Apodization of the flat mirror support of a newton telescope

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An analysis of different structures of the spiders supporting the flat mirror of a Newton type telescope was made, in order to reduce the diffraction effects of the spider on the images produced by the telescope. After applying different numerical solutions used by different authors, and without satisfactory results, a novel solution based on the analysis of the diffraction pattern of a circular aperture allowed us to find a satisfactory reduction of the diffraction pattern in the image produced by the support of the secondary flat mirror. Experimental laboratory results will be shown, using white and He-Ne laser light sources.

Keywords: Diffraction and scattering; optical instruments and equipment.

Se hizo un análisis de diferentes estructuras de las arañas de los soportes del espejo plano de un telescopio tipo Newtoniano, para reducir los efectos de difracción de la araña en las imágenes producidas por el telescopio. Después de aplicar diferentes soluciones numéricas usadas por diferentes autores, y sin resultados satisfactorios, una nueva solución basada en el análisis de patrones de difracción de aberturas circulares, nos permitió encontrar una reducción satisfactoria de los patrones de difracción en las imágenes producidos por los soportes del espejo plano secundario. Mostramos resultados obtenidos en el laboratorio, usando fuentes de luz blanca y láser de He-Ne.

Descriptores: Difracción y dispersión; instrumentos y equipos ópticos.

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1. Introduction

In Fig. 1a common image obtained with a reflecting telescope is shown, where the effect of the support system of the secondary mirror on the image are the four bright light lines, perpendicular to each other at the image. Those diffraction effects on the images are observed for any kind of reflecting telescope such as Newtonian, Cassegrain, Ritchey Chrêtien, etc. This effect is produced because the "secondary" mirror is supported by a mechanical structure of the telescope that make it possible to align of the mirrors of the telescope.

To solve the problem of the effects of the spider on the telescope images, several research papers have been published trough the years giving some solutions, such as those works by Schultz *et al.* [1],Tuvikine [2], Jacquinot [3]. As a result, for example, the methods developed by Tuvikine wer successful in improving the resolution of the images, but collateral diffraction effects on the image appeared; on the other hand, Schultz, *et al.* [1], analyzed the problem using a Bessel aperture, and applying their studies to a Cassegrain telescope; improvement in the resolution was observed, but the overall energy in the focal plane was reduced.

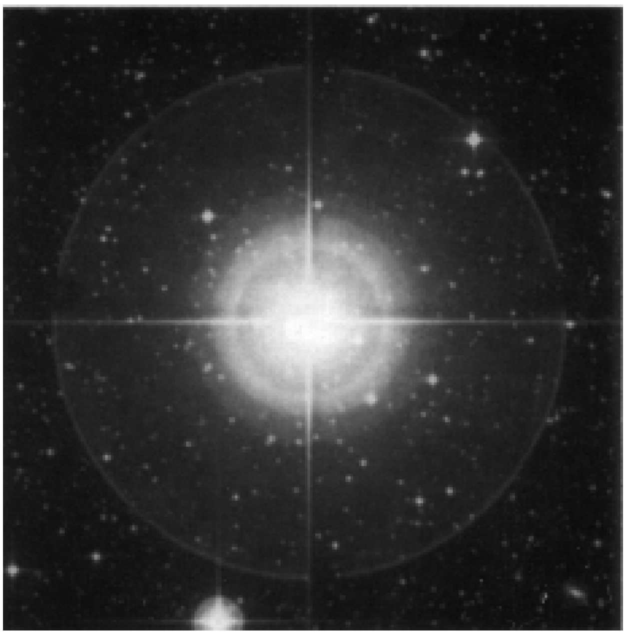

FIGURE 1. Image from a two mirror reflecting telescope.

Considering the results of the studies mentioned above, our research was focused, firstly, on finding a mathematical solution following some of the steps of the authors mentioned above, and taking into account other numerical techniques; unfortunately, unsatisfactory results were obtained for the reduction of the diffraction effects on the images observed with the telescope. Therefore, instead of a mathematical analysis to the problem, it was decided to study carefully the pattern produced by a circular aperture illuminated by a point source. In accordance with this idea, different apodizers were designed and tested in the laboratory. This task was accomplished by studing different structures of the arms of the spider, mainly by overlapping the maximum and the minimum of two close diffraction patterns; as a result, an empirical, but successful apodizer, was designed, as will be shown in the following sections.

