

**JOHN WATKINSON**

# AN INTRODUCTION TO **DIGITAL AUDIO**

**Featuring:**

- Digital audio broadcasting
- DVD audio
- Networked audio
- MPEG audio compression

**SECOND EDITION**



# Contents

|                                            |           |
|--------------------------------------------|-----------|
| <i>Preface to the second edition</i>       | xi        |
| <b>Chapter 1 Introducing digital audio</b> | <b>1</b>  |
| 1.1 Audio as data                          | 1         |
| 1.2 What is an audio signal?               | 3         |
| 1.3 Why binary?                            | 5         |
| 1.4 Why digital?                           | 9         |
| 1.5 Some digital audio processes outlined  | 9         |
| 1.6 Time compression and expansion         | 11        |
| 1.7 Error correction and concealment       | 14        |
| 1.8 Channel coding                         | 18        |
| 1.9 Audio compression                      | 18        |
| 1.10 Disk-based recording                  | 19        |
| 1.11 Rotary-head digital recorders         | 21        |
| 1.12 Digital audio broadcasting            | 21        |
| 1.13 Networks                              | 22        |
| Reference                                  | 22        |
| <b>Chapter 2 Some audio principles</b>     | <b>23</b> |
| 2.1 The physics of sound                   | 23        |
| 2.2 Wavelength                             | 24        |
| 2.3 Periodic and aperiodic signals         | 25        |
| 2.4 Sound and the ear                      | 26        |
| 2.5 The cochlea                            | 28        |
| 2.6 Mental processes                       | 29        |
| 2.7 Level and loudness                     | 31        |
| 2.8 Frequency discrimination               | 33        |
| 2.9 Frequency response and linearity       | 36        |
| 2.10 The sine wave                         | 37        |
| 2.11 Root mean square measurements         | 39        |
| 2.12 The deciBel                           | 41        |
| 2.13 Audio level metering                  | 45        |
| References                                 | 46        |

|                  |                                     |            |
|------------------|-------------------------------------|------------|
| <b>Chapter 3</b> | <b>Digital principles</b>           | <b>47</b>  |
| 3.1              | Binary codes                        | 47         |
| 3.2              | Introduction to digital logic       | 52         |
| 3.3              | The computer                        | 58         |
| 3.4              | Timebase correction                 | 60         |
| 3.5              | Multiplexing                        | 62         |
| 3.6              | Gain control                        | 63         |
| 3.7              | Digital faders and controls         | 64         |
| 3.8              | A digital mixer                     | 68         |
| 3.9              | Filters                             | 71         |
| 3.10             | FIR filters                         | 74         |
| 3.11             | Sampling-rate conversion            | 77         |
| 3.12             | Transforms and duality              | 81         |
| 3.13             | The Fourier transform               | 83         |
| 3.14             | The discrete cosine transform (DCT) | 85         |
| 3.15             | Modulo- $n$ arithmetic              | 86         |
| 3.16             | The Galois field                    | 87         |
| 3.17             | The phase-locked loop               | 89         |
|                  | References                          | 90         |
| <br>             |                                     |            |
| <b>Chapter 4</b> | <b>Conversion</b>                   | <b>92</b>  |
| 4.1              | Introduction to conversion          | 92         |
| 4.2              | Sampling and aliasing               | 94         |
| 4.3              | Reconstruction                      | 98         |
| 4.4              | Filter design                       | 99         |
| 4.5              | Choice of sampling rate             | 101        |
| 4.6              | Sample and hold                     | 103        |
| 4.7              | Sampling clock jitter               | 105        |
| 4.8              | Aperture effect                     | 108        |
| 4.9              | Quantizing                          | 109        |
| 4.10             | Quantizing error                    | 112        |
| 4.11             | Basic digital-to-analog conversion  | 122        |
| 4.12             | Basic analog-to-digital conversion  | 129        |
| 4.13             | Alternative convertors              | 134        |
| 4.14             | Oversampling                        | 138        |
| 4.15             | Oversampling without noise shaping  | 143        |
| 4.16             | Noise shaping                       | 144        |
| 4.17             | Noise-shaping ADCs                  | 148        |
| 4.18             | A one-bit DAC                       | 151        |
| 4.19             | One-bit noise-shaping ADCs          | 153        |
|                  | References                          | 155        |
| <br>             |                                     |            |
| <b>Chapter 5</b> | <b>Compression</b>                  | <b>157</b> |
| 5.1              | Introduction                        | 157        |
| 5.2              | Lossless and perceptive coding      | 159        |
| 5.3              | Compression principles              | 160        |
| 5.4              | Codec level calibration             | 164        |

