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Tailoring the Point Spread Functions of aberrated Optical Systems in the presence of Defocus with variable apodisation

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Abstract. *The two basic merit functions of the point spread function are the first an increase in the intensity of the cenral maximum and athe second a reduction in the radius of its first dark ring. These are one of the prime merit functions associated with point spread functions. Our studies entail in the estimation of the radius of the first dark ring in the obtained diffraction pattern of the obtained point image. Apertures shading with amplitude with two-zone with various filters in each zone have been considered. The influence of the filters has been analyzed to estimate the optimum value of apodisation for a given aperture in realizing the least possible radius for the first dark ring which in turn influences the resolving aspects of the optical imaging systems.*

Keywords: *Rotationally Symmetric Systems, Gaussian filter, Hanning amplitude filters, Super- resolution.*

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I. Introduction

The image of a point object is not a point due to diffraction. Instead, the image is a function of intensity which is called the point spread function (PSF). The presence of any aberration in the optical system leads to further degradation in the image intensity; as such the PSF is the response of the system to a point object. The PSF of an optical system is an important parameter for studying its imaging characteristics. In other words, the performance of an optical system significantly depends on its PSF. The study of imaging properties of optical systems suffering from aberrations from the knowledge of the PSF has become an important method in the design and testing of such systems. In the present era of photonics, where there is a wide surge of advancement of optics penetrating into all forms of technological development, especially in the field of optical imaging and telecommunications, the suppression of secondary side-lobes in the diffraction pattern also known as point spread function (PSF) is highly desirable in certain cases. The process of achieving this is known as apodisation. By properly choosing the transmission function of the pupil of the system, the intensity in the outer parts of the diffraction pattern can be totally suppressed or at least considerably reduced without increasing the dimensions of the pupil. Many apodisation filters have been proposed in instrumental optics for various purposes [1]. In the present investigation, the diffracted field characteristics of rotationally symmetric optical systems shaded with the variable apodisation with two zones have been considered to analyze the intensity distribution in terms of the width of the central maximum and reduction in the secondary maxima by shaping the circular aperture into two-zone aperture with varying central circular zone parameter. Hence, the study of imaging properties of optical systems from the knowledge of the PSF has become an important method in the design and testing of such systems [2].

II. Experimental

The far-field diffraction characteristics due to a circular aperture in an optical imaging system can be derived from its amplitude response or the amplitude PSF. The diffracted light amplitude associated with a rotationally symmetric pupil is given by [3],

$$A(Z) = 2\int_0^1 f(r) J_0(Zr) r dr \qquad (1)$$

where f(r) is the pupil function of the optical system; Z is the dimensionless variable which forms the distance of the point of observation from the centre of diffraction head; and $J_0(Zr)$ is the zero order Bessel function of the first kind; 'r' is the reduced co-ordinate on the exit-pupil of the system. The expression for annular aperture can be written as

$$A(Z) = 2\left[\int_0^a 10^{-\beta r^2} J_0(Zr)rdr + \int_a^b \cos(\pi\beta\ \mathrm{r}) J_0(Zr)rdr\right] \qquad (2)$$

In the present study, we have considered the variable apodisation with two filters one Gaussian amplitude filter in the central zone and whose pupil function can be represented by

$f(r) = 10^{-\beta r^2}$; in the inner zone and with Hanning amplitude filter which is represented by $f(r) = \cos(\pi\beta\ \mathrm{r})$ at the outer zone .

where β is the apodising parameter controlling the non-uniform transmission of the pupil. The intensity PSF B(Z) which is the real measurable quantity can be obtained by taking the squared modulus of A(Z). Thus,

$$B(Z) = |A(Z)|^2 \qquad (3)$$

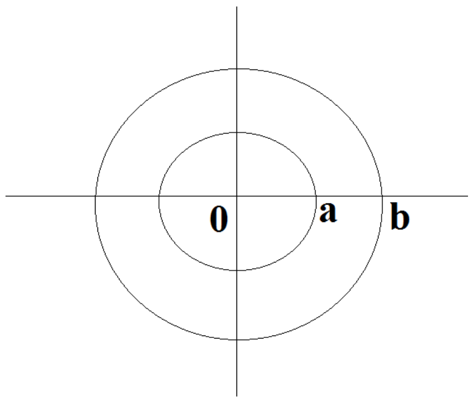


FIG.A : Two-zone aperture

III. Results And Discussion

Expressions (2) and (3) have been used to compute the point spread functions of the apodised apertures with variable apodisation using two amplitude filters. Figure 1 depicts the intensity distribution curves for various degrees of apodisation parameter for two-zone circular aperture (a=0.4) with Gaussian filter in the inner zone and Hanning filter in the outer zone. Form the profile of the intensity distribution curves it is evident that for β = 0.50, i.e., for partial apodisation there appears to be a total elimination of the optical side-lobes thus shaping the point spread function to the desired profile. However, for extreme apodisation β = 1, the intensity in the central lobe tailors to the desired profile there by an increase in the intensity of the central maximum and reduction in the value of full width at half maxima (FWHM) is the outcome by employing the variable apodisation .Table-A provides the computed values of the radius of the first, second and third dark rings for circular aperture in the case of first order filter for different values of β.

