Optical Testing Standards You Can't Afford to Ignore

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All information within is up to date as of 9.8.2025.

Course Description and Learning Outcomes

Standards foster communication with customers and build confidence in your products. Step up and beat your competition with demonstrated and expert-maintained test methods!

Many are familiar with ISO standards for Quality Management (ISO 9000) and Drawing Formats (ISO 10110). Did you know that there are over 100 ISO documents that outline specific methods to measure optical characteristics and performance? These standards address materials, coatings, laser beams, image quality, full electro-optical systems, and more. However, knowing what's out there and finding the standard you need can be challenging.

Presented by OEOSC experts (who have brought you the successful ISO 10110 courses), this interactive course will allow you to identify tests that you need for success. The full list of standard numbers and titles will be provided for your use and select tests will be discussed in detail. Alternatives for MIL Standards will be highlighted.

LEARNING OUTCOMES

1. List the multiple competitive benefits of using standardized optical tests
2. Access and navigate the wide variety of available test method documents
3. Determine which test methods are the ideal options for your work
4. Effectively present test results and reference the standards for internal, external, and marketing communications
5. Identify tests that are not standardized and communicate the needs of your industry

Course Outline and Schedule

1:30 PM	**PART I**: Introduction to standards and ISO
2:10 PM	**PART II**: Ten categories of ISO Test standards • Full list • Deep dives
3:00 PM	Coffee Break
3:30 PM	More categories and deep dives (continued)
4:30 PM	**PART III**: Test reports and advertising
4:50 PM	Summary, Resources, Final Q&A, Quiz
5:30 PM	Adjourn

PART I

Introduction to standards and the International Standards Organization (ISO)

Questions for Thought

What are the benefits of using standards?

What are the drawbacks?

Retrieved on 9.11.25 from www.allaboutlean.com/dfma-4/schraubengewinde2/

Why you need to consider standards

You are developing parts or systems

1. Not sure how to measure something? Don't re-invent the wheel! These test procedures are already written by experts. At least *get ideas* from the standards.
2. Use the same standards and training throughout research, development, and ongoing production. Consistency reduces confusion. Even if standards change, the records are there.

You are selling parts or systems

3. Your competitors are advertising their products according to a standard. Your specifications are vague. Get on board and beat them.
4. You are being transparent about how you test; your customers can then understand and feel secure about procuring your products.

You are a consumer of parts, systems, or tests

5. Compare products side by side; make better choices.
6. Have an instrument or component or material with an ISO test referenced? Dive in and find out just what it means.
7. Need to define how you want your parts tested? Read the standard so you can communicate effectively with the tester.

Why you need to consider ISO standards

- There are ~130 ISO optical *test* documents, covering a wide range of topics
- Within, there are many tests and various choices
- Test documents are comprehensive, often including appendices and related Technical Reports
- ISO documents are organized, with TOCs, diagrams, images, tables
- Formats for Test Reports are given
- ISO covers new technologies and standards are reviewed every 5 years
- ISO allows worldwide communication
- ISO tests are "peer reviewed"
- **You** have a *voice* through OEOSC!

"Standard terminology and clear definitions are needed not only to promote applications but also to encourage scientists and engineers to exchange ideas and new concepts based on common understanding."
[ISO 14880-3, introduction]

OEOSC Nuggets

“Standards facilitate commerce”

“The only thing worse than a bad standard is no standard at all”

“Standards are best appreciated when they fail”

The tortoise and the hare:

- The Fox consented to act as judge and specified 1 km for the race.
- The Fox started the runners without issue
- Who won?
- One of *many demonstrations that movement is impossible to define satisfactorily* *

Stock image, Microsoft Office 365

*retrieved on 9.11.25 from https://en.wikipedia.org/wiki/The_Tortoise_and_the_Hare

Trivia Question

What was the topic for the very first ISO Technical Committee?

a) Bicycle wheels
b) The meter
c) Screw threads
d) Gears

About ISO

A sampling of the Technical Committees

The International Organization for Standardization (ISO) is a network of national standards bodies from 164 countries, which develops voluntary, consensus-based, market relevant international standards. Standards are the distilled wisdom of people with expertise in their subject matter and who know the needs of the organizations they represent – people such as manufacturers, sellers, buyers, customers, trade associations, users or regulators.

TC 1: Screw threads

TC 22: Road vehicles

TC 60: Gears

TC 106: Dentistry

TC 133: Glass in building

TC 181: Safety of toys

TC 227: Springs

TC 249: Traditional Chinese Medicine

TC 12: Quantities and units (Sweden)

TC 20: Aircraft and space vehicles (ANSI)

TC 36: Cinematography (ANSI)

TC 42: Photography (ANSI) (ISO!)

TC 172: Optics and photonics (DIN, Secretariat)

TC 209: Cleanrooms (ANSI)

TC 211: Geographic information (Sweden)
(ex. remote sensing, sensor calibration)

TC 213: Dimensional and geometrical product specifications and verification (BSI)

TC 229: Nanotechnologies (BSI)

TC 261: Additive manufacturing (DIN)

TC 274: Light and lighting (DIN, with CIE)

Developing ISO Test Standards

https://doi.org/10.2352/EI.2022.34.9.IQSP-347

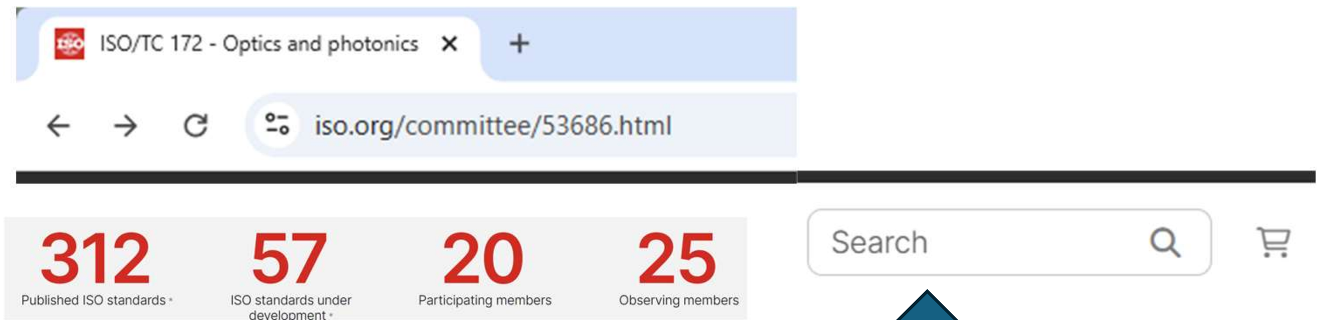
Creation and Evolution of ISO 12233, the International Standard for Measuring Digital Camera Resolution

Kenneth Parulski[1], Dietmar Wueller[2] Peter D. Burns[3] and Hideaki Yoshida[4]
[1]aKAP Innovation, LLC., [2]Image Engineering GmbH & Co.KG, [3]Burns Digital Imaging and [4]OM Digital Solutions

"Standards are valuable only if they are widely used by the industry, which means they must evolve to meet the changing needs of the industry. The biggest challenge in developing [digital photography] metrology standards is obtaining international consensus on the required and optional types of tests, analysis methods, [test charts,] and reporting requirements from the experts representing major imaging companies and other stakeholders. This takes time and requires compromises. In some situations, it is appropriate to include multiple measurement methods, and allow the industry to decide which is best."

- Development/revision of an ISO standard involves 6-7 stages
- Each takes many months

Finding ISO Test Standards



What you can see (ISO, ANSI)

Abstract
Introduction
Scope
Normative references
Terms and definitions
Table of Contents

Example: ISO 21395-1

Example: transmittance

Other searching options:
- use AI
- see lists on oeosc.org

ISO also provides...

ISO/IEC 9001 – the QMS standard
- Decision making
- Document control
- Risk management
- Continuous improvement

ISO 17025 – General requirements for the competence of testing and calibration laboratories
- Sets requirements for the competence, impartiality, and consistent operation of laboratories, ensuring accuracy and reliability of test and calibration results

Vocabulary, specifications/ "min req'ts", technical reports, and more
Ex. ISO 9211-1 – Optical coatings, Part 1: Vocabulary
Ex. ISO 8237 – Specification of chalcogenide glass used in the IR spectrum
Ex. ISO 14880/TR — Microlens array – Guidance on testing

ISO 10110 – Preparation of drawings for optical elements and systems
- A ~13 part series
- Shows how to *indicate* requirements on optics drawings

PART II
Ten(10) categories of ISO optical test standards

ISO Tests in 10 Categories

- Most tests are from TC172 (Optics and Photonics)
  - A third of TC172 documents contain test procedures (actual standards)
  - Ophthalmology measurements are omitted from this presentation
  - Those currently in development
- Tests from TC42 (Photography)
  - These titles lead off with Photography –
  - There are currently 217 documents in this technical committee
  - The bulk relates to chemical, paper, etc., many for digital still cameras
  - ~ a dozen test standards are included in this course
- Two are from TC213 (Geometrical Product Specification)
- Please note your questions on your Q&A sheet

ISO Tests in 10 Categories

1. Optical materials and coatings
2. First order optical properties
3. Radiometric properties
4. Lasers and laser-related equipment
5. Location
6. Scattered and stray light
7. Aberrations and wavefront error
8. Image quality and resolution
9. Environmental testing
10. Miscellaneous

Trivia Question

How is index of refraction measured?

Image retrieved from javalab.org/en/refraction_a_fish_under_water_en/ 7.11.25

Category 1: Optical materials and coatings

Properties of optical glass (visible)

ISO 21395-1	**Refractive index — Minimum deviation method (Ed. 1, 2020)**
ISO 21395-2	Refractive index — V-block refractometer method (Ed. 1, 2022)
ISO 17411	Test method for homogeneity of optical glasses by laser interferometry (Ed. 2, 2022)
ISO 11455	Raw optical glass — Determination of birefringence (Ed. 1, 1995)
ISO 6760-1	Temperature coefficient of refractive index of optical glasses — Minimum deviation method (Ed. 2, 2025)
ISO 6760-2	dn/dT— Interferometric method (Ed. 1, 2024)

Properties of infrared materials

ISO 17328	Test method for refractive index of infrared materials (Ed 2., 2021)
ISO 19740	Test method for homogeneity of infrared optical materials (Ed 1., 2018)
⚙ ISO 19741	Test method for striae in infrared optical materials (Ed 1., 2018)
ISO 19742	Test method for bubbles and inclusions in infrared optical materials (Ed 1., 2018)

Material durability

ISO 9385	Glass and glass-ceramics — Knoop hardness test (Ed. 1, 1990)
ISO 12844	Raw optical glass — Grindability with diamond pellets (Ed. 1, 1999)
⚙ ISO 21575	The powder test method for the water resistance of optical glass (Ed. 2, 2018)
ISO 22531	Test method for climate resistance of optical glass (Ed. 1, 2020)
ISO 8424	Resistance to attack by aqueous acidic solutions — Test method and classification (Ed. 3, 2023)
ISO 10629	Resistance to attack by aqueous alkaline solutions — Test method and classification (Ed. 1, 1996)
ISO 9689	Resistance to attack by aqueous alkaline phosphate-containing detergent solutions (Ed. 2, 2025)

Coating durability

ISO 9211-3	Environmental durability (Ed. 3, 2024)
ISO 9211-4	**Specific test methods — Abrasion, adhesion and resistance to water (Ed. 4, 2022)**

ISO 9022 series (also see Category 9)

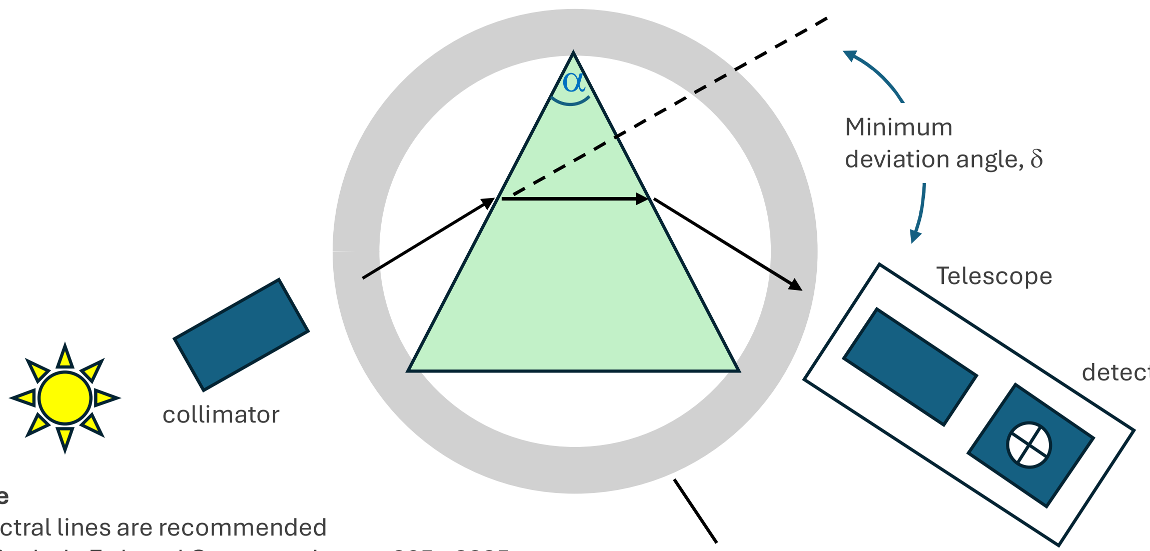
⚙ These documents are in revision
Check iso.org often!

Cat 1: Measuring refractive index (visible)

ISO 21395-1: Refractive index — Minimum deviation method (Ed. 1, 2020)

Method
Make a prism, measure *minimum* deviation angle for a series of wavelengths.
Potential measurement uncertainty 1E-05.

Specimen
A range of dimensions and apex angles is allowed
An equation is given to determine a good apex angle
Sides must be polished to 0.10-0.25 waves PV at 546 or 632.8 nm



Source
22 spectral lines are recommended
These include F, d, and C, etc., and cover 365 - 2325 nm
Others are allowed, but λ must be verified
A high degree of collimation ensures focus at detector

Goniometer
Must be capable of reading angle to 1 arcsecond measurement uncertainty

Cat 1: Measuring refractive index (visible)

ISO 21395-1: Refractive index — Minimum deviation method (Ed. 1, 2020)

Measuring the refractive index

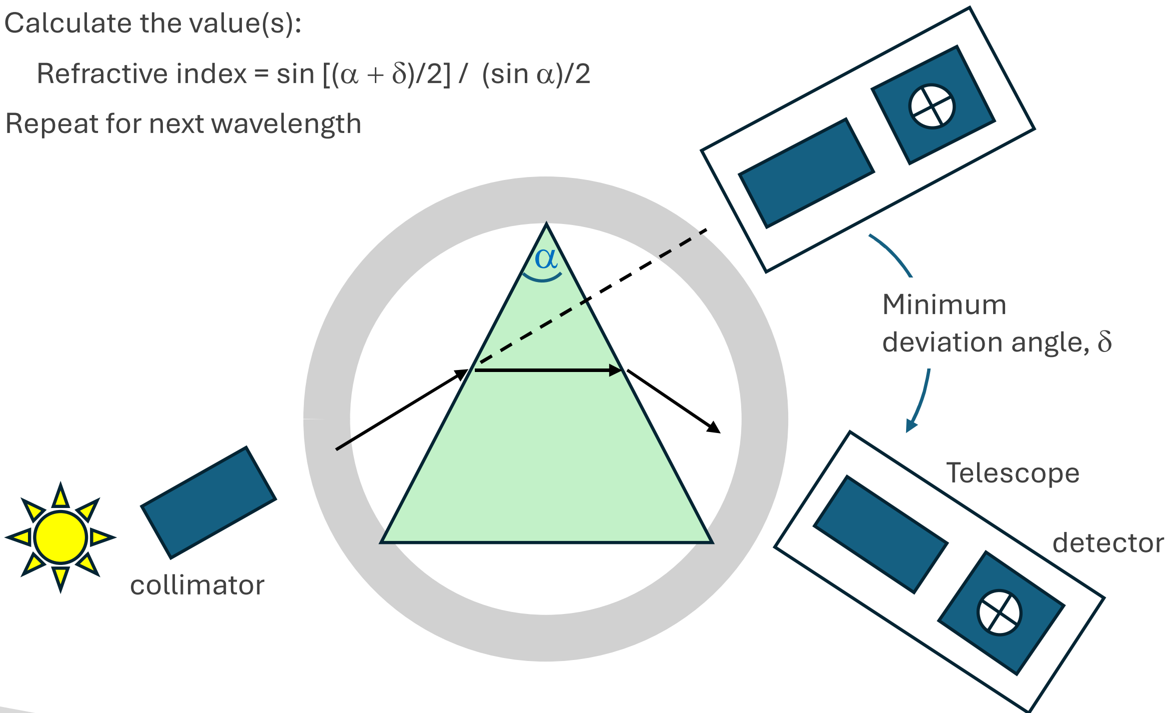
(a) Set wavelength

(b) Find the deviation angle (δ) through iterative process

(c) Calculate the value(s):

Refractive index = sin [($\alpha + \delta$)/2] / (sin α)/2

(d) Repeat for next wavelength

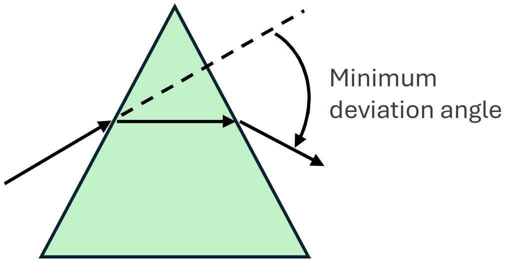


Cat 1: Measuring refractive index (visible)

ISO 21395-1: Refractive index — Minimum deviation method (Ed. 1, 2020)

Calculations

- Equations and number of decimal places required given in Annexes
- Principal dispersion, Abbe number, and relative partial dispersions
- Calculate the refractive index of sample at an arbitrary wavelength
- Correct refractive index for TPH
- Use data at two different temperatures to calculate an dN/dT
    - for absolute index
    - for relative index



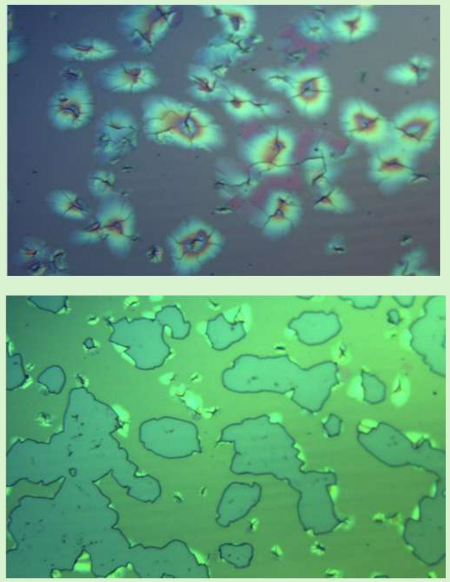
Indication and Test Report

Refractive index/indices shall be recorded to 5 decimal places

a) Method of measuring the apex angle
b) Method of measuring the minimum deviation angle
c) Measured pressure, humidity, and temperature (tols given)
d) Error in the temperature measurement
e) Any modifications to the procedure
f) Unusual findings
g) Test date

Trivia Question

What effect is shown in these photos?



