COHERENCE OF OPTICAL IMAGING SYSTEMS WITH TWO POINT OBJECTS BY APODIZED ILLUMINATION

B. Sambaiah
Chaitanya Degree College (Autonomous), Kishanpura, Hanamkonda Warangal, TS, India,
Email: sam.bokkala@gmail.com
A. Raju
Chaitanya Degree College (Autonomous), Kishanpura, Hanamkonda Warangal, TS, India,
A. Naveen
Chaitanya Degree College (Autonomous), Kishanpura, Hanamkonda Warangal, TS, India,
D. Karuna Sagar
Professor, Department of Physics, University College of Science, (O.U.), Hyderabad, TS, India
Khaja Althaf Hussian
Professor, Department of Physics, Kakatiya University Warangal, TS, India

Received: Aug. 2019 Accepted: Sep. 2019 Published: Oct. 2019

Abstract: The Super-resolution of two point objects in the case of apodised illumination effect of circular apertures in rotationally symmetric optical systems has been studied by applying the modified Sparrow criterion introduced by Asakura to suit the case of unequally bright object points. The results are presented in terms of Rayleigh and Sparrow limits obtained for coherent and incoherent illuminations. Present studied found that shaping of the aperture along with the chosen Hanning amplitude filter is effective in increasing the resolving power of the optical imaging systems.

Keywords: Defect-Of-Focus, Primary Spherical Aberration, Rayleigh and Sparrow Limits, Coherence Illumination, Incoherence Illumination, Hanning Amplitude Filters, Super-Resolutions.

1. Introduction: Two-point resolution studies forms an interesting area when the two point objects are situated within a close neighborhood of each other. The resolution necessary to satisfy astrophysical observations requires large-diameter optical systems. However, the size required for high-resolution optical systems is not practical in implementation. A circular aperture system is composed to assess the performance of optical imaging systems in judging depending upon its ability in resolving closely situated object points. There are a number of quality criteria in the field of image science; two-point resolution criterion is one of the most important and most basic measures proposed for judging the quality of optical imaging systems [1]. Rayleigh [2] criterion states that the two point sources are just resolved if the central maximum of one falls on the first minimum of central maxima produced by the other point source. Sparrow [3] proposed an alternative criterion according to which the two points are just resolved if the second derivative of the resultant image intensity distribution vanishes at the point midway between the respective Gaussian image points. Asakura [4] has modified the Sparrow criterion to be applicable for the more realistic case of unequally bright object points. In the present study this modified Sparrow criterion has been applied to optical imaging systems apodised by the first order Hanning amplitude filters.

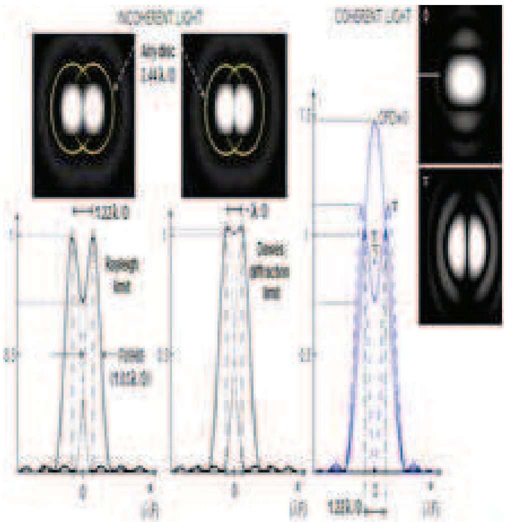

Figure 1: The Coherent and the Incoherent Extremes of Illumination are given by γ =1 And γ = 0.

2. Theory: The theoretical expression as given by Hopkins and Barham [5], for the total image intensity distribution in the image plane of an optical system, as a function of the reduced co-ordinate Z, is given by,

$$I(z) = |A(Z+B)|^2 + \alpha |A(Z-B)|^2 + 2\sqrt{\alpha}\,\gamma(Z_0)|A(Z+B)||A(Z-B)| \quad (1)$$

Where $2B=Z_0$ is the separation between the two object points, c is the ratio of their intensities, γ (Z_0) is the degree of spatial coherence of the illumination. Z is the dimensionless diffraction variable. c = 1 gives the case of equal intensities while $c \neq 1$ corresponds to unequally bright object points. Fig.1the coherent and the incoherent extremes of illuminations are given by γ =1and γ = 0, respectively; whereas $0 < \gamma < 1$ is for the partially coherent illumination. The two object points are situated with a separation Z_0 at the same distance $Z_0/2$ on either side of the optical axis. I (Z) is image intensity distribution as a function of Z, which is measured from the axis of the optical system. A (Z+B) and A (Z-B) are the normalized amplitude point spread functions for circular apertures and are given by the following expressions:

$$A(Z+B) = 2\int_0^{\varepsilon} J_0[(Z+B)r]e^{-i\phi_d}\; r\,dr \quad (2)$$

$$A(Z+B)=2\int_0^{\varepsilon} J_0\left[(Z-B)r\right]e^{-i\phi_d}\; r\,dr \qquad (3)$$