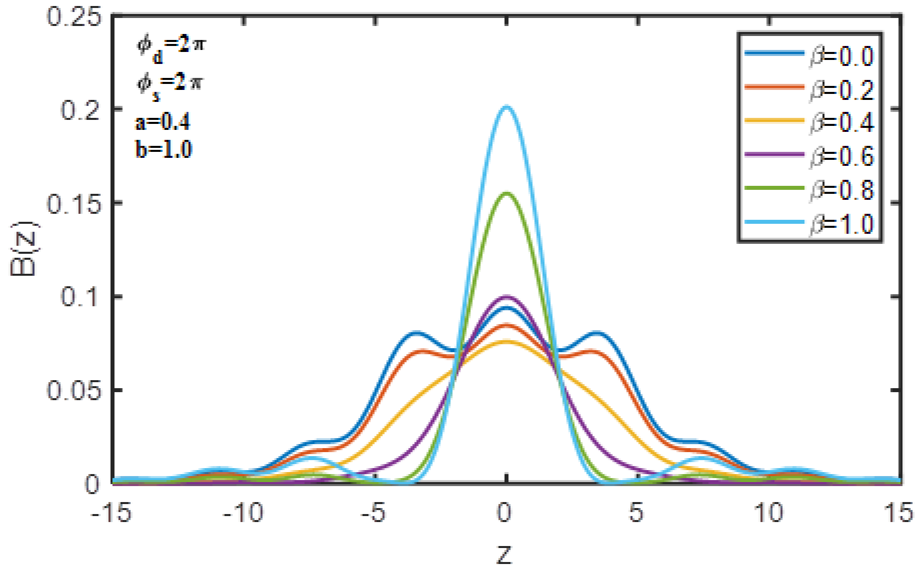


FIGURE1. Intensity distribution curves for aperture with variable apodisation.

TABLE A.

β	First Minima Position	Second Minima Position	Third Minima Position
0.00	3.8317	7.0154	10.1728
0.10	3,8581	7.0300	10.1833
0.20	3.9463	7.0797	10.2179
0.30	4.1310	7.1928	10.2980
0.40	4.5124	7.4836	10.5218
0.50	5.3304	8.5378	11.7073
0.60	6.1977	9.6078	12.8801
0.70	3.3443	7.9745	11.3037
0.80	1.5484	6.7172	9.9824
0.90	2.1656	6.8507	10.0735
1.00	2.4560	6.9826	10.1631

