Semester S1 – Module 3

Module Fundamentals of coherent photonics

TUTORIAL

SPATIAL OPTICS_3

FOURIER OPTICS – SPATIAL FILTERING

Coherent optical filtering processes can be used to observe thin phase objects, such as thin sections of organic preparations, air currents, vortices and shock waves, fingerprints, constraints on transparent materials. In this tutorial, we will study two filtering methods: strioscopy and phase contrast.

I – Strioscopy

Let us consider a rectangular pupil placed in the x_0Oy_0 plane of abscissa $z_0=0$. Its transmittance $t(x_0,y_0)$ has the following characteristics:

$$t(x_0, y_0) = 0 \; when \; |x_0| > \frac{L}{2}$$

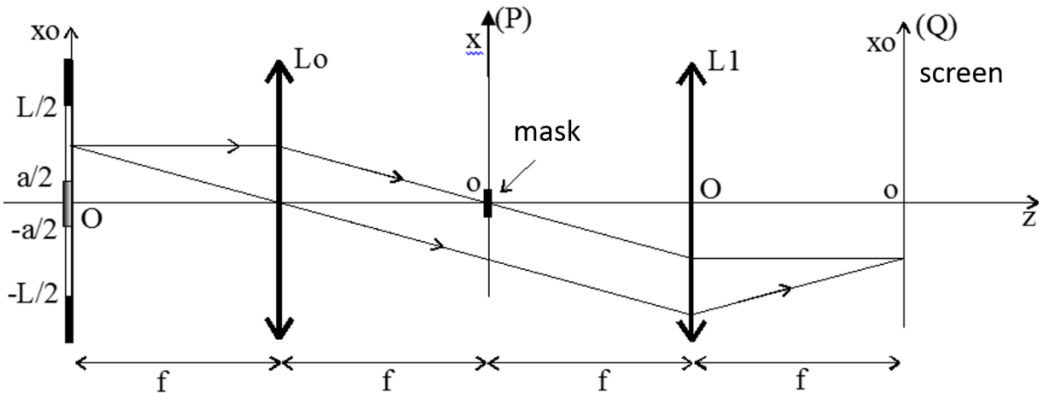
$$t(x_0, y_0) = A \; when \; -\frac{L}{2} \leq x_0 < -\frac{a}{2} \; with \; 0 < A < 1 \; and \; a \ll L$$

$$t(x_0, y_0) = Ae^{j\varphi_0} \; when \; -\frac{a}{2} \leq x_0 < \frac{a}{2} \; with \; \varphi_0 \ll 1 \; radian$$

$$t(x_0, y_0) = A \; when \; \frac{a}{2} \leq x_0 < \frac{L}{2}.$$

It is assumed that the geometry of the pupil is invariant according to Oy_0. In the whole problem, we will consider a two-dimensional problem of diffraction in the x_0Oz plane.
This pupil is illuminated in normal incidence by a monochromatic plane wave of wavelength λ, with an amplitude $E_0 = 1$.

1. Determine the mathematical expression of the electric field $E(x_0,z_0=0)$ at the pupil exit. Simplify this expression by taking into account the low value of φ_0<<1 radian.



2. Calculate the intensity of the electric field in the focal plane P of the lens L_0. Show that it results from the sum of two terms that will be graphically represented for a=L/10. The amplitudes and relative widths of the different diffraction lobes will be specified. However, on the graph, the amplitude scale will not be respected.

3. Using the afocal device in Figure 1, the image of the pupil is formed in the Q plane with a magnification of -1. An opaque mask of width $d = \frac{2\lambda f}{L}$ is placed in the P plane. Describe qualitatively the intensity profile observed in plane Q.

4. Let us now consider in the x_0Oy_0 plane, a pure phase object of transmittance $T(x_0) = ae^{j\varphi(x_0)}$ (invariance according to Oy_0). The function $\varphi(x_0)$ describes the phase structure of the object. The intensity is the same everywhere ($I(x_0) = |T(x_0)|^2 = a^2$). The goal is to make the phase structure φ visible in the intensity.
   a. For objects such as $|\varphi| \ll 1\ radian$, give the expression of $T(x_0)$.
   b. Derive an expression of the electric field in the P plane as a function of the Fourier transform $\tilde{\varphi}(\frac{x}{\lambda f})$of φ.
   c. In the plane P, an opaque mask is placed at x=0. To simplify, it is assumed that it only acts on the central frequency. Deduce the electric field in the Q plane. Compare this field to the one that would be obtained without a filtering element. Conclude.

II – Phase contrast

The same phase object is considered as in question I - 4. The opaque mask is replaced by a phase plate. We will assume that it only acts on the central frequency by shifting this part of the field from $\pi/2$ with respect to the other part of the frequency spectrum.

1. Give the new expression of intensity in the Q plane. Compare this expression with the one obtained in question I - 4.

2. The process can be improved by increasing the contrast of the filtered image (Q plane). This is achieved by combining phase contrast and amplitude attenuation of the zero order of the frequency spectrum by a factor b (0<b<1). Give the new expression of intensity.