Welcome to ...

2.717J/MAS.857J
Optical Engineering

This class is about

- Statistical Optics
  - models of random optical fields, their propagation and statistical properties (*i.e.* coherence)
  - imaging methods based on statistical properties of light: coherence imaging, coherence tomography
- Inverse Problems
  - to what degree can a light source be determined by measurements of the light fields that the source generates?
  - how much information is "transmitted" through an imaging system? (related issues: what does _resolution_ really mean? what is the space-bandwidth product?)

The van Cittert-Zernike theorem

Image credits:
hubble.nasa.gov
www.nrao.edu

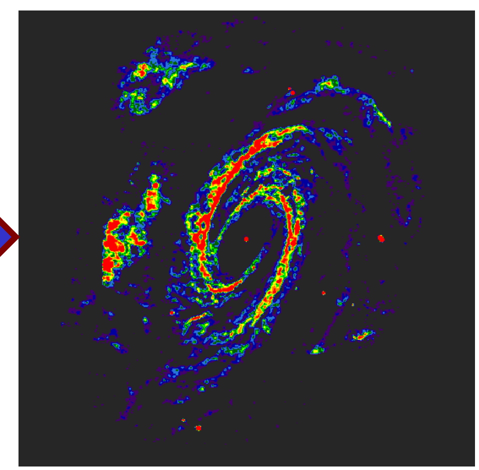
Galaxy, ~100 million light-years away

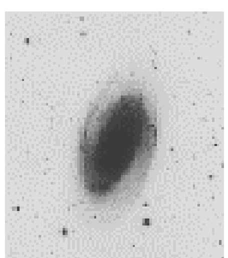
radio waves

Very Large Array (VLA)

Cross-Correlation
+
Fourier transform

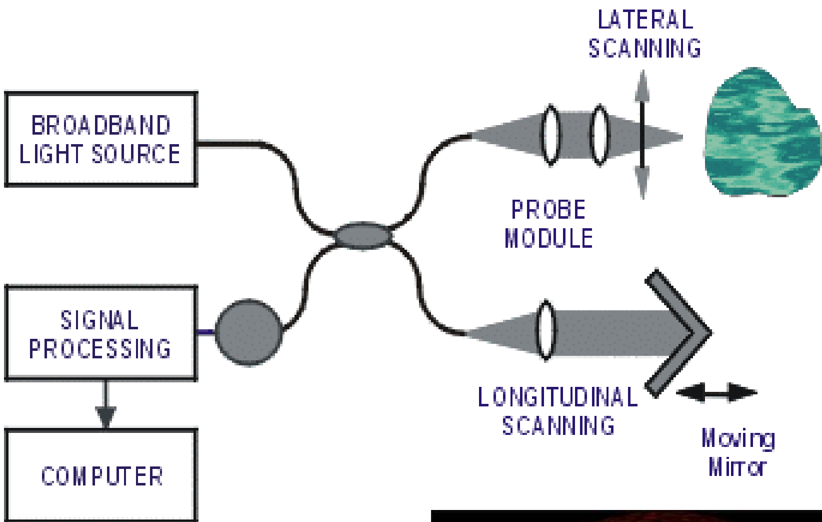
image

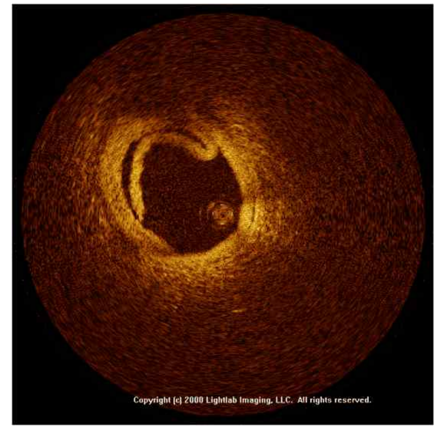


()

