

MIL-HDBK-141

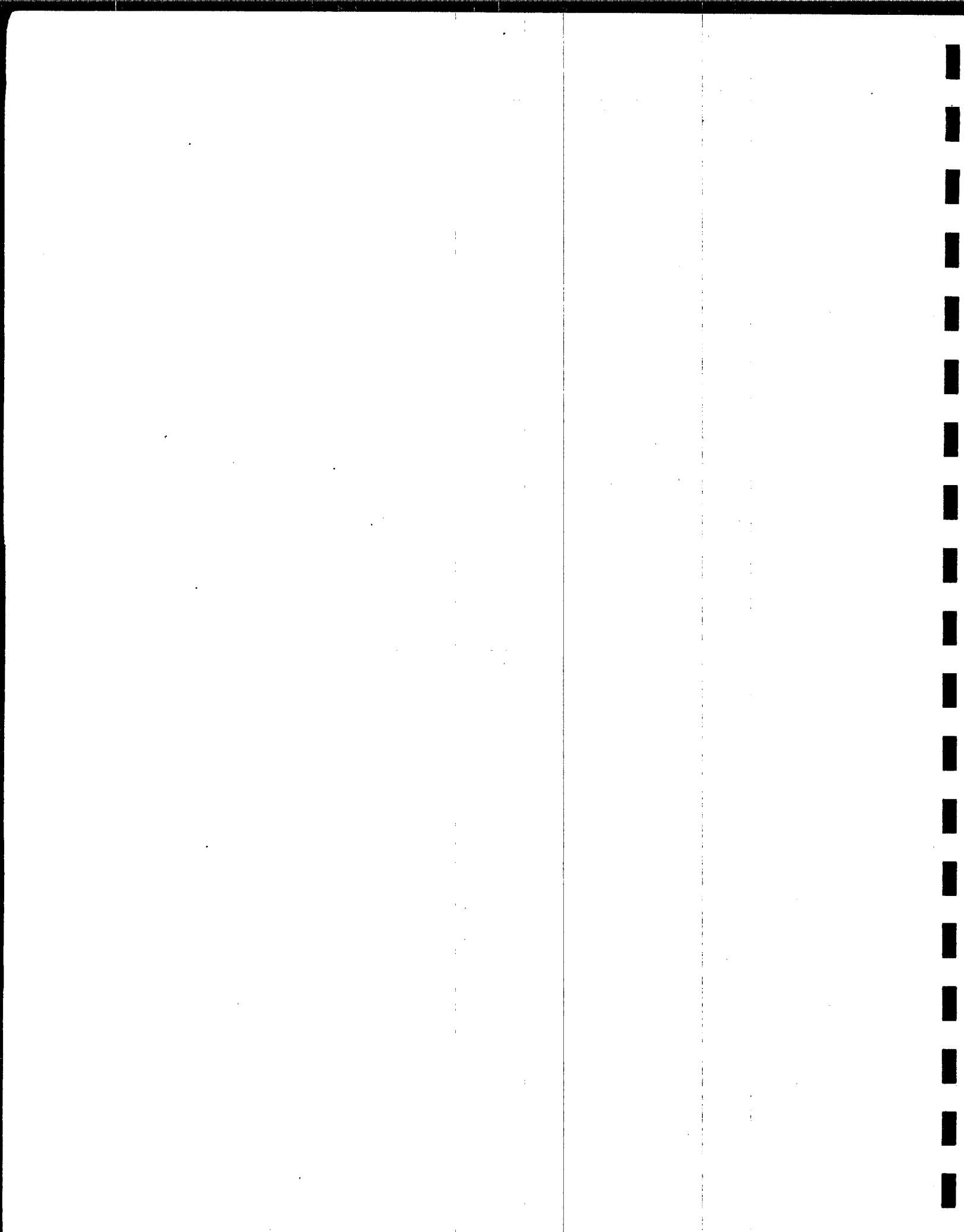
5 OCTOBER 1962

**MILITARY STANDARDIZATION HANDBOOK**

**OPTICAL DESIGN**



FSC 6650



DEFENSE SUPPLY AGENCY  
WASHINGTON 25, D.C.

