



 **WILEY**

INFRARED SYSTEM ENGINEERING

Richard D. Hudson, Jr.

Wiley Series in Pure and Applied Optics • Bahaa E. A. Saleh, Series Editor

Contents

PART 1 THE ELEMENTS OF THE INFRARED SYSTEM

Chapter 1	Introduction to Infrared System Engineering	3
1.1	The Development of the Infrared Portion of the Spectrum	3
1.2	The Market for Infrared Devices	9
1.3	System Engineering	10
1.4	The System Engineer	13
1.5	The Infrared System and the Organization of This Book	14
1.6	The Literature of the Infrared	16
1.7	The Symbols and Abbreviations Used in This Book	17
Chapter 2	Infrared Radiation	20
2.1	The Electromagnetic Spectrum	20
2.2	Terminology Used in the Measurement of Radiant Energy	23
2.3	The Measurement of Radiant Flux	30
2.4	Thermal Radiation	33
	Thermal Radiation Laws	35
2.5	Emissivity and Kirchhoff's Law	39
2.6	Selective Radiators	46
	Absorption Spectra of Gases	47
	Absorption Spectra of Liquids and Solids	50
	Molecular Emission Spectra	50
2.7	Aids for Radiation Calculations	53
	Radiation Slide Rules	53
	Charts and Monographs	57
	Tables of Blackbody Functions	60
2.8	Other Blackbody Relationships	60
	Efficiency of Radiation Production	60
	Radiation Contrast	63

Chapter 3 Sources of Infrared Radiation	67
3.1 Blackbody-Type Sources	67
Theoretical Principles	68
Construction of a Blackbody-Type Source	72
3.2 Standards for Sources of Radiant Energy	78
3.3 General-Purpose Sources of Infrared	82
The Nernst Glower	82
The Globar	83
The Carbon Arc	83
The Tungsten Lamp	83
The Xenon Arc Lamp	84
The Laser	84
The Sun	84
3.4 Targets	85
The Turbojet Engine	85
The Turbofan Engine	89
The Boeing 707 Jet Transport	90
Afterburning	96
The Ramjet	98
The Rocket Engine	99
Aerodynamic Heating	100
Personnel	103
Surface Vehicles	103
Stars and Planets	104
3.5 Backgrounds	104
The Earth	106
The Sky	108
Outer Space	109
Stars and Planets	109
 Chapter 4 Transmission of Infrared Radiation Through the Earth's Atmosphere	 114
4.1 The Earth's Atmosphere	116
4.2 Water Vapor	119
4.3 Carbon Dioxide	126
4.4 Other Infrared-Absorbing Gases	127
4.5 Field Measurements of Atmospheric Transmission	129
4.6 Laboratory and Analytical Methods of Predicting Atmospheric Transmission	136
4.7 Tables of Atmospheric Transmission Data	142
4.8 Scattering Effects in the Atmosphere	159

4.9	Transmission Through Rain	163
4.10	Atmospheric Scintillation	165
Chapter 5	Optics	171
5.1	Refraction and Reflection	171
5.2	Describing an Optical System	175
5.3	Factors Affecting Image Quality	182
	Diffraction	183
	Aberrations	186
5.4	Typical Optical Systems for the Infrared	195
	Reflective Optics	195
	Refractive Optics	200
	Miscellaneous Considerations in the Choice of Optics	201
5.5	Auxiliary Optics	202
5.6	Methods of Generating Scan Patterns	206
5.7	Optical Materials for the Infrared	209
5.8	Antireflection Coatings	218
5.9	High-Reflection Coatings	220
5.10	Optical Filters	222
5.11	Collimators	224
Chapter 6	Optical Modulation	235
6.1	Optical Filtering for Background Discrimination	236
6.2	The Use of Reticles for Background Suppression	237
6.3	The Use of Reticles to Provide Directional Information	240
	Rotating Reticles	241
	Stationary Reticles	250
	Two-Color Reticles	254
6.4	Tracking Systems Without Reticles	255
6.5	Comments on Reticle Design	256
6.6	Fabrication of Reticles	258
Chapter 7	Introduction to Detectors	264
7.1	How the Performance of a Detector is Described	266
7.2	Thermal Detectors	271
	The Thermocouple	271
	The Thermopile	272
	The Bolometer	273
	The Pneumatic or Golay Detector	274
	The Calorimetric Detector	274
	Problems of Blackening Thermal Detectors	274
7.3	Photon or Quantum Detectors	275

