Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AF07.20260462
Published: May 13, 2026

Two-Line Shrink Aperture Resolution Affected by Primary Spherical Aberration

Krishnaiah G
Research Scholar**,** BEST Innovation University, Gorantla
Assistant Professor of Physics, MALD GDC Gadwal
Jogulamba Gadwal-dist., Telangana, India
gkrish1505@gmail.com

Amaranath M
Research Scholar**,** BEST Innovation University, Gorantla
Asst. Professor, Department of Physics
Annamacharya Institute of Technology and Sciences
Hyderabad, Telangana, India
amarnath.menta@gmail.com

Mallesh Mudraboina
Assistant Professor, Department of Physics
Annamacharya Institute of Technology and Sciences
Hyderabad, Telangana, India
malleshmudraboina@gmail.com

Ram Prasad T
Assistant Professor, Department of Physics
St. Peters Engineering College,
Hyderabad, Telangana, India.
talluriramprasad123@gmail.com

Kiran Kumar T
Assistant Professor, Department of Physics
Brilliant Institute of Engineering and Technology
Hyderabad, Telangana, India
t.kirankumar@yahoo.co.in

Abstract

An optical imaging system's resolving power is primarily constrained by diffraction, which is further impacted by optical aberrations. The impact of primary spherical aberration on the resolution of two closely spaced lines when the system's aperture size is decreased is the main topic of this study. The wavelength of light and the aperture diameter determine the minimum resolvable distance between two objects, according to the classical criterion put forth by

Lord Rayleigh. Diffraction effects become more pronounced as the aperture decreases, resulting in a wider intensity distribution in the image plane and worse resolution.

Aberrations cannot be disregarded in real-world optical systems. Among these, fundamental spherical aberration—which is explained in Ludwig Seidel's classical aberration theory—contributes significantly to the deterioration of image quality. Because of this distortion, rays traveling through various aperture zones focus at various axial points, producing a blurry image with less contrast. In this paper, intensity distribution principles are used to investigate the combined effects of spherical aberration and aperture reduction on two-line resolution. The findings demonstrate that spherical aberration

greatly increases the diffraction-induced light spreading, increasing the overlap between two lines' pictures. As a result, when the aperture size lowers, the system's resolving power rapidly declin.The study emphasizes how crucial it is to reduce spherical aberration and maximize aperture design in order to improve resolution in contemporary optical imaging systems.

Keywords
Two-line resolution**,** Shrink aperture, primary spherical aberration, Point spread function, Apodisation, Optical, imaging systems

1. Introduction
An optical imaging system's resolution, which determines its capacity to discriminate between two closely spaced objects, is a crucial parameter. According to Lord Rayleigh, who determined that the minimum resolvable distance depends on the wavelength of light and the aperture diameter, diffraction is the primary factor limiting the resolving power in classical optics. Optical resolution theory is based on this idea, which is widely applied in imaging systems, telescopes, and microscopy (Lord Rayleigh, 1879).However, aberrations cause real optical systems to behave differently than ideal. Among these, fundamental spherical aberration—which Ludwig Seidel first thoroughly examined—contributes significantly to the deterioration of image quality. Spherical aberration produces a blurry image and decreased contrast because rays traveling through various aperture regions do not converge at a single focal point (Ludwig Seidel, 1857& Kingslake, 1978) previous studies have shown that both diffraction and aberrations affect an optical system's overall resolution. (Born and Wolf, 1999) provided a comprehensive theoretical framework for wave optics and image creation, while (Goodman, 2005) developed Fourier optics techniques to analyze the point spread function (PSF) and optical transfer function (OTF). When aberrations are present, these techniques are commonly employed to examine resolution limits.The impact of aperture size on resolution has also been well studied. (Hecht, 2002 and Smith, 2008) showed that decreasing the aperture broadens the distribution of image intensity by increasing diffraction effects. (Mahajan, 2011) also demonstrated that, particularly in systems with large numerical aperture, spherical aberration considerably alters the PSF and lowers image quality. Aberrations have an impact on optical performance and design, as (Shannon, 1997) explained. The combined impact of aberrations and aperture shrinking on resolution has been the subject of recent research. According to these research, spherical aberration significantly reduces the spatial frequency response and modulation transfer function (MTF), which results in poor resolution of closely spaced objects (Hopkins, H.H, 1955) Specifically, two-line resolution is a crucial criterion for assessing imaging performance since it is extremely sensitive to both diffraction and aberrations.