2. Proposal for the apodization filter

This section will explain how the design for an apodizer, that could reduce the diffraction effects on the images of a reflecting telescope was found from the overlapping of two diffraction patterns of a circular aperture. The apodizer that was designed was tested by numerical methods in the laboratory, placin the apodizer the normal linear spider of the flat mirror of a Newtonian telescope; however the method developed here can be applied to other types of telescopes. The following paragraphs will explain carefully how the successful apodizer was designed, and as was mentioned above, after several trials of combining two diffraction patterns, for a circular aperture, in different ways.

Figure 2 are shows: Fig. 2a a picture of a Fraunhofer diffraction pattern of a point source illuminating a circular aperture, Fig. 2b a diagram of this pattern shows, for the sake of simplicity, only the first three bright and dark rings; but also are shown the points O, O_2 and O_4 corresponding to the centers of the bright fringes; and O_1, O_3, and O_5 which are the centers for the dark fringes; Fig. 2c the superposition of two diffraction patterns, as those shown in Fig. 2b; but, this time, taking care that the "second" dark ring of pattern A, said point O_3, coincides with the central bright zone of pattern **A'**, that is O'.

As is well known, the position of the two first minima [4] of the diffraction pattern, of a circular aperture, are located at 1.22 and 2.23 units from the center of the pattern. If we convert these two values to centimeters, the magnification of the central part of Fig.2.c is obtained and shown in Fig. 2d. For the drawing of Fig.2.d., the thickness of the dark rings were calculated taking into account the following considerations: *i*) the addition of 10% of 1.22 to the central value of 1.22 and; *ii*) an important conceptual fact for the result of the design of the apodizer, two main points must be mentioned: first, that

