International Standard

ISO 11421

# Optics and photonics — Uncertainty of optical transfer function (OTF) measurement

*Optique et photonique — Incertitude de mesurage de la fonction de transfert optique (OTF)*

Second edition
2025-11

Reference number
ISO 11421:2025(en)

© ISO 2025



**COPYRIGHT PROTECTED DOCUMENT**

© ISO 2025

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

# Contents

Page

**Foreword** ..... **v**
**Introduction** ..... **vi**
**1 Scope** ..... **1**
**2 Normative references** ..... **1**
**3 Terms, definitions and symbols** ..... **1**
3.1 Terms and definitions ..... 1
3.2 Symbols ..... 2
**4 Sources of uncertainty in measuring equipment** ..... **3**
4.1 General ..... 3
4.2 Geometry of optical bench system ..... 4
4.2.1 General ..... 4
4.2.2 Finite object and image distance ..... 4
4.2.3 Infinite object distance and finite image distance ..... 5
4.2.4 Infinite object and image distance ..... 6
4.2.5 Suppression of image distance errors by refocusing ..... 6
4.2.6 Mounting of test piece ..... 6
4.3 Azimuth changing ..... 7
4.3.1 General ..... 7
4.3.2 Finite object and image distance ..... 7
4.3.3 Infinite object distance and finite image distance ..... 7
4.3.4 Infinite object and image distance ..... 7
4.3.5 Suppression of image distance errors by refocusing ..... 7
4.4 Alignment (orientation) of TTU and image analyser ..... 7
4.5 Correction factors ..... 8
4.5.1 General ..... 8
4.5.2 Slit width errors ..... 9
4.5.3 Correction for MTF of incoherently coupled relay lenses ..... 9
4.5.4 Spatial frequency correction for field angle ..... 9
4.5.5 Off-axis magnification errors due to image distortion using grating objects ..... 10
4.6 Image distance error ..... 10
4.7 Spatial frequency errors ..... 11
4.8 Residual aberrations in relay optics ..... 11
4.9 Spectral characteristics ..... 11
4.10 Extent of test target and/or scan and/or camera detector ..... 11
4.11 Angular response characteristics of image analyser ..... 12
4.12 Polar luminance/radiation characteristics of object generator ..... 12
4.13 Signal and data processing ..... 12
4.14 Stray radiation ..... 12
4.15 Coherent radiation ..... 12
4.16 Baseline error ..... 12
4.17 Linearity of camera detector ..... 13
**5 Methods of assessing measurement errors** ..... **13**
5.1 General ..... 13
5.2 Geometry of optical bench system ..... 13
5.2.1 Straightness of slideways ..... 13
5.2.2 Parallelism of surfaces and/or perpendicularity to reference axes ..... 16
5.2.3 Errors of rotation angles ..... 17
5.3 Collimation error (departure from infinite object distance) ..... 18
5.4 Image distance setting ..... 20
5.5 Spectral characteristics ..... 21
5.6 Extent of target and/or scan and/or camera detector ..... 22
5.7 Signal and data processing ..... 22
5.8 Polar response to image analyser ..... 22

© ISO 2025 – All rights reserved

**6 Calculation of overall uncertainty of a measurement** ..... **23**
**7 Specifying a general equipment uncertainty** ..... **24**
7.1 General ..... 24
7.2 Nominal uncertainty value (NUV) ..... 24
7.3 Standard-lens measurements (SLM) ..... 25
7.4 Audit-lens measurements (ALM) ..... 25
7.5 Slit aperture test (SAT) ..... 26
**8 Routine performance evaluation** ..... **26**
**Annex A** (normative) **Uncertainty of PTF measurement** ..... **27**
**Annex B** (informative) **Determination of rate of change of MTF with various parameters** ..... **29**
**Annex C** (informative) **Example calculation of NUV** ..... **32**
**Bibliography** ..... **44**

© ISO 2025 – All rights reserved

# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 1, *Fundamental standards*.

This second edition cancels and replaces the first edition (ISO 11421:1997), which has been technically revised.

The main changes are as follows:

— sagittal and tangential OTF were defined;

— symbols, formulae and nomenclature have been revised

— off-axis magnification errors due to image distortion using grating objects has been newly added;

— the document has been revised to be in agreement with the terms and definitions of ISO/IEC Guide 98 (GUM) and ISO/IEC Guide 99 (VIM) regarding the expression of measurement uncertainties;

— Explanations for the calculation of measurement uncertainties have been added;

— Annex C was revised.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

© ISO 2025 – All rights reserved

# Introduction

The optical transfer function (OTF) is one of the main criteria used for objectively evaluating the image-forming capability of optical, electro-optical and photographic systems.

