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IMPROVED AXIAL RESOLUTION USING ASYMMETRIC APODISATION

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ABSTRACT:
Apodisation is the technique alters the imaging properties of an optical system such that the system impulse ceases the ringing effect by manipulating its entrance pupil. It helps to differentiate direct image of faint object which is close to very bright object. The results of an optical system can be improved by two methods namely modification of the optical system and the post detection processing. The former one involves optimization of the optical system itself and the latter involves operations on the systems output. The pupil function can be modified with suitable spatial filters to obtain Asymmetric apodisation. The unwanted ringing around the point speed function (PSF) can be filtered using this technique. The point spread function (PSF) of an optical system obtained with asymmetric apodization consists of unequal distribution of intensities on either side of the central lobe. The portion of PSF with side lobes of more intensities is termed as bad side and the portion with side lobes of less intensities is termed as good side. This asymmetrical PSF is obtained by introducing apodiser in the central region and introducing semi-circular edge rings. The asymmetry in the PSF has been found to change with the width of the edge rings and on the apodization parameter of the central region. This technique can be used to calculate Full width at half maximum (FWHM) of an asymmetrically apodised point spread function. It is observed that as semi-circular ring width increases half maximum area is affected. This technique can be used to improve the quality of image with improved axial resolution, which helps in the study of microorganisms under a microscope and to study weak spectral lines in presence of bright spectral lines.

Keywords:
Point spread function, spatial filters, Asymmetric apodization,
and resolution

1. INTRODUCTION

Using our work the axial resolution of an optical system can be improved by changing the pupil function with suitable apodization. With the introduction of apodizer the imaging properties can be altered, such that a sharp image can be obtained without any ringing effect. [1]. In 1991,97 Cheng and Siu [2][4], introduced asymmetric apodization and succeed in achieving low side lobes and a sharp central peak on one side termed as 'good side' and a broader central peak with enhanced side-lobes on the other side named as 'bad-side'. In fact, the good-side was obtained at the cost of the bad-side. In further continuation of their work [3] they obtained improved side-lobe suppression. The results obtained can be considered as a breakthrough in obtaining improvised axial resolution using asymmetric apodization. Lord Rayleigh [5] who was first pointed out importance of primary corollaries in diffraction pattern and derived formulae.

k.surendar [6-8] investigated few corollaries of PSF to prove efficiency of amplitude filters and annular apertures and calculated half power diameter directly for annular and circular apertures. Dr.T.Borlinghaus [9] gave brief idea on influence of full width at half maximum on confocal optical section thickness.

In Our previous papers [10][11] we investigated the focusing properties of asymmetrically apodized optical systems for a slit, circular aperture and we showed how to achieve low side lobes and steep principal maximum simultaneously. In the present paper we did exhaust study on quality criterions of PSF to achieve good resolution. Current study extends the earlier work on asymmetrically apodised optical system with phase and amplitude filters [11].

2. THEORY

According to definition of full width at half maximum (FWHM), it is the diameter of the PSF at 50% of its peak value. It is twice the distance of the point from the centre of diffraction pattern where intensity PSF becomes one-half of maximum value. It is direct corollary of PSF apodised by complex pupil filter consists of three zones

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viz. two semi-circular rings at edges and a central zone with an amplitude apodizer, corresponding phases are $i, -i \text{ and } 0$.

B is the apodization parameter controlling the degree of non-uniformity of the transmittance $(1-4\beta\rho^2+4\beta\rho^4)$ over zone of radius (1-b). The range of values it takes are $0 \le \beta \le 1$. It is clear that for β = 0, the transmittance of this zone is uniform. Transmittance over rest of the two zones of circular aperture of unit radius is unity. The sidth of side ring is taken as b. The width of b is varies from 0 to 0.01. The structure of complex pupil filter can be seen in Figure 1 in detail.

The normalized complex field amplitude $A(u,\phi)$ on the focal region is equal to sum of three amplitudes contributing by three zones of pupil function. The distance in u that connects the 50% intensities on both sides of intensity profile can be measured as FWHM.

The diffraction field amplitude contributing by circular aperture of radius (1-b):

$$A_0(u,\phi) = \int_0^{1-b}\int_0^{2\pi}(1-4\beta\rho^2+4\beta\rho^4)\exp(iu\rho\cos(\phi-\varphi))\rho\,d\rho\,d\varphi \qquad (1)$$

Here, ρ is the normalized radial co-ordinate in pupil plane, where $u = \frac{2\pi}{\lambda}\sin\theta$.

