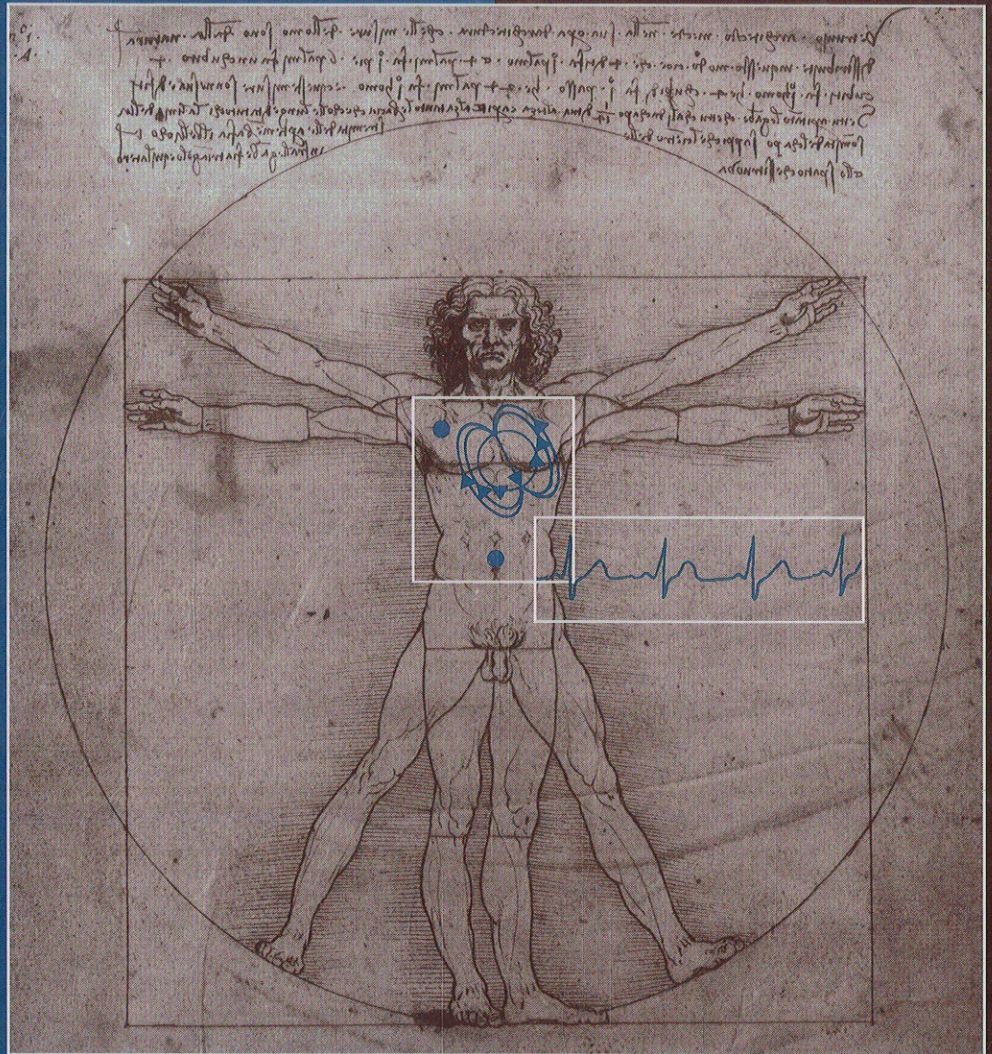


MEDICAL INSTRUMENTATION

Application and Design



John G. Webster, Editor

Fourth Edition

CONTENTS

Preface v

List of Symbols ix

1 BASIC CONCEPTS OF MEDICAL INSTRUMENTATION 1

Walter H. Olson

- 1.1 Terminology of Medicine and Medical Devices 4
- 1.2 Generalized Medical Instrumentation System 5
- 1.3 Alternative Operational Modes 7
- 1.4 Medical Measurement Constraints 9
- 1.5 Classifications of Biomedical Instruments 12
- 1.6 Interfering and Modifying Inputs 12
- 1.7 Compensation Techniques 13
- 1.8 Biostatistics 16
- 1.9 Generalized Static Characteristics 19
- 1.10 Generalized Dynamic Characteristics 25
- 1.11 Design Criteria 35
- 1.12 Commercial Medical Instrumentation Development Process 37
- 1.13 Regulation of Medical Devices 39
 - Problems 42
 - References 43