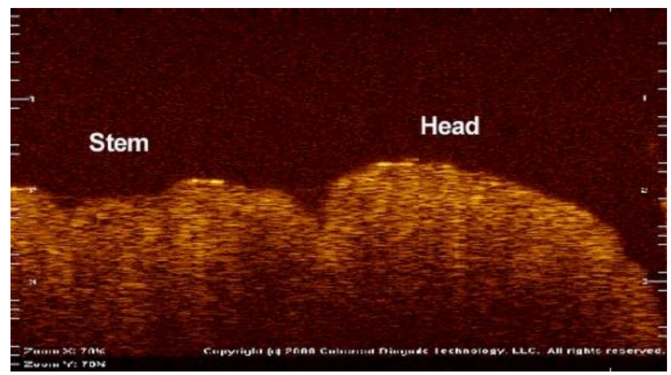
optical image

Optical coherence tomography



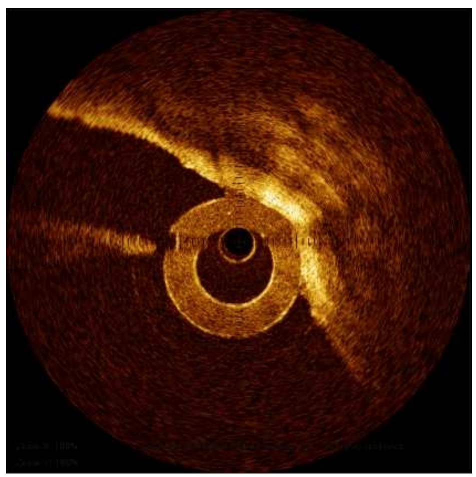


Coronary artery



Intestinal polyps

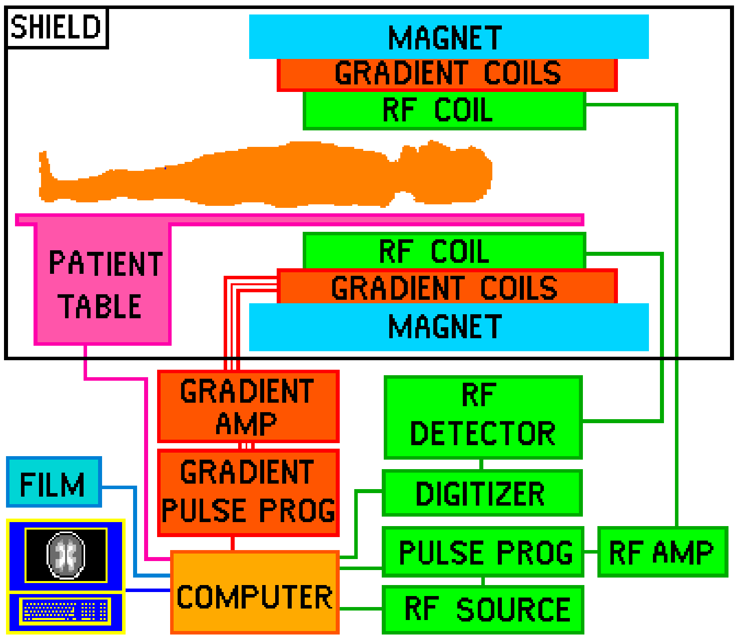
Image credits:
www.lightlabimaging.com



Esophagus

Inverse Radon transform

(*aka* Filtered Backprojection)



The principle

The hardware

The image

Magnetic Resonance Imaging (MRI)

Image credits:
www.cis.rit.edu/htbooks/mri/
www.ge.com

You can take this class if

- You took one of the following classes at MIT
  - 2.996/2.997 during the academic years 97-98 and 99-00
  - 2.717 during fall ’00
  - 2.710 during fall ’01

  OR
- You have taken a class elsewhere that covered Geometrical Optics, Diffraction, and Fourier Optics

- Some background in probability & statistics is helpful but not necessary

Syllabus (summary)

- Review of Fourier Optics, probability & statistics **4 weeks**
- Light statistics and theory of coherence **2 weeks**
- The van Cittert-Zernicke theorem and applications of statistical optics to imaging **3 weeks**
- Basic concepts of inverse problems (ill-posedness, regularization) and examples (Radon transform and its inversion) **2 weeks**
- Information-theoretic characterization of imaging channels **2 weeks**

Textbooks:

- J. W. Goodman, ***Statistical Optics***, Wiley.
- M. Bertero and P. Boccacci, ***Introduction to Inverse Problems in Imaging***, IoP publishing.

