Introduction to Holography with MATLAB - Workshop

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Photonics & FÜSX 2022

7th July 2022 @ Physicum

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OUTLINE

- Fundamentals of wave propagation
- Calibration of space in MATLAB
- Diffraction
- Interference
- Holography
- Holographic optical elements
- Cryptography
- Game

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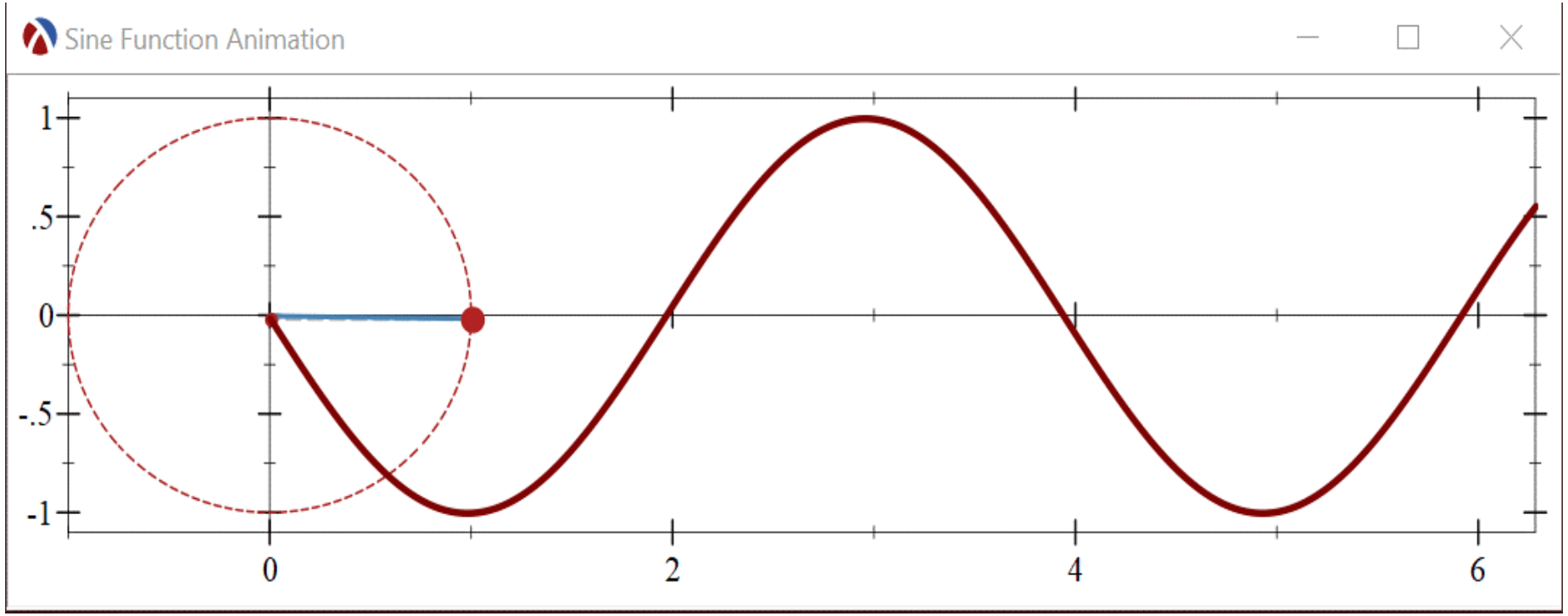
Fundamentals of wave propagation



sin θ = opposite side/Hypotenuse

Courtesy: Falstad.com, Wikipedia, Alex Harsányi

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Fundamentals of wave propagation

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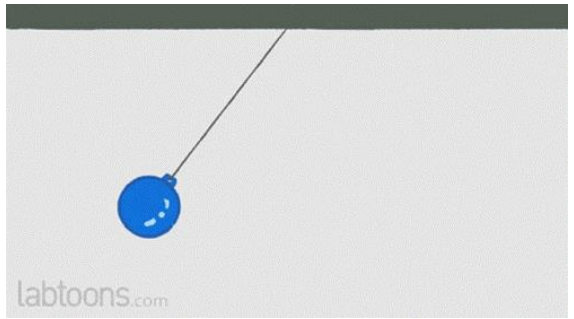
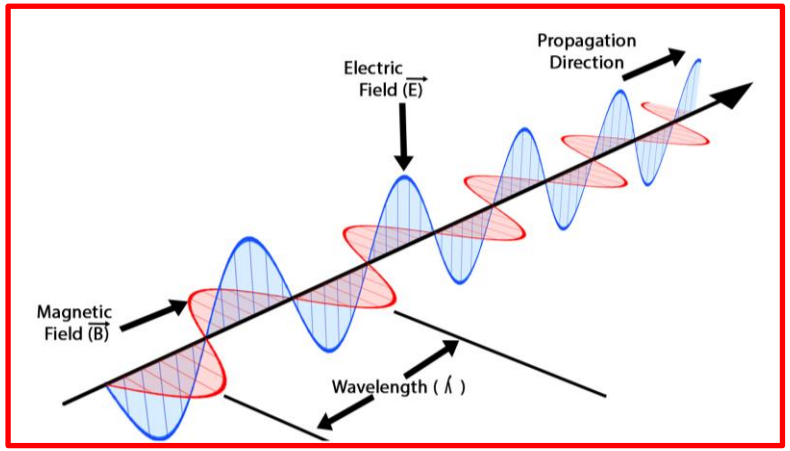
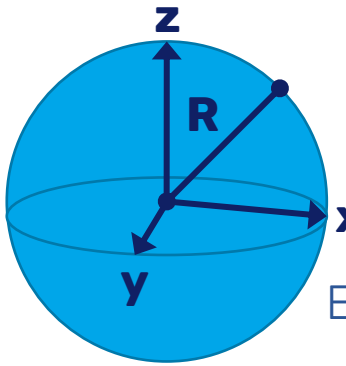




