Sound Reproduction

The Acoustics and Psychoacoustics of Loudspeakers and Rooms

Floyd E. Toole
<table>
<thead>
<tr>
<th>Content</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3.3 Measuring the Lack of Diffusion in SmallRooms</td>
<td>60</td>
</tr>
<tr>
<td>4.3.4 What is a “Small” Room?</td>
<td>62</td>
</tr>
<tr>
<td>4.3.5 Conventional ACOUSTICAL Measures in SmallListening Rooms</td>
<td>63</td>
</tr>
<tr>
<td>5 The Many Effects of Reflections</td>
<td>67</td>
</tr>
<tr>
<td>6 Reflections, Images, and the Precedence Effect</td>
<td>73</td>
</tr>
<tr>
<td>6.1 Audible Effects of a Single Reflection</td>
<td>77</td>
</tr>
<tr>
<td>6.1.1 Effects of a Single Reflection</td>
<td>79</td>
</tr>
<tr>
<td>6.1.2 Another View of the Precedence Effect</td>
<td>79</td>
</tr>
<tr>
<td>6.1.3 Reflections from Different Directions</td>
<td>80</td>
</tr>
<tr>
<td>6.2 A Reflection in the Presence of Other Reflections</td>
<td>82</td>
</tr>
<tr>
<td>6.2.1 Real Versus Simulated Rooms</td>
<td>84</td>
</tr>
<tr>
<td>6.2.2 The “Family” of Thresholds</td>
<td>85</td>
</tr>
<tr>
<td>6.3 A Comparison of Real and Phantom Images</td>
<td>85</td>
</tr>
<tr>
<td>6.4 Experimental Results with Music and Other Sounds</td>
<td>86</td>
</tr>
<tr>
<td>6.4.1 Threshold Curve Shapes for Different Sounds</td>
<td>88</td>
</tr>
<tr>
<td>6.5 Single Versus Multiple Reflections</td>
<td>89</td>
</tr>
<tr>
<td>6.6 Measuring Reflections</td>
<td>91</td>
</tr>
<tr>
<td>7 Impressions of Space</td>
<td>95</td>
</tr>
<tr>
<td>7.1 The Terminology of Spatial Perception</td>
<td>98</td>
</tr>
<tr>
<td>7.2 Listeners and Their “Preference” for Reflections</td>
<td>99</td>
</tr>
<tr>
<td>7.3 Some Reflections Are Better Than Others</td>
<td>102</td>
</tr>
<tr>
<td>7.4 Summarizing and Charting the Way Forward</td>
<td>109</td>
</tr>
<tr>
<td>8 Imaging and Spatial Effects in Sound Reproduction</td>
<td>113</td>
</tr>
<tr>
<td>8.1 First-Order Reflections</td>
<td>113</td>
</tr>
<tr>
<td>8.1.1 Some Thoughts about Loudspeaker Arrangements</td>
<td>119</td>
</tr>
<tr>
<td>8.1.2 Delayed Reflections and Reflections of Those Reflections</td>
<td>125</td>
</tr>
<tr>
<td>8.2 ASW/image Broadening and Loudspeaker Directivity on Imaging and Space</td>
<td>126</td>
</tr>
<tr>
<td>8.2.1 Testing the Effects of Loudspeaker Directivity on Imaging and Space</td>
<td>128</td>
</tr>
<tr>
<td>8.2.2 The Audible Effects of Loudspeaker Dispersion on Imaging and Space</td>
<td>128</td>
</tr>
<tr>
<td>8.2.3 Other Opinions</td>
<td>138</td>
</tr>
<tr>
<td>9 The Effects of Reflections on Sound Quality/Timbre</td>
<td>141</td>
</tr>
<tr>
<td>9.1 The Audibility of Acoustical Interference-Comb Filtering</td>
<td>142</td>
</tr>
<tr>
<td>9.1.1 Very Audible Differences from Similar-Looking Combs</td>
<td>146</td>
</tr>
<tr>
<td>9.1.2 Binaural Hearing, Adaptation, and Comb Filtering</td>
<td>149</td>
</tr>
<tr>
<td>9.1.3 An Important One-Toothed Comb—A Fundamental Flaw in Stereo</td>
<td>151</td>
</tr>
<tr>
<td>9.2 Effects of Reflections on Timbre—The Audibility of Resonances</td>
<td>155</td>
</tr>
<tr>
<td>9.2.1 What Do We Hear—Spectral Bump or Temporal Ringing?</td>
<td>157</td>
</tr>
<tr>
<td>9.2.2 Where Do We Find Timbral Identity?</td>
<td>159</td>
</tr>
<tr>
<td>10 Reflections and Speech Intelligibility</td>
<td>161</td>
</tr>
<tr>
<td>10.1 Disturbance of Speech by a Single Reflection</td>
<td>161</td>
</tr>
<tr>
<td>10.2 The Effect of a Single Reflection on Intelligibility</td>
<td>161</td>
</tr>
<tr>
<td>10.3 Multiple Reflections, Noise, and Speech Intelligibility</td>
<td>162</td>
</tr>
<tr>
<td>10.4 The Effects of “Other” Sounds—Signal-to-Noise Ratio</td>
<td>163</td>
</tr>
<tr>
<td>10.5 Listening Difficulty—A New and Relevant Measure</td>
<td>167</td>
</tr>
<tr>
<td>10.6 A Real Center Loudspeaker Versus a Phantom Center</td>
<td>168</td>
</tr>
<tr>
<td>10.7 A Portable Speech-Reproduction Test</td>
<td>168</td>
</tr>
<tr>
<td>11 Adaptation</td>
<td>171</td>
</tr>
<tr>
<td>11.1 Angular Localization—The Precedence Effect</td>
<td>172</td>
</tr>
<tr>
<td>11.2 Perceptions of Distance</td>
<td>174</td>
</tr>
<tr>
<td>11.3 Sound Quality—Timbre</td>
<td>175</td>
</tr>
<tr>
<td>11.3.1 A Massive Test with Some Thought-Provoking Results</td>
<td>177</td>
</tr>
<tr>
<td>11.3.2 A Multichannel Test—And Something Is Learned</td>
<td>179</td>
</tr>
<tr>
<td>11.4 Summary</td>
<td>180</td>
</tr>
<tr>
<td>12 Adjacent-Boundary and Loudspeaker Mounting Effects</td>
<td>183</td>
</tr>
<tr>
<td>12.1 Solid Angles and the Radiation of Sound</td>
<td>183</td>
</tr>
<tr>
<td>12.1.1 Correcting for Adjacent-Boundary Effects</td>
<td>187</td>
</tr>
<tr>
<td>12.2 Loudspeaker Mounting Options</td>
<td>188</td>
</tr>
<tr>
<td>12.3 “Boundary-Friendly” Loudspeaker Designs</td>
<td>194</td>
</tr>
<tr>
<td>13 Making (Bass) Waves—Below the Transition Frequency</td>
<td>197</td>
</tr>
<tr>
<td>13.1 The Basics of Resonances</td>
<td>198</td>
</tr>
<tr>
<td>13.2 The Basics: Room Modes and Standing Waves</td>
<td>201</td>
</tr>
<tr>
<td>13.2.1 Optimizing Room Shape and Dimensions</td>
<td>203</td>
</tr>
<tr>
<td>13.2.2 Standing Waves in Real Rooms</td>
<td>208</td>
</tr>
<tr>
<td>13.2.3 Loudspeaker and Listener Positions, Different Rooms, and Manipulating Modes</td>
<td>213</td>
</tr>
<tr>
<td>13.3 Delivering Good Bass in Small Rooms</td>
<td>216</td>
</tr>
<tr>
<td>13.3.1 Reducing the Energy in Room Modes</td>
<td>217</td>
</tr>
<tr>
<td>13.3.2 Controlling the Energy Delivered from Loudspeakers to Room Modes</td>
<td>220</td>
</tr>
</tbody>
</table>
Part Two: Designing Listening Experiences

