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College of Optical Sciences

# 11.0 System Evaluation

**We have looked at many techniques for testing optical components, now let's look at evaluating the entire system.**

# 11.0 System Evaluation

- 11.1 Resolution Tests
- 11.2 Veiling Glare
- 11.3 Spread Function Measurement
- 11.4 Encircled Energy Measurement
- 11.5 Optical Transfer Function
  - 11.5.1 Scanning Methods
  - 11.5.2 Interferogram Analysis
  - 11.5.3 Autocorrelation Method

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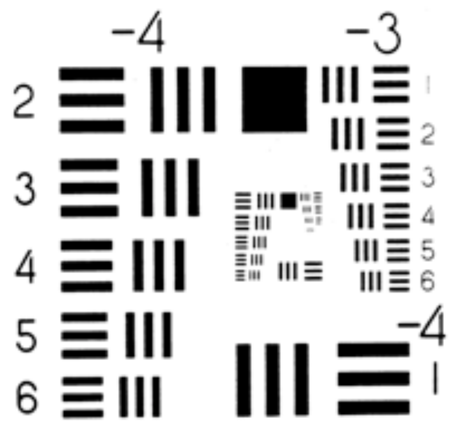
# 11.1 Resolution Tests

- **Image a resolution chart and determine the frequency for which the resolution bars can no longer be clearly observed.**
- **For the USAF resolution test target shown, there are six targets within each group. The sequence of frequencies follows a geometrical progression with a factor between successive targets of** $\sqrt[6]{2} = 1.125.$
- **Between corresponding targets in successive groups the spatial frequency changes by a factor of 2. Target 1 in group 0 has a spatial frequency of 1 line/mm.**

