Question 1. Volume Gratings

In this section, you will investigate the transmission of a volume hologram.
Use the given refractive index and propagate a Gaussian beam with a waist radius of 15 µm.

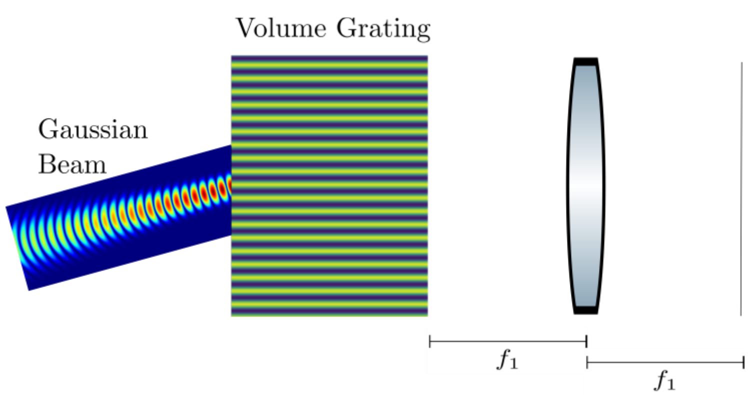
Illuminate the volume grating with different plane waves approximated by Gaussian beams propagating at different incident angle (1D only) and use BPM to propagate the beams through the volume grating. If you reuse previous code, ensure that the absorbing window is correctly adapted.

After the volume grating, use a lens with a focal length of 50 mm to transform the field into Fourier space.

Your task is to determine the angles that result in the brightest possible peak after the grating in Fourier space.

Questions:

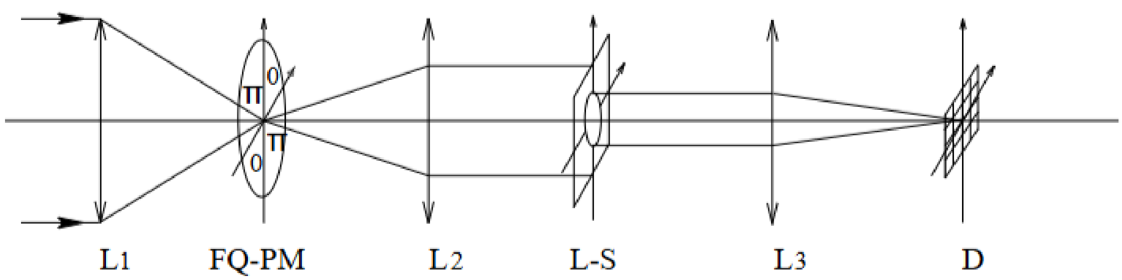
Scan the incident angle and plot the signal in the focal plane of the Fourier transform lens. Use your simulation to find the angle θ that maximizes the intensity of the diffracted beam. Compaρe your estimate with theory (Bragg angle: $\sin\theta=\lambda/2\Lambda$ where Λ is the period of the grating: $K=2\pi/\Lambda$)
[Bragg's Law – Volume Bragg Gratings]



Question 2: Design of a Coronagraph Based on a Four-Quadrant Phase Mask

A coronagraph is a telescopic attachment designed to block out the direct light from a star or other bright object so that nearby objects – which otherwise would be hidden in the object's brightness – can be resolved. Most coronagraphs are intended to view the corona of the Sun, but similar instruments are also being used to find extrasolar planets.

Placing a four-quadrant binary phase mask (0, π) (FQPM) at the Fourier plane can effectively remove the light coming from a source on the optical axis with destructive interference, while the pupil aperture L-S is used for removing the diffracted starlight. You will need implement your own quadrature phase mask or ask chat-gpt.



Build an angular propagation based simulation of the given telescope, for $f_{L1} = f_{L2} = f_{L3} = 3m$, simulation domain limited to 6 mm on one side with 1024 sampling points . $\lambda = 633\ nm$ is observed and assume light sources to be far enough from the system to consider input beams as plane waves with different directions. L-S can be ignored for simplifying the simulation.

Report the minimal angular separation and maximum intensity ratio that a star and its exoplanet can have and still be distinguished with such a system. For determining these properties, two plane waves are launched to the optical system, one being on the optical axis, and the other having a slight angle. By turning on and off the off-axis beam (exoplanet light) and observing if there is a visible final intensity distribution change, the limits of detection can be estimated.

Question 3: Unveiling an Unknown Object Through Complex Media

An unknown input transparency, f(x,y), is placed at an input plane (P1) and illuminated by a plane wave (λ=532 nm). The light then propagates through a known middle transparency (t_mid) placed at a plane P2, and further propagates to an output plane (P3) where the complex field (U_out) is recorded (see the Figure below).