Photos courtesy of Optimax Systems, Inc., 2025

Category 1: Optical coatings

The ISO 9211 series- Optical coatings

ISO 9211-1 Vocabulary – basics of different kinds of coatings, photographs of imperfections

ISO 9211-2 Optical properties – how to designate a coating, including type, T, R, tests, etc.

tests [ISO 9211-3 Environmental durability

ISO 9211-4 Specific test methods — Abrasion, adhesion and resistance to water]

Minimum requirements for optical coatings…
"Default" specifications you can refer to in your drawings. Contains R, T, abs, etc., as well as minimum environmental tests that must be passed. Each document has several choices.

ISO 9211-5 Antireflecting coatings

ISO 9211-6 Reflecting coatings

ISO 9211-7 Neutral beam splitting coatings

ISO 9211-8 Coatings used for laser optics

Relationship to ISO 9022 series (Category 9 below)

Environmental test methods series

ISO 9022 is for optical systems and has a much wider scope than 9211

But there is overlap - coating test requirements call for *many* of the 9211 conditions

i.e., heat, humidity, then do tape test

Cat 1: Coating environmental durability

ISO 9211-3: Environmental durability (Ed. 3, 2024)

Environmental "test codes" are defined:

ISO 9XXX – XX – XX
ISO Base number – conditioning method – degree of severity
Ex. ISO 9211-4-02-01: Adhesion test from ISO 9211-4
Conditioning method 02 = tape test
Degree of severity = 01 = 50 strokes with cheesecloth
Ex. ISO 9022-2-10-07: Expose to a temperature of -35°C ±3°C for 16 hours

Categories of use are defined:

Category A:	Only one coated sample is tested, and only exposed to cold and dry heat
Cats B - D:	2-4 samples, respectively
	Additional tests
	Tests are in order (don't do a thermal test on a sample that's already had an eraser test)
Cats A – D:	Default tables are provided, but you can make modifications
Category O:	This one is for special cases that do not easily fit into Categories A-D. There is a format given for mixing and matching.

Relationship to ISO 10110-9

- ISO 10110-9 shows how to *indicate* the coating(s) you want
- ISO 9211 gives
  - Scheme for test codes to put on the drawing
  - Example of table to indicate the required coating tests (step by step, interspersed with 9022 conditions, and what to do to each of N samples)
- OEOSC is making this handoff smoother
- Also see SPIE Book "Modern Optical Drawings – The ISO 10110 Companion"

Cat 1: Coatings durability tests

ISO 9211-4: Specific test methods — Abrasion, adhesion and resistance to water (Ed. 4, 2022)

There are 5 coating environmental durability tests described in this document

Abrasion tests: cheesecloth/eraser test (conditioning method 01)

Adhesion test: tape test (conditioning method 02)

Adhesion test: crosshatch test (conditioning method 03)

Resistance to water: exposure to water (conditioning method 04)

Adhesion test: pull-off test (conditioning method 05) (new/ more severe)

General information

- Coated samples must be stored under ambient conditions for at least 12 hours post-coat
- Coated samples must be properly cleaned with a nonresidue cleaning agent per an agreement between the tester and customer. The sample shall then be dried with lens tissue or a soft clean cloth.
- Specimens must be held firmly during testing – no sliding
- The head of the tester must be roughly normal to the specimen surface
- Actual components or witness samples may be used (not typically for assemblies)
- Each of the 5 has a general, test, severity, recovery, and evaluation section

Edmund optics | worldwide

MIL-SPEC Coating Testing Kit (#18-485)

Cat 1: Coatings durability tests

ISO 9211-4: Specific test methods — Abrasion, adhesion and resistance to water (Ed. 4, 2022)

1. Abrasion tests: cheesecloth/eraser test (conditioning method 01)

- Tests are to be completed with a coating abrasion tester capable of generating 5 and 10 N of force with a tolerance of ±1 N
- A stroke length of 20 mm shall be used (if the sample is large enough)
- One cycle is equal to two strokes in which the second stroke brings the tester back to the original position
- The cycle speed shall be in the range of 30-90 cycles per minute

Severity levels 01 and 02:

Cheesecloth size, thickness, warp, yarns, mass, and laundering instructions are given in Annex A.1. There is an ISO document for yarn!

Forces are 5N and number of strokes 50 and 100 (add "x N" for N times more)

Severity levels 03 and 04:

Eraser must be at least 15% pumice, manufactured by extrusion, hardness according to ISO 48-2, diameter 6.5-7mm, exposed length <= 3 mm, & more.

Forces are 10N and number of strokes 20 and 40 (x factor allowed)

Instructions for attachment of cheesecloth and eraser are given.

Evaluation: Look for any evidence of physical damage:

a) View with the unaided eye using a 15W fluorescent light in a simple black matte black box as shown in Annex C, or
b) Use ISO 14997 - Test methods for surface imperfections of optical elements (2017) – this is scratch-dig, visual method A3, or
c) View as agreed between supplier and user

Random example of one of many such products. Retrieved from nextgentest.com 7.11.25

Cat 1: Coatings durability tests

ISO 9211-4: Specific test methods — Abrasion, adhesion and resistance to water (Ed. 4, 2022)

2. Adhesion test: tape test (conditioning method 02)

Use a 12-13 mm wide clear tape with an adhesive strength on steel of >=9.8 N per 25 mm width (test according to ISO 29862). Behavior when unwinding shall be examined.

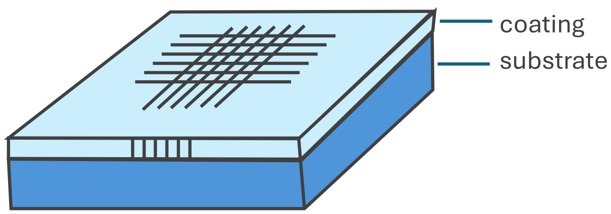
Apply at 25 mm length (when size permits), avoiding the "rim" by 2 mm.

Press and work out bubbles, then lift at an angle normal to the surface – slow, quick, and snap (severity levels)

Evaluation: With no magnification, look for evidence of coating removal, using 1 of 3 methods give for abrasion.

Stains, smears, streaks, or cloudiness are acceptable if the specimen conforms to optical and (other) environmental specifications.

3. Adhesion test: crosshatch test (conditioning method 03)



Use a razor blade or diamond scribe to cut 6 lines spaced 1.5 ± 0.5 mm with length of 15-20 mm. Rotate 90° and cut 6 more.

Do cut through the coating; do NOT cut into the substrate.

Inspect and record any initial damage.

Then use tape as in the tape test.

There is no degree of severity (omit last value)

Evaluation: There are 6 classifications (0-5), quantified by % of area detached, with some nice accompanying drawings. Magnification is allowed.

Cat 1: Coatings durability tests

ISO 9211-4: Specific test methods — Abrasion, adhesion and resistance to water (Ed. 4, 2022)

4. Adhesion test: pull-off test (conditioning method 05) (new/more severe)

Measures strength when lifting straight up (no shear forces), not peel strength
Abrade a test stamp over a 10 mm diameter
Select an adhesive (examples based on materials)
Adhere stamp surface per manufacturer to coating
- no shear forces are introduced

Use a tensile testing machine, or an analytical centrifuge (for multiple samples)

Pull linearly at 10N/s until rupture occurs
Use ISO 10365 to evaluate the failure "pattern"
Determine failure mode
- if coating failed (coating strength = value)
- if adhesive failed (coating strength > value)

Image retrieved on 8.5.25 from www.instron.com/en/products/testing-systems/universal-testing-systems/low-force-universal-testing-systems/

Cat 1: Coatings durability tests

MIL → ISO

Coating Tests		
MIL-PRF-13830B, Appendices B, C	General Spec for Optical Components	Active, 1997
MIL-C-48497A	Durability for single or multi-layer coating	Inactive 1997
MIL-C-675 C	AR coating of glass optical elements	Active, 1980
MIL-M-13508 C	Front surface aluminized mirror	Inactive 1997
MIL-F-48616	General Spec for infrared filter (coatings)	Inactive 1997
MIL-C-14806A	Reflection reducing coating for cover glass and lighting wedges	Inactive 1997

→ ISO 9211 series
ISO 9022 series

The ISO standards have been brought into harmony with the MIL standards for both durability tests and environmental testing. Possible exceptions exist for MIL-F-48616 and MIL-C-14806A.

Category 2: First order properties

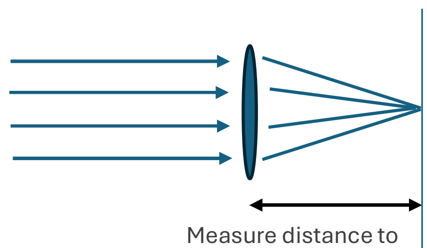
Standard	Title	First Order Properties Measured
ISO 517	Apertures and related properties pertaining to photographic lenses – Designations and measurements (Ed. 3, 2008)	Diameter of entrance pupil (2 methods) **Effective focal length (2 methods)**
ISO 14490-1	Test methods for telescopic systems – Test methods for basic characteristics (Ed. 1, 2005)	Angular mag, EP diameter, EP' diameter, eye relief, FOV in object space, FOV in image space, collimation of rays, image rotation, closest distance of observation
ISO 14490-2	Test methods for telescopic systems – Test methods for binocular systems (Ed. 1, 2005)	Non-parallelism of axes, interpupillary distance, relative difference in magnification, focusing difference
ISO 14490-3	Test methods for telescopic systems – Test methods for telescopic sights (Ed. 3, 2021)	Axial parallax, parallax, ER, ER range, critical ER, reticle tracking, LOS shift due to zooming/ due to focusing
ISO 14490-4	Test methods for telescopic systems – Test methods for astronomical telescopes (Ed. 1, 2005)	Clear aperture of objective (3 methods) Focal lengths (obj and eyepiece, nodal slide method)
ISO 14490-8	Test methods for telescopic systems – Test methods for night-vision devices (Ed. 1, 2011) Select sections: 4, 6-10	Magnification, field of view, EP' diameter, ER, zero-position of dioptre scale, image rotation, non-parallelism of axes
ISO 15227	Microscopes – Testing of stereomicroscopes (Ed. 1, 2000)	Long list – mags, mag difference, axes difference, focal shift, focal difference, image rotation difference, more…
ISO 8600-3	Medical endoscopes and endotherapy devices – Determination of field of view and direction of view of endoscopes with optics (Ed. 2, 2019)	Field of view, direction of view (see LOS)
ISO 14880-3	Microlens arrays – Test methods for optical properties other than wavefront aberrations (Ed. 2, 2024)	Effective back or front focal length, uniformity of focal spots
ISO 14880-4	Microlens arrays – Test methods for geometrical properties (Ed. 2, 2024)	Pitch, lens sag, thickness, radius of curvature

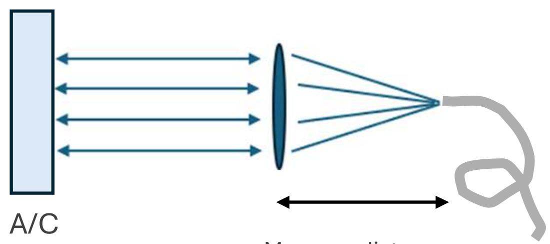
You can go "off label" on any test if your system doesn't fit neatly into the definition. Be transparent.

Cat 2: Focal length

ISO 517 Apertures and related properties pertaining to photographic lenses – Designations and measurements (Ed. 3, 2008)

Thin lens
Lab 101





Cat 2: Focal length

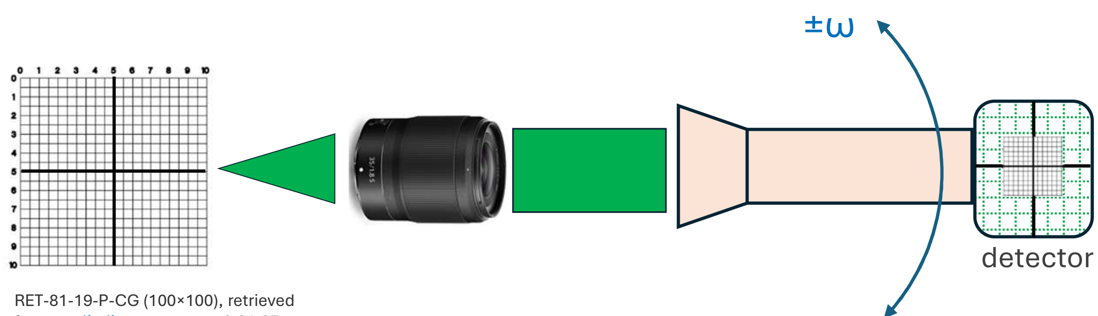
ISO 517 Apertures and related properties pertaining to photographic lenses – Designations and measurements (Ed. 3, 2008)

5.2.2.1 Focal Length Method 1

Equipment: 546 nm source, engraved scale, slide and pivot mechanics/goniometer, telescope fitted with reticle

Procedure

- Set to F/5.6 (if possible)
- Find nodal point of lens and set tele to rotate about
- Set engraved scale in front focal plane



RET-81-19-P-CG (100×100), retrieved from appliedimage.com on 6.21.25

EFL = limit as $\omega \rightarrow 0$ [$h'/\tan(\omega)$]

Cat 2: Focal length

ISO 517 Apertures and related properties pertaining to photographic lenses – Designations and measurements (Ed. 3, 2008)

5.2.2.2 Focal Length Method 2

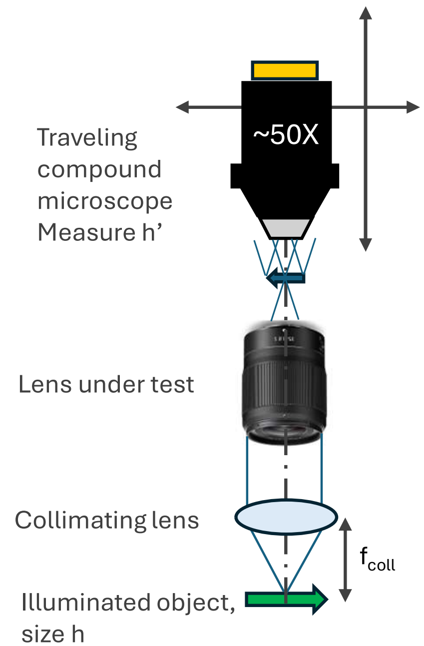
Equipment: 546 nm source, engraved scale (0.002 mm accuracy), collimator ($f_{coll} > f_{LUT}$), traveling microscope

Procedure

- Collimate an object of known height h with a collimator f_{coll}
- Set lens under test to F/5.6, if possible
- Image with camera lens and measure with microscope the height h’

$$f = f_{coll} \times [h'/h]$$

- Commercially available instruments use small slit spacing (h) and measure h’



Cat 2: Focal length

Additional notes

Limitations

- Infinity is defined as 5 x EFL
- Methods work best for EFL range 20 - 500 mm,
    - No alternatives given for macro or telephoto lenses
    - Should be able to adapt for general cases of optical systems
- No EFL error budgets or even tolerances are given in this doc
- EFL measurement uncertainty typically not demanding
- This is common for TC42 standards

Also included in this document

- Standard F-number list (stops, half stops)
- Tolerances on F-number (5%-16%, depending on F#)
- Markings on product
- How to measure the entrance pupil diameter
    - Two methods

Category 3: Radiometric properties

General

ISO 15368	**Measurement of reflectance of plane surfaces and transmittance of plane parallel elements (Ed. 2, 2021)**
ISO 15368-2	Measurement of reflectance of plane surfaces and transmittance of PPEs – Internal transmittance
ISO 13653	General optical test methods – Measurement of relative irradiance in the image field (Ed. 2, 2019)

Digital still cameras (DSC)

ISO 8478	Camera Lenses – Measurement of ISO spectral transmittance (Ed. 2, 2017)
ISO 12232	Photography – Determination of exposure index, ISO speed ratings, standard output sensitivity, and recommended exposure index (Ed. 3, 2019)
ISO 2827	Photography – Electronic flash equipment — Determination of light output and performance (Ed. 2, 1988)
ISO 14524	Photography – Electronic still picture imaging – Methods for measuring opto-electronic conversion functions (**OECFs**) (Ed. 2, 2009)

Other optical systems

ISO 14990-8	Test methods for telescopic systems – Test methods for night-vision devices (Ed. 1, 2011)
ISO 14490-5	Test methods for telescopic systems — Test methods for transmittance (Ed. 3, 2021)
ISO 11315-1	Photography – Projection in indoor rooms — Screen illumination test for still projectors (Ed. 1, 1997)
ISO 19056-1	Image brightness and uniformity in bright field microscopy (Ed. 1, 2015)
ISO 19056-2	Illumination properties related to the colour in bright field microscopy (Ed. 1, 2019)
ISO 19056-3	Incident light fluorescence microscopy with incoherent light sources (Ed. 1, 2022)

Cat 3: Measurement of R and T

ISO 15368   Measurement of reflectance of plane surfaces and transmittance of plane parallel elements (Ed. 2, 2021)

