IEC 61280-1-4

Edition 2.0 2009-11

INTERNATIONAL STANDARD

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colour inside

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 à fibres optiques –
Partie 1-4: Sous-systèmes généraux de télécommunication – Méthode de mesure du flux inscrit de la source lumineuse

IEC 61280-1-4:2009

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES –

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

FOREWORD

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

This second edition cancels and replaces the first edition published in 2003. This second edition constitutes a technical revision. The significant technical changes with respect to the previous edition are described in the introduction.

The text of this standard is based on the following documents:

FDIS	Report on voting
86C/920/FDIS	86C/932/RVD

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

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

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 publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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0 Introduction

0.1 General

This part of IEC 61280 is used to measure the encircled flux of a multimode light source. Encircled flux is a measure, as a function of radius, of the fraction of the total power radiating from a multimode optical fibre's core.

The basic approach is to collect 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*. Intensity has dimension optical power per area; incremental flux has dimension power per differential of radius; and encircled flux has dimension total optical power, all three being functions of radius.

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.

0.2 Changes from previous edition

This edition of the standard differs from its predecessor in both scope and content. Many of the content changes improve the measurement precision. Several changes have been made to the computation procedure:

- the integration methodology of the radial functions was simple summation, and is now specified to use trapezoidal integration or other higher-order techniques (see 9.3);
- a baseline subtraction step is specified to improve immunity to DC drifts (see 9.2.2 and 9.2.3);
- the ring width parameter is explicitly specified (see 9.2.1);
- the integration limit is specified (see 9.3).

The geometric calibration of the apparatus microscope now specifies either (depending on the application) the methodology of IEC 61745 or the original technique using the micropositioning stage (see Clause 7). Pixel sensitivity uniformity correction is now optional.

0.3 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, as asymmetries in the launched optical flux distributions will dominate any lopsidedness of the test jumper assembly. 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.)

0.4 Assumptions applicable to the characterization of measurement sources

Measurement sources are assumed to be sufficiently broadband and incoherent that speckle is not a problem, and to have a sufficiently symmetrical nearfield distribution 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 standard.

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 is intended to characterize the encircled flux of two types of light sources: transmission light sources, which are usually coherent and substantially under-excite the mode volume of a multimode fibre, and measurement light sources, which are incoherent and excite most of the mode volume of a multimode fibre.

This part of IEC 61280 sets forth a standard 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. This revision of IEC 61280-1-4 continues to fulfil its original purpose, characterization of transmission light sources, which enables the accurate mathematical prediction of minimum guaranteed link length in 1 gigabit per second or greater fibre optic data communication systems. New to this revision is support for improved measurement precision of insertion loss in multimode fibre optic links through the characterization of measurement light sources.

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

2 Normative references

The following referenced documents are indispensable for the application 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*

IEC 61745:1988, *End-face image analysis procedure for the calibration of optical fibre geometry test sets*

3 Terms and definitions

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

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. 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 (can be a calibration light source, a transmission light source or a 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

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 the baseline intensity. This value is determined from a region of the computed near field just outside the core boundary.

D the distance from the centre of the centroid image to the nearest boundary of the image.

D_L, D_R, D_T, D_B the set of distances from the centre of the centroid image to, respectively, the left, right, top and bottom boundaries of the image. The minimum of this set is used to compute D.

$EF(i)$ the encircled flux vector.

i the index parameter used in the parametric result vectors $\overline{R}(i)$, $\overline{I}(i)$ and $EF(i)$.

I_{dark} the matrix of pixel intensities of a dark image as measured by the detector and digitizer.

I_{raw} the matrix of pixel intensities of the light source, before correction, as measured by the detector and image digitizer.

$I_{r,c}$ near-field intensity matrix. This is a matrix of pixel intensities, based on I_{raw}, as measured by the detector and corrected using U and I_{dark}..

$\overline{I}(i)$ the 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 the number of rings used to compute the 1-D near field.

N_r the number of rows in an image. All columns in an image have the same number of rows.

N_c the number of columns in an image. All rows in an image have the same number of columns.

P_{Max} the most intense valid pixel in the centroid image.

