 shows an example of shading characteristics.

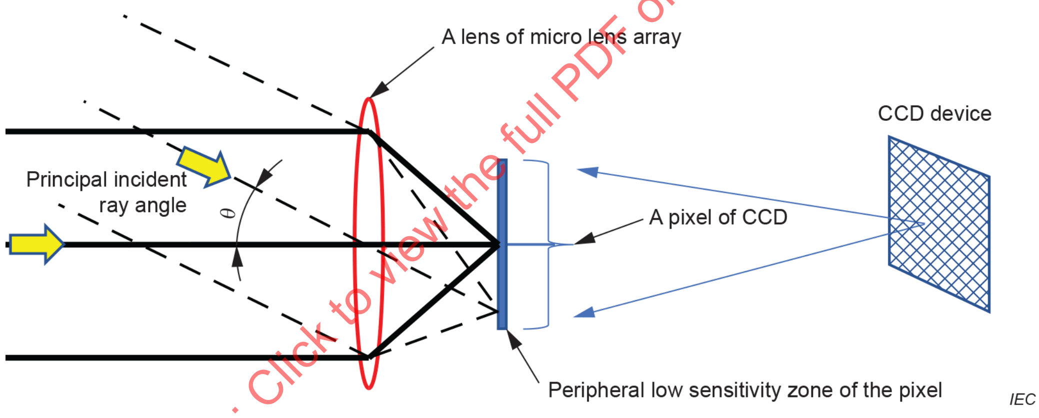


Figure C.1 – Scheme of shading effect

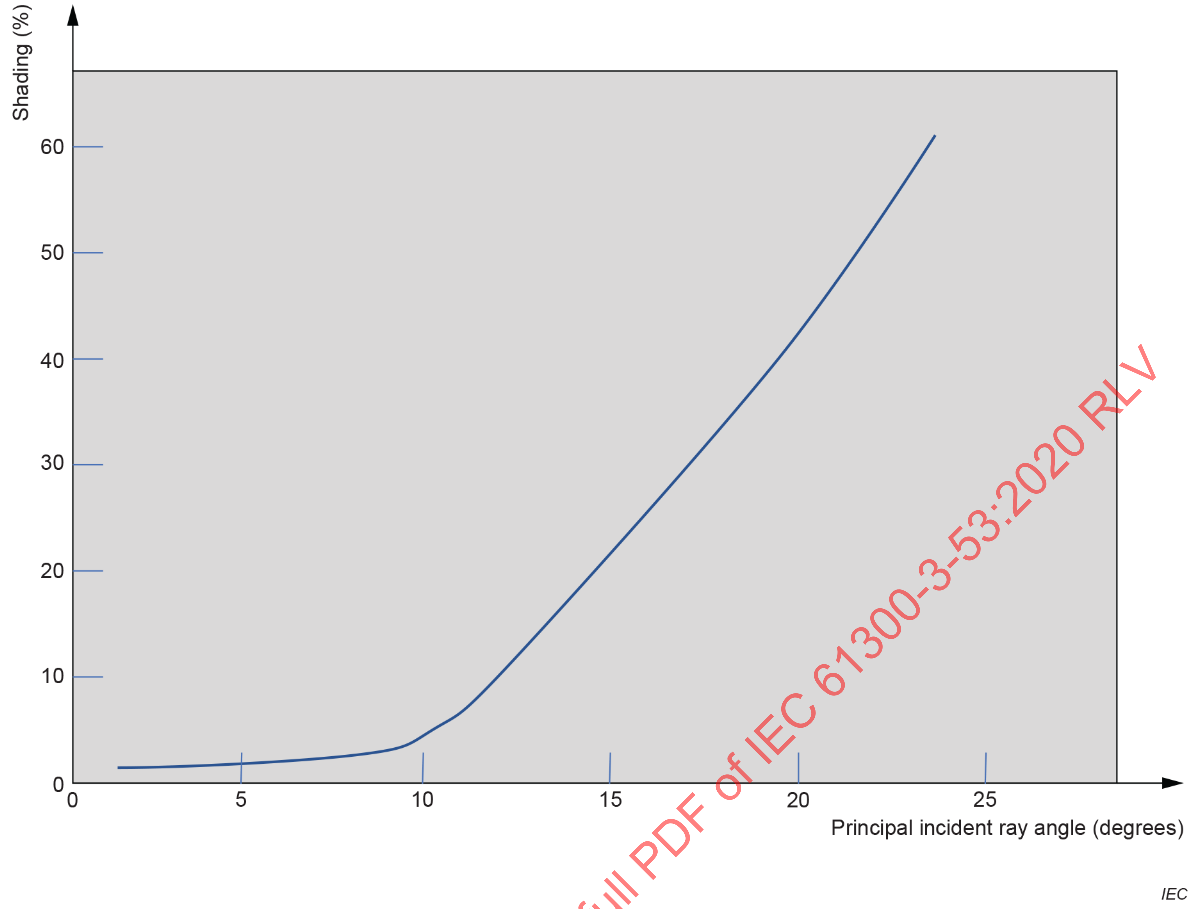


Figure C.2 – Example of shading characteristics

Annex D
(normative)

Launch optics for the EAF template compliance test

D.1 General

IEC 61300-1:2016, Clause 10, specifies an EAF template for A3e optical fibre. However, some launching conditions provide abnormal MPDs which deliver improper attenuation values because of the unevenness of optical power distribution in the core. In order to avoid these conditions, the EAF measurement for the EAF template compliance test shall be operated using the setup as described in Clause D.2.

D.2 Setup

Launch fibre shall be wrapped 5 times with a diameter of 10 mm as shown in Figure D.1. Wrapping the fibre on a round bar of 10 mm diameter should keep the required state.

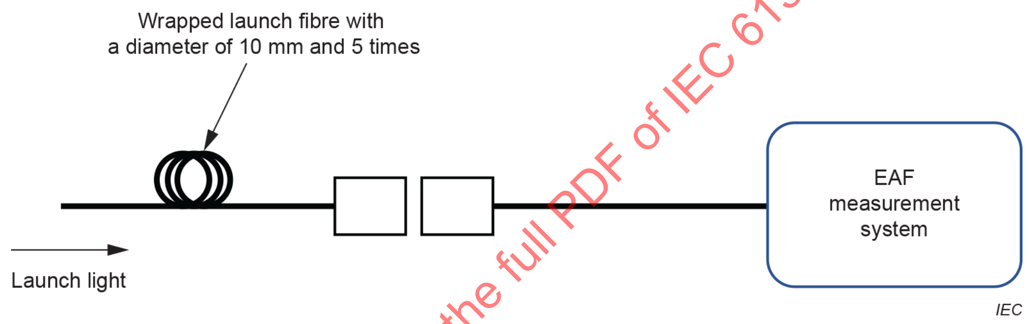


Figure D.1 – Schematic view of the setup for the EAF compliance test

Bibliography

~~MOST Specification of Physical Layer Rev. 1.1, 09/2003~~

~~IEC 60793-2-30, *Optical fibres – Part 2-30: Product specifications – Sectional specification for category A3 multimode fibres*~~

~~IEC 60793-2-40, *Optical fibres – Part 2-40: Product specifications – Sectional specification for category A4 multimode fibres*~~

~~IEC 60793-1-43, *Optical fibres – Part 1-43: measurement methods and test procedures – Numerical aperture*~~

IEC 61745, *End-face image analysis procedure for the calibration of optical fibre geometry test sets*

MOST Specification of Physical Layer Rev. 1.1, 09/2003

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IEC 61300-3-53

Edition 2.0 2020-12

INTERNATIONAL STANDARD

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**Fibre optic interconnecting devices and passive components – Basic test and measurement procedures
Part 3-53: Examinations and measurements – Encircled angular flux (EAF) measurement method based on two-dimensional far field data from multimode waveguide (including fibre)**

**Dispositifs d'interconnexion et composants passifs fibroniques – Procédures fondamentales d'essais et de mesures –
Partie 3-53: Examens et mesures – Méthode de mesure du flux angulaire inscrit (EAF) fondée sur les données bidimensionnelles de champ lointain d'un guide d'ondes multimodal (fibre incluse)**

IEC 61300-3-53:2020-12(en-fr)

CONTENTS

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FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – BASIC TEST AND MEASUREMENT PROCEDURES

Part 3-53: Examinations and measurements – Encircled angular flux (EAF) measurement method based on two-dimensional far field data from multimode waveguide (including fibre)

FOREWORD

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International Standard IEC 61300-3-53 has been prepared by subcommittee 86B: Fibre optic interconnecting devices and passive components, of IEC technical committee 86:Fibre optics.