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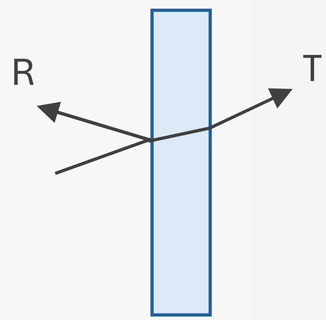


Cat 3: Measurement of R and T

ISO 15368 Measurement of reflectance of plane surfaces and transmittance of plane parallel elements (Ed. 2, 2021)

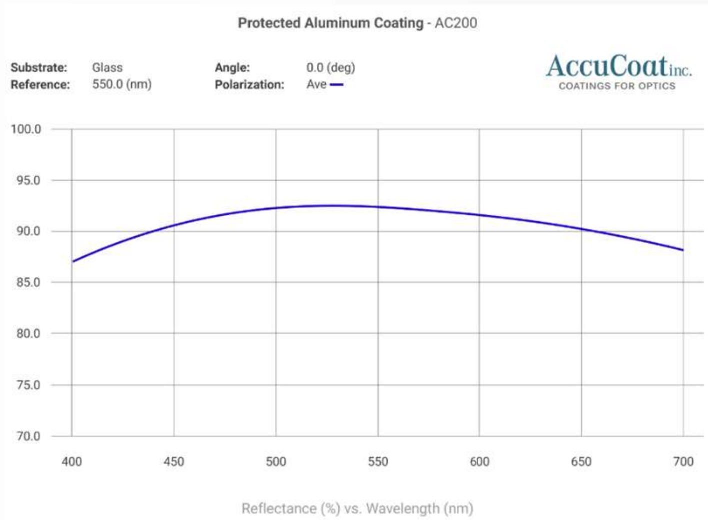


Image retrieved from https://accucoatinc.com/mirror-optical-coatings/ac_200/ on 7.17.25

Data Sheet

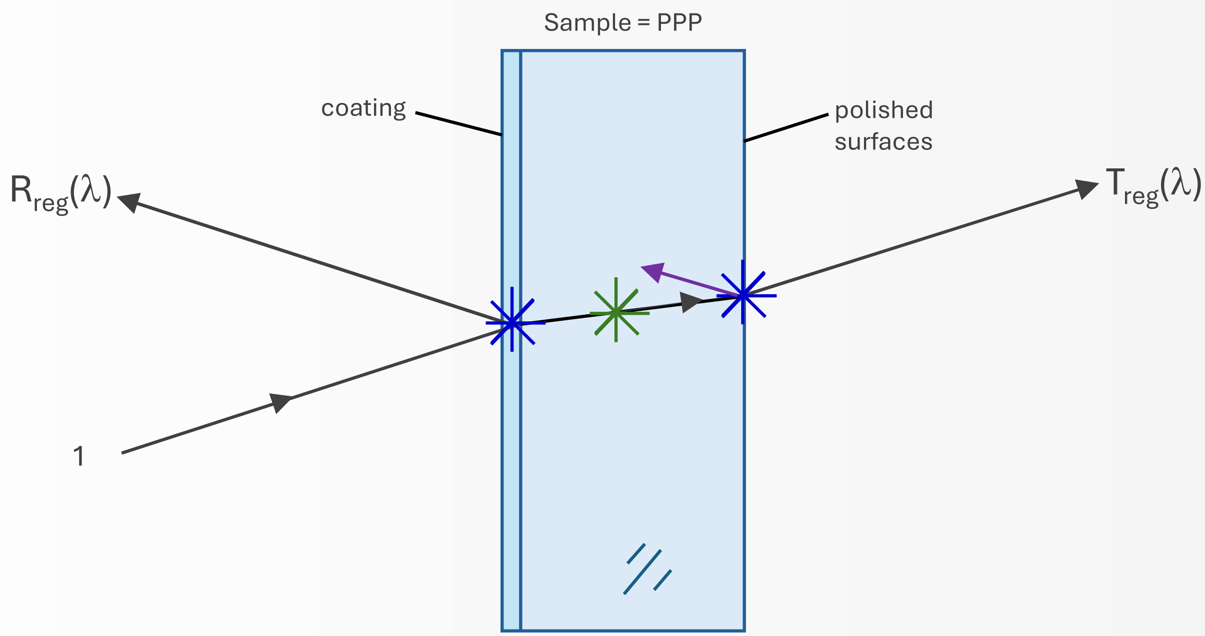
SCHOTT N-BK 7®
517642.251

Internal Transmittance τ_i		
λ [nm]	τ_i (10mm)	τ_i (25mm)
2500	0.665	0.360
2325	0.793	0.560
1970	0.933	0.840
1530	0.992	0.980
1060	0.999	0.997
700	0.998	0.996
660	0.998	0.994
620	0.998	0.994
580	0.998	0.995
546	0.998	0.996
500	0.998	0.994
460	0.997	0.993
436	0.997	0.992
420	0.997	0.993
405	0.997	0.993

Image retrieved from https://www.schott.com/shop/advanced-optics/en/Optical-Glass/SCHOTT-N-BK7/c/glass-SCHOTT%20N-BK7%C2%AE on 7.17.25

Cat 3: Measurement of R and T

ISO 15368   Measurement of reflectance of plane surfaces and transmittance of plane parallel elements (Ed. 2, 2021)

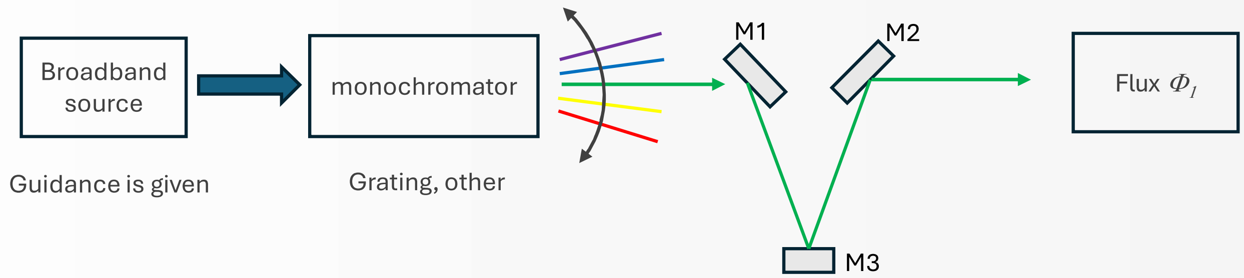


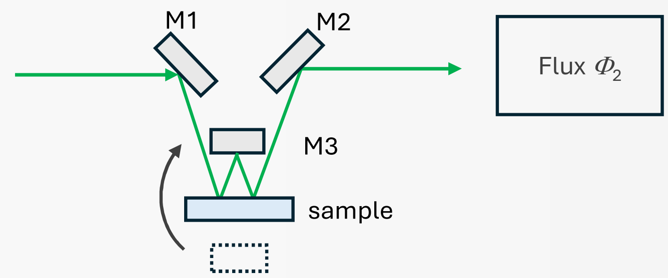
$$T_{reg} = 1 - [R_{reg,\,s1} + R_{diff,\,s1} + A_{coat} + (1 - T_{int}) + R_{int} + R_{diff,\,s1}]$$

$$T_{reg} = 1 - [0.04 + 0.02 + 0.01 + (1 - 0.95) + 0.04 + 0.02] = 0.82$$

Cat 3: Measurement of R and T: Regular Reflectance

ISO 15368





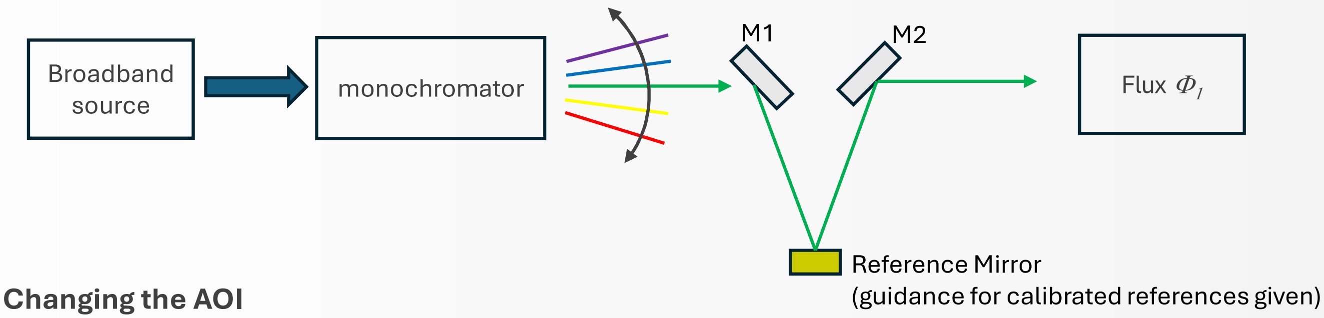
Disadvantages

- Heavy dependence on power stability
- Limitations on AOI range and/or
- Positions on M1, M2, and M3 must have consistent R

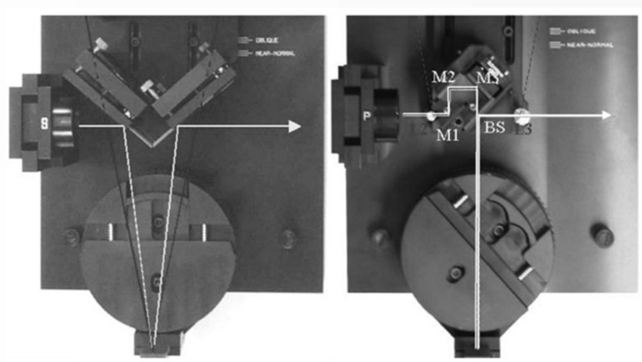
$$R_{reg}(\lambda) = \Phi_2 / \Phi_1$$

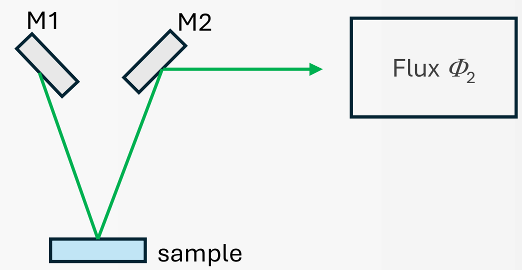
Cat 3: Measurement of R and T: Relative Reflectance

ISO 15368



Changing the AOI





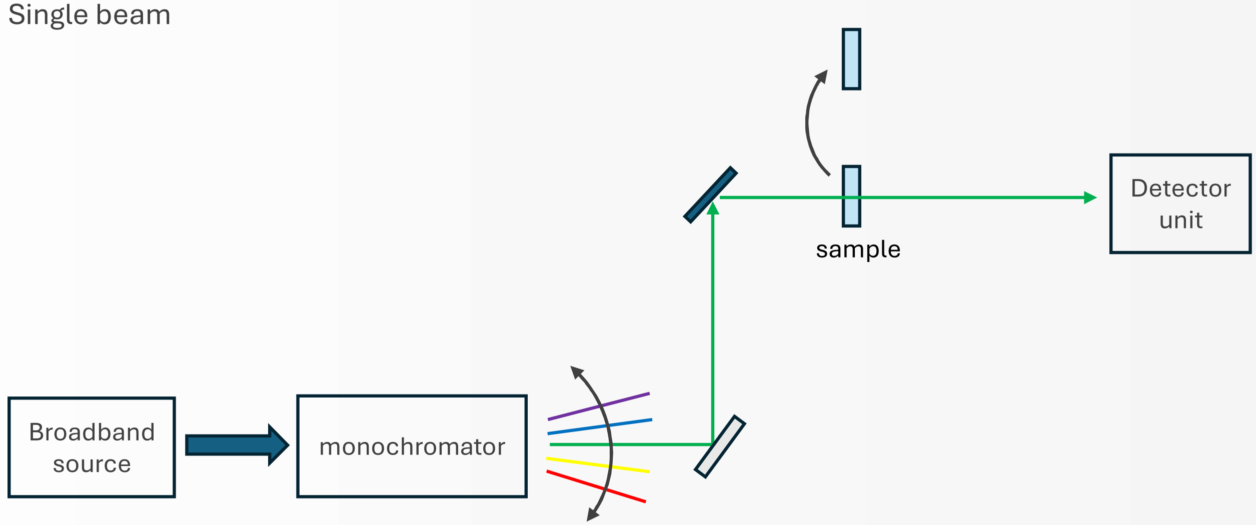
OMT Solutions white paper "Directional Reflection measurements on highly reflecting coatings," van Nijnatten, de Wolf, and Schoofs, retrieved 7.31.25 from shop.perkinelmer.com/product/L6020055

$$R_{rel}(\lambda) = \Phi_2 / \Phi_1$$

Cat 3: Measurement of R and T: Regular Transmittance

ISO 15368

Single beam



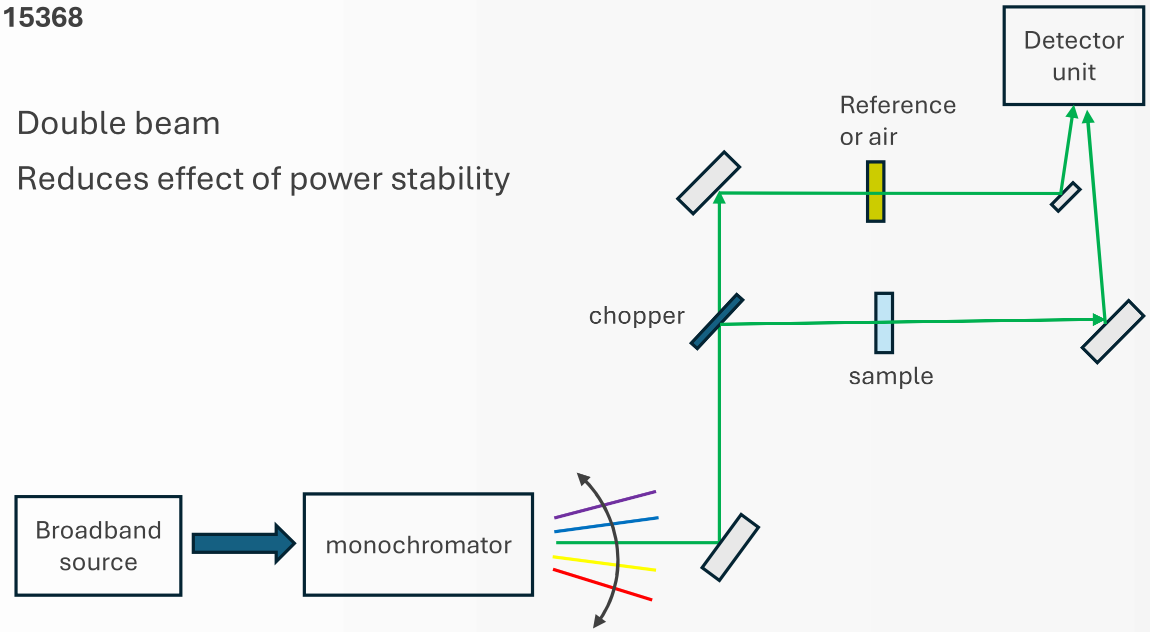
$$T_{reg}(\lambda) = \frac{\Phi_{\text{sample in beam}}}{\Phi_{\text{sample out}}}$$

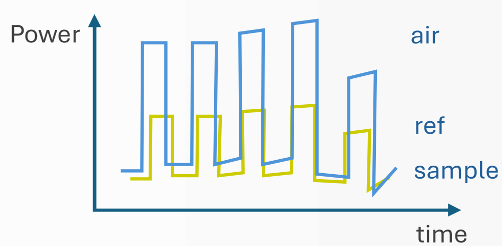
Cat 3: Measurement of R and T: Reg/Rel Transmittance

ISO 15368

Double beam

Reduces effect of power stability



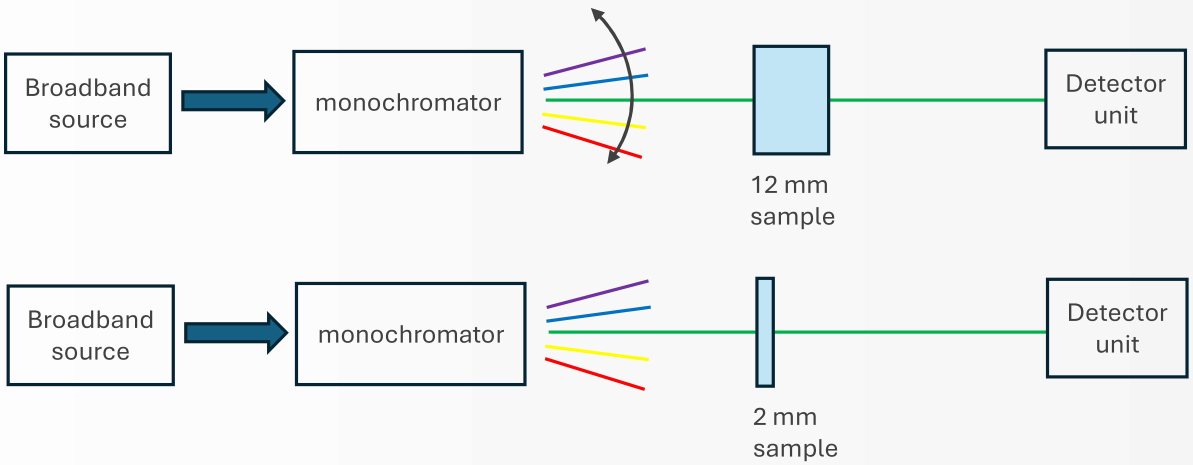


$$T_{reg}(\lambda) = \frac{\Phi\,(\text{sample path})}{\Phi\,(\text{air path})}$$

$$T_{rel}(\lambda) = \frac{\Phi\,(\text{sample path})}{\Phi\,(\text{ref path})}$$

Cat 3: Measurement of R and T: Internal Transmittance

ISO 15368



Samples have the same:

- Batch
- Surface polish
- Wedge
- Alignment
- Uncoated
- Source power (use double beam/chop)

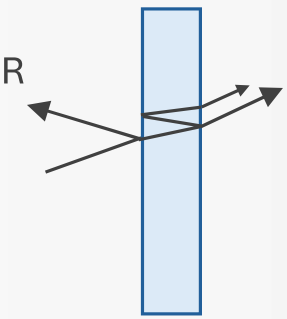
$$T_{int}(\lambda)\text{, over 10 mm} = \frac{T_{reg}\,(12\text{ mm})}{T_{reg}\,(2\text{ mm})}$$

$$T_{int}(\lambda)\text{, over 25 mm} = \frac{T_{reg}\,(30\text{ mm})}{T_{reg}\,(5\text{ mm})}$$

Cat 3: Measurement of R and T: Internal Transmittance

ISO 15368

$$T_{reg} = 1 - [R_{reg,\,s1} + R_{diff,\,s1} + A_{coat} + (1-T_{int}) + R_{int} + R_{diff,\,s1}]$$



Energy in the double reflection

For very low T, it is negligible (absorbed)

For very high T, it is ~the same in both samples

For moderate T, can cause an error in T_{int} measurement

- correct with calculation

ISO 15368-2 Measurement of reflectance of plane surfaces and transmittance of PPEs – Internal transmittance (WD -> CD stage)

This document will supplement ISO 15368 for Internal Transmittance only

More guidance on:

- Preparing samples
- What thicknesses to use
- How to do calculations to account for multiple reflections

Cat 3: Measurement of R and T

ISO 15368

Common Sources of Error

Fluctuation of the incident flux

Wavelength uncertainty

Monochromator for dispersive type spectrophotometers

Interferometer for FTS type

Table is given with typical values in different spectral regions

Monochromator stray optical radiation (specular and diffuse)

Monochromator baseline reproducibility

Sample

- Parallelism of the sample
- Misalignment of the sample
- Internal reflections

Linearity of the detection system

Beam divergence – see double beam

Typical measurement uncertainties are given

Trivia Question

What is the MIL standard for laser damage?

