Institute of Applied Physics
Friedrich-Schiller-Universität Jena

Metrology and Sensing

Lecture 10-3: Measurement of basic system properties

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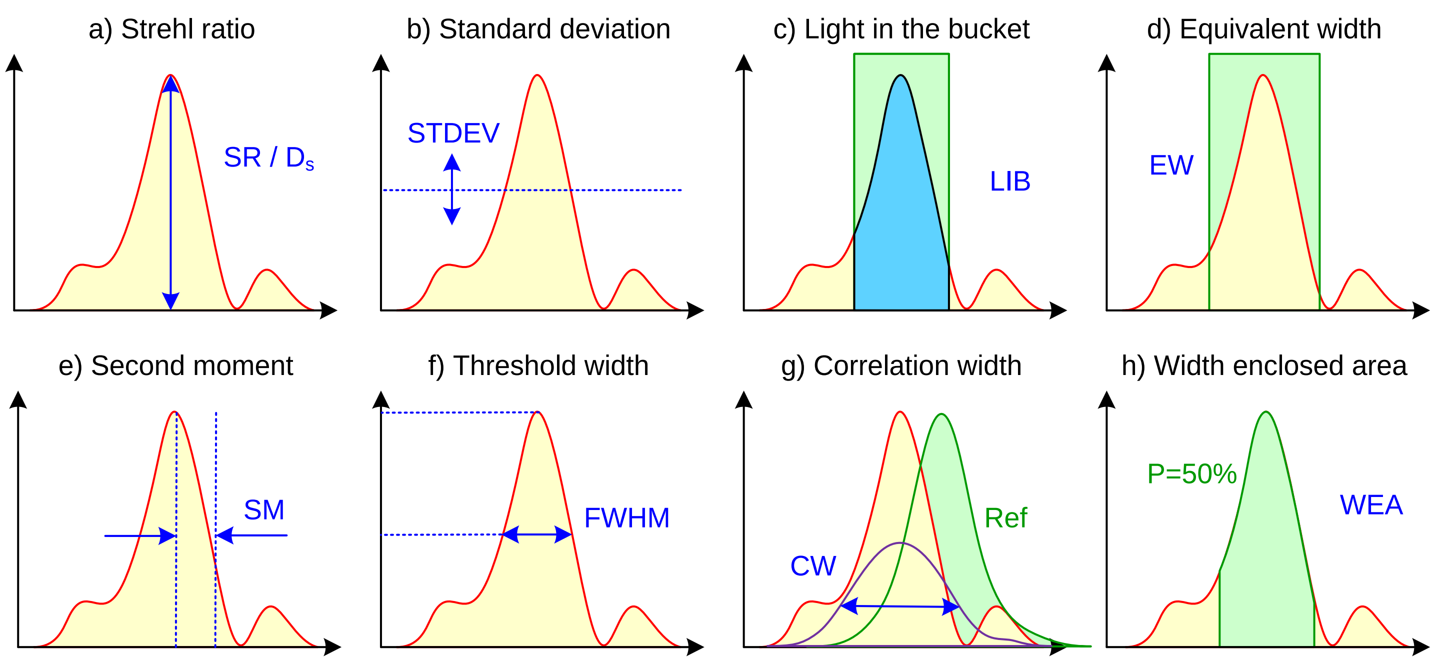
Content

- Point Spread function
- MTF measurement

Physical Image Quality Criteria

- Wavefront
  PV-, rms-value, fractional pupil area
  Rayleigh-, Marechal criteria for diffraction limit

- Point spread function
  Strehl ratio, width, second moment, area equivalent, correlation, power in the bucket



MTF Measurement

- Definitions:
  1. Fourier transform of PSF

$$H_{OTF}(v) = \iint I_{PSF}(x) \cdot e^{2\pi i v x'} dx'$$

  2. Autocorrelation of pupil function

$$H_{OTF}(v) = \int P\left(x_p + \frac{\lambda f v}{2}\right) P^*\left(x_p - \frac{\lambda f v}{2}\right) dx_p$$

- Overview: classification

1. Imaging of special test structures and analyzing the corresponding image contrast behavior
   1.1 If the structures are sine grating structures, a single frequency response is determined
   1.2 If the structures have a large frequency content like points, lines, edges or bar patterns, a careful analysis of the higher frequency components and calculation the OTF from the measurement data must be performed

2. Direct measuring of the autocorrelation function of the optical system pupil corresponding to the Duffieux-integral formulation of the transfer function

3. Measurement of the point spread function and digital calculation of the transfer function by performing the Fourier transform.

