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# Optics and photonics — Holography —

## Part 1:
## Methods of measuring diffraction efficiency and associated optical characteristics of holograms

*Optique et photonique — Holographie —*

*Partie 1: Méthodes de mesurage de l'efficacité de diffraction et caractéristiques optiques associées aux hologrammes*



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# Foreword

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The committee responsible for this document is ISO/TC 172, *Optics and Photonics*, Subcommittee SC 9, *Electro-optical systems*.



ISO 17901 consists of the following parts, under the general title *Optics and photonics — Holography*:

— *Part 1: Methods of measuring diffraction efficiency and associated optical characteristics of holograms*

— *Part 2: Methods for measurement of hologram recording characteristics*

 

# Introduction

The aim of this part of ISO 17901 is to specify the terms related to holograms and basic measurement methods to characterize them.

A hologram is an optical device utilizing interference and diffraction phenomena and is characterized differently from optical devices based on reflection, refraction, and scattering. By exploiting the characteristics of holograms, they have been successfully applied in numerous applications such as displays, metrology, and anti-counterfeit security.

The expanded market in holography has generated a need to agree on basic terms and definitions for holograms and measurement methods and this part of ISO 17901 aims to satisfy that need.

# Optics and photonics — Holography —

# Part 1: Methods of measuring diffraction efficiency and associated optical characteristics of holograms

## 1 Scope

This part of ISO 17901 specifies the terms related to optical characteristics of holograms, the method to measure their diffraction efficiency, and the angular and wavelength selectivity measurement methods. These measurement methods are applicable to any type of hologram if the hologram yields a simple diffraction pattern, which means the reconstructed wave can be clearly separated from other diffracted and non-diffracted waves. In other words, holograms that yield complex diffraction patterns are excluded. There are no restrictions on the materials used to form the holograms.

## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.



ISO 15902, *Optics and photonics — Diffractive optics — Vocabulary*



## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15902 and the following apply.

**3.1**
**hologram**
interference pattern formed between the wave emitted from the object and its coherent reference wave, which is recorded in the recording material

Note 1 to entry: The holograms also include those formed through embossed copying of surface relief or those recording the periodic structure spatially by etching or engraving.

**3.2**
**object wave**
**object beam**
wave emitted from an object and entering the recording material in the course of recording the hologram

**3.3**
**reference wave**
**reference beam**
wave entering the recording material while forming a certain angle with the object wave in the course of recording the hologram

**3.4**
**illuminating wave**
**illuminating beam**
wave allowed to enter the hologram when reconstructing the image from the hologram

 

**3.5**
**reconstructed wave**
**reconstructed beam**
wave diffracted by the hologram

Note 1 to entry: Generally, this term indicates either the +first-order diffracted wave or –first-order diffracted wave but can indicate second or higher order diffracted waves.

**3.6**
**specular wave**
perfectly reflected light waves, to be distinguished from diffuse reflection

**3.7**
**transmission hologram**
hologram using transmission reconstructed waves

Note 1 to entry: A hologram recording the interference pattern between objects and reference waves from the same side of the recording material is a transmission hologram.

**3.8**
**reflection hologram**
hologram using reflection reconstructed waves

Note 1 to entry: A reflection hologram recording the interference pattern between an object wave and the reference wave from the mutually opposite sides of the recording material is generally a volume reflection hologram and is also called a Lippmann or Lippmann Denisyuk hologram. Of the *surface relief hologram* (3.13), the hologram using the wave reflected from the relief surface is a surface relief reflection hologram.



**3.9**
**phase hologram**
hologram having a spatially-periodic phase modulation structure



**3.10**
**amplitude hologram**
hologram having a spatially-periodic amplitude modulation structure

**3.11**
**volume hologram**
hologram causing Bragg diffraction

Note 1 to entry: A hologram having a sinusoidal refractive–index distribution is one whose hologram recording layer is sufficiently thicker than the interval of interference fringes. Holograms characterized by a Q-value $Q \gg 1$ are considered to be volume holograms.

**3.12**
**plane hologram**
hologram causing Raman-Nath diffraction

Note 1 to entry: This type of hologram is the one whose hologram recording thickness is sufficiently smaller than the interval of interference fringes. Holograms characterized by a Q-value $Q < 1$ are considered to be plane holograms.

**3.13**
**surface relief hologram**
hologram recording the interference pattern as relief structure in the surface of the hologram recording material

**3.14**
**Q-value**
in the periodic structure based on the sinusoidal refractive-index distribution, the value of Q defines the thickness of the diffraction grating and is determined by the following formula:

$$Q = \frac{2\pi\lambda T}{\bar{n}d^2}$$

where

- $T$ is the thickness of hologram (μm);
- $\lambda$ is the wavelength in air (μm);
- $d$ is the interval of interference fringe (μm);
- $\bar{n}$ is the mean refractive-index of hologram

Note 1 to entry: This value is used to classify the hologram into the volume hologram and the plain hologram. Note that this value is applicable only to the cyclic structure based on the sinusoidal refractive-index distribution.

**3.15**
**diffraction efficiency**
<of the hologram> ratio of the radiant flux of the reconstructed wave relative to the radiant flux of the illuminating wave

Note 1 to entry: The diffraction efficiency of holograms is generally expressed as a percentage (%).

