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Effect Of Central Circular Obscuration On The Intensity Of Point Spread Function

Padamuttum Anitha[1], N Sabitha[2], Dasari Karuna Sagar[3]
1, 2 Research Scholar, Dept. of Physics, Osmania University, Hyderabad, Telangana, India 500007
3 Optics Research Group, Department of Physics, University College of Science, OU Hyderabad, Telangana India 500007

Abstract
The Point Spread Function (PSF) is a fundamental concept in the field of optics, describing the response of an optical system to a point source of light. This study aims to investigate the effects of central circular obscuration on the intensity characteristics of the PSF. The research employs theoretical analysis, to comprehensively explore how the size and position of the obscuration influence the intensity distribution within the PSF. This study also focuses on investigating the impact of central circular obscuration on the FWHM of the PSF.

Keywords: *Point Spread Function, PSF intensity, central circular obscuration, optical systems, Full Width at Half Maximum (FWHM), image resolution.*

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I. INTRODUCTION

In the field of optics, the Point Spread Function (PSF) plays a fundamental role in characterizing the response of an optical system to a point source of light. A critical parameter associated with the PSF is the Full Width at Half Maximum (FWHM), which represents the width of the PSF at half its maximum intensity. A. V. Hakobyan Byurakan Astrophysical Observatory, Armenia carried out investigations like PSF,FWHM and annular apertures. Understanding the FWHM is essential for determining image resolution, quality, and overall system performance [1, 4]. The use of obscured circular apertures in optical systems has significant effects in practical applications, particularly in imaging. Central circular obscuration, wherein a portion of the aperture's centre is blocked or obscured, is a common design feature in various optical instruments, including telescopes, cameras, microscopes, and other imaging devices Adnan Falih Hassan Aldehadhawe Ban Hussein Ali Alrueshdy offered a different explanation for Central circular obscuration and the use of obscured aperture appears obvious in imaging by the optical system sand astronomical telescopes.[2-4].In many optical instruments, central circular obstructions, such as secondary mirrors or camera apertures, are commonly encountered due to design constraints and practical considerations. These obstructions can significantly impact the PSF's characteristics, including the FWHM, yet their effects on this key parameter have not been extensively explored. This knowledge gap highlights the need for a comprehensive investigation into the influence of central circular obscuration on the FWHM of the PSF.

II. THEORY

The expression for the amplitude PSF for the chosen amplitude aperture for the Gaussian focal plane, is given by

$$G_F(0,\quad Z) = 2\int_0^1 f(r)\ J_0(Zr)rdr \qquad (1)$$

Where *f(r)* is the Gaussian type apodization function, Z - is the reduced dimensionless diffraction coordinate, J_0 - the zero-order Bessel function of the first kind and the parameter ‘r’ is the polarizer radial coordinator.

The expression used to compute the intensity distribution in the image plane for a point object by complex pupil function is given by

$$B_F(\phi_d,\ Z) = \left[2\int_\varepsilon^a f_1(r)\exp\left[-i\left(\frac{1}{2}\phi_d r^2\right)\right] J_0(Zr)rdr \ -\frac{\pi}{3}\int_a^1 f_2(r)\exp\left[-i\left(\frac{1}{2}\phi_d r^2\right)\right] J_0(Zr)rdr\right]^2$$
(2)

Where $f_1(r)$ is Co-sinusoidal, and $f_2(r)$ is Hanning mask pupil functions for the amplitude apodization of the pupil transmission. And Z is the reduced dimensionless diffraction coordinate in the image plane.
The amplitude filter that was used to apodize the exit pupil of the rotationally symmetric optical imaging system is given by

$$f(r) = Cos(\pi \beta r) \qquad \text{[Hanning amplitude filter]} \qquad (3)$$

$$f(r) = \frac{(1+\beta \cos(\pi r^2))}{1+\beta} \qquad \text{[Cosinusoidal amplitude filter]} \qquad (4)$$

Where $f(r) =$ the pupil functions, $\beta =$ the apodization parameter, and $r =$ Normalized distance of the point on the pupil from the centre.

