INTRODUCTION TO

LENS DESIGN

With Practical ZEMAX® Examples

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With Practical ZEMAX® Examples

Joseph M. Geary

Center for Applied Optics
University of Alabama in Huntsville

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藏书章

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Preface

This book evolved from an introductory course in lens design sponsored by the Center for Applied Optics for use in the Optical Science & Engineering doctoral program at the University of Alabama in Huntsville. At the inception of this course, I searched for a lens design textbook and found, to my surprise and dismay, that there really were none! Although there were several good books about lens design (see the booklist in Appendix A), these tended to be either monographs or compilations of different designs. None were written with students (or instructors) in mind. Hopefully this book is a step in the pedagogical direction. As I began preparing lectures it also seemed obvious that no modern lens design course could be given without thoroughly integrating one of the commercially available lens design codes into the syllabus. For a variety of reasons (including user friendliness and cost effectiveness) ZEMAX was selected.

This is not a textbook in the traditional sense. It is a formalized embodiment of lectures with assigned homework and exams. The course is designed around a 14-week semester (MWF) with enough material to fill 38 lectures of 55 minutes each. The material is at the first-year graduate level, and is intended as a first course in lens design. It is also structured to be hands-on and engineering oriented. A solid footing in undergraduate geometrical optics (Appendix A) is the only prerequisite. Math requirements are modest: algebra, trig, geometry, and calculus. Although this course is about lens design, I believe its scope is more general in that it can provide optical engineers with important tools and skills that will be useful in their professional careers.

Though written in lecture format and suitable for classroom use, the book is primarily designed for self-study. As such it can be used on three distinct levels. Obviously, the full benefit will be had by those having access to ZEMAX (and the accompanying manual). However, I believe enough information is provided (particularly with the help of Appendices C and E) to allow readers using alternate codes (such as Code-V, SYNOPSIS, and Super OSLO) to work the examples and assignments in a beneficial manner. Finally, for readers who do not have any major code readily available, a great deal can still be learned about design and analysis in conjunction with working the manual calculation problems and by doing the thin lens pre-designs preceding code work.

With a few exceptions, the backbone of the course is the photographic lens, and we follow an almost historic development. There are ten photographic lens design problems from the simple Wollaston landscape lens to the more complex achromatic telephoto. Along the way we visit such things as the Rapid Rectilinear and Cooke Triplet. The design principles covered in the course include: lens bend-

ing, stop shift, symmetry, element splitting, color correction, aberration balancing, field flattening, aspherics, as well as the proper use and construction of the merit function. Though ZEMAX is an integral part of the course, its use will not be blind. Manual thin lens pre-design calculations provide the starting prescriptions for every ZEMAX homework. Paraxial ray tracing, element power computations, and aberration calculations are utilized throughout the course. Consequently, all designs are firmly anchored by theory.

Of equal importance to the design principles covered in the course are the analytical tools used to determine the quality of the design. ZEMAX and its sister codes are built upon a strong tradition of optical analysis, and will provide the user with a rich variety of numbers and plots (such as axial color and ray fan plots, spot diagrams, and MTF). This course will provide the student with a thorough understanding of where these numbers come from and what the plots mean. This understanding is supported by 26 assignments evenly split between "pencil and paper" calculations and ZEMAX code work. The course is structured so that students start using ZEMAX in the very first week, and every week thereafter. This affects the arrangement of material because roughly every third lecture focuses on a specific lens design and provides background for the ZEMAX assignment.

I would like to dedicate this book to Professors Roland Shack and Bob Shannon who were my mentors at the Optical Sciences Center. I also want to include Prof. Rudolph Kingslake in this dedication. All three have provided inspiration for this work, and I thank each for the things I've learned from them.

My thanks to Dr. John Dimmock, Director of both the Center for Applied Optics and the Optical Sciences and Engineering program, for his generous support in developing the lens design course upon which this book is based. I also owe a debt of gratitude to all the reviewers of the manuscript. In alphabetical order they are: Dr. Richard Buchroeder, Dr. Qian Gong (Swales Aerospace), Dr. John Loomis (University of Dayton Research Institute), Dr. Malcolm MacFarlane (Goodrich), Mr. Ken Pitalo (University of Alabama in Huntsville), Dr. Pat Reardon (University of Alabama in Huntsville), Dr. Babak Saif (Space Telescope Institute), Dr. José Sasian (University of Arizona), Dr. Lynn Seppala (Lawrence Livermore National Laboratory), Dr. Bob Shannon (University of Arizona), Dr. Greg Smith, Dr. Phil Stahl (Marshall Space Flight Center), Dr. Harold Suiter, Dr. Bill Swantner (BSC Optics), and Dr. Mary Turner (Focus Software Inc.). The constructive criticism provided by these professionals has greatly improved the quality of this work. Finally, I want to thank my daughter, Jennifer, for the fine art work she contributed to this book.

Note on ZEMAX: ZEMAX SE versions 6.0 – 7.2 have been used in the development of this book and in the instruction of this course. I have found that different versions can give slightly different numbers for variables in the lens data editor and for operand values in the merit function editor at the end of an optimization run. The differences tend to be of no significance. I provide many design examples using ZEMAX optimization where specific numerical values are pointed out or tabulated. For those using other versions of ZEMAX, please do not be

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surprised if your post-optimization numbers do not agree precisely with mine. They should, however, be reasonably close.

Instructor Note: I found the use of a computer projector absolutely indispensable in teaching this course. I strongly encourage any instructor to employ a computer projector not only for homework reviews but also for live demonstrations of ZEMAX features, and for illustrating design principles.

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October 15, 2002

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Chapter 1

Agenda

1.1 Introduction

1.1.1 Why Lens Design?

Lens design used to be a skill reserved for a few professionals. They employed company proprietary optical design and analysis software which was resident on large and expensive mainframes. Today, with readily available commercial design software and powerful personal (and portable) computers, lens design tools are accessible to the general optical engineering community. Consequently, some rudimentary skill in lens design is now expected by a wide range of employers who utilize optics in their products. Lens design is, therefore, a strong component of a well-rounded education in optics, and a skill valued by industries employing optical engineers.

1.1.2 Type of Course

This is an introductory lens design course at the first-year graduate level. It is a nuts and bolts, hands-on oriented course. A good working knowledge of geometric optics (as may be found in such texts as Hecht and Zajac's *Optics* or Jenkins and White's *Fundamentals of Optics*) is presumed. Photographic lenses will form the backbone of the course. We will follow an historic progression (which also has correspondence from simpler to more complex systems). The code used is Focus Software's ZEMAX® and the student must have access to a PC running ZEMAX. The math level required is not taxing: algebra, trigonometry, geometry (plane and analytic), and some calculus. A book list of references is provided in Appendix A.

1.1.3 Acquired Skills

This course will provide you with three basic skills: manual, design code, and design philosophy. The manual skills will include first and third order hand calculations and thin lens pre-designs. (Analysis skills are illustrated in Figure 1.1). The code skills will include prescription entry, variable selection, merit function construction and optimization, and design analysis. The design philosophy includes understanding specifications, selecting a starting point, and developing a plan of attack.

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