This second edition cancels and replaces the first edition in 2015. This edition constitutes a technical revision.

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

a) the scope of the applicable wave guides, and graded index multimode optical wave guide and fibre have been included;
b) the structure of 5.3 has been rearranged;
c) Annex C and Annex D have been added.

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

FDIS	Report on voting
86B/4343/FDIS	86B/4373/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 61300, published under the general title *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures*, 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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FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – BASIC TEST AND MEASUREMENT PROCEDURES

Part 3-53: Examinations and measurements – Encircled angular flux (EAF) measurement method based on two-dimensional far field data from multimode waveguide (including fibre)

1 Scope

This part of IEC 61300 defines the encircled angular flux measurement of multimode waveguide light sources, in which most of the transverse modes are excited. The term "waveguide" is understood to include both channel waveguides and optical fibres but not slab waveguides.

The applicable fibre types are the followings:

- A1 specified in IEC 60793-2-10;
- A3 specified in IEC 60793-2-30;
- A4 specified in IEC 60793-2-40.

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 60793-2-10, *Optical fibres – Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres*

IEC 60793-2-30, *Optical fibres – Part 2-30: Product specifications – Sectional specification for category A3 multimode fibres*

IEC 60793-2-40, *Optical fibres – Part 2-40: Product specifications – Sectional specification for category A4 multimode fibres*

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

IEC 61300-1:2016, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 1: General and guidance*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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
encircled angular flux
EAF
fraction of the total optical power radiating from a multimode waveguide's core within a certain solid angle

3.2
Fraunhofer far field
far field which occurs when

$$L \gg D^2/\lambda$$

where

L is the distance of the detection plane from the waveguide end facet;

D is the diameter of the multimode waveguide core or strictly mode field diameter;

λ is the wavelength.

3.3
***fθ* lens**
lens converting the angle of incidence of the input beam, θ, into the output beam height, h

Note 1 to entry: The relationship between them is $h = f\theta$, where f is the focal length of the lens.

3.4
mode power distribution
MPD
relative mode power in each of the mode groups of a multimode fibre

[SOURCE: IEC 62614-2:2015, 3.5, modified – The words "often shown graphically" have been deleted.]

3.5
numerical aperture
NA
sine of the vertex half-angle of the largest cone of meridional rays that can enter or leave the core of an optical waveguide, multiplied by the refractive index of the medium in which the cone is located

3.6
far field pattern
FFP
angular distribution of light radiating from a waveguide's core, which corresponds to the optical power distribution on a plane normal to the waveguide axis some distance from its end facet

Note 1 to entry: The distance depends on the largest waveguide cross section, a, the wavelength, λ, and the angle, φ, to the optical axis. In the far field region, the shape of the distribution does not change as the distance from the waveguide end facet increases; the distribution only scales in size with distance, L.

$$L >> \frac{2a^2(\cos\varphi)^2}{\lambda}$$

3.7
far field image
far field pattern formed on an imaging device

3.8
neutral density filter
ND filter
filter that attenuates light of all colours equally

4 Measurement conditions

Optical fibres which are applied to this measurement are specified in IEC 60793-2-10, IEC 60793-2-30 and IEC 60793-2-40. The measurement ambient condition shall be the standard atmospheric conditions specified in IEC 61300-1.

5 Apparatus

5.1 General

The optical source multimode waveguide shall be long enough to ensure that all cladding modes are stripped by passage through the waveguide. Often, the fibre coating or tight buffer is sufficient to perform this function. Alternatively, a cladding mode stripper shall be used in the source launch multimode optical fibre. An example of a typical cladding mode stripper which would be suitable for optical fibre is sufficient windings of the fibre around a mandrel of an appropriate diameter. The windings also have a more important essential effect to fully fill the transverse modes across the maximum mode field diameter. It should be checked that all of the transverse modes of the fibre are sufficiently well excited. See Annex D. This can be done by comparing the FFPs for different lengths of the launch fibre or different light sources. Once the FFP no longer changes in form as the launch fibre length is increased, there is no need to increase the length further.

5.2 Measurement method 1: $f\theta$ lens imaging

5.2.1 General

In theory, this measurement method, which is effectively a coherent optical method to Fourier transform the near field to the far field using a lens, does not operate well using very wideband optical sources. Experimentally, it has been shown to operate sufficiently well for sources up to 30 nm bandwidth, which are most commonly used.

Figure 1 below shows the apparatus configuration. The measurement system consists of a micro-positioner, a far field broadband optical system, an imaging device (e.g. camera) and computer (EAF analyser module). An appropriate type of camera (imaging device) shall be chosen to suit the wavelength under test.

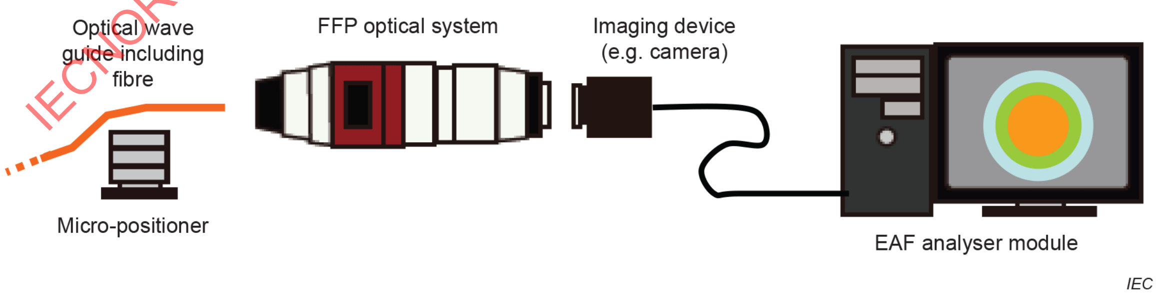


Figure 1 – Apparatus configuration of measurement method 1: $f\theta$ lens imaging

5.2.2 Micro-positioner

The micro-positioner shall hold the optical source (including the waveguide) and be able to move in three directions (X, Y, Z). Angular movement for the optical system is recommended.

5.2.3 FFP optical system

As shown in Figure 2, an $f\theta$ lens can directly convert the light from the multimode waveguide to a far field image; however, scaling the far field image in order to fit the image sensor in the imaging device and adjustment of the light intensity in order to prevent saturation is required. The FFP optical system is chosen to operate at the measurement wavelength across the required measurement bandwidth to match that of the detection system. See Annex A for more information.