III. RESULTS AND DISCUSSIONS

This study aims to provide the impact of central circular obscuration and apodization parameter on the PSF of optical imaging systems, particularly in highly defocused situations. The MatLab program and the Gaussian quadrature method are used to carry numerical integration method to analyze the results. The central circular obscuration refers to blocking the central part of the optical system's aperture, creating a circular area with no light transmission. In this study, two different values of the central circular radius are considered: ε=0.2 and ε=0.4. This means that the size of the central obscured region is changed to explore how it affects the PSF. By varying the value of ε, the study aims to analyze how the size of the obscured region impacts the intensity distribution and overall characteristics of the PSF. Larger values of ε result in more pronounced effects on the PSF, affecting the resolution and quality of the optical system's imaging capabilities.

Apodization is a technique used to modify the intensity distribution at the edges of the aperture to reduce diffraction effects. The apodization parameter (β) controls the order or strength of the apodization function. By adjusting the value of β, the study aims to examine how different levels of apodization impact the PSF.

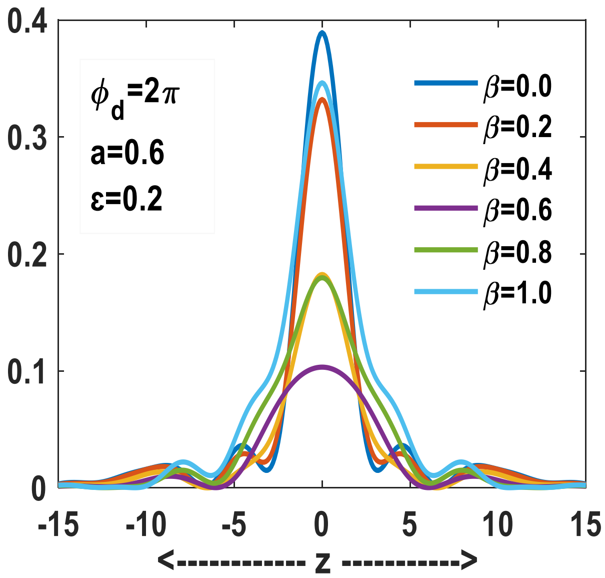

Fig. 1 INTENSITY DISTRIBUTION CURVES

From figure 1 it can be observed that the intensity distribution curves under the effect of central circular obscuration apodised with the Cosinusoidal amplitude filter at the inner zone and the Hanning amplitude filter at the outer zone. Central circular obscured radius ε is fixed at 0.2, with highly defocused optical system with the variable apodization parameter β. The intensity distribution curves for the highly apodized optical system (with larger values of β) show lower intensity in the central maxima compared to the Air case, and the PSF under the highly apodized conditions exhibits a more spread-out distribution compared to the Air case.

The decrease in intensity in the central maxima for the highly apodized optical system suggests that the apodization is affecting the PSF characteristics, resulting in a more spread-out central lobe with lower intensity compared to the unmodified PSF (Air case).

