Truncated apodizers for engineering the point spread function

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Abstract

Efficient truncated apodizers have been presented for modulating the point spread function of the optical system in the presence of a high level of primary aberrations. It has shown that the resolution of the apodized optical system is increased with the degree of apodization β (a shaded region across the pupil function) and the central obstruction ratio ε. It is evidenced by the presence of a narrow central lobe and minimal sidelobes in the resulting PSF intensity profile curves and the presence of a steep dip in the resulting composite intensity distributions of two overlapping incoherent point sources.

Keywords

Apodization, point spread function (PSF), two-point resolution, aberrations

1. Introduction

The apertures with different transmission functions play a vital role in modifying the point spread function (PSF) in numerous applications. Recently, many studies have drawn attention to developing this property [1-2]. An aberrated optical system results in the PSF with non-zero first minima, enhanced sidelobes due to the displacement of internal energy of the central lobe, widened central lobe, and shifted first minima positions, which represent the fundamental problem in aberrated optical systems [1-2]. The aberrated optical system and efficient apodization techniques focus on eliminating the well-known effects induced by various optical aberrations [1-2]. However, it varies from one optical system to another and strongly depends on the coherence conditions and apodization mechanisms to be applied [1]. The proposed truncated apodizers can modify the focal properties of an aberrated optical system, such as suppressing sidelobe levels, narrowing the central lobe, leading to low FWHM. The current study is instrumental in interpreting the interference of intensity distributions of two-point sources under incoherent light of illumination [1].

2. Numerical simulation

Following the scalar wave-diffraction theory, a monochromatic plane wave incident on the truncated apodizer yields diffraction, and that converges at the focal point. An iterative numerical integration method developed and applied to calculate the resultant intensity distribution of the PSF, which is proportional to the Fourier transform of the light field distribution across the apodizing pupil plane. The general expression for the amplitude distribution of light field in the focal region of the optical system obtained, thus [1, 2]:

$$B(Z) = 2\int_{\varepsilon}^{1} f(r)\ \exp(-i(\Phi_a)\, J_0(Zr)\, r dr \qquad (1)$$

In equation (1), *f(r)* is the Gaussian-type apodization function with the apodization controlling parameter β. Note that ε is the central obstruction ratio, Z is the reduced dimensionless diffraction coordinate. Here J_0 represents the Bessel function of the first kind and zero-order. The parameter ‘r’ is the radial coordinate in the pupil plane, and Φ_a is the aberrations function. However, primary monochromatic aberrations considered in this study are the defocusing effect and primary spherical aberrations. The resultant intensity PSF of the aberrated optical system is measured from equation (2).

$$I(Z) = |B(Z)|^2 \qquad (2)$$

3. Discussion

Figure 1(a) represents the Airy PSF, in which the internal energy of the central lobe is displaced into the sidelobe region. For β = 0.5, ε = 0.8, the central lobe is narrowed, and sidelobes are flattened to low-intensity levels, and the resulting PSF measured with low FWHM (Annular-IV in Fig.1(a)). In the presence of the same truncated apodizers, the resolution of two overlapping point sources is also investigated, and the corresponding results are shown in Fig. 1(b). For β = 0.5, ε = 0.8, the two incoherent point sources are well-resolved, and the super-resolving nature of the apodizer is verified.