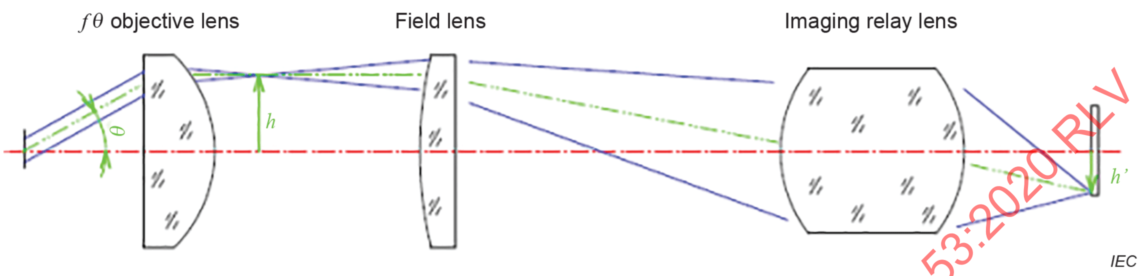


Figure 2 – Far field optical system diagram

5.2.4 Imaging device

Imaging device includes a camera, CCD, CMOS, etc. that can detect images. The detector is typically a charge coupled device (CCD) or a complementary metal oxide semiconductor (CMOS) camera. The type of imaging device shall be chosen by the measurement wavelength. Absolute intensity measurement is not required.

5.2.5 Computer (EAF analyser module)

Since the acquired image contains many thousands of pixels, and the image conversion into encircled angular flux requires substantial computation, a computer is required. The computer shall be connected to the imaging device through an image acquisition board (or with an embedded image acquisition circuit), and beam analysis software which enables the computer as a EAF analyser shall be installed.

5.3 Measurement method 2: direct imaging

5.3.1 General

In this method, far field images are acquired directly by an imaging device without any optical system. The distance between the optical waveguide source under test and the imaging device shall be long enough to achieve Fraunhofer far field.

NOTE A CCD device generally consist of CCD semiconductor tip and micro lens array to get higher sensitivity practically, then the structure generates shading effect which is incident angle dependent sensitivity consequently. For more information, see Annex C and Figure 3.

See detail information of imaging device setup in Annex B.

When the far field image is larger than the area of the imaging device, multiple images shall be taken and stitched together to configure a complete far field image.

5.3.2 Micro-positioner

Both the input multimode waveguide source and the photo detector (PD) shall be mounted on motorized translation Astages. The motorized translation stages shall operate for both coarse alignment with tenths millimetres step movement for wide position and accurate alignment with sub-micron step adjustment to maximize the light through the waveguide.

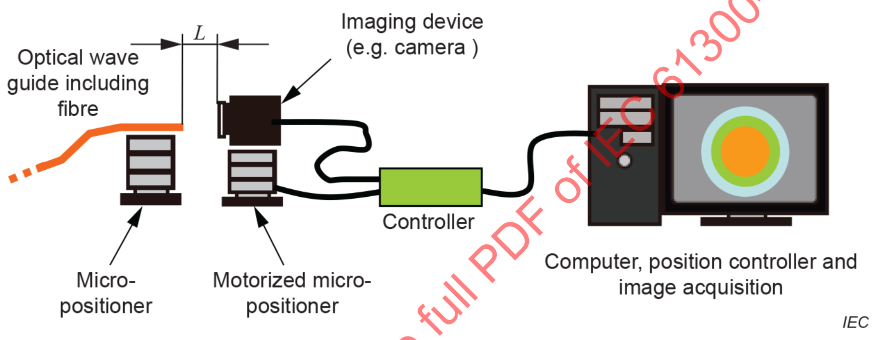
5.3.3 Imaging device

An imaging device includes a camera, CCD, CMOS, etc. that can detect images. An imaging device plane without any lens system shall be placed sufficiently far from the optical source launch multimode waveguide facet so as to be in the Fraunhofer far field.

The imaging device may, for example, be a CCD camera with its lens removed so that the light distribution falls directly on the CCD chip. The lateral position from the optical axis in the far field shall be converted to an angle of divergence from the optical axis. The angle is the arctangent of the ratio of the lateral X or Y position to the distance L. Therefore, considerable care shall be taken to accurately measure L.

5.3.4 Computer, position controller and image acquisition

The computer controls the position of the imaging device (camera) so that the proper image(s) is(are) acquired. If the far field image is too large to shoot an single image, the computerized controller moves the imaging device to the several different positions to acquire multiple images which are finally combined and become one far field image.



NOTE A CCD device generally consist of CCD semiconductor tip and micro lens array to get higher sensitivity practically, then the structure generates shading effect which is incident angle dependent sensitivity consequently. For more information, see Annex C.

Figure 3 – Apparatus configuration of measurement method 2: direct imaging

6 Sampling and specimens

The sampling and preparation procedures for the light sources which launch light into multimode waveguides to be tested shall be documented. The light sources under test shall have an operating wavelength compatible with the detector and $f\theta$ lens, and have optical connectors or splices compatible with the input port of the apparatus. The construction details of the light sources are not otherwise specified.

7 Geometric calibration

7.1 General

Calibration of the apparatus is critical to the accuracy of this measurement procedure. Calibration shall be performed periodically. If the calibration is known to drift significantly during a measurement interval, the drift of the source(s) shall be identified and eliminated. If the apparatus is disassembled or its components in or affecting the optical path are otherwise manipulated, calibration shall be performed before measurements are made.

The purpose of geometric calibration is to obtain the measurement data needed to compute the conversion factor. The factor shall be used to convert camera coordinates to light launching angle relative to the optical axis of optical waveguide.

7.2 Light source

The calibration light source shall be broadband and incoherent, in order to avoid speckle noise issues, and shall have a sufficiently symmetrical far field distribution so that the calculated centroid of the far field indicates the location of the optical centre axis of the waveguide with sufficient accuracy for the purposes of this document.

7.3 Procedure

Calibration shall be performed to measure the conversion factor that relates the light launching angle to the pixel of the detector corresponding to this angle. The factor has a unit of degree per pixel and shall be used to convert imaging device coordinates to far field angle coordinates. The collimated light source for geometric calibration, shown in Figure 4, shall have a spectral power distribution similar to that of the measurement light source and the central wavelength within 30 nm around the nominal wavelength of the measurement light source.

The calibration procedure is stated below:

Step 1: set a collimated light source whose incident angle relative to the optic axis of the far field optical system can be precisely controlled; and

NOTE An example of the calibration apparatus is shown in Figure 4.

Step 2: measure the conversion factors from the whole range of angles to be measured with an interval small enough (e.g. 1°) to enable accurate interpolation.

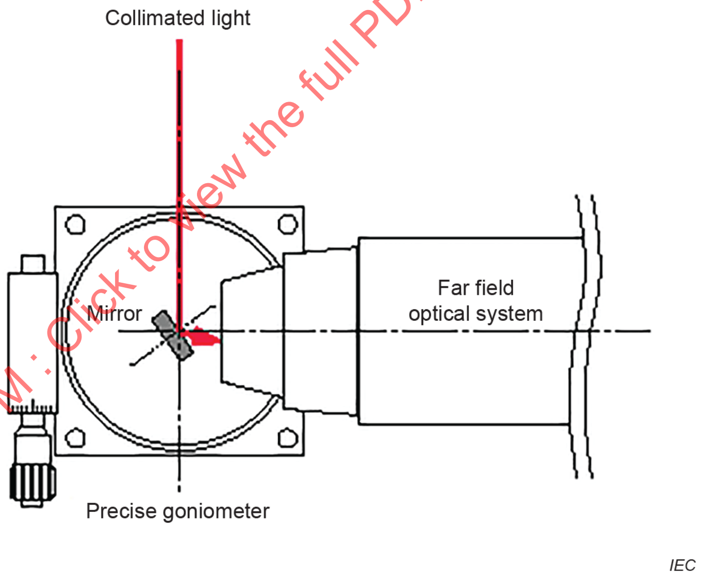


Figure 4 – Calibration apparatus example

8 Measurement procedure

8.1 Safety

All procedures in which a light emitting diode (LED) or a laser source is used as the optical source shall be carried out using safety precautions in accordance with IEC 60825-1.