MTF-Curve sagittal / tangential

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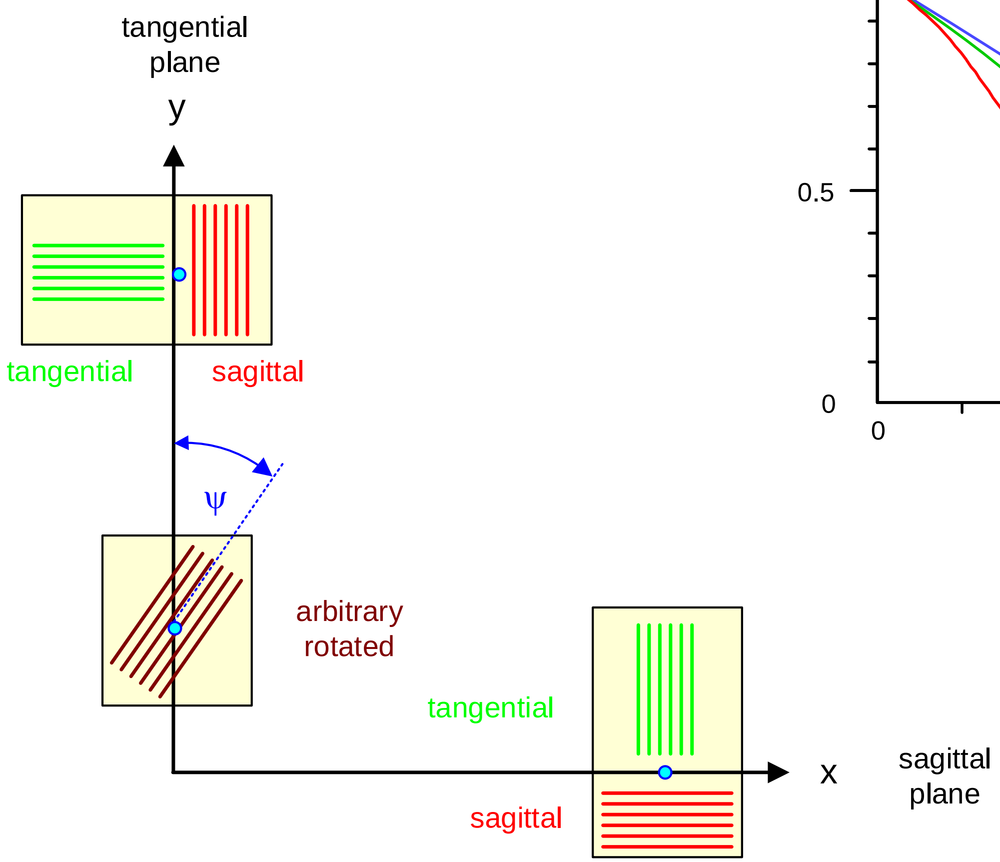
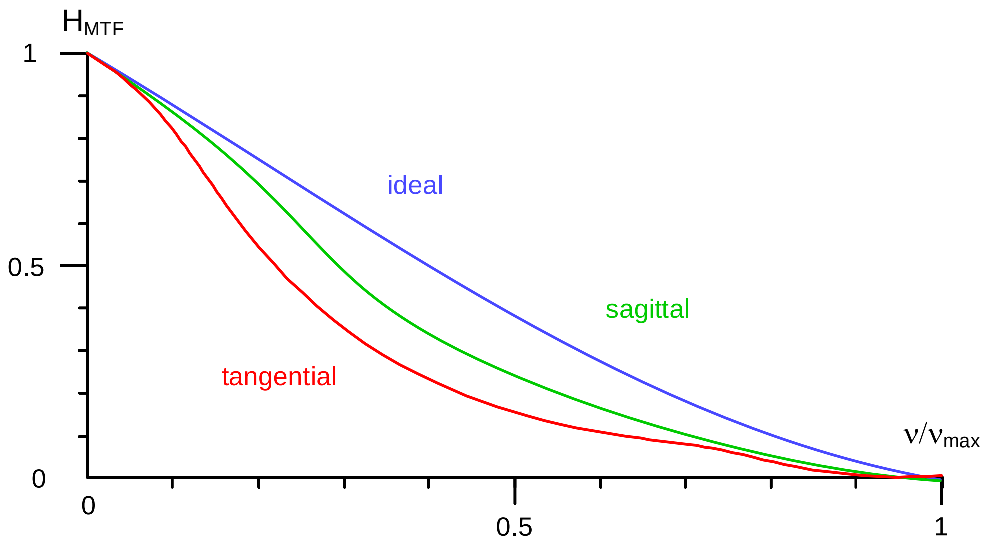
- Due to the asymmetric geometry of the psf for finite field sizes, the MTF depends on the azimuthal orientation of the object structure
- Generally, two MTF curves are considered





