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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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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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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- withdrawn,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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

The contents of the corrigendum 1 (2023-06) have been included in this copy.

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
***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, ~~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: *fθ* 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.

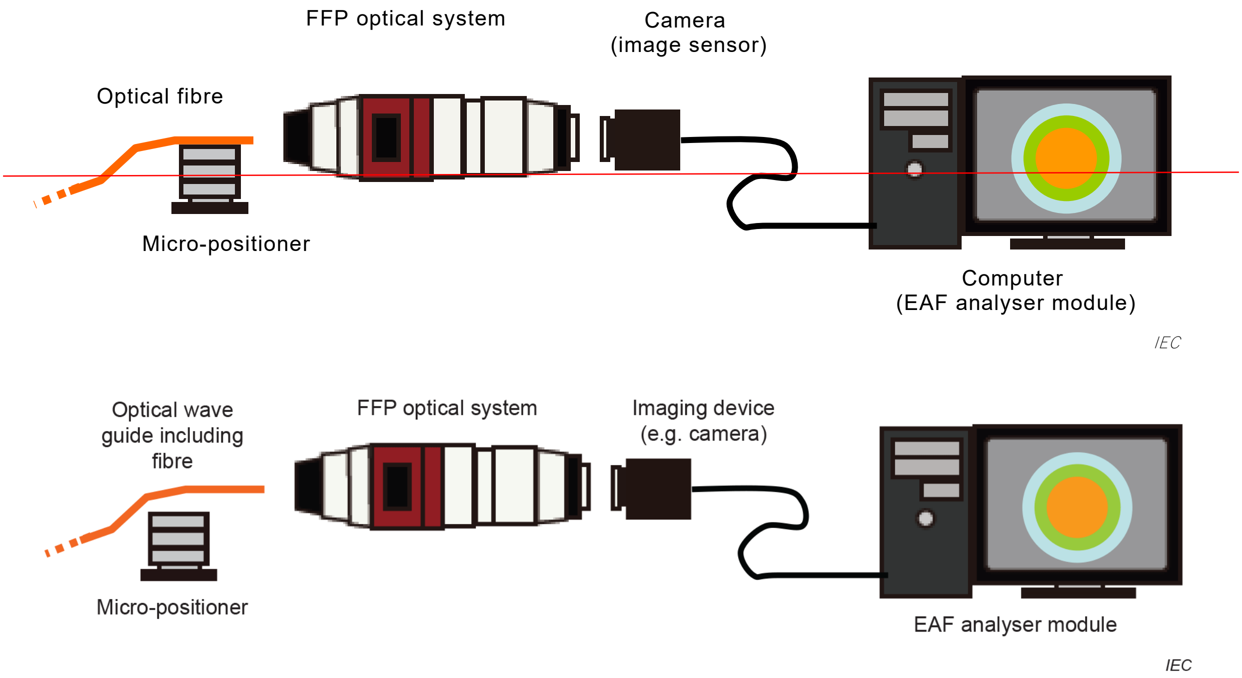


Figure 1 – Apparatus configuration of measurement method 1: *fθ* lens imaging

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 *fθ* 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.

