

## CONTENTS

---

Foreword	xi
Preface	xv
List of Symbols	xxi
<b>Chapter 1 Optimization</b>	<b>1</b>
1.1 Special characteristics of lens design as an optimization problem	2
1.2 The nature of the merit function	2
1.2.1 The Strehl ratio	2
1.2.2 MTF optimization	2
1.2.3 General comments	3
1.2.4 Comparison with the optical thin-film design problem	3
1.2.5 Nonlinearity of the aberrations	4
1.2.6 Changes needed to reduce high-order aberrations	5
1.2.7 A method of visualizing the problem of optimization in lens design	5
1.3 Theory of damped least squares (Levenberg-Marquardt)	6
1.4 Some details of damped least squares as used in lens design	8
1.4.1 Paraxial (first-order) properties	8
1.4.2 Seidel and Buchdahl coefficients	9
1.4.3 Transverse ray or wavefront aberrations	9
1.4.4 Aberration balancing and choice of weighting factors	9
1.4.5 Damping	11
1.4.6 Control of physical constraints	12
1.4.7 Control of glass boundary conditions	20
1.4.8 Solves	23
1.4.9 Lagrange multipliers	25
1.5 Some reasons for the success of the DLS method	25
1.6 Experiments with optimization programs	26
1.6.1 Effect of changing the damping factor	26
1.6.2 Effect of scaling the parameter changes	27
1.7 An optimization example	29
References	34

<b>Chapter 2</b>	<b>Buchdahl Aberrations</b>	<b>37</b>
2.1	Third-order coefficients	37
2.2	Fifth-order coefficients	38
2.3	Comparison with H.H. Hopkins notation	39
2.4	Examples	39
2.4.1	Double Gauss	39
2.4.2	Shafer lens with zero third- and fifth-order aberrations	45
	References	49
<b>Chapter 3</b>	<b>Synthesis of New Lens Designs</b>	<b>51</b>
3.1	Choice of a starting point	51
3.1.1	Modification of an existing design	51
3.1.2	Purchase of a competing lens	52
3.1.3	Analytic solutions	52
3.1.4	Nonanalytic synthesis of new design forms	52
3.2	Examples	53
3.2.1	A unit magnification telecentric doublet pair	53
3.2.2	A simple zoom lens	59
3.3	The use of catalog components	67
3.3.1	Singlets	68
3.3.2	Doublets and triplets	68
3.3.3	Meniscus singlets	69
3.3.4	Field flatteners	70
3.3.5	Cemented triplets	71
	References	72
<b>Chapter 4</b>	<b>Lenses for 35-mm Cameras</b>	<b>73</b>
4.1	The triplet	74
4.2	The tessar	75
4.3	The double-Gauss (planar-type)	78
4.4	The Sonnar	82
4.5	Wide-angle lenses for rangefinder cameras (Zeiss Biogon)	84
4.6	Wide-angle lens for rangefinder camera (Schneider Super-Angulon)	86
4.7	Wide-angle lenses for SLR cameras	89
4.8	Telephoto lens	91
4.9	Long-focus telephoto lens	93
4.10	Lens for compact point-and-shoot camera	95
4.11	Single lens for disposable cameras	97
	References	99

<b>Chapter 5</b>	<b>Secondary Spectrum and Apochromats.</b>	<b>101</b>
5.1	Apochromatic doublets	101
5.2	Apochromatic triplets	104
5.3	Petzval lenses	105
5.4	Double-Gauss lenses	106
5.5	Telephoto lenses	108
5.6	Zoom lenses	108
5.7	Microscope objectives	108
5.8	Secondary spectrum correction with normal glasses	108
5.8.1	Liquids	108
5.8.2	Diffraction optics	109
5.8.3	McCarthy-Wynne principle	109
5.8.4	Schupmann principle	112
5.9	Transverse secondary spectrum	115
	References	115
<b>Chapter 6</b>	<b>Lenses for Laser Applications</b>	<b>117</b>
6.1	Gaussian beams	117
6.2	Laser beam expanders	118
6.2.1	Two-lens beam expanders	118
6.2.2	Three-lens beam expanders	122
6.3	F-Theta lenses	124
6.4	Lenses for optical disks	126
6.5	Laser diode collimators	129
	References	130
<b>Chapter 7</b>	<b>Microscope Objectives</b>	<b>133</b>
7.1	Classical microscope objectives	133
7.2	Flat-field microscope objectives	135
7.3	Oil-immersion objectives	141
	References	144
<b>Chapter 8</b>	<b>Microlithographic Projection Optics</b>	<b>145</b>
8.1	Unit-magnification zero-power monocentric systems	145
8.1.1	Dyson 1× relay	146
8.1.2	Offner 1× relay	148
8.2	Wynne-Dyson 1× relay	149
8.3	Wynne-Offner 1× relay	152
8.4	Reduction lenses	153
8.5	Catadioptric reduction systems	163
8.6	Catoptric reduction systems	167
	References	170