15 Multichannel Options for Music and Movies ........................................ 271
   15.1 A Few Definitions ....................................................... 271
   15.2 The Birth of Multichannel Audio .................................... 273
   15.3 Stereo—An Important Beginning .................................... 276
   15.4 Quadraphonics—Stereo Times Two .................................. 278
   15.5 Multichannel Audio—Cinema to the Rescue! ..................... 280
   15.6 Multichannel Audio Comes Home .................................. 281
   15.6.1 THX Embellishments ............................................. 282
   15.7 Multichannel Audio—The Ambisonics Alternative ............... 285
   15.8 Upmixer Manipulations: Creative and Entrepreneurial Instincts at Work ............................................................... 287
   15.8.1 The Fosgate 6-Axis Algorithm .................................. 287
   15.8.2 The Harman/Lexicon Logic 7 Algorithm ...................... 288
   15.8.3 “Surround-Sound” Upmixing ................................. 288
   15.9 Multichannel Audio Goes Digital and Discrete .................. 290
   15.9.1 Comments on Codecs ............................................ 290
   15.10 Finding the Optimum Channel/Loudspeaker Arrangement ....... 292
       15.10.1 Scientific Investigations Look at the Options ............. 292
       15.10.2 Optimizing the Delivery of Envelopment .................. 294
| 13.3.3 | Step One: General Recommendations for Rectangular Rooms | 222 |
| 13.3.4 | Step Two: Digging Deeper for Clarification | 223 |
| 13.3.5 | Step Three: Optimizing Room Dimensions for Various Subwoofer Configurations | 228 |
| 13.3.6 | Step Four: Electronically Managing the Sound Field | 230 |
| 13.3.7 | Getting Good Bass in Small Rooms | 236 |
| 13.3.8 | Stereo Bass: Little A Go about Even Less | 238 |
| 13.4 | Looking at Time and Frequency Domains | 239 |
| 13.4.1 | “Natural” Acoustical Equalization Versus Electronic Equalization | 240 |
| 13.4.2 | Another Room, Another Problem—A Very Different Solution | 243 |
| 13.5 | Time and Frequency Domain—Measurement Resolution | 245 |
| 13.5.1 | Practical Resolution Issues—How Some Reputations Get Tarnished | 247 |
| 14 | Summary of Part One: Looking for a Way Forward | 249 |