$E(\mathbf{R})=(E_{max}/|\mathbf{R}|)\sin(k\mathbf{R})$

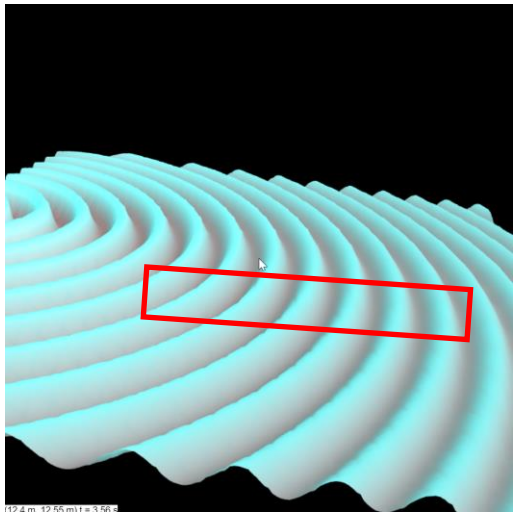


$e^{i\theta}=\cos(\theta)+i\sin(\theta)$

Complex Amplitude

$E(\mathbf{R})=(E_{max}/|\mathbf{R}|)\exp(ik\mathbf{R})$

$\mathbf{R}=\sqrt{x^2+y^2+z^2}$

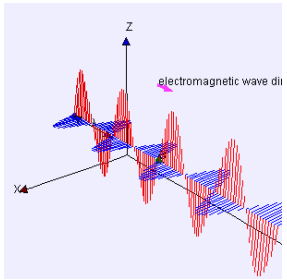


z

$E(z)=E_{max}\sin[(2\pi/\lambda)\cdot z)] = E_{max}\sin(k\cdot z)$

Wave number

$T = \lambda/c$



$E(t)=E_{max}\sin[(2\pi/T)\cdot t)] = E_{max}\sin(\omega t)$

Angular frequency

$E(z,t)=E_{max}\sin(kz-\omega t)$

Freezing time

$E(z)=E_{max}\sin(kz)$

Courtesy: Falstad.com, Wikipedia, Alex Harsányi

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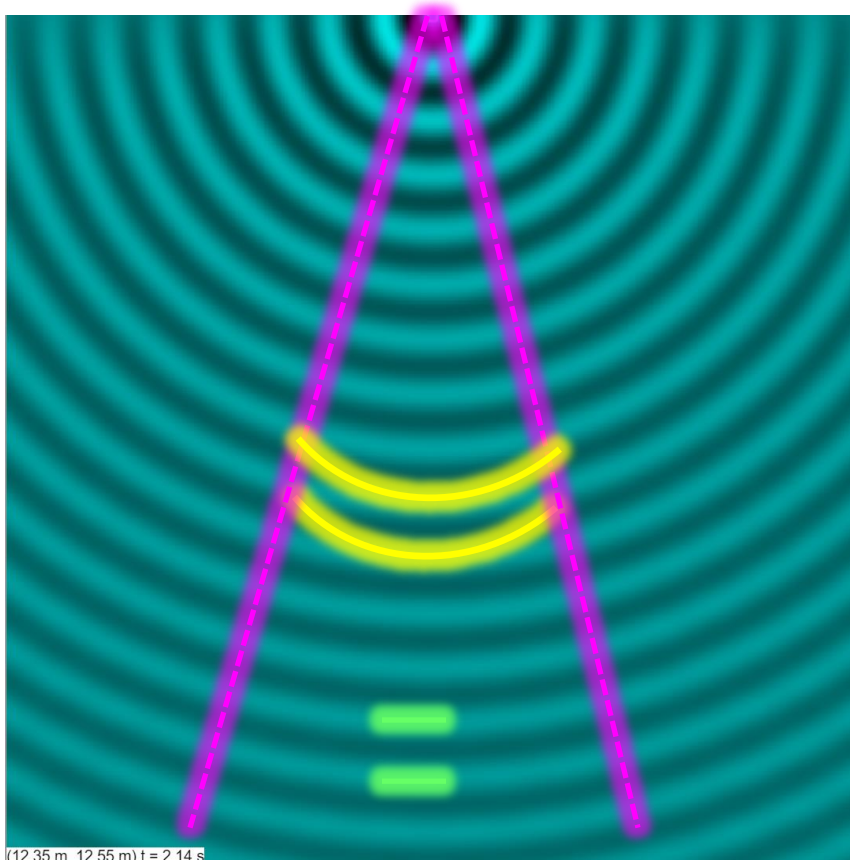
Fundamentals of wave propagation



Spherical wave

$E(\mathbf{r})=(A_0/r)\exp(-jkr)$

Paraboloidal wave

$$r=\sqrt{x^2+y^2+z^2}=z\sqrt{1+\theta^2}=z\left(1+\frac{\theta^2}{2}-\frac{\theta^4}{8}+\cdots\right)$$
$$\approx z\left(1+\frac{\theta^2}{2}\right)=z+\frac{x^2+y^2}{2z}.$$

$E(\mathbf{r})=(A_0/z)\exp(-jkz)\ \exp[-jk(x^2+y^2)/2z]$

Plane wave

$E(\mathbf{r})=A\exp(-jkz)$

Important to understand Fourier optics

Courtesy: Falstad.com, Saleh and Teich Fundamentals of photonics

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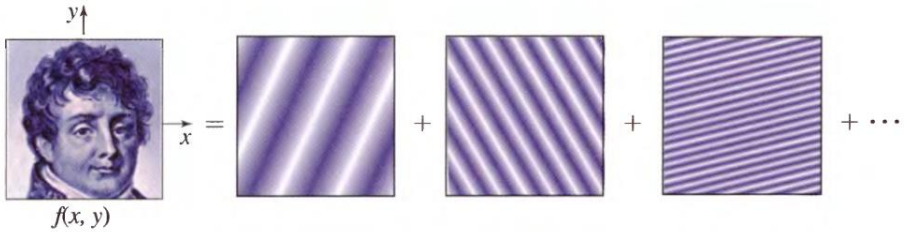
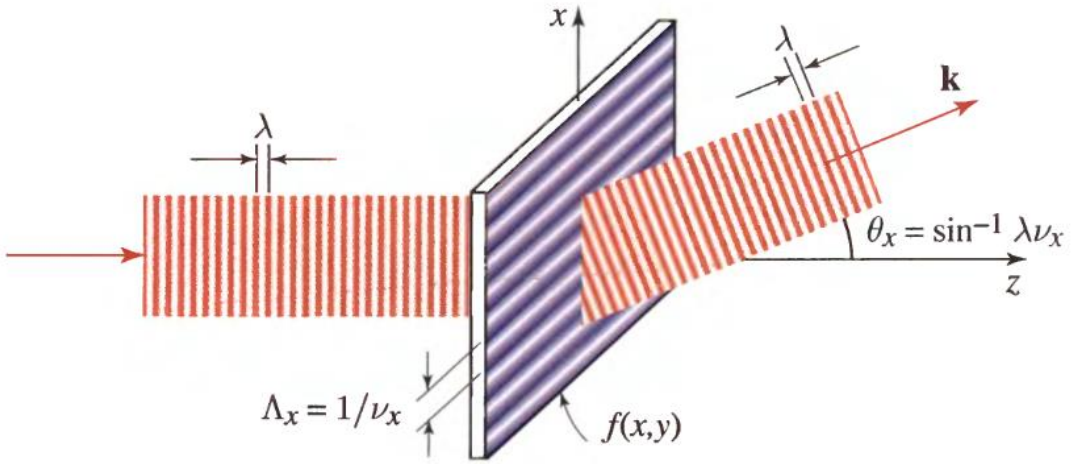
Fundamentals of wave propagation