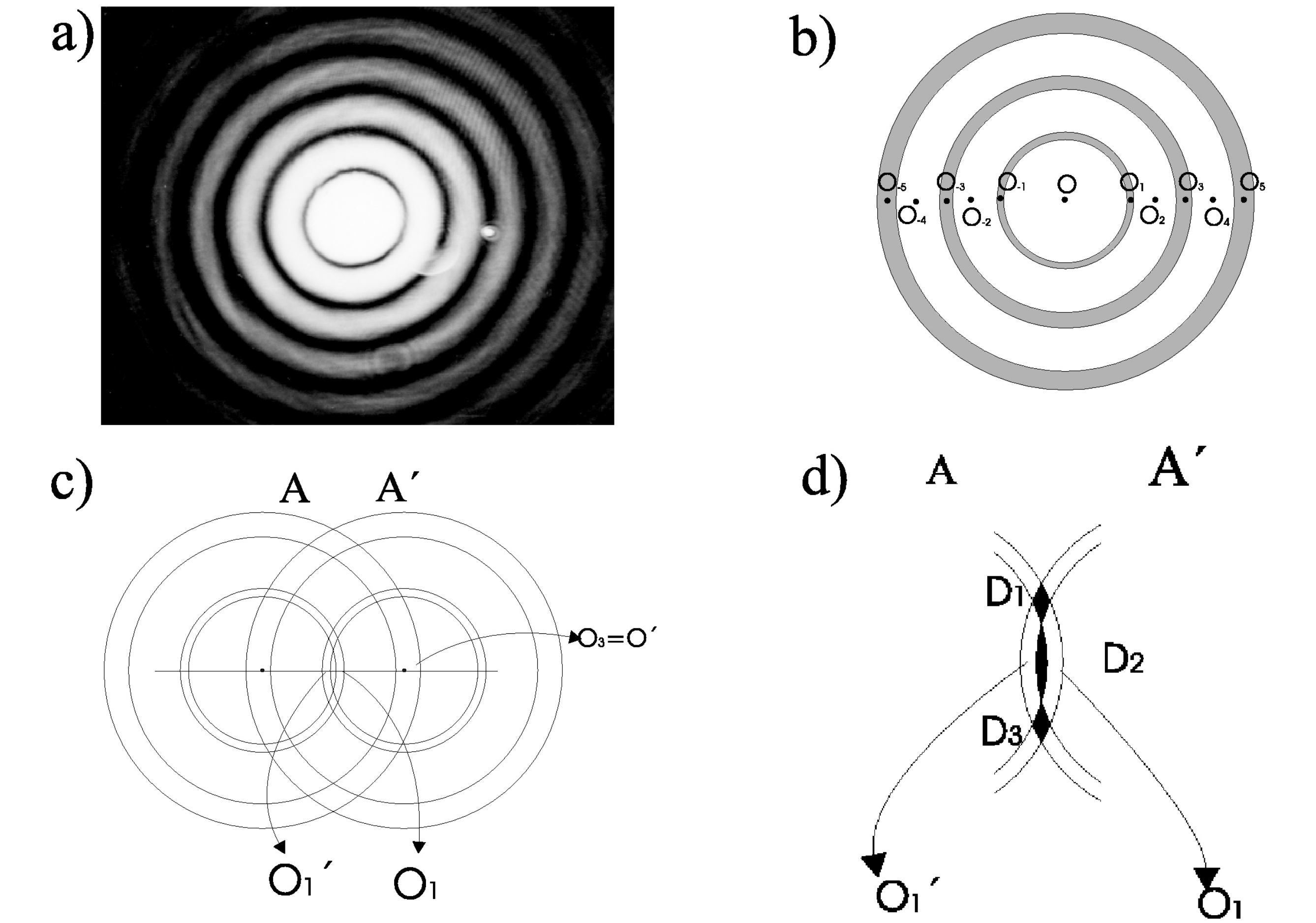

FIGURE 2. a) Airy's pattern for a circular aperture. b) Diagram for the three inner bright and dark rings of the so called Airy's pattern. c) Superposition of two shifted diffraction patterns. d) Magnification of the central region of the two shifted diffraction patterns, mainly with only the two inter bright and dark rings.

the second dark ring of the diffraction pattern must be positioned at the central maxima of the second shifted diffraction pattern, Fig. 2c; and second, that numerical values of the positions of the maxima and minima of the diffraction patterns must be converted into centimeters for the geometrical drawing.

A magnification of Fig. 2c of the crossing of the two shifted patterns is shown in Fig. 2d. By crossing the two first dark rings centered at O_1' and O_1, the structure of the apodizer was found. The shape of the apodizer selected after different trials was the one with two diamond dark zones D_1 and D_3, Fig. 2d, which are the upper and lower intersections of the first two dark rings; and the zone D_2 which is an elliptical clear zone between those two dark inner rings.

As has already been mentioned, after trying different overlapping structures of the diffraction patterns, the overlapping, shown in Fig. 2d, was the apodizer that gave the best results in our experiments. However, the most important aspect that should be mentioned here, is the fact that the magnification of the pattern shown in Fig. 4d, was done taking into account the positions of the dark rings of the Airy pattern for a circular aperture, and therefore this method can be applied for any type of astronomical telescope.

3. Experimental results

The Newton telescope used in our experiment has the following characteristics: diameter 140 mm, focal length 1200 mm, flat elliptical mirror with 40 mm in the minor axis; the length of the linear support of the secondary mirror is equal to 55 mm. For improving the images observed with a Newton telescope in the laboratory, Fig. 3a is shows a scaled size of the apodizer used in the experiment, with physical units in mm. The new shape for the support of the spider, of the secondary mirror, were positioned the normal flat support of the mirror of the telescope, Fig. 3b. Normal supports, as such those used, are made from thin metallic blades.

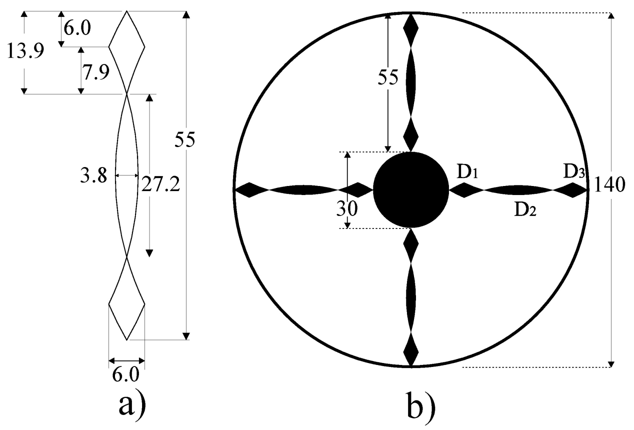

FIGURE 3. Apodizer proposed for the spider of the flat mirror of a Newtonian Telescope, the apodizer that was designed was located upon the normal spider of the flat mirror.

