Imaging Optics

Lecture 1

Demetri Psaltis

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Photos


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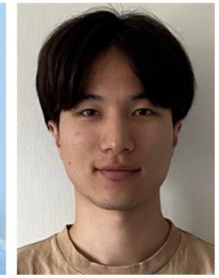
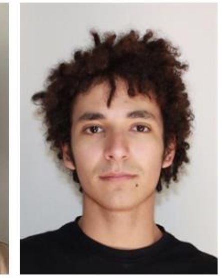

Matsuo Ryoga
Electrical and Electronics Engineering, 2023-2024, Master semester 2


Perez Grether Damian Sebastian
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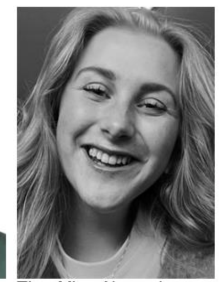
Thor Mina Alexandra
EL Exchange, 2023-2024, Spring semester


Tscherrig Samira Lena
Microengineering, 2023-2024, Master semester 2


Von Wattenwyl Louis Francois Robert
Microengineering, 2023-2024, Master semester 4


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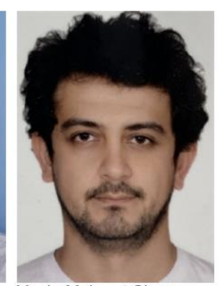

Yayla Mahmut Sinan
Photonics (edoc), EDOC

Imaging Optics MICRO-421

Practical information

Lecturer: Prof. Demetri Psaltis demetri.psaltis@epfl.ch
Assistant: Felix Wechsler and Zahra Basiri

Schedule: Fridays 10:15 to 13:00 In-class ELG120
Homework: The homework consists of problems associated with the exercises using BPM started in class BPM.
Class exercises: Please bring laptop to class with MATLAB or Python
Grading:
50% weekly homework (typically BPM plus normal problems)
- **1/3 of the homework grade in class exercise, 2/3 to be completed at home**
- **20 points per week penalty for late submissions with a maximum penalty 50 points out of 100**

25% mid-term exam
25% final exam
10% Bonus points for in class quizes
Suggested book: Introduction to Fourier Optics, Joseph Goodman

Course website
All information, lecture notes, presentations, homework, and announcement for
the course will be available on:

http://moodle.epfl.ch
course ID: MICRO-421
password for resources: imaging

BPM code

TOPICS

1. Optical beam propagation; free space
2. Plane waves, lens-less imaging
3. Fresnel Diffraction, thin transparencies
4. Imaging, lenses, eye
5. Microscopy
6. Waveguides, Endoscopy
7. Midterm
8. Coherence, interferometry, OCT
9. Periodic structures
10. 3D display
11. 3D printing
12. Holography
13. Ptychography, Tomography.
14. Final

Plan for today

1. Beam propagation method (BPM)
2. Some images
3. Felix presents Julia and BPM code
4. Start homework

Imaging

From Wikipedia, the free encyclopedia

Imaging is the representation or reproduction of an object's form; especially a visual representation (i.e., the formation of an image).

D

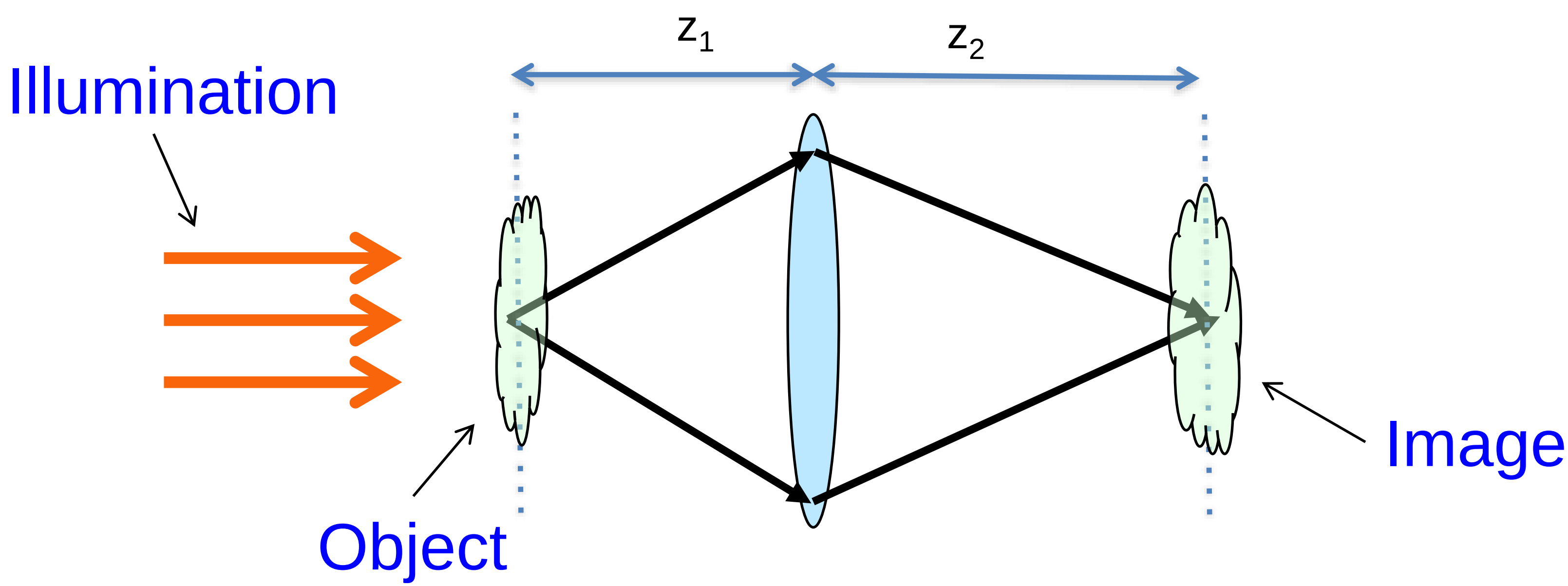
what is imaging

Imaging refers to the creation of visual representations of objects, structures, or processes through the use of various technologies or techniques. It can be used in a variety of fields, such as medicine, science, engineering, and entertainment.

In medical imaging, for example, images are created using techniques such as X-rays, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound to visualize internal organs, tissues, and bones. These images can help doctors diagnose and treat various medical conditions.

In science, imaging techniques such as electron microscopy and fluorescence microscopy can be used to study the structure and function of cells and molecules.

Imaging System



$$\frac{1}{F} = \frac{1}{z_1} + \frac{1}{z_2} \qquad M = -\frac{z_2}{z_1}$$

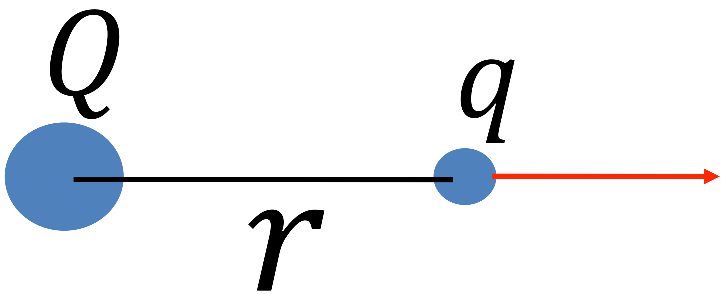
MAXWELL EQUATIONS

$$\nabla \times \vec{E} = -\mu \frac{\partial \vec{H}}{\partial t}$$

$$\nabla \times \vec{H} = \varepsilon \frac{\partial \vec{E}}{\partial t} + \vec{J}$$

$$\nabla \bullet \varepsilon \vec{E} = \rho$$

Electric Field (E in Volts/m)