Time domain

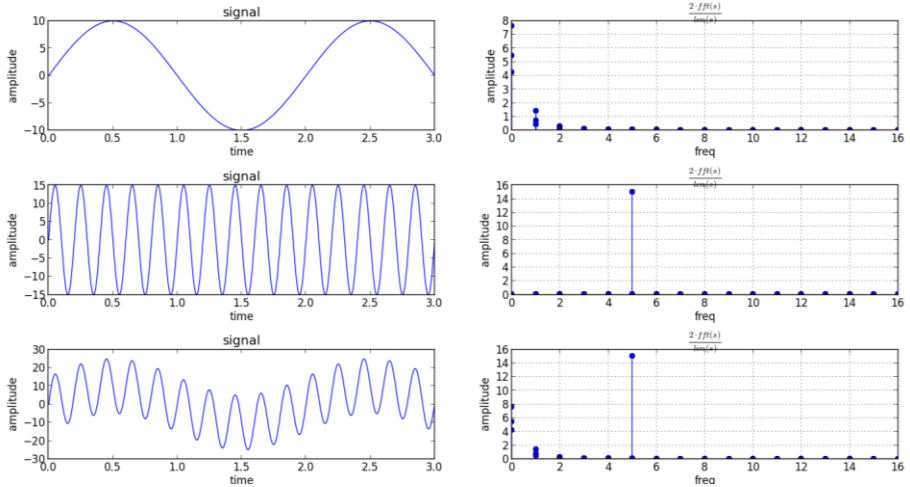
Space domain





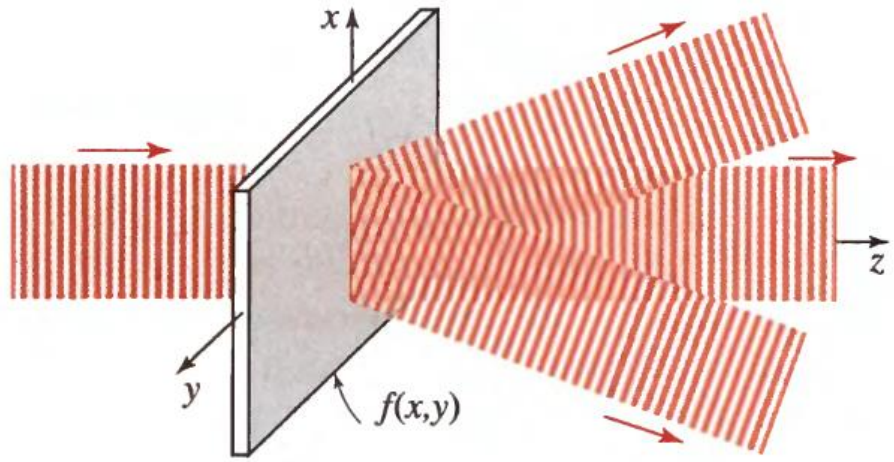
Space/Time domain

Spatial frequency/ Frequency domain



Space domain

Spatial frequency domain



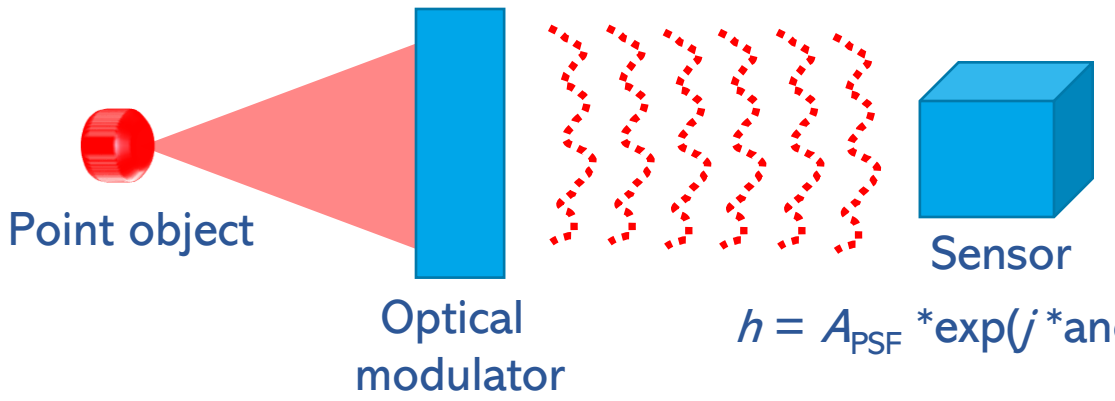
Courtesy: Stack overflow, Saleh and Teich Fundamentals of photonics

Fundamentals of wave propagation

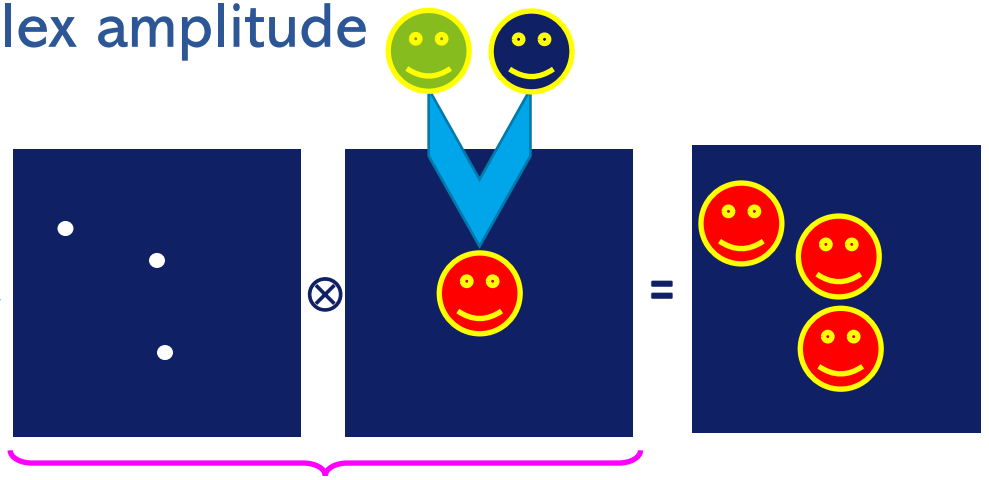
Coherent systems – Linearity: Linear in complex amplitude

$$I_i = \left| h \otimes U_o \right|^2$$

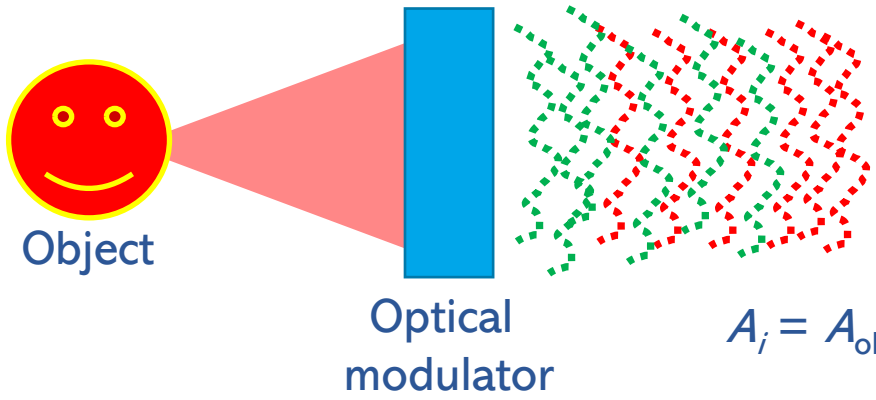
Convolution



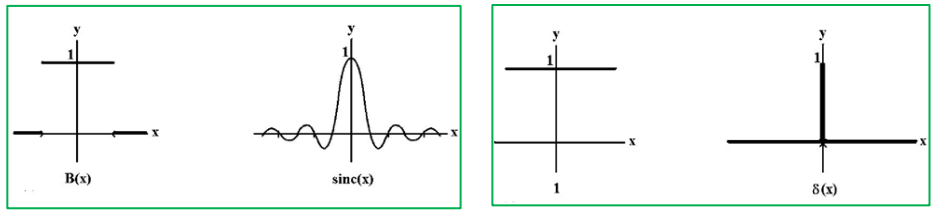
$h = A_{PSF} * \exp(j * \text{angle}_{PSF})$



$$F^{-1}\left[F\{\ \} \times F\{\ \} \right]$$



$A_i = A_{obj} * \exp(j * \text{angle}_{obj})$



Courtesy: Falstad.com, Wikipedia, Alex Harsányi

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Calibration of space in MATLAB