The proper size of the designed apodizer, in particular for this Newtonian telescope, was constructed by taking the size of the apodizer of Fig. 2d; with a length of about 12.5 mm; and since the length of the support of the telescope is equal to 55 mm, a scale factor was obtained that allowed us to obtain the real size of the apodizer. Figure 3a shows the real dimension of the apodizer, and Fig. 3b how they look as the spider of the flat mirror.

Therefore, for other telescopes, the starting point will be to consider the apodizer size in Fig. 2d; and according to the length of the linear support of the secondary mirror, either flat or with a different shape, a scale factor should be derived for the construction of the real size of the apodizer.

Figure 4 shows a picture of the experimental setup, with the Newtonian telescope illuminated by a collimated beam. This picture can be easily understood from the diagram in Fig. 5a, where the different components of the experiment are described. In order to observe an improvement in the images observed with the Newtonian telescope. Figure 5b shows the four different structures used of the spider, for our experiment and simulations. The apodizer designed is compared with the customary spider with three and four arms. Figures 5b, A and B shows the three arm support systems. However, for the support in Fig. 5a, screws were used, and in Fig. 5b thick wires were used; in both cases similar diameters for the supporting arms were employed. Figures 5b, C and D, shows the classical four arm supports schemes, with simple wires in Fig. 5c and B;the apodizer that was designed corresponding to Fig. 3a, as in Figs. 5b and D.

Figure 6 shows the experimental images observed with the telescope for the four different supports, and Fig. 5b for the spider of the secondary flat mirror. The experiments in the case of Fig. 6 were conducted using a He-Ne laser as a light source. For a better understanding about the results observed, in the lower right corner of each picture of Figs. 6, are written the capital letters that correspond to the type of supporting system of the flat mirror, described in Fig. 5b.

Figure 7 shows the results obtained by numerical simulation, using a computer program carried out in MATLAB®, but scaled for publication; these simulations mean the Fourier transform for each of the cases of the spiders of Figs. 5b, A, B, C, and D. As can be observed, the simulated images, Fig. 7, have a close resemblance to those images obtained in the experiment in Fig. 6.

From these experimental and simulated results, the reduction of the diffraction effects became evident when the designed apodizer of Fig. 3 was used. This fact can be observed by comparing of the experimental images of Figs. 6c and 6d; and those experimental results are supported by the simulated images of Figs. 7c and 7d. Therefore, an important conclusion is that the apodizer designed, Fig. 3, that is located along the linear support of the spider, gave successful results in diminishing the diffraction effects of conventional spiders.

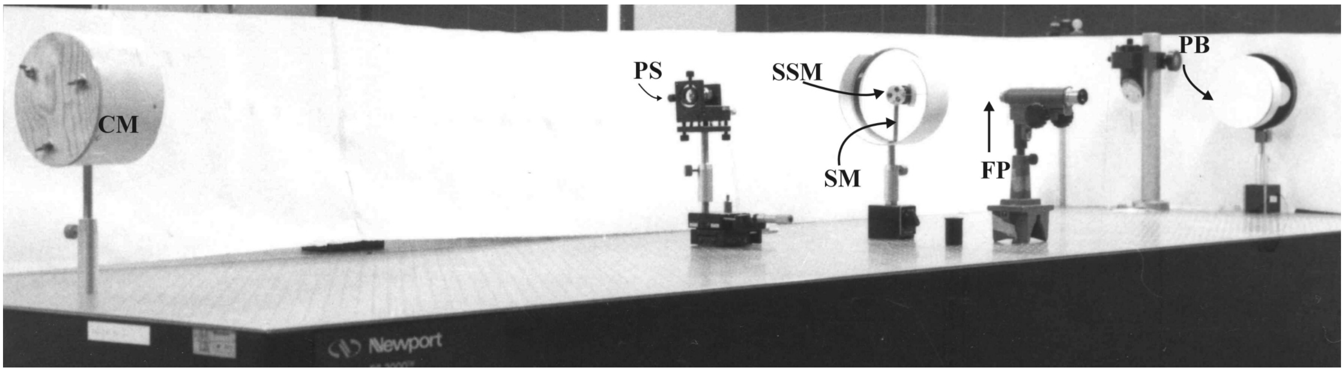

FIGURE 4. Picture of the experimental set up with a Newton telescope, and a collimating system illuminating the telescope.