MIL-HDBK-141  
Optical Design  
5 October 1962

1. This handbook was developed by the Department of Defense with the assistance of a leading optical manufacturer. Major contributions were made by persons who, by virtue of experience in their particular fields, are recognized as qualified authorities on the subject of optical design.

2. This publication was approved on 5 October 1962 for printing and inclusion in the military standardization handbook series.

3. This document provides engineering personnel with an introduction to optical theory, and treats to an advanced level the fundamentals and principles of optical design. It is expected that wide distribution of the methods of design and computation presented in this handbook will result in a more efficient and accurate method of complying with military optical requirements.

4. To aid in maintaining the intended status of this handbook as a source of prevailing information, readers are encouraged to report any errors and suggestions for changes and additions to the Standardization Division, Defense Supply Agency, Washington 25, D. C.

This handbook contains copyright material.

## CONTENTS

<b>SECTION 1. INTRODUCTION .....</b>	<b>1-1</b>
1.1 Scope .....	1-1
1.2 Definitions .....	1-2
1.3 Reference documents .....	1-5
<b>SECTION 2. FUNDAMENTALS OF GEOMETRICAL OPTICS<sup>1</sup> .....</b>	<b>2-1</b>
2.1 General .....	2-1
2.2 Law of refraction .....	2-1
2.3 Law of reflection .....	2-3
2.4 Total internal reflection .....	2-4
2.5 Index of refraction .....	2-4
2.6 Dispersion of light .....	2-5
2.7 Characteristics of optical glass .....	2-6
<b>SECTION 3. CONSIDERATIONS OF PHYSICAL OPTICS<sup>2</sup> .....</b>	<b>3-1</b>
3.1 Introduction .....	3-1
3.2 Physical nature of light .....	3-1
3.3 Interference between waves .....	3-4
<b>SECTION 4. VISUAL OPTICS<sup>3</sup> .....</b>	<b>4-1</b>
4.1 Introduction .....	4-1
4.2 Anatomy of the eye .....	4-1
4.3 Optical constants of the eye .....	4-3
4.4 Image formation and the retina .....	4-5
4.5 Seeing .....	4-10
4.6 Movement of the eyes .....	4-14
4.7 Binocular vision .....	4-16
4.8 Fatigue and ageing .....	4-18
<b>SECTION 5. FUNDAMENTAL METHODS OF RAY TRACING<sup>1</sup> .....</b>	<b>5-1</b>
5.1 General .....	5-1
5.2 Definitions and conventions .....	5-3
5.3 Basic ray trace procedure .....	5-5
5.4 Skew ray trace equations for spherical surfaces .....	5-5
5.5 Skew ray trace equations for aspheric surfaces .....	5-13
5.6 Meridional rays .....	5-21
5.7 Graphical ray tracing procedure .....	5-26
5.8 Differential ray tracing procedure .....	5-27
5.9 Paraxial rays .....	5-32
5.10 Graphical ray trace for paraxial rays .....	5-34
5.11 Different "orders" of optics .....	5-35
<b>SECTION 6. FIRST ORDER OPTICS<sup>1</sup> .....</b>	<b>6-1</b>
6.1 General .....	6-1
6.2 Numerical tracing of paraxial rays .....	6-1
6.3 Optical invariant .....	6-5
6.4 Linearity of paraxial ray tracing equations .....	6-8
6.5 Cardinal points of an optical system .....	6-10
6.6 Calculation of focal length from finite conjugate data .....	6-17

Ref 1, 2, 3 - See page vi for Author.