2. Literature Review
Lord Rayleigh's criterion is frequently used to characterize the resolution of an optical system, which is essentially defined by diffraction. This theory establishes the fundamental limit of resolution in optical systems and states that two objects can only be resolved when the center maximum of one diffraction pattern coincides with the initial minimum of the other (Research Gate, 2005).In real-world imaging systems, diffraction and the spreading of light in the image plane—which is defined by the point spread function (PSF)—both limit resolution. The PSF is a measure of how a point item is viewed, and its broadening directly impairs the system's capacity to discriminate between things that are closely spaced (Science Direct, 2023). In order to comprehend and enhance optical resolution, precise PSF measurement is crucial. Image quality is further degraded by optical aberrations. The distribution of light in the focal region is greatly impacted by primary spherical aberration, which is explained in Ludwig Seidel's aberration theory. According to studies, spherical aberration results in blurry pictures and decreased contrast (PMC, 2017) by changing the wavefront and causing rays from various aperture zones to focus at different places. The modulation transfer function (MTF), which is derived from the PSF and characterizes the system's response to spatial

frequencies, can also be used to examine how spherical aberration affects image quality. A decline in MTF denotes a loss of contrast and resolution as a result of aberrations (PMC, 2017).The importance of aperture size in determining resolution has also been highlighted by recent studies. High spatial frequency information (PMC, 2013) is further degraded when the aperture shrinks because diffraction effects increase and the effective aperture contributing to image creation may become diminished or non-uniform when spherical aberration is present. Furthermore, it has been shown that spherical aberration correction greatly enhances resolution and picture quality in sophisticated optical systems like microscopy (PubMed, 2010).Overall, prior research suggests that the resolution of two closely spaced lines is significantly influenced by the combined effects of diffraction, aperture size, and primary spherical aberration. For the purpose of designing contemporary optical systems, it is crucial to investigate two-line shrink aperture resolution under spherical aberration circumstances.

3. Methodology

A basic optical imaging system with a circular aperture is taken into consideration. The resolving power of the system is investigated using two parallel line objects.

The Lord Rayleigh criterion is used to determine the system's theoretical resolution.

d = 1.22\frac{\lambda}{D}

where ddd is the minimum resolvable distance, λ\lambda λ is the wavelength of light, and DDD is the aperture diameter

To investigate its impact on picture formation, primary spherical aberration—described in Ludwig Seidel's classical aberration theory—is introduced to the optical system.

For each aperture size, the picture of two lines is examined as the aperture diameter is progressively decreased.

The minimal separation between the two lines is noted. By examining the picture intensity profiles and point spread function (PSF), the resolution change is investigated.

4. Mathematical Expressions for the Evaluation of Two-Line Resolution for Shrink Apertures

In this section, a general mathematical formulation for the complex amplitude distribution in the defocused plane of apodised optical system in the presence of spherical aberrations has been carried out. From expression (2.19) as formulated in chapter-2, the expression for complex amplitude for a shrink aperture can be written as (5.1) (Figure 1).

$$B(Z) = \left| 2\int_0^{\varepsilon} f(r)\ Cos\{(Z+Z_0)r\}dr + 2c\int_0^{\varepsilon} f(r)\ \ Cos\{(Z-Z_0)r\}dr \right|^2$$

Where f(r) is the chosen amplitude filter. In the present study the following filters are employed: Hanning amplitude filter (f_1), Barlett filter (f_2), Shaded aperture filter (f_3) and Lancoz filter (f_4). They are represented mathematically as follows:

$$f(r_2) = 1 - \beta r$$
$$f(r_1) = \cos(\pi\beta r)$$

$$f(r_3) = 1 - \beta r^2$$
$$f(r_4) = \sin\frac{(\pi\beta r)}{(\pi\beta r)}$$

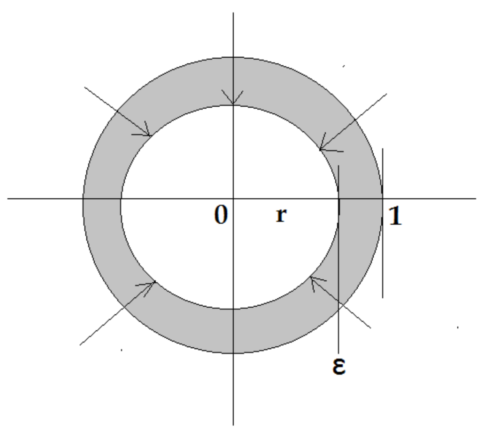

Fig.5-A: Schematic representation of Shrink aperture

Figure 1. Schematic representation of Shrink Apertures

The shrink aperture can be represented schematically as follows: Figure 1 presents the schematic representation of Shrink aperture. Here the periphery (outer portion) of the aperture is reduced. For $\varepsilon \neq 1$ represents the shrink aperture.