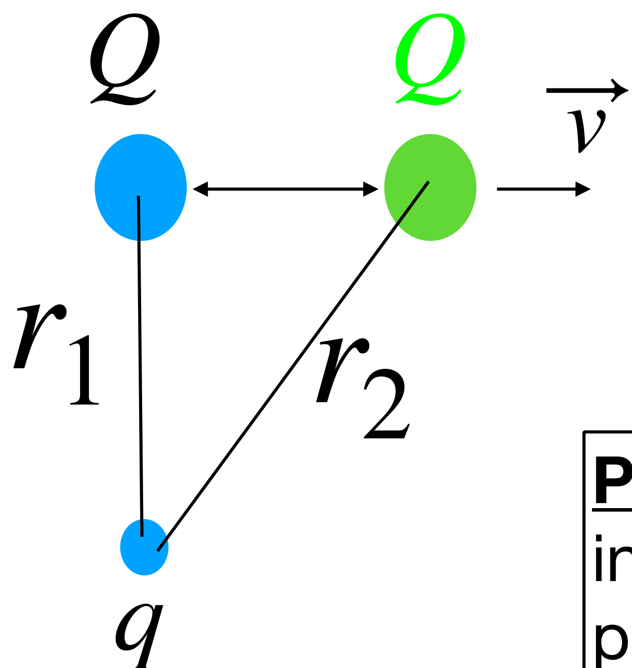
Charge   Charge

$$F = \frac{Qq}{4\pi\epsilon r^2} = Eq$$

Coulomb force

F and *E* are vectors

Charges moving at Constant Velocity



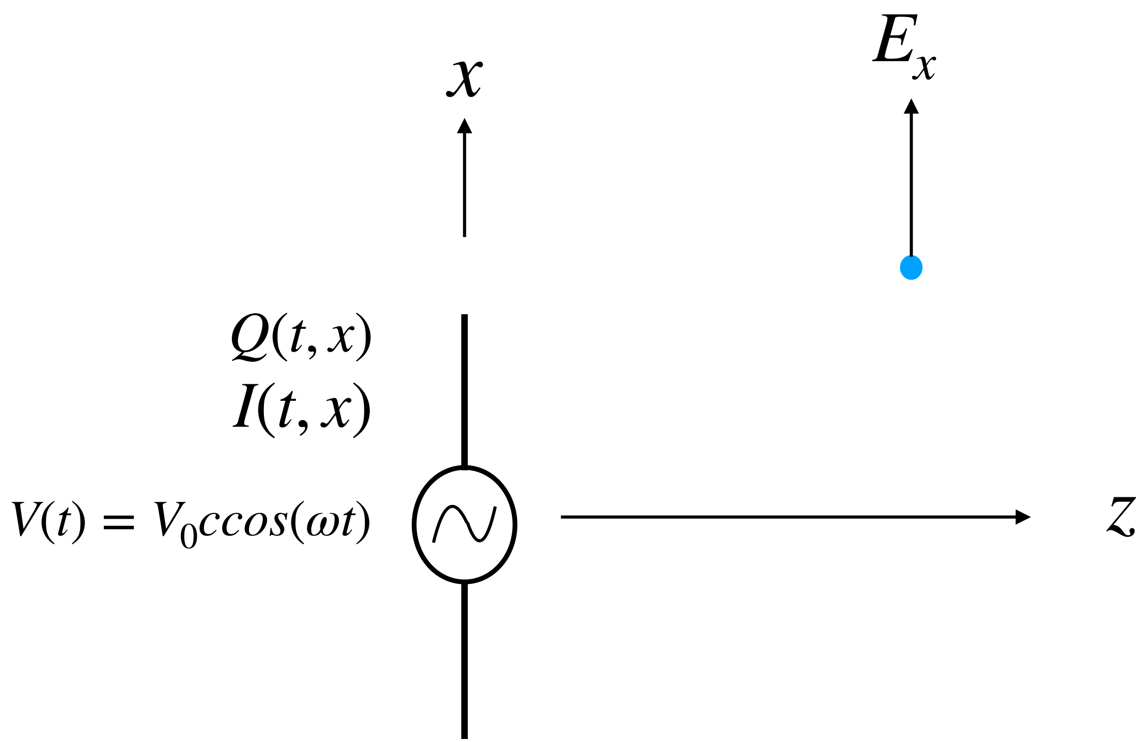
$$r_1,\ r_2 >> \Delta x$$

$$\Delta t = \frac{\Delta x}{v} < \frac{r_1}{c}$$

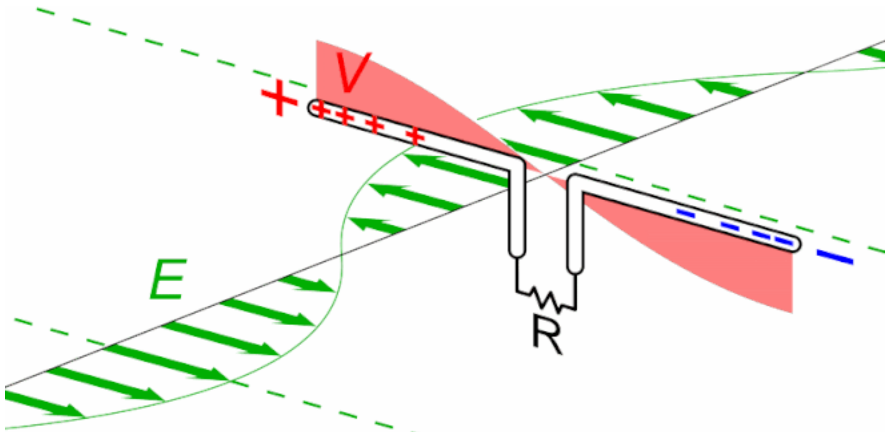
Problem: It appears that information about the position of Q can reach q faster than the speed of light

Answer: Magnetism

Accelerating Charges: Radiation



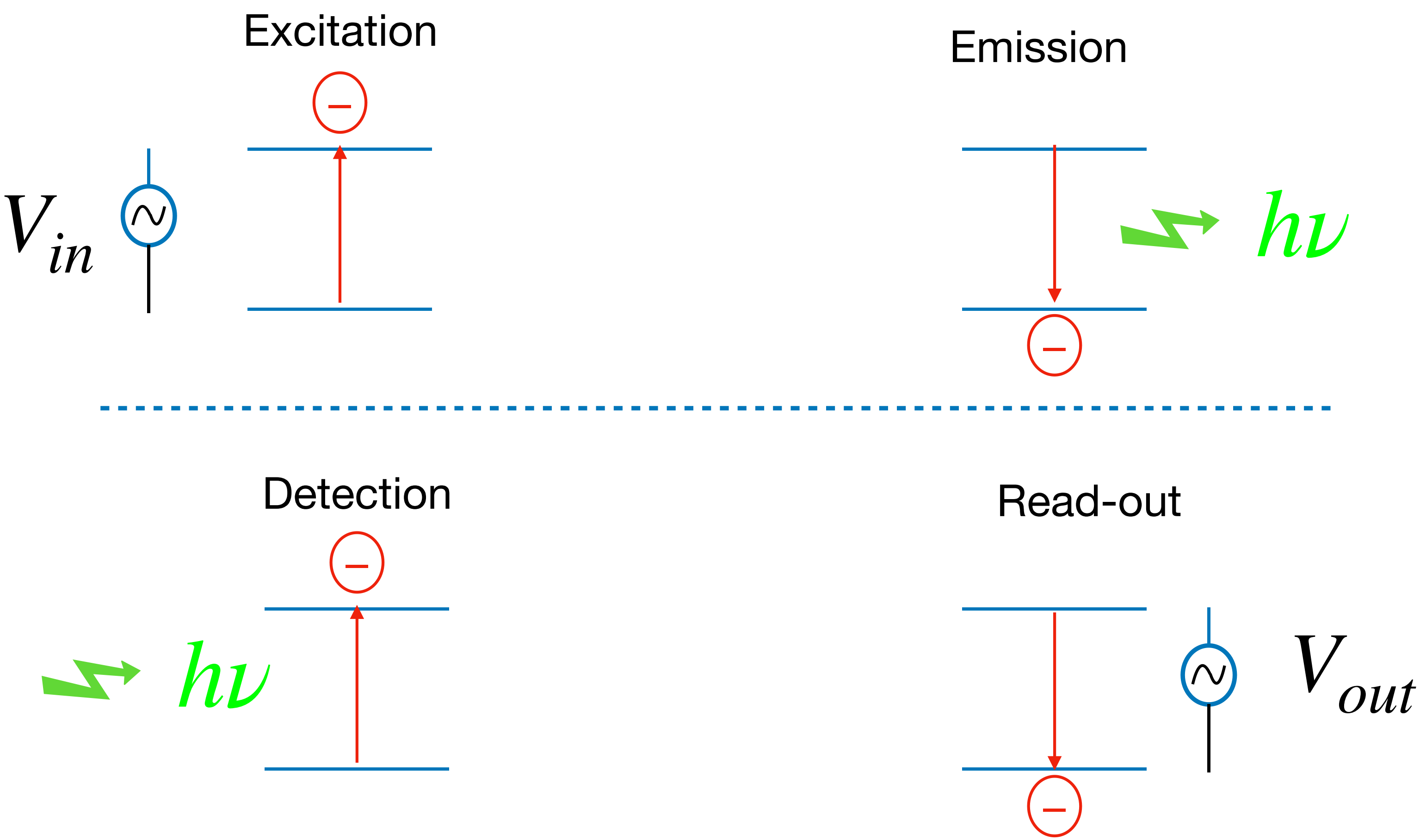
$$E_x = A(x, y, z)cos[\omega t + \phi(x, y, z)]$$