|      |                         |     |
|------|-------------------------|-----|
| 5.5  | Quality measurement     | 165 |
| 5.6  | The limits              | 166 |
| 5.7  | Some guidelines         | 167 |
| 5.8  | Audio compression tools | 168 |
| 5.9  | Sub-band coding         | 172 |
| 5.10 | Transform coding        | 175 |
| 5.11 | Compression formats     | 176 |
| 5.12 | MPEG Layer I            | 177 |
| 5.13 | MPEG Layer II           | 181 |
| 5.14 | MPEG Layer III          | 183 |
| 5.15 | MPEG-2 AAC              | 185 |
|      | References              | 191 |

## **Chapter 6 Digital coding principles 193**

|      |                                                                |     |
|------|----------------------------------------------------------------|-----|
| 6.1  | Introduction                                                   | 193 |
| 6.2  | Types of transmission channel                                  | 194 |
| 6.3  | Transmission lines                                             | 195 |
| 6.4  | Types of recording medium                                      | 197 |
| 6.5  | Magnetic recording                                             | 197 |
| 6.6  | Azimuth recording and rotary heads                             | 203 |
| 6.7  | Optical and magneto-optical disks                              | 204 |
| 6.8  | Equalization and data separation                               | 206 |
| 6.9  | Slicing and jitter rejection                                   | 208 |
| 6.10 | Channel coding                                                 | 213 |
| 6.11 | Simple codes                                                   | 215 |
| 6.12 | Group codes                                                    | 218 |
| 6.13 | Randomizing and encryption                                     | 220 |
| 6.14 | Synchronizing                                                  | 221 |
| 6.15 | Basic error correction                                         | 222 |
| 6.16 | Concealment by interpolation                                   | 225 |
| 6.17 | Parity                                                         | 225 |
| 6.18 | Block and convolutional codes                                  | 228 |
| 6.19 | Cyclic codes                                                   | 230 |
| 6.20 | Introduction to the Reed–Solomon codes                         | 235 |
| 6.21 | Correction by erasure                                          | 243 |
| 6.22 | Interleaving                                                   | 244 |
| 6.23 | Product codes                                                  | 245 |
|      | Appendix 6.1 Calculation of Reed–Solomon generator polynomials | 247 |
|      | References                                                     | 249 |

## **Chapter 7 Transmission 250**

|     |                                              |     |
|-----|----------------------------------------------|-----|
| 7.1 | Introduction                                 | 250 |
| 7.2 | The AES/EBU interface                        | 250 |
| 7.3 | Channel status                               | 255 |
| 7.4 | User bits                                    | 259 |
| 7.5 | MADI – Multi-channel audio digital interface | 259 |
| 7.6 | Fibre-optic interfacing                      | 263 |

|      |                                          |     |
|------|------------------------------------------|-----|
| 7.7  | Synchronizing                            | 263 |
| 7.8  | Asynchronous operation                   | 265 |
| 7.9  | Routing and networks                     | 266 |
| 7.10 | Networks                                 | 268 |
| 7.11 | FireWire                                 | 274 |
| 7.12 | Broadband networks and ATM               | 276 |
| 7.13 | Introduction to NICAM 728                | 282 |
| 7.14 | Audio in digital television broadcasting | 287 |
| 7.15 | Packets and time stamps                  | 289 |
| 7.16 | MPEG transport streams                   | 290 |
| 7.17 | Clock references                         | 291 |
| 7.18 | Program Specific Information (PSI)       | 292 |
| 7.19 | Introduction to DAB                      | 294 |
|      | References                               | 297 |