5. Results and Discussions

The intensity of the two-line objects in the image plane has been computed, using the expressions (5.1) for shrink apertures, by using Matlab-7.2 to study the effects of apodisation; defect of focus; primary spherical aberration and primary coma on the performance of optical imaging systems. The apodisation parameter (β) is varied from 0 to 1 in steps of 0.25. Here for β = 0, the optical system is said to be unapodised system and for the values of $\beta \neq 0$ represents the apodised system. β = 0 corresponds to the Airy case (perfect lens). The optical system aberrated with primary spherical aberration (φ_s)

Figure 2 shows the intensity distribution profiles of the two line objects when the optical system is subjected to extreme primary spherical aberration with $\Phi_s = 2\pi$, separated by various distances Z_0. When the aperture shrinkage parameter is at $\varepsilon = 0.9$ for equal intensity ratio between the two-line objects for all the four filter. From the intensity distribution curves it is clearly visible that for $Z_0 = 5$ and above the two-line objects exhibit a clear resolution. For small apodisation values and higher primary spherical aberrations, the resolution limit increases thereby decreasing the resolving ability of the optical system.

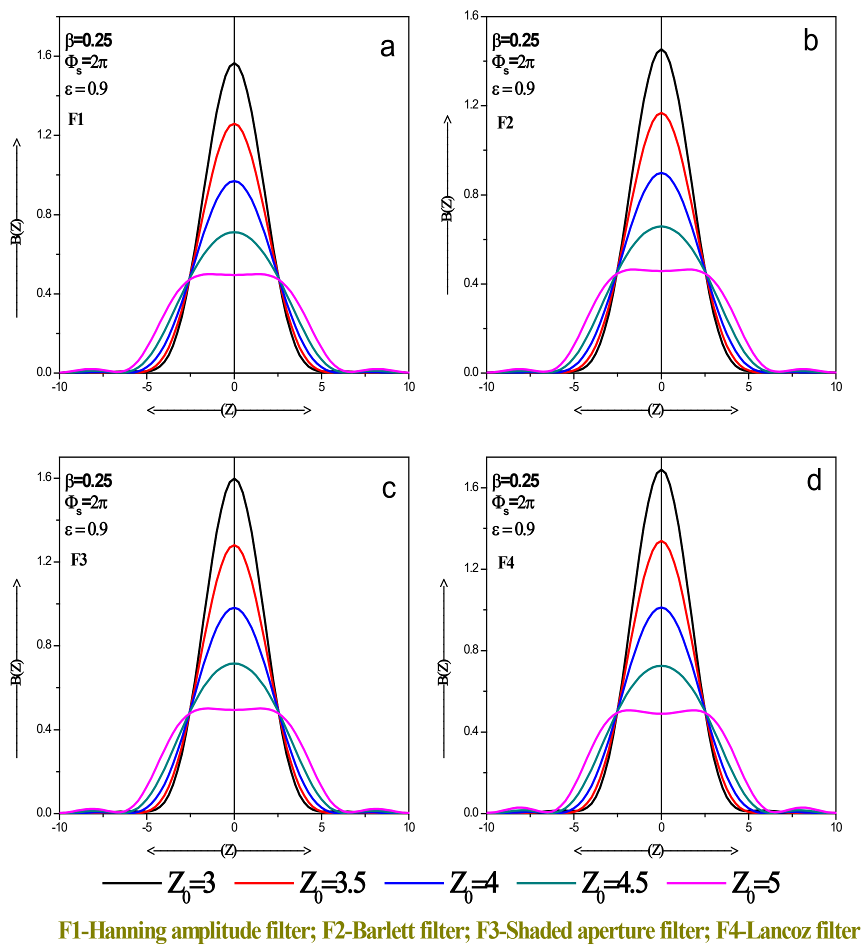

Figure 2. Intensity distribution curves of two-line objects separated by the distance Z_0=3 and above in the increments of 0.5 at higher values of primary spherical aberration.

6. Conclusions

The impact of primary spherical aberration on the two-line resolution of an optical system with a decreasing aperture was examined in this work. The findings demonstrate that while spherical aberration further disperses the light in the image plane, decreasing the aperture enhances diffraction effects. The pictures of two closely spaced lines start to overlap and become hard to tell apart as a result of this combined effect. Consequently, the optical system's resolving power gradually declines as the aperture size lowers. The study demonstrates that two-line resolution is greatly reduced by primary spherical aberration, particularly in systems with tiny apertures. For optical instruments to produce better images, spherical aberration must be properly corrected.