$$\text{Spatial freq. in lines/mm} = 2^{\left(G+(P-1)/6\right)}$$



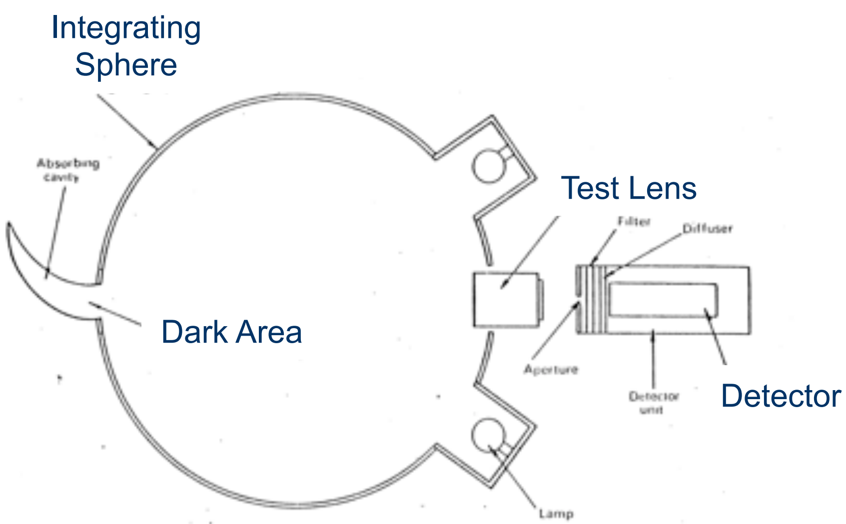
# 11.2 Veiling Glare

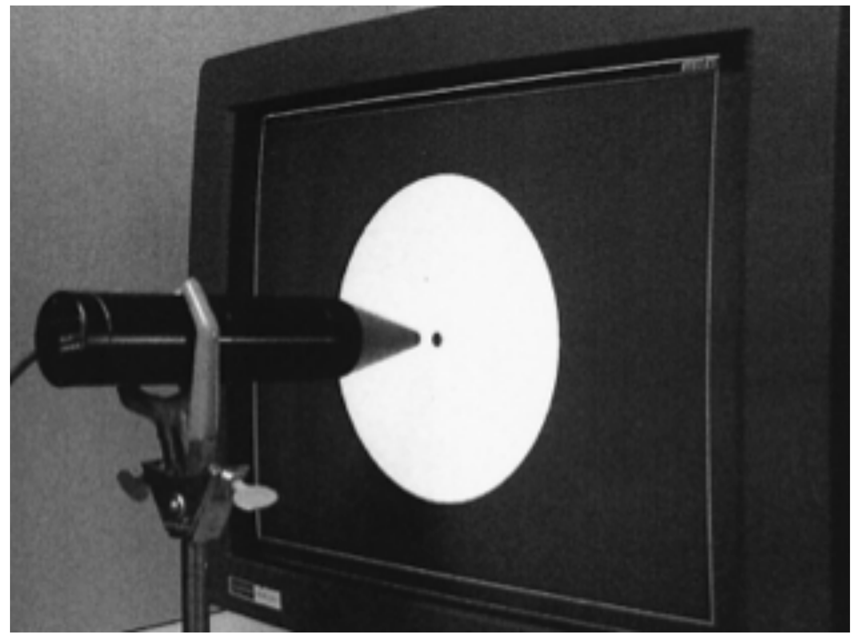
- Unwanted radiation that can reduce image contrast of an optical or electro-optical imaging system is called veiling glare. Veiling glare in display devices is also important.
- Sources in imaging systems include
  - Internal multiple reflections between the lens surfaces.
  - Scatter from lens surfaces due to scratches and imperfections in the polish, dirt and dust, fingerprints, grease, and poor antireflection coatings.
  - Bulk scatter from the glass interior and from bubbles and striae.
  - Scatter from optical cements.
  - Scatter and reflections from the ground edges of the lens elements, internal lens mounts, and the internal surface of the lens barrel.
  - Fluorescence of the glass or optical cements.

# Measuring Veiling Glare

- A convenient method for measuring veiling glare consists of mounting a strip of dead-black material such as velvet across the rear of an integrating sphere or light box, and using the lens to form an image of the black strip on a detector.
- The veiling glare index, VGI, is the ratio of the illumination at the center of the image of the black area superimposed on an extended field of uniform luminance, to the illumination at the same point of the image plane when the black area is removed.
- The advantage of using a long strip instead of a small patch is that the veiling glare can be determined at various points across the field of the lens

# Veiling Glare Measuring Instrument



**Measuring veiling glare of display**

**Ref: A. Badano and M. Flynn, Appl. Opt, 39 (13), 2059-2066, (2000).**

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# 11.3 Spread Function Measurement

- Often use CCD for measuring the point spread function. The effect of any optics used to magnify the point-spread function must be well known.
- Sometimes measure the line-spread function.
- An interferometric test can determine the wavefront produced by the system under test. The point-spread function is calculated by finding the Fourier transform of the wavefront and squaring the result.
  - This technique generally works well, but it must be remembered that the wavefront is being sampled, and frequency components higher than the sampling frequency will be absent.

# 11.4 Encircled Energy Measurement

- Calculate or measure the amount of light in a circular region in the point spread function as a function of radius.
- The measurement or calculation of the flux in a circular region must be made when the center of the region has been located according to some rule.
  - For an image that is symmetrical, the choice or origin is evidently the center of symmetry of the image.
  - If the image is not symmetrical, the circular region can be moved in either one or two dimensions to maximize the flux in the region. The various size regions can each be moved to maximize the amount of light in each, or they can all have the same center, which is the center for maximizing the amount of light in a given size circular region.

# 11.5 Optical Transfer Function

- The optical transfer function (OTF) is the most important function used in image evaluation. After a brief discussion of the meaning of the OTF we will discuss three measurement techniques:
  - 11.5.1 Scanning Method
  - 11.5.2 Interferogram Analysis
  - 11.5.3 Autocorrelation Method

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# Optical Transfer Function Notes