The terms used in the measurement of OTF are defined in ISO 9334, whilst ISO 9335 covers the actual principles and procedures of measurement. A further International Standard, ISO 9336 (all parts), deals with specific applications in various optical and electro-optical fields and is in several parts, each dealing with a particular application.

Although ISO 9335 lists the main factors which influence the uncertainty of OTF measurement and describes procedures which are aimed at achieving accurate and repeatable results, it does not cover in detail the techniques and procedures for evaluating the uncertainty of OTF measuring equipment and for estimating the uncertainty in measurements made on specific imaging systems.

The present document lists the main sources of uncertainty in OTF measuring equipment and provides guidance on how these can be assessed and how the results of these assessments can be used in estimating the uncertainty in any measurement of OTF. One of the aims in preparing this document is to encourage the setting of more realistic uncertainty levels for the results of OTF measurements. Another is to encourage the use of methods of expressing the uncertainty of OTF test equipment which recognize the fact that the uncertainty of a particular measurement is a function of both the equipment and the test piece.

© ISO 2025 – All rights reserved

# Optics and photonics — Uncertainty of optical transfer function (OTF) measurement

## 1 Scope

This document gives general guidance on evaluating the sources of error in optical transfer function (OTF) equipment and in using this information to estimate errors in a measurement of OTF. It also gives guidance on assessing and specifying a general uncertainty for a specific measuring equipment, as well as recommending methods of routine assessment.

The main body of this document deals exclusively with the modulation transfer function (MTF) part of the OTF. The phase transfer function (PTF) is dealt with relatively briefly in Annex A.

## 2 Normative references

There are no normative references in this document.

## 3 Terms, definitions and symbols

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:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

### 3.1 Terms and definitions

**3.1.1**
**standard lens**
single- or multi-element lens which has been constructed with a level of uncertainty which is sufficient to ensure that for precisely specified conditions of measurement the MTF is equal to that predicted from theoretical calculations to an uncertainty of better than 0,05 (MTF units)

Note 1 to entry: In order to achieve this uncertainty, standard lenses are usually of simple construction and therefore of limited performance. An example of a widely used lens is the 50 mm focal length piano-convex lens described in Reference [3]. This and several other standard test lenses (including afocal systems and lenses operating in the infrared wavelength bands) are available commercially.

**3.1.2**
**audit lens**
single- or multi-element lens of stable construction whose uncertainty of construction is not sufficient to enable the MTF to be predicted by calculation from design data (usually as a result of the complexity of the lens), but whose "accepted" values for the MTF under precisely defined measuring conditions have been obtained by measurements done by a reputable authority (preferably a national standards laboratory, if such a service is available)

© ISO 2025 – All rights reserved

**3.1.3**
**sagittal OTF**
test pattern which is constant (shows no periodic variation) in the direction parallel to a line through the centre of the image circle

Note 1 to entry: A fixed and defined azimuthal orientation of the sample under test is required for the terms sagittal OTF and tangential OTF to be unambiguous.

Note 2 to entry: See also ISO 9334[6] and Figure 1. An illustration can also be found in Reference [9].

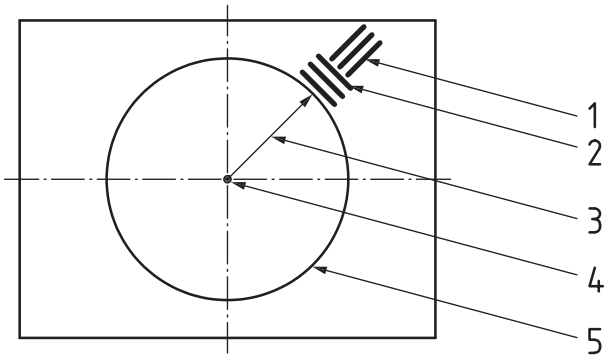
Note 3 to entry: In literature, the term “sagittal” is used synonymous with “radial”.

**3.1.4**
**tangential OTF**
test pattern which is constant (shows no periodic variation) in the direction parallel to a tangent of the image circle

Note 1 to entry: A fixed and defined azimuthal orientation of the sample under test is required for the terms sagittal OTF and tangential OTF to be unambiguous.

Note 2 to entry: See also ISO 9334[6] and Figure 1. An illustration can also be found in Reference [9].

Note 3 to entry: In literature, the term tangential is employed synonymous with “meridional.”