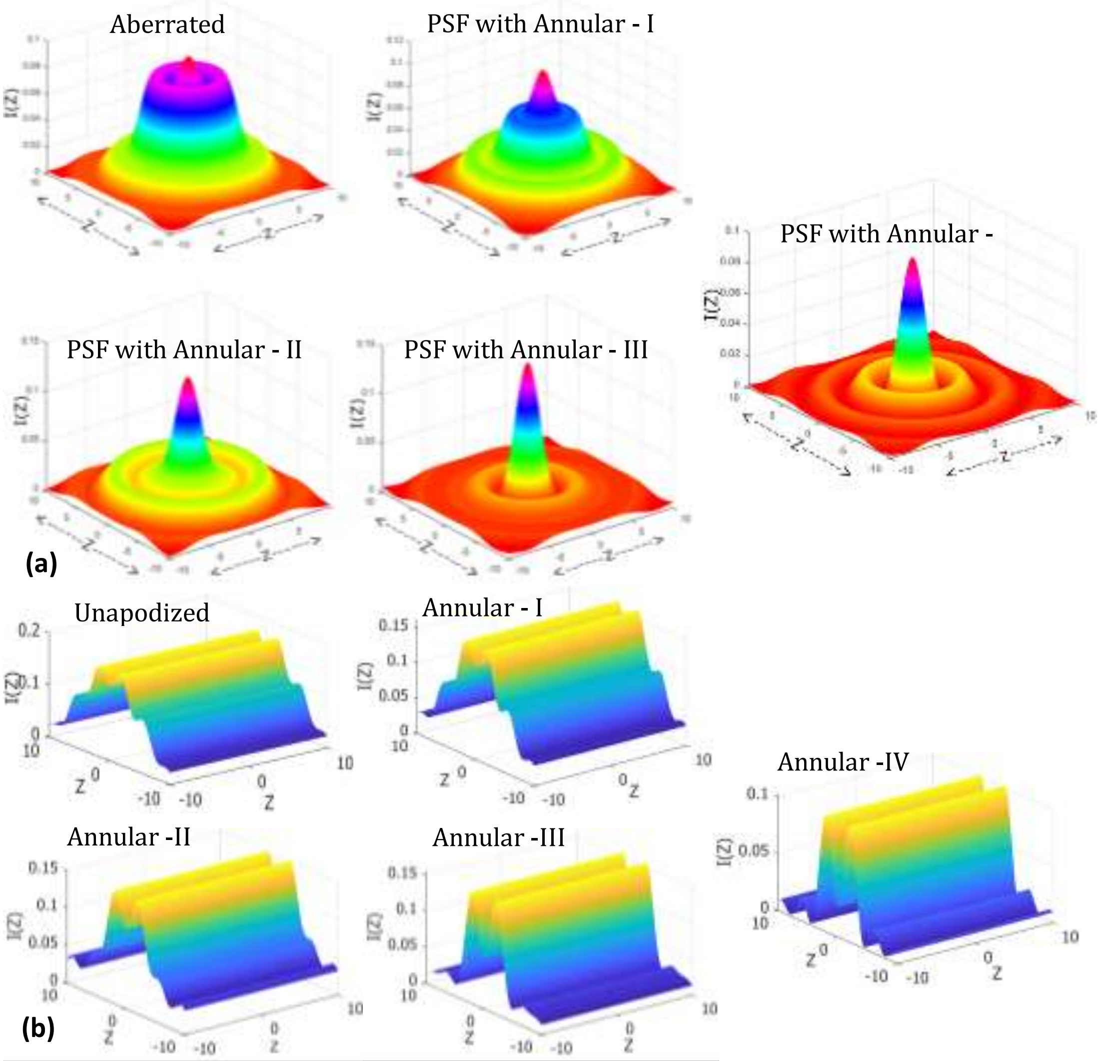

Figure 1: (a) PSF intensity distributions in the presence of high levels of primary aberrations for different truncated apodizers. **(b)** Corresponding composite intensity distributions from two mutually incoherent point sources separated by the distance is equal to the Rayleigh limit (1.22λ /D), D: Aperture diameter. The truncated apodizers investigated in the form of Annular-I [β=0.5, ε= 0.2], Annular-II [β=0.5, ε= 0.4], Annular-III [β=0.5, ε= 0.6], and Annular- IV [β=0.5, ε= 0.8]

4. References

[1] Reddy, A.N.K. Apodization for improving the two-point resolution of coherent optical systems with a defect of focus / A.N.K. Reddy, S.N. Khonina // Appl. Phys. B. – 2018. – Vol. 124(229). – P. 1-9.

[2] Reddy, A.N.K. Effects of aberrations on the point spread function and the two-point resolution with versatile apodization pupils / A.N.K. Reddy, M. Hashemi, D.K. Sagar // Pramana – J. Phy. – 2020. – Vol. 94(145). – P. 1-10.