- See notes

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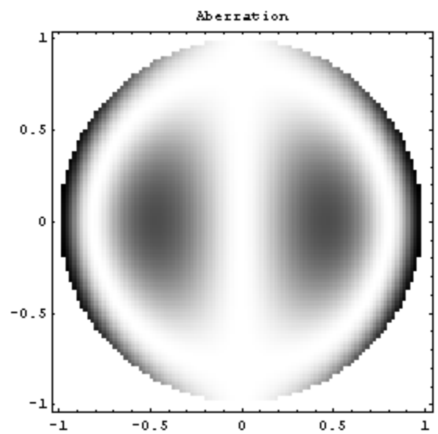
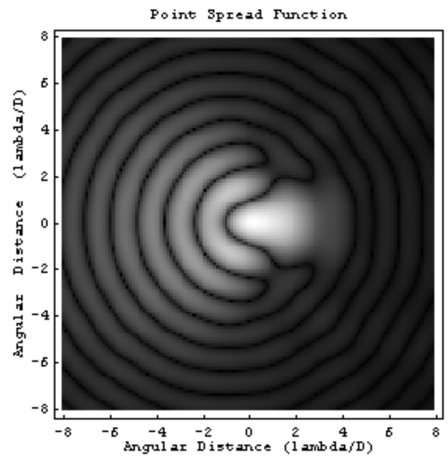
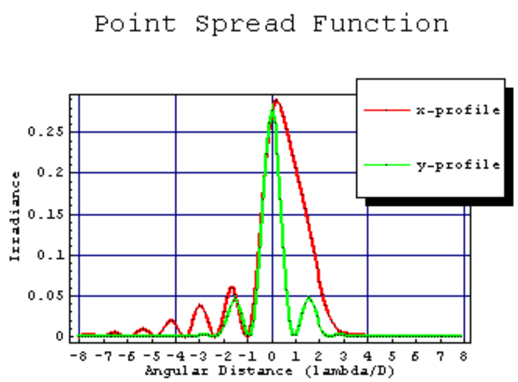
# Aberration, PSF and MTF

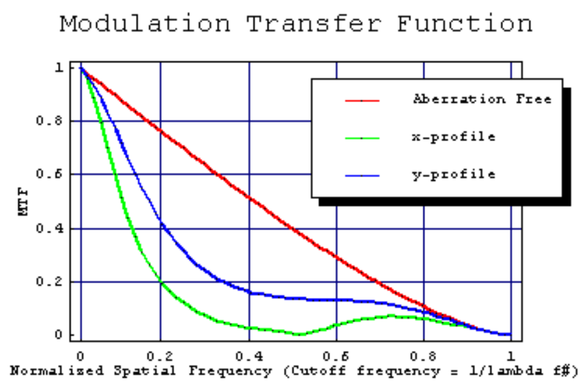
$$\text{Aberration XY} = 1.5\,x^3 + x\,(-1. + 1.5\,y^2)$$

$$\text{Aberration Polar} = 0.5\,\rho\,(-2 + 3\,\rho^2)\,\mathrm{Cos}[\theta]$$

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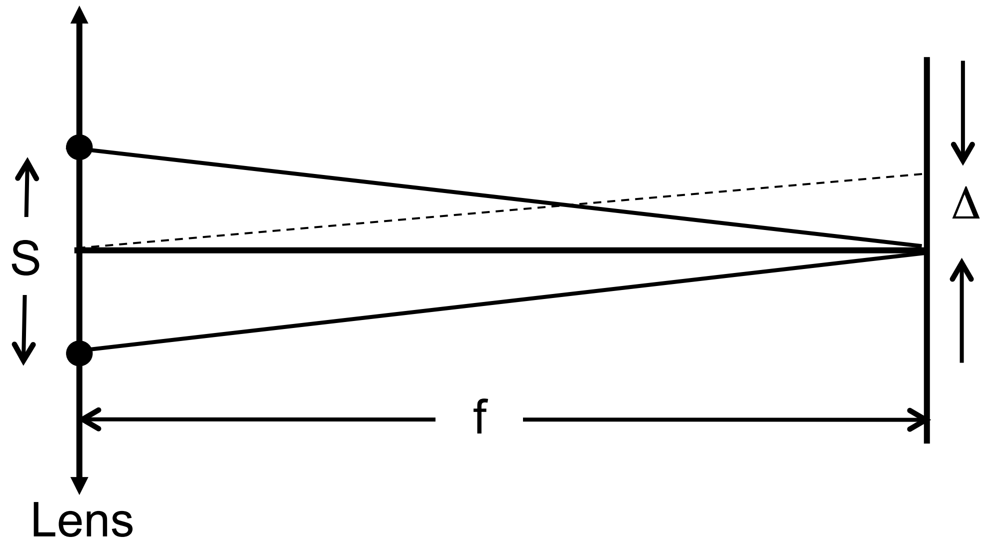
# Physical Explanation of OTF