**Part Two: Designing Listening Experiences**

| 15 | Multichannel Options for Music and Movies | 271 |
| 15.1 | A Few Definitions | 271 |
| 15.2 | The Birth of Multichannel Audio | 273 |
| 15.3 | Stereo—An Important Beginning | 276 |
| 15.4 | Quasaphonics—Stereo Times Two | 278 |
| 15.5 | Multichannel Audio—Cinema to the Rescue | 280 |
| 15.6 | Multichannel Audio Comes Home | 281 |
| 15.6.1 | THX Embellishments | 282 |
| 15.7 | Multichannel Audio—The Ambisonics Alternative | 285 |
| 15.8 | Upmixer Manipulations: Creative and Entrepreneurial Instincts at Work | 287 |
| 15.8.1 | The Fogate 6-Axis Algorithm | 287 |
| 15.8.2 | The Harman/Lexicon Logic 7 Algorithm | 288 |
| 15.8.3 | “Surround-Sound” Upmixing | 288 |
| 15.9 | Multichannel Audio Goes Digital and Discrete | 290 |
| 15.9.1 | Comments on Codecs | 291 |
| 15.10 | Finding the Optimum Channel/Loudspeaker Arrangement | 292 |
| 15.10.1 | Scientific Investigations Look at the Options | 294 |
| 15.10.2 | Optimizing the Delivery of Envelopment | 294 |
| 15.10.3 | Summary | 298 |
| 15.11 | Recommendations | 300 |
| 15.11.1 | The ITU Perspectives | 302 |
| 15.11.2 | Other Perspectives | 303 |
| 15.12 | Assigning the Channels and the Center-Rear Option | 305 |
| 16 | Putting Theory Into Practice: Designing a Listening Experience | 307 |
| 16.1 | The Room | 308 |
| 16.2 | Basic Video | 312 |
| 16.2.1 | The Cinema Reference | 312 |
| 16.2.2 | Transferring the Video Experience to Homes | 314 |
| 16.3 | Merging Audio and Video | 316 |
| 16.4 | Directivity Requirements for the Loudspeakers | 321 |
| 16.4.1 | Delivery of the Direct Sounds: Localization | 321 |
| 16.4.2 | L, C, R First Lateral Reflections | 322 |
| 16.4.3 | The Surround Loudspeakers—Horizontal Dispersion Requirements | 325 |
| 16.4.4 | Outside the Sweet Spot: The Effect of Propagation Loss | 328 |
| 16.5 | A Summary of Loudspeakers and the Acoustical Treatments in Rooms | 333 |
| 16.5.1 | LF, CF, and RF Loudspeakers | 333 |
| 16.5.2 | The Surround Loudspeakers | 335 |
| 16.5.3 | Propagation Loss | 336 |