J_0 being the Bessel function of first kind and zero order, r is the normalized distance of a general point on the exit pupil varying from 0 to 1. In the present case, as the first order Hanning amplitude filter is used for apodizing the optical system, the above Eqs. (2) And (3) become,

$$A(Z+B)=2\int_0^{\varepsilon} f(r)\, J_0\left[(Z+B)r\right]\; e^{-i\phi_d}\; r\,dr \qquad (4)$$

$$A(Z-B)=2\int_0^{\varepsilon} f(r)\, J_0\left[(Z-B)r\right]\; e^{-i\phi_d}\; r\,dr \qquad (5)$$

where f(r) is the pupil function of the first order Hanning amplitude filter [6] and is given by

$$f(r)=Cos(\pi\,\beta\, r) \qquad (6)$$

The variable β is the apodizastion parameter controlling the degree of non-uniformity of the transmission over the exit pupil in the range of $0 \le \beta \le 1$. For β = 0, f(r) = 1 which implies the uniform transmittance over the exit pupil. Thereby, for β = 0 the filter function becomes an Airy pupil. If the defocus parameter (Φ_{d}). For chosen apodizer the amplitude transmittance decreases monotonically from the center towards the edges of the pupil. Higher spatial frequency components of the object are diffracted by a larger angle and hence these go predominantly through the edge of the aperture. As the pupil transmittance is decreased at the edges as compared to that of the center, which results in the reduction in the higher spatial frequency components in the image. This manifests as partial or complete suppression of the undesired optical side lobes, which consequently enhances imaging characteristics. However, for shrink apertures the expressions for the amplitude PSF can be expressed as

$$A(Z\pm B)=2\int_{\varepsilon}^{\varepsilon} f(r)\; J_0\left[(Z\pm B)r\right]\; e^{-i\phi_d}\; r\,dr \qquad (7)$$

where ε is the symmetric obscuration parameter whose value specifies the amount of shrink in the aperture. Therefore, the expression for the total image intensity distribution is given by

$$I(Z)=\left|A(Z+B)\right|^2+\alpha\left|A(Z-B)\right|^2$$
$$+2\sqrt{\alpha}\,\gamma\left|A(Z+B)\right|\left|A(Z-B)\right| \qquad (8)$$

The modified Sparrow criterion introduced by Asakura [4] states that, "the resolution is retained when the second derivative of the image intensity distribution vanishes at a certain point $\left(Z=Z_0^1\right)$ between two Gaussian image points, with the condition that this point Z_0^1 should be a solution for the first derivative of the image intensity distribution becoming zero". This can be expressed mathematically as

$$\left|\frac{\partial^2 I(Z)}{\partial Z^2}\right|_{Z=Z_0^1}=0 \qquad (9)$$

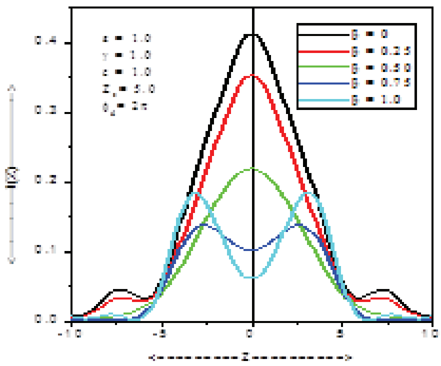

Figure 2: Intensity Distribution Curves Varying from Apodisation Parameter in Coherence Illumination with Defocused Plane

3. Results and Discussion: Expressions (8) and (9) have been used to compute values of the image intensity distribution of the two point objects and the Sparrow and Rayleigh limits of the optical systems with circular apertures apodised with the chosen Hanning amplitude filter scenario. The results have been compared with that of the Airy case. Table-1 gives the computed values of Sparrow and Rayleigh limits (SL & RL) for clear aperture (β = 0), for various degrees of defect-of-focus when the optical imaging system is illuminated with coherent light and the two object points are of equal intensities (c = 1). With highly aperture ($\varepsilon \neq 1$) the sparrow limit as well as the Rayleigh limits decreases with decrease in the value of ε, thereby enhancing the resolving power of the optical system. The intensity distribution in the resultant image of two-point objects produced by the optical imaging system, apodised with Hanning amplitude filter, is calculated using the expression (8) by employing the WOLFRAM MATHEMATICS 7.0

