

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Optical fibres –

Part 1-45: Measurement methods and test procedures – Mode field diameter

Fibres optiques –

Partie 1-45 : Méthodes de mesure et procédures d'essai – Diamètre du champ de mode



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OPTICAL FIBRES –

**Part 1-45: Measurement methods and test procedures –
Mode field diameter**

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IEC 60793-1-45 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics. It is an International Standard.

This third edition cancels and replaces the second edition published in 2017. This edition constitutes a technical revision.

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

- a) Modification of the minimum distance between the fibre end and the detector for the direct far field scan (Annex A).
- b) Generalization of the requirement for the minimum dynamic range for all fibre types (Annex A).

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

Draft	Report on voting
86A/2300/CDV	86A/2366/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 in the IEC 60793 series, published under the general title *Optical fibres*, 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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

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OPTICAL FIBRES –

Part 1-45: Measurement methods and test procedures – Mode field diameter

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the mode field diameter (MFD) of single-mode optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

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 60793-1-40, *Optical fibres – Part 1-40: Attenuation measurement methods*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

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>

3.2 Abbreviated terms

The abbreviated terms are given in Table 1.

Table 1 – Abbreviated terms

Abbreviated term	Full term
CCD	charge-coupled devices
FWHM	full width half maximum
MFD	mode field diameter
OTDR	optical time domain reflectometer
RTM	reference test method

4 General consideration about mode field diameter

The mode field diameter measurement represents a measure of the transverse extent of the electromagnetic field intensity of the guided mode in a fibre cross section, and it is defined from the far-field intensity distribution as a ratio of integrals known as the Petermann II definition. See Formula (1).

The definitions of mode field diameter are strictly related to the measurement configurations. The mathematical equivalence of these definitions results from transform relationships between measurement results obtained by different implementations summarized in Figure 1.

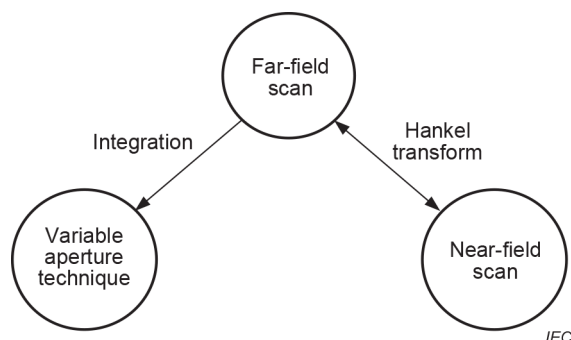


Figure 1 – Transform relationships between measurement results

Four methods are described for measuring mode field diameter:

- method A: direct far-field scan;
- method B: variable aperture in the far field;
- method C: near-field scan;
- method D: bi-directional backscatter using an optical time domain reflectometer (OTDR).

All four methods apply to all categories of type B single-mode fibre shown in IEC 60793-2 and operating near 1 310 nm or 1 550 nm. Method D is not recommended for the measurement of fibres of unknown type or design.

Information common to all four methods is contained in Clause 1 to Clause 11, and information pertaining to each individual method appears in Annex A, Annex B, Annex C, and Annex D respectively.

5 Reference test method

Method A, direct far-field scan, is the reference test method (RTM), which shall be the one used to settle disputes.

6 Apparatus

6.1 General

The following apparatus is common to all measurement methods. Annex A, Annex B, Annex C, and Annex D include layout drawings and other equipment requirements for each of the four methods, respectively.

6.2 Light source

For method A, method B and method C, use a suitable coherent or non-coherent light source, such as a semiconductor laser or a powerful filtered white light source.

A monochromator or interference filter(s) may be used, if required, for wavelength selection. The detail specification shall indicate the wavelength of the source. The full width half maximum (FWHM) spectral line width of the source shall ≤ 10 nm, unless otherwise specified.

The source power level shall be chosen so it is not impacting the repeatability of the mode diameter measurement.

The source power shall be stable for the complete duration of the measurement.

See Annex D for method D.