P_{Min} the least intense valid pixel in the centroid image.

R the radial coordinate, in µm, of the centre of any pixel, referenced to the optical centre X_0, Y_0.

$\overline{R}(i)$ the ring-smoothed radial vector, each element being the arithmetic average of the radii of all the pixels in the i^{th} ring.

S_c the column-weighted summation of all pixel intensities greater than T in the centroid image.

$S_I(i)$ the intensity summation vector used in ring smoothing.

S_P the summation of all pixel intensities greater than T in the centroid image.

$S_N(i)$ the pixel counting vector used in ring smoothing.

$S_R(i)$ the radius summation vector used in ring smoothing.

S_r the row-weighted summation of all pixel intensities greater than T in the centroid image.

T the threshold used to determine which pixels in the centroid image will be used to determine the optical centre. All pixels greater than or equal to T are used to compute the centroid.

$U_{r,c}$ the sensitivity correction matrix, applied to a dark-subtracted image to reduce non-uniformity of the detector's pixel-to-pixel conversion efficiency.

W the half-width, in µm, of the rings used to compute the 1-D near field.

X_0 the x-axis (column) location of the centre of the centroid image.

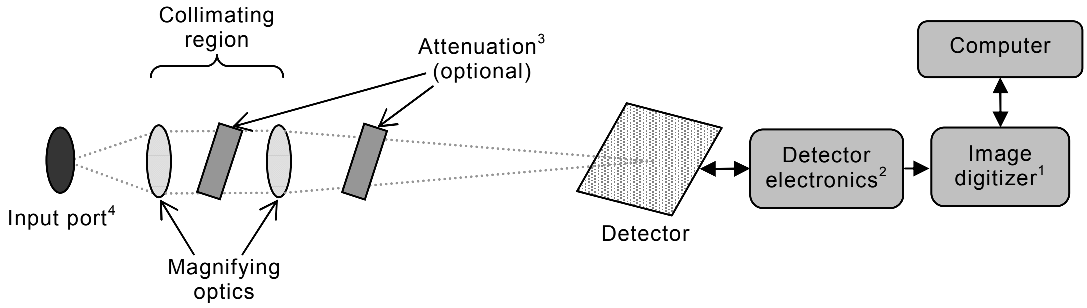
Y_0 the y-axis (row) location of the centre of the centroid image.

5 Apparatus

5.1 Common apparatus

5.1.1 General

The Figure 1 below shows an apparatus block diagram.



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

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

[3] 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.

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

IEC 2207/09

Figure 1 – Apparatus block diagram

5.1.2 Computer

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

5.1.3 Image digitizer

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

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

5.1.4 Detector

The detector is typically a CCD or CMOS camera. Other types of array cameras may be considered. In any case, detectors shall be both nominally linear and memoryless; this excludes for instance lead sulphide vidicon detectors. Absolute radiometric measurement of flux (optical power flow) is not required.

Automatic circuitry in the detector, for example AGC or 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 accuracy of measurement. The corrected conversion efficiency non-uniformity 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 may be taken as unity). Sometimes, the correction matrix may be supplied by the detector supplier. In other cases, the correction matrix shall be determined by the procedure outlined in A.2.

Detectors can have invalid pixels, these are pixels whose corrected conversion efficiency exceeds ± 5 % of the average conversion efficiency of the detector; invalid pixels will often produce no signal or 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.

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.

5.1.5 Magnifying optics

Suitable optics shall be provided which projects the magnified image of the input port onto the detector such 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 1 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 7 of this standard determine the actual magnification.

NOTE 2 When characterizing measurement light sources, measurement precision is important, so optical distortion is kept to a minimum. Care in selection and application of the lenses and other optical components should be considered. Plan-type microscope objectives are an example of suitable optics. The procedures found in IEC 61745 can be used to assess the optical integrity of the apparatus.

NOTE 3 Reflections from optical surfaces may seriously degrade the measurement of encircled flux. Anti-reflection coating at the wavelength of measurement or other forms of reflection control may be considered to reduce reflections.

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.

5.1.6 Attenuation

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 may be introduced.

