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Fibre optic communication subsystem test procedures – Part 1-4: General communication subsystems – Light source encircled flux measurement method

Procédures d’essai des sous-systèmes de télécommunication fibroniques – Partie 1-4: Sous-systèmes généraux de télécommunication – Méthode de mesure du flux inscrit de la source optique

IEC 61280-1-4:2023-01(en-fr)

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FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES –

Part 1-4: General communication subsystems – Light source encircled flux measurement method

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IEC 61280-1-4 has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics. It is an International Standard.

This third edition cancels and replaces the second edition published in 2009. This edition constitutes a technical revision.

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

a) improvement of calibration procedure and calibration traceability;
b) improvement of fibre shaker description and requirements;
c) addition of pulsed light sources;
d) removal of a poorly traceable calibration process using a micro positioner.

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

Draft	Report on voting
86C/1806/CDV	86C/1828/RVC

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts of the IEC 61280 series can be found, under the general title *Fibre optic communication subsystem test procedures*, 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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

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- withdrawn,
- replaced by a revised edition, or
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INTRODUCTION

This part of IEC 61280 specifies how to measure the encircled flux of a multimode light source. Encircled flux is a fraction of the cumulative output power to the total output power as a function of radial distance from the centre of the multimode optical fibre's core.

The basic approach is to collect two-dimensional (2D) nearfield data, using a calibrated camera, and to mathematically convert the 2D data into three normalized functions of radial distance from the fibre's optical centre. The three functions are intensity, incremental flux, and encircled flux. The intensity represents optical power per surface area (in watts per square meter). The incremental flux represents optical power per radius differential (in watts per meter), and the encircled flux represents a fraction of the cumulative output power to the total output power.

These three radial functions are intended to characterize fibre optic laser sources either for use in mathematical models predicting the minimum guaranteed length of a communications link, or to qualify a light source to measure insertion loss in multimode links.

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FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES –

Part 1-4: General communication subsystems – Light source encircled flux measurement method

1 Scope

This part of IEC 61280 establishes the characterization process of the encircled flux measurement method of light sources intended to be used with multimode fibre.

This document sets forth a procedure for the collection of two-dimensional fibre optic nearfield greyscale data and subsequent reduction to one-dimensional data expressed as a set of three sampled parametric functions of radius from the fibre's optical centre.

Estimation of the fibre core diameter is not an objective of this document.

2 Normative references

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

3 Terms and definitions

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

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

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

3.1
calibration light source
light source used to find the optical centre of a multimode fibre

3.2
centroid image
image used to determine the optical centre of the multimode fibre core

3.3
corrected image
image which has had a dark image subtracted from it and whose elements have had uniformity correction applied

3.4
dark image
image taken with the measured light source either turned off or not installed in the input port

Note 1 to entry: Stray light and electrical signals of the detection system will remain in the dark image.

3.5
image
two-dimensional rectangular array of numbers whose elements are pixels and whose pixel values linearly correspond to the optical power falling on the pixels

3.6
light source
something that emits light that is coupled into a fibre, the output of which can be measured

EXAMPLE Calibration light source, transmission light source, light source used for attenuation measurements.

3.7
measurement light source
light source intended to be used in the measurement of attenuation

3.8
nominal core radius
half the nominal core diameter of the multimode fibre to be measured

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3.9
ring smoothing
technique to reduce the two dimensional near field image into a 1-D near field intensity profile while cancelling the effects of the periodic spacing of imager pixels of finite area

3.10
transmission light source
light source used to transmit digital data over multimode fibre optic links

3.11
uniformity correction
process to correct the sensitivity of a pixel so that it performs substantially like an average pixel

3.12
valid pixel
optical detection element in the detector matrix whose sensitivity, when corrected, is within 5 % of the mean sensitivity of the average conversion efficiency of the detector

4 Symbols

B	baseline intensity NOTE 1 This value is determined from a region of the computed near field just outside the core boundary.
D	distance from the centre of the centroid image to the nearest boundary of the image
D_L, D_R, D_T, D_B	set of distances from the centre of the centroid image to, respectively, the left, right, top and bottom boundaries of the image NOTE 2 The minimum of this set is used to compute D.
$EF(i)$	encircled flux vector
$EF'(i)$	non-normalized encircled flux vector