MTF Measurement

- Conditions for measuring the incoherent transfer function:

1. An object is illuminated by incoherent light.
2. The object acquires, through its structures, all relevant spatial frequencies that have to be measured.
3. The object is imaged by the test system.
4. Spatial resolution is provided for the detection of the image intensity. As a rule this is achieved by an adjustable slit located in front of the detector. Alternatively, the slit can be fixed and scanning is accomplished by the imaged grating or object structure.
5. The contrast is derived from the intensity distribution and analysed as a function of the spatial frequency

- Possible test structures of the object:

1. Point object
2. Edge object
3. Line object or slits
4. Bar pattern
5. Random transparencies
6. Sine gratings with one or several periods
7. Special test charts like the Siemens star

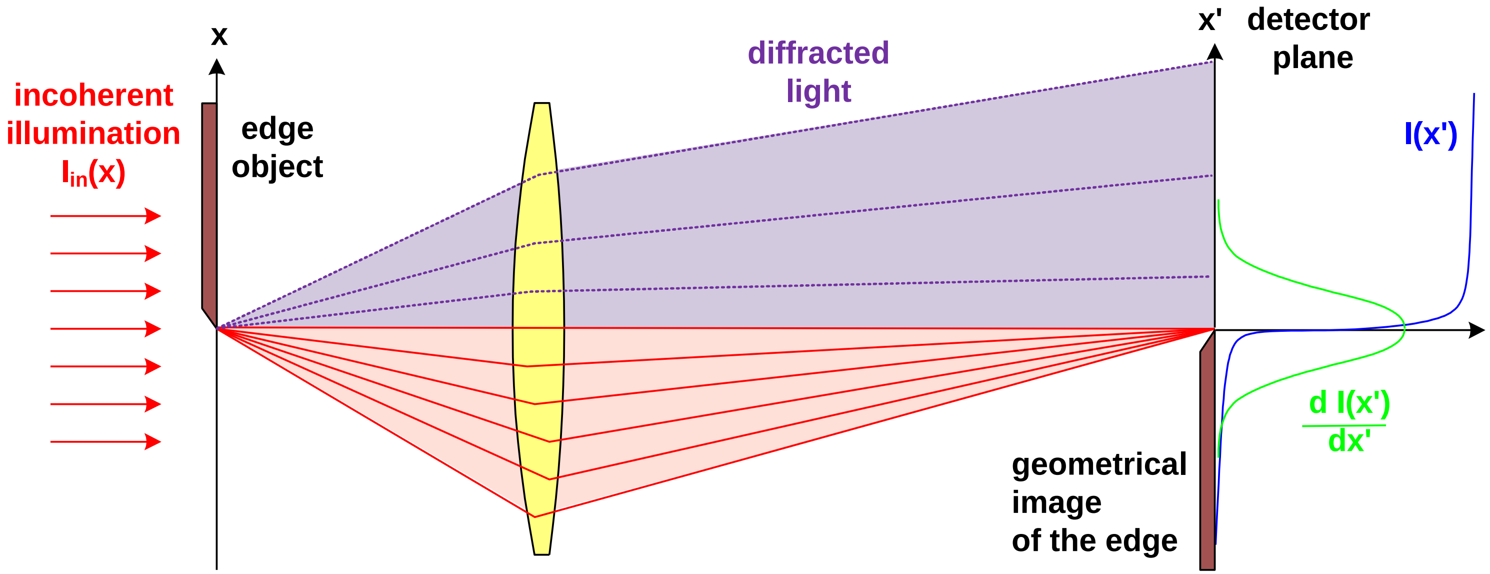
MTF-Measurement by Edge Spread Function

- Measurement of an edge image
- Evaluating the derivative:
  Line spread function

