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Effect of Variable Apodization Functions on the Image Quality of Optical System

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ABSTRACT

Apodization of pupil with various amplitude filters have been investigated for altering the point spread function for diffraction-limited optical systems' pictures of point objects by employing various filters, such as connes and tringle filters. We have shown that, for different levels of amplitude apodization, the lower values. An observation that these filters give good results for lower values of the apodization parameter. (FWHM) Full width at half maximum of the point spread function (PSF) is smaller than the Airy PSF, improving the performance of the optical system.

Keywords: optical system, intensity Point spread function, Amplitude filters

INTRODUCTION

The point spread function is a useful concept in astronomical imaging, Fourier optics, electron microscopy, fluorescence microscopy and 3D microscopy, etc. [1,2]. By knowing the PSF of the system, we can determine the accuracy of the optical system. In addition, apertures with different transmission functions play an important role in modulating the point spread function (PSF). In many applications, the point spread function (PSF) is significantly modified by the apertures with various transmission functions. Changing the pupil function of an optical system with the appropriate apodization plays an important role in improving the resolution of the system. Apodization can be defined as a method that changes the image properties of an optical system [3,4]. the improving of intensity point spread function received attention from numerous studies, A. Reddy et al [5] attempted to increase the resolution of the apodized optical system with the selected degree of apodization parameter γ. P. Thirupathi et al [6] studied the full width at half power FWHM an optical system with a set of Higher-Order parabolic filters in order to increase the resolving power of an optical system. Salkapuram V. R. et al [7] three amplitude-apodization pupils to decrees the FWHM of optical system. Ghada S. K. et al [8] where a solution is computed for the equivalent filters as a function of the scattering point for a spherical reference optical system of different order. In this study, we applied an elastic apodization technique to enhance the incoherent optical distribution of a point source with a round pupil. The proposed apodizer filters change the focal properties of the optical system, such as narrowing of the focal density, which leads to the PSF of the optical system with a lower half-width.

THEORY

The amplitude function of incoherent point sources' diffraction field expression is provided by [9]:

$$A(u,v) = \int_y \int_x f(x,y) \cdot e^{i2\pi(ux+vy)} dxdy \text{..........(1)}$$

where f(x, y) Pupillary function of the visual system. u, v are dimensionless coordinate variables that form the distance from the center of the diffraction head to the observation point. (x, y) is the contraction coordinator at the pupil exit of the system. [10]

$$f(x,y) = \tau(x,y) \cdot e^{ikW(x,y)} \text{..........(2)}$$

τ(x,y): pupil transparency, It depicts the exit pupil's actual amplitude distribution;

W(x, y): the aberration function (=0).

Two amplitude filters' diffraction fields are expressed as follows:

$f_1=(1-\gamma r)$ (Triangular filter)

f2= 〖(1-γ^2 r^2)〗 ^2 (connes filter)

f_1 (x): the pupil function with a triangle amplitude,

f2 (x): the optical system's Connes amplitude pupil function [11, 12].

where γ is the apodization parameter that control the degree of non-uniformity of the pupil transmittance. One may represent the complex amplitude using the pupil function of the Fourier transform. [13]

$$A(u,v) = \int_y \int_x f(x,y)\, e^{i2\pi(ux+vy)} dxdy \qquad 3$$

by taking the squared modulus of A(u,v) The intensity PSF I(u, v) which is the real measurable quantity is given:

$I(u,v) = |A(u,v)|^2$ … (4)

$I(z) = |A(z)|^2$ … (5)

The dimensionless diffraction variables z = 2 π u, and m = 2 π v.

Because of the symmetry of intensity distribution, m = 0.

$I(u,v) = |A(u,v)|^2$ … (6)

$I(z) = |A(z)|^2$ … (7)

The general expression for the point source image intensity distribution created by an optical system is found in equation (7). [14]

RESULTS AND DISCUSSION

The numerical resultant amplitude functions of the incoherent point sources are calculated from equation (3) by employing MTHCAD, while the intensity PSF was numerically measured from Equation (7). Figure (1) and figure (2) displays the PSF intensity distribution curves apodized by Triangular amplitude filter and Connes filter for various values of apodization function . This is a function of the distance (z) from the canter of the image. Table 1 and 2 list the intensities point spread function values. The listed values are used to characterize the apodized PSF. From both the figures and the tables, it is clear that the resulting intensity PSF distribution produced in the Gaussian focus plane (=0) shows no discernible alterations. As the magnitude of the apodization parameter g increases, the intensity PSF value lowers. The center peak intensity using the Coons filter reduces to 0.923 at the same value of =0.2 as does the central peak intensity using the Triangular filter, which lowers to 0.75 as =0.2. By applying the Marechal criterion to the results obtained in this paper for both aopdize filters, we find that, for the system considered using the Triangular filter, the value of β must be within the range 0<≤0.2, and for the Conns filter, the value of g must be within the range 0≤≤0.4 in order to obtain a good quality image of point object.