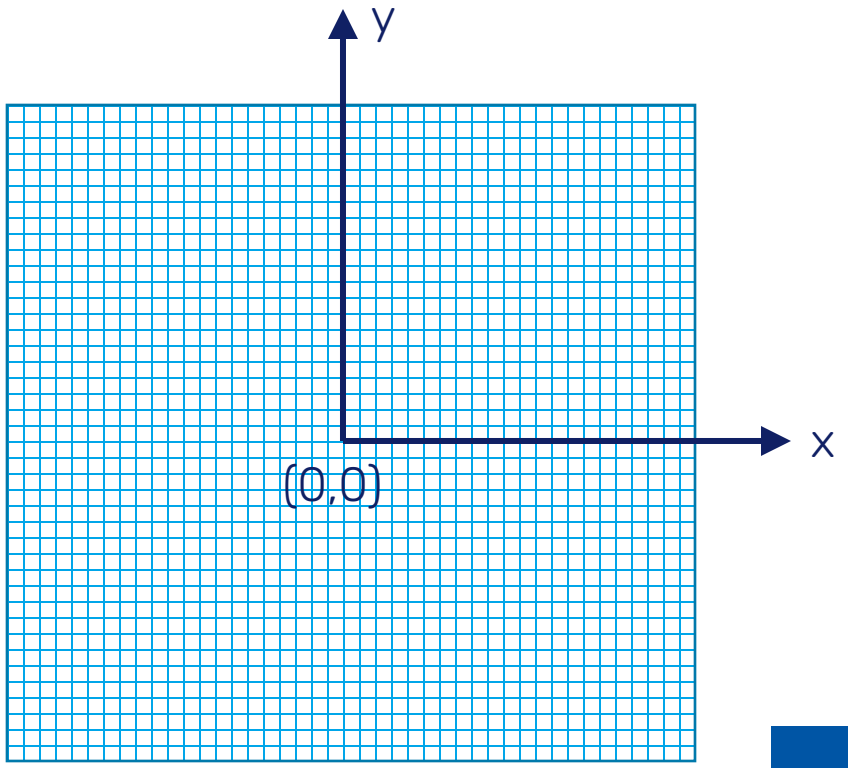
Step – 1 Set the matrix size N

Step – 2 Set origin to the center for x and y axes

Step – 3 Define pixel size

Step – 4 Define Wavelength

Step – 5 Create calibrated space



Exercise - 1 Create two squares each with a length of 50 pixels and spacing of 50 pixels one of the square has a phase of pi and the other has a phase of pi/2

File – Calibration.m

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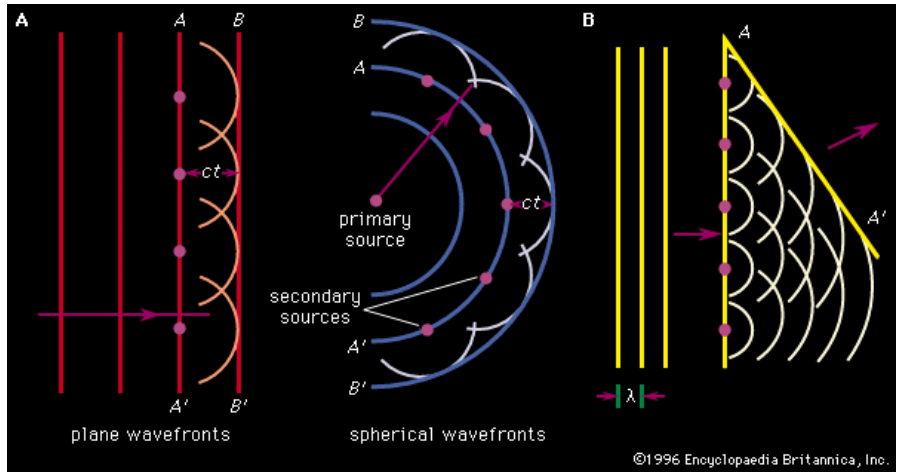
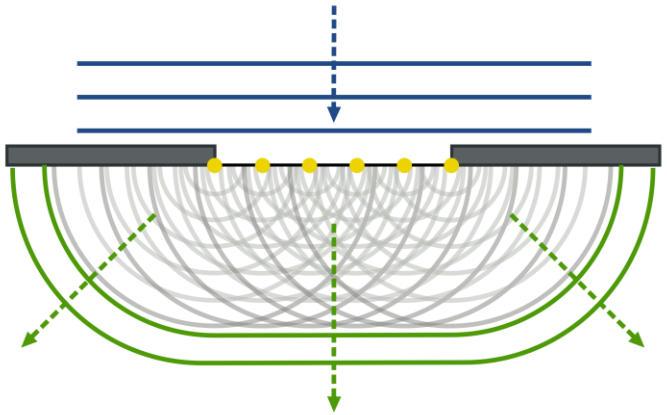
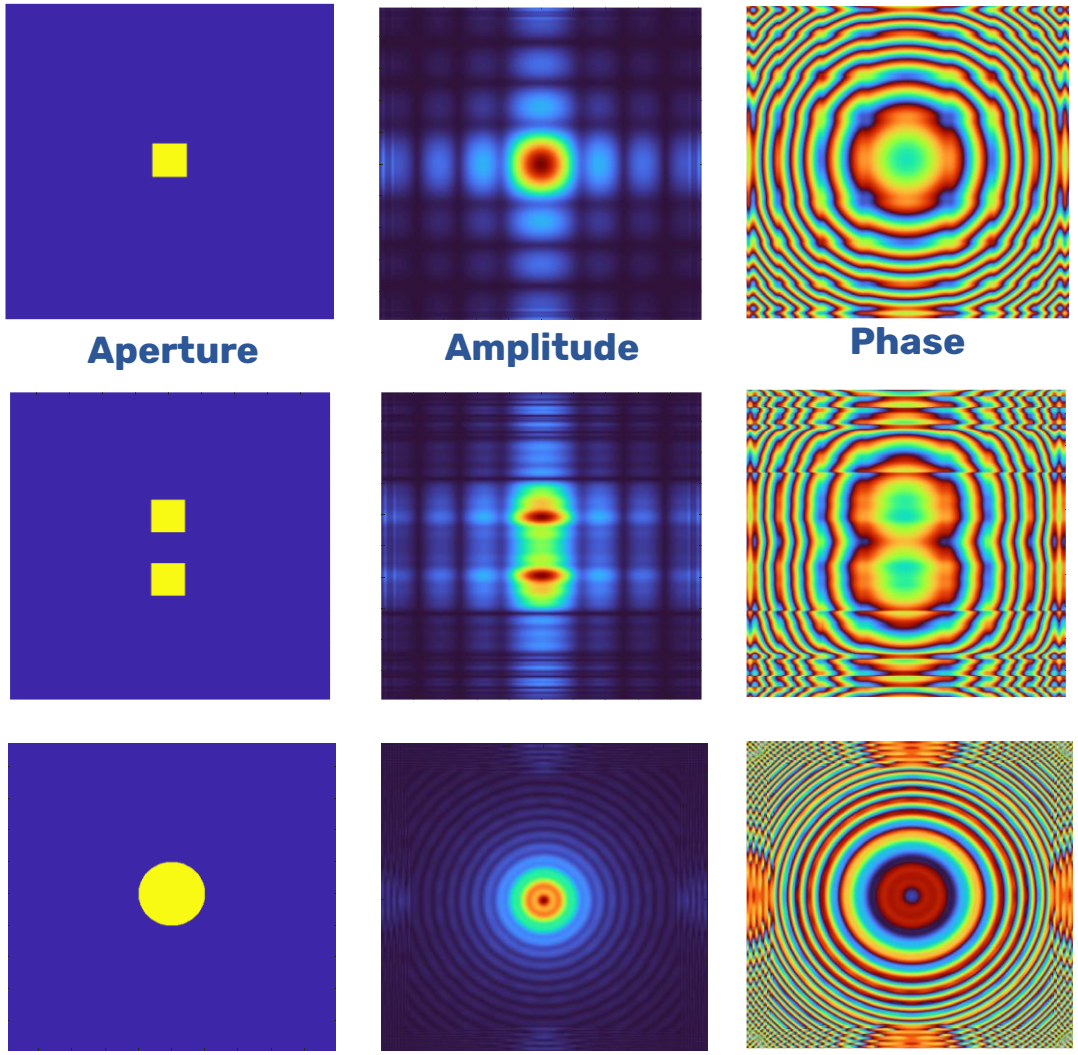
Diffraction of light