The diffraction field amplitudes contributing by left and right semi circular ring:

$$A_1(u,\phi) = i\int_{1-b}^{1}\int_{\frac{\pi}{2}}^{\frac{3\pi}{2}}\exp(iu\rho\cos(\phi-\varphi))\rho\,d\rho\,d\varphi \qquad (2)$$

$$A_2(u,\phi) = -i\int_{1-b}^{1}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\exp(iu\rho\cos(\phi-\varphi))\rho\,d\rho\,d\varphi \qquad (3)$$

Hence, the field amplitude can be written as

$$A(u,\phi) = A_0(u,\phi) + A_1(u,\phi) + A_2(u,\phi) \qquad (4)$$

The intensity PSF $I(u) = |A(u,\phi)|^2$, which is measurable quantity can be obtained. We have suggested a new quality criterion HWHM on either side of apodised PSF, is evaluated as the distance from centre of diffraction to where intensity of main peak becomes 50% of its peak value. For all symmetric pupil functions, FWHM is an image quality criterion whenever the PSF with non-zero minimum. Our present work is dealing with asymmetric pupil filters where PSF shifts towards worst side of pattern as degree of apodization increases. So instead of FWHM, HWHM becomes a quality assessment parameter whenever the PSF is asymmetric, carries non – zero minima for higher degree of apodisation.

3. RESULTS AND DISCUSSIONS

The effects of asymmetric apodization on the PSF have been investigated for various values of widths of the semi-circular rings at edges, azimuth angle and the transmittance of the central circular region of the circular aperture. Individual and combined effects of above parameters on FWHM and HWHM of apodised PSF have been discussed. The results have been obtained from equation (4) by employing a twelve-point Gauss quadrature numerical method of integration. An iterative method is applied to find 50% peak intensity positions in distance u from diffraction center on either side of diffraction head. We are successful to reporting the results of HWHM on good and bad side. HWHM is a new quality criterion, which describes distribution of half maximum area on good and bad side of PSF of asymmetric apodization. From Listed values in Table 1, a direct corollary FWHM is function of semi-circular ring width b for different values of apodization parameter β depicted in figure (2) for various amount of apodization parameter β. It shows that as the semi-circular ring width b increases 0 to 0.1 FWHM also increases and then decreases with semi-circular ring width. Further in decrease is boosting by degree of apodisation. For β = 0, as b increases from 0 to 0.03, FWHM increases from 3.2327 to 3.2839 and then

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for higher values of b FWHM decreases. Figure (5) shows that, for unapodised case FWHM is 3.24 units. As degree of apodization increases, FWHM obtained lower values than that of airy case. This can be seen in more detail from listed values in Table 1.

Figures (3) & (4) and listed values in Table 2, 3 reveal the effect of asymmetric apodization on distribution of half maximum area on either sides of PSF. This distribution is presented as HWHM on good and bad side. As semi-circular ring width b increases 0 to 0.1, HWHM on good side is getting narrow for various values of apodization parameter β. For higher degree of apodisation, HWHM focused more on good side. It tells us that low side lobes and steep central lobe on good side. For it the optimum values of b and β are 0.04 and 0.4, respectively. Clearly says that, for all values of apodization parameter β, as b increases from 0 to 0.1 in steps of 0.01 HWHM on good side becomes narrower at cost of broadened HWHM on bad side. This simultaneous effect is clear evidence for super resolution phenomenon. It can be seen in more detail from figure (6) that on left half axis the main peak is broadened and shifted while on right half axis the main peak is narrower with which enables to resolve two objects in close proximity.

This is a very important aspect of our present study. This criterion is important when image quality is limited by factors external to the optical system. For large amounts of aberrations, it is sensitive. The well-established Rayleigh criterion becomes inapplicable in dealing with non-zero minima of asymmetric PSF. In such cases the asymmetrically apodised optical system may be evaluated by its HWHM (half width at half maximum).