## **Chapter 8 Digital audio tape recorders 299**

|      |                                     |     |
|------|-------------------------------------|-----|
| 8.1  | Rotary versus stationary heads      | 299 |
| 8.2  | PCM adaptors                        | 299 |
| 8.3  | Introduction to DAT                 | 300 |
| 8.4  | DAT specification                   | 306 |
| 8.5  | DAT block diagram                   | 307 |
| 8.6  | Track following in DAT              | 309 |
| 8.7  | DAT data channel                    | 311 |
| 8.8  | Multi-channel rotary-head recorders | 314 |
| 8.9  | Stationary-head recorders           | 316 |
| 8.10 | DASH format                         | 318 |
| 8.11 | DCC – Digital Compact Cassette      | 320 |
|      | References                          | 324 |

## **Chapter 9 Magnetic disk drives 325**

|      |                                  |     |
|------|----------------------------------|-----|
| 9.1  | Types of disk drive              | 325 |
| 9.2  | Structure of disk                | 327 |
| 9.3  | Principle of flying head         | 327 |
| 9.4  | Reading and writing              | 328 |
| 9.5  | Moving the heads                 | 331 |
| 9.6  | Rotation                         | 333 |
| 9.7  | Servo-surface disks              | 333 |
| 9.8  | Soft sectoring                   | 333 |
| 9.9  | Winchester technology            | 334 |
| 9.10 | Rotary positioners               | 335 |
| 9.11 | The disk controller              | 337 |
| 9.12 | Defect handling                  | 339 |
| 9.13 | Digital audio disk system        | 342 |
| 9.14 | Arranging the audio data on disk | 343 |
| 9.15 | Spooling files                   | 344 |
| 9.16 | Broadcast applications           | 344 |
| 9.17 | Sampling rate and playing time   | 345 |
|      | References                       | 345 |

|                   |                                        |            |
|-------------------|----------------------------------------|------------|
| <b>Chapter 10</b> | <b>Digital audio editing</b>           | <b>347</b> |
| 10.1              | Introduction                           | 347        |
| 10.2              | Editing with random access media       | 347        |
| 10.3              | Editing on recording media             | 348        |
| 10.4              | The structure of an editor             | 349        |
| 10.5              | Timecode                               | 350        |
| 10.6              | Locating the edit point                | 350        |
| 10.7              | Editing with disk drives               | 354        |
| 10.8              | Editing in DAT                         | 356        |
| 10.9              | Editing in open-reel digital recorders | 357        |
| 10.10             | Jump editing                           | 357        |
|                   | References                             | 360        |
| <br>              |                                        |            |
| <b>Chapter 11</b> | <b>Optical disks in digital audio</b>  | <b>361</b> |
| 11.1              | Types of optical disk                  | 361        |
| 11.2              | CD and MD contrasted                   | 364        |
| 11.3              | CD and MD – disk construction          | 365        |
| 11.4              | Rejecting surface contamination        | 366        |
| 11.5              | Playing optical disks                  | 369        |
| 11.6              | Focus and tracking systems             | 372        |
| 11.7              | Typical pickups                        | 376        |
| 11.8              | CD readout in detail                   | 379        |
| 11.9              | How optical disks are made             | 383        |
| 11.10             | How recordable MiniDiscs are made      | 385        |
| 11.11             | Channel code of CD and MiniDisc        | 386        |
| 11.12             | Error-correction strategy              | 393        |
| 11.13             | Track layout of MD                     | 397        |
| 11.14             | Player structure                       | 398        |
|                   | References                             | 405        |
| <br>              |                                        |            |
|                   | <i>Glossary</i>                        | 406        |
|                   | <i>Index</i>                           | 409        |