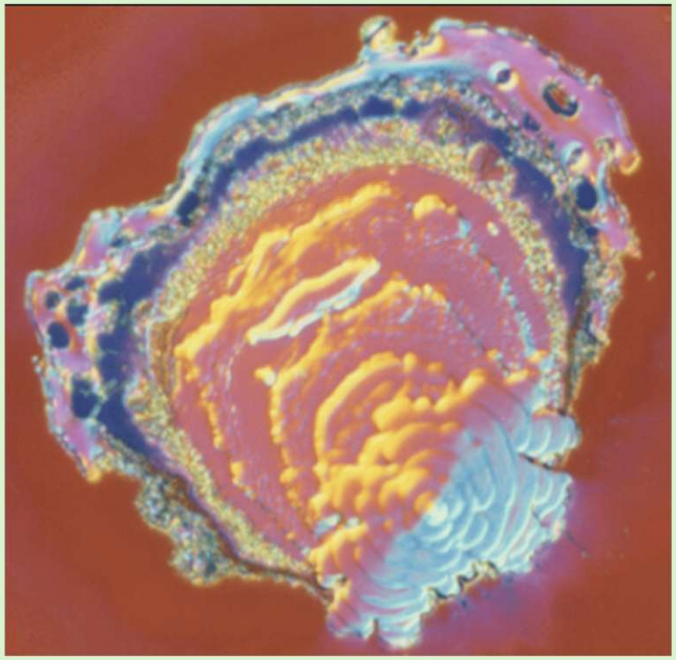


Image retrieved from https://www.quantel-laser.com/en/laser-damage-test-services.html. July 9, 2025.

Category 4: Lasers

Laser beam properties

ISO 11146-1	Test methods for laser beam widths, divergence angles and beam propagation ratios – Stigmatic and simple astigmatic beams (Ed. 2, 2021)
ISO 11146-2	Test methods for laser beam widths, divergence angles and beam propagation ratios – General astigmatic beams (Ed. 2, 2021)
ISO 22247	Effective numerical aperture of laser lenses – Definition and verification procedure (Ed. 1, 2022)
ISO 11554	Test methods for radiant beam power, radiant energy and temporal characteristics (Ed. 5, 2025)
ISO 11670	Test methods for laser beam parameters — Beam spatial stability (Ed. 2, 2003)
ISO 13694	Test methods for laser beam power (energy) density distribution (Ed. 3, 2018)
ISO 15367-1	Test methods for determination of the shape of a laser beam wavefront – Terminology and fundamental aspects (Ed. 1, 2003)
ISO 15367-2	Test methods for determination of the shape of a laser beam wavefront — Shack-Hartmann sensors (Ed. 1, 2005)

Properties of ultrashort laser pulses (IN DEVEL)

ISO 13682-2	Determination of the properties of ultrashort laser pulses – Autocorrelation measurement method

Category 4: Lasers (continued)

Spectral T/R/A

ISO 13695	Test methods for the spectral characteristics of lasers (Ed. 2, 2024)
ISO 13697	Test methods for specular reflectance and regular transmittance of optical laser components (Ed. 1, 2006)
ISO 13142	Cavity ring-down method for high-reflectance and high-transmittance measurements (Ed. 2, 2021)
ISO 11551	Test method for absorptance of optical laser components (Ed. 3, 2019)
ISO/TR 22588	Measurement and evaluation of absorption-induced effects in laser optical components (Ed. 1, 2005)
ISO 23701	Photothermal technique for absorption measurement and mapping of optical laser components (Ed. 1, 2023)

Laser damage

ISO 21254-2	**Test methods for laser-induced damage threshold – Threshold determination (Ed. 1, 2011)**
ISO 21254-3	Test methods for laser-induced damage threshold – Assurance of laser power (energy) handling capabilities (Ed. 1, 2011)
ISO/TR 21254-4	Test methods for laser-induced damage threshold – Inspection, detection and measurement (Ed. 1, 2011)
ISO 22248	Test methods for laser-induced damage threshold – Classification of medical beam delivery systems (Ed. 1, 2020)
ISO 11810	Test method and classification for the laser resistance of surgical drapes and/or patient protective covers — Primary ignition, penetration, flame spread and secondary ignition (Ed. 2, 2015)
ISO 11990	Lasers and laser-related equipment — Determination of laser resistance of tracheal tube shaft and tracheal tube cuffs (Ed. 3, 2018)
ISO 20811	Laser-induced molecular contamination testing (Ed. 1, 2017)

Cat 4: Laser damage threshold determination

ISO 21254-2 Test methods for laser-induced damage threshold – Threshold determination (Ed. 1, 2011)

ISO 10110-17 is the document that tells you how to *indicate* the *specification* on the *component* drawing. Last update 2004, confirmed in 2022.

ISO 21254-1, Edition 2, was just published: Test methods for laser-induced damage threshold – Definitions and general principles. To be used along with ISO 211254-2.

A review of ISO 21254 for end users

a) Test variables

b) Mechanisms of laser damage

c) Sample preparation

d) Exposure and inspection options

e) Determining results

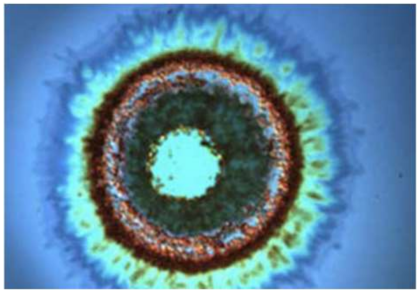


Image retrieved on 7.9.25 from https://spicatech.com/testing/laser-induced-damage/laser-damage-threshold/

Cat 4: Laser damage threshold determination

ISO 21254-2

(a) Variables

Nominal coating	Laser wavelength	Repetition rate/cw
Coating issues	Irradiance (J/cm^2)	Number of pulses (S)
Coating defects	Irradiance profile	AOI
Substrate type	• Diameter	Polarization
Substrate issues	• Flat top or Gaussian	Site location(s)/overlap
Surface roughness	• Hot spots	Cleanliness/contamination
Surface cosmetics	Pulse width (FWHM)	Pre/conditioning

- LIDT results are HIGHLY dependent on these exact parameters and combinations thereof
- Results do not behave well if not well-controlled and should always be considered <u>estimates</u>
- ISO requires the tester to provide an error budget that includes uncertainties in contributors such as detector calibration, beam diameter stability, etc.

(b) Mechanisms of laser damage

Damage is caused by thermal, mechanical, and electrical effects, depending on the above-listed variables

- Thermal stress – cracking, fractures
- Mechanical deformation, stress, shockwaves
- Dielectric breakdown from multiphoton or avalanche ionization (esp. for ps or fs pulses)

Damage can occur in the coating, the bulk material, at either surface, and/or through back reflection.

(c) Sample preparation

Cat 4: Laser damage threshold determination

ISO 21254-2

(d) Exposure and inspection options

- **Acceptance** testing (See ISO 21254-3)
  - Generally non-destructive testing
  - Possible test instructions: "*Coated optical surface to be certified at 5 J/cm^2 to 98% confidence that there are no more than 3 damage-initiation sites over the CA. The CA for this part has an area of 14.2 cm^2.*"
  - There are 2 methods, one considerably more costly

- LIDT determination by a **classical** procedure:
  1. 1-on-1: Sites are spaced out (no overlap)
     Each site gets one pulse
     Each irradiance level gets several sites
     Repeat for several irradiance levels
  2. S-on-1: Same as 1-on-1, but specify a series of S pulses at each site

  - Look for permanent damage (can be done the next day)
  - Use differential interference contrast (DIC) microscopy, total mag must be >= 150X
  - Each site has a binary outcome

- F-LIDT determined by a **functional** procedure (NEW in 21254-1):
  - Looking for any observable or measurable change
  - Requires *in-situ* detection with a *functional* test
  - Example is a scatter sensor, but could be something else defined by end user

  3. R(S)-on-1 (R = ramp): Can specify single (S=1) or multiple pulses
     Stay at *same site* while ramping up the irradiance
     Use when the optic is small and/or curved
     Use when no prior LiDT data is available

Cat 4: Laser damage threshold determination

ISO 21254-2

(d) Exposure and inspection options (continued)

4. <u>Raster scan test</u>: Create raster pattern
With overlap (i.e., so entire sample sees no less than 90% of peak irradiance)
Repeat across *same* entire area at next irradiance level
Addresses concerns for large samples or samples with low defect density

Appendix A gives additional guidance on selecting from the four different procedures

Cat 4: Laser damage threshold determination

ISO 21254-2

(e) Determining results for LIDT and F-LIDT

LIDT (1. and 2.)
Estimated as the highest quantity of laser irradiation incident upon the optical component featuring zero probability of damage.

F-LIDT (3. and 4.)
The highest estimated quantity of laser irradiation incident upon the optical component with no deterioration according to a user-defined functional criteria of damage, specific to end use application.

- Two ways to determine:

1. Linear extrapolation
2. HBFD average method

Others fit curves (see Edmund Optics Knowledge Center), but ISO currently does not allow

At least be clear about fit method.

Cat 4: Laser damage threshold determination

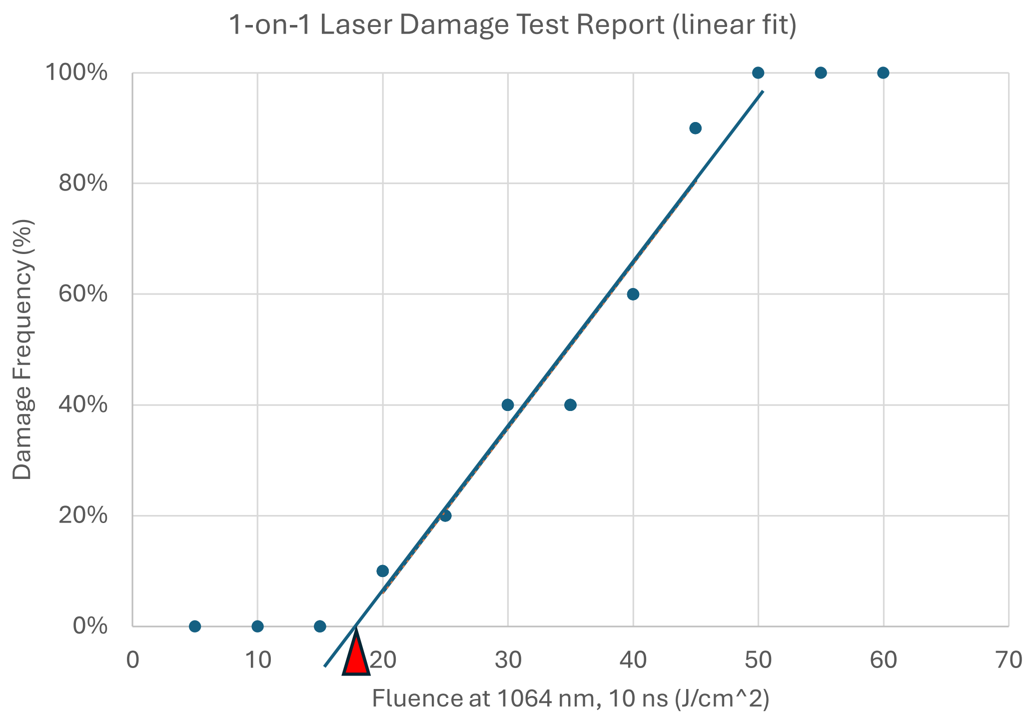
ISO 21254-2

Example of 1-on-1 or S-on-1 data

Test Results	0=no damage 1=damage detected									
Fluence (J/cm^2)	site 1	site 2	site 3	site 4	site 5	site 6	site 7	site 8	site 9	site 10	% damage sites
5	0	0	0	0	0	0	0	0	0	0	0%
10	0	0	0	0	0	0	0	0	0	0	0%
15	0	0	0	0	0	0	0	0	0	0	0%
20	0	0	0	0	0	0	0	0	1	0	**10%**
25	0	0	0	1	1	0	0	0	0	0	**20%**
30	0	1	1	0	0	1	1	0	0	0	**40%**
35	1	0	1	0	1	1	0	0	0	0	**40%**
40	0	1	1	0	0	1	1	0	1	1	**60%**
45	1	0	1	1	1	1	1	1	1	1	**90%**
50	1	1	1	1	1	1	1	1	1	1	100%
55	1	1	1	1	1	1	1	1	1	1	100%
60	1	1	1	1	1	1	1	1	1	1	100%

Cat 4: Laser damage threshold determination

ISO 21254-2



Linear Extrapolation: LIDT = 17.9 J/cm^2

HBFD = avg (15, 20): LIDT = 17.5 J/cm^2

Overall measurement uncertainty is typically much larger than this difference

Category 5: Location

Field procedures for testing geodetic and surveying instruments

ISO 17123-2	Levels (Ed. 1, 2001)
ISO 17123-3	**Theodolites (Ed. 1, 2001)**
ISO 17123-4	Electro-optical distance meters (Ed. 2, 2012)
ISO 17123-5	Total stations (Ed. 3, 2018)
ISO 17123-6	Rotating lasers (Ed. 4, 2025)
ISO 17123-7	Optical plumbing instruments (Ed. 1, 2005)
ISO 17123-8	GNSS field measurement systems in real-time kinematic (RTK) (Ed. 2, 2015)
ISO 17123-9	Terrestrial laser scanners (Ed. 1, 2018)
ISO 17123-10	UAV photogrammetry (under development)
ISO 17123-11	Global navigation satellite systems (Ed. 1, 2025)

Other location

ISO 16331-1	Performance of handheld laser distance meters (Ed. 2, 2017)
ISO 8600-3	Determination of field of view and direction of view of endoscopes with optics (Ed. 2, 2019)
ISO 14490 series	Test methods for telescopic systems Covered in First Order Properties (Category 1), but also has LOS considerations, such as parallax, parallelism, image rotation, and shift in LOS due to focus/zoom

Remote Sensing? Try ISO 19124, ISO 19130, and ISO 19159

Cat 5: Location: Theodolites

ISO 17123-3: Field procedures for testing geodetic and surveying instruments- Theodolites (Ed. 1, 2001)

Cost effective method of precision measurement of LOS

These standards are not concerned with instrument details

- Data collection and statistics
- The GUM is a normative reference for this procedure

Features

Tribrach

- attaches to tripod
- adjustable to center over benchmark
- adjustable to tilt to gravity (iterate)

Telescope

- illuminated reticle
- rotates between Face I and Face II
- aux low magnification sights

Horizontal and vertical scales

- graduated
- lockable

Potential measurement uncertainty - arcseconds

LEICA NA Digital Theodolite 20X. Image retrieved from www.grainger.com on 7.11.25.

Cat 5: Location: Theodolites

ISO 17123-3: Field procedures for testing geodetic and surveying instruments- Theodolites (Ed. 1, 2001)

GeoMax ZIPP02 2-Second Digital Theodolite 789310*

Retrieved 8.8.25 from www.brunson.us/plug-target-theodolite-45-deg18-0001

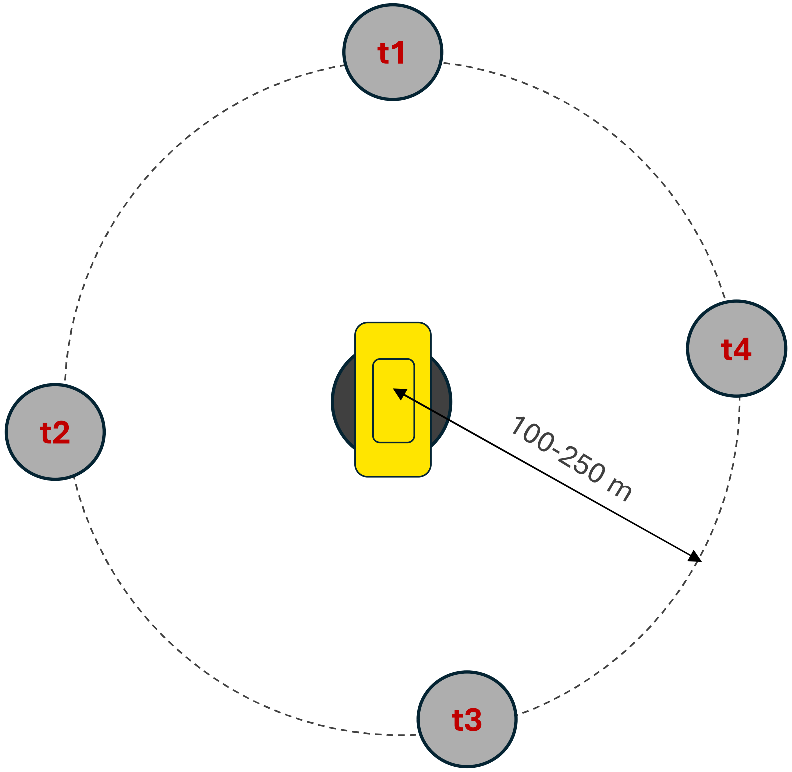


*Image retrieved from https://tigersupplies.com/products/zipp02-2-second-theodolite on 7.11.25.