What you have to do

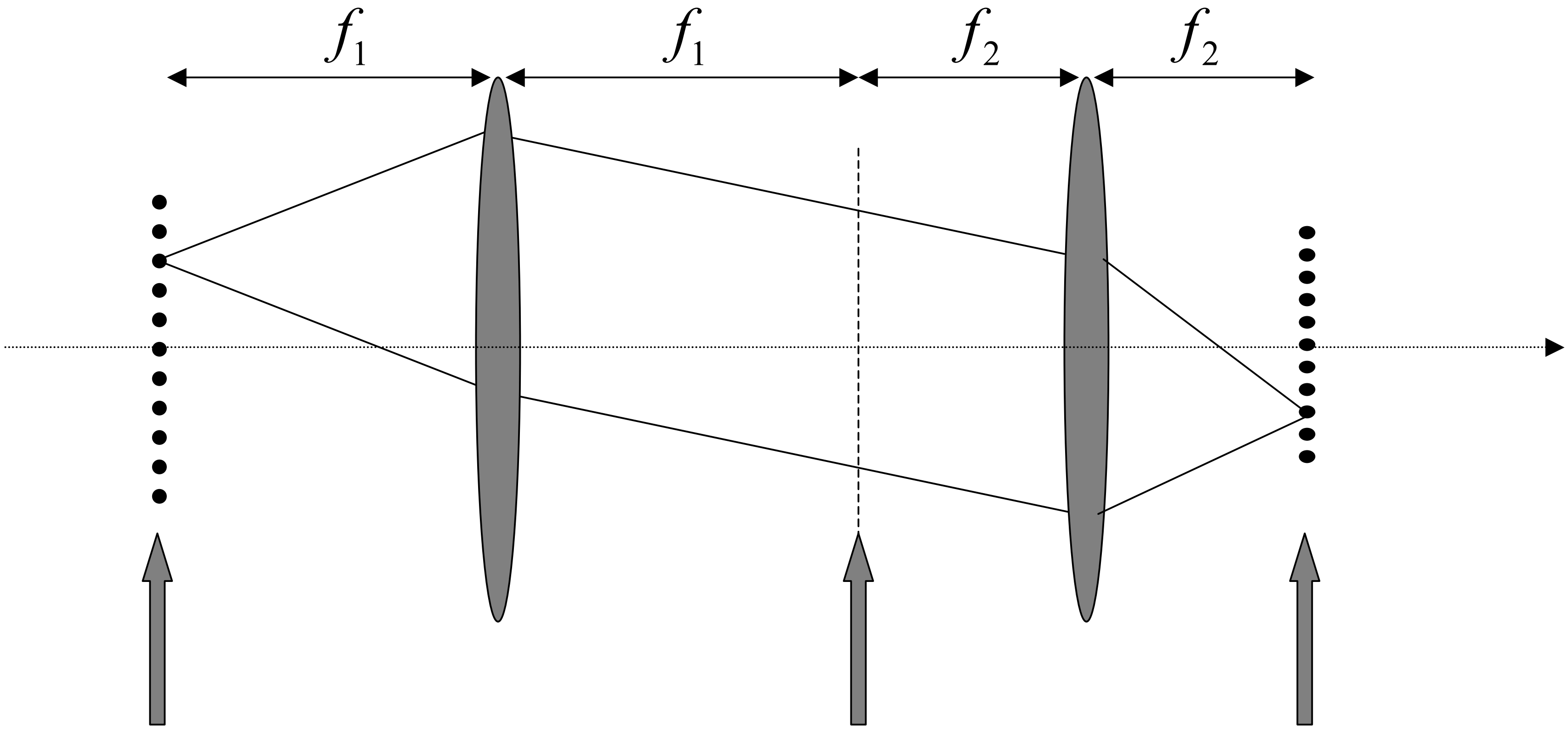
- 4 homeworks (1/week for the first 4 weeks)
- 3 Projects:
  - Project 1: a simple calculation of intensity statistics from a model in Goodman (~2 weeks, 1-page report)
  - Project 2: study one out of several topics in the application of coherence theory and the van Cittert-Zernicke theorem from Goodman (~4 weeks, lecture-style presentation)
  - Project 3: a more elaborate calculation of information capacity of imaging channels based on prior work by Barbastathis & Neifeld (~4 weeks, conference-style presentation)
- Alternative projects ok
- No quizzes or final exam

Administrative

- Broadcast list will be setup soon
- Instructor's coordinates

  George Barbastathis
- *Please do not phone-call*
- Office hours TBA
- Class meets
  - Mondays 1-3pm (main coverage of the material)
  - Wednesdays 2-3pm (examples and discussion)
  - presentations only: Wednesdays 7pm-??, pizza served