V
E
R

Black Body Radiation

Utraviolet catastrophy

Quantum Optics



MAXWELL EQUATIONS

$$\nabla \times \vec{E} = -\mu \frac{\partial \vec{H}}{\partial t}$$

$$\nabla \times \vec{H} = \varepsilon \frac{\partial \vec{E}}{\partial t} + \vec{J}$$

$$\nabla \bullet \varepsilon \vec{E} = \rho$$

Wave Equation

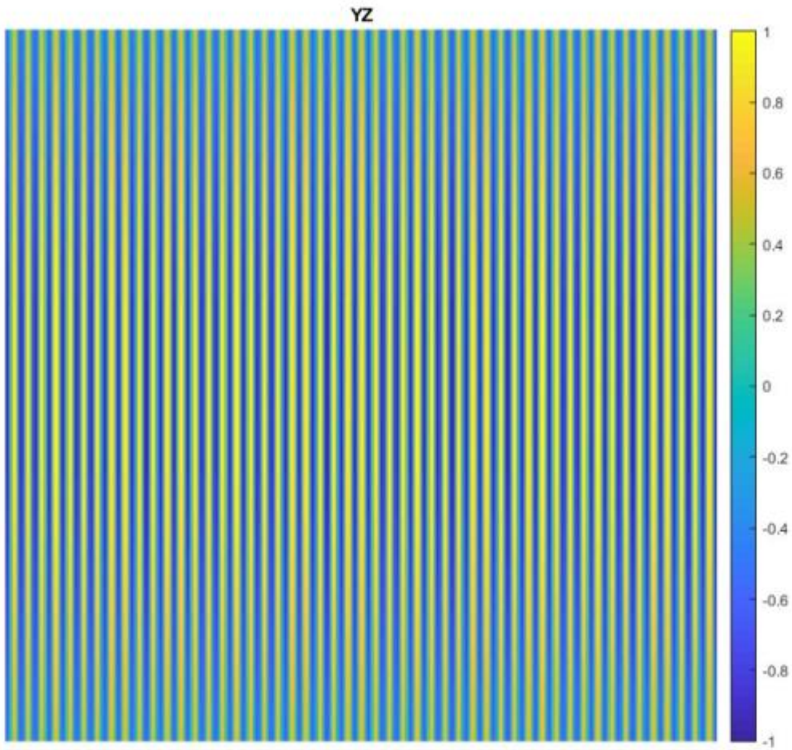
$$\frac{\partial^2 E_x}{\partial x^2} + \frac{\partial^2 E_x}{\partial y^2} + \frac{\partial^2 E_x}{\partial z^2} = -\omega^2 \mu \varepsilon E_x$$

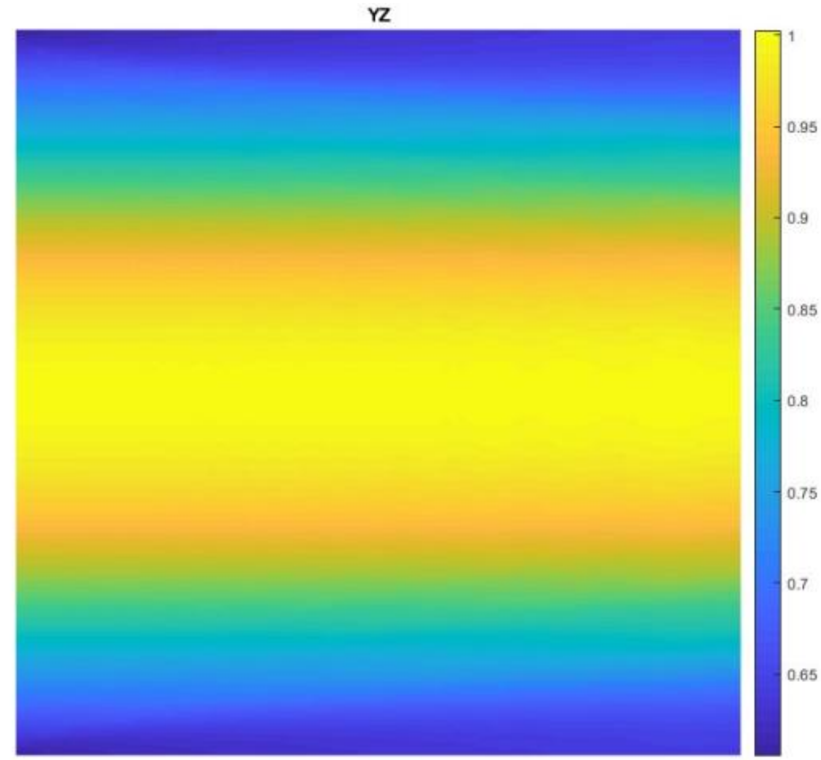
Electric Field Notation

$$E(x, y, z, t) = |A(x, y, z)| \cos[\omega t - \phi'(x, y, z)]$$

$$E(x, y, z, t) = |A(x, y, z)\,| \cos[\omega t - kz - \phi(x, y, z)]$$

$$E(x, y, z, t) = Re\{|A(x, y, z)| e^{-j\phi(x,y,z)}\, e^{j[\omega t - kz]}\}$$





Field vs Envelope

Beam propagation equation

$$\frac{dA}{dz} = - \frac{j}{2k}\left(\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2}\right)$$

Derivation of BPM

$$E_x(x,y,z,t) = A(x,y,z)e^{j(wt-kz)}$$

A Þ *slow envelope*

$$\frac{\partial^2 E_x}{\partial x^2} = \frac{\partial}{\partial x}\left(\frac{\partial A}{\partial x}\right)e^{j\omega t}e^{-jkz} = \frac{\partial^2 A}{\partial x^2}e^{j\omega t}e^{-jkz}$$ same for y

$$\frac{\partial^2 E_x}{\partial z^2} = \frac{\partial}{\partial z}\left(\frac{\partial A}{\partial z}e^{-jkz} - jkAe^{-jkz}\right)e^{j\omega t} = \left(\frac{\partial^2 A}{\partial z^2} - 2jk\frac{\partial A}{\partial z} - k^2 A\right)e^{j\omega t}e^{-jkz}$$