6.7	Systems of thin lenses in air .....	6-17
6.8	Optical systems involving mirrors .....	6-19
6.9	Differential changes in first order optics .....	6-23
6.10	Chromatic aberration .....	6-26
6.11	Entrance and exit pupils, the chief ray and vignetting .....	6-37
 SECTION 7. SIMPLE THIN LENS. OPTICAL SYSTEMS <sup>1</sup> .....		 7-1
7.1	Introduction .....	7-1
7.2	Simple magnifier .....	7-1
7.3	Microscope .....	7-4
7.4	Telescope .....	7-8
7.5	Optical relay systems, Periscopes .....	7-8
7.6	Galilean telescope .....	7-11
 SECTION 8. ABERRATION ANALYSIS AND THIRD ORDER THEORY <sup>1</sup> ..		 8-1
8.1	Significance of ray trace data .....	8-1
8.2	Spot diagram .....	8-1
8.3	Meridional and skew fans .....	8-3
8.4	Use of third order theory in aberration analysis .....	8-3
8.5	Zero-degree image in D light .....	8-5
8.6	Imagery for an off-axis object point .....	8-9
8.7	Calculation of third order contributions .....	8-14
8.8	Afocal optical systems .....	8-15
8.9	Stop shift equations .....	8-16
8.10	Thin lens aberration theory .....	8-18
 SECTION 9. METHOD OF LENS DESIGN <sup>4</sup> .....		 9-1
9.1	Process of designing a lens system .....	9-1
9.2	Description and analysis of basic procedure .....	9-1
9.3	Summary of equations used in calculation of third order aberrations .....	9-11
 SECTION 10. AN APPLICATION OF THE METHOD OF LENS DESIGN <sup>4</sup> .		 10-1
10.1	Step one - selecting the lens type .....	10-1
10.2	Step two - first order thin lens solution .....	10-2
10.3	Step three - third order thin lens solution .....	10-13
10.4	Step four - thick lens first order and third order aberrations ..	10-17
10.5	Step five - tracing a few selected rays .....	10-19
10.6	Step six - readjusting third order aberrations .....	10-20
10.7	Evaluation of over-all performance .....	10-27
10.8	Summary .....	10-27
 SECTION 11. TELESCOPE OBJECTIVES <sup>4</sup> .....		 11-1
11.1	Introduction .....	11-1
11.2	Design procedure for a thin lens telescope objective .....	11-3
11.3	Design procedure for a thick lens telescope objective .....	11-6
11.4	Secondary spectrum of telescope objectives .....	11-18
11.5	Summary .....	11-25
 SECTION 12. LENS RELAY SYSTEMS <sup>4</sup> .....		 12-1
12.1	Introduction .....	12-1
12.2	The basic lens problem of a relay system .....	12-1
12.3	A visual system. Numerical example .....	12-1

Ref 1, 4 -See page vi for Author.

