Interference and diffraction effects generated by multiple apertures

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Interference and diffraction effects generated by multiple apertures

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ABSTRACT

The effects of interference and diffraction produced by a bidimensional structure composed of multiple and identical apertures are studied. The apertures have different shapes, sizes and spatial distribution. Such effects are competitive during the propagation, that is, in some planes the interference effects are more visible, while in others prevail the diffraction ones.

Keywords: Interference, Fraunhofer diffraction, Fresnel diffraction, Fresnel zones.

1. INTRODUCTION

Let's consider a diffracting structure composed by multiple identical apertures, arranged in a bidimensional way, either periodic or non periodically. The effects of interference and diffraction produced by the structure in the different planes during its propagation are competitive, this is, in some planes the interference effects are more visible, while in others prevail the diffraction ones. In the diffraction, the individual effects become more evident for each aperture; while, in the interference the collective effects are quite notorious.

For an appropriate analysis of these effects and, of course of the diffracting structure, is necessary to determine each of these effects in a separate form. Thus, it is convenient to establish, by means of an appropriate and simple criterion, the regions where the interference prevails over the diffraction and vice versa; as well as, those regions where there is not a clear prevalence of an effect over the other one.

The objective of this work is to establish a criterion that allows the delimitation of the regions previously mentioned. This criterion will be established from the number of Fresnel zones[1-3]. These zones are determined from an axial point in the observation plane.

Computer simulations were performed to illustrate the different situations.

2. BASIC THEORY

The diffracting structure is inscribed in a circle of radio R, this structure is illuminated by a spherical wave that comes from a coherent punctual source S located at a distance r_o of the plane that contains such structure. The number of Fresnel zones is calculated from the point P; where the line $\overline{SP}$ goes through the center of the circle that circumscribes the structure and is perpendicular to it, the corresponding setup is shown in Fig. 1.

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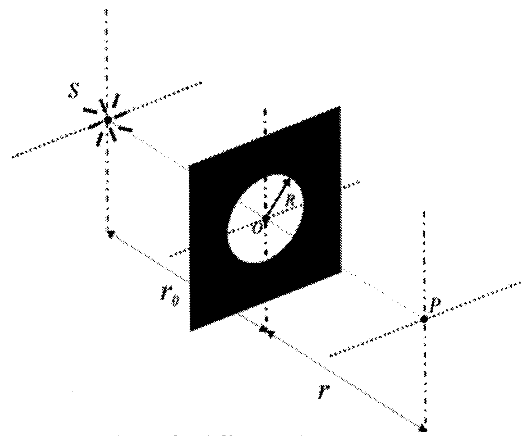

Fig. 1: Setup for diffraction by a circular aperture

Considering that $r \wedge r_o >> R$ y $R >> \lambda$, where λ is the wavelength, for calculating the number of Fresnel zones, the parabolic approach can be used. Therefore, the number of Fresnel zones N will be given by[3,4]

$$N = \frac{R^2}{\lambda}\left(\frac{1}{r_o} + \frac{1}{r}\right) \tag{1}$$

Let's denote by N_0 the number of Fresnel zones for an individual aperture and by N the number of Fresnel zones subtended by the diffracting structure from that same point.

In this case, a plane wave illumination will be employed, it means $r_0 \to \infty$; therefore the number of Fresnel zones turns into:

$$N = \frac{R^2}{\lambda r} \tag{2}$$

3. COMPUTER SIMULATIONS

The c alculations have been performed u sing a simulation p ackage that works a ccording to the modified convolution approach[5] on a matrix of 512x512 points with the sample interval equivalent to $10\,\mu m$. A coherent source of wavelength equivalent to $\lambda = 632.8\,nm$ and two diffracting structures were used, the structures are shown in the Fig. 2(a) and (b).