Exercise - 2 Create a ring with a thickness of 5 pixels and outer diameter of 55 pixels and calculate the diffraction pattern at 20 cm

Files – Square_slit.m, Square_double_slits.m and Airy_disc.m

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Courtesy: Britannica Encyclopedia, Wikipedia

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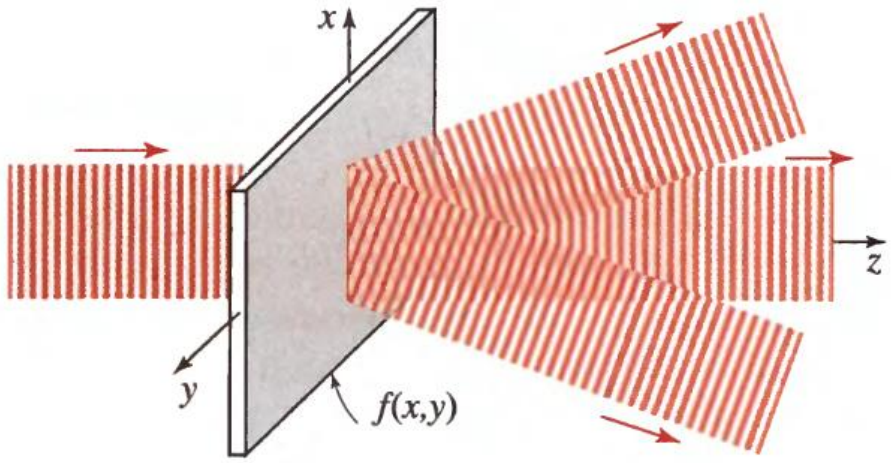
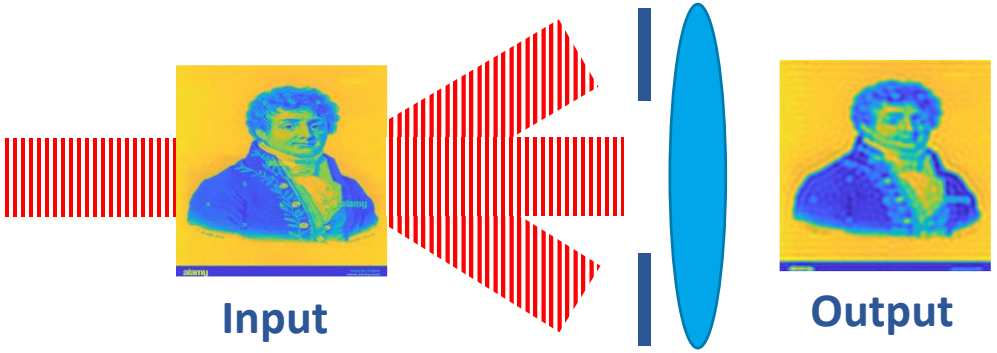
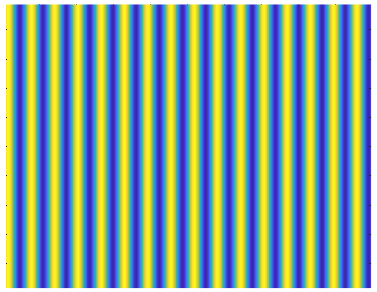
Diffraction of light

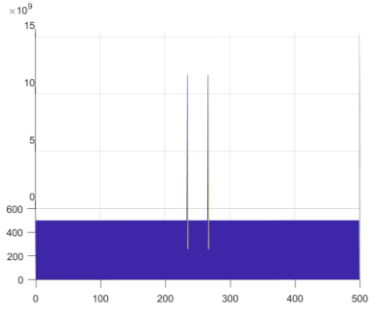




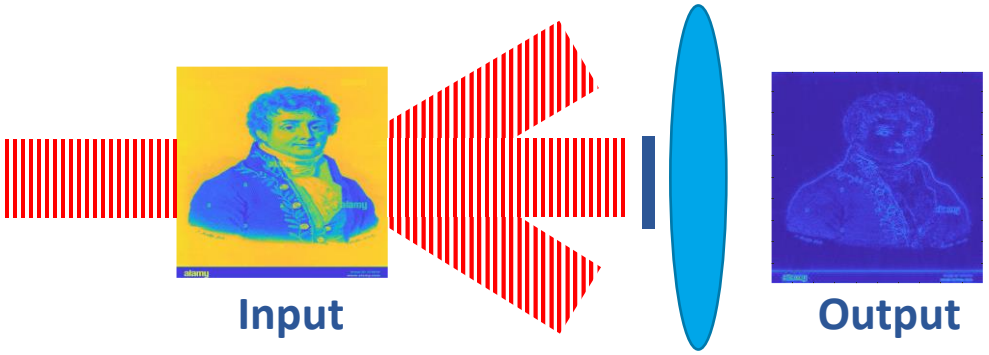
Low pass filtering



Space domain



Spatial Frequency domain



High pass filtering

Exercise - 3 Create two different spatial frequencies, sum them and observe in spectrum domain

Exercise - 4 Create bandpass filtering for the Image

Files – Fourier1.m, and Picture.m

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Courtesy: Saleh and Teich Fundamentals of photonics