The Photoelectric Detector	276
The Photoconductive Detector	278
The Photovoltaic or <i>p-n</i> Junction Detector	284
The Photoelectromagnetic Detector	286
Spectral Response of Photon Detectors	286
Fabrication of Photon Detectors	287
7.4 The Comparison of Detectors	287
7.5 Optically Immersed Detectors	289
7.6 Imaging Detectors	296
Infrared Film	296
The Image Converter	296
The Vidicon	297
The Photothermionic Image Converter	299
The Evaporograph	299
The Infrared-Sensitive Phosphor	299
Chapter 8 Noise	304
8.1 Types of Noise	305
Johnson or Thermal Noise	306
Shot Noise	308
Partition Noise	309
1/ <i>f</i> Noise	309
Generation-Recombination Noise	309
Radiation or Photon Noise	310
Temperature Noise	310
Summary — Noise in Detectors	310
8.2 Equivalent Noise Bandwidth	311
8.3 The Statistical Description of Noise	313
8.4 Meters for the Measurement of Noise	316
Peak-Responding Meter	317
Rms-Responding Meter	317
Average-Responding Meter	317
8.5 Noise Figure	318
Chapter 9 The Measurement of Detector Characteristics	321
9.1 Quantities To Be Measured	321
9.2 The Basic Detector Test Set	322
9.3 Use of the Basic Detector Test Set	330
Measurement of Detector Area	330
Determining the Operating Point of a Detector	330
Determining the Operating Point for a Detector that Requires Bias	334

Determining the Operating Point for a Self-Generating Detector	336
Calibrating the Amplification of the Test Set	337
Measurement of Frequency Response	339
Measurement of the Detector Noise Spectrum	339
Calculation of the Various Figures of Merit	340
9.4 The Measurement of Spectral Response	340
9.5 The Measurement of Time Constant	345
9.6 The Measurement of Detector Response Contours	346
Chapter 10 Modern Detectors and the Ultimate Limits on Their Performance	348
10.1 Background-Limited Photon Detectors	348
10.2 Limitations on the Performance of Thermal Detectors	357
10.3 Considerations in the Selection of a Detector	358
10.4 Engineering Data on Selected Detectors	363
Chapter 11 Techniques for Cooling Detectors	373
11.1 Packaging Cooled Detectors	374
11.2 Low-Temperature Coolants	376
11.3 Open-Cycle Refrigerators	377
Liquid-Transfer Refrigerators	377
Joule-Thomson Refrigerators	380
Solid-Refrigerant Coolers	384
Radiative-Transfer Coolers	385
Comparison of Typical Open-Cycle Refrigerators	386
11.4 Closed-Cycle Refrigerators	386
Joule-Thomson (Closed-Cycle) Refrigerators	387
Claude Refrigerators	388
Stirling Refrigerators	389
Refrigerators Using Other Refrigeration Cycles	390
Comparison of Typical Closed-Cycle Refrigerators	391
11.5 Solid-State Refrigerators	391
Thermoelectric Refrigerators	391
Thermomagnetic Refrigerators	394
11.6 Integrating the Detector and Refrigerator	394
Chapter 12 Signal Processing and Displays	398
12.1 General Considerations	399
12.2 Preamplifiers	400
Preamplifiers Using Vacuum Tubes	401
Preamplifiers Using Transistors	405

	Preamplifiers Using Microelectronics	405
12.3	Additional Considerations in Signal Processing	408
12.4	Multiple-Channel Systems	410
12.5	Displays	411
Chapter 13	The Analysis of Infrared Systems	417
13.1	The Generalized Range Equation	417
	Tradeoff Analysis	420
13.2	The Generalized Range Equation for a Background-Limited Detector	421
13.3	The Range Equation for Specific Types of Systems	423
	Search Systems	424
	Tracking Systems that Use Reticles	426
	Tracking Systems that Use Pulse Position Modulation	428
13.4	Line-Scan Thermal Mapping Systems	428
13.5	Radiometry	432
13.6	The Specification of System Performance	435
Chapter 14	The Design of an Infrared Search System	438
14.1	Preliminary Studies	438
14.2	System Synthesis and Analysis	441
14.3	Tradeoff Studies and Final System Design	447
 PART II THE APPLICATIONS OF INFRARED TECHNIQUES		
Chapter 15	An Introduction to the Applications of Infrared Techniques	455
15.1	The Applications of Infrared Techniques	458
15.2	Miscellaneous References	459
Chapter 16	Military Applications of Infrared Techniques	464
16.0	General	466
16.1	Search, Track, and Ranging Applications	469
	16.1.1 Search Systems	469
	16.1.2 Track Systems	475
	16.1.3 Search and Track Systems	477
	16.1.4 Weapon Guidance	479
	16.1.5 Navigation and Flight Control Systems	486
	16.1.6 Ranging Systems	489
16.2	Radiometric Applications	490
	16.2.1 Measurement of Flux	490