Table 1: FWHM of apodised PSF for all values of β and b

b	β=0	β=0.2	β=0.4	β=0.6	β=0.8	β=1
0	3.2327	3.2357	3.2399	3.2460	3.2558	3.2739
0.01	3.2603	3.2668	3.2754	3.2873	3.3046	3.3313
0.02	3.2778	3.2835	3.2898	3.2954	3.2959	3.2708
0.03	3.2839	3.2843	3.2809	3.2678	3.2290	3.1172
0.04	3.2781	3.2689	3.2494	3.2087	3.1216	2.9371
0.05	3.2609	3.2385	3.1991	3.1279	2.9987	2.7745
0.06	3.2332	3.1958	3.1354	3.0370	2.8791	2.6416
0.07	3.1967	3.1439	3.0645	2.9454	2.7721	2.5363
0.08	3.1534	3.0865	2.9916	2.8589	2.6801	2.4533
0.09	3.1056	3.0268	2.9206	2.7805	2.6024	2.3874
0.1	3.0553	2.9671	2.8536	2.7109	2.5373	2.3350

Table 2: HWHM on good side of PSF for all values of b and β

b	β=0	β=0.2	β=0.4	β=0.6	β=0.8	β=1
0	1.6163	1.6179	1.6200	1.6230	1.6279	1.6370
0.01	1.5639	1.5564	1.5457	1.5295	1.5021	1.4461
0.02	1.5033	1.4836	1.4552	1.4111	1.3340	1.1728
0.03	1.4342	1.3993	1.3486	1.2690	1.1304	0.8560
0.04	1.3568	1.3043	1.2279	1.1093	0.9106	0.5568
0.05	1.2718	1.2002	1.0972	0.9417	0.6967	0.3079
0.06	1.1805	1.0896	0.9618	0.7764	0.5038	0.1113
0.07	1.0844	0.9757	0.8270	0.6210	0.3370	0.0423

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0.08	0.9855	0.8615	0.6973	0.4796	0.1956	0.1630
0.09	0.8858	0.7497	0.5753	0.3535	0.0765	0.2589
0.1	0.7871	0.6424	0.4627	0.2420	0.0240	0.3363

Table 3: HWHM on bad side of PSF for all values of b and β

b	β=0	β=0.2	β=0.4	β=0.6	β=0.8	β=1.0
0	1.6163	1.6179	1.6199	1.6230	1.6279	1.6370
0.01	1.6965	1.7105	1.7297	1.7577	1.8025	1.8852
0.02	1.7745	1.7999	1.8345	1.8844	1.9619	2.0980
0.03	1.8497	1.8849	1.9323	1.9988	2.0986	2.2612
0.04	1.9213	1.9645	2.0215	2.0994	2.2110	2.3802
0.05	1.9891	2.0383	2.1018	2.1862	2.3019	2.4666
0.06	2.0528	2.1062	2.1736	2.2606	2.3754	2.5303
0.07	2.1123	2.1683	2.2375	2.3243	2.4352	2.5786
0.08	2.1680	2.2251	2.2944	2.3793	2.4845	2.6162
0.09	2.2198	2.2771	2.3452	2.4270	2.5260	2.6464
0.1	2.2682	2.3247	2.3909	2.4689	2.5613	2.6712