8.2 Far field image acquisition

8.2.1 General

Acquiring an image is central to the measurement of encircled angular flux. The approach to image acquisition depends on the general characteristics of the light source being measured.

8.2.2 Waveguide end-face alignment

A waveguide end-face shall be placed at the front focal point of the FFP optical system. The live far field image acquired on the computer display shall be adjusted to be in the centre of the display using the X and Y axes of the micro-positioner, and to a minimum diameter and in focus using the Z axis of the micro-positioner in 5.2.2.

8.2.3 Light source image acquisition

Measurement light sources shall be sufficiently incoherent and shall be sufficiently intense to easily get good dynamic range, although attenuation may be required using neutral density (ND) filter(s). The acquired image shall be shown in the PC display as in Figure 5. The picture may be displayed with false colour in Figure 6.

Figure 5 – Acquired far field image

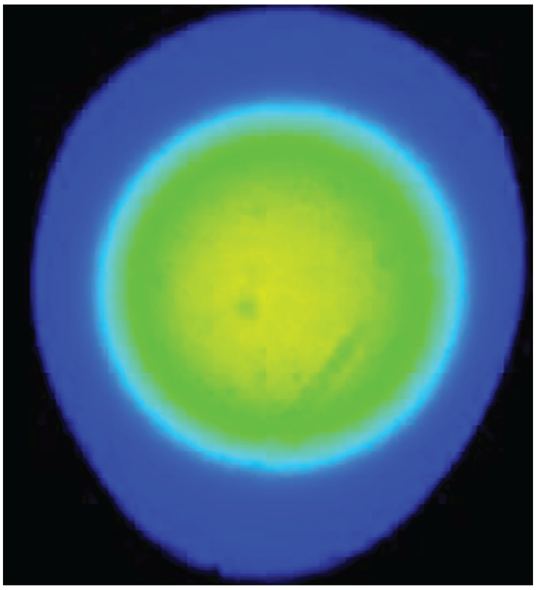


Figure 6 – Acquired far field image with false colour

8.3 Removal of background noise

The dark current of the camera which is acquired by obscuring the input light beforehand shall be removed from the acquired image, or 0,5 % intensity of the peak power in the acquired image shall be set as a background level.

8.4 Centre determination

8.4.1 General

One of the two methods shall be used.

8.4.2 Method A: Optical centre determination

The encircled angular flux is computed with respect to the optical centroid of the FFP distribution. As shown in Figure 7, the centroid of the acquired image shall be determined with the use of Formula (1).

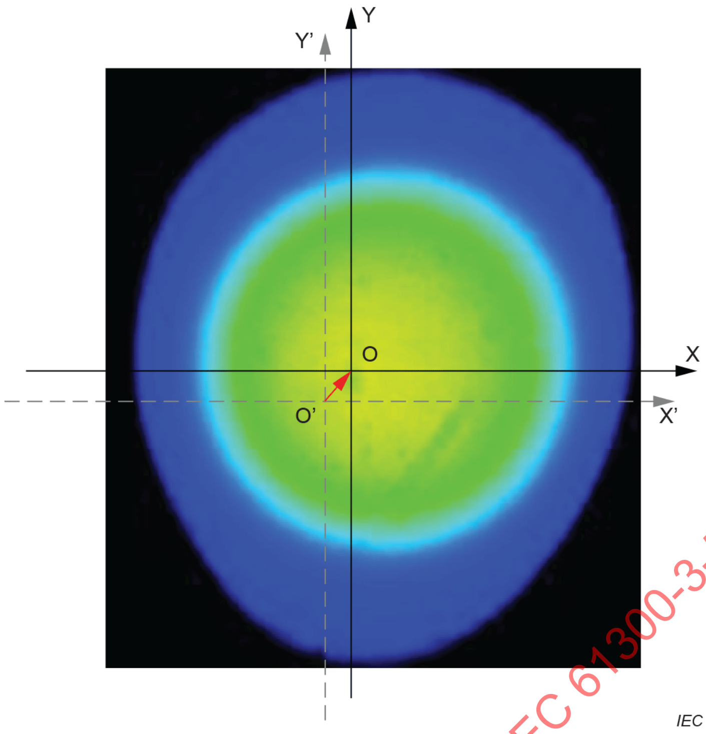


Figure 7 – Optical centre determination

$$O(x=0,\ y=0)=O'(x'=0,\ y'=0)-\left(\frac{\sum_{x'} x' \sum_{y'} I(x',y')}{\sum_{x'}\sum_{y'} I(x',y')},\ \frac{\sum_{x'} y' \sum_{y'} I(x',y')}{\sum_{x'}\sum_{y'} I(x',y')}\right) \tag{1}$$

where

O' is the origin of FFP optical system;

O is the calculated centroid of the acquired image;

(x', y') is the x-y coordinates based on the FFP optical system origin;

$I(x', y')$ is the light intensity at coordinate (x', y').

8.4.3 Method B: Mechanical centre determination

The encircled angular flux is computed with respect to the optical central axis of the measurement optics. The optical central axis of the measurement optics, O_m, shall be determined by measuring the far field pattern of a reference waveguide. The reference waveguide shall be a single-mode fibre, and the end-face of the fibre should be perpendicular to the optical axis.

$$O_m(x_m=0,\ y_m=0)=O'_m(x'_m=0,\ y'_m=0)-\left(\frac{\sum_{x'} x'_m \sum_{y'} I(x'_m,y'_m)}{\sum_{x'}\sum_{y'} I(x'_m,y'_m)},\ \frac{\sum_{x'} y'_m \sum_{y'} I(x'_m,y'_m)}{\sum_{x'}\sum_{y'} I(x'_m,y'_m)}\right) \tag{2}$$

where

O'_m is the origin of direct imaging;

O_m is the calculated centroid of the acquired image;

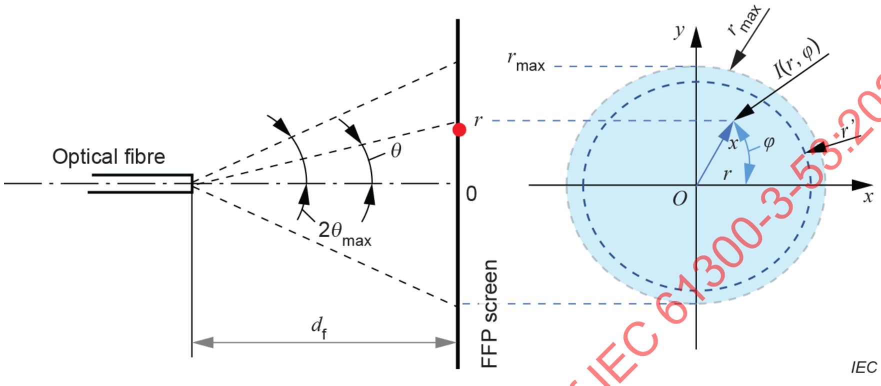
(x'_m, y'_m) is the x-y coordinates based on the direct imaging origin.

$I(x'_m, y'_m)$ is the light intensity at coordinate (x'_m, y'_m).

For method B, O'_m shall be fixed during a series of measurements.

