

Warren J. Smith

PRACTICAL OPTICAL SYSTEM LAYOUT

*And Use of
Stock Lenses*



Published

HECHT • *The Laser Guidebook*

MELZER, MOFFITT • *Head Mounted Displays*

SMITH • *Modern Optical Engineering*

SMITH • *Modern Lens Design*

WAYNANT, EDIGER • *Electro-Optics Handbook*

WYATT • *Electro-Optical System Design*

MILLER, FRIEDMAN • *Photonics Rules of Thumb*

Other Books of Interest

OPTICAL SOCIETY OF AMERICA • *Handbook of Optics, Second Edition,*
Volumes I, II

KEISER • *Optical Fiber Communications*

SYMS, COZENS • *Optical Waves and Devices*

CHOMYCZ • *Fiber Optical Installations*

*To order or receive additional information on these or any other
McGraw-Hill titles, in the United States please call 1-800-722-4726.
In other countries, contact your local McGraw-Hill representative.*

Practical Optical System Layout

And Use of
Stock Lenses

Warren J. Smith

*Chief Scientist
Kaiser Electro-Optics, Inc.
Carlsbad, California
and Consultant
in Optics and Lens Design*

McGraw-Hill

New York San Francisco Washington, D.C. Auckland Bogotá
Caracas Lisbon London Madrid Mexico City Milan
Montreal New Delhi San Juan Singapore
Sydney Tokyo Toronto

Library of Congress Cataloging-in-Publication Data

Smith, Warren J.

Practical optical system layout / and use of stock lenses / Warren J. Smith.

p. cm.

Includes index.

ISBN 0-07-059254-3

1. Optical instruments—Design and construction. 2. Lenses.

I. Title.

TS513.S56 1997

681'.4—DC21

95-12535

CIP

McGraw-Hill



A Division of The McGraw-Hill Companies

Copyright © 1997 by The McGraw-Hill Companies, Inc. All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

1 2 3 4 5 6 7 8 9 0 DOC/DOC 9 0 2 1 0 9 8 7

ISBN 0-07-059254-3

The sponsoring editor for this book was Stephen S. Chapman, the editing supervisor was Paul R. Sobel, and the production supervisor was Pamela A. Pelton. It was set in Century Schoolbook by Estelita F. Green of McGraw-Hill's Professional Book Group composition unit.

Printed and bound by R. R. Donnelley & Sons Company.

McGraw-Hill books are available at special quantity discounts to use as premiums and sales promotions, or for use in corporate training programs. For more information, please write to the Director of Special Sales, McGraw-Hill, 11 West 19th Street, New York, NY 10011. Or contact your local bookstore.

Information contained in this work has been obtained by The McGraw-Hill Companies, Inc. ("McGraw-Hill") from sources believed to be reliable. However, neither McGraw-Hill nor its authors guarantee the accuracy or completeness of any information published herein, and neither McGraw-Hill nor its authors shall be responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that McGraw-Hill and its authors are supplying information but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.



This book is printed on recycled, acid-free paper containing a minimum of 50% recycled, de-inked fiber.

Contents

Preface	ix
Introduction	xi

Chapter 1 The Tools	1
1.1 Introduction, Assumptions, and Conventions	1
1.2 The Cardinal (Gauss) Points and Focal Lengths	2
1.3 The Image and Magnification Equations	4
1.4 Simple Ray Sketching	12
1.5 Paraxial Raytracing (Surface by Surface)	17
1.6 The Thin Lens Concept	22
1.7 Thin Lens Raytracing	23
1.8 The Invariant	26
1.9 Paraxial Ray Characteristics	26
1.10 Combinations of Two Components	27
1.11 The Scheimpflug Condition	35
1.12 Reflectors, Prisms, Mirrors, etc.	37
1.13 Collected Equations	40
Chapter 2 The Basic Optical Systems	49
2.1 Introduction	49
2.2 Stops and Pupils	49
2.3 Afocal Systems: General	57
2.4 Telescopes and Beam Expanders	59
2.5 Afocal Attachments: Power and Field Changers	66
2.6 Bravais System	68
2.7 Field Lenses; Relay Lenses; Periscopes	70
2.8 Magnifiers and Microscopes	76
2.9 Telephoto and Retrofocus Arrangements	80
2.10 Collimators	82
2.11 Anamorphic Systems	82
2.12 Zoom and Varifocal Systems	87

2.13	Mirror Systems	88
2.14	Collected Equations	96
Chapter 3 Condensers, Illuminators, Photometry, Etc.		101
3.1	Interchangeability of Sources and Detectors	101
3.2	Koehler Illumination System	101
3.3	Critical Illumination	104
3.4	Illumination Smoothing Devices	105
3.5	Liquid Crystal Display (LCD) and Digital Micromirror Device (DMD)	106
3.6	Projectors	106
3.6	Photometry, Radiometry, Illumination, Etc.	110
Chapter 4 System Limits: Performance and Configuration		117
4.1	Introduction	117
4.2	The Diffraction Limit	117
4.3	Image Sensor Limits	121
4.4	Diffraction Limit vs. Sensor Limit	123
4.5	The Optical Invariant	125
4.6	Source and Detector Size Limits	126
4.7	Depth of Focus	127
Chapter 5 How to Lay Out a System		129
5.1	The Process	129
5.2	The Algebraic Approach	131
5.3	The Numerical Solution Method	135
5.4	First-Order Layout by Computer Code	138
5.5	A Quick Rough Sketch	140
5.6	Chromatic Aberration and Achromatism	143
5.7	Athermalization	144
5.8	Sample System Layout	145
Chapter 6 Getting the Most Out of "Stock" Lenses		153
6.1	Introduction	153
6.2	Stock Lenses	153
6.3	Some Simple Measurements	155
6.4	System Mock-up and Test	159
6.5	Aberrations	163
6.6	Capabilities of Various Lens Types	171
6.7	Unusual Lens Types	174
6.8	How to Use a Singlet (Single Element)	178
6.9	How to Use a Cemented Doublet	179

6.10	Combinations of Stock Lenses	180
6.11	Sources	189

Bibliography	193
Index	195

The Basic Optical Systems

2.1 Introduction

The optics used for most applications are founded on what might be called the basic “standard” optical systems. And, in fact, almost all optical systems are modifications or combinations of these “standard” or basic systems. The principles of these systems are well understood, and their primary characteristics and limitations can be expressed by simple mathematical relationships. This chapter is intended as an exposition of the concepts and principles of these basic systems. The reader can utilize these systems as building blocks to synthesize a customized solution to the requirements of the application at hand.

2.2 Stops and Pupils

We begin with a discussion of an often neglected but vital aspect of optical systems, the concept of the *aperture stop*. In every optical system there is some feature, usually a diameter, which limits the size or diameter of the beam of rays which can pass through the system. If the system consists of just a single simple lens, the aperture stop is just the clear aperture of the lens. In a typical camera lens the iris diaphragm is the aperture stop. In a telescope the clear aperture of the objective lens (or that of the primary mirror) is ordinarily the aperture stop. Often the aperture stop is referred to simply as “the stop.”

Figure 2.1 illustrates several examples of aperture stops. Note that Fig. 2.1C and D shows exactly the same system, except that the objective lens diameter is larger in Fig. 2.1D. This shifts the beam-limiting