**3.16**
**angular selectivity**
<of the hologram> dependence of the radiant flux of the reconstructed wave on the angle of incidence of the illuminating wave if the hologram is reproduced while using a monochromatic illuminating wave

**3.17**
**wavelength selectivity**
<of the hologram> dependence of the radiant flux of the reconstructed wave on the wavelength of the illuminating wave if the hologram is reproduced while keeping the angle of incidence of illuminating wave constant



## 4 Symbols and abbreviated terms

$\eta$ Diffraction efficiency (%)

## 5 Principles

The diffraction efficiency is determined by measuring the radiant flux of the reconstructed wave or the zero-order diffracted wave while the illuminating wave enters the hologram. The absolute diffraction efficiency, which is the ratio of the radiant flux of reconstructed wave relative to that of the illuminating wave, is the basis of the measurement. The relative diffraction efficiency, which is the ratio of the radiant flux of the reconstructed wave relative to that of the sum of the radiant fluxes of all diffraction orders, might be important for certain applications. There is also a simplified method to determine the diffraction efficiency from the spectral distribution of either the transmittance or reflectance of the hologram. Finally, the angle selectivity of the hologram is determined from diffraction efficiency as a function of the angle of incidence and the wavelength selectivity is determined from the diffraction efficiency as a function of the wavelength.

## 6 Measurement methods

### 6.1 General

This part of ISO 17901 covers the measurement of the diffraction efficiency as well as the angle selectivity and wavelength selectivity as described below. Since for multiple purposes there is more than one definition of diffraction efficiency, its measurement shall be made according to the method appropriate to the purpose.

When the hologram to be measured is formed through the two-flux interference of reference waves, they are assumed to be plane waves. If the reference waves are not plane waves, the method can be applied by using either the absolute diffraction efficiency or relative diffraction efficiency. If this applies, the fact shall be cited clearly in the report.

This part of ISO 17901 is applicable to holograms formed by the method other than two-flux interference of laser beams, such as the embossed hologram formed by transferring and reproducing the interference pattern, the hologram formed by the electron beam lithography system, and all other etching or engraving methods. If any alternative method is used, that fact shall be cited clearly in the report.

## 6.2 Definition of the coordinate system

The axis of coordinates and the angle of waves are defined as follows.

a) The recording material (or hologram) plane shall be the *xy*-plane while the axis vertical to the plane shall be the *z*-axis.

b) For the *z*-axis, the advance direction of the object or reconstructed wave shall be positive.

c) As shown in Figure 1, the angle of incidence $\theta$ [degree (°) or rad] is formed between the *z*-axis in the positive direction and the extension of the incident wave. The positive $\theta$–symbol indicates a counter-clockwise direction.



**a) Wave advancing in the +*z* direction** **b) Wave advancing in the −*z* direction**

**Key**

1 incident light wave

2 recording material or hologram

**Figure 1 — How to establish the coordinate system and wave angle in measurement of optical characteristics of holograms**

## 6.3 Hologram measurement environment

Measurement of the diffraction efficiency shall be made inside a dark room at room temperature and in atmosphere with stable relative humidity (or under conditions designed to prevent entry of stray light into the detector).

 

## 6.4 Measurement device and measures

The measurement shall use the following equipment and measures, as required, according to the measurement method.

a) Light source

The light source for laser should ensure high temporal stability of the output (for example, ±5 % or less in output fluctuation over 30 min). The white-light illuminating source, if used, should provide a continuous spectrum over the measuring wavelength range concerned.

b) Mirror

The surface accuracy of mirrors should be sufficiently high (for example, better than 1/10 of the appropriate wavelength).

c) Holder

The holder should be able to move within a movable range equivalent approximately to the test piece size while holding the hologram.

d) Detector

The detector should have sufficient dynamic range and response relative to the intensity to be measured and should have been calibrated.

e) Monochromator



The monochromator should have a spectral resolution of 1 nm or less within the wavelength range to be measured.

f) Integrating sphere



Spherical optical component with the inner wall covered by a light diffusing material of high reflectance which can collect beams and homogenize them through spatial integration.

NOTE A typical coating material used for integrating spheres is barium sulfate.

## 6.5 Diffraction efficiency measurement method

### 6.5.1 General

In the strict sense of the word, diffraction efficiency is the absolute diffraction efficiency as measured according to the method described in 6.5.2.

However, the absolute diffraction efficiency might not be appropriate to represent the characteristics of certain recording materials that cause loss of light due to the hologram's reflection, scattering, absorption, and contraction properties. In such a case, it is recommended to apply the method described in 6.5.3.

In the case of volume holograms with expansion or contraction in the recording material, measurement of the diffraction efficiency might result in the lower R-value because of failure to meet the Bragg condition when the angle of incident [degree (°) or rad] or the wavelength of the illuminating wave is equal to that of the reference wave. In such an event, the transmission hologram requires adjustment of the angle of incidence of the illuminating wave, as required, for measurement of the diffraction efficiency. For the volume reflection hologram, either the spectral diffraction efficiency by transmittance measurement as described in 6.5.4 or the spectral diffraction efficiency by reflectance measurement as described in 6.5.5 can be used.

Generally, these four types of diffraction efficiency have different values for the same hologram so that the diffraction efficiency shall be used separately by identifying which measurement method has been applied to the efficiency concerned.