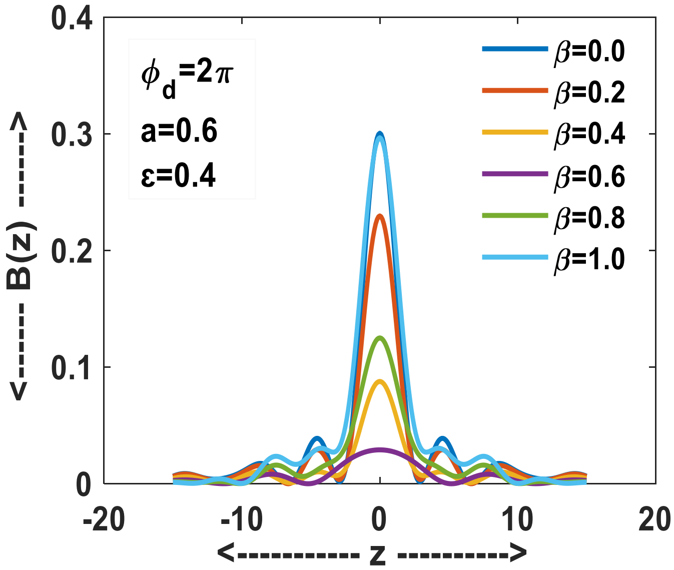

Fig. 2 INTENSITY DISTRIBUTION CURVES

Fig.2 depicts the intensity distribution of PSF generated by the optical system under the influence of central circular obscuration. The PSF intensity distribution is analysed for the optical system under the influence of extreme defocus with a value of Φd = 2π For the extreme defocused value Φ_d =2π, and the apodization parameter β is varied from 0 to 1, and with the central obscuration parameter ε set to 0.4, the intensity in the central maxima remains almost the same for both the highly apodized and the Airy case (unmodified PSF). This means that the central bright spot in the PSF has a similar intensity level for both cases. Despite the central maxima having almost the same intensity, the first minima (the first dark ring in the PSF) is minimized for the highly apodized optical system. This suggests that apodization with higher values of β effectively reduces the intensity of the first dark ring in the PSF.

From the combined observations of both Figure 1 and Figure 2, we can deduce that the highly apodized case with a central obscuration parameter (ε) set to 0.4 leads to an increase in intensity at the central maximum. Additionally, the intensity is narrowed, meaning that the central bright spot becomes more concentrated.

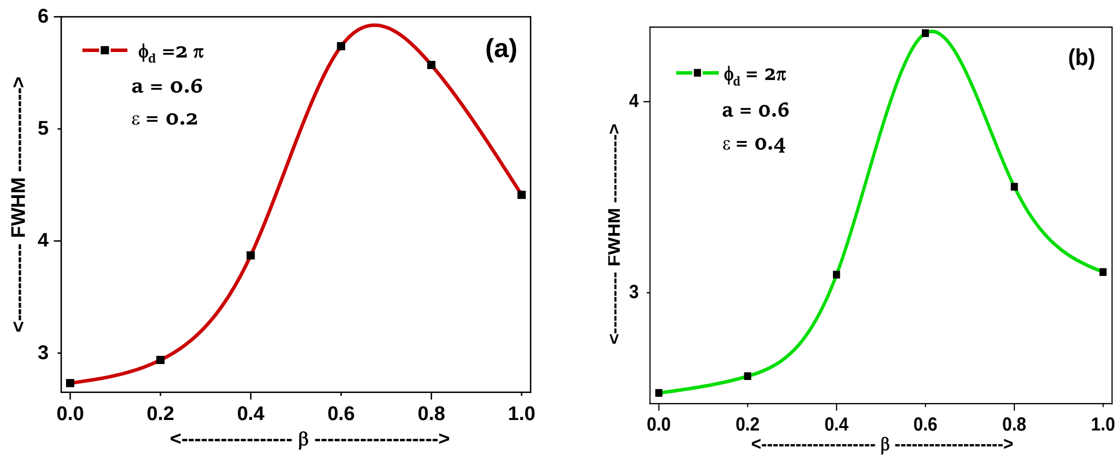

Fig.3

FWHM for ε = 0.2: In Fig. 3(b), the FWHM has a higher value of 4.41075 for the highly apodized case with ε = 0.2. A higher FWHM suggests that the central peak of the PSF is broader, indicating a decrease in resolution.

FWHM for ε = 0.4: In Figure 3(a), the FWHM has a lower value of 3.10786for the highly apodized case with ε = 0.4. A lower FWHM means that the central peak of the PSF is more concentrated and narrower, which is generally associated with improved resolution. A narrower FWHM indicates that the PSF has a higher degree of localization and better ability to distinguish closely spaced details in an image.

It can be concluded that a higher value of the central obscured parameter ε (ε = 0.4) leads to an improvement in resolution, as evidenced by the narrower FWHM in Figure 3(a). This result indicates that the optical system with ε = 0.4 and high apodization is capable of producing a more focused and sharper image with better resolution compared to the case with ε = 0.2.

IV. CONCLUSIONS

The results of the present work have indicated that using central circular obscured apodizers with higher values of ε=0.4 has led to remarkable improvements in the PSF's characteristics under high defocusing and high apodization conditions. This could manifest as a more concentrated and sharper central peak, a narrower Full Width at Half Maximum (FWHM), and other desirable features related to image quality and resolution. This has potential implications for various applications in which high-resolution imaging are crucial, such as astronomy, microscopy, and remote sensing, among others.

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