Plugging back into the wave equation and dropping the oscillatory terms that are common to all terms we obtain:

$$\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2} + \frac{\partial^2 A}{\partial z^2} - 2jk\frac{\partial A}{\partial z} - k^2 A = -\omega^2 \mu\varepsilon A$$

Recognizing that

$$-k^2 A = -\omega^2 \mu\varepsilon A$$

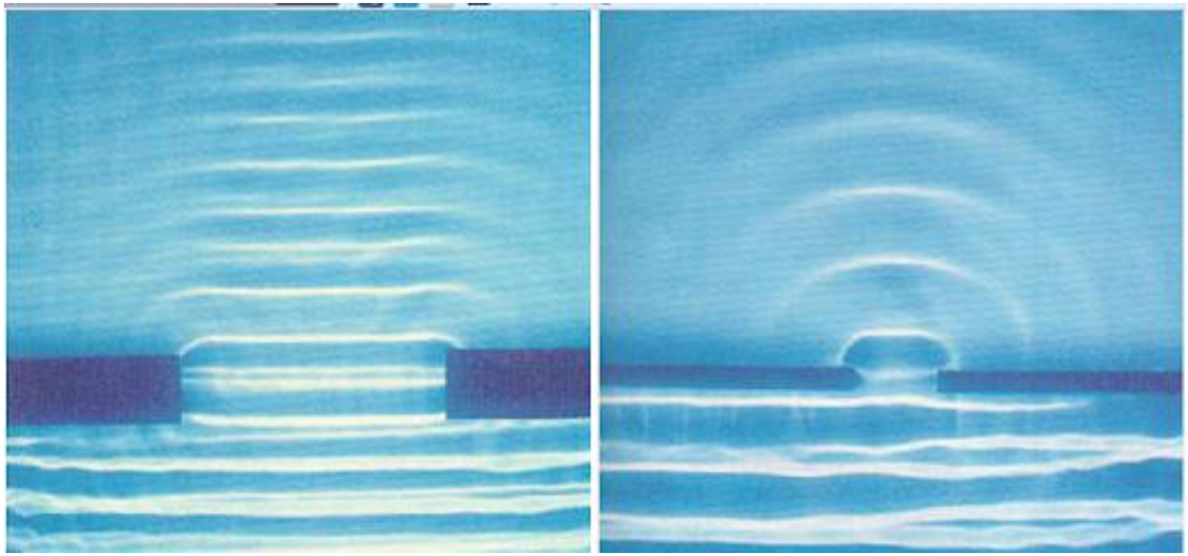
and making the approximation that the second derivative in z of the A envelope (slowly varying in z) is negligible we obtain

$$2jk\frac{\partial A}{\partial z} \simeq \frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2}$$

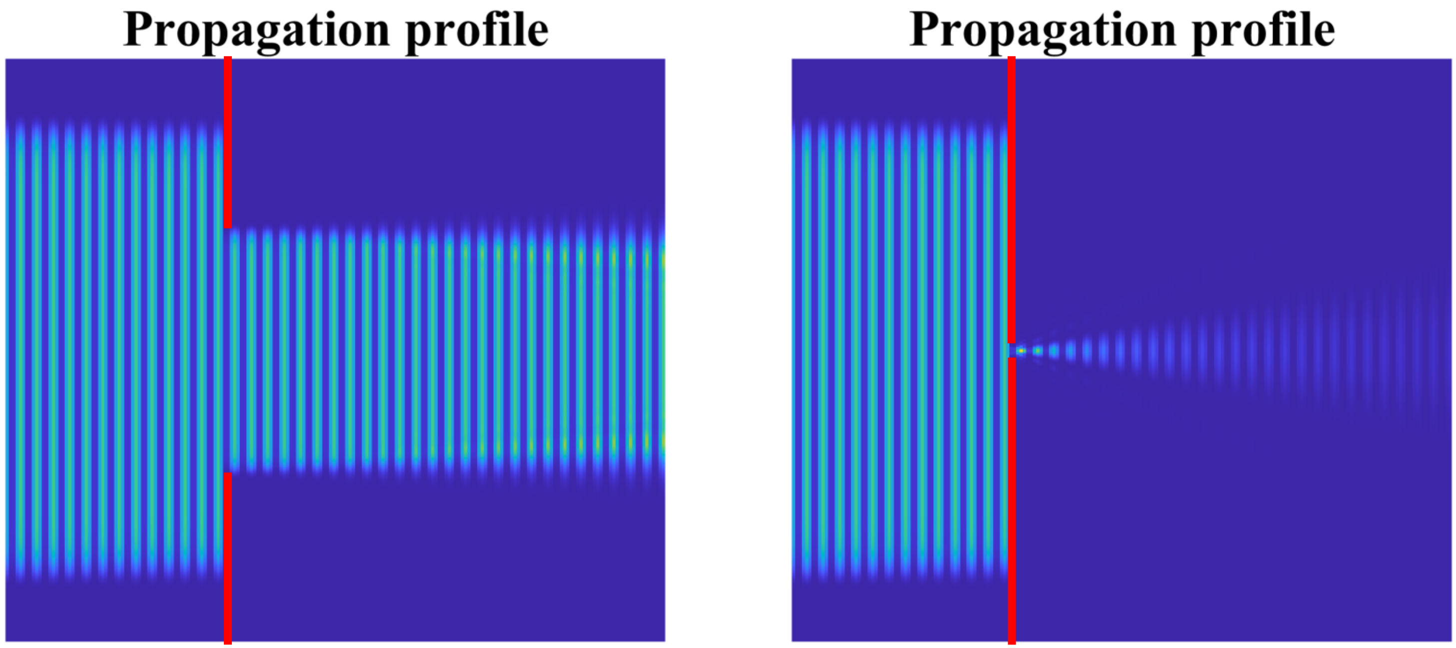
or

$$\boxed{\frac{\partial A}{\partial z} \simeq -\frac{j}{2k}\left(\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2}\right)} \xrightarrow{FT} \boxed{\tilde{A}(k_x,k_y,z) = e^{j\left[\frac{k_x^2+k_y^2}{2k}\right]z}\tilde{A}(k_x,k_y,z=0)}$$