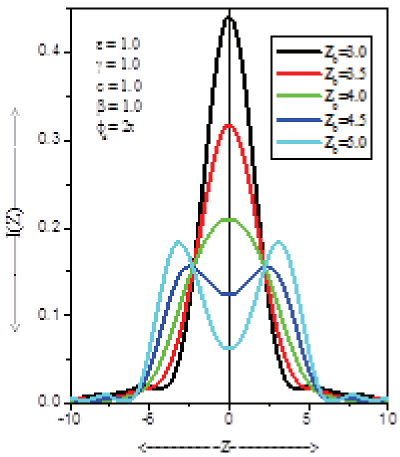

Figure 3: Intensity Distribution Curves Varying from Two Point Objects (Z_0) in Coherence Illumination with Defocued ($\phi d=2\pi$)

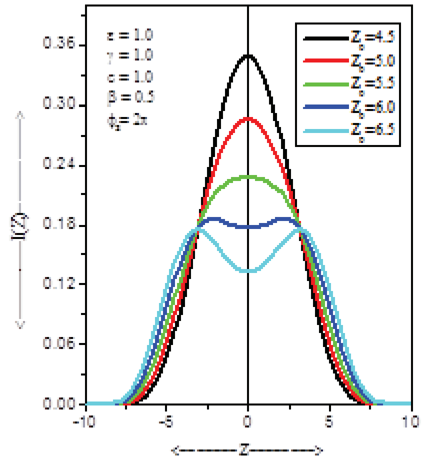

Figure 4: Intensity Distribution Curves Varying from Two Point Objects (Z_0) in Coherence Illumination with Defocued $\phi_s=2\pi$

The results of the investigations made on the influence of various parameter considered such as apodising parameter (β), the intensity ratio of the two point objects (c), the degree of coherence (γ), the defect-of-focus (ϕ_d),primary spherical aberration (ϕ_s) have been presented. The intensity distribution I (Z) in the resultant image of two-point objects has been computed as a function of dimensionless diffraction variable Z which is varying from -10 to +10. The variations in the resultant intensity, Rayleigh and Sparrow limits have been discussed in the feature are observed for various defocused planes. Fig.2 depict the intensity distribution curves for various values of separation between two object points (z_o), varying the apodisation parameter β. The two points are said to be resolved in Sparrow sense for z_o=3.7650 dimensionless diffraction units. Influence of the apodisation on the optical imaging system for equally bright object points that is separated under coherence illumination in the case of circular aperture at defocusing plane $\phi_d = 2\pi$. It is observed that the two points are resolved for higher values of apodisation $\beta > 0.75$. Fig.3 displays the intensity distribution curves for various separation distance Z_0 between the two object points on the optical imaging system when the intensity ratio between the two object points are of equal intensity. The system is under the coherent illumination and observed at different defocused planes. There is a clear resolution for all values of Z_0 ranging from 4.5. The dip at the center of the intensity curves is more pronounced for higher values of Z_0 . Fig.3 displays the intensity distribution curves for various separation distance Z_0 between the two object points on the optical imaging system when the intensity ratio between the two object points are of equal intensity. The system is under the coherent illumination and observed at different defocused planes. There is a clear resolution for all values of Z_0 ranging from 4.5. The dip at the center of the intensity curves is more pronounced for higher values of Z_0 . Figs.4 and 5 show the effect of apodisation

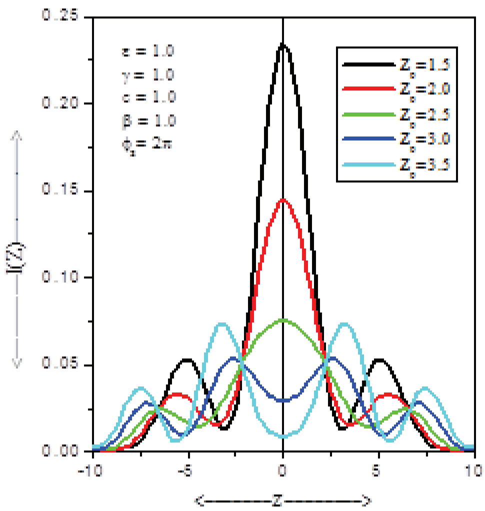

Figure 5: Intensity Distribution Curves Varying from Two Point Objects (Z_o) In Coherence Illumination with Defocues (ϕ_s=2π), Highly Apodisation Parameter (6=1)

parameter (β), on the optical imaging system when the intensity ratios between the two object points being $c = 1.0$ and with coherent illumination $\gamma = 1.0$ in the case of circular aperture. The two points are resolved for separation values greater than $Z_0 = 6.0$. For an apodised system with highly apodisation parameter $\beta = 1$ the resolution is seen even for $Z_0 = 3.0$.

4. Conclusions: The process of apodised the optical system with Hanning amplitude filter, suppresses fully or partially the optical side-lobes of the individual point spread functions. The apodisation parameter is effective in shaping the point spread function so that there is an improvement of resolution of two point objects rendering the optical system to be more effective in their resolution. Hence, the Hanning amplitude filters are effective in enhancing the resoling power of the given optical imaging system.

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