Cat 5: Location - Theodolites

ISO 17123-3: Field procedures for testing geodetic and surveying instruments- Theodolites (Ed. 1, 2001)

Simplified Test, Horizontal (units are gon = grad) — units are mgon

series i	set j	target k	X(j,k,I)	X(j,k,II)	avg* X(j,k)	norm -> t1 X'(j,k)	avg X(k)	d =1000 x (X(j,k) - avg X(k))	r (j,k) = d(j,k)-d(j)	r^2(j,k)
1	1	1	310.475	110.47	310.5	0.0000	0.0000	0.0	-0.0417	0.00
		2	6.131	206.126	6.1	95.6560	95.6553	-0.7	-0.7083	0.50
		3	130.481	330.477	130.5	220.0065	220.0058	-0.7	-0.7083	0.50
		4	208.878	8.872	208.9	298.4025	298.4040	1.5	1.4583	2.13
							mean =	**0.04**		
	2	1	376.749	176.744	376.7	0.0000	*0.0000*	0.0	-0.5417	0.29
		2	72.403	272.398	72.4	95.6540	*95.6553*	1.3	0.7917	0.63
		3	196.753	396.749	196.8	220.0045	*220.0058*	1.3	0.7917	0.63
		4	275.154	75.148	275.2	298.4045	*298.4040*	-0.5	-1.0417	1.09
							mean =	**0.54**		
	3	1	42.0	242.0	42.0	0.000	*0.0000*	0.0	0.5833	0.34
		2	137.705	337.7	137.7	95.656	*95.6553*	-0.7	-0.0833	0.01
		3	262.056	62.05	262.1	220.007	*220.0058*	-0.7	-0.0833	0.01
		4	340.454	140.449	340.5	298.405	*298.4040*	-1.0	-0.4167	0.17
							mean =	**-0.58**		

*After correcting II by ±200 gons (grads)

Variance = sum (squares) = 6.29

SD = SQRT (variance/n)

n = (no. targets - 1) x (no. sets -1) = 6

Standard deviation = 1.024 mgons

Cat 5: Location - Theodolites

ISO 17123-3: Field procedures for testing geodetic and surveying instruments- Theodolites (Ed. 1, 2001)

The Full Test employs 5 targets and 4 series

Questions:

1. Is the overall experimental standard deviation, *s*, less than the manufacturer's σ (or some other predetermined spec)?
2. Is there any significant difference between results from different
   - operators?
   - theodolites?
   - environments?

In essence, this is a gauge R&R study

Not standardized by ISO

ISO 12888 has detailed examples of R&R studies for 4 systems

☆ Actual measurement-taking procedures and permissible deviations are in TC59

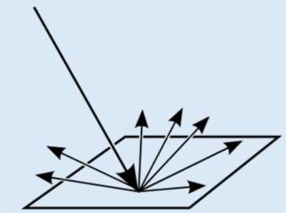
- Buildings and civil engineering works
- Overlaps with > 15 other TCs

Group Question

What are the sources of stray light?

Microsoft Office 365 stock image

Category 6: Scattered and stray light



Surfaces

ISO 14997	Test methods for surface imperfections of optical elements (Ed. 3, 2017)
ISO 21477	Preparation of drawings for optical elements and systems – TR: Surface imperfection specification and measurement systems (Ed. 1, 2017)
ISO 25178	Geometrical product specifications (GPS) — Surface texture: Areal – Design and characteristics of (various) instruments (various)
ISO 21290	Geometrical product specifications (GPS) — Surface texture: Profile (3 parts, 2021)

Components

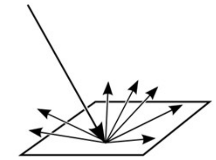
ISO 13696	Test method for total scattering by optical components (Ed. 2, 2022)
ISO 19962	Spectroscopic measurement methods for integrated scattering by plane parallel optical elements (Ed. 1, 2019)
ISO 19986	Lasers and laser-related equipment — Test method for angle resolved scattering (Ed. 1, 2020)

Systems

ISO 9358	**Veiling glare of image forming systems – Definitions and methods of measurement (Ed. 1, 1994)**
ISO 14490-6	Test methods for telescopic systems – Test methods for veiling glare index (Ed. 2, 2014)
ISO 18844	**Photography – Digital cameras – Image flare measurement (Ed. 1, 2017)**

Cat 6: Scattered and stray light - TC172

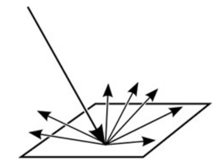
ISO 9358 Veiling glare – Definitions and methods of measurement (1994)



- This document is currently being updated
- **Lens** only
- New title is Stray Light
    - Definition: unwanted radiation that reaches the image
- Veiling Glare Index (VGI) remains
- Glare Spread Function (GSF) remains
- Adding Point Source Transmission (PST)
- Harmonizing with TC42 Image Flare

Microsoft Office 365 stock image

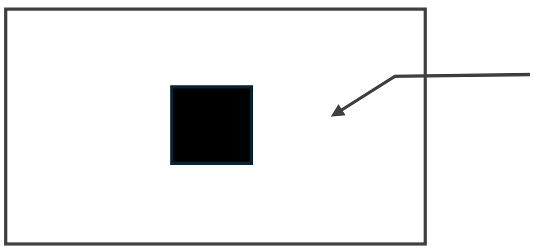
Cat 6: Scattered and stray light - TC172



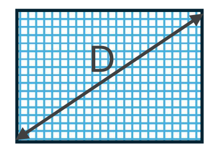
ISO 9358 Veiling glare – Definitions and methods of measurement (1994)

Veiling Glare Index (VGI)

= the “Integral Method of Stray Light Measurement”



Black area may be a circle, square, or band (VGIB) with dimensions D/10



Extent of image for lens under test

Think of the square as the image area of interest in an extended scene

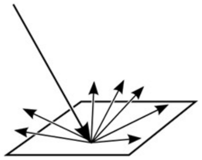
- ✓ glare from other parts of the frame reduce the image contrast
- ✓ for infinite object distance, must consider > FOV

VGI = ratio of irradiances (black/ white) over the same area (remove the black area)

- ✓ “same area” = same setup with black area moved
- ✓ typically expressed as a percentage

The VGI test results in a single value per field position – presented in tabular or graphical form

This is the test called by ISO 14990-6 [terrestrial telescopes (vs. astronomical)]

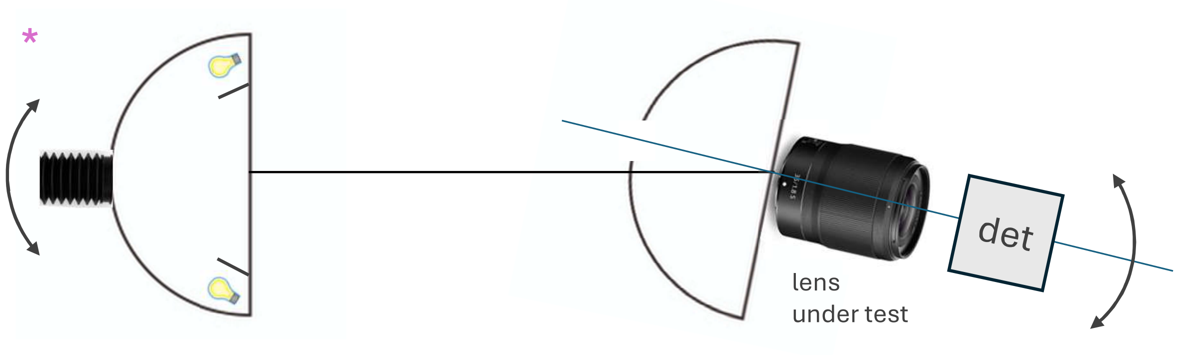


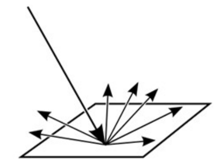
Cat 6: Scattered and stray light - TC172

ISO 9358 Veiling glare – Definitions and methods of measurement (1994)

Setup/Procedure for VGI (Clause 4.1)

- **Classification A: Object effectively at infinity**
  - "Black area" is a beam trap in an integrating sphere
  - This covers > 2π
  - Slide the black trap away for each field position tested
  - If EFL< integrating sphere diam/10, full sphere
  - If EFL longer, use 2 half spheres*
  - Guidance is given if you need to use a collimator
- **Classification B: Finite object distance**
- **Classification C: Object finite, but inaccessible**



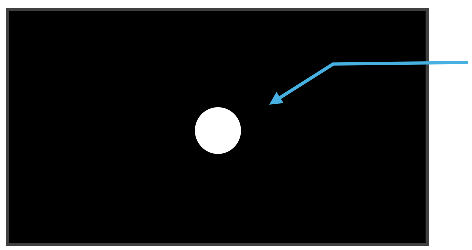


Cat 6: Scattered and stray light - TC172

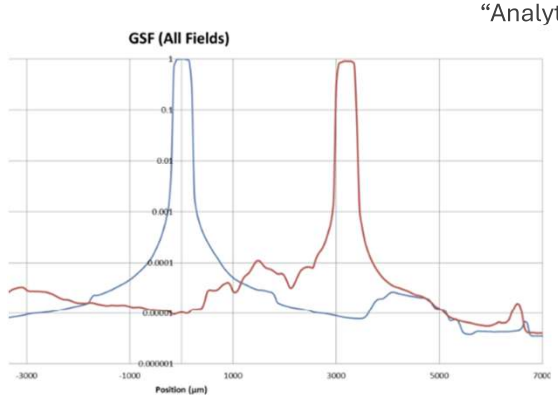
ISO 9358 Veiling glare – Definitions and methods of measurement (1994)

Glare Spread Function (GSF)

= the "Analytical Method of Stray Light Measurement"



- Think of the sun outside the FOV or a headlight in a not-so-bright scene
- The "source" diameter is 1/20th the full FOV of the system
- Assess different field angles, including outside the FOV in object space
- Could examine all field positions initially (time-consuming), then narrow down as problems are solved.
- Scan is just a line (no effect outside H/V measured)
- "Analytical": VGI can be predicted from GSF



"Typical ISO 9358 GSF Measurement Results obtained at 0 and 15 degrees." Image retrieved on 7.11.25 from white paper from www.optikos.com/articles/stray-light

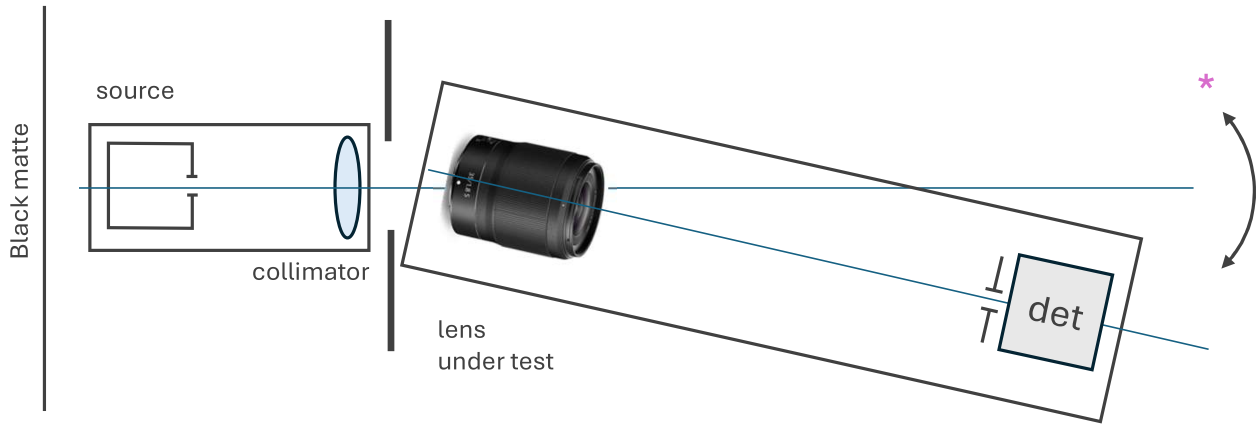
☆ Point Source Transmission (PST) is similar but assesses a point source and considers the *total energy* in the full FOV for each position

Cat 6: Scattered and stray light - TC172

ISO 9358 Veiling glare – Definitions and methods of measurement (1994)

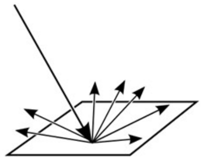
Setup/Procedure for GSF (Clause 4.2)

- Create "source" with simple diffuser or through Kohler illumination, for example, for uniformity
- The source can be moved laterally, or the lens/detector assembly can be tilted* to assess the field
- The detector, or small aperture, can be moved laterally as well to collect the data
- Present as "detector scan" or "source scan" as plot or table



Cat 6: Scattered and stray light - TC172

ISO 9358 Veiling glare – Definitions and methods of measurement (1994)

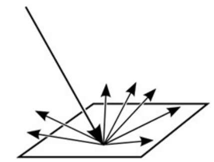


General considerations

- "Typical" arrangements are given, but others are given and okay if you meet the requirements
    - Integrating sphere not the only way to measure VGI
    - Alternative box designs are shown
- Targets must be Lambertian and uniform
    - Radiance constant to ±5% over central area, ±8% over full target
    - Source must be stable and linear to within these limits
- Veiling glare caused by auxiliary components must be << that from the test lens
- Black/white transitions must all be in focus
- Field angles – 0, 0.3, 0.5, and 0.7 recommended for VGI; no guidance for GSF
- Detectors
    - Must have high dynamic range (10^4 – 10^6)
    - Guidance given on blackening detector assembly
    - Responsivity of detector must be constant to 5% up to ±45° and 10% up to ±90°
- Use filters to mimic your actual spectral response
- There are guidelines for error contributors, and the report must contain an estimate of measurement uncertainty

Cat 6: Scattered and stray light – TC42

ISO 18844 – Digital cameras – Image flare measurement (Ed. 1, 2017)

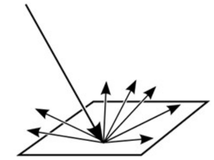


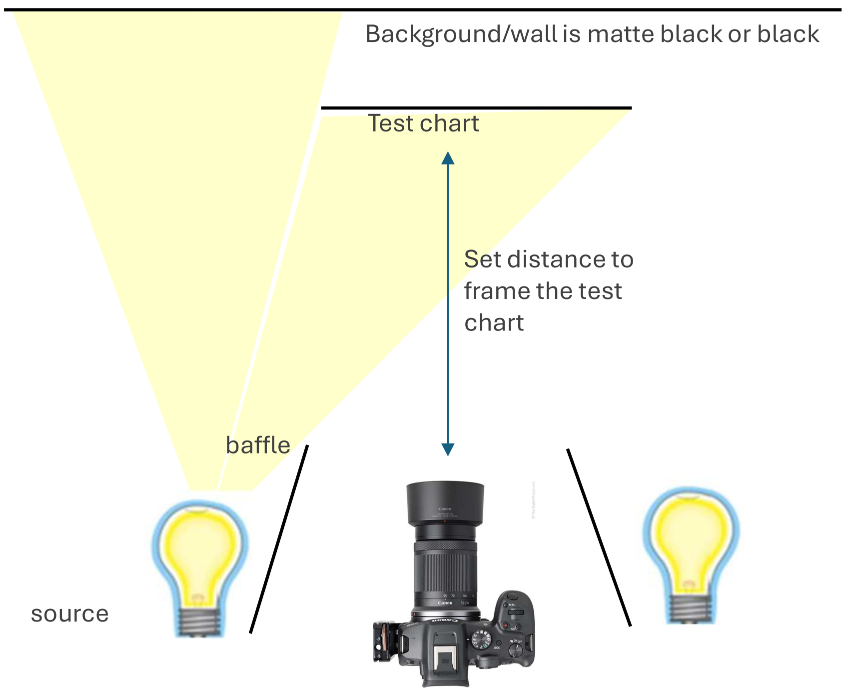
Introduction

- “Image flare” is defined as the signal in a processed image by a digital **camera** from light detected by an image sensor that does not originate from the corresponding point in object space
- Image processing can compensate for flare, but not always
    - It’s highly variable, and attempts to remove can make things worse
    - Image flare includes the effect of this and other image processes
- In addition to the contributors listed in ISO 9358, ISO 18844 lists “the optical system as measured by point spread function including spherical and chromatic aberrations”
- Targets are printed
    - Reflective test or transmission test with light box (less baffling required)
    - There is some flexibility in the chart design
- Presentation of results is less than clear
- IEC 62676-5 is a similar test and applies to surveillance video
- IEEE 2020 also tests stray light and applies to automotive imaging

Cat 6: Scattered and stray light – TC42

ISO 18844 – Digital cameras – Image flare measurement (Ed. 1, 2017)





Shooting conditions

Illuminance 1,000-2,000 lx
Luminance 318-637 cd/m^2

Non-uniformity < 5% (PV)
Color temp 5700±1000K
IEC reference given

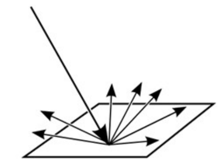
Adjust white balance to neutral
Minimize gain as possible
Focus

Shoot RAW or use minimum compression setting

Use lens hood only if came bundled with the product

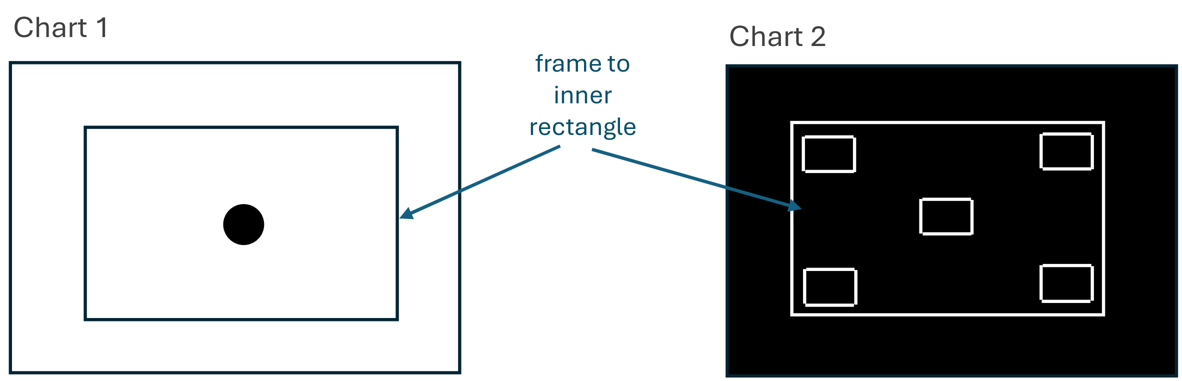
Cat 6: Scattered and stray light – TC42

ISO 18844 – Digital cameras – Image flare measurement (Ed. 1, 2017)



Charts (targets)

Specs are given for contrast ratio, surface scatter (reflective or transmissive charts), border size, inner rectangle size, test "area" size, line thickness, etc.