The 4F system



$$g_1(x, y)$$

object plane

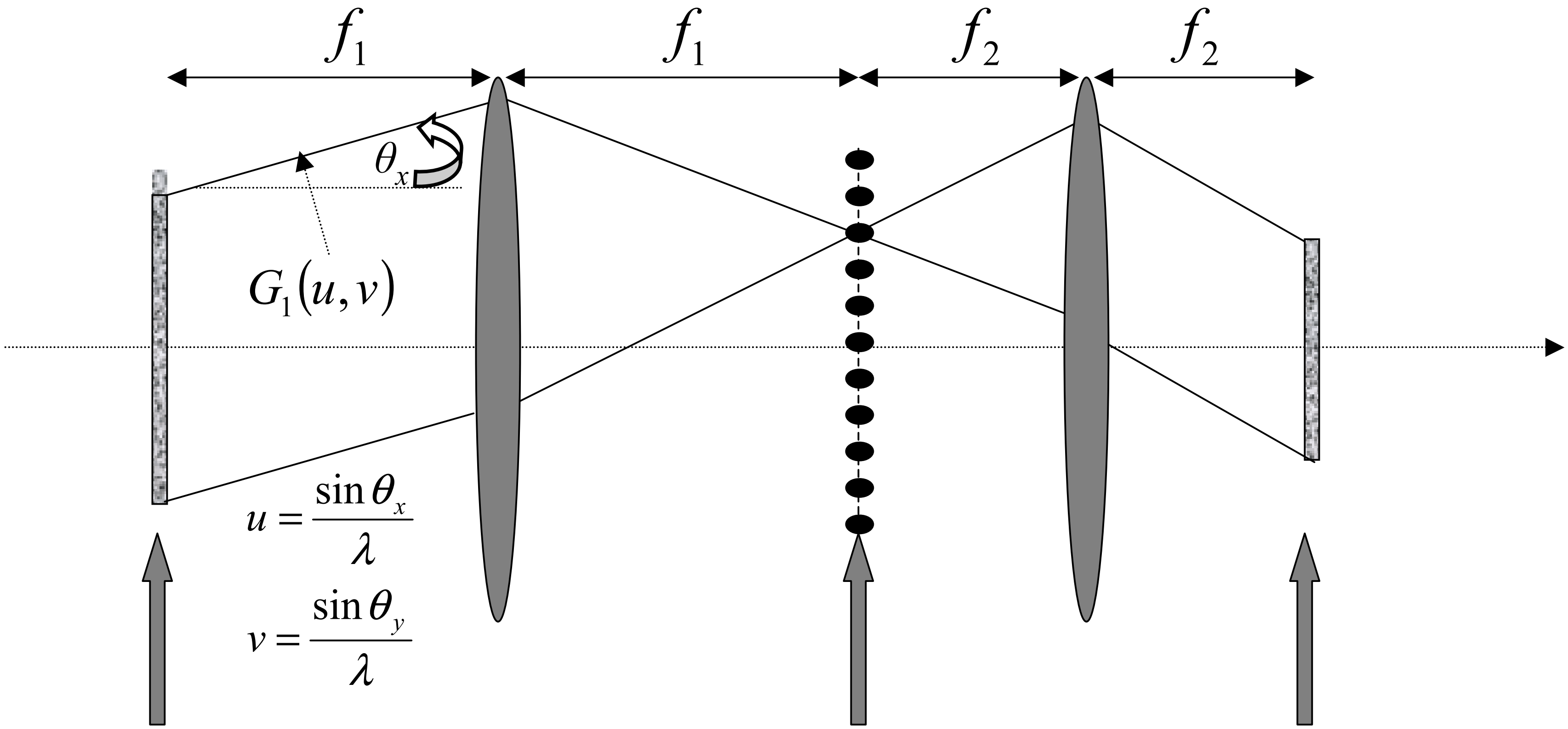
$$G_1\left(\frac{x''}{\lambda f_1}, \frac{y''}{\lambda f_1}\right)$$

