OPTICAL DESIGN
for
VISUAL SYSTEMS
Tutorial Texts Series

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Introduction to the Series

The Tutorial Texts series was initiated in 1989 as a way to make the material presented in SPIE short courses available to those who couldn’t attend and to provide a reference book for those who could. Typically, short course notes are developed with the thought in mind that supporting material will be presented verbally to complement the notes, which are generally written in summary form, highlight key technical topics, and are not intended as stand-alone documents. Additionally, the figures, tables, and other graphically formatted information included with the notes require further explanation given in the instructor’s lecture. As stand-alone documents, short course notes do not generally serve the student or reader well.

Many of the Tutorial Texts have thus started as short course notes subsequently expanded into books. The goal of the series is to provide readers with books that cover focused technical interest areas in a tutorial fashion. What separates the books in this series from other technical monographs and textbooks is the way in which the material is presented. Keeping in mind the tutorial nature of the series, many of the topics presented in these texts are followed by detailed examples that further explain the concepts presented. Many pictures and illustrations are included with each text, and where appropriate tabular reference data are also included.

To date, the texts published in this series have encompassed a wide range of topics, from geometrical optics to optical detectors to image processing. Each proposal is evaluated to determine the relevance of the proposed topic. This initial reviewing process has been very helpful to authors in identifying, early in the writing process, the need for additional material or other changes in approach that serve to strengthen the text. Once a manuscript is completed, it is peer reviewed to ensure that chapters communicate accurately the essential ingredients of the processes and technologies under discussion.

During the past nine years, my predecessor, Donald C. O’Shea, has done an excellent job in building the Tutorial Texts series, which now numbers over forty books. It has expanded to include not only texts developed by short course instructors but also those written by other topic experts. It is my goal to maintain the style and quality of books in the series, and to further expand the topic areas to include emerging as well as mature subjects in optics, photonics, and imaging.

Arthur R. Weeks, Jr.
Invivo Research Inc. and University of Central Florida
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Foreword

The optical design of visual systems inherently has many subtleties associated with the task. In effect, we are coupling a manufactured optical system of glass and/or plastic lenses to the human eye. The eye is in effect a camera with a lens and a sensor, similar to a film or digital camera, with the retina being the analog of the film or CCD. The subtleties include pupil matching, gimbaling or rotating the eye, eye relief or clearance, eye pupil diameter, and of course matters relating to resolution and visual acuity.

Bruce Walker has brought all of these design issues to the reader in this new book. You will learn about simple to complex visual optical systems, including the more basic magnifiers and eyepieces, as well as more complex and complete optical systems and instruments such as microscopes, telescopes, periscopes, borescopes, and more.

While you may not design visual optical systems every day, this is a book you should have on your shelf, so that when the need comes up, you will be able to effectively cut through the mystique and proceed with the task at hand.

Robert E. Fischer
August 2000
Preface

In the field of optical engineering there exists a complete genre of instruments that are intended to be used with the human eye as the final system sensor. The optical design of such instruments involves a unique approach, dealing with a special set of requirements and design methods. This book will provide the reader with a basic understanding of these methods and the reasons behind them.

Initial chapters will deal with the human eye, its unique design characteristics and its function. A mathematical model of the eye, closely simulating the dimensions and performance of the typical eye, and suitable for computer analysis, will be generated. Computer simulation and analysis will be used to establish a baseline of performance for this eye model. This analysis of the visual system includes the use of an Aerial Image Modulation (AIM) curve, which describes the performance of the visual sensor, i.e., the eye’s retina. While generation of this AIM curve has involved some assumptions, it has been based on known characteristics of the retina. Results found when combining the Modulation Transfer Function (MTF) of the model eye with this AIM curve are consistent with the resolving capability of the typical visual system. This will permit performance comparisons in later chapters to determine the effectiveness of a variety of designs. Some time will be spent on describing the various reasons for the introduction of optical instruments that are intended to enhance the performance of the naked eye.

The simple magnifier (loupe), the eyepiece, and the microscope represent the most basic tier of optical designs for visual applications where near objects are being viewed. When viewing objects at great distances, the eyepiece is combined with an objective lens to form a telescope design. Several telescope designs will be developed and described in some detail. Design procedures will illustrate how these telescope designs are modified to make them suitable for a variety of applications.

In a number of unusual applications, it is required that a relatively large distance exist between the objective and the eyepiece of a telescope design. The basic submarine periscope and the field of industrial and medical borescope design will be discussed in order to demonstrate the interesting and unique aspects of these instruments.

Finally, the topic of biocular lens designs will be touched upon. In a biocular design the optics must be configured such that a common object
can be viewed by both eyes simultaneously. This leads to a lens system that is quite large physically, and has a small f-number (often around f/1.0). The design of a biocular lens is complicated by the fact that the relatively small pupil of the eye is sampling the output of this large lens. Several designs in this category will be presented.

Each design that is to be presented here (including the model eye) has been generated using the OSLO optical design software package from Sinclair Optics. Optical design methods and procedures will be discussed in some detail, with emphasis on the real world reasons behind them. While the typical reader may not use this information to make him or herself into a bonafide optical designer, a familiarity with this category of instruments and the design methods involved in creating them will permit an intelligent exchange of concepts and ideas with the Optical Designer on the program.

The level of mathematics and physics involved in the preparation of this book has been limited to fundamental algebra and trigonometry, along with the basic principles of optics that will be found in all basic optics textbooks. In this age, the lens design software package and the modern personal computer have assumed much of the heavy lifting (in a mathematical sense).

It is hoped that this book will successfully convey to the reader an understanding and appreciation of the basic human visual system, its function, and its rather remarkable performance capabilities. Second, the reader should come away with an understanding of the many unique considerations involved in the optical design of a system to be used in conjunction with the visual system. As is often the case, while the flexibility and responsiveness of the visual system tends to simplify the actual design process, the design is simultaneously made more difficult by the optical and physical limitations of that same visual system.

It is recognized that in most engineering fields (and optics is not an exception), the most effective engineering solutions involve the serious balancing of numerous design considerations, i.e., trade-offs. This book will be useful to the optical designer, as well as others peripherally involved, in helping to decide on the most effective way of incorporating those many compromises into a successful final design.

Readers are invited to visit the author's web site at www.waoptics.com, and to submit any questions or comments dealing with the content of this book via the e-mail link that will be found at that site.

Bruce H. Walker
July 2000
Acknowledgments

Working in the field of engineering invariably exposes one to organizations and personnel that are quite rigid in their ideas and procedures. As a result, when one attempts to branch into the area of technical writing for external publication, it is quite likely that some resistance to that move will be encountered. Over the years this author has had this experience. Fortunately, in the end, that resistance has been more than offset by the support and encouragement of many. For that, I would like to take this opportunity to thank the following people:

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