References:

Born, M., and Wolf, E., *Principles of Optics*, 7th Edition, Cambridge University Press, 1999
PMC, 2017, Effect of spherical aberration on optical quality, 2017.
H. H., "The Frequency Response of a Defocused Optical System," *Proceedings of the Royal Society A*, 1955.
Hecht, E., *Optics*, 4th Edition, Addison-Wesley, 2002.
Goodman, J. W., *Introduction to Fourier Optics*, 3rd Edition, Roberts & Company, 2005.
Kner, P., "High-resolution microscopy with aberration correction," *J. Microscopy*, 2010.
Kingslake, R., *Lens Design Fundamentals*, Academic Press,1978
Lord Rayleigh, *Investigations in Optics*, Philosophical Magazine, 1879.
Ludwig Seidel, *On the Theory of Optical Aberrations*, Astronomische Nachrichten, 1857.
Mahajan, V. N., *Aberration Theory Made Simple*, SPIE Press, 2011.
PSF and resolution in optical systems," Research Gate publication, 2025.
Shannon, R. R., *the Art and Science of Optical Design*, Cambridge University Press, 1997.
Smith, W. J., *Modern Optical Engineering*, McGraw-Hill, 2008.
T.Kiran Kumar Thesis Osmania University, 2017
Xu, R., "Impact of Primary Spherical Aberration…," *Ophthalmic Physiol Opt*, 2013.
Yao, C., "Optical Aberration Correction in Imaging Systems," *Sensors*, 2021.

Biographies

Krishnaiah G is an Assistant professor of Physics, MALD Govt. Degree College Gadwal, and Jogulamba Gadwal Dist.Telangana State. I have been working in this College Since 2013. 12 Years of teaching experience to U.G. Level. Received Master of Science (Physics) from Osmania University college of Science, Saifabad, Hyderabad. I am qualified Telangana State Eligibility Test-2022. Research Scholar in Physics, Bharatiya Engineering Science and Technology Innovation University- (BESTIU), A.P. I Published 8 research articles in reputed National & International Journals. I would like to express my sincere gratitude to research supervision Dr. T. Kiran Kumar Asst. Professor of Physics Brilliant Institute of Engineering and Technology, Abdullapurmet, Hyderabad, R.R.DT-501505.

Amaranath Menta is an Assistant professor in the department of Physics at Annamacharya Institute of Technology and Sciences, Hyderabad. Received Master of Science (Physics) from Acharya Nagarjuna University, Guntur and Master of Technology from Jawaharlal Nehru Technological University, Hyderabad. He has 16 years of teaching experience to Engineering students and published 6 research articles in reputed national and international journals. Research Scholar in Physics, Bharatiya Engineering Science and Technology Innovation University- (BESTIU), Andhra Pradesh, India and experience in teaching physics experiments to engineering students. Presented paper in **IEOM Society**, 4th Indian International Conference on Industrial Engineering and operations management, Hyderabad.

Mallesh Mudraboina is an Assistant professor in the department of Physics at Annamacharya Institute of Technology and Sciences, Hyderabad, Telangana-501512, Received Master of Science (Physics) from Osmania University, Hyderabad, Telangana and Bachelor of Education, from Osmania University, Hyderabad, Telangana. He has 6 years of teaching experience to Intermediate education in Telangana, and 9 years of teaching experience to Engineering students and published 1 research article in reputed national and international journal.Qualified in Telangana State Eligibility Test-2018, He has Student Counsellor Certificate holder from MCRHRDC, Hyderabad, and Govt. of Telangana, Hyderabad, Telangana.

Dr.Ram Prasad T earned his B. Sc and M. Sc in Physics from Acharya Nagarjuna University in 2004 & 2007 respectively. He accomplished a Doctorate in Physics from Rayalaseema University, Kurnool, Andhra Pradesh in 2019. In He is currently working as Associate Professor in Physics in the Department of Basic Sciences and Humanities in St.Peters Engineering College, Hyderabad, Telangana, India. He published in 15 National and International journals, conducted workshops and FDP's in Physics. His main research work was focused on Material Science in Physics. He has 18 years of experience driven to inspire students to pursue academic and personal Excellence.

Dr.Kiran KumarT is an Assistant Professor in Brilliant Institute of Engineering And Technology, Abdullapurmet, and Telangana. He received his PhD in Physics from Osmania University 2017. He received his M.Sc. from Osmania University in 2005 and B.Sc. from Kakatiya University in 2003. He has served in academics for more than 15 years. He as published 35 research papers in National and International journals. He was guiding 3 research scholars in collaboration with Bharatiya Engineering Science and Technology Innovation University, Gownivaripaill, Gorantla in Andhra Pradesh for their Ph.D. He conducted various Seminars, Workshops © **IEOM Society** International Proceedings of the International Conference on Industrial Engineering and Operations Management and has participated several National and International Conferences. His areas of interest are Physics-Optics. He has the membership in IAENG [International Association of Engineers]-229904 & SDIWC [Society of Digital Information and Wireless Communications]-23036. Editorial Board Member in International Journal of Recent Research in Thesis and Dissertation (IJRRTD), Editorial Board Member in International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS) He was awarded Best Research Paper by in IJARTET, Volume 4, Issue 8, and August 2017. He has got Young Scientist Award by IARDO on 10th February 2019.