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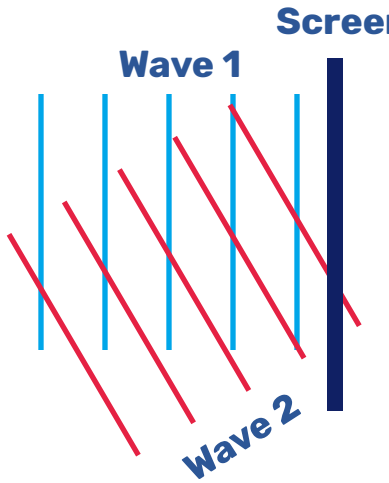
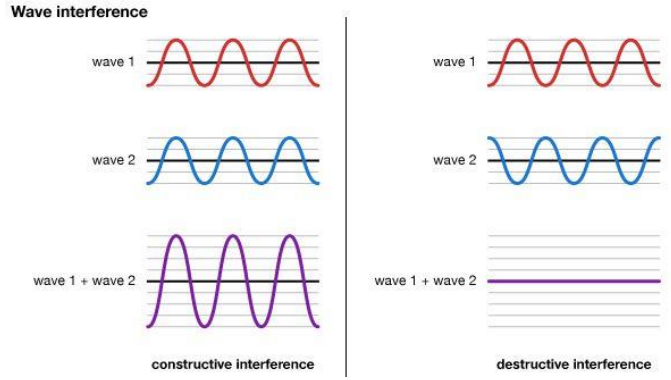
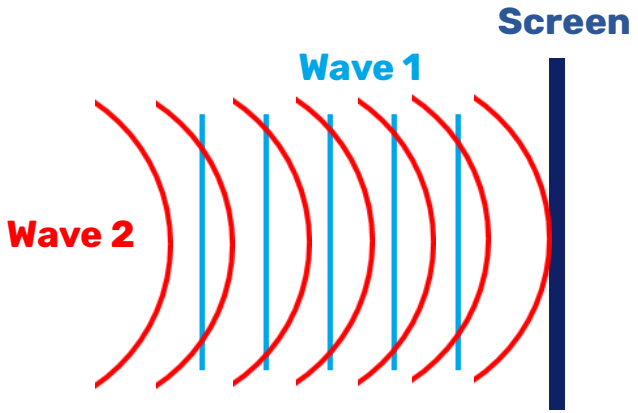
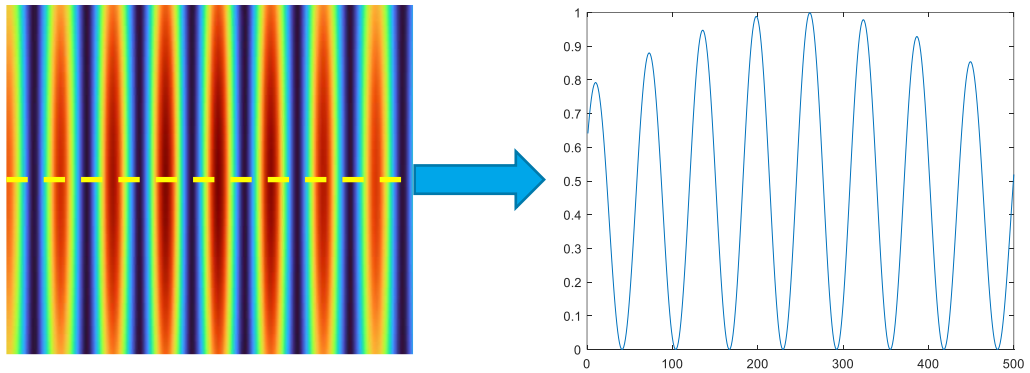
Interference – two and three beams

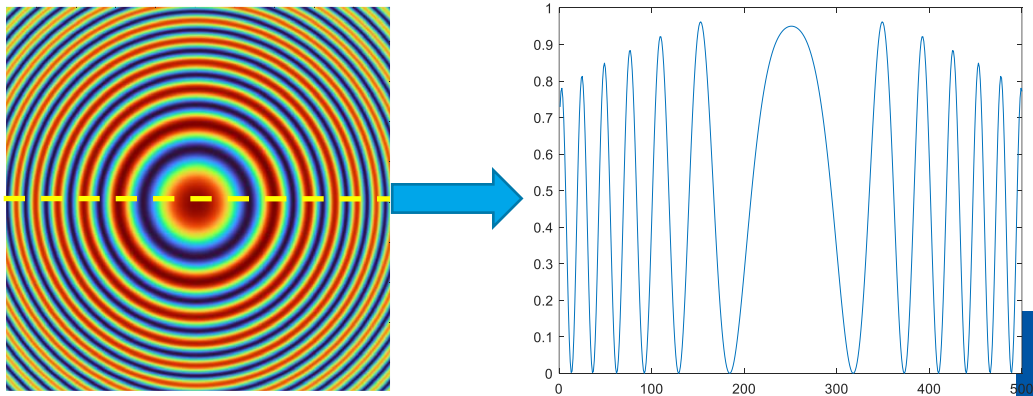








Exercise - 5 Create three wave interference with plane waves and synthesize the interference pattern



Exercise - 6 Create a conical wave and interfere it with a tilted plane wave and synthesize the interference pattern

Files: Two_plane_waves.m, Spherical_plane_waves.m

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Courtesy: Britannica Encyclopedia, Wikipedia

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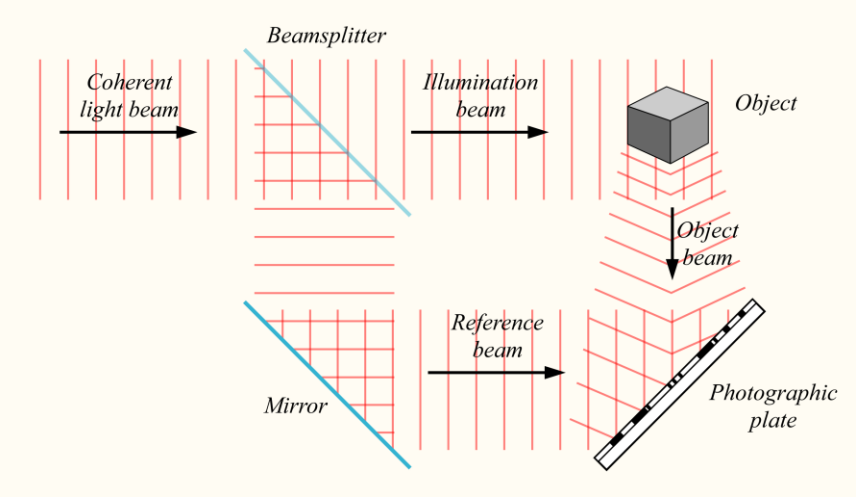
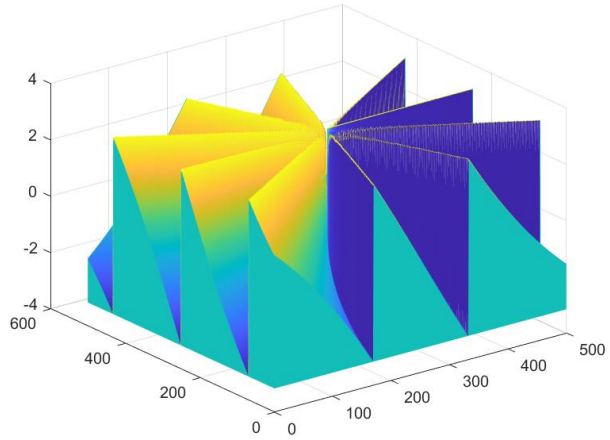
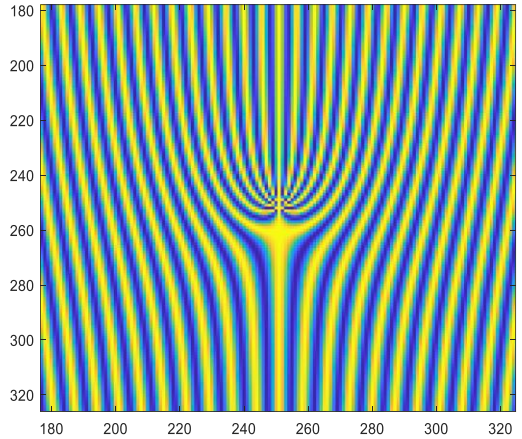
Holography – Recording and reconstruction