- When testing on axis only, use a "black area" like shown
- To address other field points,
  - various "black areas" may be added
  - arrange diagonally in the "inner rectangle"
- The total of the black areas shall be no larger than 5% of the inner area of the rectangle

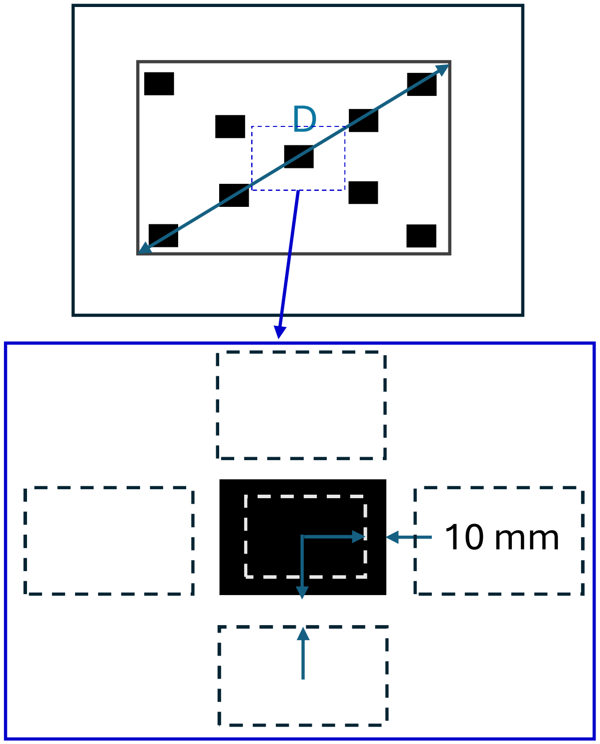
- White on black
- Test "areas" can be rectangles or circles, for either Chart 1 or Chart 2
- Draw white lines around the corresponding part of the center black area of Chart 1
- The total length of the white lines shall be the same as the total of side lengths of the center black area of Chart 1.

Cat 6: Scattered and stray light – TC42

ISO 18844 – Digital cameras – Image flare measurement (Ed. 1, 2017)

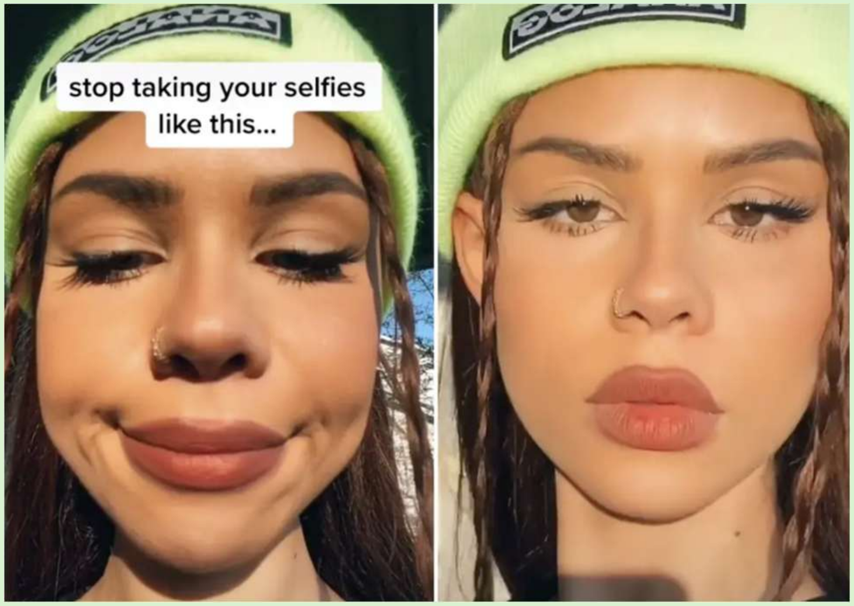
Processing and Results

- Use equation for converting 8-bit digital signal to Y luma values from the R, G, B channels
- Determine which pixels to use for "black" and "white," using the following rules:
  - Let D = 700 mm, so D/70 = 10 mm
  - Only use black pixels within a 10 mm border
  - White areas to use are above, below, and to the left and right of the black areas, with the same area, and spaced by D/70
- Select "Measurement type" A, B, and C:
  - Depends on chart characteristics, contrast ratio, exposure type
  - Flare equations are slightly different for A, B, and C (correction factors)
- For measurement Type C (high contrast):
  - The "white part" should be shot so that values are 225±25
  - Calculate image flare, $F = \frac{L_{black}}{L_{white}} \times 100$



Trivia Question

What aberration do we see here?



Retrieved from https://www.businessinsider.com/selfie-hack-front-camera-zoom-distort-facial-features-beauty-gurus-2020-4 on 7.17.25

Category 7: Aberrations and wavefront error

ISO 14490-9 Test methods for telescopic systems – Test methods for field curvature (Ed. 1, 2019)

ISO 9039 Quality evaluation of optical systems – Determination of distortion (Ed. 2, 2008)

ISO 17850 Photography – Geometric distortion (GD) measurements (Ed. 1, 2015)

ISO 14490-10 Test methods for telescopic systems – Test methods for axial color performance (Ed. 1, 2021)

ISO 19084 Photography – Digital cameras – Chromatic displacement measurements (Ed. 1, 2015)

ISO 14880-2 Microlens arrays – Test methods for wavefront aberrations (Ed. 2, 2024)

ISO 14880-3 Microlens arrays – Test methods for optical properties other than wavefront aberrations (Ed. 2, 2024)

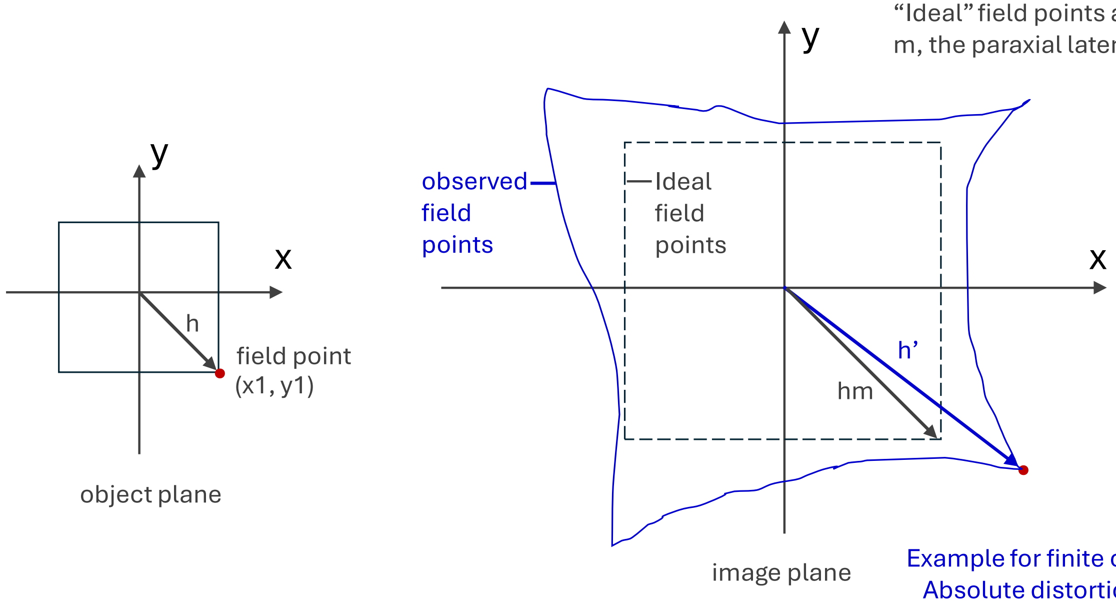
ISO/TR 14999-2 Interferometric measurement of elements and optical systems - Measurement and evaluation techniques (Ed. 2, 2019)

ISO/TR 16743 Wavefront sensors for characterising optical systems and optical components (Ed 1., 2013)

Cat 7: Distortion measurement – TC172

ISO 9039 Quality evaluation of optical systems – Determination of distortion (Ed. 2, 2008)

“Ideal” field points are determined by m, the paraxial lateral magnification



Example for finite object/finite image:
Absolute distortion = h’ - hm
Relative distortion = 100 (h’ – hm)/hm

Cat 7: Distortion measurement – TC172

ISO 9039 Quality evaluation of optical systems – Determination of distortion (Ed. 2, 2008)

Basic operation

- Light must go from object to image
- Target is a precision grid, a reticle, slit, or pinhole
  - Move the object in plane, or
  - Tilt the optical system about its nodal point
- For object or image at infinity:
  - Use telescope in autocollimation to project or collect rays
  - substitute ω for h
  - Set ups are given for all 4 combinations
- Measure h and h' (or ω and ω') for a series of field points
- Measure the magnification as the field → (0,0)
- Calculate h'-hm for each
- Create a table or plot of results; there is no curve fitting
  - There are 7 recommended field angles
  - Measure along 45° diagonals

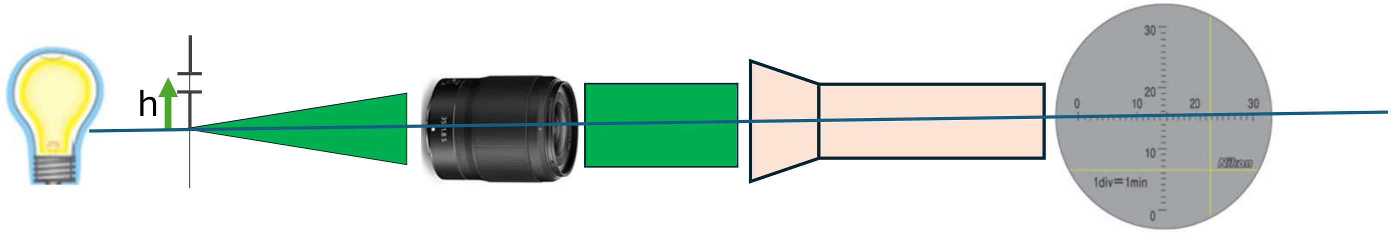


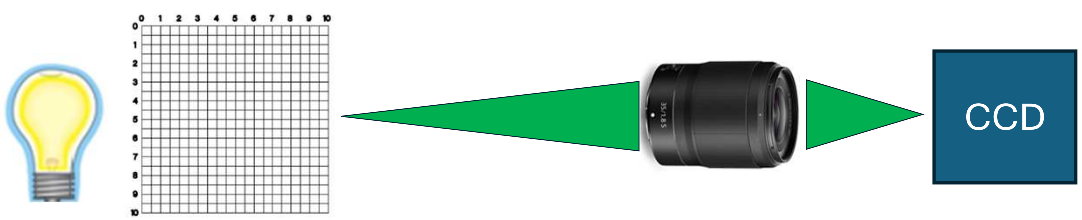
Image retrieved 6.21.25 from
industry.nikon.com/en-us/products

Cat 7: Distortion measurement – TC172

ISO 9039 Quality evaluation of optical systems – Determination of distortion (Ed. 2, 2008)

Measurement uncertainty

- Align your optical axis
  - Guidance is given
  - Appendix A contains provides the math for shifting the zero point
- Ensure that image and object planes are parallel (refocus carefully between fields)
- Set up so that focusing of system is the same as in practical use
- If magnification or relay lenses area used for re-imaging, care must be taken to prevent vignetting
- Auxiliary optics must have no distortion or be carefully calibrated
- Error in instruments (i.e., positioning pinhole, centroiding on image, autocollimator, swivel mechanism) must be 5-10 less than the tolerance (the error being measured)
  - If not, a measurement uncertainty shall be calculated and reported



RET-81-19-P-CG (100×100), retrieved from appliedimage.com on 6.21.25

Cat 7: Distortion measurement – TC42

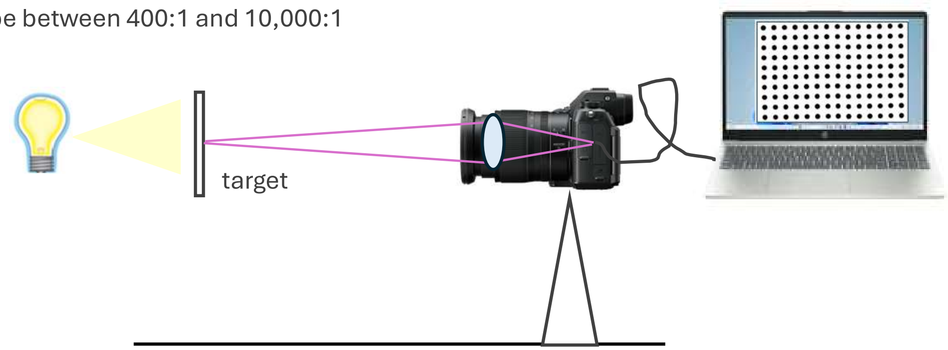
ISO 17850 Photography – Geometric distortion (GD) measurements (2015)

General

- Includes the effects of the lens + sensor + digital processing
- Distortion is radial only (state of art does not create significant tangential distortion)
- Distortion that does not conform the barrel or pincushion types is called *wave distortion*
- Sensor tilt and decenter is fixed (no zero shifting)

The target

- A regular grid of dots (common) or lines (history in analog video)
- Guidelines for size, number, and spacing of target features
- The target object must be planar; a table is given to relate curvature of the chart to measurement error
- Can back or front-illuminate with ±10% uniformity
- Specular reflections must not enter camera
- 2 light sources, suggested at ±45 degrees
- Baffle to prevent direct stray light into camera
- Contrast must be between 400:1 and 10,000:1

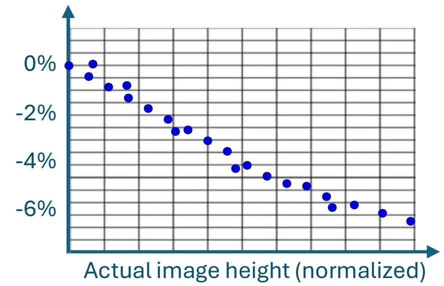


Cat 7: Distortion measurement – TC42

ISO 17850 Photography – Geometric distortion (GD) measurements (2015)

Setup

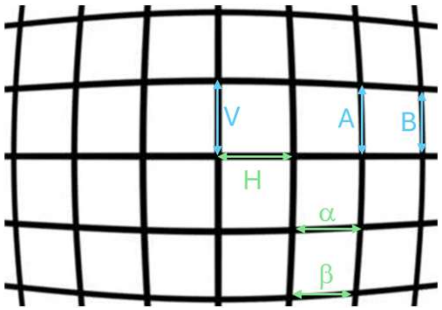
- Target distance and size calculations are given
- Schemes for alignment are given (target (x,y) position and tilt)
- Camera settings given
  - Ex. exposure level, gain, white balance, green channel only, max all quality factors, focus
- F# not specified



Results

- *Local* geometric distortion (dots)
  - "Local" distortion, D_{local} = 100% x (h' – hm)/hm
  - A Matlab script for locating the dots is given
  - Pincushion will be +; barrel will be –
  - Plot or table: Δh vs. actual image height, h'
  - A single, PV, value may be reported

- *Line* geometric distortion (line grid)
  - Find the max and min dimensions of *each* rectangle
    - $D_{Horizontal}$ = 100% x (A-B)/ nominal height
    - $D_{Vertical}$ = 100% x (α–β) / nominal width
    - Special rules for other shapes
  - D_{line} = RSS (horiz, vert)
  - Presentation examples give *one* value:
    - ISO line geometric distortion +2.5%
    - Could tabulate or plot all results



Category 7: Aberrations and wavefront error

ISO 14999: Interferometric measurement of optical elements and optical systems

Part 1 (2005): **Terms, definitions and fundamental relationships**

Wave theory, coherence, principal layout of an interferometer

Part 2 (2019): **Measurement and evaluation techniques**

Part 3 (2005): **Calibration and validation of interferometric test equipment and measurements**

Measurement uncertainty sources, combination, homogeneity testing, absolute calibration

Part 4 (2015): **Interpretation and evaluation of tolerances specified in ISO 10110**

This doesn't cover *everything* in ISO 10110!

Surface and wavefront specifications: Slope specification, Zernike definitions, single-pass vs. double-pass

Part 4 (2025): *Draft in preparation*

Interpretation and evaluation of surface form and wavefront deformation tolerances specified in ISO 10110

More appropriate title

Broadens to other measurement methods (i.e., profilometer for surface slope)

Better interpretation of Zernike residual and slope deviation quantities

Category 7: Aberrations and wavefront error

ISO 14999-2 Interferometric… Measurement and evaluation techniques (Ed. 2, 2019)

Theory

- Common path
- Single vs. double pass
- Reflectivity and fringe contrast
- Various interferometer types
- Phase unwrapping methods
- Surface and wavefront polynomials

Issues

- Mount induced deformation
- Thermal and vibrational stability
- Refractive index of air
- Retrace error
- Effects of cosmetic errors and contamination (don't "just" remove spikes!)

Practice

- How to use internal fringes to assess element wedge
- Do not blindly accept results
- Repeatability NOT = measurement certainty
- Operator to operator error
- Three independent measures
- File saving structure

Category 7: Aberrations and wavefront error

ISO 14999-2 Interferometric… Measurement and evaluation techniques (Ed. 2, 2019)

Understanding measurement errors: Four(4) interesting tests

1. **Collimation test**
   - The beam exiting the interferometer should be collimated
2. **Alignment sensitivity procedure**
   - Reveals the aberrations that would be occur for errors in alignment of transmission sphere/flat and/or parts under test
3. **Alignment reticle test**
   - Send the beam back with a corner cube mirror/prism with known angular accuracy
4. **Coherent noise sensitivity**
   - Those diffraction patterns from dust, cosmetics, and stray light

Trivia Question

What is the name of this target?