NOTE 2 Changing the attenuation between the optical centre image and the image of the measured source may 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.

5.1.7 Micropositioner (optional)

The micropositioner 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 micropositioner. 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 8.3.

When used, the purpose of the micropositioner 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 7). Mechanical locking mechanisms or their equivalents are required for all three axes to prevent mechanical drift during measurement. The micropositioner 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). When geometric calibration is done using the micropositioner (see Clause 7 and Annex C), the performance requirements are specified in Annex B; otherwise, the only performance requirement is in the focal axis, which shall have high enough resolution to bring the fibre end into sufficient focus to achieve the required measurement precision.

5.1.8 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 micropositioner is used, the proximal end will be attached to the micropositioner.

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

See 5.2 and 5.3 for particular requirements.

5.1.9 Calibration light source

The calibration light source is used when calibrating the apparatus (see Clause 7). 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 may 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) may be used to overfill the test jumper assembly's fibre. 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 (full width, 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.

5.2 Transmission source apparatus

5.2.1 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).

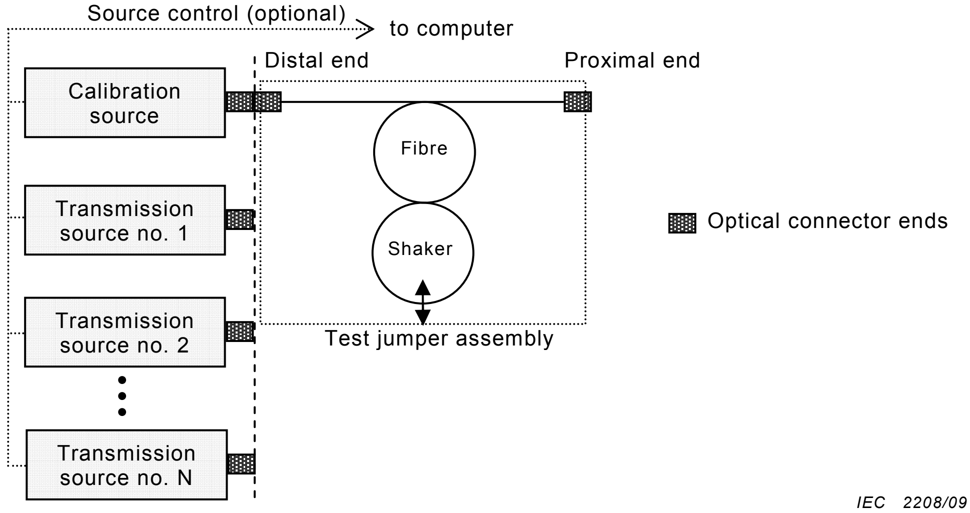


Figure 2 – Typical set-up for transmission source measurement

5.2.2 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 only used 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 fibre with a core diameter of either 50 µm or 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.

5.2.3 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 as the image is averaged, speckle in the averaged imaged will be reduced. Speckle reduction can be accomplished in a variety of ways, and shall be good enough to ensure sufficient repeatability in the measurement of encircled flux. Shaking of the test jumper assembly with a mechanical device is required to reduce speckle.

Part of the test jumper assembly shall be mechanically shaken continuously in each of three nominally orthogonal directions (using three independent shaker mechanisms) during the measurement, making at least one hundred shake cycles in each of the three directions during the measurement period. The shake frequencies in the three directions shall be chosen such that the three shake cycles synchronize no more often than once every five hundred cycles of the middle shake frequency.

A fibre shaker mechanism may be of any design as long as it induces large amplitude movements and flexing in the optical fibre. Fibre transverse displacements of more than 25 mm are suggested. The fibre shakers shall include a fibre holding fixture for securely holding the fibre.

One exemplary mechanism, shown in Figure 3, has three turns of fibre coiled into a 3-ply figure-eight arrangement, with the loops each being approximately 120 mm in diameter. A motor-driven eccentric drives a slider back and forth at about one stroke per second, alternately flattening and stretching one loop of the figure eight with 25-mm amplitude. Three such mechanisms in series will consume about $3*3*(2*\pi*0,120) = 6,8$ m of the test jumper assembly's fibre.