**Key**
1 sagittal to image circle
2 tangential to image circle
3 image pattern vector
4 center of image field
5 image circle

**Figure 1 — Sagittal and tangential OTF, excerpt from ISO 9334:2012, Figure 1**

## 3.2 Symbols

| Symbol | Meaning | Unit |
|---|---|---|
| $h$ | object height | mm, mrad, degree |
| $h'$ | image height | mm, mrad, degree |
| $\Delta h'$ | error in image height | mm, mrad, degree |
| $l$ | object distance | mm |
| $l'$ | image distance | mm |
| $\Delta l$ | error in object distance, is indexed to distinguish error sources | mm |
| NOTE The notation $m(r,l,h)$, $m'(r,l',h')$, $p'(r,l',h')$ etc. denotes that these parameters are functions of both spatial frequency $r$, *image or object distance* $l'$ *and* $l$, and image or object height $h'$ or $h$ (i.e. the value of the parameter is different for different frequencies, distance and different image heights). | | |

© ISO 2025 – All rights reserved

| Symbol | Meaning | Unit |
|---|---|---|
| $\Delta l'$ | error in image distance, is indexed to distinguish error sources | mm |
| $P_f$ | best focus point | mm |
| $\Delta a$ | angular departure of object slide from perpendicularity to reference axis | rad |
| $\Delta a'$ | angular departure of image slide from perpendicularity to reference axis | rad |
| $i_l$ , $i_{l'}$ | Auxiliary distance describing intermediate object distance or intermediate image distance. | mm |
| $M$ | magnification | dimensionless |
| $r$ | spatial frequency | $mm^{-1}$, $mrad^{-1}$, $degree^{-1}$ |
| $\Delta r$ | error in spatial frequency | $mm^{-1}$, $mrad^{-1}$, $degree^{-1}$ |
| $m(r,l,h)$ | rate of change of MTF with object distance | $mm^{-1}$ |
| $m'(r,l',h')$ | rate of change of MTF with image distance | $mm^{-1}$ |
| $p(r,l,h)$ | rate of change of MTF with object height | $mm^{-1}$ |
| $p'(r,l',h')$ or $p'(r,l',\omega)$ | rate of change of MTF with image height | $mm^{-1}$, $mrad^{-1}$, $degree^{-1}$ |
| $\omega$ | field angle | mrad, degree |
| $\Delta\omega$ | error in field angle | mrad, degree |
| $f_c$ | focal length of collimator | mm |
| $f_s$ | focal length of sample under test | mm |
| $\psi$ | azimuth angle | degree |
| $\Delta\psi$ | error in azimuth angle between slits | degree |
| $R$ | (test lens focal length)/(collimator focal length) or (decollimator focal length)/(collimator focal length) | dimensionless |
| $g'$ | width of slit referred to image plane | mm |
| $L'$ | length of shorter slit referred to image plane | mm |
| $MTF_C$ | MTF of relay lens | dimensionless |
| $r_0$ | spatial frequency for zero field angle | $mm^{-1}$, $mrad^{-1}$, $degree^{-1}$ |
| $n'(r,l',h')$ | rate of change of MTF with spatial frequency | mm, mrad, degree |
| $\Delta MTF(r)$ | error in MTF, is indexed to distinguish error sources | dimensionless |
| $\Delta MTF_C(r)$ | MTF error of the relay lens | dimensionless |
| $\Delta MTF_{rl}(r)$ | MTF errors resulting from aberrations of relay lens error | dimensionless |

NOTE The notation $m(r,l,h)$, $m'(r,l',h')$, $p'(r,l',h')$ etc. denotes that these parameters are functions of both spatial frequency $r$, *image or object distance* $l'$ *and* $l$, and image or object height $h'$ or $h$ (i.e. the value of the parameter is different for different frequencies, distance and different image heights).

# 4 Sources of uncertainty in measuring equipment

## 4.1 General

In this clause the main sources of uncertainty in OTF measuring equipment are listed and the effects on a measurement of MTF are described (brief comments on the measurement of PTF is found in Annex A). This clause does not establish a GUM[4] (Guide to the Expression of Uncertainty in Measurement, ISO/IEC Guide 98) conform uncertainty budget, but is treating common measurement errors. To establish a measurement uncertainty, the probability density functions of the respective measurement errors need to be identified. The measurement uncertainty is then established based on the probability density function. Usually, an expectation value of the measurand with an assigned standard uncertainty of the measurand is reported. In case of an expanded uncertainty, also a coverage interval is defined (expressed by the coverage factor $k_p$

© ISO 2025 – All rights reserved