| 17 | Loudspeakers I: Subjective Evaluations | 337 |
| 17.1 | The Genesis of a Life’s Work | 339 |
| 17.2 | Subjective Measurements of Loudspeakers—Turning Opinion Into Fact | 344 |
| 17.3 | Controlling the Experimental Variables | 346 |
| 17.3.1 | Controlling the Physical Variables | 346 |
| 17.3.2 | Controlling the Psychological Variables | 349 |
| 17.3.3 | Controlling the Experimental Variables | 352 |
| 17.4 | Hearing Performance in Listening Tests | 353 |
| 17.5 | Bias from Nonauditory Factors | 357 |
| 17.6 | Subjective Evaluations of Direction and Space—And More | 362 |
| 17.7 | Creating a Listening Environment for Loudspeaker Evaluations | 362 |

| 18 | Loudspeakers II: Objective Evaluations | 365 |
| 18.1 | Two Simple Source Configurations | 366 |
| 18.1.1 | Point Sources: Spherical Spreading, Near- and Far-Field Designations | 366 |
18.1.2 Line Sources: Cylindrical Spreading ........................................... 368
18.2 Measuring the Essential Properties of Loudspeakers ...................... 372
  18.2.1 What Do We Need to Know? .................................................. 373
  18.2.2 Improved Data Gathering and Processing ............................... 376
  18.2.3 Interpreting the Data: Exercises in Detection ......................... 380
  18.2.4 The Relationship Between Anechoic Data and Room Curves ......... 383
  18.2.5 Sound-Absorbing Materials and Sound-Scattering Devices .......... 383
  18.2.6 The “X” Curve—The Standard of the Motion Picture Industry ...... 385
  18.2.7 Trouble in Paradise—The Pros Must Set an Example ................ 389
18.3 Comparing the Subjective and Objective Domains ............................. 390
  18.3.1 Measurements ....................................................................... 390
  18.3.2 A Contemporary Test ............................................................ 393
18.4 The Real World of Consumer Loudspeakers ...................................... 395
  18.4.1 Examples of Freestanding L, C, R Loudspeakers ....................... 396
  18.4.2 Horizontal Center-Channel Loudspeakers ................................ 399
  18.4.3 Multidirectional Surround Loudspeakers ................................ 399
  18.4.4 The Perfect Surround Loudspeaker? ....................................... 407
  18.4.5 Equalizing the Surround Channels ......................................... 409
18.5 Examples of Professional Monitor Loudspeakers ................................ 410
  18.5.1 Professional-Audio Loudspeaker Performance Objectives ......... 415
18.6 Other Measurements: Meaningful and Mysterious ............................ 418
  18.6.1 Phase Response—Frequencies Above the Transition Zone .......... 418
  18.6.2 Phase Response—The Low Bass ............................................. 420
  18.6.3 The Loudspeaker/Amplifier Interface: Impedance, Wire, and Damping Factor ................................................................. 421
  18.6.4 Observations on Sensitivity Ratings and Power Amplifiers .......... 425
  18.6.5 To Be Continued .................................................................... 427
19 Psychoacoustics—Explaining What We Measure and Hear .................... 429
  19.1 Loudness and the Basics of Hearing ........................................... 429
    19.1.1 Equal-Loudness Contours and Loudness Compensation .......... 432
    19.1.2 Equal-Loudness Contours and Deteriorated Hearing .............. 434
    19.1.3 Loudness as a Function of Angle ........................................ 437
22.5.2 Surround Loudspeakers ............................................. 514
22.5.3 Localizing the Surround Loudspeakers,
   Envelopment, and Propagation Loss ......................... 515
22.5.4 In-Wall, In-Ceiling Options ................................. 516
22.6 Level and Time Adjustments and Equalization .......... 516
  22.6.1 Level and Time .................................................. 516
  22.6.2 Equalization ...................................................... 517
22.7 In Conclusion .......................................................... 519

REFERENCES ......................................................................................... 523
INDEX .................................................................................................... 541
Index