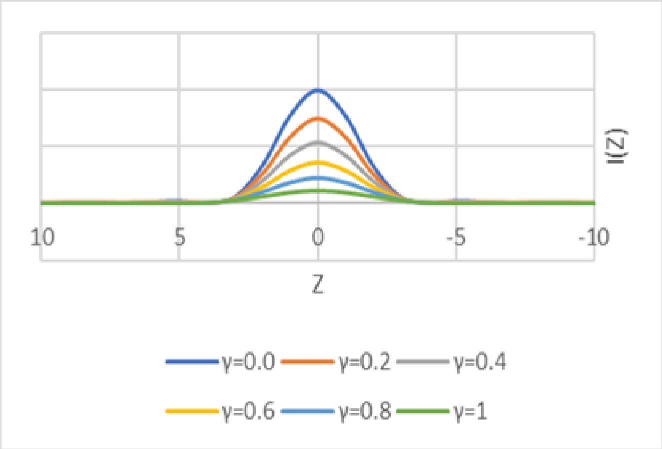

Figure (1): PSF intensity distribution apodized by Triangular filter for different values of γ

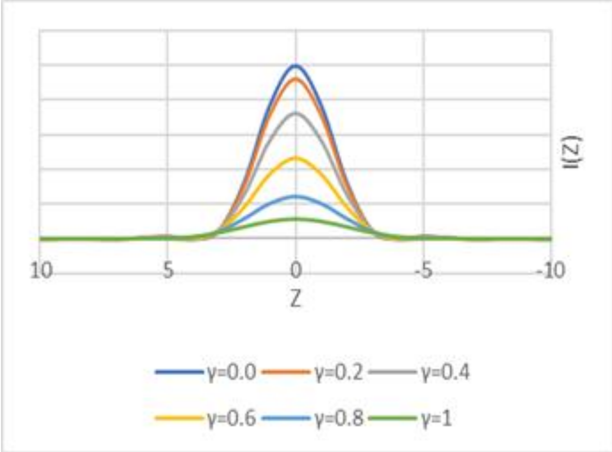

Figure (1): PSF intensity distribution apodized by connes filter for different values of γ

Table (1): Intensity PSF for various values of γ (Triangular filter)

z	$\gamma = 0.0$	$\gamma = 0.2$	$\gamma = 0.4$	$\gamma = 0.6$	$\gamma = 0.8$	$\gamma = 1$
-10	7.56E-05	7.00E-05	6.46E-05	5.94E-05	5.45E-05	4.97E-05
-9	2.97E-03	2.00E-03	1.22E-03	6.35E-04	2.38E-04	3.21E-05
-8	3.44E-03	2.19E-03	1.22E-03	5.33E-04	1.26E-04	4.03E-07
-7	1.79E-06	5.79E-06	1.21E-05	2.07E-05	3.15E-05	4.47E-05
-6	8.51E-03	5.50E-03	3.14E-03	1.44E-03	3.96E-04	3.35E-06
-5	1.70E-02	9.94E-03	4.67E-03	1.37E-03	3.23E-05	6.58E-04
-4	1.09E-03	1.02E-04	1.65E-04	1.28E-03	3.45E-03	6.67E-03
-3	0.051	0.045	0.04	0.035	3.00E-02	0.026
-2	0.333	0.26	0.197	1.42E-01	9.70E-02	0.06
-1	0.775	0.587	0.425	2.89E-01	1.79E-01	0.096
0	1	0.751	0.538	0.36	0.218	0.111
1	0.775	0.587	0.425	2.89E-01	1.79E-01	0.096
2	3.33E-01	0.26	0.197	1.42E-01	9.70E-02	0.06
3	5.10E-02	0.045	0.04	0.035	3.00E-02	0.026
4	1.09E-03	1.02E-04	1.65E-04	1.28E-03	3.45E-03	6.67E-03
5	1.70E-02	9.94E-03	4.67E-03	1.37E-03	3.23E-05	6.58E-04
6	8.51E-03	5.50E-03	3.14E-03	1.44E-03	3.96E-04	3.35E-06
7	1.79E-06	5.79E-06	1.21E-05	2.07E-05	3.15E-05	4.47E-05
8	3.44E-03	2.19E-03	1.22E-03	5.33E-04	1.26E-04	4.03E-07
9	2.97E-03	2.00E-03	1.22E-03	6.35E-04	2.38E-04	3.21E-05
10	7.56E-05	7.00E-05	6.46E-05	5.94E-05	5.45E-05	4.97E-05