12.4	Secondary color in a relay system .....	12-2
12.5	Further details on design of doublets as relay lenses .....	12-2
12.6	Double relay systems .....	12-3
12.7	Summary .....	12-4
 SECTION 13. MIRROR AND PRISM SYSTEMS <sup>4</sup> .....		 13-1
13.1	Introduction .....	13-1
13.2	Reflection .....	13-1
13.3	Location of image .....	13-4
13.4	Orientation of image .....	13-6
13.5	Image sphere .....	13-10
13.6	Reflection from two mirrors .....	13-13
13.7	Typical prism systems .....	13-15
13.8	Tunnel diagram .....	13-21
13.9	Aberrations introduced by prisms .....	13-23
13.10	Prism data sheets .....	13-25
 SECTION 14. EYEPIECES <sup>4</sup> .....		 14-1
14.1	General principles .....	14-1
14.2	Method of description .....	14-1
14.3	Huygenian eyepiece .....	14-2
14.4	Ramsden eyepiece .....	14-4
14.5	Kellner eyepiece .....	14-6
14.6	Orthoscopic eyepiece .....	14-8
14.7	Symmetrical (Plössl) eyepiece .....	14-10
14.8	Berthele eyepiece .....	14-12
14.9	Erfle eyepiece .....	14-14
14.10	Modified Erfle eyepiece .....	14-16
14.11	Wild eyepiece .....	14-18
14.12	Summary .....	14-20
 SECTION 15. COMPLETE TELESCOPE <sup>4</sup> .....		 15-1
15.1	Introduction .....	15-1
15.2	Design problem .....	15-1
15.3	Preliminary considerations .....	15-1
15.4	Design refinement .....	15-2
15.5	Completed design .....	15-3
 SECTION 16. APPLICATIONS OF PHYSICAL OPTICS <sup>2</sup> .....		 16-1
16.1	Introduction .....	16-1
16.2	Fizeau interferoscope .....	16-3
16.3	Twyman-Green interferometer .....	16-5
16.4	Effect of monochromaticity on fringe contrast .....	16-7
16.5	Effect of pinhole size on contrast .....	16-8
16.6	Young's pinhole interferometer .....	16-9
16.7	Lloyd's interferometer .....	16-12
16.8	Fresnel coefficients for normal incidence .....	16-12
16.9	Interference with plane parallel plates and distant light sources .....	16-14
16.10	Interference with plane parallel plates and nearby light sources .....	16-16
16.11	Haidinger's interference fringes .....	16-17
16.12	Fizeau fringes .....	16-19
16.13	Newton's rings and Newton's fringes .....	16-19
16.14	Complex numbers .....	16-26
16.15	Transmittance of plane parallel plates .....	16-28
16.16	Reflectance from plane parallel plates .....	16-32
16.17	Multiple beam interference fringes from slightly inclined surfaces .....	16-34

16.18	Measurements with monochromatic light .....	16-37
16.19	Method of channeled spectra .....	16-41
16.20	Interpretation of measurements with channeled spectra .....	16-41
16.21	Huygen's principle .....	16-45
16.22	Fraunhofer diffraction .....	16-47
16.23	Fraunhofer diffraction from a rectangular aperture .....	16-49
16.24	Fraunhofer diffraction from circular apertures .....	16-50
16.25	Diffraction from spherical wavefronts .....	16-52
16.26	Primary diffraction integrals with objectives having circular apertures .....	16-54
16.27	Resolution with circular apertures .....	16-56
16.28	Out-of-focus aberration .....	16-58
 SECTION 17. OPTICAL MATERIAL <sup>5</sup> .....		17-1
17.1	Introduction .....	17-1
17.2	Refracting material characteristics .....	17-1
17.3	Refractivity and dispersion .....	17-3
17.4	Inclusions .....	17-4
17.5	Environmental characteristics .....	17-5
17.6	Refractive materials for specific wavelength ranges .....	17-5
17.7	Reflecting materials .....	17-8
17.8	Availability, cost, ease of working .....	17-10
 SECTION 18. ATMOSPHERIC OPTICS <sup>6</sup> .....		18-1
18.1	Introduction .....	18-1
18.2	Extinction .....	18-1
18.3	Extinction and visual instruments .....	18-4
18.4	Extinction and photographic instruments .....	18-5
18.5	Seeing .....	18-6
18.6	Thermal effects .....	18-8
18.7	Atmospheric contaminants .....	18-9
18.8	Effect of atmospheric optics on instrument design .....	18-10
 SECTION 19. OPTICS FOR MISSILE TRACKING <sup>7</sup> .....		19-1
19.1	Introduction .....	19-1
19.2	Refractive systems .....	19-2
19.3	Reflective systems .....	19-7
19.4	Catadioptric systems .....	19-10
19.5	Applied systems .....	19-14
 SECTION 20. APPLICATIONS OF THIN FILM COATINGS <sup>8</sup> .....		20-1
20.1	Introduction .....	20-1
20.2	Manufacture of multilayer filters .....	20-14
20.3	Antireflection coatings .....	20-18
20.4	Reflectivity of multilayers with periodic structure .....	20-39
20.5	Long-wave pass filters .....	20-56
20.6	Short-wave pass filters .....	20-63
20.7	Beam splitters .....	20-64
20.8	Mirrors .....	20-68
20.9	Band pass filters .....	20-71
20.10	Fabry-Perot type filters (interference filters) .....	20-71
20.11	References for further study .....	20-91