Page references followed by "f" denote figures; those followed by "t" denote tables

A
• Absolute loudness, 347-348
  * absorbers
    - low frequency active, 220
    - mechanically resonant, diaphragmatic, 219, 476
    - acoustically resonant, Helmholtz, 220, 477
  - resistive, historical origins, 17, fibrous and foam materials, 217, 219, 476-477
    - random incidence absorption coefficients, 482f
    - directional absorption coefficients, 483
    - thickness requirements, 494

• Absorption, 472-473, 476-477
  - absorbers, audience, concert, 44f, 84, 474, 479, 484, 493
carpets, 476f
- defined and discussed, 472-476
- diffusers with and without fabric cover, 509
drapes, 478f
- fiberglass (and mineral wool and foam slab)
  - random incidence, 482f
  - random incidence with air space behind, 482f
  - as a function of incident angle, 453f
  - seats, 479f
  - walls, 490f
  - AC-5, 290

• Acoustical crosstalk, subwoofers/satellite, 417, 500
  - cancellations, 120-121, 139, 158

• Acoustical crosstalk cancellation, 272, 277

• Acoustical damping, low frequency, 225

• Acoustical equalization vs. electronic equalization, 240-242

• Acoustical interference, audibility of comb filtering, 142-154
  - description of, 54, 143f, 261, 403
  - in dipole surround loudspeakers, 405-406, 514-515
  - timbre changes caused by, 141-142

• Acoustically "transparent" projection screens, 490-492

• Amplifiers, power
  - constant voltage source, 421
  - loudspeaker interface with, 421-425
  - and loudspeaker sensitivity ratings, 425-426
  - solid-state, 415
  - tube, 425

• Amplitude-panning in surround systems, 279

• Analog tape recorder, phase shift in, 420

• Anecdoic chambers
  - low-frequency calibration of, 387
  - absorbers used in, 485
  - measurement setup in, 377f

• Anecdoic loudspeaker measurements, 377-380

• Angles
  - loudness and, 457
  - solid, 453-454

• Angular dispersion requirements, 321, 334-335

• Angular localization, 171-174

• Apparent source width
  - center channel potential for, 123
  - definition of, 84, 50, 51f, 69, 99, 113, 258
early spatial impression, 97
generation of, 79, 88, 96-99, 120
interspersal cross-correlation and, 104f, 106f, 204
Klippel experiments, 458
A weighting, 347f-348
Acoustic Research AR-3, 340, 341f
live vs. reproduced demonstrations, 14
ASC Tube Trap, 219
ASHRAE, 441
Association model of hearing, 38
ASW, see Apparent source width
Audio
high-resolution, 442-444
multichannel, see Multichannel audio
professional audio, 19-24, 415-418
video merged with, 314-331
Audio industry standards, 19-20, 415-418
Auditory filter bandwidths, 145-146, 450-451
Auditory reflex, 437-439
Aural architects, 15, 34
Auratone 5C, 22f, 411-412, 413f
A weighting, 347f-348
B Background noise, 163, 439-441
Backboard masking, 437
Balanced noise criterion, 440f
Bass
amplitude equalization of, 240-245
importance of in subjective ratings, 197, 462-464
phase response in low bass, 420-423
pitch-shifting in, 244-245
loudness growth of 43f
phase equalization of, 420 resonances in small rooms, 201-216
controller resonance in small rooms, 197, 216-239
rectangular rooms, subwoofer arrangements in 232-238, 509-511f
stereo, 238-239
summary of, 266-267
Bass efficiency matrices, 225
Bass management, 277
Bass-relief ports, 454-455
"Bass traps," 237, 476-477
Benade paradox, 67, 68f, 95, 429, 430, 467
Bass in subjective judgments 857-862
Bidirectional in-phase loudspeakers, 120, 195, 399-407, 404f, 500f, 541-515
Bidirectional surround loudspeakers, see Bidirectional in-phase, and Bidirectional out-of-phase loudspeakers.
Binaural (right/left) interactions, 173, see also Binaural hearing
Binaural
definition, 271-272
discrimination, 80-81, 435-436
crosstalk cancellation, 272, 277
hearing, 149-151
mechanism, 176
recordings, 178, 273-274 (defined)
room scanning, 179
Bipole, see Bidirectional in-phase loudspeakers
Blind listening tests, 349-352
Blind versus sighted listening tests, 357-382
Blumlein-EMI patent, 273
Bolt "blob," 205, 207f
Bookshelf loudspeakers, mounting of, 159-190f
Breaking-in, of loudspeakers, 353
of listeners to new formats, 7
Broadband noise, 150
B weighting, 347f-348
C Car audio Noise in, 440f
surround in, 289
Carpet, 477, 507
Ceiling, acoustical treatment, 506-507
Center channel loudspeaker, 120-123, 155, 259, 262, 323, 399, 400-401f
Acoustical perspective of, 475f
Center-star loudspeaker, 305, 502
Central spectrum, 150
Channel(s)
see Channel numbering, 399
Channel separation in stereo bass, 549
Cinema
audio system calibration, X-curve
audio systems in, 313f
aural architecture applied to, 24
horizontal viewing angles in, 312
multichannel audio and, 273, 280-281, 293f
picture reproduction in, 313f
seam-dip effect in, 49-50f
Circle of confusion, 18-19, 19f, 23
Classical music
room acoustics and, 30-31
sound reproduction effects on, 9
Classrooms
description of, 41
speech intelligibility in, 48-49
Close-miked vocals, 168, 445-446
Codes, 291-299
Comb filter, comb filtering
availability of, 145-151
calculations, 144
definition of, 142-143f
description of, 69, 82, 88, 109, 127, 263, 503
Compromise localizations, 409
Concert halls
absorption coefficients, 441
acoustical measurements in, 27-28f, 43-51
fan-shaped, 32
future trends in design of, 33
"he-f," 33
historical, 32, 40
listening room vs., 296-30
modern trends, 32
orchestra size matched with, 51
rectangular-shaped (shoebox), 32
room acoustic in, 27, 52
size of, 30-31, 40
sound fields in
absorption, 44, 44f
critical distance, 46
diffuse fields, see Diffuse sound fields
ray acoustics, 43
reflections, 50-51
reverberation, 43-45
seat-dip effect, 49-50f
summary of, 253-254
Diffuse sound fields
see Ray acoustics, 43
Next page
Index