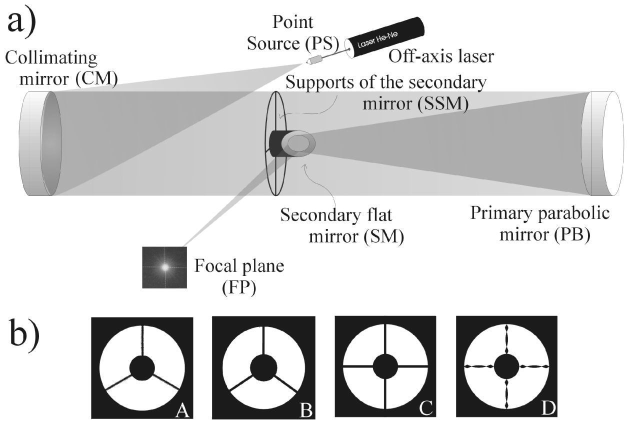

FIGURE 5. a) Scheme of the laboratory experimental set up. b) The four structures of the spider used in our experiment: A) with three-screw; B) with three wires; C) with four-wire; D) with the proposed four-arm spider.

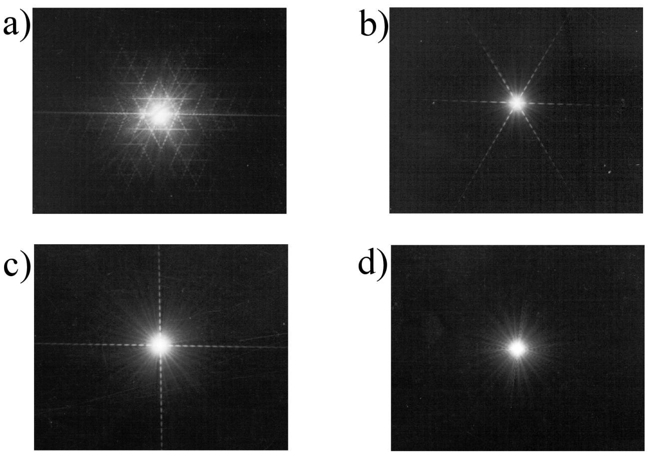

FIGURE 6. Experimental results of the telescope images, using a white He-Ne laser, for each one of the spider structures shown in Fig. 5b, and the experimental set up of Figs. 4 and 5a.

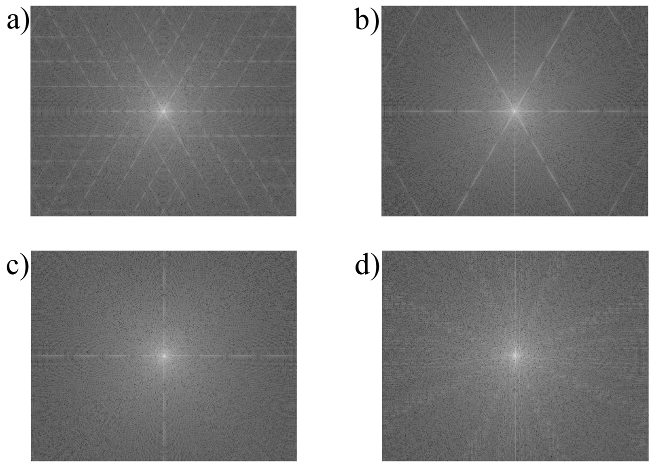

FIGURE 7. Simulated Fourier transform for each one of the spiders shown in Fig. 5b.

Figure 8 shows the experimental results when a white light source was used. Hence, similar diffraction patterns can be observed surrounding the images of the telescope, using either a He-Ne laser or a white light sources, as can be see in Figs. 6 and 8, respectively.