$$I_{LSF}(x') = \frac{d\, I_{ESF}(x')}{d\, x'}$$

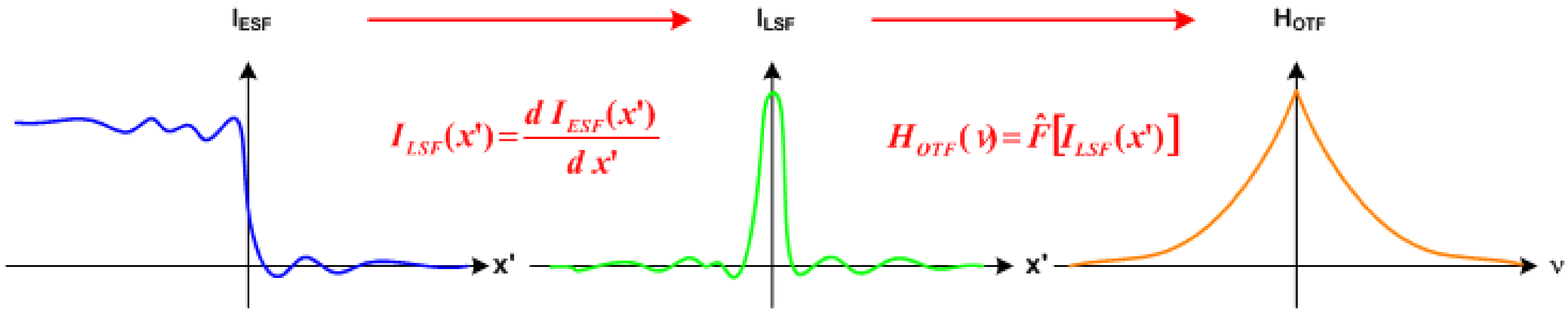
- Fourier transform:
  optical transfer function

$$H_{OTF}(s) = \hat{F}\left[I_{LSF}(x') \right]$$



MTF-Measurement by Edge Image Analysis

- mathematical relationships



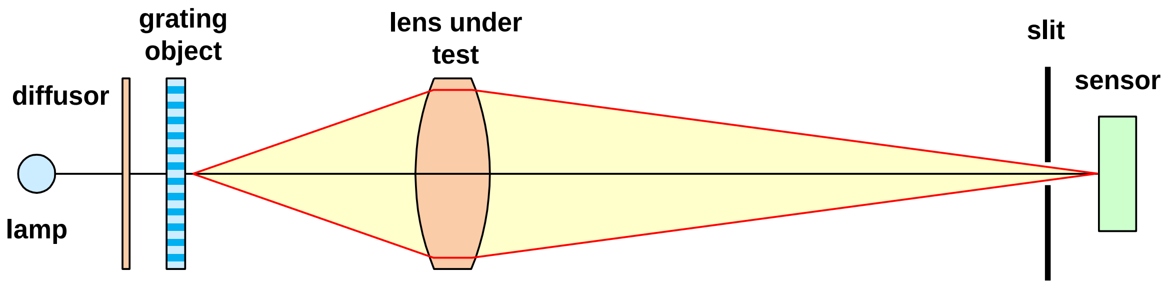
- Direct analysis of the frequency content