Fractional-octave bandwidth analyzers, 247-248f
Frequency-dependent interaural cross-correlation, 297
Frequency response
anechoic measurements of loudspeakers, 377f-379
audibility of variations in, 446-451
description of, 372-373
steady-state vs. transient state in rooms, 240-246f
Frequency shifting of room modes, 423-424f
Frequency-weighting curves, 347f, 347-348
Full space, 184
Fusion zone, fusion interval, 73, 79-80f

Glass fiber, 471, 476, 482
“Great debate” issues in subjective audio, 345
Group delay, 420
Gypsum board, 479-480

Haas effect, 73-76, see also, Precedence effect
Haas equal-loudness experiment, 302
Haas fusion zone, 76, see also fusion zone, fusion interval
Harman International
data-gathering system at, 277-278
Harman/Lexicon logic 7 algorithm, 288
Harmonic distortion, 452
HDTV, 314
Headphone reproduction, 273-274, 273-274
Head-related transfer functions, 37-38, 81, 437
Head-shadowing effect, 153
Hearing
association model of, 38
audible frequency range for, 440f, 441-443
boundaries of, 440f, 441-443
equal-loudness contours and, 454-457
hierarchical levels of, 24-25
influence in listening tests, 355-357
loss, damage to, 166-167, 353-357, 430-431f, 434-437
occupational-induced loss of, 430-431f
thresholds, 438f, 438f, 441
Heisenberg’s uncertainty principle, 345
Helmholtz absorbers, 220, 477
Helmholtz resonances, 198
“Hi-fi concert halls,” 33
High fidelity, 14, 141
High-Q resonances, 198
as a correlate of preference, 104f
description of, 32, 105, 106f, 317
generated by multiple loudspeakers, 295f, 296f
envelopment and, 294-295, 317
frequency-dependent, 297
in a listening room, 117f, 317
summary of, 258-259
Interaural intensity differences, 196
Interaural time differences, 102
in a listening room, 117f, 317
summary of, 258-259
Interaural intensity differences, 102
Interaural time differences, 102
Intermodulation distortions, 452
inverse-square law, definition, 366
its effect on envelopment, 317, 330f
In-wall loudspeakers, 513, 516
Isotropic sound field, 61
In-fill loudspeakers, 516
ITU-R BS.775-2 recommendation, 301