16.3	Spectroradiometric Applications	491
16.3.1	Target and Background Signatures	491
16.3.2	Miscellaneous	493
16.4	Thermal Imaging Applications	494
16.4.1	Reconnaissance	494
16.5	Applications Involving Reflected Flux	497
16.5.1	Applications of Image Converter Tubes	498
16.5.2	Infrared Photography	502
16.6	Applications Involving a Cooperative Source	502
16.6.1	Terrestrial Communications	503
16.6.2	Ranging	506
16.6.3	Infrared Countermeasures	507
16.6.4	Command Guidance	508
Chapter 17	Industrial Applications of Infrared Techniques	511
17.1	Search, Track, and Ranging Applications	511
17.1.1	Search Systems	512
17.2	Radiometric Applications	513
17.2.1	Measurement of Temperature	513
17.2.2	Position Sensing	522
17.3	Spectroradiometric Applications	523
17.3.1	Measurement of Temperature	523
17.3.2	Miscellaneous	524
17.4	Thermal Imaging Applications	527
17.4.1	Nondestructive Test and Inspection	528
17.5	Applications Involving Reflected Flux	531
17.5.1	Applications of Image Converter Tubes	531
17.5.2	Infrared Photography	532
17.5.3	Miscellaneous	532
17.6	Applications Involving a Cooperative Source	533
17.6.1	Intrusion Detection	533
17.6.2	Miscellaneous	534
Chapter 18	Medical Applications of Infrared Techniques	537
18.1	Search, Track, and Ranging Applications	538
18.1.1	Obstacle Detection (Passive)	538
18.2	Radiometric Applications	539
18.2.1	Measurement of Temperature	539
18.3	Spectroradiometric Applications	541
18.3.1	Miscellaneous	541
18.4	Thermal Imaging Applications	541
18.4.1	Diagnostic Assistance	542

18.5	Applications Involving Reflected Flux	547
18.5.1	Applications of Image Converter Tubes	547
18.5.2	Infrared Photography	548
18.5.3	Miscellaneous	549
18.6	Applications Involving a Cooperative Source	550
18.6.1	Obstacle Detection (Active)	550
Chapter 19	Scientific Applications of Infrared Techniques	551
19.1	Search, Track, and Ranging Applications	552
19.1.1	Search and Track Systems	553
19.1.2	Navigation and Flight Control Systems	554
19.2	Radiometric Applications	563
19.2.1	Measurement of Temperature	563
19.2.2	Measurement of Flux	575
19.2.3	World Weather Watch	579
19.3	Spectroradiometric Applications	581
19.3.1	Remote Sensing of the Earth and its Atmosphere	581
19.3.2	Remote Sensing of Astronomical Bodies	586
19.3.3	Instrumentation and Miscellaneous Applications	594
19.4	Thermal Imaging Applications	599
19.4.1	Earth Resource Surveys	599
19.4.2	Meteorological Applications	603
19.4.3	Lunar and Planetary Studies	605
19.4.4	Miscellaneous	606
19.5	Applications Involving Reflected Flux	607
19.5.1	Infrared Photography	607
19.5.2	Reflectance Properties of Materials	612
19.6	Applications Involving a Cooperative Source	613
19.6.1	Space Communications	613
19.6.2	Miscellaneous	614
Appendix 1	The Symbols and Abbreviations Used in This Book	615
a.	Simple English Letter Symbols	615
b.	Simple Greek Letter Symbols	617
c.	Special and Composite Symbols	617
d.	Selected Abbreviations	618
Appendix 2	Symbols and Nomenclature for Radiometry and Photometry	619
Appendix 3	Conversion Factors	623
Appendix 4	The Unpublished Literature of the Infrared	626
Index		631