4. Analysis of the experimental results

For the three-screw supports shown in Figs. 6a, 7a, and 8a, a rather complicated diffraction pattern could be observed, with a 6-peak star figure. For the three and four wire supports, six and four lines of diffraction can also be observed as it is shown in Figs. 6b, 7b and 8b, and Figs. 6c, 7c and 8c, respectively. For the case of Figs. 6d and 8d, where the apodizer that was designed has been used as support system, the diffraction effects have been almost eliminated; as can also be seen in the simulation of Fig. 7d. However a careful analysis of Figs. 6d, 7d, and 8d, where the apodizer designed has been used to show that, even though the diffraction effects have been reduced, some diffraction effects around the central area of the images remain. A special comment regarding the simulation patterns, is that they have been scaled for publication.

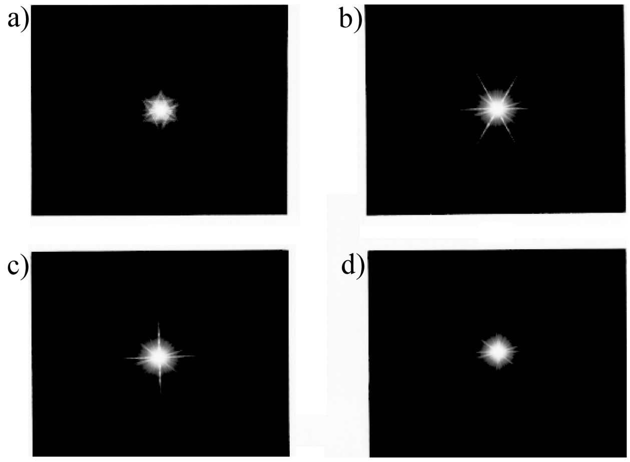

FIGURE 8. Experimental results of the telescope images, using a white light source, for each one of the spider structures shown in Fig. 5b, and the experimental set up of Fig. 4.

In order to have a different type of information about the diffraction effects of the flat mirror spiders in the telescope images, Fig. 9 shows some image irradiance scans along a horizontal line of the images. These scans correspond to the four different spider geometries supporting the secondary mirror. The rotated 45° scan in Fig. 9a was done for the special case of the spider with a three-screw support system; and the horizontal central scans for the other three images of Fig. 6 are shown in Figs. 9b, 9c, and 9d. The best irradiance profile has been obtained for the designed spider Fig. 8d; where it can be seen how the diffraction effects have been reduced; since the ripple of Fig. 9d is much smaller (below 0.1) than the ones seen in Figs. 9b and 9c, whose ripples appeared close to 0.6 and 0.45, respectively. From a qualitative analysis of Figs. 9b, 9c, and 9d, in Table I records the values of the intensity with respect to the x coordinate from the central peak, for the three first secondary maxima, after scaling the squares of the figure into milimiters.

TABLE I. Position x and intensity I values of a lineal central scanning of diffraction patterns.

Figure	9b	9c	9d
x position/ Irradiance value	x/I	x/I	x/I
First secondary maximal	2.2/0.57	3.7/0.47	2.6/0.16
Second secondary maximal	3.7/0.33	4.4/0.30	3.2/0.09
Third secondary maximal	5.6/0.20	5.9/0.20	3.7/0.06

From Table I and with reference to Figs. 9b, 9c, and 9d, it can be seen that the position x of the secondary maxima are closer to the central maxima for Fig. 9d, and also the intensity values drop drastically by about a factor of three for the same Fig. 9d with respect Fig. 9c.