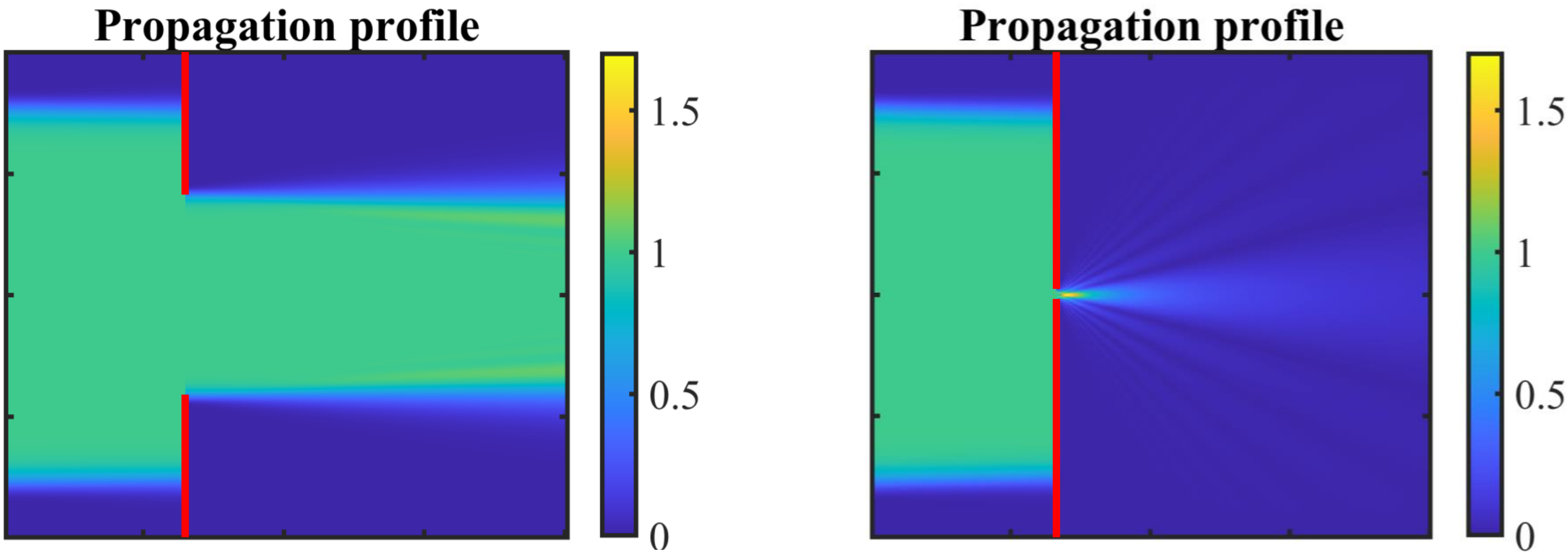
Diffraction of sea waves



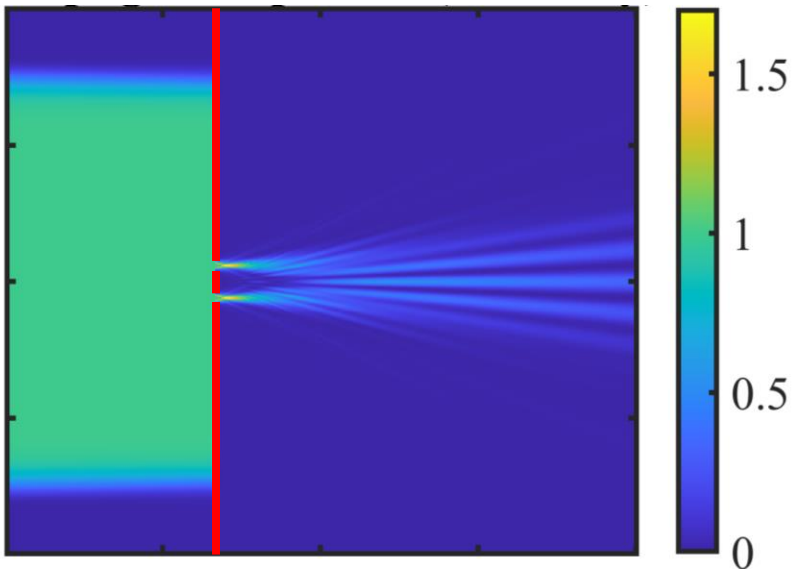
Diffraction of light

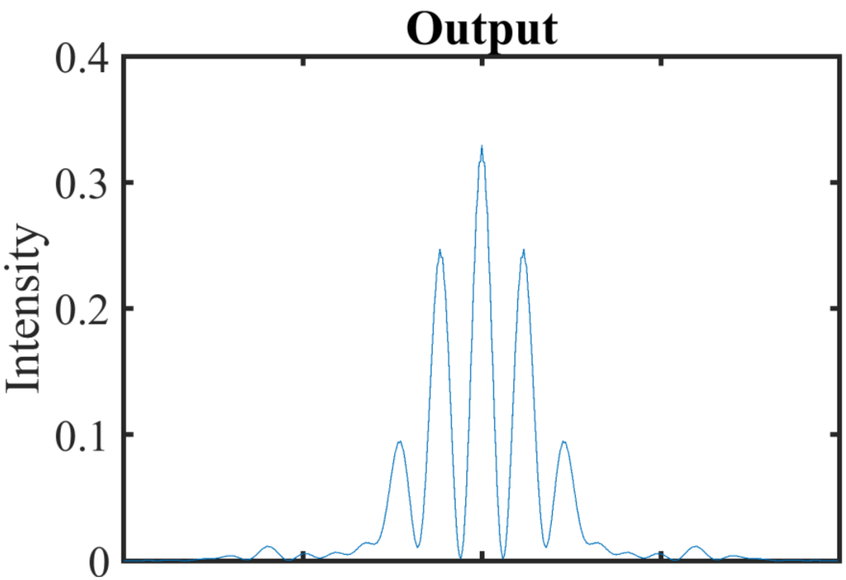


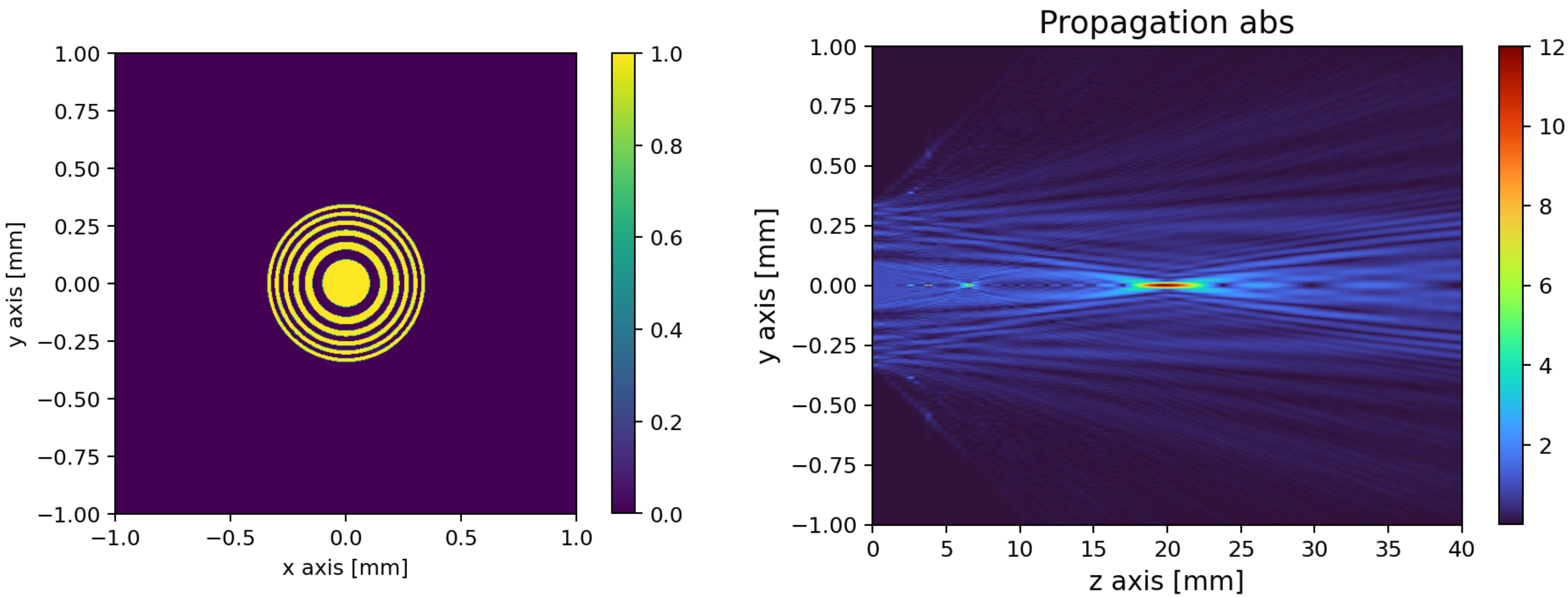