$\Delta$ = fringe spacing

$$S\frac{\Delta}{f} = \lambda$$

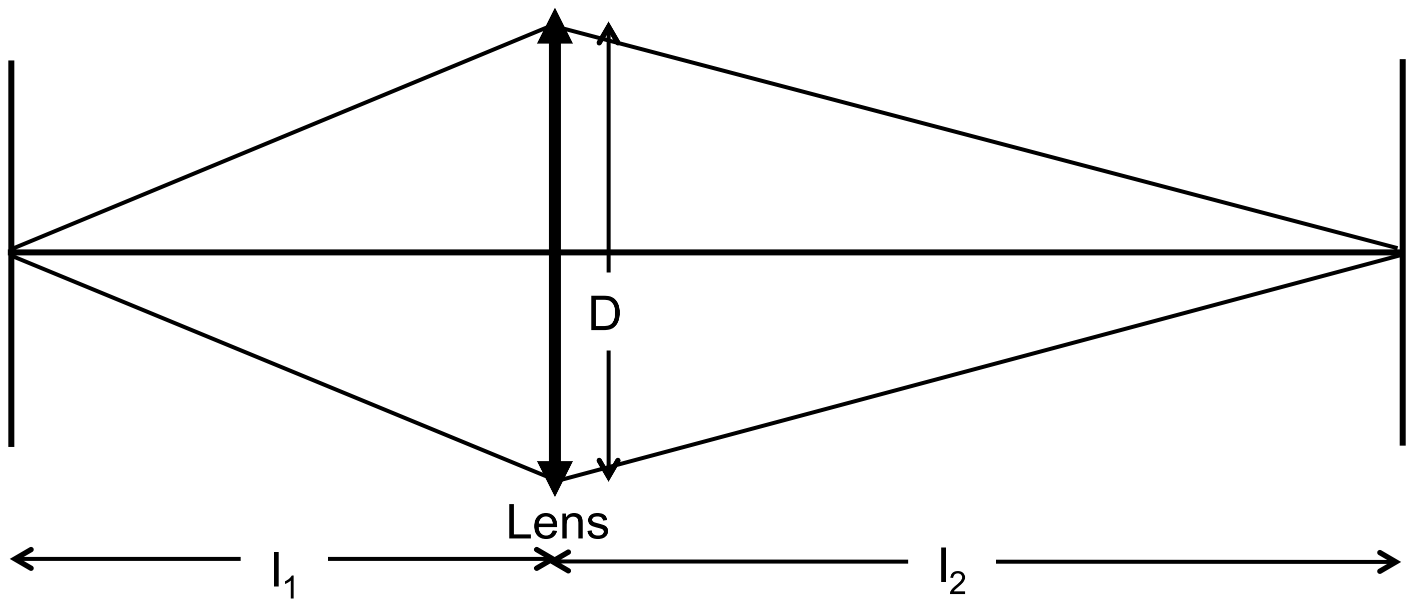
$$\nu = \text{fringe frequency} = \frac{1}{\Delta}$$

$$\nu = \frac{S}{\lambda f}$$

Let $\nu_c$ = cutoff frequency $\quad \nu_c = \dfrac{D}{\lambda f} = \dfrac{1}{\lambda f^{\#}}$

**The smaller S, the more pairs of points of a given spacing S. Aberrations would cause fringe position being different for different pairs of points of given S and hence reducing fringe contrast.**

# Cutoff Frequency in Object and Image Space




Cutoff frequency in object space

$$\nu_c = \frac{D}{\lambda l_1}$$

Cutoff frequency in image space

$$\nu_c = \frac{D}{\lambda l_2}$$

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# 11.5.1 Scanning Methods

- See notes

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# 11.5.2 Interferogram Analysis

- The point spread function can be obtained from an interferogram by taking a Fourier transform of the wavefront and squaring the result.
- The optical transfer function can then be obtained from the point spread function by taking another Fourier transform.
- The modulus of the OTF gives the MTF.

# 11.5.3 Autocorrelation Method

- The OTF is given by the autocorrelation of the pupil function.
- The most common technique for determining the OTF involves measuring the pupil function using an interferometer and then using a computer to digitally find the autocorrelation of the pupil function and hence, both the phase and magnitude of the OTF.
  - This technique for finding the OTF does not take into account any scattering in the system; it accounts only for pupil shape and wavefront aberrations.
  - Generally measurements are performed at a single wavelength, although if dispersions are known, the OTF can be calculated for white light.

