Field Guide to

Geometrical Optics

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Welcome to the *SPIE Field Guides*! This volume is one of the first in a new series of publications written directly for the practicing engineer or scientist. Many textbooks and professional reference books cover optical principles and techniques in depth. The aim of the *SPIE Field Guides* is to distill this information, providing readers with a handy desk or briefcase reference that provides basic, essential information about optical principles, techniques, or phenomena, including definitions and descriptions, key equations, illustrations, application examples, design considerations, and additional resources. A significant effort will be made to provide a consistent notation and style between volumes in the series.

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The *SPIE Field Guides* are intended to be living documents. The modular page-based presentation format allows them to be easily updated and expanded. We are interested in your suggestions for new *Field Guide* topics as well as what material should be added to an individual volume to make these Field Guides more useful to you. Please contact us at fieldguides@SPIE.org.

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Field Guide to Geometrical Optics

The material in this *Field Guide to Geometrical Optics* derives from the treatment of geometrical optics that has evolved as part of the academic programs at the Optical Sciences Center at the University of Arizona. The development is both rigorous and complete, and it features a consistent notation and sign convention. This material is included in both our undergraduate and graduate programs. This volume covers Gaussian imagery, paraxial optics, first-order optical system design, system examples, illumination, chromatic effects and an introduction to aberrations. The appendices provide supplemental material on radiometry and photometry, the human eye, and several other topics.

Special acknowledgement must be given to Roland V. Shack and Robert R. Shannon. They first taught me this material "several" years ago, and they have continued to teach me throughout my career as we have become colleagues and friends. I simply cannot thank either of them enough.

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This *Field Guide* is dedicated to my wife, Kay, and my children, Jake and Katie. They keep my life in focus (and mostly aberration free).

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Glossary

Unprimed variables and symbols are in object space.
Primed variables and symbols are in image space.

Frequently used variables and symbols:

a	Aperture radius
A, A'	Object and image areas
B'	Image plane blur criterion
BFD	Back focal distance
c	Speed of light
C	Curvature
CC	Center of curvature
d, d'	Front and rear principal plane shifts
D	Diopters
D	Diameter
D	Airy disk diameter
DOF	Depth of focus, geometrical
E, E_V	Irradiance and illuminance
EFL	Effective focal length
EP	Entrance pupil
ER	Eye relief
f, f_E	Focal length or effective focal length
f_F, f'_R	Front and rear focal lengths
$f/\#$	F-number
$f/\#_W$	Working F-number
δf	Longitudinal chromatic aberration
F, F′	Front and rear focal points
FFD	Front focal distance
FFOV	Full field of view
FOB	Fractional object
FOV	Field of view
h, h'	Object and image heights
H	Lagrange invariant
H	Normalized field height
H, H_V	Exposure
HFOV	Half field of view
I	Optical invariant
I, I_V	Intensity and luminous intensity
L	Object-to-image distance
L, L_V	Radiance and luminance

L_H	Hyperfocal distance
L_{NEAR}, L_{FAR}	Depth of field limits
LA	Longitudinal aberration
m	Transverse or lateral magnification
$\overline{m}$	Longitudinal magnification
m_V	Visual magnification (microscope)
M, M_V	Exitance and luminous exitance
MP	Magnifying power (magnifier or telescope)
MTF	Modulation transfer function
n	Index of refraction
N, N'	Front and rear nodal points
NA	Numerical aperture
OPL	Optical path length
OTL	Optical tube length
P	Partial dispersion ratio
P, P′	Front and rear principal points
PSF	Point spread function
Q	Energy
r_P	Pupil radius
R	Radius of curvature
s	Surface sag or a separation
s, s'	Object and image vertex distances
S	Seidel aberration coefficient
SR	Strehl ratio
t	Thickness
T	Temperature
TA	Transverse aberration
TA_{CH}	Transverse axial chromatic aberration
TIR	Total internal reflection
Δt	Exposure time
u, $\bar{u}$	Paraxial angles; marginal and chief rays
U	Real marginal ray angle
V	Abbe number
V, V′	Surface vertices
W	Wavefront error
W_{IJK}	Wavefront aberration coefficient
WD	Working distance
x, y	Object coordinates
x', y'	Image coordinates

Glossary (cont.)

x_P, x_P	Normalized pupil coordinates
XP	Exit pupil
$y, \bar{y}$	Paraxial ray heights; marginal and chief rays
z	Optical axis
z, z'	Object and image distances
δz	Image plane shift
δz	Depth of focus, diffraction
$\Delta z, \Delta z'$	Object and image separations
α	Dihedral angle or prism angle
δ	Prism deviation
δ_{MIN}	Angle of minimum deviation
$\delta\phi$	Longitudinal chromatic aberration
Δ	Prism dispersion
ε	Prism secondary dispersion
$\varepsilon_X, \varepsilon_Y$	Transverse ray errors
ε_Z	Longitudinal ray error
θ	Angle of incidence, refraction or reflection
θ	Azimuth pupil coordinate
θ_C	Critical angle
$\theta_{1/2}$	Half field of view angle
κ	Conic constant
λ	Wavelength
ν	Abbe number
ρ	Reflectance
ρ	Normalized pupil radius
τ	Reduced thickness
ϕ	Optical power
Φ, Φ_V	Radiant and luminous power
$\omega, \bar{\omega}$	Optical angles; marginal and chief rays
Ω	Solid angle
Ж	Lagrange invariant