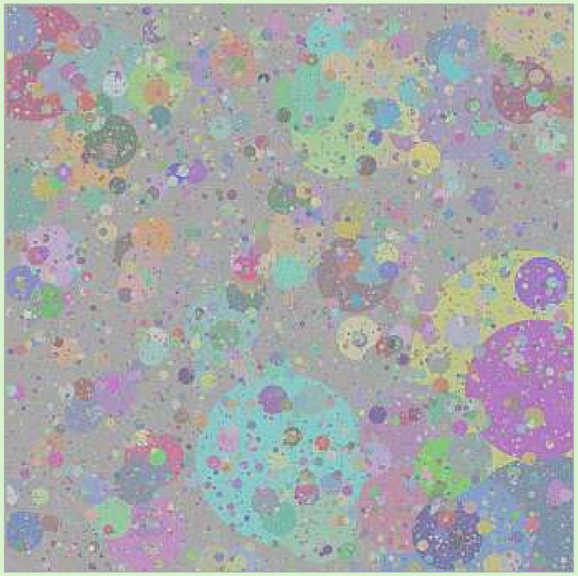


Image retrieved on 8.12.25 from www.imatest.com/docs/random/

Category 8: Image quality and resolution

Optical Transfer Function

ISO 9335 **Optical transfer function – Principles and procedures of measurement (Ed. 3, 2025)**
ISO 9336-1 Optical transfer function — Interchangeable lenses for 35 mm still cameras (Ed. 2, 2010)
ISO 9336-3 Optical transfer function — Telescopes (Ed. 2, 2020)
ISO 11421 Accuracy of optical transfer function (OTF) measurement (Ed. 1, 1997)

Modulation Transfer Function

ISO 15529 **Optical transfer function – Principles of measurement of modulation transfer function (MTF) of sampled imaging systems (Ed. 3, 2010)**
ISO 12233 **Photography – Digital Cameras – Resolution and spatial frequency responses (Ed. 5, 2024)**
ISO 8600-5 Medical endoscopes and endotherapy devices – Determination of optical resolution of rigid endoscopes with optics (Ed. 2, 2020)

Other

ISO 15795 Quality evaluation of optical systems – Assessing the image quality degradation due to chromatic aberrations (Ed. 1, 2002)
ISO 14490-4 Test methods for telescopic systems – Test methods for astronomical telescopes (Ed. 1, 2005)
ISO 14490-7 Test methods for telescopic systems – Test methods for limit of resolution (Ed. 2, 2016)
ISO 14490-8 Test methods for telescopic systems – Test methods for night-vision devices (Ed. 1, 2011)
ISO 20490 Measuring autofocus repeatability of sharpness and latency (Ed. 1, 2024)
ISO 19093 Photography – Digital Cameras – Measuring low-light performance (Ed. 1, 2018)
ISO 19567-2 Photography — Digital cameras — Texture analysis using stochastic pattern (Ed. 1, 2019)

Category 8: Modulation transfer function- TC172

ISO 15529 Measurement of MTF of sampled imaging systems (2010)

- HEAVY on theory
- Test intended for optical system only (no detector, no image processing)
- "Sampled," not "isoplanatic" (continuous assessment of field points) = discrete pixels
- This standard contains several techniques
- Object is generally a slit, f(x)
  - Flexible if you satisfy the correct parameters
  - Slit width implications
    - Light level vs. true impulse response/correction
  - Position slit around the field
    - Standard indicates you can automate the scanning and collect data quickly with video
  - An alternative is to rotate to a well-defined field angles, then refocus
  - Aberrations, as well as registration of slit image with pixels, matter
  - Slit can be rotated to assess resolution at 45° and/or to deal with aliasing
- Importance of increasing the light level toward the corners of the field
- Set your aperture (F#), be clear about how you focus (for example, a 0.05 MTF tolerance)
- Guidelines depending on relationship between cutoff frequency and detector Nyquist
  - Methods to assess aliasing and create a reconstruction function

Category 8: Modulation transfer function- TC172

ISO 15529 Measurement of MTF of sampled imaging systems (2010)

f(x) = slit

$g(x) = f(x) \otimes h(x)$

Image = object convolved with transfer function

g(x) = aberrated image of slit

$F(f_x) = \mathcal{FT}(\text{slit})$
=linear comb. of sine waves

$G(f_x) = F(f_x) \times H(f_x)$

$G(f_x) = \mathcal{FT}(\text{image})$

$H(f_x) = OTF = G(f_x) / F(f_x)$
Modulus [OTF] = $MTF_{lens}(f_x) \le 1$

Category 8: Modulation transfer function- TC172

ISO 9335 OTF – Principles and procedures of measurement (2025)

Back up to ISO 9335 for:

Set up

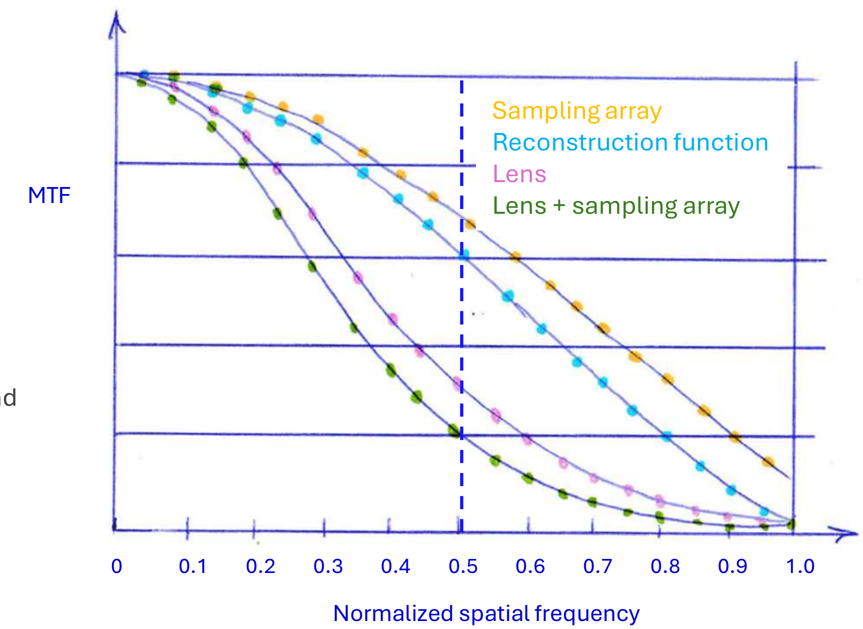
- Environment
- Mounts
- Focusing
- Auxiliary imaging components
- Veiling glare, noise, SNR
- Parallelism of image

Measurement uncertainty/calibration

- List of 21 uncertainty checks in 5 categories
    - Radiometry, geometry, auxiliary optics, environment, and verification devices

Presentation of results

- List of 19 parameters to include in report
- Many examples of reported data and curves
- Statement of uncertainty not required, but if you include one, use ISO 11421



Category 8: Modulation transfer function- TC42

ISO 12233 Resolution and spatial frequency responses (2024)

General

Technical procedure to generate SFR

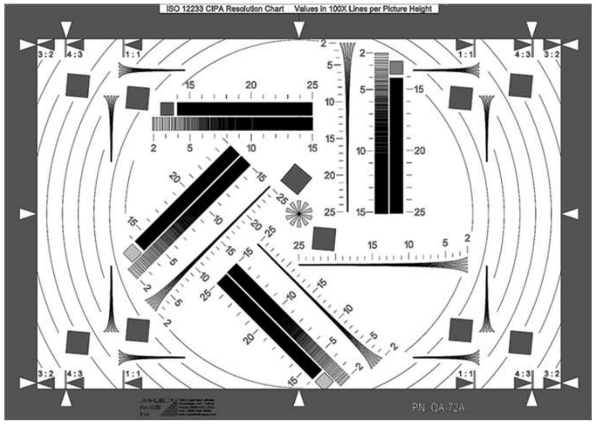
= "a numerical description of how contrast is changed by a camera as a function of spatial frequencies"

Designed specifically for full digital system

- you can still use it for lens only!

Setup

- Spectrally neutral lighting (see ISO 14524)
- Illumination uniformity within 10% of center
- Area behind chart matte black or black
- Use baffles to prevent stray light
- Use framing arrows to adjust object distance and chart height
- Calculate line width/picture height (LW/PH) to normalize spatial frequency (cycles/pixel)
- How to set focus (flexible)
- Set F# and adjust exposure for near maximum (i.e., 256)
- Record data compression setting
- Gamma correction on, white balance, etc.
- Typically, run through various f-numbers and gain levels



CIPA resolution chart. Retrieved from https://www.appliedimage.com/product/qa-72a-p-rm/ on 7.15.25

The overall chart has a lot of white to approximate actual scenes

Category 8: Modulation transfer function- TC42

ISO 12233 Resolution and spatial frequency responses (2024)

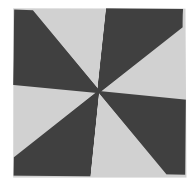
1. Visual method

- Hyperbolic wedge
- Spatial frequency changes hyperbolically along length
- How to judge/ takes training!

Image retrieved on 8.1.25 from https://atari.com/

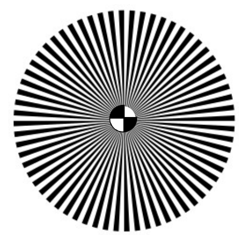
2. Edge-SFR method

- Use low contrast edges on slanted star
- Slant helps with aliasing; 4 angular orientations
- The ESF is converted to a LSF, a discrete Fourier transform is computed, the SFR is ABSO [DFT]
- First algorithm written at Kodak
- Get Matlab software at www.iso.org/12233



3. Sinewave-SFR method (latest)

- True sine wave
- Large range of angular orientations and spatial frequencies
- Needed for cameras with advanced spatial processing
- Get Matlab software at www.iso.org/12233



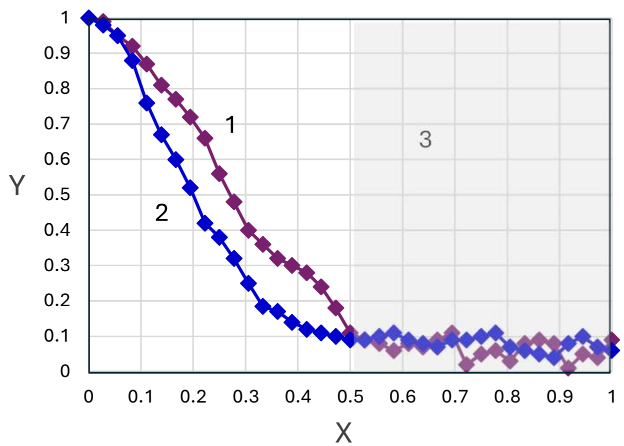
A comparison of edge-based and sine-based SFRs can be useful

Category 8: Modulation transfer function- TC42

ISO 12233 Resolution and spatial frequency responses (2024)

Results

Digital camera SFR example plot



X normalized spatial frequency (cycles/pixel)

Y edge spatial frequency response (e-SFR)

1 Horizontal e-SFR

2 Vertical e-SFR

3 Aliased region

Test report

Full description of target and illumination
Full description of lens
Full description of camera and settings

Visual method

Report minimum resolution only

- *at least* 4 directions (H, V, ±45°)

Spatial frequency response (SFR)

Modulation vs. frequency or freq. vs. mod.
32 spatial frequencies
Mod = avg [H, Z,+45°, -45°]
Identify potential aliasing region
Field angles not mentioned anywhere in the normative sections

Measurement uncertainty estimate is not explicitly required

Trivia Question

Can you find the aliasing in this image?

Retrieved from https://community.usa.canon.com/t5/EOS-DSLR-Mirrorless-Cameras/Moir%C3%A9-pattern-with-EOS-R6-Mark-II/td-p/542874 7.15.25

Trivia Question

What is this?

Retrieved from https://www.theweathernetwork.com/en/news/science/earth-science/ice-rime-and-hoar-frost-pov-point-of-viewer-snow-and-ice-trees on 7.11.25

Category 9: Environmental testing

General

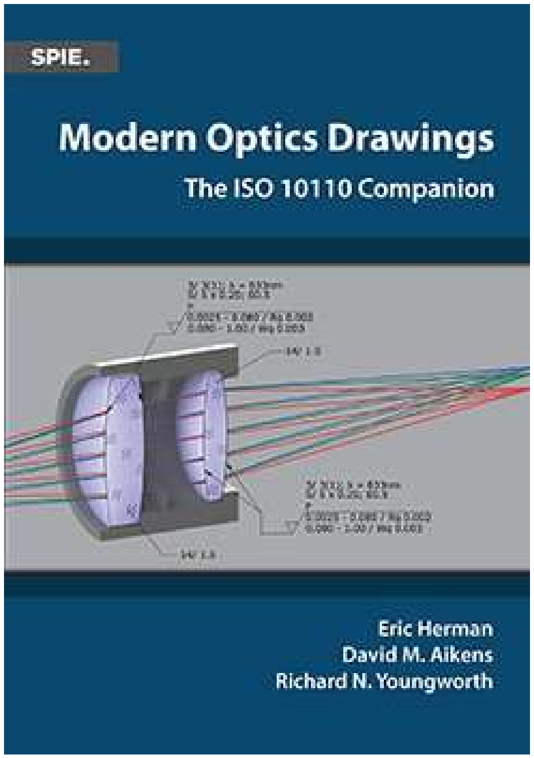
ISO 9022-1	**Environmental test methods – Definitions, extent of testing (Ed. 3, 2016)**
ISO 10109	**Guidance for selection of environmental tests (Ed. 3, 2024)**
ISO 20711	Environmental requirements – Test requirements for telescopic systems (Ed. 1, 2017)

Specific

ISO 9022-2	**[Environmental test methods –] Cold, heat and humidity (Ed. 3, 2015)**
ISO 9022-3	Mechanical stress (Ed. 4, 2022)
ISO 9022-4	Salt mist (Ed. 3, 2014)
ISO 9022-6	Dust (Ed. 2, 2015)
ISO 9022-7	Resistance to drip or rain (Ed. 2, 2015)
ISO 9022-8	High internal pressure, low internal pressure, immersion (Ed. 2, 2015)
ISO 9022-9	Solar radiation and weathering (Ed. 2, 2016)
ISO 9022-11	Mould growth (Ed. 2, 2015)
ISO 9022-12	Contamination (Ed. 2, 2015)
ISO 9022-14	Dew, hoarfrost, ice (Ed. 2, 2015)
ISO 9022-17	Combined contamination, solar radiation (Ed. 2, 2015)
ISO 9022-20	Humid atmosphere containing sulfur dioxide or hydrogen sulfide (Ed. 2, 2015)
ISO 9022-22	Combined cold, dry heat or temperature change with bump or random vibration (Ed. 1, 2012)
ISO 9022-23	Low pressure combined with cold, ambient temperature and dry or damp heat (Ed. 3, 2023)

ISO 9022 is focused on optics and photonics (many selected from IEC standards); refers to IEC standards for polluted atmospheres and precipitation.

Cat 9: Environmental testing: Resources



Chapter 11 covers environmental testing, and the drawing codes to specify test details.

SPIE Paper
Eric Herman, David M. Aikens, "Using ISO environmental standards in an ISO 10110 format drawing," Proc. SPIE 12221, Optical Manufacturing and Testing XIV, 122210A (3 October 2022); https://doi.org/10.1117/12.2633441

Cat 9: Environmental testing

ISO 10109 and the ISO 9022 series

Environments

ISO 10109 lists 13 choices, including Arctic or Antarctic climates, global inland, global coastal, altitudes to 30,000 meters, altitudes to 80,000 meters, cold climates, humid hot climates, dry hot climates, with weather protection, and temperature- and humidity-controlled laboratories.

Temperature, humidity, and pressure ranges are given for the 13 environments in **ISO 10109**.
In many cases, also given are solar irradiance, dew or ice buildup, precipitation (rain, snow, hail).
You know by now that you aren't required to stick to any of these environments, but you can get a very good start.

Coding system for defining tests

ISO 9022-1 provides a system for:

Test steps: preconditioning, initial test, conditioning, intermediate test, recovery, and final test.

Conditioning methods are numbered 10-91 and span 9022-2 through -23 (see next slide)

Severity levels choices are in the individual test documents

States of operation are:

0- Normal transport/storage
1- Ready, but not powered up
2- In operation

Example: Test 9022-33-5-0 = Instrument is packaged for transport. Perform free fall test from 500 ± 5 mm.