6.3 Input optics

For method A, method B, and method C, an optical lens system or fibre pigtail may be employed to excite the sample. It is recommended that the power coupled into the sample be relatively insensitive to the position of its input end face. This can be accomplished by using a launch beam that spatially and angularly overfills the input end face.

If using a butt splice, employ index-matching material between the fibre pigtail and the sample to avoid interference effects. The coupling shall be stable for the duration of the measurement.

See Annex D for method D.

6.4 Input positioner

Provide means of positioning the input end of the sample to the light source. Examples include the use of x-y-z micropositioner stages, or mechanical coupling devices such as connectors, vacuum splices, or three-rod splices. The position of the fibre shall remain stable over the duration of the measurement.

6.5 Cladding mode stripper

Use a device that extracts cladding modes. Under some circumstances, the fibre coating will perform this function.

6.6 High-order mode filter

Use a means to remove high-order propagating modes in the wavelength range that is greater than or equal to the cut-off wavelength of the sample. For example, a one-turn bend with a radius of 30 mm on the fibre is generally sufficient for most B-652, B-653, B-654, B-655, B-656 and B-657 fibres. For some B-657 fibres, smaller radius, multiple bends, or longer sample length can be applied to remove high-order propagating modes.

6.7 Output positioner

Provide a suitable means for aligning the fibre output end face to allow an accurate axial adjustment of the output end, such that, at the measurement wavelength, the scan pattern is suitably focused on the plane of the scanning detector. Such coupling may include the use of lenses or a mechanical connector to a detector pigtail.

Provide means such as a side-viewing microscope or camera with a crosshair to locate the fibre at a fixed distance from the apertures or detectors. It can be sufficient to provide only longitudinal adjustment if the fibre is constrained in the lateral plane by a device such as a vacuum chuck (this depends mainly upon the size of the light detector).

6.8 Output optics

See the appropriate annex: Annex A, Annex B, Annex C or Annex D.

6.9 Detector

See the appropriate annex: Annex A, Annex B, Annex C or Annex D.

6.10 Computer

Use a computer to perform operations such as controlling the apparatus, taking intensity measurements, and processing the data to obtain the final results. For individual details, see the appropriate annex: Annex A, Annex B, Annex C or Annex D.

7 Sampling and samples

7.1 Sample length

For method A, method B and method C, the sample shall be a known length, typically $2\text{ m} \pm 0,2\text{ m}$ for most B-652, B-653, B-654, B-655, B-656 and B-657 fibres. For some B-657 fibres, longer sample length can be used to avoid high-order propagating modes, 22 m for example.

For method D, OTDR, the sample shall be long enough to exceed (or be positioned beyond) the dead zone of the OTDR, with both ends accessible, as described in the backscatter test method in IEC 60793-1-40.

7.2 Sample end face

Prepare a flat end face, orthogonal to the fibre axis, at the input and output ends of each sample.

8 Procedure

See Annex A, Annex B, Annex C and Annex D for method A, method B, method C, and method D, respectively.

9 Calculations

9.1 Basic formulae

The basic formulae for calculating mode field diameter are Formula (1) for method A, Formula (2) for method B and Formula (6) for method C. For additional calculations, see the appropriate annex: Annex A, Annex B, Annex C or Annex D. Sample data sets for method A, method B and method C are included in Annex E.

9.2 Method A – Direct far-field scan

The following formula defines the mode field diameter for method A in terms of the electromagnetic field emitted from the end of the sample.

Calculate the mode field diameter by scanning the far-field data and evaluating the Petermann II integral, which is defined from the far-field intensity distribution:

$$2W_0 = \frac{\lambda\sqrt{2}}{\pi} \left[\frac{\int_0^{\pi/2} P_F(\theta) \sin(\theta) \cos(\theta) d\theta}{\int_0^{\pi/2} P_F(\theta) \sin^3(\theta) \cos(\theta) d\theta} \right]^{1/2} \quad (1)$$

where

$2W_0$ is the mode field diameter in μm ;

$P_F(\theta)$ is the far-field intensity distribution;

λ is the wavelength of measurement in μm ;

θ is the angle in the far-field measurement from the axis of the fibre.