2 BASIC SENSORS AND PRINCIPLES 45

Robert A. Peura and John G. Webster

- 2.1 Displacement Measurements 45
- 2.2 Resistive Sensors 46
- 2.3 Bridge Circuits 53
- 2.4 Inductive Sensors 53
- 2.5 Capacitive Sensors 56
- 2.6 Piezoelectric Sensors 58
- 2.7 Temperature Measurements 62
- 2.8 Thermocouples 63

2.9	Thermistors	66
2.10	Radiation Thermometry	69
2.11	Fiber-Optic Temperature Sensors	74
2.12	Optical Measurements	74
2.13	Radiation Sources	75
2.14	Geometrical and Fiber Optics	79
2.15	Optical Filters	82
2.16	Radiation Sensors	83
2.17	Optical Combinations	86
	Problems	87
	References	88

3

AMPLIFIERS AND SIGNAL PROCESSING

91

John G. Webster

3.1	Ideal Op Amps	91
3.2	Inverting Amplifiers	93
3.3	Noninverting Amplifiers	96
3.4	Differential Amplifiers	97
3.5	Comparators	100
3.6	Rectifiers	102
3.7	Logarithmic Amplifiers	103
3.8	Integrators	104
3.9	Differentiators	107
3.10	Active Filters	108
3.11	Frequency Response	110
3.12	Offset Voltage	112
3.13	Bias Current	114
3.14	Input and Output Resistance	115
3.15	Phase-Sensitive Demodulators	117
3.16	Timers	120
3.17	Microcomputers in Medical Instrumentation	122
	Problems	123
	References	125

4

THE ORIGIN OF BIOPOTENTIALS

126

John W. Clark, Jr.

4.1	Electrical Activity of Excitable Cells	126
4.2	Volume-Conductor Fields	135
4.3	Functional Organization of the Peripheral Nervous System	138
4.4	The Electroneurogram	140

- 4.5 The Electromyogram 144
- 4.6 The Electrocardiogram 147
- 4.7 The Electroretinogram 158
- 4.8 The Electroencephalogram 163
- 4.9 The Magnetoencephalogram 181
- Problems 182
- References 186

5 BIOPOTENTIAL ELECTRODES 189

Michael R. Neuman

- 5.1 The Electrode–Electrolyte Interface 189
- 5.2 Polarization 192
- 5.3 Polarizable and Nonpolarizable Electrodes 196
- 5.4 Electrode Behavior and Circuit Models 202
- 5.5 The Electrode—Skin Interface and Motion Artifact 205
- 5.6 Body-Surface Recording Electrodes 209
- 5.7 Internal Electrodes 215
- 5.8 Electrode Arrays 220
- 5.9 Microelectrodes 222
- 5.10 Electrodes for Electric Stimulation of Tissue 231
- 5.11 Practical Hints in Using Electrodes 233
- Problems 235
- References 239

6 BIOPOTENTIAL AMPLIFIERS 241

Michael R. Neuman

- 6.1 Basic Requirements 241
- 6.2 The Electrocardiograph 243
- 6.3 Problems Frequently Encountered 254
- 6.4 Transient Protection 264
- 6.5 Common-Mode and Other Interference-Reduction
Circuits 266
- 6.6 Amplifiers for Other Biopotential Signals 269
- 6.7 Example of a Biopotential Preamplifier 274
- 6.8 Other Biopotential Signal Processors 275
- 6.9 Cardiac Monitors 282
- 6.10 Biotelemetry 287
- Problems 288
- References 291

7

BLOOD PRESSURE AND SOUND

293

Robert A. Peura

- 7.1 Direct Measurements 295
- 7.2 Harmonic Analysis of Blood-Pressure Waveforms 300
- 7.3 Dynamic Properties of Pressure-Measurement Systems 301
- 7.4 Measurement of System Response 308
- 7.5 Effects of System Parameters on Response 310
- 7.6 Bandwidth Requirements for Measuring Blood Pressure 311
- 7.7 Typical Pressure-Waveform Distortion 311
- 7.8 Systems for Measuring Venous Pressure 313
- 7.9 Heart Sounds 314
- 7.10 Phonocardiography 318
- 7.11 Cardiac Catheterization 318
- 7.12 Effects of Potential and Kinetic Energy on Pressure Measurements 323
- 7.13 Indirect Measurements of Blood Pressure 325
- 7.14 Tonometry 330
 - Problems 335
 - References 336

8

MEASUREMENT OF FLOW AND VOLUME OF BLOOD

338

John G. Webster

- 8.1 Indicator-Dilution Method That Uses Continuous Infusion 338
- 8.2 Indicator-Dilution Method That Uses Rapid Injection 341
- 8.3 Electromagnetic Flowmeters 344
- 8.4 Ultrasonic Flowmeters 350
- 8.5 Thermal-Convection Velocity Sensors 361
- 8.6 Chamber Plethysmography 364
- 8.7 Electrical-Impedance Plethysmography 366
- 8.8 Photoplethysmography 372
 - Problems 374
 - References 375

9 MEASUREMENTS OF THE RESPIRATORY SYSTEM

377

Frank P. Primiano, Jr.