In the simulation process, the diffraction pattern generated at a r distance of the structure was calculated, when it is illuminated by a monochromatic wave plane. Three regions are defined for the analysis of the results, according to the different values that N and N_o take:

1. Region of Fraunhofer: $N < 1$, and therefore $N_o < 1$.
2. Region of transition: $N > 1$, but, $N_o < 1$.
3. Region of Fresnel: $N_o > 1$, that implies $N > 1$

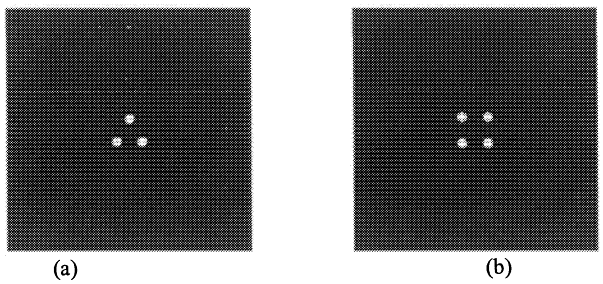

Fig 2. Diffracting structures: (a) triangular structure, formed by three identical circular apertures, placed in the vertexes of an equilateral triangle and (b) square structure, formed by four identical circular apertures, placed in the vertexes of a square.

Table 1: Simulation results: diffraction patterns generated by the triangular structure for different number of Fresnel zones N.

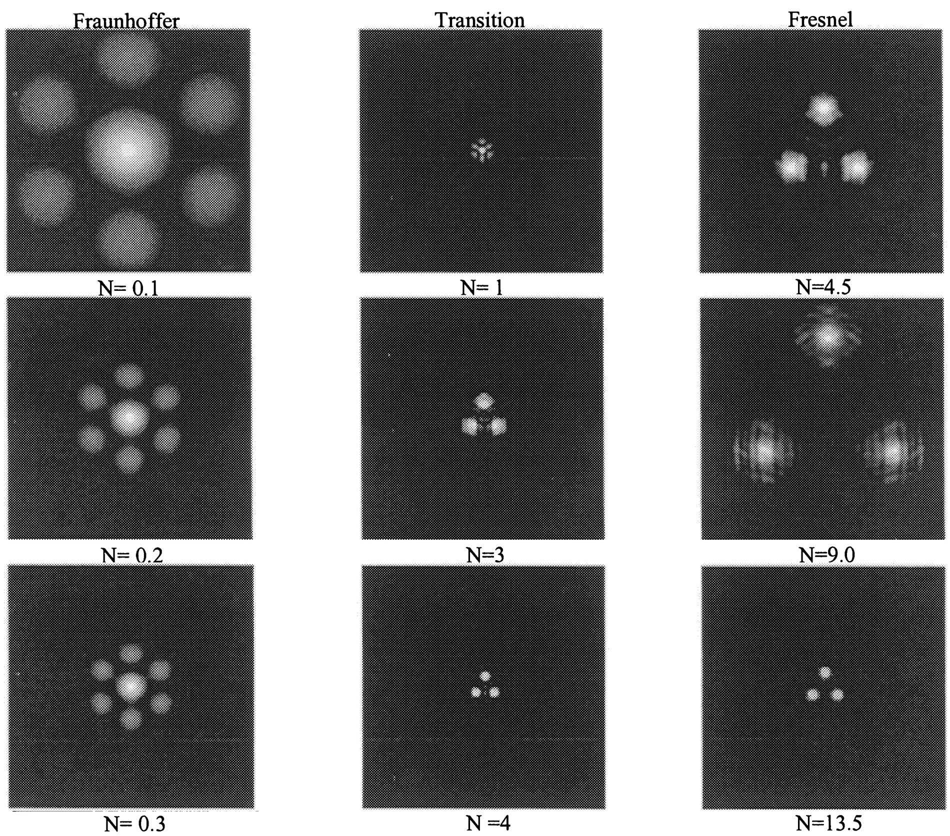

Table 2: Simulation results: diffraction patterns generated by the square structure for different number of Fresnel zones N.