Fourier plane

$$g_1\left(-\frac{f_1}{f_2}x', -\frac{f_1}{f_2}y'\right)$$

Image plane

The 4F system



$g_1(x, y)$

object plane

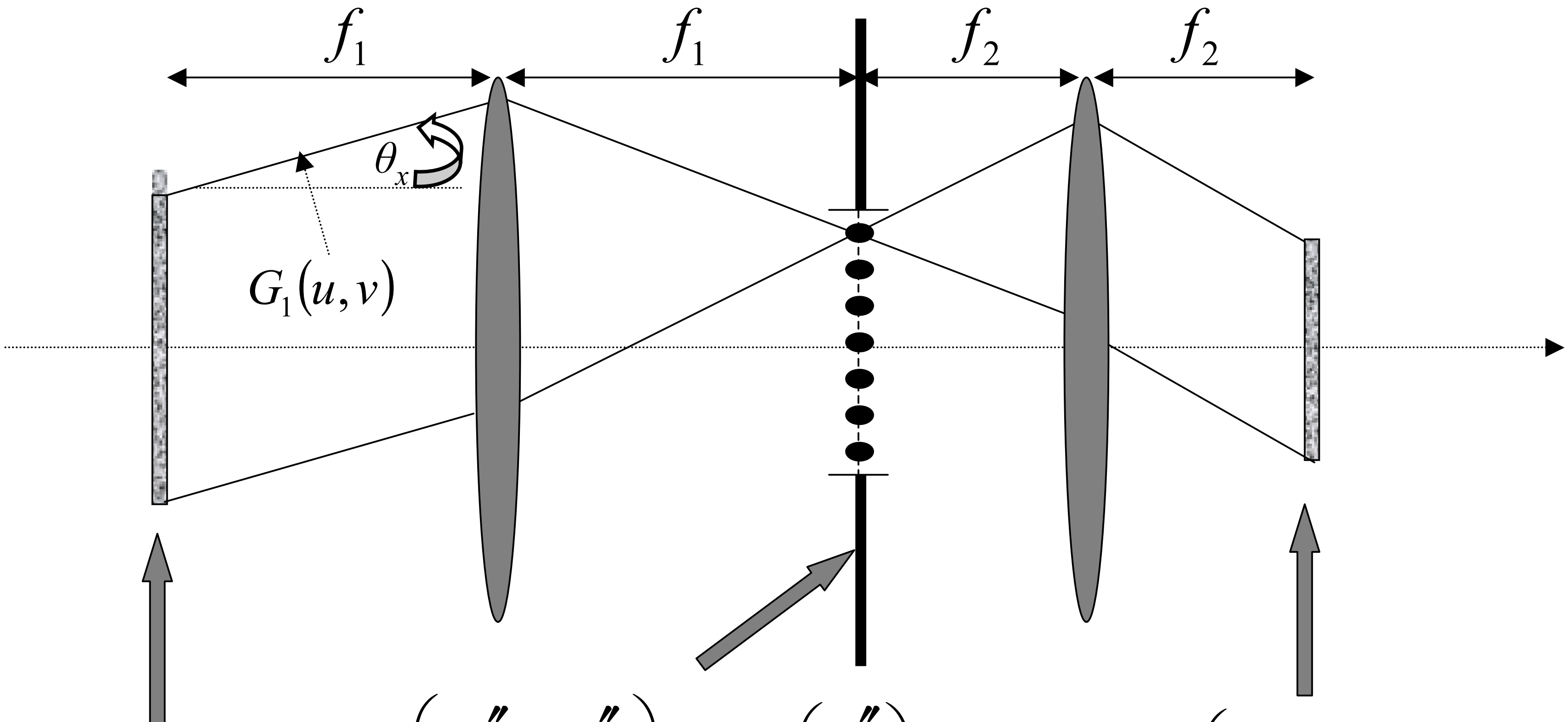
$G_1\left(\frac{x''}{\lambda f_1}, \frac{y''}{\lambda f_1}\right)$

Fourier plane

$g_1\left(-\frac{f_1}{f_2}x', -\frac{f_1}{f_2}y'\right)$

Image plane

The 4F system with FP aperture



$$g_1(x,y)$$

object plane

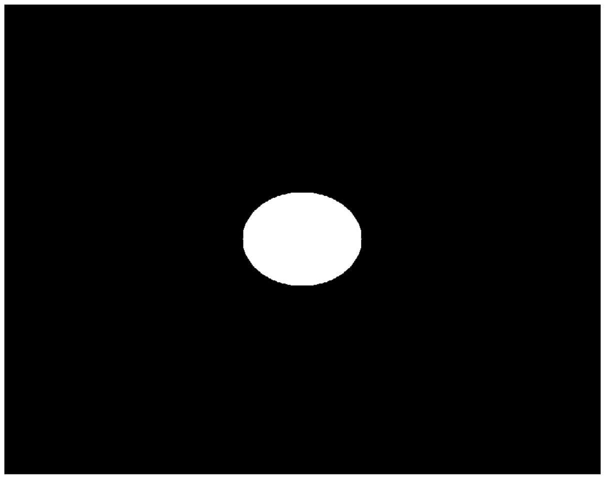
$$G_1\left(\frac{x''}{\lambda f_1},\frac{y''}{\lambda f_1}\right)\times \mathrm{circ}\left(\frac{r''}{R}\right)$$

Fourier plane: aperture-limited

$$(g_1 * h)\left(-\frac{f_1}{f_2}x',-\frac{f_1}{f_2}y'\right)$$

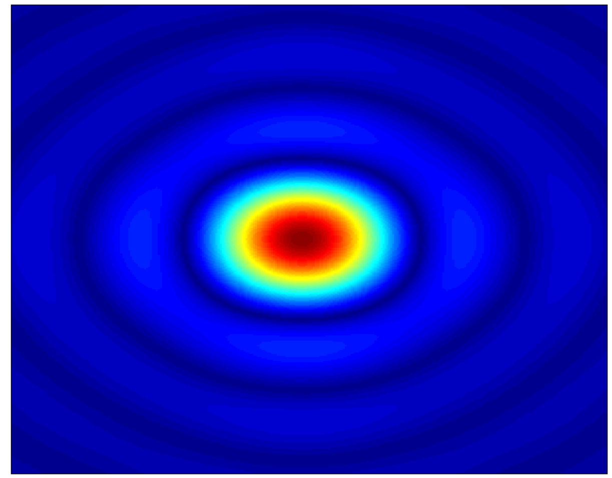
Image plane: blurred
(i.e. low-pass filtered)