Envelope



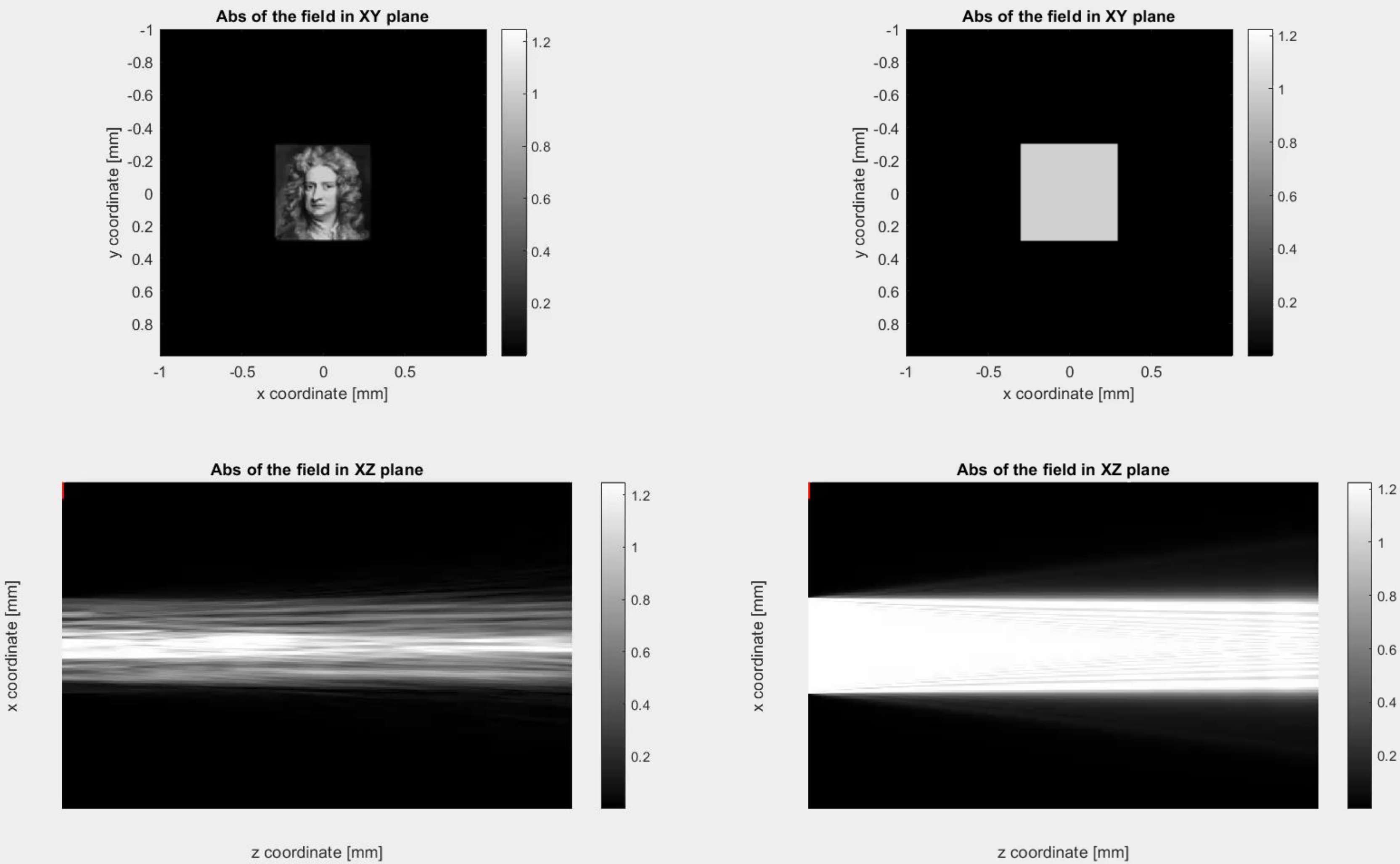
Young’s experiment



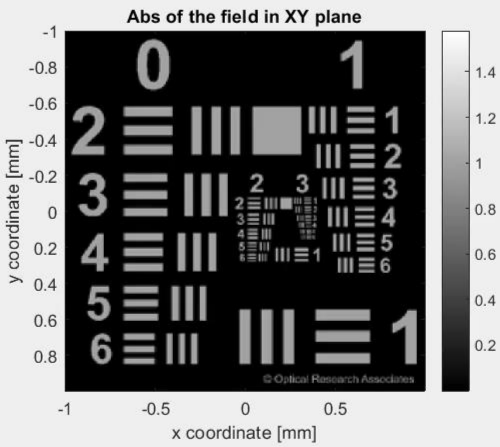


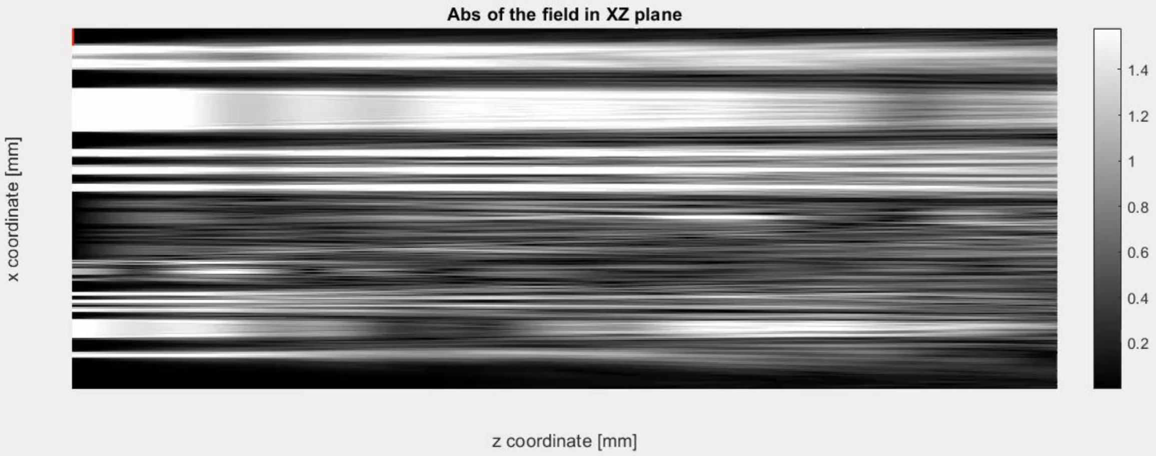

Propagation abs
y axis [mm]
x axis [mm]
z axis [mm]

