

References

- Arfken, G., *Mathematical Methods for Physicists*, 3rd ed., Academic Press, Orlando, Florida (1985).
- Basu, S. and L. M. Gutheinz, “Fractional power in the bucket, beam quality and M^2 ,” *Proc. SPIE* **7579**, 75790U (2010) [doi: 10.1117/12.846382].
- Born, M. and E. Wolf, *Principles of Optics*, 6th ed., Pergamon Press, Oxford (1980).
- Carter, W. H., “Spot size and divergence for Hermite Gaussian beams of any order,” *Appl. Opt.* **19**(7), 1027–1029 (1980).
- Fox, A. G. and T. Li, “Resonant modes in a maser interferometer,” *Bell Syst. Tech. J.* **40**, 453 (1961).
- Gaskill, J. D., *Linear Systems, Fourier Transforms and Optics*, John Wiley & Sons, New York (1978).
- Gerchberg, R. and W. Saxton, “A practical algorithm for the determination of the phase from image and diffraction plane pictures,” *Optik* **35**(2), 237–246 (1972).
- Goodman, J. W., *Introduction to Fourier Optics*, McGraw-Hill, New York (1968).
- International Standards Organization (ISO), “Lasers and Laser-Related Equipment—Test methods for laser beam parameters: beam widths, divergence angle and beam propagation factor,” ISO 11146:1999, International Standards Organization, Geneva (1999).
- International Standards Organization (ISO), “Lasers and Laser-Related Equipment: Test methods for laser beam widths, divergence angles and beam propagation ratios,” ISO 11146-3:2004, International Standards Organization, Geneva (2004).
- International Standards Organization (ISO), “Lasers and Laser-Related Equipment: Test methods for laser beam widths, divergence angles and beam propagation ratios,” ISO 11146-1:2005, International Standards Organization, Geneva (2005).
- Janssen, A. J. E. M., S. van Haver, P. Dirksen, and J. J. M. Braat, “Zernike representation and Strehl ratio of optical systems with variable numerical aperture,” *J. Mod. Opt.* **55**(7), 1127–1157 (2008).

- Johnston, T. F. and M. W. Sasnett, "Characterization of Laser Beams: The M^2 Model," in *Handbook of Optical and Laser Scanning*, G. F. Marshall and G. E. Stutz, Eds., Marcel Dekker Inc., New York (2004).
- Kant, I., *Critique of Pure Reason*, J. M. D. Meikljohn, Translator, in *Great Books of the Western World, Encyclopedia Britannica* **52** (1952).
- Kolmogorov, A., "A refinement of previous hypotheses concerning the local structure of turbulence in a viscous incompressible fluid at high Reynolds number," *J. Fluid Mech.* **13**, 82–85 (1962).
- Maréchal, A., "Étude des effets combinés de la diffraction et des aberrations geometriques sur l'image d'un point lumineux," *Revue d'Optique Théorique et Instrumentale* **26**(9), 257–277 (1947).
- Motes, R. A. and R. W. Berdine, *Introduction to High-Power Fiber Lasers*, Directed Energy Professional Society, Albuquerque, New Mexico (2009).
- Phillips, R. L. and L. C. Andrews, "Spot size and divergence for Laguerre Gaussian beams of any order," *Appl. Opt.* **22**(5), 643–644 (1983).
- Ross, T. S., "An analysis of a non-Gaussian, Gaussian laser beam," *Proc. SPIE* **6101**, 610111 (2006) [doi: 10.1117/12.640436].
- Ross, T. S., "The effect of aperturing on laser beam quality," *Solid State and Diode Laser Technology Review*, Technical Summary (Section on Beam Combination and Control), Directed Energy Professional Society, Albuquerque, New Mexico (2007).
- Ross, T. S., "Limitations and applicability of the Maréchal approximation," *Appl. Opt.* **48**(10), 1812–1818 (2009).
- Ross, T. S. and W. P. Latham, "Appropriate measures and consistent standard for high-energy laser beam quality," *J. Dir. Energy* **2**, 22–58 (2006).
- Saleh, B. and M. Teich, *Fundamentals of Photonics*, John Wiley & Sons, New York (1991).
- Siegman, A. E., *Lasers*, University Science Books, Mill Valley, California (1986).
- Siegman, A. E., "How to (Maybe) Measure Laser Beam Quality," from October 1997 OSA Conference on Diode Pumped Solid State Lasers: Applications and Issues (DLAI), Optical Society of America, Washington, D.C. (1998).

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