8.5 Computation of encircled angular flux

Before computation of encircled angular flux, the x-y coordinates are converted to polar coordinates using r and φ as shown in Figure 8 (b). Figure 8 (a) shows the side view of the fibre and the emitted beam. Applying r and φ to encircled flux equation, light intensity distribution on an FFP screen is described in Formula (3).



a) Side view b) Image sensor plane

Figure 8 – Transformation of x-y to polar coordinates on the image sensor plane

$$EF(r') = \frac{\int_0^{2\pi} \int_0^{r'} I(r,\varphi) \cdot r \cdot dr \cdot d\varphi}{\int_0^{2\pi} \int_0^{r_{max}} I(r,\varphi) \cdot r \cdot dr \cdot d\varphi} \quad (3)$$

Here is a simple Formula (4) to show the relationship between r, θ and d_f, and its differential form, Formula (5):

$$r = d_f \cdot \tan(\theta) \quad (4)$$

$$r \cdot d_r = d_f^2 \cdot \sin(\theta) \cdot \cos^{-3}(\theta) \cdot d\theta \quad (5)$$

Replacing r with θ using Formula (4) and Formula (5), Formula (6) is obtained. This shows EAF value $E(\theta')$.

$$E(\theta') = \frac{\int_0^{2\pi} \int_0^{\theta'} I(r,\varphi) \cdot \frac{\sin(\theta)}{\cos^3(\theta)} \cdot d\theta d\varphi}{\int_0^{2\pi} \int_0^{\theta_{max}} I(r,\varphi) \cdot \frac{\sin(\theta)}{\cos^3(\theta)} \cdot d\theta d\varphi} \quad (6)$$

where

r is the radial distance from the origin corresponding to an angle between one ray emitted from the multimode waveguide and the optical axis of the multimode waveguide;

r_{max}	is the radial distance from the origin corresponding to the maximum ray angle, which is approximately 30° for category A3 multimode fibre for example;
φ	is a circular angle in polar coordinates;
θ	is an angle between one ray emitted from the multimode waveguide and the optical axis;
θ_{max}	is the maximum ray angle, which is approximately 30° for category A3 multimode fibre for example;
d_f	is the distance between the end of multimode optical waveguide and FFP screen;
O and O_m	are the calculated centroids discussed in 8.4.

An example of EAF is shown in Figure 9.

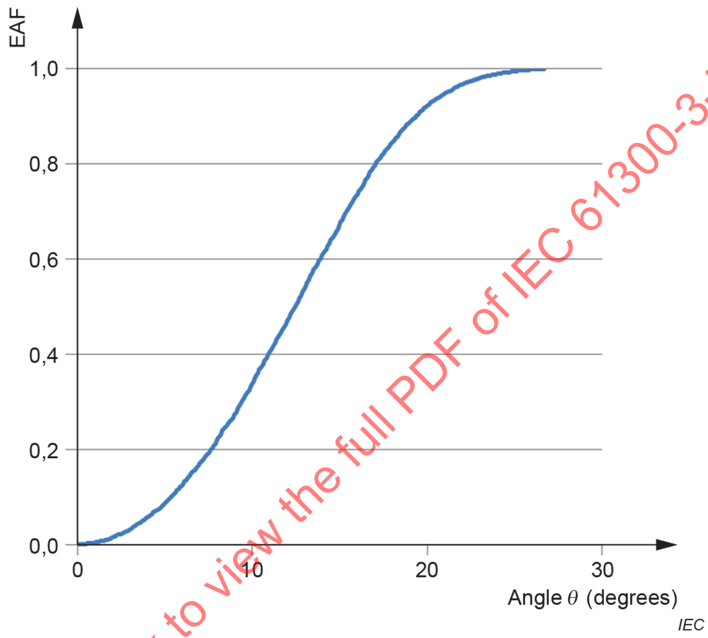


Figure 9 – Typical encircled angular flux chart

9 Results

9.1 Information available with each measurement

Report the following with each measurement:

- date and time of measurement;
- identification of source;
- nominal wavelength of source;
- method of centre determination;
- the encircled angular flux at each angle shall be reported after a series of measurements is completed;
- EAF as a graph as a function of angle θ (Figure 9), including any specified template limits.

For method B, specify the single-mode fibre and multimode fibre connectors and their lateral and angular tolerances, if the measurements are referenced to the connector.

9.2 Information available upon request

The following information shall be available upon request:

- date of most recent calibration of equipment;
- method of calibration of equipment;
- the integration limit parameters (larger than the angle corresponding to the NA of the specimen and less than the field of view);
- the original images used in the computations;
- the derived centre, and if different, the centroid image;
- the angular data functions computed in 8.5.

10 Details to be specified

The following details, as applicable, shall be stated in the relevant specification:

- type of source to be measured;
- sampling requirements, if any;
- criteria to be met by sources;
- any deviations to the procedure that may apply;
- angle θ at which the EAF is to be reported;
- the EAF template used to report results;
- measurement uncertainty.

Annex A
(informative)

System recommendations –
Measurement method 1: far field optical system

A.1 General

An *fθ* lens can directly convert the distribution of intensity as a function of input light angle to the distribution of intensity as a function of radius in the far field. However, scaling the far field image in order to fit the image sensor in the camera may be required. In addition, adjustment of the input light intensity in order to prevent the saturation of the image sensor may also be required using an ND filter(s). Accordingly, the far field optical system consists of *fθ* (telecentric) optical system and imaging optical system (relay lens). An ND filter may be placed at the filter port. Figure A.1 shows an example of an optical system using *fθ* lens.

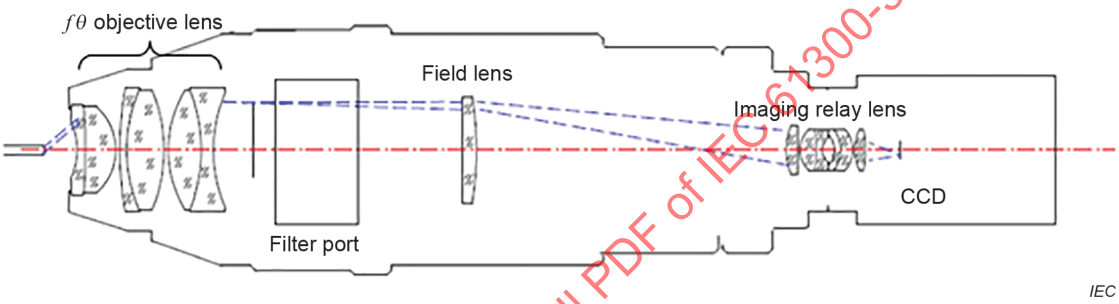


Figure A.1 – An example of an optical system using an *fθ* lens

A.2 Recommendations

Recommended specifications of the far field optical system are:

Main lens system:	*fθ* objective lens
Range of measurement angle to the optical axes:	±40° (NA = 0,64)
Resolution of measurement angle:	0,1° or less

Annex B
(informative)

System recommendations – Measurement method 2: direct imaging

B.1 General

The principle of this measurement method is that light diverges from the step index multimode waveguide connected to the light source and this light is allowed to diverge in free space without passing through any lenses, prisms, apertures or other optical elements before it impinges on the photodiode or CCD or CMOS detector apart from the case of the integrating sphere where multiple internal reflections are permitted.

B.2 Recommendations

The distance L between the imaging device and the waveguide end facet is much larger than the core size of the waveguide, so the field captured is the far field distribution. It should be confirmed that all of the light distribution is detected by the CCD camera, which may require the camera to be moved closer to the light source or alternatively multiple images may be stitched together.