Hologram recording set up



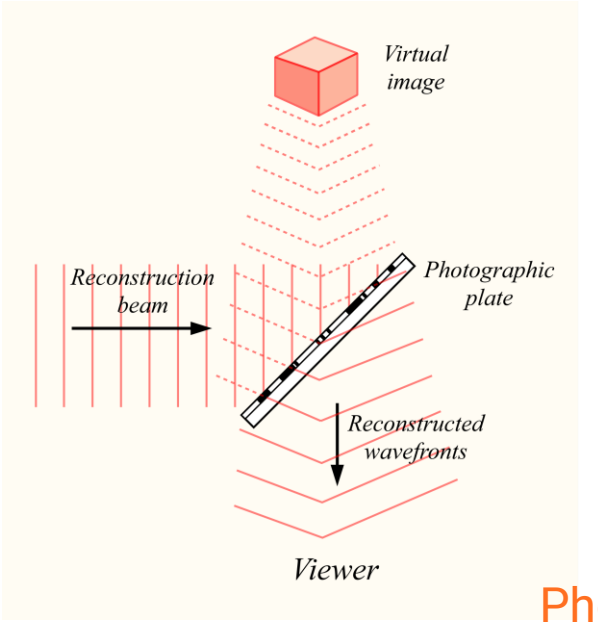


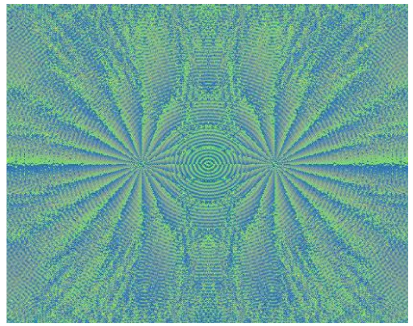
Phase object



Computer generated Hologram

Hologram reconstruction





Reconstruction

Files: Spiral_object.m

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Courtesy: Wikipedia

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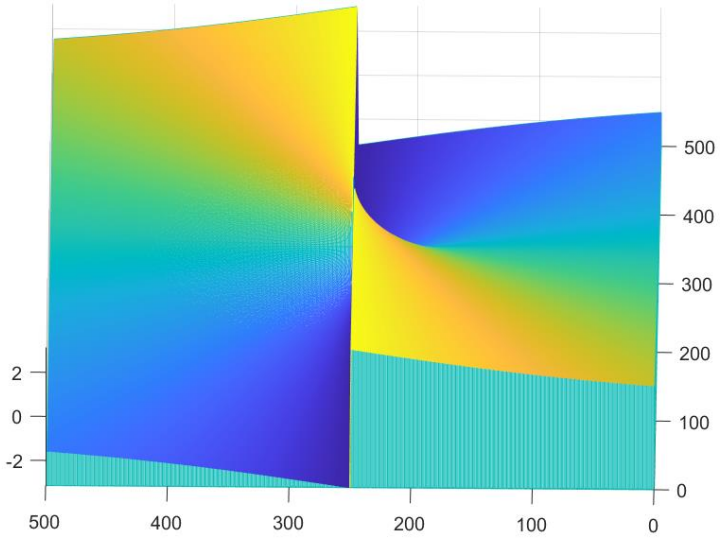
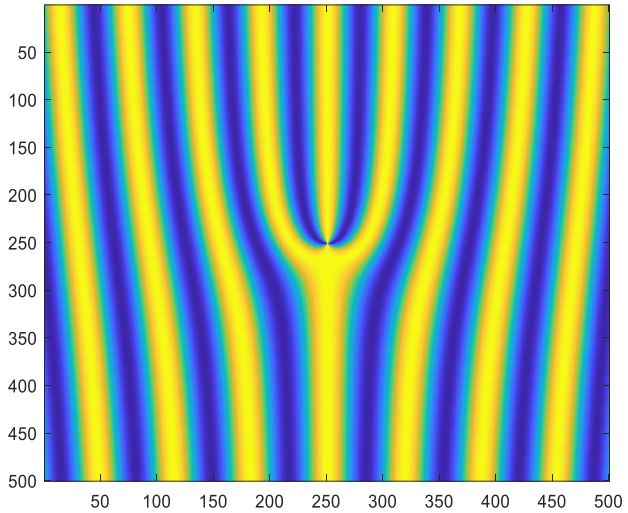
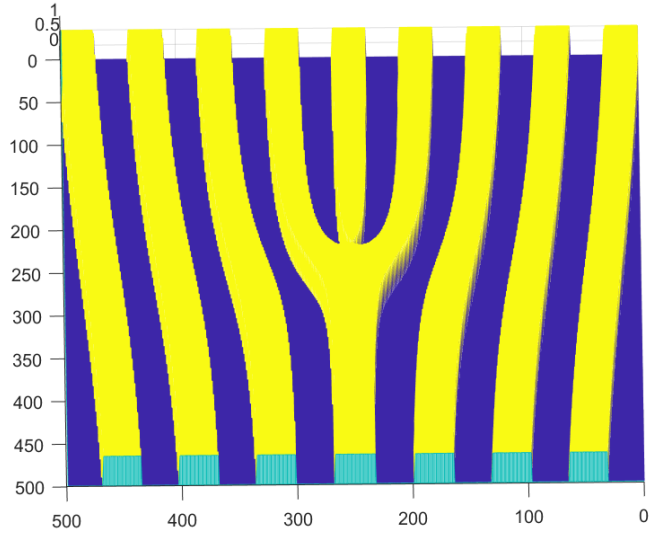
Holographic optical elements