i	index parameter used in the parametric result vectors and $EF(i)$
I_{dark}	matrix of pixel intensities of a dark image as measured by the detector and digitizer
I_{raw}	matrix of pixel intensities of the light source, before correction, as measured by the detector and image digitizer
$I_{\text{r,c}}$	near-field intensity matrix
	NOTE 3 This is a matrix of pixel intensities, based on I_{raw}, as measured by the detector and corrected using U and I_{dark}.
$I(i)$	ring-smoothed intensity vector, each element being the arithmetic average of the set of radial coordinates of all the pixels in a given ring
N_{R}	number of rings used to compute the 1-D near field
N_{r}	number of rows in an image
	NOTE 4 All columns in an image have the same number of rows.
N_{c}	number of columns in an image
	NOTE 5 All rows in an image have the same number of columns.
P_{Max}	most intense valid pixel in the centroid image
P_{Min}	least intense valid pixel in the centroid image
R	radial coordinate, in µm, of the centre of any pixel, referenced to the optical centre X_0, Y_0
$R(i)$	ring-smoothed radial vector, each element being the arithmetic average of the radii of all the pixels in the i^{th} ring
R_{max}	integration limit along the radius
S_{c}	column-weighted summation of all pixel intensities greater than T in the centroid image
$S_{\text{I}}(i)$	intensity summation vector used in ring smoothing
S_{P}	summation of all pixel intensities greater than T in the centroid image
$S_{\text{N}}(i)$	pixel counting vector used in ring smoothing
$S_{\text{R}}(i)$	radius summation vector used in ring smoothing
S_{r}	row-weighted summation of all pixel intensities greater than T in the centroid image
S_{X}	horizontal geometric calibration factor (along columns)
S_{Y}	vertical geometric calibration factor (along rows)
T	threshold used to determine which pixels in the centroid image will be used to determine the optical centre
	NOTE 6 All pixels greater than or equal to T are used to compute the centroid.
$U_{\text{r,c}}$	sensitivity correction matrix, applied to a dark-subtracted image to reduce non-uniformity of the detector's pixel-to-pixel conversion efficiency
W	half-width, in µm, of the rings used to compute the 1-D near field
X_0	X axis (column) location of the centre of the centroid image
Y_0	Y axis (row) location of the centre of the centroid image

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5 Assumptions

5.1 Assumptions applicable to the characterization of data sources

The 50 µm or 62,5 µm core near-parabolic graded-index multimode fibre used as the "test jumper assembly" is treated as if it possessed perfect circular symmetry about its optical centre, because asymmetries in the launched optical flux distributions will dominate any distortions introduced by the test jumper assembly, such as lateral and angular misalignments. It is further assumed that all cladding modes will be stripped by passage through the specified ten metres or more of fibre. The modes of a mode group need not carry equal flux. In fact, with such short fibres, one thousand metres or less, unequal distribution of flux in the modes of a group is the norm, not the exception.

5.2 Assumptions applicable to the characterization of measurement sources

Measurement sources are assumed to be sufficiently broadband and incoherent, so that speckle is not a problem, and to have a sufficiently symmetrical nearfield distribution, so that the truncated centroid of that nearfield indicates the location of the optical centre of the fibre with sufficient accuracy for the purposes of this document.

6 Apparatus

6.1 Common apparatus

6.1.1 General

Figure 1 below shows an apparatus block diagram.

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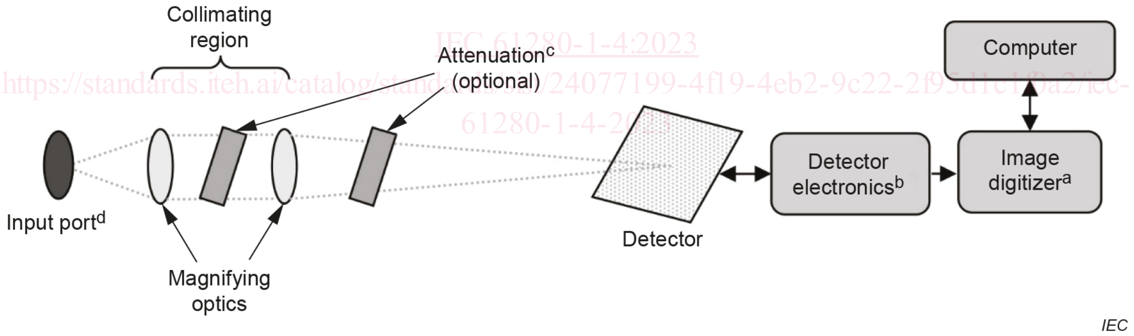

[a] The image digitizer can be either part of a camera or a computer add-in board.

[b] The detector electronics are usually integral to the camera and digitizer.

[c] Attenuation is best placed in the collimating region of the optical path, but not all optical designs will have an accessible collimating region. When this is not possible, the attenuation should be placed on the detector side of the optics.

[d] When a micro positioner (not shown) is employed, the input port will be physically attached to it.

Figure 1 – Apparatus block diagram

6.1.2 Computer

A computer is required, because the acquired image contains many thousands of pixels, and the reduction of the image to encircled flux requires substantial computation. The computer will usually be connected to the image digitizer to control the acquisition of an image through software and can also control the micro positioner (and the source, if correlated double sampling is implemented).

