

# Contents

|          |                                                                          |           |
|----------|--------------------------------------------------------------------------|-----------|
| <b>1</b> | <b>Introduction</b>                                                      | <b>1</b>  |
| 1.1      | General Principles of Microphone Arrays                                  | 1         |
| 1.2      | The Paradigm for the Design and Implementation of<br>Differential Arrays | 9         |
| 1.3      | Organization of the Book                                                 | 10        |
|          | References                                                               | 11        |
| <b>2</b> | <b>Problem Formulation</b>                                               | <b>15</b> |
| 2.1      | Signal Model                                                             | 15        |
| 2.2      | Beampattern                                                              | 17        |
| 2.3      | Gain in Signal-to-Noise Ratio (SNR)                                      | 24        |
| 2.4      | Vandermonde Matrix                                                       | 28        |
|          | References                                                               | 30        |
| <b>3</b> | <b>Study and Design of First-Order Differential Arrays</b>               | <b>33</b> |
| 3.1      | Principle                                                                | 33        |
| 3.2      | First-Order Dipole                                                       | 34        |
| 3.3      | First-Order Cardioid                                                     | 40        |
| 3.4      | General First-Order Differential Array                                   | 45        |
| 3.5      | Steering                                                                 | 55        |
|          | References                                                               | 58        |
| <b>4</b> | <b>Study and Design of Second-Order Differential Arrays</b>              | <b>59</b> |
| 4.1      | Principle                                                                | 59        |
| 4.2      | Second-Order Dipole                                                      | 60        |
| 4.3      | Second-Order Cardioid, Hypercardioid, Supercardioid, and<br>Quadrupole   | 65        |
| 4.4      | Design of Another Well-Known Second-Order Cardioid                       | 85        |
| 4.5      | Steering                                                                 | 93        |
|          | References                                                               | 93        |

5 Study and Design of Third-Order Differential Arrays with Three Distinct Nulls ..... 95

5.1 Principle ..... 95

5.2 Differential Arrays with Three Distinct Nulls..... 96

5.3 Generalization ..... 111

References ..... 113

6 Minimum-Norm Solution for Robust Differential Arrays .. 115

6.1 Adaptive Beamforming versus Differential Arrays ..... 115

6.2 Minimum-Norm Filter ..... 118

6.3 Design Examples ..... 119

6.3.1 First-Order Cardioid..... 119

6.3.2 Second-Order Cardioid..... 126

6.3.3 Third-Order Cardioid ..... 132

6.3.4 Third-Order DMA..... 138

References ..... 144

7 Study and Design of Differential Arrays with the MacLaurin’s Series Approximation ..... 145

7.1 Principle ..... 145

7.2 First-Order Differential Arrays ..... 146

7.3 Second-Order Differential Arrays ..... 149

7.4 Third-Order Differential Arrays ..... 164

7.5 Adaptive Beamforming versus Differential Arrays..... 178

References ..... 179

Index ..... 181