$$H_{MTF}(\nu) = \left| \frac{A'(\nu)}{A(\nu)} \right|$$

- Problem: zero crossing points
  solution: filtering, windowed calculation

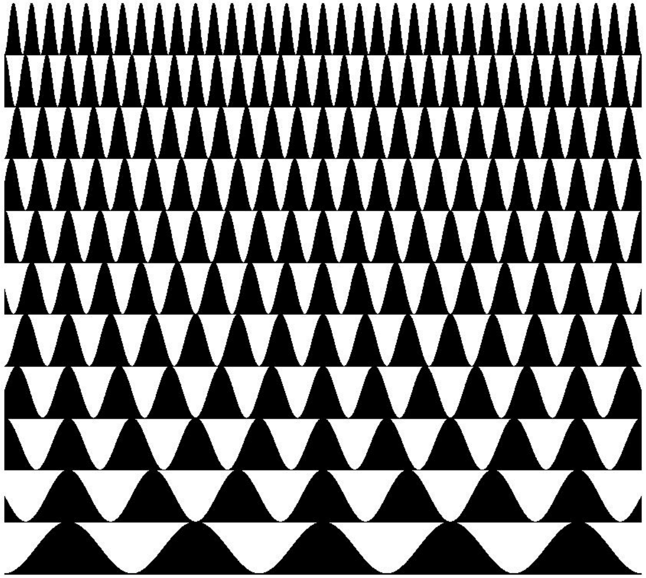
MTF-Measurement by Imaging Gratings

- Setup:
  Imaging of a grating



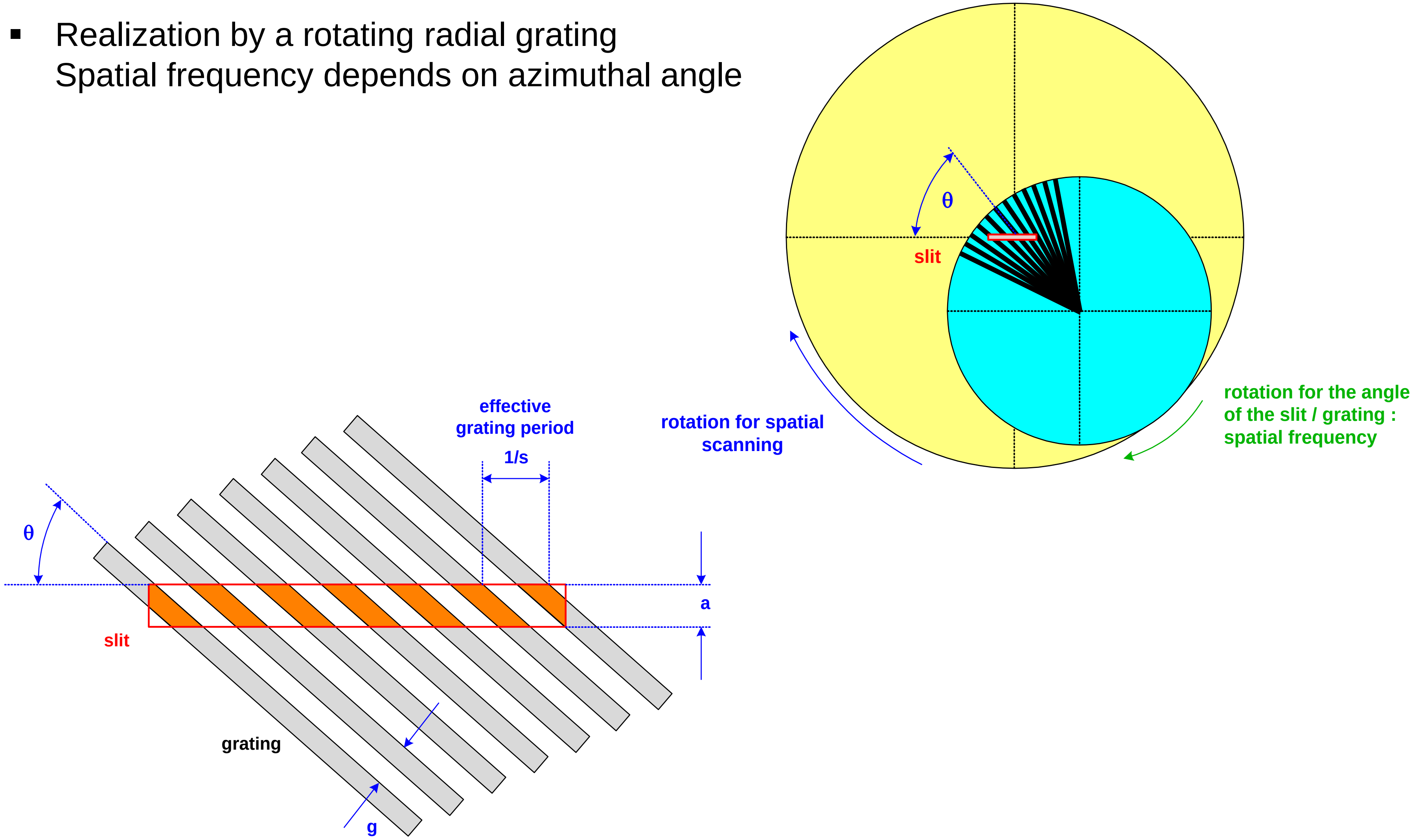
- Possible realizations:
  1. Density type grating, the sine wave is modelled by gray levels
  2. Area type gratings, the sine wave is modelled by geometrical sine-shaped structures

- Area coded sine grating:



MTF-Measurement by Imaging Gratings

- Realization by a rotating radial grating
  Spatial frequency depends on azimuthal angle



Sources of Errors in MTF Measurements

Typical shortcomings of MTF measurements:

1. Mechanical tolerances of the movable parts of the setup like line scan, rotatable edges and alignment errors

2. Application of precise correction factors for finite size slits

3. Truncation errors of the finite lengths structures of the object

4. Calibration of the spatial frequency variable, in particular for finite fields of view with projection changes of lengths and pattern widths

5. Poorly known residual aberrations of auxiliary optical components

6. Use of incorrect spectral and coherence constraints of the illumination

7. Shortcomings of sensor performance

8. Perturbing glare and stray light