<b>SECTION 21. COATING OF OPTICAL SURFACES<sup>2</sup></b>	21-1
21.1 Introduction .....	21-1
21.2 Definitions and principles .....	21-1
21.3 Zero reflectance from non-absorbing monolayers and substrates .....	21-27
21.4 Matrix methods .....	21-30
21.5 Quaternion methods .....	21-35
21.6 Monolayer coatings .....	21-41
21.7 Bilayer coatings .....	21-49
21.8 Trilayers .....	21-64
21.9 Quadrilayers .....	21-66
21.10 Quarter-wave multilayers .....	21-67
21.11 Materials and texts .....	21-77
<b>SECTION 22. INFRARED OPTICAL DESIGN<sup>5</sup></b>	22-1
22.1 Introduction .....	22-1
22.2 Infrared optical material .....	22-1
22.3 Environmental requirements .....	22-2
22.4 Operational requirements .....	22-2
22.5 Near infrared region .....	22-3
22.6 Intermediate and far infrared region .....	22-5
22.7 Summary and conclusion .....	22-12
<b>SECTION 23. MICROSCOPE OPTICS<sup>9</sup></b>	23-1
23.1 Introduction .....	23-1
23.2 Characteristics .....	23-1
23.3 Components of a compound microscope .....	23-3
23.4 Darkfield microscopy .....	23-11
23.5 Ultramicroscopy .....	23-15
23.6 Phase microscopy .....	23-16
23.7 Interference microscopy .....	23-19
23.8 Polarizing microscopy .....	23-23
23.9 Fluorescence microscopes .....	23-23
23.10 Stereoscopic microscope .....	23-24
23.11 Petrographic microscope .....	23-24
<b>SECTION 24. DESIGN PHASE OPTICAL TESTS<sup>2</sup></b>	24-1
24.1 Introduction .....	24-1
24.2 Calculation of Seidel aberrations .....	24-2
24.3 Spot diagram .....	24-3
24.4 Phase front calculations .....	24-4
<b>SECTION 25. PRODUCTION PHASE OPTICAL TESTS<sup>2</sup></b>	25-1
25.1 Introduction .....	25-1
25.2 Focal length .....	25-1
25.3 Longitudinal spherical aberration .....	25-3
25.4 Coma .....	25-4
25.5 Astigmatism and curvature field .....	25-4
25.6 Distortion .....	25-5
25.7 Auxiliary optical measurements .....	25-5
25.8 Optical devices, testing systems and procedures .....	25-8
25.9 Ronchi test .....	25-20
25.10 Foucault test .....	25-24
25.11 Star test .....	25-29

SECTION 26. EVALUATION PHASE OPTICAL TESTS <sup>2</sup> .....	26-1
26.1 Resolving power tests .....	26-1
26.2 General discussion of sine-wave testing .....	26-10
26.3 Sine-wave testing with sine-wave targets .....	26-12
26.4 Sine-wave testing with square-wave targets .....	26-17
APPENDIX .....	27-1
INDEX .....	28-1

REF	AUTHOR
1.	Dr. Robert E. Hopkins, University of Rochester Dr. Richard Hanau, University of Kentucky
2.	Dr. Harold Osterberg, American Optical Company
3.	Dr. Oscar W. Richards, American Optical Company
4.	Dr. Robert E. Hopkins, University of Rochester
5.	Mr. A. J. Kavanagh, American Optical Company
6.	Dr. Ralph Wight, Photronics Corporation
7.	Dr. Seymour Rosin, Scanoptic, Incorporated
8.	Dr. Philip Baumeister, University of Rochester
9.	Mr. Alva Bennett, American Optical Company