<b>Chapter 9</b>	<b>Zoom Lenses</b>	<b>173</b>
9.1	General principles	173
9.1.1	Control of chromatic aberration	173
9.1.2	Field curvature	173
9.1.3	Minimization of movements	174
9.2	Two-component zooms	174
9.2.1	Minus-plus plastic disposable zoom	174
9.2.2	Plus-minus plastic disposable zoom	175
9.2.3	A typical minus-plus zoom	177
9.2.4	A typical plus-minus zoom	178
9.3	Three-component zooms	179
9.4	Four-component zooms	181
9.5	Zoom relays	188
9.6	Zoom telescopes	189
9.7	Zoom modules	190
	References	190
<b>Chapter 10</b>	<b>Decentered and Asymmetric Systems</b>	<b>193</b>
10.1	General properties of decentered systems	193
10.2	Coordinate systems	194
10.3	Interpretation of results	196
10.4	New-axis surface	197
10.5	Toroids	197
10.6	Offset surfaces (or off-axis surfaces)	198
10.7	Convention for mirrors	198
10.8	Kutter system	199
10.9	Single parabolic mirror	202
10.9.1	Alpha rotations	204
10.9.2	Beta rotations	205
10.9.3	Alpha and beta rotations	206
10.10	Scanning systems	207
10.11	The "active" side of a surface	209
10.12	X-ray telescopes	210
10.12.1	WOLTER2 example	210
10.12.2	WOLTER1 example	211
<b>Chapter 11</b>	<b>Design for Manufacturability</b>	<b>215</b>
11.1	Tolerancing	215
11.2	Simplicity of design	216
11.3	Air spaces	217
11.4	Glass components	218
11.5	Glass choice	220
11.6	Mirror surfaces	220

11.7	Redesign for actual "melt" data	220
11.8	Use of existing tools and test plates	221
11.9	Selective assembly and adjustment after assembly	221
11.10	General points	221
	References	222
	<b>INDEX</b>	
	<b>Index</b>	<b>223</b>

In following the work for *Fundamental Optical Design*, I think it is helpful for the reader to understand the background of how the two books were made possible, and why we ask all readers of this volume to read the earlier volume. It is rather similar whatever we read, fact or fiction, we have a better understanding if we start from the beginning.

At the time of the initial publishing discussions, we all assumed that Michael's book would fit the style and category of SPIE's Tutorial Text Series, which is based on their short courses. The idea was to capture Michael's very successful style of teaching and be reflective of his association with many of the internationally famous optical designers at Imperial College London, where he trained and taught and with whom he was a consultant, pre-innovator in optical design teaching, and of the optical design program later known as SIGMA. This group included Prof. H.H. Hopkins, Prof. Charles Wynne, Prof. W.D. Wright, and Prof. Walter Welferd.

Michael Kluger died four days after he signed the original publishing contract with SPIE Press. Following his death, hundreds of colleagues and former students wrote to me from all over the world expressing their admiration for Michael's warmth/charming experience, and style of teaching. It was clear to me from this unanimous and overwhelming expression that I should find a way to maintain, not only with practicing optical designers, but with future students of optical design, a continuity of this relationship between student and teacher. Perseus' publication of his book was the obvious choice.

To this end, I reviewed each and every set of course notes that Michael had given, sifting through the material to avoid duplication. Eventually, I had collected and sorted all the relevant source material. However, this material could not be Michael's book per the original agreement.

This compiled source material included special courses given at specific optical design requirements for whichever group he was teaching. For example, the material included courses given at the Institute Galileo, Florence. It also contained a hands-on course in practical lens design given at the Wilson School in Optics, held at The International Centre for Theoretical Physics in Trieste, Italy. Michael gave courses in Australia, Singapore, and Europe, including courses in Germany and the UK. Also, a course was given at Imperial College London for 50 students from Samsung, Korea. The optical designers from Samsung came with their specific problems, and these were worked through individually with Michael's assistance.