The 4F system with FP aperture



Transfer function:
circular aperture

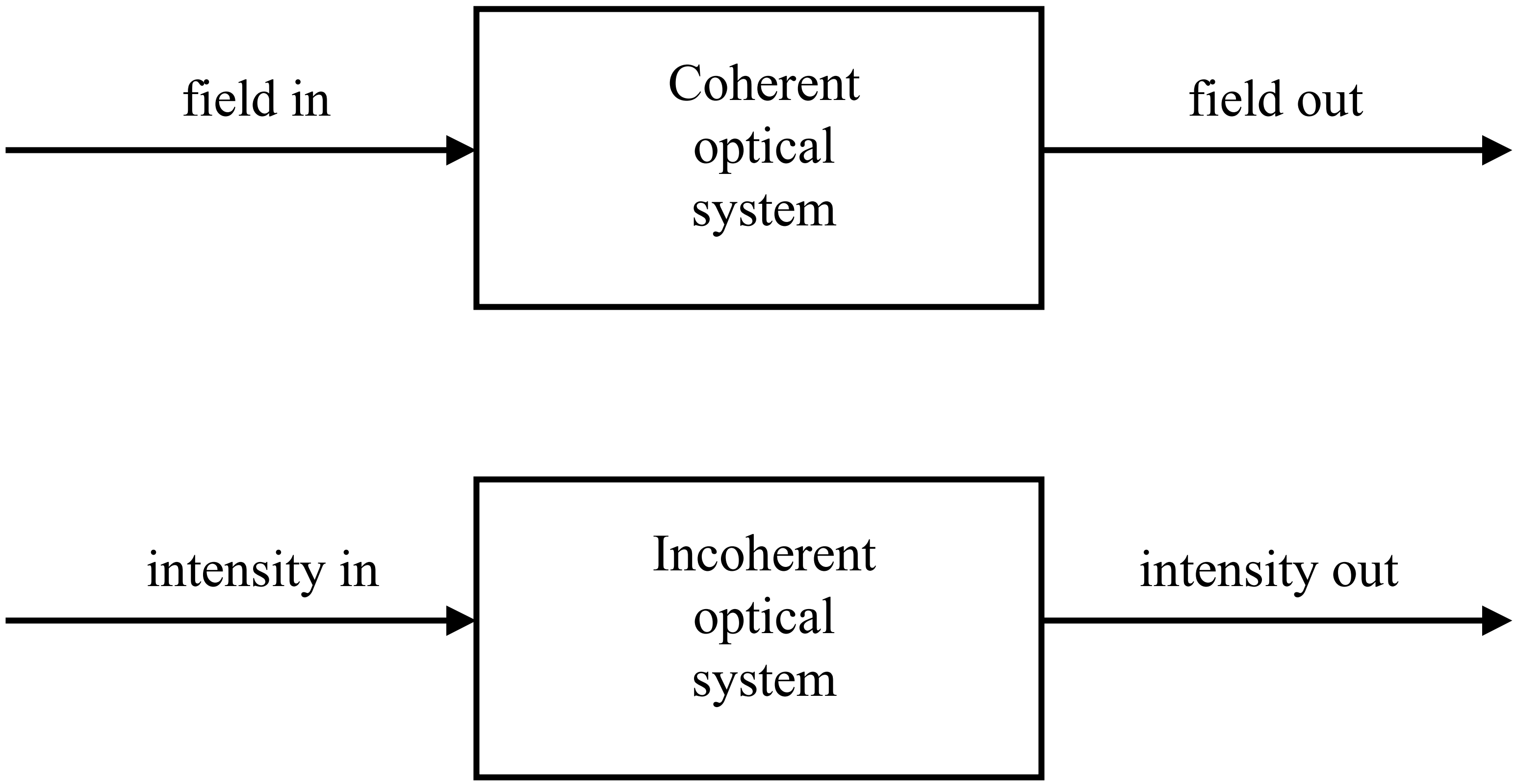
$$\mathrm{circ}\left(\frac{r''}{R}\right)$$



