

## CONTENTS

### Preface

### I. GENERAL INFORMATION FROM CLASSICAL ELECTRODYNAMICS

#### Chapter 1

|  |    |
|--|----|
| BASIC MATHEMATICAL RELATIONSHIPS OF ELECTRODYNAMICS .....                                      | 3  |
| 1.1. Maxwell Equations and Electrodynamic Potentials .....                                     | 3  |
| 1.2. Solutions of Maxwell Equations for Isotropic Homogeneous Medium and Harmonic Fields ..... | 9  |
| 1.3. Reduced Equations for Electrodynamics of Stationary Currents .....                        | 13 |
| 1.4. Solutions of Electrodynamic Equations for Simple Structures of Medium .....               | 17 |

#### Chapter 2

|  |    |
|--|----|
| INTEGRAL EQUATIONS OF ELECTRODYNAMICS IN ELECTROCARDIOLOGICAL PROBLEMS ..... | 29 |
| 2.1. Lead Field in Bioelectric and Biomagnetic Measurements .....            | 29 |
| 2.2. Equivalent Electric Generator and Equivalent Medium .....               | 33 |
| 2.3. Integral Equations for Isotropic, Piecewise-Homogeneous Medium .....    | 36 |

#### Chapter 3

|  |    |
|--|----|
| MULTIPOLE EXPANSION AND MULTIPOLE EQUIVALENT GENERATOR .....   | 45 |
| 3.1. Multipole Expansion of Electric Potential .....   | 45 |
| 3.2. Inherent Coordinate System of Generator .....   | 57 |
| 3.3. Multipole Expansion of Scalar Magnetic Potential .....  | 60 |
| 3.4. Determination of Multipoles Based on Expanding Vector Potential in Series of Spherical Functions .....                          | 67 |
| 3.5. Determination of Multipoles Based on Expanding Vector Potential in Taylor Series .....  | 72 |
| 3.6. Calculation of Multipole Components from Experimental Measurements .....  | 76 |
| Appendix A. Expressions for Legendre Polynomials, Associated Legendre Functions, and Surface Spherical Functions of Low Orders ..... | 80 |
| Appendix B. Expressions for Evaluating Multipole Components in Transformed Coordinates .....   | 82 |

### II. ELECTRODYNAMIC ASPECTS OF MATHEMATICAL MODELING IN ELECTROCARDIOLOGY

#### Chapter 4

|   |    |
|---|----|
| MATHEMATICAL DESCRIPTION OF MYOCARDIAL ELECTRIC AND MAGNETIC FIELDS ON CELL AND TISSUE LEVELS ..... | 87 |
| 4.1. Heart Excitation Cycle and Transmembrane Potential of Myocardial Cells .....                   | 87 |
| 4.2. Equivalent Generators for Excitable Cell with Arbitrary Shape .....                            | 89 |
| 4.3. Equivalent Generators for Cylindrical Excitable Cell .....                                     | 94 |

|  |     |
|--|-----|
| <b>Chapter 5</b>   |     |
| MATHEMATICAL DESCRIPTION OF MYOCARDIAL ELECTRIC AND MAGNETIC FIELDS ON WHOLE HEART LEVEL .....   | 111 |
| 5.1. Forward and Inverse Electrodynamic Problems in<br>Electrocardiology; Noninvasive Identification of Bioelectric Generator .....    | 111 |
| 5.2. Examples of Mathematical Description of Heart Equivalent Electric Generator Using Multipole Components .....                      | 114 |
| <b>Chapter 6</b>   |     |
| INFLUENCE OF PHYSICAL MEDIUM STRUCTURE ON SOLUTION OF ELECTROCARDIOLOGICAL PROBLEMS .....  | 131 |
| 6.1. Methodological Approaches to Evaluation of Physical Medium Effects .....  | 131 |
| 6.2. Model of Anisotropic Homogeneous Myocardium .....   | 132 |
| 6.3. Closed Front of Depolarization in Anisotropic Myocardium .....  | 148 |
| 6.4. Model of Anisotropic Region of Myocardium with Plane Boundary .....   | 154 |
| 6.5. Homogeneous Spherical Model of Heart and Chest .....  | 163 |
| 6.6. Homogeneous Model of Chest with Realistic Shape .....   | 168 |
| 6.7. Heterogeneous Multilayer Spherical Model of Heart and Chest .....   | 171 |
| <b>III. TOPOGRAPHIC CONCEPTS OF INTERPRETING ELECTRIC AND MAGNETIC MEASUREMENTS IN NONINVASIVE ELECTROCARDIOLOGY</b>                   |     |
| <b>Chapter 7</b>   |     |
| BODY SURFACE MAPPING OF ELECTRIC AND MAGNETIC FIELDS OF HEART .....  | 189 |
| 7.1. Informational Contents and Spatial Approximation of Electric and Magnetic Fields of Heart .....                                   | 189 |
| 7.2. Principles of Lead Setup for Body Surface Mapping .....   | 205 |
| 7.3. Diagnostic Interpretation of Body Surface Distributions of Electric Potential and Magnetic Induction (Empirical Approaches) ..... | 221 |
| <b>Chapter 8</b>   |     |
| NONINVASIVE MAPPING OF CHARACTERISTICS OF HEART ELECTRIC STATE .....   | 245 |
| 8.1. Noninvasive Mapping of Epicardial Electric Potential .....  | 245 |
| 8.2. Isochrone Mapping of Ventricular Depolarization Based on Double-Layer Cardiogenerator Model on Myocardial Surface .....           | 252 |
| 8.3. Mapping of Ventricular Excitation Characteristics on Quasiepicardium Based on Thin-Wall Model of Heart .....                      | 256 |
| 8.4. Simplified Mapping of Ventricular Excitation Characteristics, Using Heart Vector .....  | 262 |
| 8.5. Mapping of Currents Aroused by Cardiogenerator, Using Magnetic Field Measurements .....   | 264 |
| <b>Chapter 9</b>   |     |
| NONINVASIVE LOCATION OF ELECTROPHYSIOLOGICAL HEART PHENOMENA BY MEANS OF DIPOLE MODELS OF CARDIOGENERATOR .....                        | 269 |
| 9.1. Types of Dipole Models of Cardiogenerator .....   | 269 |

|  |     |
|--|-----|
| 9.2. Multiple-Dipole Models with Restricted Localizations and Dipole<br>Moments of Constituent Dipoles ..... | 270 |
| 9.3. Single-Dipole Model without Restrictions.....   | 275 |
| 9.4. Two-Dipole Model without Restrictions.....  | 284 |
| 9.5. Dipole Models Identified from Magnetic Field Measurements .....   | 286 |
| IV. CONCLUSION.....  | 295 |
| V. REFERENCES .....  | 301 |
| VI. INDEX.....   | 325 |