NOTE 1 The integration limits are shown to be from zero to $\pi/2$, but it is understood that the integrands approach zero with increasing argument so that, in practice, the integrals can be truncated.

NOTE 2 P_F is $F^2(\theta)$ in ITU-T documents.

The far-field method for obtaining the mode field diameter of a single-mode fibre is a two-step procedure. First, measure the far-field radiation pattern of the fibre. Second, use a mathematical procedure based on the Petermann II far-field definition to calculate the mode field from far-field data, as described in Formula (1).

Annex E provides sample data and calculated $2W_0$ values for verifying the numerical evaluation of the Petermann II Integral. The sample data are in the form of the folded power, $P_F(\theta)$, as a function of the angle, θ .

9.3 Method B – Variable aperture in the far field

Formula (2) defines the mode field diameter for method B in terms of the electromagnetic field emitted from the end of the sample.

Calculate the mode field diameter, $2W_0$, as follows:

$$2W_0 = \left(\frac{\lambda}{\pi D} \right) \left[\int_0^\infty a(x) \frac{x}{(x^2 + D^2)^2} dx \right]^{-1/2} \quad (2)$$

where

$2W_0$ is the mode field diameter, in μm ;

λ is the wavelength of measurement, in μm ;

D is the distance between the aperture and the fibre, in mm;

$a(x)$ is the complementary aperture transmission function, calculated as

$$a(x) = 1 - \frac{P(x)}{P(\text{max})} \quad (3)$$

where

$P_{(x)}$ is the power measured through an aperture of radius, x , or half angle, θ ;

$P_{(\max)}$ is the maximum power, assuming an infinite aperture;

x is the aperture radius, calculated as

$$x = D \tan(\theta) \quad (4)$$

Another equivalent expression of Formula (2) is

$$2W_0 = \frac{\lambda\sqrt{2}}{\pi} \left[\int_0^\infty a(\theta) \sin 2\theta d\theta \right]^{-1/2} \quad (5)$$

The variable aperture far-field method for obtaining the mode field diameter of a single-mode fibre is a two-step procedure. First, measure the two-dimensional far-field pattern as the power passing through a series of transmitting apertures of various size. Second, use a mathematical procedure to calculate the mode field diameter from the far-field data.

The mathematical basis for the calculation of mode field diameter is based on the Petermann II far-field definition from Formula (1). Formula (2) and Formula (5) can be derived from Formula (1) by integration.

9.4 Method C – Near-field scan

The following formula defines the mode field diameter for method C in terms of the electromagnetic field emitted from the end of the sample.

Calculate the mode field diameter from the measured near-field intensity distribution, using the following integral:

$$2W_0 = 2 \left(\frac{\int_0^\infty r f^2(r) dr}{\int_0^\infty r \left(\frac{df(r)}{dr} \right)^2 dr} \right)^{1/2} \quad (6)$$

where

$2W_0$ is the mode field diameter, in μm ;

r is the radial coordinate, in μm ;

$f^2(r)$ is the near-field intensity distribution.

NOTE The upper integration limits are shown to infinity, but it is understood that since the integrands approach zero with increasing argument, in practice the integrals can be truncated. A smoothing algorithm can be used for the calculation of the derivative.

The near-field scan method for obtaining the mode field diameter of a single-mode fibre is a two-step procedure. First, measure the radial near-field pattern. Second, use a mathematical procedure to calculate the mode field diameter from the near-field data.

The mathematical basis for the calculation of the mode field diameter is based on the Petermann II definition from Formula (1). The near field, $f(r)$, and the far field, $F(\theta)$, form a Hankel transform pair. By Hankel transforming and using $P_F = F^2(\theta)$, it is possible to derive Formula (6) from Formula (1), and vice versa.

10 Results

10.1 Information available with each measurement

Report the following information with each measurement:

- date and title of measurement;
- identification of sample;
- optical source wavelength;
- mode field diameter(s), in micrometres.

10.2 Information available upon request

The following information shall be available upon request:

- measurement method used: method A, method B, method C or method D;
- type of optical source used and its spectral width (FWHM);
- description of equipment;
- description of high-order modes filter;
- details of computation technique;
- date of latest calibration of measurement equipment.