6.1.3 Image digitizer

The nearfield of the fibre core is imaged onto the detector and then digitized by the image digitizer. The image digitizer can be an integral part of a camera, which also contains the detector, or can be an add-in frame-grabber board in the computer.

Automatic circuitry in the digitizer, for example automatic gain control (ABC) often found in video cameras, shall be disabled.

6.1.4 Detector

The detector is typically a charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS) camera. Other types of array cameras can be considered. In any case, detectors shall be both nominally linear and memoryless. Absolute radiometric measurement of flux (optical power flow) is not required.

Automatic circuitry in the detector, for example automatic gain control often found in video cameras, shall be disabled.

The difference in conversion sensitivity from pixel to pixel in the detector will affect the measurement accuracy. The non-uniformity in the corrected conversion efficiency of the detector shall not exceed ±5 %. It is possible to calibrate and correct a detector, whose uncorrected uniformity is worse than 5 %, by applying a pixel-by-pixel sensitivity correction matrix, U, to the raw image. Often, this correction is part of the camera function (and so each element of U can be taken as unity). Sometimes, the correction matrix can be provided by the detector supplier. In other cases, the correction matrix shall be determined by the procedure outlined in Clause A.2.

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Detectors can have invalid pixels, which are pixels whose corrected conversion efficiency exceeds ±5 % of the average conversion efficiency of the detector. Invalid pixels will often produce no signal, a completely saturated signal, or be stuck at some intermediate value. Detectors whose invalid pixel count exceeds 0,1 % of the total number of pixels shall be rejected.

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In most cameras and image digitizers, the setting of the "black level" is user adjustable. Since the detector will be slightly noisy, it is important that the detector and digitizer do not clip random black signals at zero (in common systems, random noise in a detector will have a standard deviation less than 0,5 % of the saturation level). To ensure no clipping of the noise, when settable, set the black level to produce a small positive signal (typically at least five times the standard deviation of the noise) when no light is impinging on the detector.

6.1.5 Magnifying optics

Suitable optics shall be provided to project the magnified image of the input port onto the detector, in such a way that the detector can measure the entire nearfield flux distribution. The numerical aperture of the magnifying optics shall exceed the nominal numerical aperture of the fibres (as specified in the fibre's family specification) used in calibration or measurement. Microscope objectives are often appropriate for this purpose.

NOTE When a microscope objective is used, its actual magnification as used in the present apparatus generally will not be the same as the nominal magnification factor engraved into the side of the objective, because the present apparatus differs from the standard microscope for which that nominal magnification factor was computed. The geometric calibration procedures outlined in Clause 8 determine the actual magnification.

Reflections from optical surfaces can seriously degrade the measurement of encircled flux. Anti-reflection coating at the wavelength of measurement or other forms of reflection control can be considered to reduce reflections.

Measurement precision is important when characterizing measurement light sources, so that optical distortion is kept to a minimum. Careful selection and application of the lenses and other optical components is recommended. Plan-type microscope objectives are an example of suitable optics. The procedures found in IEC 61745:2017 can be used to assess the optical integrity of the apparatus.

It is important that the distance between the detector and all elements of the magnifying optics be held fixed once calibration is performed. When the relationship between these elements changes, the magnification is expected to change enough that recalibration will be required. Focusing shall be accomplished by changing only the distance between input port and the magnifying optics.

6.1.6 Attenuator

Often, the optical flux of the source will saturate the detector and the only effective solution is to employ optical attenuation. Any attenuation element shall not reduce the numerical aperture of the optical system and shall not be the source of significant reflections or optical distortions, which will bias the resulting encircled flux.

NOTE 1 When neutral density filters are used in the optical system, geometric distortions can be introduced.

NOTE 2 Changing the attenuation between the optical centre image and the image of the measured source can cause the location of the optical centre of the measurement source to move away from that determined using the optical centre image, causing errors in the resulting radial data functions.

6.1.7 Micro positioner (optional)

The micro positioner is an optional part of the apparatus. Depending on the apparatus design, it is possible to rely on connector ferrule geometry to place the image completely onto the detector without a micro positioner. In many implementations, only a focus adjustment (Z axis) is necessary, and in some cases, all three axes may only require alignment during construction or maintenance of the apparatus. Using the ferrule to place the fibre core image onto the detector does not relieve the requirement of finding the optical centre as required by 9.3.

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When used, the purpose of the micro positioner is to bring the projected image of the fibre face into focus on the detector and to determine the magnification of the apparatus (see Clause 8). Mechanical locking mechanisms or their equivalents are required for all three axes to prevent mechanical drift during measurement. The micro positioner can optionally be driven by motors and can optionally employ feedback mechanisms to control the actual position of the stage (and thus the fibre face).