Recommended setup specifications are:

Distance of detection surface from waveguide end facet:	$L \gg D^2/\lambda$
Range of measurement angle to the optical axes:	±40° (NA = 0,64)
Resolution of measurement angle:	0,1° or less

Annex C
(informative)

Shading effect of CCD devices: incident ray angular sensitivity

C.1 General

It is generally known that a CCD device consist of a CCD semiconductor tip and a micro lens array. The purpose of the lens array is to maximize the CCD sensitivity. At the same time, the structure causes the incident angle dependent sensitivity. When FFP image is gotten with use of direct imaging method with CCD camera, the higher angle image data may be affected by the shading effect. The shading effect is strongly dependent upon the actual CCD product structure and the tester should consult the CCD camera manufacturer shading characteristics, then adjust the measurement result using the data, although self-correction function may be included in some CCD devices.

C.2 Scheme of shading and example of the characteristics

Figure C.1 shows a scheme of shading effect of a CCD device.

Figure C.2 shows an example of shading characteristics.

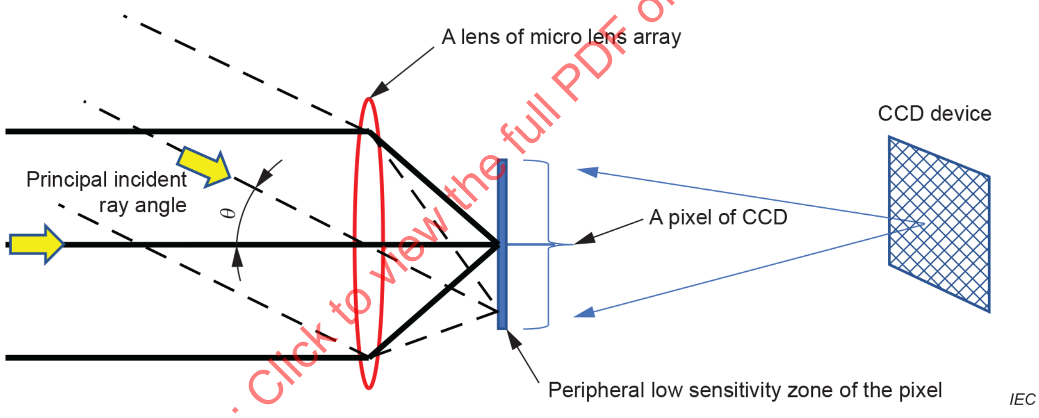


Figure C.1 – Scheme of shading effect

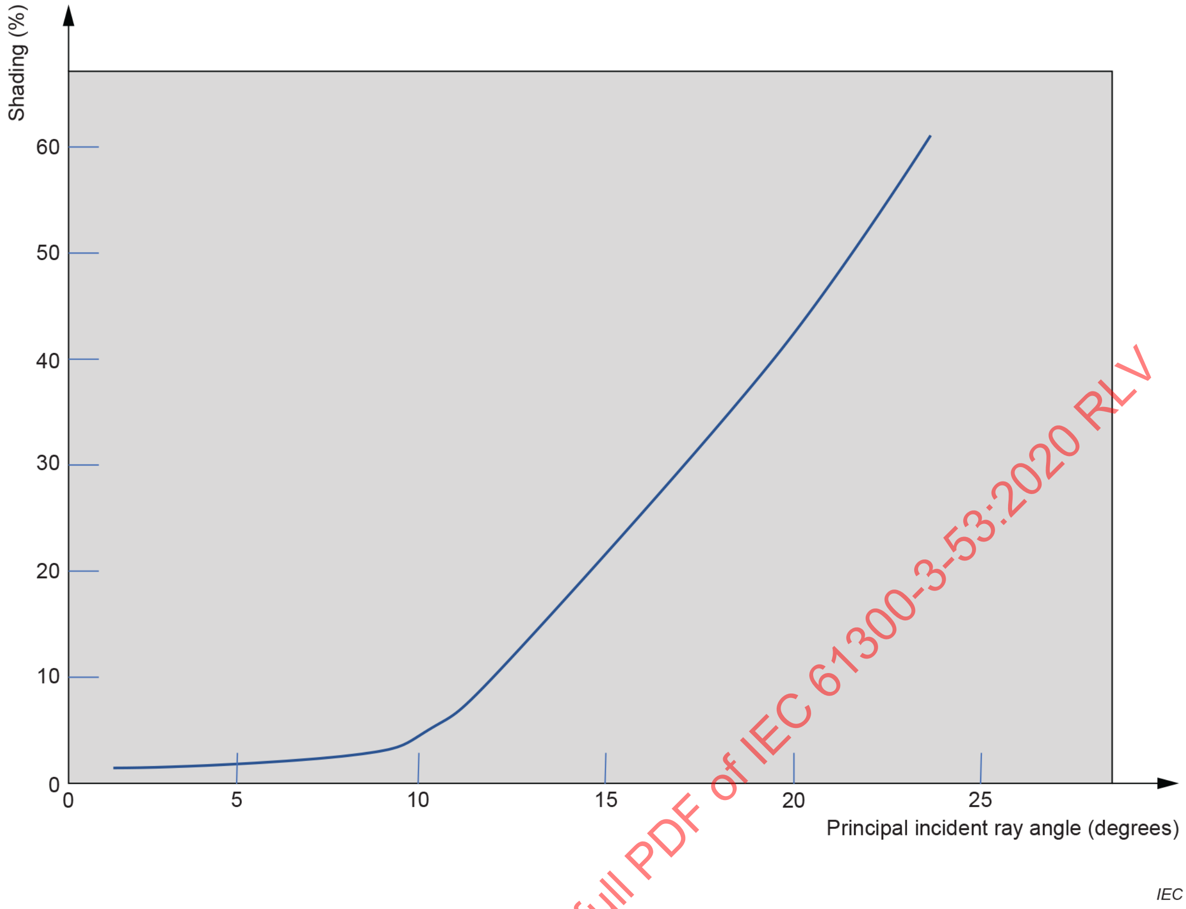


Figure C.2 – Example of shading characteristics

Annex D
(normative)

Launch optics for the EAF template compliance test

D.1 General

IEC 61300-1:2016, Clause 10, specifies an EAF template for A3e optical fibre. However, some launching conditions provide abnormal MPDs which deliver improper attenuation values because of the unevenness of optical power distribution in the core. In order to avoid these conditions, the EAF measurement for the EAF template compliance test shall be operated using the setup as described in Clause D.2.

D.2 Setup

Launch fibre shall be wrapped 5 times with a diameter of 10 mm as shown in Figure D.1. Wrapping the fibre on a round bar of 10 mm diameter should keep the required state.

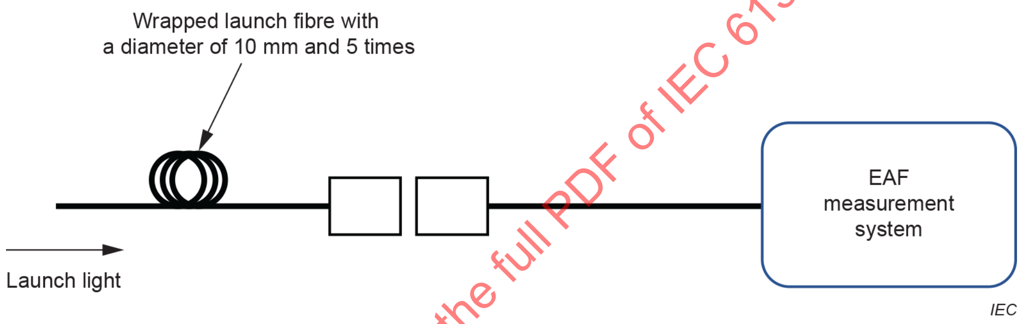


Figure D.1 – Schematic view of the setup for the EAF compliance test

Bibliography

IEC 61745, *End-face image analysis procedure for the calibration of optical fibre geometry test sets*

MOST Specification of Physical Layer Rev. 1.1, 09/2003

SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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DISPOSITIFS D'INTERCONNEXION ET COMPOSANTS PASSIFS FIBRONIQUES – PROCÉDURES FONDAMENTALES D'ESSAIS ET DE MESURES –

Partie 3-53: Examens et mesures – Méthode de mesure du flux angulaire inscrit (EAF) fondée sur les données bidimensionnelles de champ lointain d'un guide d'ondes multimodal (fibre incluse)

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Cette deuxième édition annule et remplace la première édition parue en 2015. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) la portée des guides d'ondes applicables, ainsi que la fibre et le guide d'ondes optiques multimodaux à gradient d'indice ont été inclus;
b) restructuration de 5.3;
c) ajout de l'Annexe C et de l'Annexe D.