11 Specification information

The detail specification shall specify the following information:

- type of fibre to be measured;
- failure or acceptance criteria;
- information to be reported;
- any deviations to the procedure that apply.

Annex A (normative)

Requirements specific to method A – Mode field diameter by direct far-field scan

A.1 Apparatus

A.1.1 General

Annex A describes apparatus in addition to the requirements set down in Clause 6.

Figure A.1 illustrates a typical set-up for measurement by direct far-field scan.

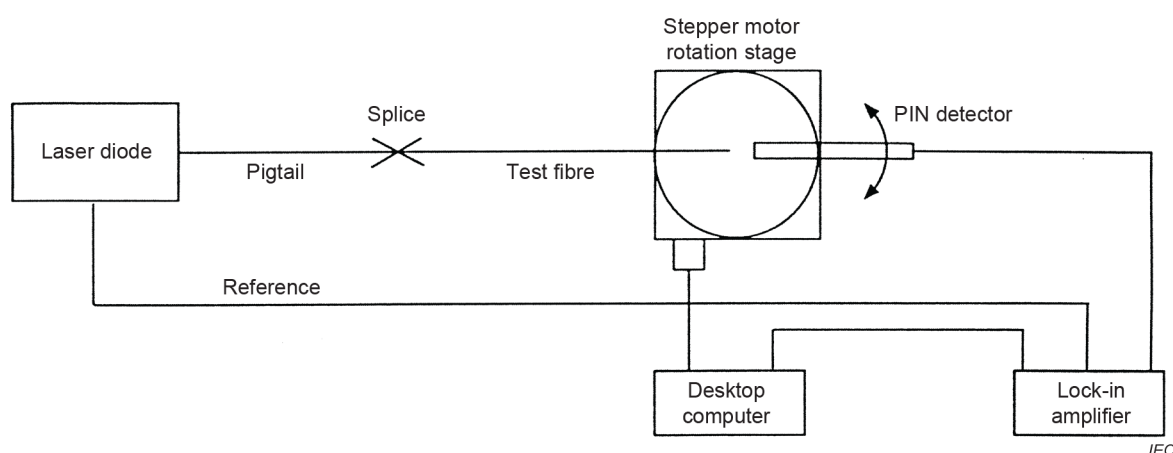


Figure A.1 – Far-field measurement set

A.1.2 Scanning detector assembly – Signal detection electronics

Use a mechanism to scan the far-field intensity distribution. Use a scanning device capable of 0,5° steps or finer to scan the detector. Use a means of aligning the fibre axis with respect to the rotation plane of the detector, and of aligning the fibre end-face with the centre of rotation of the scan. A typical system might include a PIN photodiode, operating in a photovoltaic mode, amplified by a current-input preamplifier, with synchronous detection by a lock-in amplifier. The detector should be at least 10 mm from the fibre end (to ensure the detector to scan the far field), and the detector's active area should not subtend an angle too large in the far field.

To ensure this, place the detector at a distance d from the fibre end with $d = K \times \frac{2w.b}{\lambda}$

where

$2w$ is the expected mode field diameter of the sample,

b is the diameter of the active area of the detector,

λ is the wavelength,

K is the resolution factor which value is big enough to prevent the degradation of the far field scan and its impact on the calculation of the mode field diameter.

A value of K , greater than 20, is suitable for most fibre types and guarantees less than 0,1 % of error in the mode field diameter calculation.

For accurate measurements, the dynamic range of the measurement should be greater than 50 dB. The maximum scan half-angle depends on the fibre type and should be chosen so that the far field scan is characterized down to 50 dB of the maximum signal.

Reducing the dynamic range (or maximum scan half-angle) requirements can introduce errors.

A.1.3 Computer

A typical system should also include a computer to process the far-field data.

A.2 Procedure

Align the fibre in the system, prepared as described in Clause 6, with its output end aligned on the detector assembly for maximum power.

Scan the detector in $0,5^\circ$ steps, equally spaced, and record the detector power.