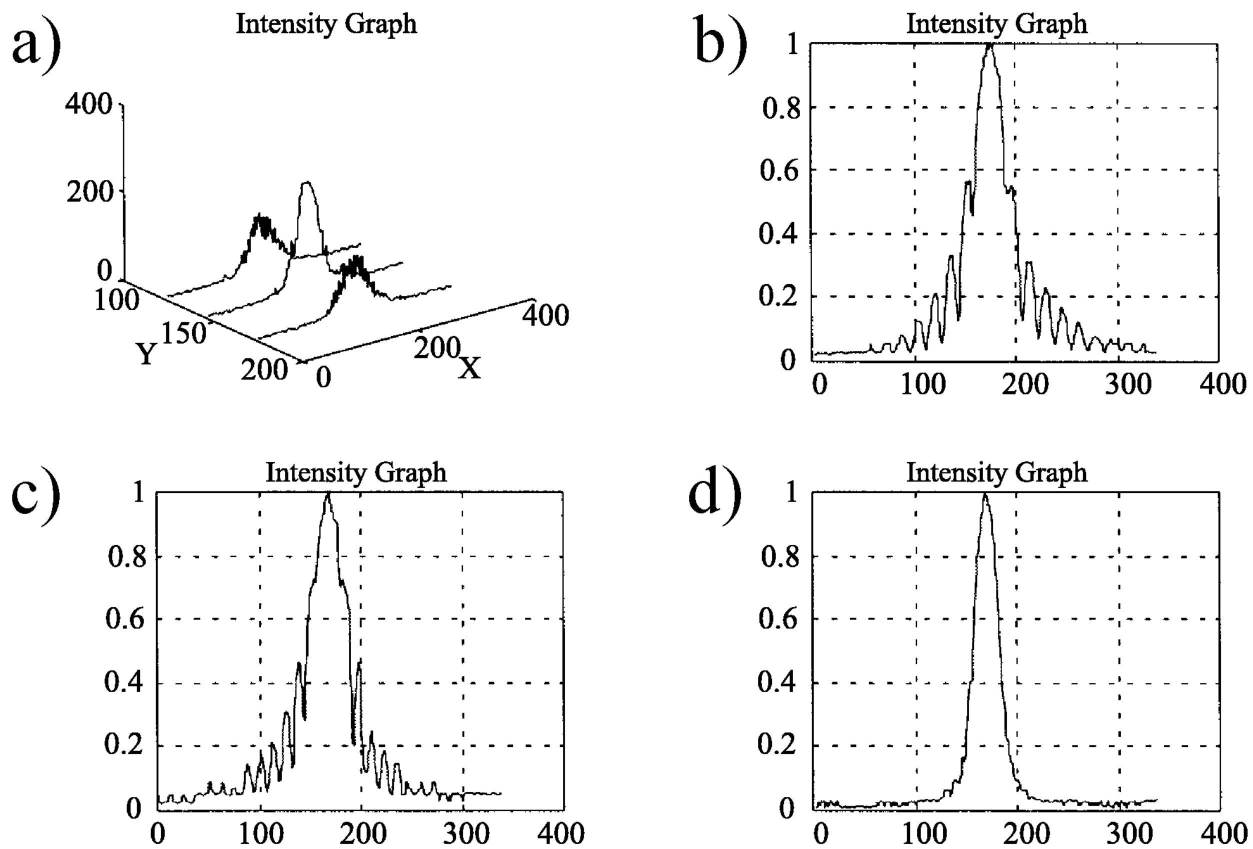

FIGURE 9. Image irradiance scans, along a line, for each case of the spiders support shown in Fig. 5b; using a He-Ne laser illumination. For Fig. 6a a rotated scan was done.

5. Conclusions

It has been shown by experiment at the laboratory, and by simulations in a computer, that the designed spider based an empirical study of the superposition of two diffraction patterns, shifted laterally one with respect to the other, that the diffraction effects on the telescope images have been improved. From the results obtained with this type of spider or apodizer, the diffraction effects on the images of the telescope were reduced drastically; as can be seen, by comparison, in Figs. 6, 7, and 8 the diffraction lines perpendicular to the central bright core of the image are diminished. In Fig. 9d the ripple of the secondary maxima is decreased in the case of the spider that was designed. Therefore, the goal that certain design for the spider can reduce the diffraction effects, was reached to our satisfaction.

On the other hand, after some analysis of the results, it is clear that the binary apodizer pattern developed is, in fact, a kind of binary hologram that was first described by Brown and Lohmann [6], where the radial position selects the phase information. A Fresnel zone plate, for instance, can be considered a crude Brown and Lohmann binary hologram, where the amplitude is modulated by the width of the structure. For future work, the idea is to concentrate our design efforts on selecting the widths (amplitudes) that can lead to an optimal behavior of the spider, according to some measurable criterion. Preliminary results on the topic described were reported in the OSA Annual Meeting of 2000 [7].

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