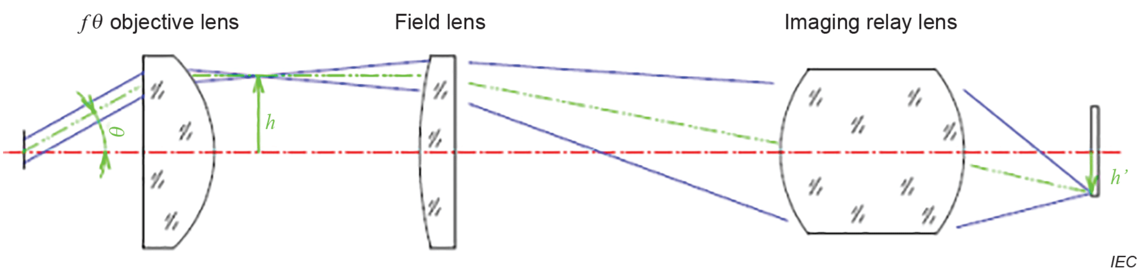


Figure 2 – Far field optical system diagram

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.~~

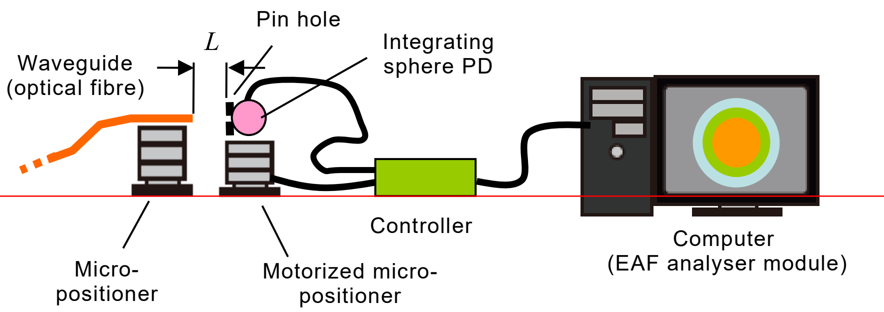
~~5.3.4 Alignment~~

~~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~~

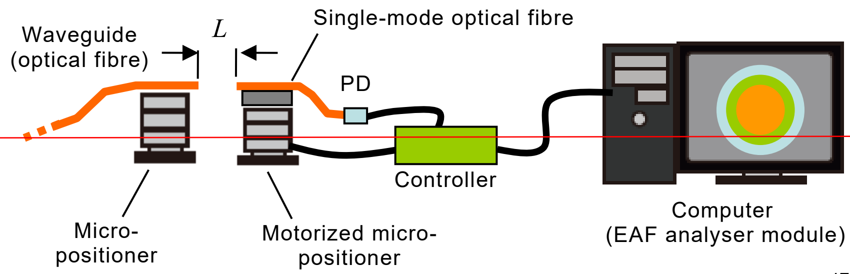
~~power so avoiding inconsistencies due to laser speckle and spatial variation of efficiency across the photodiode detector. In this method the integrating sphere and its pinhole are moved in X and Y to sample the far field. This has the advantage that a very large area can be sampled. Moreover, it can 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~~

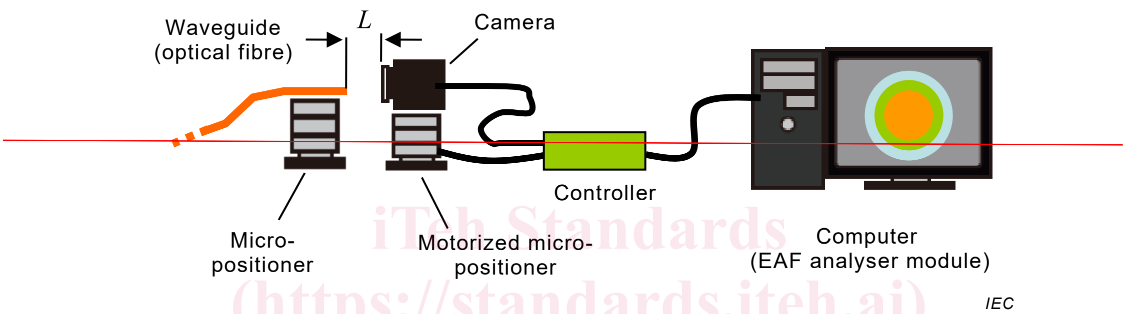
~~The single-mode optical fibre shall be placed sufficiently far from the optical source launch multimode waveguide facet so as to be in the Fraunhofer or far field. The Fraunhofer far field occurs when $L >> D^2/\lambda$ where L is the distance of the detection plane from the waveguide end facet, D 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 fθ 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.