

**OPTICAL AND ELECTRO-OPTICAL
ENGINEERING SERIES**

MODERN LENS DESIGN

A Resource Manual

WARREN J. SMITH
GENESEE OPTICS SOFTWARE, INC.

ROBERT E. FISCHER & WARREN J. SMITH, Series Editors

Modern Lens Design

A Resource Manual

Warren J. Smith

Chief Scientist

Kaiser Electro-Optics, Inc.

Carlsbad, California

Genesee Optics Software, Inc.

Rochester, New York

McGraw-Hill, Inc.

New York St. Louis San Francisco Auckland Bogotá
Caracas Lisbon London Madrid Mexico Milan
Montreal New Delhi Paris San Juan São Paulo
Singapore Sydney Tokyo Toronto

Library of Congress Cataloging-in-Publication Data

Smith, Warren J.

Modern lens design : a resource manual / Warren J. Smith and
Genesee Optics Software, Inc.

p. cm.—(Optical and electro-optical engineering series)

Includes index.

ISBN 0-07-059178-4

I. Lenses—Design and construction—Handbooks, manuals, etc.

I. Genesee Optics Software, Inc. II. Title. III. Series.

QC385.2.D47S65 1992

681'.423—dc20

92-20038

CIP

Copyright © 1992 by McGraw-Hill, 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 8 7 6 5 4 3 2

ISBN 0-07-059178-4

*The sponsoring editor for this book was Daniel A. Gonneau, the
editing supervisor was David E. Fogarty, and the production
supervisor was Suzanne W. Babeuf. It was set in Century Schoolbook
by McGraw-Hill's Professional Book Group composition unit.*

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

OPTICS TOOLBOX is a registered trademark of Genesee Optics
Software, Inc.

Information contained in this work has been obtained by McGraw-Hill, Inc., 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.

Contents

Preface ix

Chapter 1. Introduction	1
Chapter 2. Automatic Lens Design: Managing the Lens Design Program	3
2.1 The Merit Function	3
2.2 Optimization	5
2.3 Local Minima	6
2.4 Types of Merit Functions	8
2.5 Stagnation	9
2.6 Generalized Simulated Annealing	10
2.7 Considerations about Variables for Optimization	10
2.8 How to Increase the Speed or Field of a System and Avoid Ray Failure Problems	14
2.9 Test Plate Fits, Melt Fits, and Thickness Fits	16
2.10 Spectral Weighting	18
2.11 How to Get Started	19
Chapter 3. Improving a Design	25
3.1 Standard Improvement Techniques	25
3.2 Glass Changes (Index and V Value)	25
3.3 Splitting Elements	27
3.4 Separating a Cemented Doublet	30
3.5 Compounding an Element	30
3.6 Vignetting and its Uses	33
3.7 Eliminating a Weak Element; the Concentric Problem	34
3.8 Balancing Aberrations	35
3.9 The Symmetrical Principle	39
3.10 Aspheric Surfaces	40

v

Chapter 4. Evaluation: How Good Is This Design?	43
4.1 The Uses of a Preliminary Evaluation	43
4.2 OPD versus Measures of Performance	43
4.3 Blur Spot Size versus Certain Aberrations	47
4.4 MTF—The Modulation Transfer Function	48
Chapter 5. Lens Design Data	49
5.1 About the Sample Lenses	49
5.2 Lens Prescriptions, Drawings, and Aberration Plots	50
5.3 Estimating the Potential of a Design	54
5.4 Scaling a Design, Its Aberrations, and Its MTF	57
5.5 Notes on the Interpretation of Ray Intercept Plots	58
Chapter 6. Telescope Objectives	63
6.1 The Thin Doublet	63
6.2 Secondary Spectrum (Achromatic Systems)	72
6.3 Spherochromatism	75
6.4 Zonal Spherical Aberration	75
6.5 Induced Aberrations	79
6.6 Three-Element Objectives	79
Chapter 7. Eyepieces and Magnifiers	87
7.1 Eyepieces	87
7.2 Two Magnifier Designs	89
7.3 Simple Two- and Three-Element Eyepieces	92
7.4 Four-Element Eyepieces	92
7.5 Five-Element Eyepieces	101
7.6 Six- and Seven-Element Eyepieces	101
Chapter 8. Cooke Triplet Anastigmats	123
8.1 Airspaced Triplet Anastigmats	123
8.2 Glass Choice	125
8.3 Vertex Length and Residual Aberrations	125
8.4 Other Design Considerations	127
Chapter 9. Reverse Telephoto (Retrofocus and Fish-Eye) Lenses	147
9.1 The Reverse Telephoto Principle	147
9.2 The Basic Retrofocus Lens	148
9.3 The Fish-Eye, or Extreme Wide-Angle Reverse Telephoto, Lenses	150

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.