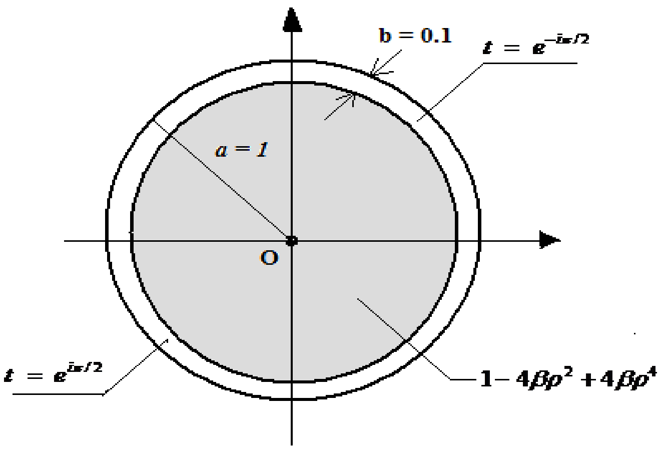

Figure 1: Structure of three-zone complex pupil filter

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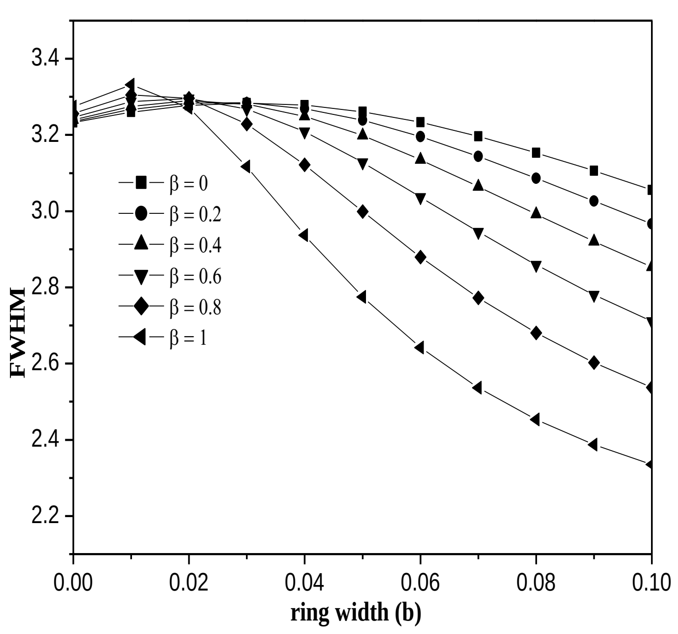

Figure 2: FWHM as function of semi-circular ring width b for different values of β

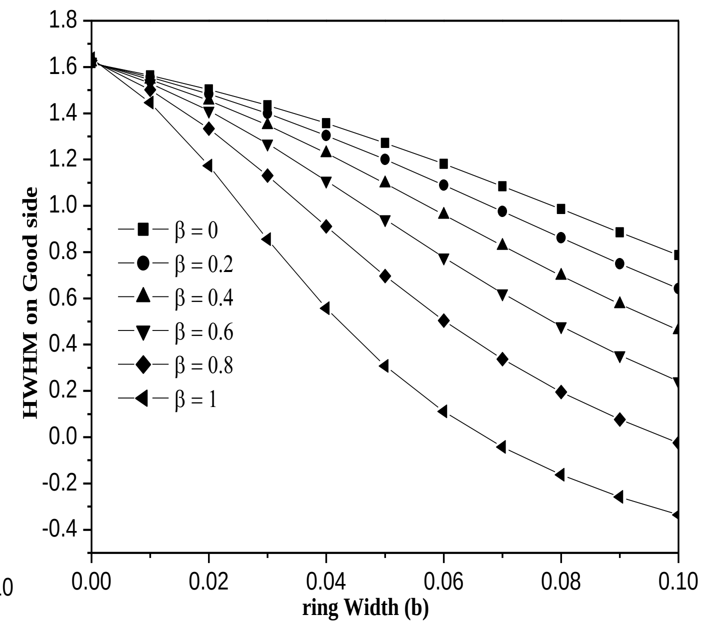

Figure 3: Effect of asymmetric apodisation on HWHM (good side)

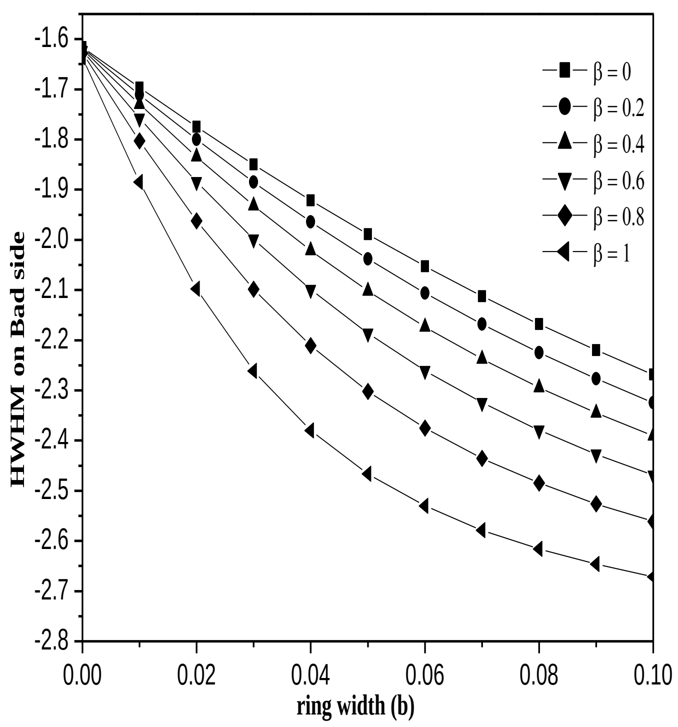

Figure 4: Effect of asymmetric apodization on HWHM (bad side)