6.1.8 Input port

The input port is where the calibration artefacts and measurement samples are connected to the apparatus. The input port characteristics depend on which type of source is to be characterized.

When characterizing transmission light sources, the input port is the distal end of the test jumper assembly. The proximal end of the test jumper assembly will be imaged onto the detector. When a micro positioner is used, the proximal end will be attached to the micro positioner.

When characterizing measurement light sources, the input port is commonly a connector bulkhead or its equivalent. When a micro positioner is employed, the bulkhead will be attached to the micro positioner.

See 6.2 and 6.3 for particular requirements.

6.1.9 Calibration light source

The calibration light source is used when calibrating the apparatus (see Clause 8). When this source is used to illuminate the test jumper assembly, the calibration source shall overfill the modes of the jumper. Optionally, a mode scrambler can be used with the chosen calibration source to ensure more uniform overfilling of the fibre. See IEC 60793-1-41 for information on mode scramblers.

Any spectrally broad non-coherent light source, such as a tungsten-halogen lamp, a xenon arc lamp, or a light-emitting diode (LED), can be used to overfill the fibre of the test jumper assembly. When calibrating the apparatus for the characterization of measurement light sources, the centre wavelength of the calibration source shall be within 30 nm of the nominal wavelength of the light sources to be qualified, and its spectral width (i.e., full width at half maximum) shall be no more than 100 nm. When calibrating the apparatus for the characterization of transmission light sources, the spectral characteristics of the calibration source are not specified, but it is recommended that its spectrum be similar to the sources to be characterized. The chosen calibration source shall be stable in intensity over a time period sufficient to perform the measurements.

6.2 Transmission source apparatus

6.2.1 General

When characterizing transmission light sources, the input port of the apparatus consists of two elements, the test jumper assembly and the fibre shaker (see Figure 2 below).

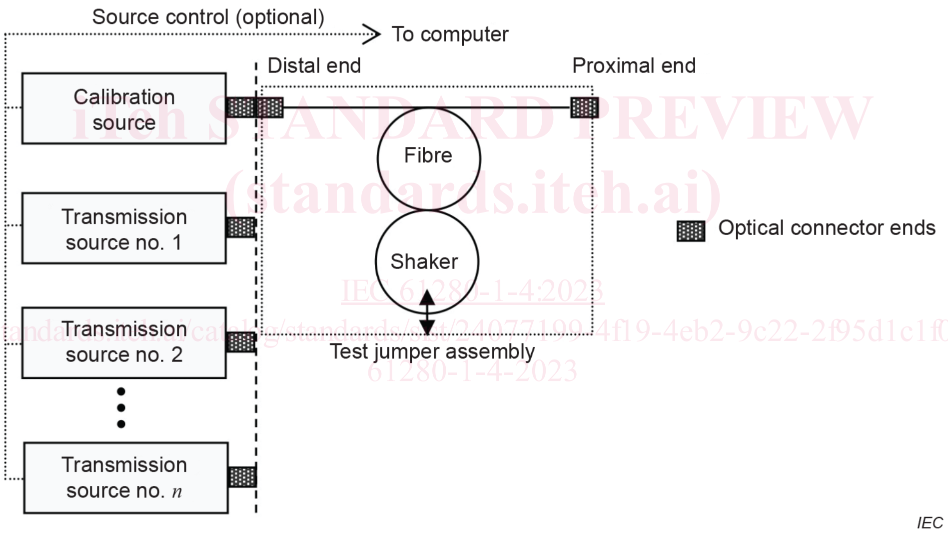

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Figure 2 – Typical set-up for transmission source measurement

6.2.2 Test jumper assembly

The purpose of the test jumper assembly is to strip cladding modes, and to allow speckle to be averaged out by mechanical flexing of a portion of the test jumper assembly. The test jumper assembly is used only when qualifying light sources for multimode transmission.

The test jumper assembly shall be at least 10 m in length, made of germanium-doped near-parabolic graded-index fused-silica multimode "glass", an IEC 60793-2-10 class A1-OM2 to OM5 fibre with a core diameter of 50 µm or class A1-OM1 fibre with a core diameter 62,5 µm. The test jumper assembly shall consist of a single, uncut length of fibre with connectors at each end. The test jumper assembly connectors shall have single-mode mechanical tolerances, even though the fibre is multimode.

6.2.3 Fibre shaker

The purpose of the fibre shaker is to change the differential path length of the various modes in the test jumper, ensuring that speckle in the averaged image will be reduced, as the image is averaged. Speckle reduction can be accomplished in a variety of ways and shall be good