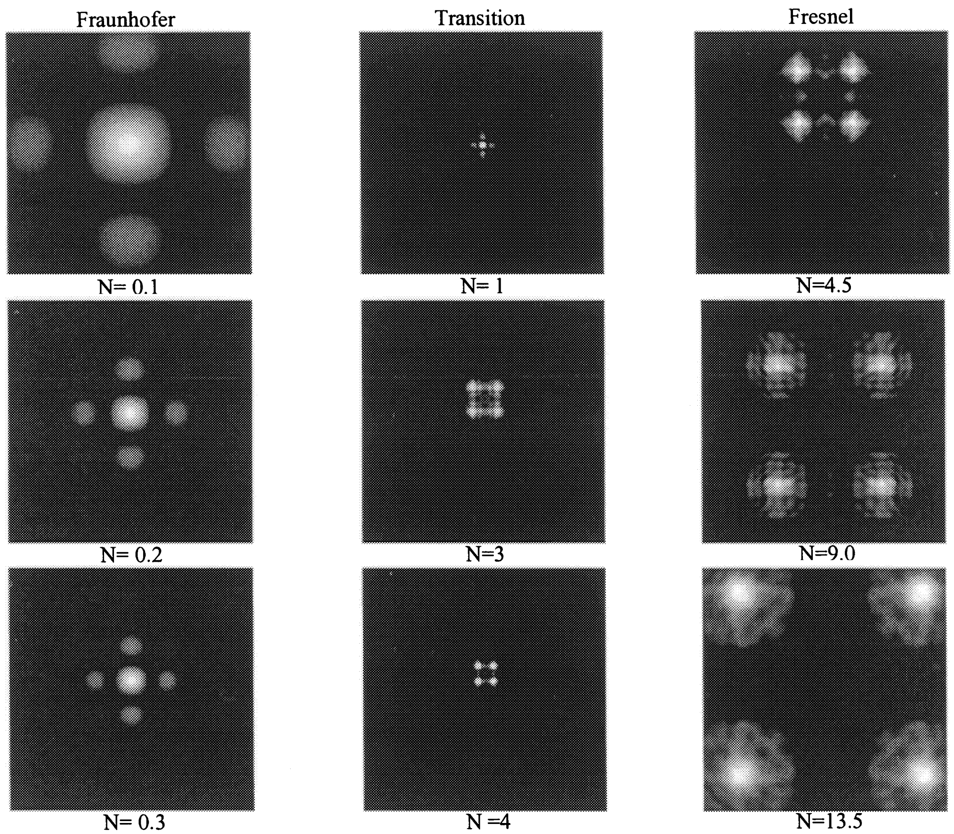

Fig. 3. Results of computer simulations: (a) Fourier transform of the triangular structure and (b) Fourier transform of the square structure.

4. CONCLUSIONS

The number of Fresnel zones *N,* is the main parameter that determines when the effect of interference prevails over the diffraction one and the kind of diffraction generated by the diffracting structure.

Also, the recognition of the shape of the apertures that conform the structure can be obtained from the number of Fresnel zones N that subtend the structure.

If $N>1$, the effect of interference is tenuous and function, either for the number of apertures or their separation. In this case, there is little information about the periodicity and the effect of diffraction is described by means of the Fresnel transform.

When $N<1$, the effects of interference are visible and predominate in relation to the diffraction ones and essentially independent from the separation and the number of the apertures. In the case $N \leq 1$, the effects of diffraction are described by means of the Fourier transform (Fraunhofer diffraction) and prevail the information of the periodicity.

For $N \leq 0.33$ is practically impossible to deduce the shape of the apertures. When $N>0.33$ the recognition of the shape of the apertures increases proportionally to the growth of *N*, being important when $N>1$.

There is a very good matching between the Fourier transform of the structure and its diffraction pattern when $N \leq 0.3$.

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