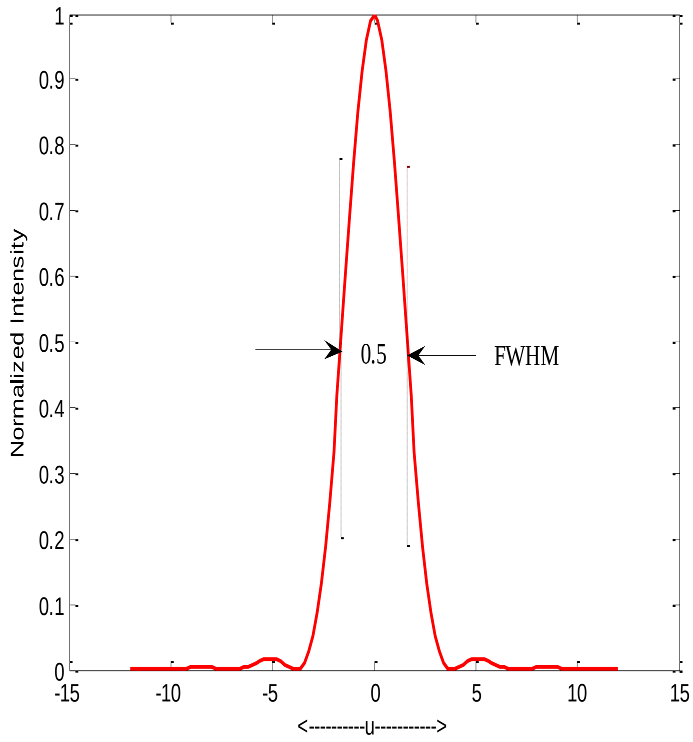

Figure 5: FWHM of Unapodized Case (Airy)

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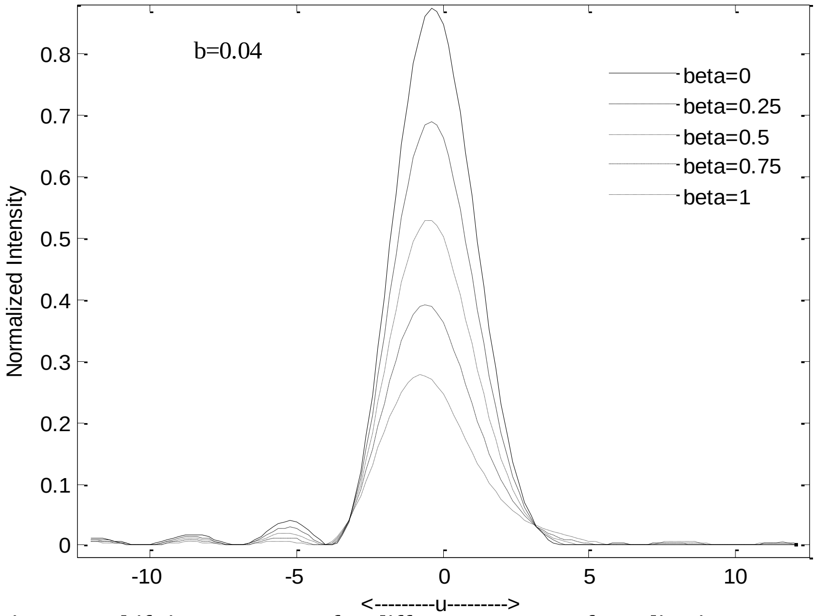

Figure 6: Shift in PSF curves for different amount of apodisation parameter β

CONCLUSIONS

Finally, we may conclude that our investigations aimed high resolution with half maximum studies of intensity profile in axial distance u has been evaluated by considering three level complex pupil filters. By performing asymmetric apodization we obtained FWHM lower than that of airy case where as image quality criterion HWHM is broadened on bad side at cost of narrower HWHM on good side. The asymmetry increases with the widths of semi-circular rings and promoting by increase in apodization parameter β. In this way we succeeded to overcome limitations to improve resolution axially using thee level complex pupil filter.

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