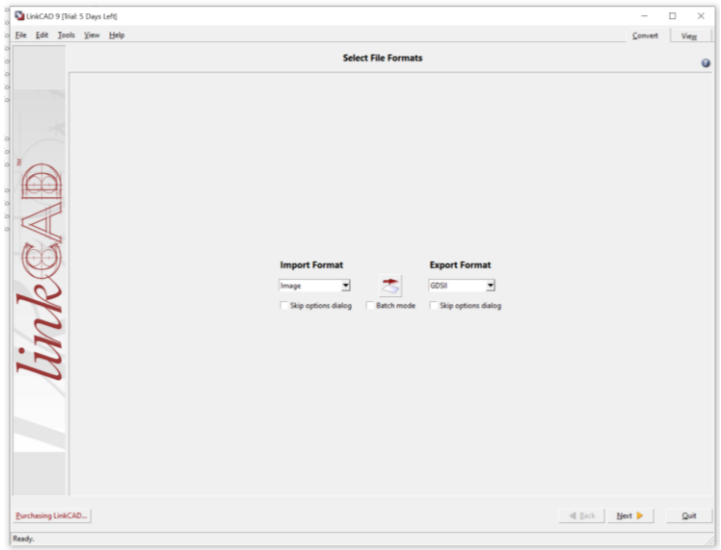
Spiral phase with topological charge 2

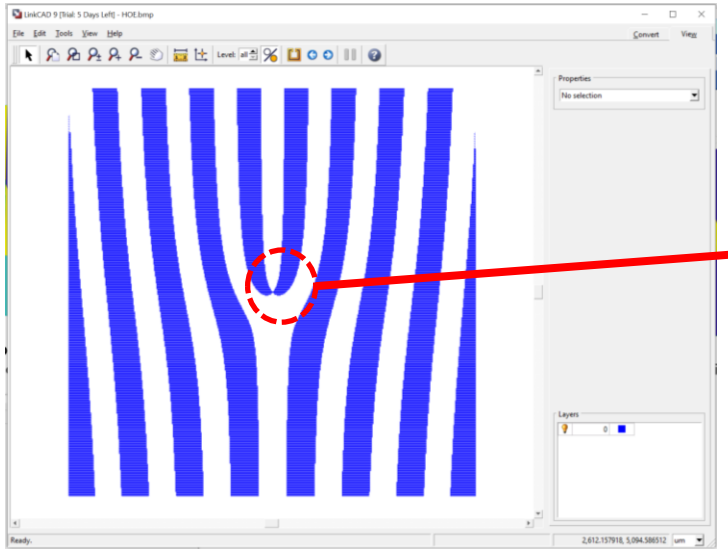


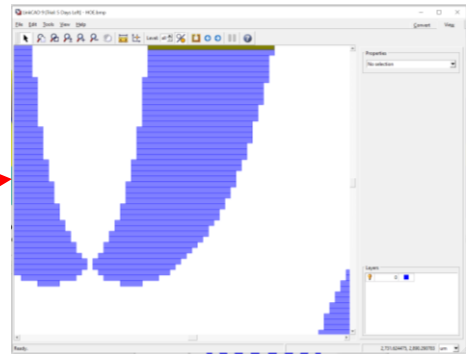
Computer generated Hologram



Holographic optical element







Files: HOE.m

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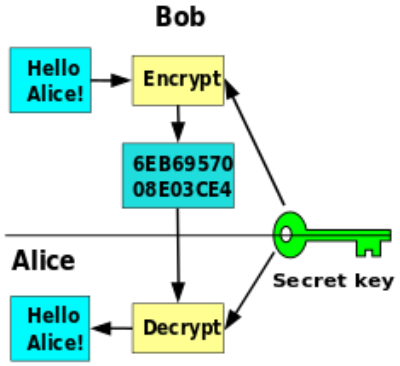
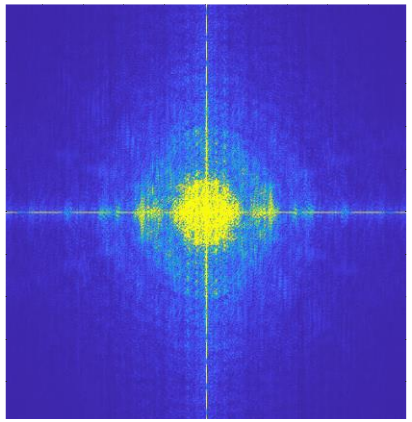
Cryptography

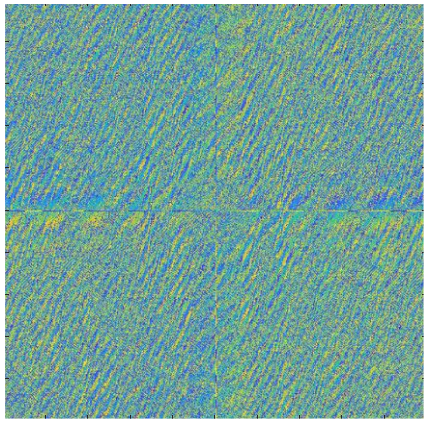
Cryptography is the art of securing information



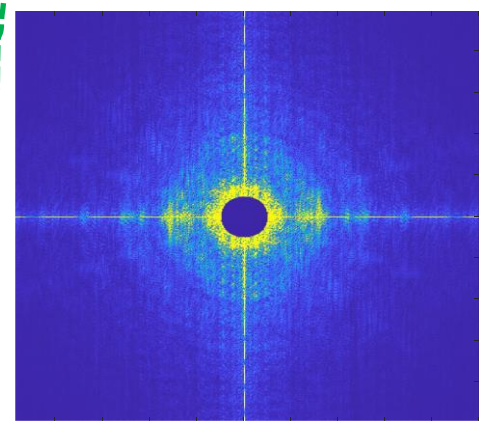
Complete message

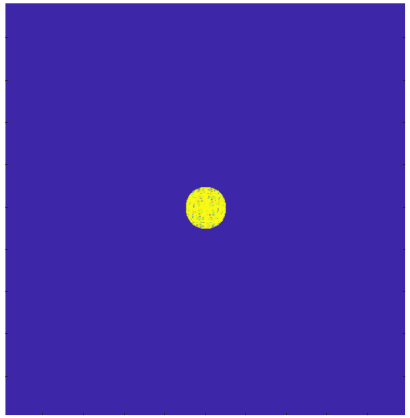


Magnitude of spectrum

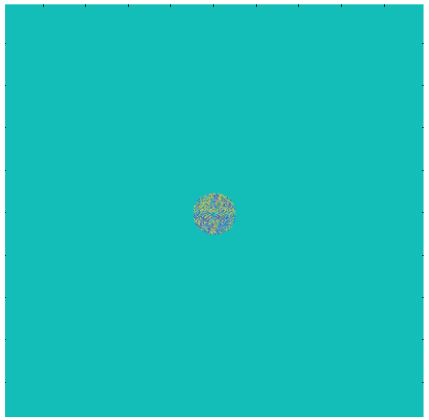


Phase of spectrum



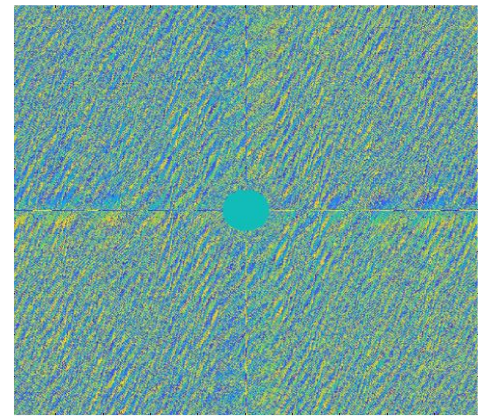


Magnitude of spectrum with low pass filter



Phase of spectrum with low pass filter

Public message



Private keys

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Files: Cryptography.m

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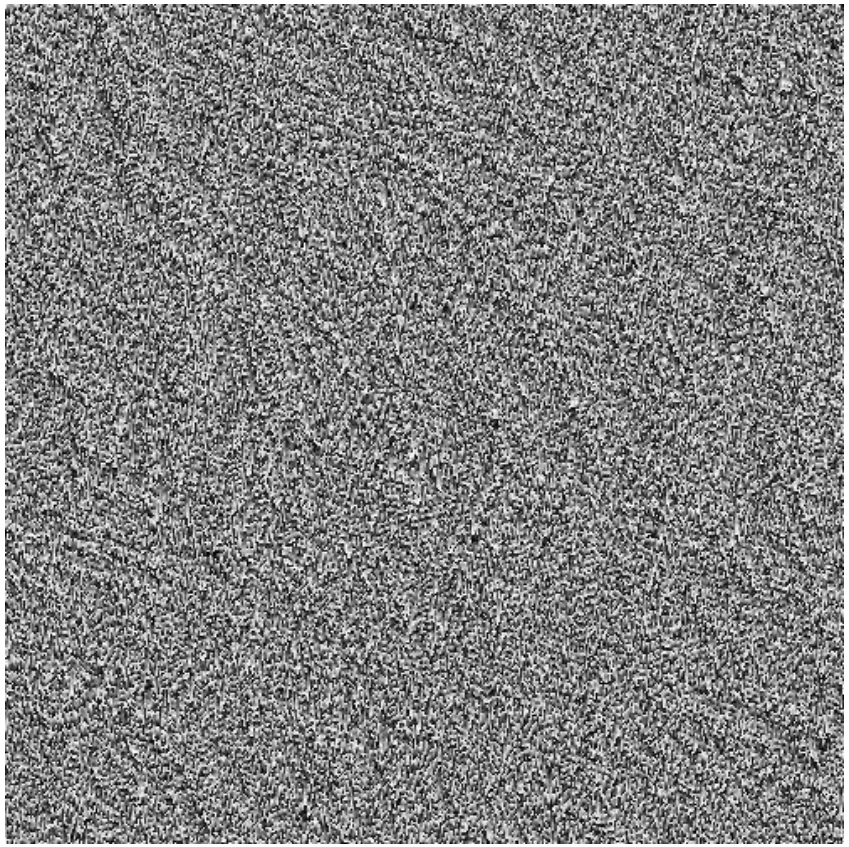
Game

- I am Phase
- I like to travel afar
- Find my magnitude at my new place



Photonics & FÜSX 2022 Files: Clue1.jpg

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Questions ???

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