Diffraction Sir Isaac Newton vs Square aperture

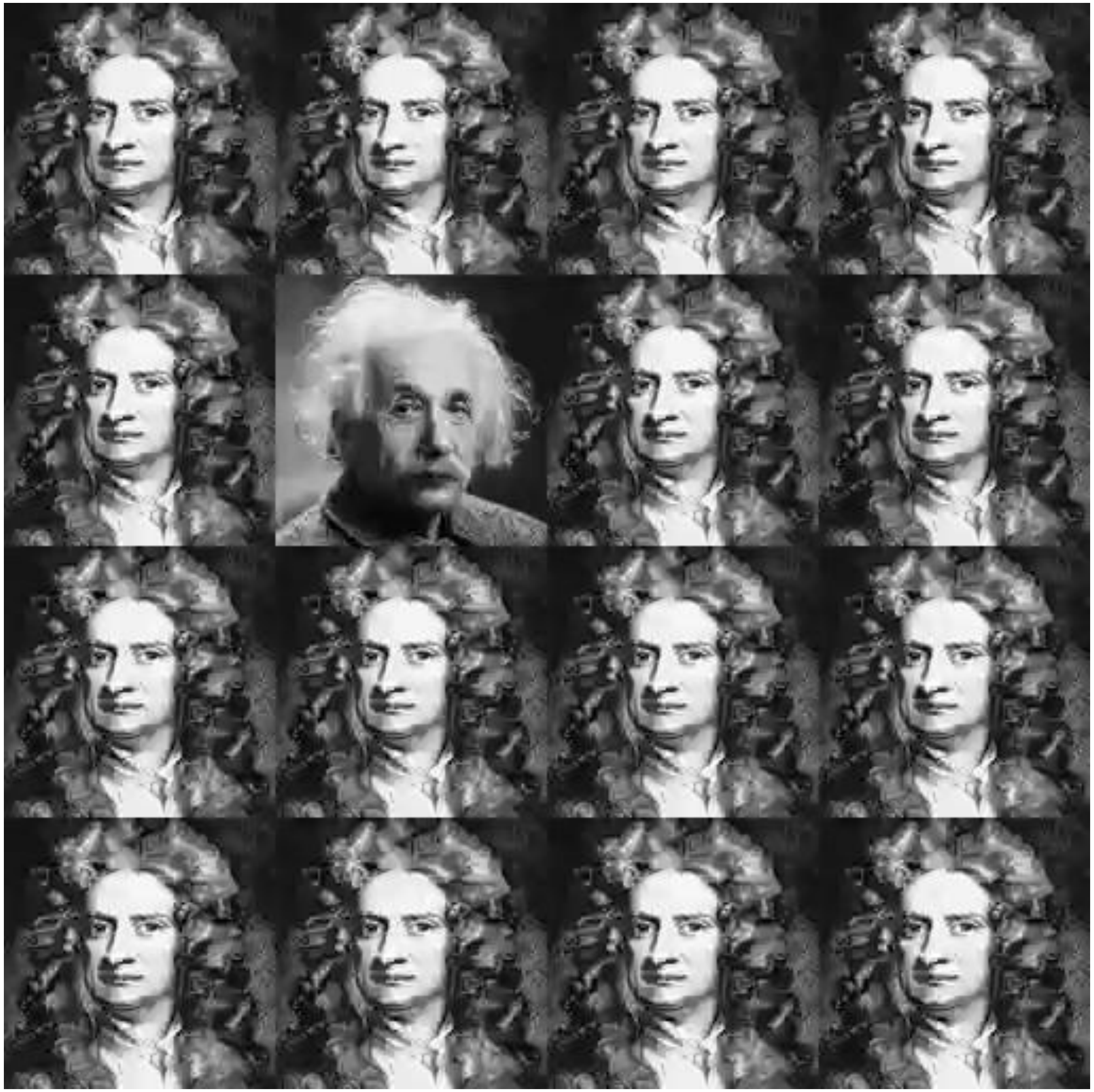


Air Force chart





Talbot

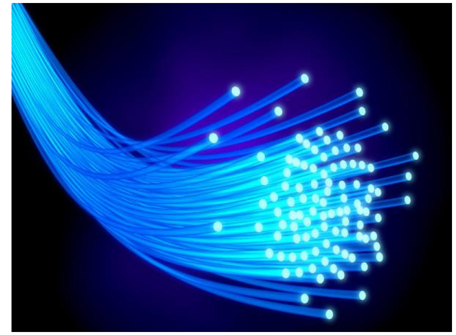


Just after sunset

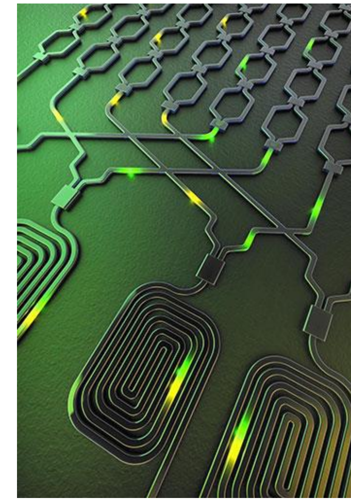
Optical technologies probably started with lenses for vision, microscopy and telescopes (Galileo). This continues to this day but there is a lot more.

Lighting; From torches, to Edison's light bulbs to today's LED lights. **Nobel**

Lasers: Stimultated emission (Einstein), laser **Nobel**

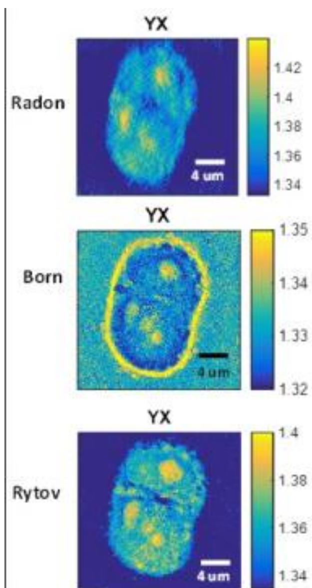


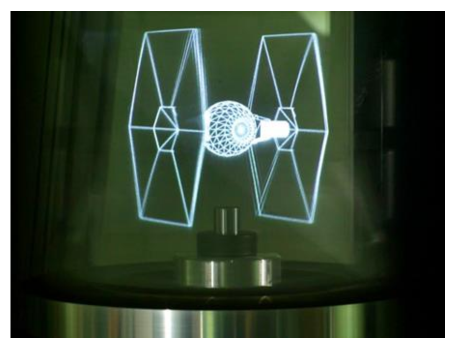
Communication: From smoke signals today's free space optics but also fiber optics. **Nobel**



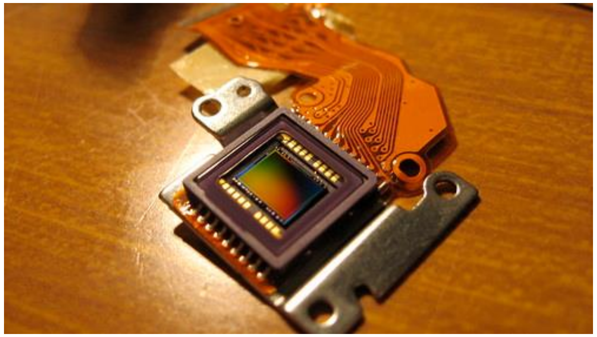
Computing: Optical interconnects in computers, data centers, silicon photonics