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
86B/4343/FDIS	86B/4373/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 61300, publiées sous le titre général, *Dispositifs d'interconnexion et composants passifs fibroniques – Procédures fondamentales d'essais et de mesures* peut être consultée sur le site web de l'IEC.

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DISPOSITIFS D'INTERCONNEXION ET COMPOSANTS PASSIFS FIBRONIQUES – PROCÉDURES FONDAMENTALES D'ESSAIS ET DE MESURES –

Partie 3-53: Examens et mesures – Méthode de mesure du flux angulaire inscrit (EAF) fondée sur les données bidimensionnelles de champ lointain d'un guide d'ondes multimodal (fibre incluse)

1 Domaine d'application

La présente partie de l'IEC 61300 définit la mesure du flux angulaire inscrit de sources de rayonnement lumineux dotées d'un guide d'ondes multimodal, pour lequel la plupart des modes transversaux sont excités. On considère que le terme "guide d'ondes" inclut à la fois des guides d'ondes de canal et des fibres optiques, mais pas des guides d'ondes rectangulaires rigides.

Les types de fibres applicables sont les suivants:

- A1 spécifié dans l'IEC 60793-2-10;
- A3 spécifié dans l'IEC 60793-2-30;
- A4 spécifié dans l'IEC 60793-2-40.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60793-2-10, *Fibres optiques – Partie 2-10: Spécifications de produits – Spécification intermédiaire pour les fibres multimodales de catégorie A1*

IEC 60793-2-30, *Optical fibres – Part 2-30: Product specifications – Sectional specification for category A3 multimode fibres* (Disponible en anglais seulement)

IEC 60793-2-40, *Fibres optiques – Partie 2-40: Spécifications de produits – Spécification intermédiaire pour les fibres multimodales de catégorie A4*

IEC 60825-1, *Sécurité des appareils à laser – Partie 1: Classification des matériels et exigences*

IEC 61300-1:2016, *Dispositifs d'interconnexion et composants passifs fibroniques – Procédures fondamentales d'essais et de mesures – Partie 1: Généralités et lignes directrices*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1
flux angulaire inscrit
EAF
fraction de la puissance optique totale rayonnée par le cœur d'un guide d'ondes multimodal dans un certain angle solide

Note 1 à l'article: L'abréviation "EAF" est dérivée du terme anglais développé correspondant "encircled angular flux".

3.2
champ lointain de Fraunhofer
champ lointain apparaissant lorsque

$$L \gg D^2/\lambda$$

où

L est la distance du plan de détection par rapport à la facette d'extrémité du guide d'ondes;

D est le diamètre du cœur du guide d'ondes multimodal, ou au sens strict, le diamètre du champ de modes;

λ est la longueur d'onde.

3.3
lentille $f\theta$
lentille convertissant l'angle d'incidence du faisceau d'entrée, θ, en hauteur du faisceau de sortie, h

Note 1 à l'article: La relation entre ces deux grandeurs est $h = f\theta$, où f est la longueur focale de la lentille.

3.4
distribution de puissance modale
MPD
puissance modale relative dans chaque groupe de modes d'une fibre multimodale

Note 1 à l'article: L'abréviation "MPD" est dérivée du terme anglais développé correspondant "mode power distribution".

[SOURCE: IEC 62614-2:2015, 3.5, modifiée – Les mots "souvent représentée de manière graphique" ont été supprimés.]

3.5
ouverture numérique
NA
sinus du demi-angle au sommet du plus grand cône de rayons méridiens pouvant entrer dans le cœur d'un guide d'ondes optique ou le quitter, multiplié par l'indice de réfraction du milieu dans lequel est situé le cône

Note 1 à l'article: L'abréviation "NA" est dérivée du terme anglais développé correspondant "numerical aperture".

3.6
diagramme de champ lointain
FFP
distribution angulaire de la lumière rayonnée par le cœur d'un guide d'ondes, qui correspond à la distribution de la puissance optique sur un plan normal à l'axe du guide d'ondes à une certaine distance de sa facette d'extrémité

Note 1 à l'article: La distance dépend de la plus grande section du guide d'ondes, a, de la longueur d'onde, λ, et de l'angle, φ par rapport à l'axe optique. Dans la région de champ lointain, la forme de la distribution ne change pas lorsque la distance par rapport à la facette d'extrémité du guide d'ondes augmente; la distribution est simplement mise à l'échelle avec la distance, L.

$$L >> \frac{2a^2 (\cos \varphi)^2}{\lambda}$$

Note 2 à l'article: L'abréviation "FFP" est dérivée du terme anglais développé correspondant "far field pattern".

3.7
image de champ lointain
diagramme de champ lointain formé sur un dispositif d'imagerie

3.8
filtre à densité neutre
filtre ND
filtre qui atténue de manière égale le rayonnement lumineux de toutes les couleurs

Note 1 à l'article: L'abréviation "ND" est dérivée du terme anglais développé correspondant "neutral density".

4 Conditions de mesure

Les fibres optiques qui sont appliquées à cette mesure sont spécifiées dans l'IEC 60793-2-10, l'IEC 60793-2-30 et l'IEC 60793-2-40. Les conditions ambiantes de mesure doivent correspondre aux conditions atmosphériques normales spécifiées dans l'IEC 61300-1.

5 Appareillage

5.1 Généralités

Le guide d'ondes optique source multimodal doit être d'une longueur suffisante pour que tous les modes de gaine soient extraits en traversant le guide d'onde. Le revêtement de la fibre ou un revêtement protecteur serré suffit souvent pour remplir cette fonction. En variante, un extracteur de modes de gaine doit être utilisé dans la fibre optique multimodale d'injection source. Un extracteur de modes de gaine type convenant pour une fibre optique est obtenu par exemple avec un nombre suffisant d'enroulements de la fibre autour d'un mandrin d'un diamètre approprié. Les enroulements ont également un effet essentiel plus important en ce qu'ils remplissent entièrement les modes transversaux sur le diamètre maximal des champs de mode. Il convient de vérifier que tous les modes transversaux de la fibre sont suffisamment bien excités. Voir l'Annexe D. Ceci peut être réalisé en comparant les FFP pour différentes longueurs de la fibre d'injection ou différentes sources de rayonnements lumineux. Lorsque la forme du FFP ne varie plus à mesure que la longueur de la fibre d'injection augmente, il est inutile de continuer à augmenter la longueur.

5.2 Méthode de mesure 1: imagerie de lentille $f\theta$

5.2.1 Généralités

En théorie, cette méthode de mesure qui est effectivement une méthode optique cohérente pour effectuer une transformation de Fourier du champ proche en champ lointain en utilisant une lentille, ne fonctionne pas bien si l'on utilise des sources optiques à très large bande. Il a été démontré expérimentalement qu'elle fonctionnait suffisamment bien pour des sources d'une largeur de bande allant jusqu'à 30 nm, qui sont les plus couramment utilisées.

