Introduction to
Infrared System Design

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SERIES INTRODUCTION

The Tutorial Texts series was begun in response to requests for copies of SPIE short course notes by those who were not able to attend a course. By policy the notes are the property of the instructors and are not available for sale. Since short course notes are intended only to guide the discussion, supplement the presentation, and relieve the lecturer of generating complicated graphics on the spot, they cannot substitute for a text. As one who has evaluated many sets of course notes for possible use in this series, I have found that material unsupported by the lecture is not very useful. The notes provide more frustration than illumination.

What the Tutorial Texts series does is to fill in the gaps, establish the continuity, and clarify the arguments that can only be glimpsed in the notes. When topics are evaluated for this series, the paramount concern in determining whether to proceed with the project is whether it effectively addresses the basic concepts of the topic. Each manuscript is reviewed at the initial state when the material is in the form of notes and then later at the final draft. Always, the text is evaluated to ensure that it presents sufficient theory to build a basic understanding and then uses this understanding to give the reader a practical working knowledge of the topic. References are included as an essential part of each text for the reader requiring more in-depth study.

One advantage of the Tutorial Texts series is our ability to cover new fields as they are developing. In fields such as sensor fusion, morphological image processing, and digital compression techniques, the textbooks on these topics were limited or unavailable. Since 1989 the Tutorial Texts have provided an introduction to those seeking to understand these and other equally exciting technologies. We have expanded the series beyond topics covered by the short course program to encompass contributions from experts in their field who can write with authority and clarity at an introductory level. The emphasis is always on the tutorial nature of the text. It is my hope that over the next five years there will be as many additional titles with the quality and breadth of the first five years.

Donald C. O'Shea
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PREFACE

The notes that were the basis for this tutorial text have been compiled over a period of about thirty years. During that time there have been many changes in the field of infrared technology. For the most part these changes have been incorporated in the basics, for basics are basic. I have had the privilege of investigating many different problems, either as an industrialist, in my former incarnation at the Honeywell Radiation Center (now Loral), as a teacher, and as a consultant. In the latter role I have worked for both the government as a critic and design reviewer as well as a creator.

Each of the design examples originated as a real problem. I have altered them to protect the innocent and to make the problems more interesting. This was done chiefly in the *Peacekeeper* and ICBM detector problems to make the choices among the options somewhat less obvious.

I have concentrated on the optics and detector aspects of infrared system design. Although the mechanical design of the structures is equally important, the techniques are those normally taught to the mechanical engineer and are not peculiar to infrared systems. A similar situation is true with respect to the electronics of the system.

I am indebted to those who first challenged me with these. I am also indebted to my past three employers—The University of Michigan, Honeywell, and The University of Arizona—for keeping me employed all those years. (Sometimes you can fool all of the people all of the time!)

I am also indebted to SPIE for the fine job they did in the publication. This is due mainly to Mary Kalbach Horan, the eloquent editor, Don O'Shea, the persistent and perspicacious Series editor, and George Zissis, the careful and consummate critic—and friend.

I wish to dedicate this book to my patient wife of over forty years, Mary Lou, who frequently asked, "And what are you doing in front of that computer today?"

My long-time friend Stan Ballard said, "It is nice to have written a book." He was right.

William L. Wolfe
Tucson, Arizona
1996

SYMBOLS & NOTATION

α	absorptivity
α	angle
β	absorption coefficient
β	resolution angle
γ	angle
Δf	bandwidth
ϵ	emissivity
η	quantum efficiency
η	efficiency
θ	pixel angle
Θ	field angle
λ	wavelength
ν	frequency
π	3.14159...
ρ	reflectivity
ρ	distance
σ	wave number
σ	Stephan Boltzmann constant
τ	transmissivity
τ	time constant
ϕ	pixel angle
ω	radian frequency
Ω	solid angle
Ω'	projected solid angle
A	area
B	bandwidth
c	speed of light
C	contrast
c_1	first radiation constant
c_2	second radiation constant
D	detectivity
D^*	specific detectivity
E	incidance (irradiance)
f	focal length
f	frequency
F	Focal point
F	optical speed
g	recombination factor
G	optical gain
GCF	geometric configuration factor
h	Planck's constant
i	image distance
k	radian frequency
K	proportionality constant
L	radiance
m	detector number
M	exitance (emittance)
M	modulation
MRTD	minimum resolvable temperature difference
n	refractive index
N	number
NA	numerical aperture
NEP	noise equivalent power
NETD	noise equivalent temperature difference
o	object distance
q	electronic charge
$\Re$	responsivity
R	range, distance
$R(\lambda)$	general radiometric quantity
SNR	signal-to-noise ratio
t	time
T	temperature
TDI	time delay and integration
Th	throughput
U	energy
V	voltage
x	dimensionless frequency
y	displacement
Z	throughput

SUPERSCRIPTS AND SUBSCRIPTS

$\Delta\lambda$	spectral band
1,2	first, second...
a	atmospheric
AA	astigmatism
b	bidirectional
BB	blackbody
CA	coma
d	detector
g	gap
h	horizontal
h	hemispherical
i	incident
m	detector number
m	maximum
max	maximum
ms	mean square
n	noise
o	optics
os	optics at source
q	photon
r	reflected
s	source, signal
SA	spherical
so	source at optics
t	transmitted
v	vertical, visible