Medicine, biology: Endoscopy, microscopy, laser surgery, optogenetics **Nobel**





Displays. CRT's to LC displays, to 3D. (holography and light field) **Nobel**

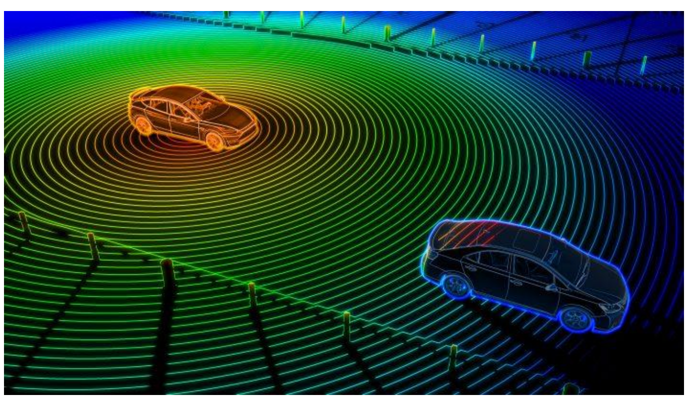


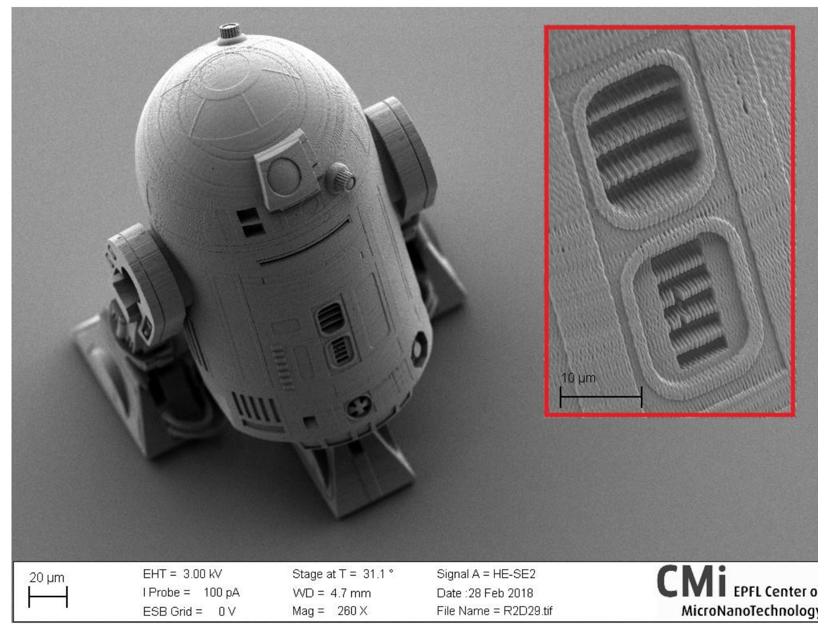
Sensors Image sensors, Doppler, 3D measurement, chemical, etc, Nobel for CCD

Astronomy; From Galileo to the gravity wave detector **Nobel**

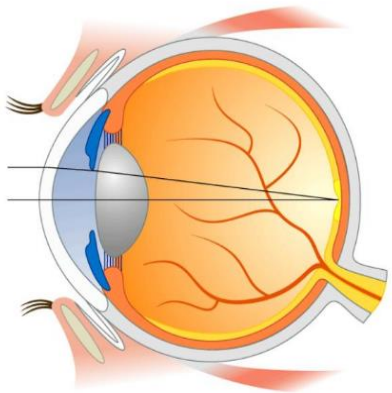
Energy; Photovoltaics and solar fuels (artificial photosynthesis)

Transportation: Lidar for self-driving cars

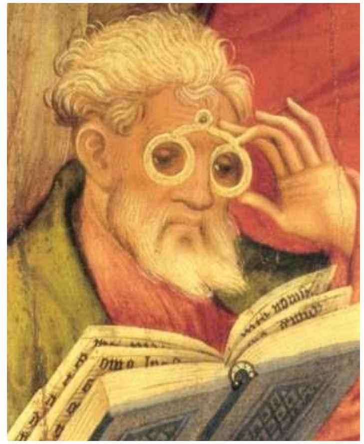




Manufacturing: From laser machining to 3D Printing



Eye
530M BC



Glasses
1306 AD

Telescopes
1609 AD

Microscope
1620 AD

Camera
?
1826 AD

Endoscope
?
1805 AD
1853 AD

Photolithography
?
1826 AD
1958 AD

Egypt, 4500 years ago...

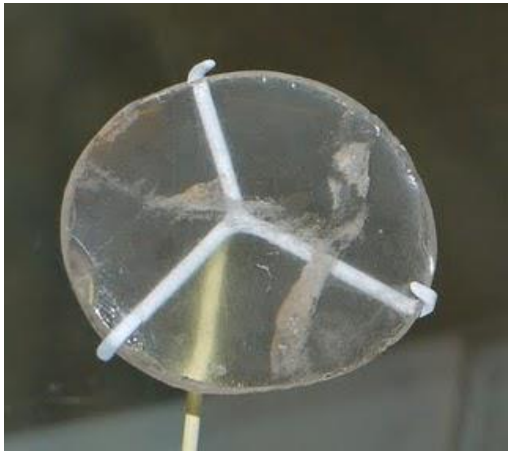
Troy

Heinrich Schliemman, ~40 lenses

Nirmud lens; 3000 years ago

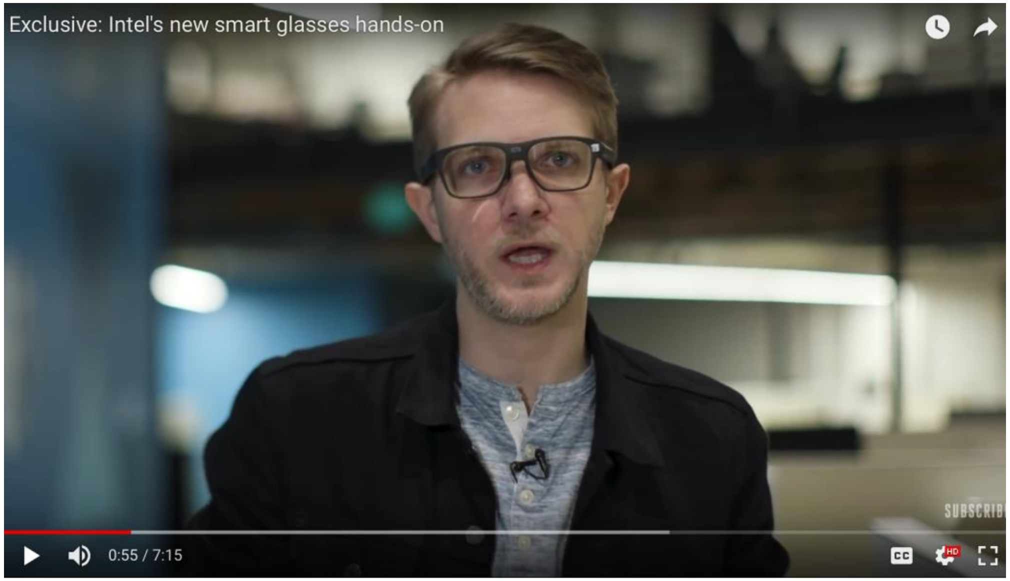
Assyrian palace of Nirmud

3x lens, F=12cm



Eyeglasses

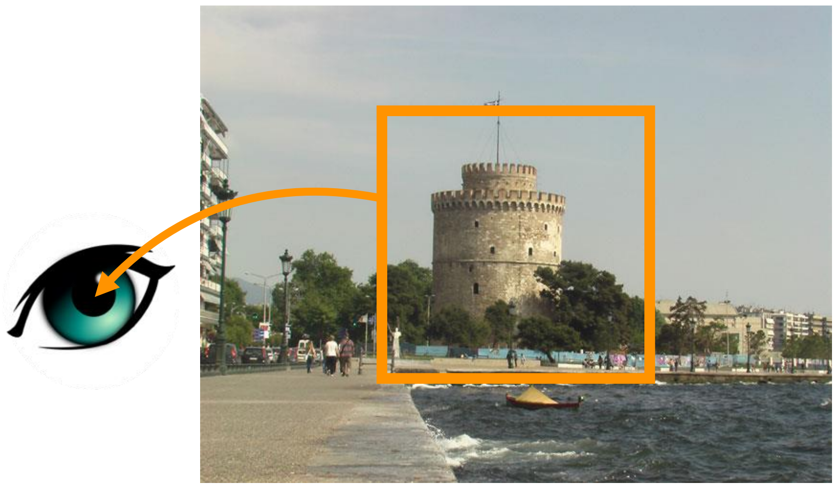
1306 Giordano da Pisa speech: *eyeglasses were invented 20 years ago*



INTEL MADE SMART GLASSES THAT LOOK NORMAL

https://www.theverge.com/2018/2/5/16966530/intel-vaunt-smart-glasses-announced-ar-video

Seeing through fog



$$B = L(A)$$

The lens of the human eye inverts the free space transformation

$$\underbrace{\left(\nabla^2 + k^2 n(\mathbf{r}^2)\right)}_{L'} A = 0 \qquad B' = L'(A)$$

The linear transformation has now changed and the eye lens yields a result that is not the original image

BPM in Julia

by

Felix Wechsler