Impulse response:
Airy function

$$\mathrm{jinc}\left(\frac{r'R}{\lambda f_2}\right)$$

Coherent vs incoherent imaging



Coherent vs incoherent imaging

Coherent impulse response
(field in ⇒ field out)

$$h(x,y)$$

Coherent transfer function
(FT of field in ⇒ FT of field out)

$$H(u,v) = \mathrm{FT}\{h(x,y)\}$$

Incoherent impulse response
(intensity in ⇒ intensity out)

$$\tilde{h}(x,y) = |h(x,y)|^2$$

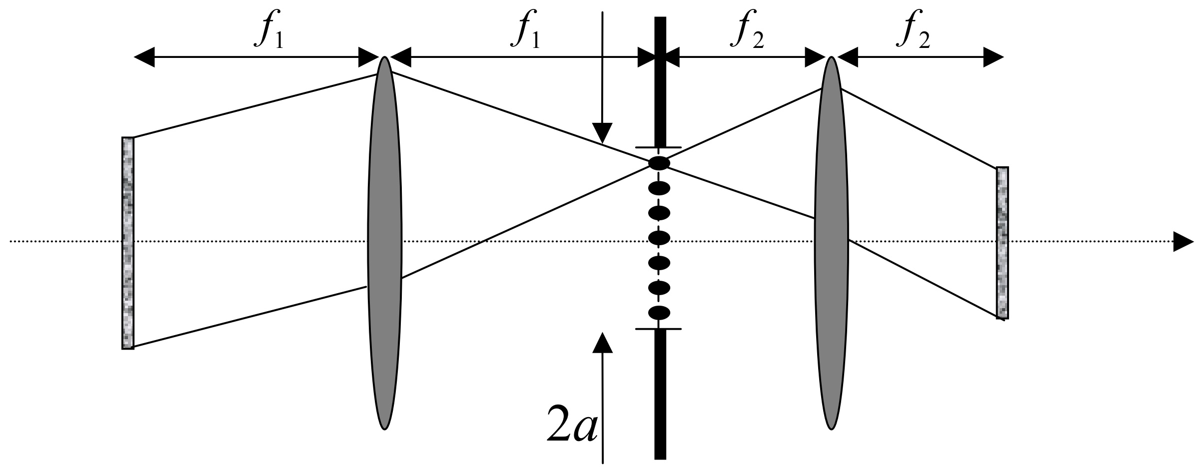
Incoherent transfer function
(FT of intensity in ⇒ FT of intensity out)

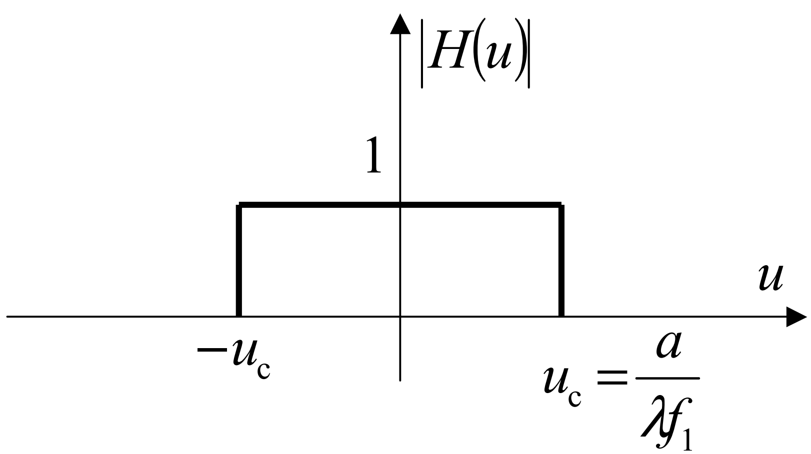
$$\tilde{H}(u,v) = \mathrm{FT}\{\tilde{h}(x,y)\} = H(u,v) \otimes H(u,v)$$

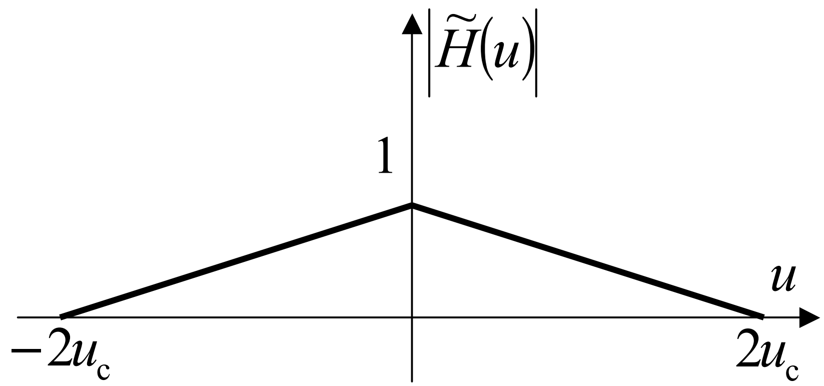
$\left|\tilde{H}(u,v)\right|$: Modulation Transfer Function (MTF)