Calculate a value of the Petermann II integral from the recorded data and use it to compute the fibre mode field diameter as described in Formula (1), and in Clause A.3.

A.3 Calculations

A.3.1 Determine folded power curve

The folded power curve for $0 \leq \theta_i = \theta_{\max}$ is

$$P_F(\theta_i) = \frac{P(\theta_i) + P(\theta_{-i})}{2} \quad (\text{A.1})$$

where

$P_F(\theta_i)$ is the folded power curve;

$P(\theta_{-i})$ is the measured power as a function of the angular position, θ_i (radians), indexed by i .

A.3.2 Compute the top (T) and bottom (B) integrals of Formula (1)

Use an appropriate numerical integration technique to compute the integrals of Formula (1). The following is an example using the rectangular method. Any other integration method shall be at least as accurate as this one.

$$T = \sum_0^n P_F(\theta_i) \sin(\theta_i) \cos(\theta_i) d\theta \quad (\text{A.2})$$

$$B = \sum_0^n P_F(\theta_i) \sin^3(\theta_i) \cos(\theta_i) d\theta \quad (\text{A.3})$$

where

P_F is the folded power curve;

θ_i is the angular position, indexed by i (radians);

$d\theta = \theta_1 - \theta_0$.

A.3.3 Complete the calculation

$$\text{MFD} = 2W_0 = \left(\frac{\lambda\sqrt{2}}{\pi} \right) \sqrt{\frac{T}{B}} \quad (\text{A.4})$$

where

$2W_0$ is the mode field diameter, in μm ;

T is from Formula (A.2);

B is from Formula (A.3).

A.4 Sample data

See Table E.1 for a sample data set as calculated in Clause A.3.

Annex B (normative)

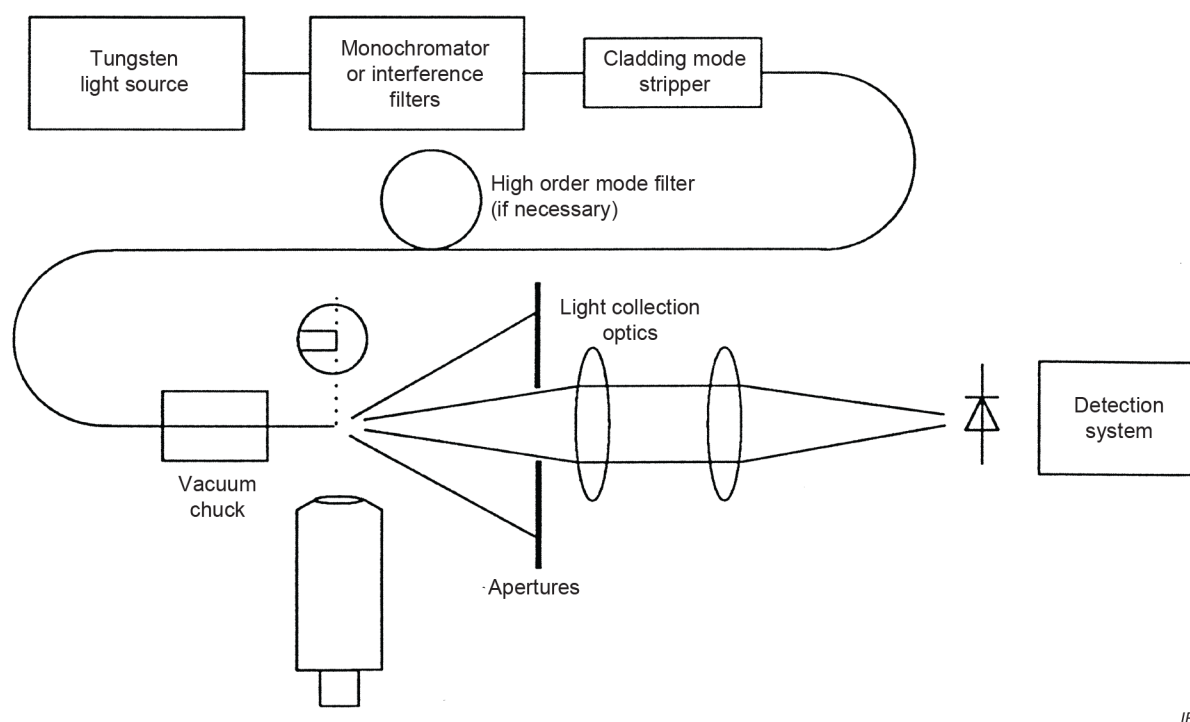
Requirements specific to method B – Mode field diameter by variable aperture in the far field