- 9.1 Modeling the Respiratory System 378
- 9.2 Measurement of Pressure 385
- 9.3 Measurement of Gas-Flow 388
- 9.4 Lung Volume 396
- 9.5 Respiratory Plethysmography 404
- 9.6 Some Tests of Respiratory Mechanics 411
- 9.7 Measurement of Gas Concentration 425
- 9.8 Some Tests of Gas Transport 436
 - Problems 443
 - References 446

10 CHEMICAL BIOSENSORS

449

Robert A. Peura

- 10.1 Blood-Gas and Acid-Base Physiology 451
- 10.2 Electrochemical Sensors 453
- 10.3 Chemical Fibrosensors 461
- 10.4 Ion-Selective Field-Effect Transistor 475
- 10.5 Immunologically Sensitive Field-Effect Transistor 478
- 10.6 Noninvasive Blood-Gas Monitoring 479
- 10.7 Blood-Glucose Sensors 486
- 10.8 Electronic Noses 492
- 10.9 Lab-on-a-Chip 493
- 10.10 Summary 494
 - Problems 495
 - References 495

11 CLINICAL LABORATORY INSTRUMENTATION

498

Lawrence A. Wheeler

- 11.1 Spectrophotometry 499
- 11.2 Automated Chemical Analyzers 508
- 11.3 Chromatology 512
- 11.4 Electrophoresis 515

- 11.5 Hematology 517
- Problems 526
- References 527

12 MEDICAL IMAGING SYSTEMS

528

Melvin P. Siedband

- 12.1 Information Content of an Image 528
- 12.2 Modulation Transfer Function 535
- 12.3 Noise-Equivalent Bandwidth 536
- 12.4 Television Systems 537
- 12.5 Radiography 540
- 12.6 Computed Radiography 549
- 12.7 Computed Tomography 553
- 12.8 Magnetic Resonance Imaging 561
- 12.9 Nuclear Medicine 566
- 12.10 Single-Photon Emission Computed
Tomography 572
- 12.11 Positron Emission Tomography 573
- 12.12 Ultrasonography 576
- 12.13 Contrast Agents 585
- Problems 587
- References 589

13 THERAPEUTIC AND PROSTHETIC DEVICES

590

Michael R. Neuman

- 13.1 Cardiac Pacemakers and Other Electric
Stimulators 590
- 13.2 Defibrillators and Cardioverters 606
- 13.3 Mechanical Cardiovascular Orthotic
and Prosthetic Devices 611
- 13.4 Hemodialysis 615
- 13.5 Lithotripsy 618
- 13.6 Ventilators 619
- 13.7 Infant Incubators 622
- 13.8 Drug Delivery Devices 624
- 13.9 Surgical Instruments 629
- 13.10 Therapeutic Applications of the Laser 632
- Problems 633
- References 635

14 ELECTRICAL SAFETY

638

Walter H. Olson

- 14.1** Physiological Effects of Electricity 639
- 14.2** Important Susceptibility Parameters 641
- 14.3** Distribution of Electric Power 646
- 14.4** Macroshock Hazards 650
- 14.5** Microshock Hazards 653
- 14.6** Electrical-Safety Codes and Standards 658
- 14.7** Basic Approaches to Protection Against Shock 659
- 14.8** Protection: Power Distribution 660
- 14.9** Protection: Equipment Design 663
- 14.10** Electrical-Safety Analyzers 667
- 14.11** Testing the Electric System 667
- 14.12** Tests of Electric Appliances 669
 - Conclusion 673
 - Problems 673
 - References 674

APPENDIX

676

-
- A.1** Physical Constants 676
 - A.2** International System of Units (SI) Prefixes
(Thompson and Taylor, 2008) 676
 - A.3** International System of Units
(Thompson and Taylor, 2008) 677
 - A.4** Abbreviations 678
 - A.5** Chemical Elements 681

INDEX

683