You are provided with two scenarios:

1. **Scenario A:** You are given the recorded output field U_out_A.pt and the corresponding middle transparency t_mid_A.pt, which is known to be **phase-only**.
2. **Scenario B:** You are given a *different* recorded output field U_out_B.pt and its corresponding middle transparency t_mid_B.pt, which has both **gain and loss** (amplitude and phase modulation).

The original unknown input transparency f(x,y) is **the same** in both scenarios. Your goal is to reconstruct this f(x,y) as accurately as possible for both scenarios. For each scenario, provide: A clear visualization (amplitude and phase) of your reconstructed f(x,y), a brief explanation of the method you employed for reconstruction and why it was chosen for that particular scenario, a comparison and discussion on the quality of your reconstructions for f(x,y) from both scenarios. If there are differences, explain why.

You are given a Jupyter notebook that contains the physical parameters, helper functions, and the specific angular spectrum propagator function **that was used to generate** the complex output fields you will be working with.

Hint: Direct methods like phase conjugation or time reversal are effective for lossless, phase-only systems but may not yield perfect reconstructions if there is gain and/or loss within the system. In such cases, an iterative approach might be necessary to achieve a more accurate reconstruction of f(x,y).

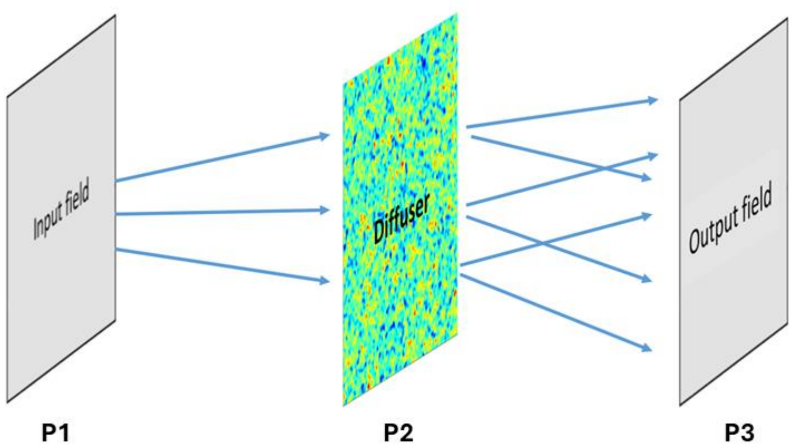
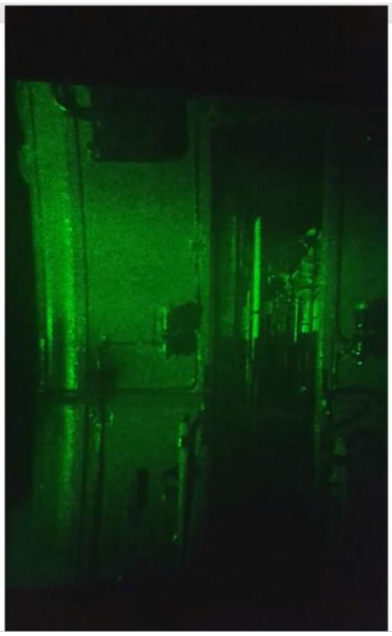
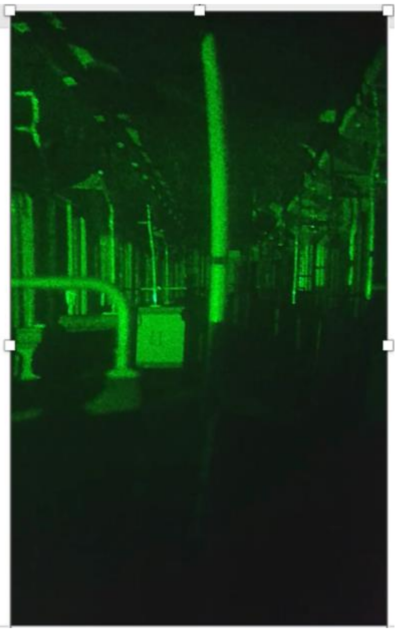


Figure: Unknown Object Through Complex Media

Bonus question: The train video.





A B

The frame on the left (A) was recorded with my cell phone camera from further back from the one on the right (B). We see in frame B the interior of the train wagon but this interior “blocked” in A by the wall of the wagon. Since there was no physical wall in the reconstruction of hologram, the question arises, what “blocked” in A the interior that is visible in B.

Hint: Think about how the hologram was recorded.