# Use Lateral Shear Interferometer to Measure OTF - I

A lateral shear interferometer can be used to calculate the autocorrelation of the pupil function in an analog fashion. It can be shown that if the two interfering beams in a lateral shear interferometer have the same intensity, the total flux in the interference pattern is given by

$$F = 2c\left\{1 + Abs\left[OTF\left[\nu,\psi\right]Cos\left[\delta - \theta\left[\nu,\psi\right]\right]\right]\right\}$$

2c is the average amount of flux in the two interfering wavefronts, and $\delta$ is the phase difference between the two sheared wavefronts due to path differences in the interferometer. $\theta[\nu,\psi]$ is the phase of the OTF.

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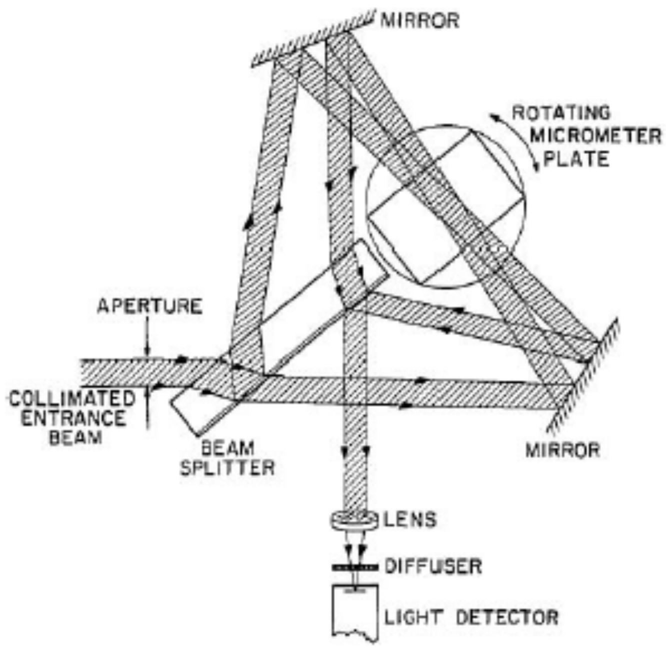
# Use Lateral Shear Interferometer to Measure OTF - II

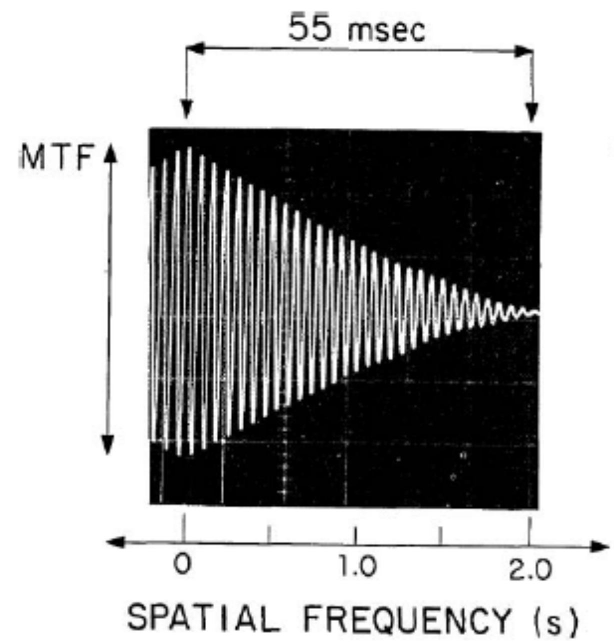
If $\delta$ is made to vary linearly with time, the modulation of the output signal as a function of shear gives the MTF, and the phase of the signal gives the phase of the OTF. The relationship between shear and spatial frequency is given by

$$\nu = \frac{S}{D}\frac{1}{\lambda f\#}$$

where (S/D) is the ratio of the shear distance to the exit pupil diameter, and f# is the f/number of the optical system.

# One Lateral Shear Interferometer for Measuring MTF




**Ref: Kelsall, Appl. Opt., 12, 1398 (1973)**

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