FIGURE2: Intensity distribution curves for aperture with a =0.6

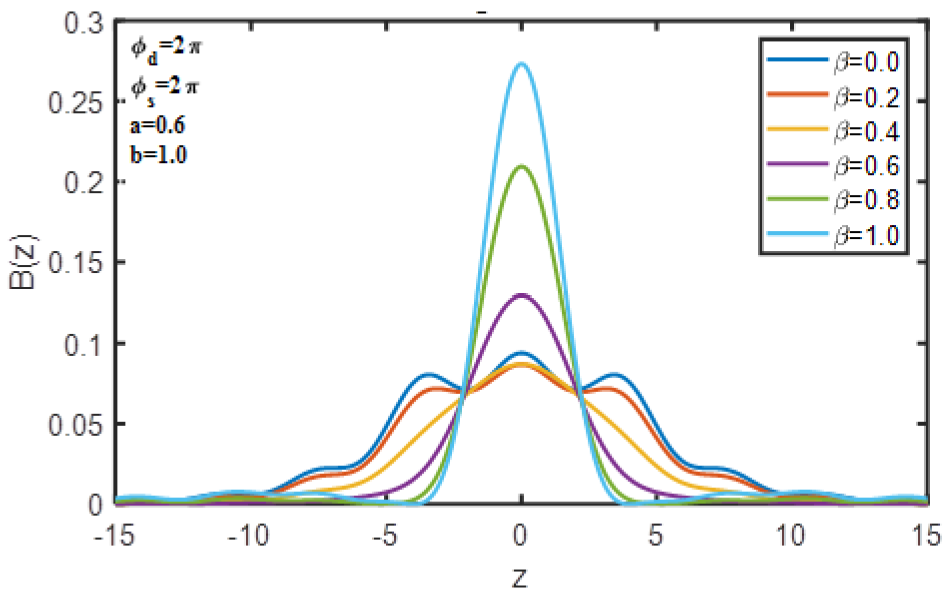


Figure 2 depicts the intensity distribution curves for various amounts of apodisation parameter for two-zone circular aperture (a=0.6) with Happ-genzel filter in the inner zone and Hanning filter in the outer zone. Form the profile of the intensity distribution curves it is evident that for β = 0.50, i.e., for partial apodisation there appears to be a total elimination of the optical side-lobes and for higher values of apodisation with β = 1, the intensity in the central lobe shapes to the desired profile resulting in an increase in the intensity of the central maximum and reduction in the reduction in the radius of the first dark ring , in other words the energy in the central maximum is increase with reduced size of the spot rendering it to be super-resolved.

FIGURE3: Intensity distribution curves for aperture with a =0.7

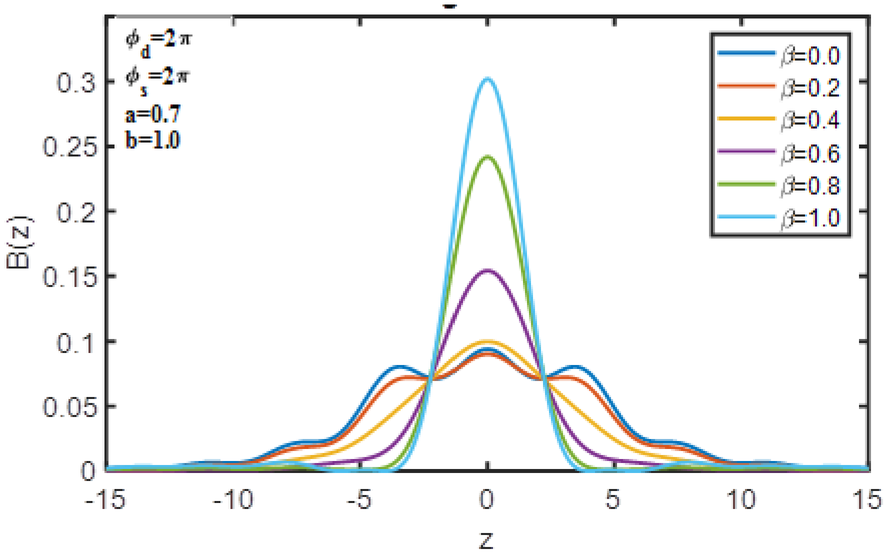
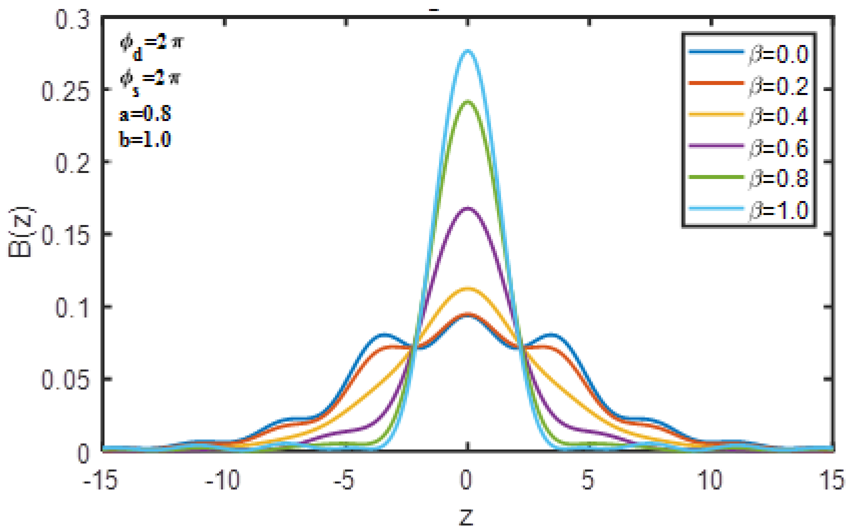


FIGURE4: Intensity distribution curves for aperture with a = 0.8



Figures 3 and 4 depicts the intensity distribution curves for central zone with a = 0.7 and a = 0.8

IV. Conclusions

The process of apodising the optical system with variable apodisation amplitude filter, suppresses fully or partially the optical side-lobes. For β = 0.5 these side-lobes are totally eliminated for all the four orders of the optical filter considered. The radius of the first dark ring for clear apertures gets reduced by about one third for two-zone aperture (a = 0.5). Energy is transferred from the Airy disc to surrounding rings, resulting in the increases in the strength of the optical side-lobes. By employing Gaussian amplitude filters in the central zone and Hanning amplitude filter in the outer zone results in a feature effective in shaping the point spread function of the given optical systems.

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