Cat 9: Environmental testing

ISO 9022 test conditions (in order of 9022 Part -X)

ISO 9022-2 Cold, heat, and humidity
-10: Cold
-11: Dry heat
-12: Damp heat
-13: Condensation
-14: Slow temperature change
-15: Rapid temperature change (shock)
-16: Damp heat, cyclic

ISO 9022-3 Mechanical stress
-30: Shock
-31: Bump
-32: Drop and topple
-33: Free fall
-34: Bounce
-35: Steady-state acceleration (centrifugal)
-36: Sinusoidal vibration
-37: Random vibration

ISO 9022-4 Salt mist
-40: Salt mist

ISO 9022-6 Dust
-52: Blowing dust

ISO 9022-7 Resistance to drip or rain
-72: Drip
-73: Steady rain
-74: Driving rain

ISO 9022-8 High internal pressure, low internal pressure, immersion
-80: High internal pressure
-81: Low internal pressure
-82: Immersion

ISO 9022-9 Solar radiation and weathering
-20: Solar radiation
-21: Laboratory weathering

ISO 9022-11 Mould growth
-85: Mould growth

ISO 9022-12 Contamination
-86: Basic cosmetic substances and artificial hand sweat
-87: Laboratory agents
-88: Production plant resources
-89: Fuels and resources for aircraft, naval vessels, and land vehicles

Cat 9: Environmental testing

ISO 9022 test conditions (in order of 9022 Part -X)

ISO 9022-14 Dew, hoarfrost, ice
-75: Dew
-76: Hoarfrost
-77: Ice covering followed by the process of thawing

ISO 9022-17 Combined contamination, solar radiation
-90: Basic cosmetic substances and artificial hand sweat, combined with solar radiation
-91: Fuels and other resources for aircraft, naval vessels, and land vehicles, combined with solar radiation

ISO 9022-20 Humid atmosphere containing sulfur dioxide or hydrogen sulfide
-41: Humid atmosphere containing sulfur dioxide (SO_2)
-42: Humid atmosphere containing hydrogen sulfide (H_2S)

ISO 9022-22 Combined cold, dry heat or temperature change with bump or random vibration
-22: Cold, dry heat or temperature change combined with bump or random vibration

ISO 9022-23 Low pressure combined with cold, ambient temperature and dry or damp heat
-45: Low ambient pressure combined with ambient
-46: Low ambient pressure combined with dry heat
-47: Low internal pressure combined with damp heat, pressure difference low
-48: Low internal pressure combined with damp heat, pressure difference medium
-49: Low internal pressure combined with damp heat, pressure difference high
-50: Low ambient pressure combined with cold, including hoarfrost and dew
-51: Low ambient pressure combined with cold, without hoarfrost and dew

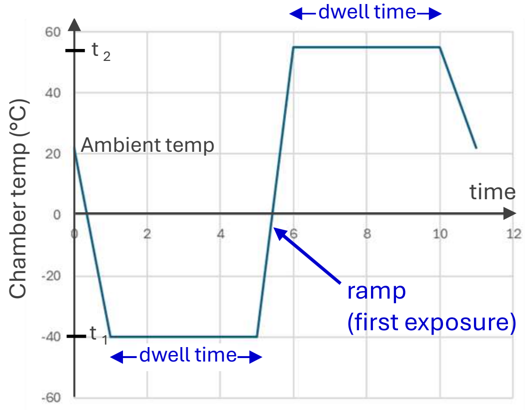
Cat 9: Environmental testing

Conditioning method 15

Thermal shock from ISO 9022-2:2015

- Specimens are placed in conditioning chambers that provide air circulation
- The number, method of installation, and location of the heat sensors must be specified
- Specimen arrangement must ensure uniform conditioning
- Condensate shall not drip onto the sample(s)
- Exposure shall not begin until the temperature change is <1°C/hour for heat dissipating elements (i.e., ceramics)
- Environmental test ISO 9022-15-3-0

Degree of severity		01	02	03	04	05
Test chamber temperature (C°)	t_2	20 ± 2	40 ± 2	55 ± 2	70 ± 2	70 ± 2
	t_1	-10 ± 2	-25 ± 2	-40 ± 2	-55 ± 2	-65 ± 2
Temperature difference (°C)		30	65	95	125	135
Number of cycles				5		
Dwell time at t_1 and t_2		Dwell until the specimen is within ±3°C of the chamber temperature, but no less than 2.5 hours.				
Time allowed for ramp		<= 20 s for small chambers (<= 10 kg); for larger chambers, the time must be recorded and < 10 min.				
State of operation		0, 1, or 2 (state of operation 2 should be justified)				



Cat 9: Environmental testing

ISO vs. MIL?

MIL-STD-810H Paragraph		See ISO 9022-
500.6	Low Pressure (Altitude)	-8, -23
501.7	High Temperature	-2
502.7	Low Temperature	-2
503.7	Temperature Shock	-2
504.3	Contamination by Fluids	-12, -17
505.7	Solar Radiation (Sunshine)	-9
506.6	Rain	-7
507.6	Humidity	-2, -20
508.8	Fungus	-11 (mold only)
509.7	Salt Fog	-4
510.7	Sand and Dust	-6 (covers both)
511.7	Explosive Atmosphere	
512.6	Immersion	
513.8	Acceleration	-3
514.8	Vibration	-3
515.8	Acoustic Noise	-3 or ISO 10816
516.8	Shock	-3
517.3	Pyroshock	
518.2	Acidic Atmosphere	-20
519.8	Gunfire Shock	
520.5	Combined Environments	-17, -20, -22, 23
521.4	Icing/Freezing Rain	-14
522.2	Ballistic Shock	
523.4	Vibro-Acoustic/Temperature	-22
524.1	Freeze / Thaw	
525.2	Time Waveform Replication	-3 (electro-shaker)
526.2	Rail Impact	
527.2	Multi-Exciter Test	-3 doesn't have simultaneous axes
528.1	Mechanical Vibrations of Shipboard Equipment (Type I - Environmental and Type II - Internally Excited)	

See 9022-3 (511.7 Explosive Atmosphere, 517.3 Pyroshock, 519.8 Gunfire Shock, 522.2 Ballistic Shock)

Environments not covered in ISO TC172 (Immersion, Freeze / Thaw, Rail Impact, Multi-Exciter Test, Shipboard Equipment)

Category 10: Miscellaneous tests

ISO 12005	Test methods for laser beam parameters — Polarization (Ed. 3, 2022)
ISO 24013	Measurement of phase retardation of optical components for polarized laser radiation (Ed. 2, 2023)
ISO 17901-1	Holography – Methods of measuring diffraction efficiency and associated optical characteristics of holograms (Ed. 1, 2015)
ISO 17901-2	Holography – Methods of measurement of hologram recording characteristics (Ed. 1, 2015)
ISO 516	Photography – General definition and mechanical shutter measurements (Ed. 4, 2019)
ISO 15781	Photography – Digital still cameras – Measuring shooting time lag, shutter release time lag, shooting rate, and start-up time lag (Ed. 3, 2019)
ISO 21550	Photography – Electronic scanners for photographic images – dynamic range measurements (Ed. 1, 2004)

PART III

Test reports and advertising

Test Reports

Not exactly standardized!

Test report guidance varies

- Many provide lists in a Test Report section:
  - Ex. ISO 21395-1: items (a)-(i)
  - Ex. ISO 9335: items (a)-(s)
  - Ex. ISO 21254: total of 29 items
  - Use the exact lettering/numbering given
- Others do not contain an itemized list:
  - Ex. ISO 517, ISO 9211, and ISO 9022
  - You should still supply a Test Report
  - The requirements are obvious throughout
- ChatGPT does a great job creating forms

Many have provisions for stating instances in which there were *specific deviations* or *unusual features*

Many indicate that a measurement error shall be included

- A simple estimate of uncertainty
- Some give error budget contributor list or examples
- If ISO 17025 accredited, you *must* provide error budgets *and* traceability to SI units

Detailed, formatted test reports foster confidence in labs and products!

Test Reports

Detailed example: Laser damage

A run number shall be assigned to each specimen tested. The data shall be retained at the test lab indefinitely for reference.

A. **Test lab information**: (1) org name and address, (2) date, (3) operator ID

B. **Specimen information**: (1) part or witness sample? (2) specimen manufacturer, (3) how stored, cleaned, and conditioned, and (4) specifications for normal use (λ, pulse duration, polarization, AOI, and purpose), and (5) S/N and manufacturing date (if part)

C. **Test specifications:**
1) reference to ISO 21254-1, test protocol, evaluation method, damage criteria, description of test equipment (including focusing system),
2) laser parameters;
3) diagrams showing spatial and temporal profiles of pulse
4) error budget
5) location of test sites on the specimen;
6) methods for cleaning and storage conditioning;
7) test environment;
8) total irradiated area per test (detailed definition within)

RANDOM
- pulse-to-pulse energy stability
- effective beam diameter stability
- pulse-to-pulse temporal profile stability

SYSTEMATIC
- calibration of energy monitor
- focus error
- other

D. **Information on the result:**
1) results of the test, including a references to the specific clauses of the standard; diagrams not required, but common
2) documentation of unusual features or specific deviations from procedures in technical notes.

Test Reports

Laser damage graphics for test report

Fig 1. Temporal profile and pulse width data extracted from Leukos ELECTRO-VIS 400 Test Report COC504-01

Figure 2. Beam profile and statistics (Leukos and DataRay)

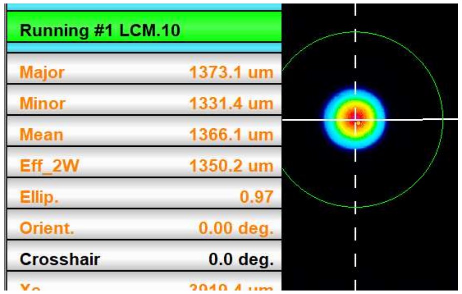


Figure 3. Photo of damaged coating

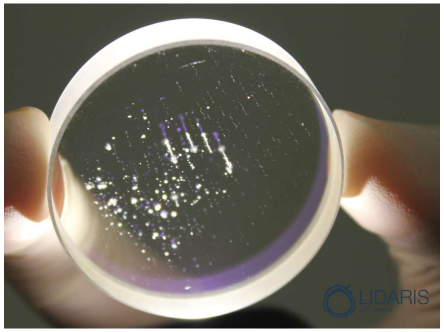
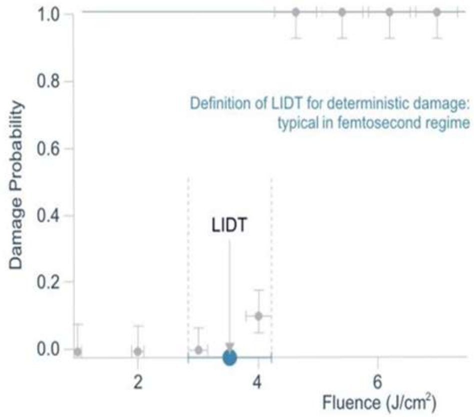


Figure 4. Typical 1-on-1 damage plot



Figures 3 and 4 retrieved on 8.13.25 from https://lidaris.com/lidt-infobase/laser-induced-damage-threshold-lidt/

Guide to the expression of uncertainty in measurement (the GUM)

The guide to uncertainty in measurement was prepared by a joint working group consisting of members of:

- BIPM: Bureau International des Poids et Mesures
- IEC: International Electrotechnical Commission
- ISO: International Organization for Standardization

Support also from:

- IFCC: International Federation of Clinical Chemistry
- IUPAC: International Union of Pure and Applied Chemistry
- IUPAP: International Union of Pure and Applied Physics
- OIML: International Organization of Legal Metrology

Together, the members are the Joint Committee for Guides in Metrology (JCGM)

Guide to the expression of uncertainty in measurement (the GUM)

ISO	Title	JCGM*
ISO/IEC Guide 99 (2007)	International **vocabulary** of metrology (VIM)	JCGM 200
ISO/IEC Guide 98-1 (2024)	**Introduction** to the guide to the expression of uncertainty in measurement	JCGM GUM-1 (2023); previously the introduction was JCGM 104
ISO/IEC Guide 98-2	*never published; proposed material is in -1*	*N/A*
ISO/IEC Guide 98-3 (2008)	**Guide** to the expression of uncertainty in measurement (GUM)	JCGM 100 (2008)
Suppl 1 (2008)	Propagation of distributions using a **Monte Carlo** method	JCGM 101 (2008)
Suppl 2 (2011)	**Extension** to any number of output quantities	JCGM 102 (2011), Supplement 2
Suppl 3 never published	*Modeling*	*Previously JCGM 103; moved to JCGM GUM-6*
ISO/IEC Guide 98-4 (2012)	Role of measurement uncertainty in **conformity** assessment	JCGM 106 (2012)
ISO/IEC Guide 98-5 (in devel)	**Examples** (previously titled "applications of the least-squares method")	N/A
ISO/IEC Guide 98-6 (2021)	Developing and using **measurement models** (many examples given)	JCGM GUM-6 (2020); excerpts from JCGM 100 and JCGM 101 (2008)

*Free at www.bipm.org/en/committees/jc/jcgm/publications

Also see the NIST Technical Note 1297: *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*

Referencing test standards

In your test report, on your website

What NOT to do

- Confuse test standard use with *accreditation/certification* (i.e., ISO 9001, ISO 17025)
    - products are not "approved" or "accredited" or "certified" by ISO
- "Meets ISO 12345"
- Competitors can challenge ISO claims through the National Advertising Division

What TO do

- Cite the document number including the year of last publication
- Include the full title of the document when possible
- Include the lab or certifying body if applicable (especially if independent)
- <u>Example 1</u>: "Tested **in accordance with** ISO 15529:2010, Optical transfer function – Principles of measurement of modulation transfer function (MTF) of sampled imaging systems"
- <u>Example 2</u>: "Independent testing conducted by MyLabs, Inc. **in accordance with** ISO 11146-1:2021, Test methods for laser beam widths, divergence angles and beam propagation ratios – Stigmatic and simple astigmatic beams, and ISO 11146-2:2023, Test methods for laser beam widths, divergence angles and beam propagation ratios – General astigmatic beams"
- Use a footnote if too wordy
- Use clear language when a partial document is used or a modification is made

Test Reports

Wording for specific deviations, unusual features, and more

Examples

Specific deviation

1. Testing was completed at 632.8 nm, though the actual instrument source is 650 nm. Ray trace analysis confirms that the error in chromatic aberration due to the different in wavelength is <1% of the allowable error.

Unusual feature

2. We noticed a spike in stray light between the 0.4 and 0.5 field angles. This was determined to be due to an LED in the lab and therefore is not considered true stray light.

Off label use

3. Although ISO 517 is intended to be used for photographic lenses, we use it to measure the focal lengths of our transmission spheres. There are no known conflicts with this approach.

4. The tests given in ISO 17123-3:2001 Annex B were used to determine whether the difference between the autocollimator angles in the various conditions was statistically significant.

Cite partial document

5. The sag of the mirror blanks was determined to be within specification during test according to ISO 14999-2, Table 2.

Example here of “use 30 watt cool fluorescent lamp to inspect for

See ISO 22531

Procedure for polishing and cleaning the specimens

B.1 Specimen polishing

These lamps may be banned by 2027

The polished specimen is prepared as follows:

a) Polish both 30 mm × 30 mm faces with cerium oxide to a level such that no grinding streak can be observed by visual inspection under a 32 W cool white fluorescent lamp.

b) Immediately remove contamination from the polished surfaces with an organic solvent, etc.

c) Do not touch the polished surface of the specimen; instead, use a vertical holding jig to transfer the specimen in order to avoid contamination of the specimen surface.

d) Store the specimen in a desiccator, and use it within 24 h after polishing excluding the period of time during which the protective film is on it.

Just add a postit to last slide and mention this issue after #1 as another example- ASK Them what they might

Summary

Resources

Course Summary

Course Learning Outcomes

1. List the multiple competitive benefits of using standardized optical tests
2. Access and navigate the wide variety of available test method documents
3. Determine which test methods are the ideal options for your work
4. Effectively present test results and reference the standards for internal, external, and marketing communications
5. Identify tests that are not standardized and communicate the needs of your industry

- ❑ Full list and select examples of the ~130 ISO standards for optical tests
- ❑ Most MIL standards are covered by ISO
- ❑ Standards contain a lot of information and provide flexibility

Resources

- Peruse standards and prices
  - iso.org
  - webstore.ansi.org
  - chatGPT

- All OEOSC short courses (www.oeosc.org/training)

  SC01 – Understanding Scratch Dig
  SC02 – Advanced Surface Inspection Workshop
  SC03 – Modern Optics Drawing
  SC04 – Understanding Waviness and Roughness
  SC05 – Introduction to Optics Drawings
  SC06 – A Practical Guide to Specifying Optical Components
  SC07 – Optical Testing Standards You Can't Afford to Ignore

  Courses are available for your organization, college, or conference

- Opportunity to create curriculum and/or teach standards
  - Share your expertise and get paid!
  - Contact Brian Monacelli at BMonacelli@Pasadena.edu

- Join OEOSC
  - We are seeking experts in optical design and manufacturing for participation in both national and international standards development efforts.
  - See benefits and membership application at www.oeosc.org/about-us/why-join/

Resources

- Search spie.org for the ~40 papers published by OEOSC members and others about standards in optics and photonics

- Pay attention to AmeriCOM
  - americom.org, Fairport NY
  - Monthly newsletter: https://americom.org/optics-insider/

- Accreditation (i.e., ISO 17025) and certification (i.e., ISO 9001):
  - Learn and implement the standards
  - Pursue audits through:
    - ANSI National Accreditation Board (anab.org),
    - American Association for Laboratory Accreditation (a2la.org), or
    - National Voluntary Laboratory Accreditation Program (nist.gov/nvlap)

- Comments or questions for the OEOSC?
  - www.oeosc.org/about-us/contact-us/
  - Contact *me* and I will direct you to the right person in OEOSC

Disclaimers

None of the following organizations is endorsed by Redhead Optical, AmeriCOM, OEOSC, or SPIE. Their materials are used only to better illustrate the use of standards.

Accucoat
Applied Image
Atari
Brunson
Canon
DataRay
DXOMARK
Edmund Optics
Geomax
Grainger
Image Engineering
ImaTest
Instron
Leica
Leukos
Lidaris
Next Gen Material Testing
Nikon
Open AI
Optikos
Optimax
Perkin Elmer
Quantel Laser
Schott
Spica
TriOptics
Zeiss

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*Zach Strobehn, CMM Optic**
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*Richie Youngworth, RiYo LLC**
Dave Shelton, AmeriCOM
Justin Sigley, AmeriCOM
Kish Thakurwani, Optimax
Tsion Teklemarin, Optimax
Jim Scott, Optikos
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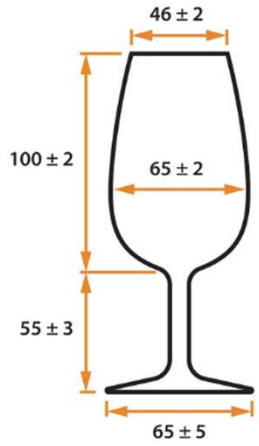
John Carlino, Westech Optical
Mike Pomerantz, Monroe Community College
Rebekah Brandt, Arkaby Consulting
Kate Medicus, Ruda Optical

** OEOSC member*

Thank you for your attention!



ISO 3591

WINE TASTING GLASS

OVERALL HEIGHT:
155 MM (±5)

VOLUME CAPACITY:
215 ML (±10)

DIMENSIONS SHOWN IN MILLIMETERS

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www.redheadoptical.com/courses

Final Q&A

Quiz