La Figure 1 ci-dessous représente la configuration de l'appareillage. Le système de mesure est constitué d'un micropositionneur, d'un système optique à large bande de champ lointain, d'un dispositif d'imagerie (par exemple une caméra) et d'un ordinateur (module analyseur d'EAF). Un type de caméra (dispositif d'imagerie) approprié doit être choisi en fonction de la longueur d'onde soumise à essai.

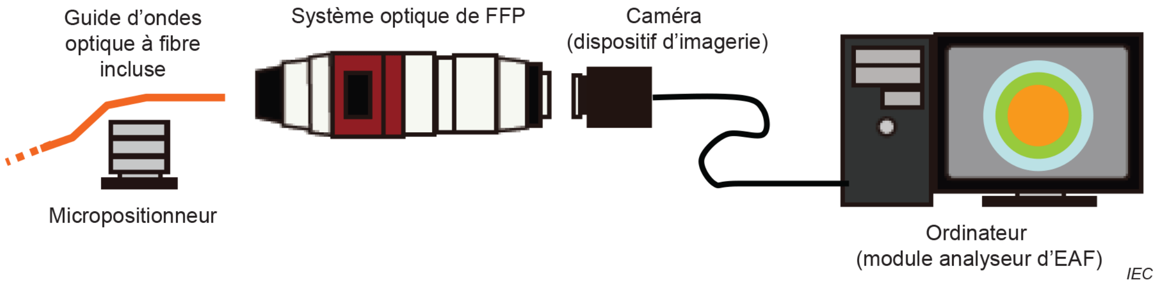

Figure 1 – Configuration de l'appareillage – Méthode de mesure 1: imagerie de lentille $f\theta$

5.2.2 Micropositionneur

Le micropositionneur doit maintenir la source optique (guide d'ondes inclus) et pouvoir se déplacer dans trois directions (X, Y, Z). Un mouvement angulaire du système optique est recommandé.

5.2.3 Système optique de FFP

Comme cela est représenté à la Figure 2, une lentille $f\theta$ peut convertir directement le rayonnement lumineux, provenant du guide d'ondes multimodal, en une image de champ lointain; toutefois, il est nécessaire de procéder à une mise à l'échelle de l'image de champ lointain pour adapter le détecteur d'image du dispositif d'imagerie et de régler l'intensité lumineuse pour empêcher une saturation. Le système optique de FFP est choisi de manière à fonctionner à la longueur d'onde de mesure sur toute la largeur de bande de mesure exigée pour correspondre à celle du système de détection. Voir l'Annexe A pour de plus amples informations.

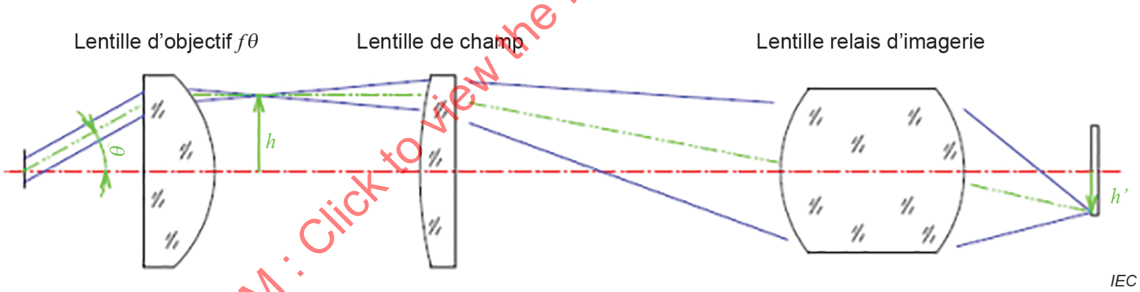

Figure 2 – Schéma du système optique de champ lointain

5.2.4 Dispositif d'imagerie

Un dispositif d'imagerie comprend une caméra, un dispositif de transfert de charge (CCD, charge-coupled device), un dispositif à semiconducteur complémentaire à oxyde métallique (CMOS, complementary metal oxide semiconductor), etc. qui peut détecter des images. Le détecteur est habituellement un CCD ou un CMOS. Le type de dispositif d'imagerie doit être choisi en fonction de la longueur d'onde de mesure. Une mesure de l'intensité absolue n'est pas exigée.

5.2.5 Ordinateur (module analyseur d'EAF)

Puisque l'image acquise contient des milliers de pixels et que la conversion de l'image en flux angulaire inscrit nécessite d'importants calculs, un ordinateur est nécessaire. L'ordinateur doit être raccordé au dispositif d'imagerie par l'intermédiaire d'une carte d'acquisition d'image (ou avec un circuit d'acquisition d'image incorporé), et un logiciel d'analyse de faisceau qui permet à l'ordinateur de fonctionner comme un module analyseur d'EAF doit être installé.

5.3 Méthode de mesure 2: imagerie directe

5.3.1 Généralités

Avec cette méthode, les images de champ lointain sont directement acquises par un dispositif d'imagerie sans aucun système optique. La distance entre le guide d'ondes optique source soumis à essai et le dispositif d'imagerie doit être d'une longueur suffisante pour atteindre le champ lointain de Fraunhofer.

NOTE Un dispositif CCD est généralement constitué d'une pointe semiconductrice de CCD et d'un réseau de microlentilles permettant d'obtenir une grande sensibilité en pratique. Puis, la structure génère en conséquence un effet d'ombrage qui correspond à la sensibilité en fonction de l'angle d'incidence. Pour de plus amples informations, voir l'Annexe C et la Figure 3.

Se reporter à l'Annexe B pour les informations détaillées de la configuration du dispositif d'imagerie.

Lorsque l'image de champ lointain est plus grande que la zone couverte par le dispositif d'imagerie, plusieurs images doivent être prises et assemblées afin de former une image de champ lointain complète.

5.3.2 Micropositionneur

Le guide d'ondes source multimodal d'entrée et le détecteur à photodiode (DP) doivent tous deux être montés sur des éléments de translation motorisés. Ces éléments doivent fonctionner tant pour un alignement grossier avec un déplacement par échelons de dixièmes de millimètres pour la position large, que pour un alignement précis avec un réglage par échelons submicroniques permettant d'augmenter au maximum la lumière traversant le guide d'ondes.

5.3.3 Dispositif d'imagerie

Un dispositif d'imagerie comprend une caméra, un dispositif de transfert de charge (CCD), un dispositif à semiconducteur complémentaire à oxyde métallique (CMOS), etc. qui peut détecter des images. Un plan de dispositif d'imagerie sans aucun système de lentille doit être installé suffisamment loin de la facette du guide d'ondes multimodal d'injection de la source optique pour se trouver dans le champ lointain de Fraunhofer.

Le dispositif d'imagerie peut être, par exemple, une caméra CCD dont la lentille a été retirée, de sorte que la distribution de lumière tombe directement sur la puce CCD. La position latérale par rapport à l'axe optique dans le champ lointain doit être convertie en angle de divergence par rapport à l'axe optique. L'angle est l'arc tangent du rapport de la position latérale X ou Y sur la distance L. Une mesure précise de L exige donc le plus grand soin.

5.3.4 Ordinateur, régulateur de position et acquisition d'image

L'ordinateur régule la position du dispositif d'imagerie (caméra) de manière à acquérir la ou les images adéquates. Si l'image de champ lointain est trop grande pour qu'une seule image puisse être capturée, le régulateur informatisé déplace le dispositif d'imagerie dans différentes positions pour acquérir plusieurs images qui sont ensuite réunies en une seule image de champ lointain.