$\tilde{H}(u,v)$: Optical Transfer Function (OTF)

Coherent vs incoherent imaging



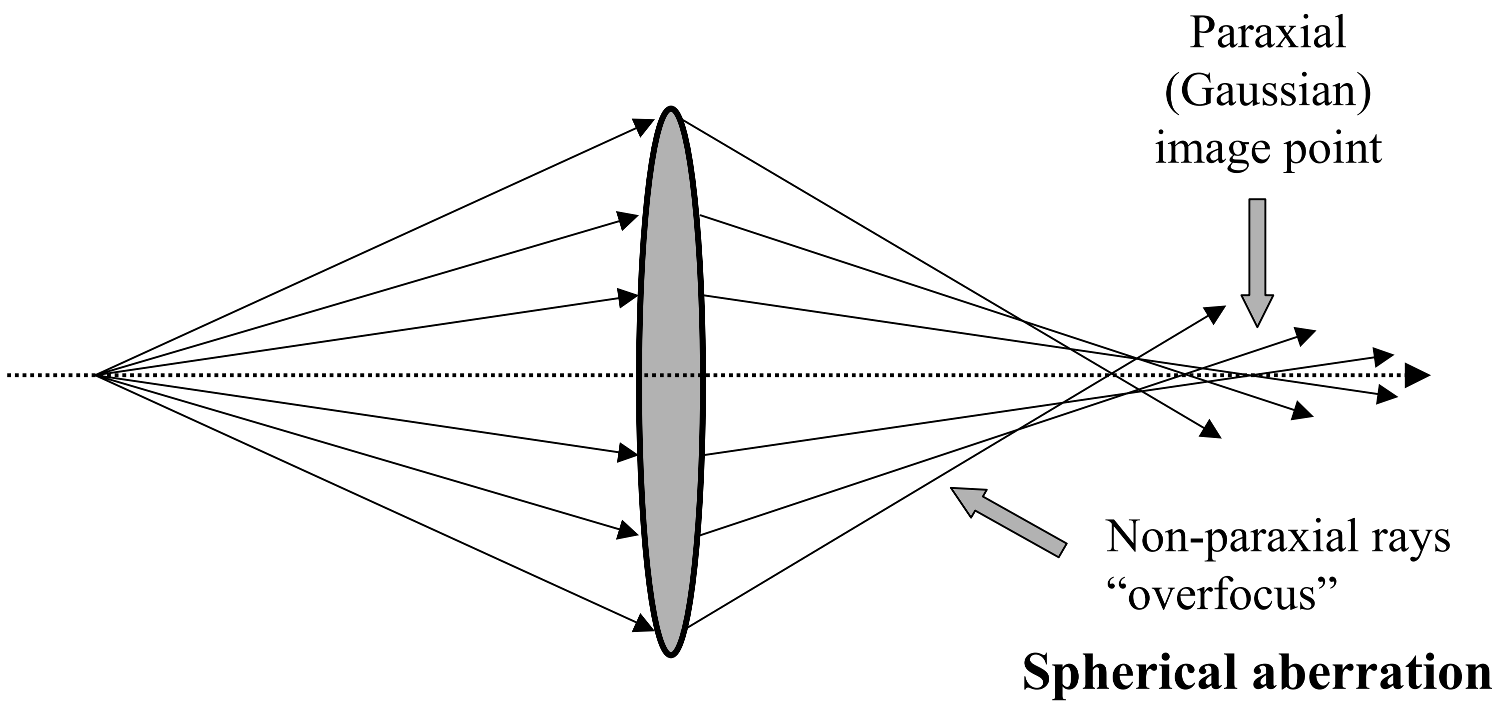




Coherent illumination

Incoherent illumination

Aberrations: geometrical



• Origin of aberrations: nonlinearity of Snell's law (n sinθ=const., whereas linear relationship would have been $n\theta$=const.)
• Aberrations cause practical systems to perform *worse* than diffraction-limited
• Aberrations are best dealt with using optical design software (Code V, Oslo, Zemax); optimized systems usually resolve ~3-5λ (~1.5-2.5μm in the visible)

Aberrations: wave

Aberration-free impulse response $h_{\substack{\text{diffraction}\\\text{limited}}}(x,y)$

Aberrations introduce additional phase delay to the impulse response

$$h_{\text{aberrated}}(x,y) = h_{\substack{\text{diffraction}\\\text{limited}}}(x,y)\,\mathrm{e}^{i\varphi_{\text{aberration}}(x,y)}$$

Effect of aberrations on the MTF