Table(2): Intensity PSF for various values of γ (cones filter)

z	$\gamma = 0.0$	$\gamma = 0.2$	$\gamma = 0.4$	$\gamma = 0.6$	$\gamma = 0.8$	$\gamma = 1$
-10	7.56E-05	7.74E-05	7.92E-05	7.02E-05	3.85E-05	8.73E-07

z	$\gamma = 0.0$	$\gamma = 0.2$	$\gamma = 0.4$	$\gamma = 0.6$	$\gamma = 0.8$	$\gamma = 1$
-9	2.97E-03	2.58E-03	1.62E-03	6.31E-04	7.63E-05	1.58E-05
-8	3.44E-03	2.86E-03	1.54E-03	3.84E-04	3.87E-07	8.28E-05
-7	1.79E-06	9.83E-06	6.02E-05	1.66E-04	2.17E-04	6.11E-05
-6	8.51E-03	7.58E-03	5.20E-03	2.41E-03	4.37E-04	7.23E-05
-5	1.70E-02	1.40E-02	7.97E-03	1.95E-03	3.11E-05	2.18E-03
-4	1.09E-03	5.42E-04	1.54E-05	1.79E-03	6.68E-03	0.012
-3	0.051	0.051	0.049	0.047	4.20E-02	0.034
-2	0.333	0.313	0.258	1.87E-01	1.18E-01	0.067
-1	0.775	0.717	0.566	3.76E-01	2.06E-01	0.098
0	1	0.923	0.72	0.467	0.247	0.111
1	0.775	0.717	0.566	3.76E-01	2.06E-01	0.098
2	3.33E-01	0.313	0.258	1.87E-01	1.18E-01	0.067
3	5.10E-02	0.051	0.049	0.047	4.20E-02	0.034
4	1.09E-03	5.42E-04	1.54E-05	1.79E-03	6.68E-03	0.012
5	1.70E-02	1.40E-02	7.97E-03	1.95E-03	3.11E-05	2.18E-03
6	8.51E-03	7.58E-03	5.20E-03	2.41E-03	4.37E-04	7.23E-05
7	1.79E-06	9.83E-06	6.02E-05	1.66E-04	2.17E-04	6.11E-05
8	3.44E-03	2.86E-03	1.54E-03	3.84E-04	3.87E-07	8.28E-05
9	2.97E-03	2.58E-03	1.62E-03	6.31E-04	7.63E-05	1.58E-05
10	7.56E-05	7.74E-05	7.92E-05	7.02E-05	3.85E-05	8.73E-07

In the table 3 and 4, we have presented the computed values of the quality assessment parameter FWHM and the HWHM for both Triangular and cones filter respectively. The diameter of the PSF at half of its highest value is called full width at half maximum, or FWHM. It is equal to twice the distance between the point and the center of the diffraction pattern at which the intensity of the PSF drops to half of its maximum value. The tables' listed data show that the FWHM drops from 3.5 to 3.4. with increase the values of γ.

Table 3: FWHM and HWHM of apodised PSF for the values of γ

γ	PSF	FWHM	HWHM
0	1	3.5	1.75
0.1	0.871	3.4	1.7
0.2	0.751	3.44	1.72
0.3	0.64	3.4	1.7
0.4	0.538	3.5	1.75

Table 4: FWHM and HWHM of apodised PSF for the values of γ

γ	PSF	FWHM	HWHM
0	1	3.5	1.75

γ	PSF	FWHM	HWHM
0.1	0.98	3.47	1.73
0.2	0.923	3.42	1.71
0.3	0.833	3.43	1.71
0.4	0.72	3.44	1.72

CONCLUSIONS

In the present study, the intensity redistribution of the apodized PSF is determined for different values of γ under the effect of both triangular and connes pupil filters. It is evident that the pupil values of apodization (γ = 0.1,0.2) is efficient in improving the way optical systems function in relation to apodization pupils (□= 0.3, and 0.75). The evaluated values of FWHM indicate that the proposed apodizer filters can increase the resolution of optical system even under the incoherent illumination by decreases the FWHM, this is useful not only in astronomy, but also in the development of optics for use in microscopes, telescopes, and beam-focusing systems.

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