B.1 Apparatus

B.1.1 General

Annex B describes apparatus in addition to the requirements in Clause 6.

Figure B.1 illustrates a typical set-up for the measurement by variable aperture in the far field.



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Figure B.1 – Variable aperture by far-field measurement set

B.1.2 Output variable aperture assembly

B.1.2.1 Principle

Place a device consisting of round, transmitting apertures of various sizes (such as an aperture wheel) at a distance of at least $100 W_0^2/\lambda$ from the sample, and use it to vary the power detached from the fibre output far field pattern. Typically, the apertures are located 20 mm to 50 mm away from the fibre end.

Use a means of centring the apertures with respect to the pattern to decrease the sensitivity to fibre end angle. Use a sufficient number and size of apertures such that the measurement results are not unduly affected by the inclusion of any additional aperture. In addition, take care to ensure that the largest apertures are of sufficient size to avoid truncation of the collected pattern.

NOTE 1 Optical alignment is critical.

NOTE 2 The number and size of the apertures are critical to the accuracy of this method. The optimum can vary depending on the design of the fibres being tested. Verification of a particular selection can be completed by comparison with method A, direct far-field.

B.1.2.2 Equipment requirements for category B-652, B-654 and B-657 fibre

The accuracy of the mode field diameter measurement given by this procedure depends on the maximum numerical aperture of the measurement set. For category B-652, B-654, and B-657 fibre, the error is typically 1 % or less for a measurement set with a maximum numerical aperture of 0,25. If less error is desired, or if the sample has a mode field diameter less than 8,2 µm, use either of two approaches:

- a) use a measurement system with a maximum numerical aperture of 0,35 or greater; or
- b) determine a mapping function that relates the measurement of category B-652, B-654, and B-657 fibre on limited aperture measurement set to that of a set with 0,35 or greater numerical aperture.

B.1.2.3 Equipment requirements for category B-653, B-655, and B-656 fibres

The maximum numerical aperture of the measurement set shall be $\geq 0,40$ for fibres with mode field diameters ≥ 6 µm.

B.1.3 Output optics system

Use an optical system, such as a pair of lenses, mirrors, or other suitable arrangement, to collect all the light transmitted through the aperture, and to couple it to the detector.

B.1.4 Detector assembly and signal detection electronics

Use a detector that is sensitive to the output radiation over the range of wavelengths to be measured and that is linear over the range of intensities encountered. A typical system can include a germanium or InGaAs photodiode, operating in the photovoltaic mode, and a current-sensitive preamplifier, with synchronous detection by a lock-in amplifier. Generally, a computer is required to analyze the data.

B.2 Procedure

- a) Place the sample, prepared as described in Clause 6, in the input and output alignment devices, and adjust it for the correct distance to the aperture assembly.
- b) Set the aperture assembly to a small aperture and adjust the far field to an aperture lateral alignment for maximum detected power.
- c) Measure the detected power for each of the apertures.
- d) Calculate the mode field diameter per Formula (2) and Clause B.3.
- e) Repeat steps b), c) and d) for each specified measurement wavelength.

B.3 Calculations

B.3.1 Determine complementary aperture function

Determine the complementary aperture function for each aperture, from 1 to n :

$$a(\theta_i) = 1 - \frac{P(\theta_i)}{P(\theta_n)} \quad (\text{B.1})$$

where

$a(\theta_i)$ is the complementary function for each aperture, indexed with i , from 1 to n ;

$P(\theta_i)$ is the measured power as a function of the angular position, θ_i , indexed by i .