J
Jazz
early recordings of, 8
sound reproduction effects on, 193-194
JBL Professional, 389, 411

K
KEF Concert, 340-341f
KEF 105.2, 130f
KEMAR mannequin, 153
Klippel experiments, 457-461

L
Lateral fraction method, 102-105
Lateral reflections see first-order reflections
Lateral diffusivity, 461
Late reflections, 378, 378
Law of the first wavefront, 73
see also, Precedence effect
Legendre contour, 372
In-head localization, 135
...
Limp-mass diaphragmatic absorber, 219

Line sources
Applications, 329-333, 502, 515-516
cylindrical spreading, 368-372
description of, 369f
propagation characteristics, 329-333
truncated lines, 331-332

Listeners
hearing ability of, 351, 435-437
judgment ability or aptitude of, 350-351
nonauditory factors that affect, 357-362
Listening difficulty vs. speech intelligibility, 167-168
Listening rooms.
See also Rooms,
Room acoustics
acoustical materials in, 479-481, 505-508, 506f
acoustical measurements in, 63-65
bass in small rooms, 216-238
background noise, criteria for evaluating, 439-441
calculating the modes, 203-205f
definition of a small room, 62-63
designing a floor plan, 316-321, 499-502
"ideal room" concepts, 203-208, 500
lack of diffusion in, 60-62, 113-115f
nonrectangular, 204, 206f
prime listening location, 318, 328
rectangular, subwoofer arrangements in, 222-238, 509-511£
reverberation time, 64-65, 309-310f
room modes and standing waves, 201-216
sound fields in, 53-65, 474-475f
sound field management in, 230-236
standing waves in, 201-216
subwoofer arrangements in, 216-238
sweet spot, see prime listening location, above.
T-bar ceiling in, 226
transition frequency, 54-59, 59f

Logic 7 algorithm, 288
Loudness
of common sounds, 431
compensation, 432-434
effect of direction, 107f, 437, 438f
as a factor in listening tests, 346-348
as a function of hearing loss, 434-435f
equal-loudness contours, 432-437
single-number measurements of, 346-347
summing of multiple reflections, 90-91, 90f
Loudspeaker(s)
acoustic center of, 191-192f
adjacent-boundary effects, 188-188
single-number measurements of, 346-347

bifidirectional in phase, 136, 195, 509-407, 404, 503,
514-515
bidirectional out-of-phase, 127, 285, 327, 331, 399-407,
404, 406, 514-515
bookshelf, mounting options
188-194
"boundary-friendly" designs of, 194-196
"breaking in," 353
center channel, real vs. phantom images, 120-121f, 123, 151-154,
and first lateral reflections, 333,
horizontal center designs, 399,
398-401f, view of listening room, 475f
reflections from room boundaries, 119-126,
center-rear, 303, 502
central-room monitor, 20-24,
196, 411-418
dipole (true)
description and directivity pattern, 127f
coupling response, 130, 341f
dipole surround, see bifidirectional
out-of-phase measurements of, 321-327, 334, 503f
energy coupling to room modes, 230-231
far-field, 366, 367f
flush-mounted placement of, 194-195, 513
free-standing, 194, 294-399, 500
frequency response, early school theories of thought, 342-343
guidelines for choosing, 346-347
summing of multiple reflections, 90-91, 90f
Loudspeaker(s)
aural center of, 191-192f
adjacent-boundary effects, 188-188
single-number measurements of, 346-347

INDEX 545
Index

Page dimensions: 1190.0x841.0

creation of, 120
description of, 38, 119
sound quality of, 151-152

[Image 0x0 to 1190x841]
interpreted as noise (historical), need for reverberation in recordings, 102 a requirement for live performance and recording, 35-37 speech intelligibility affected by, 48 summary of, 233-255 Reverberation chambers, 61, 474 Reverberation distance, 448-449, 452 Reverberation radius, See Critical distance Reverberation time calculation of, 44-45 description of, 18, 508-509 in listening rooms, 63, 311, 508-509 measurement of in small rooms, 63-64 effects of adding furnishings to empty room, 310f in concert halls and opera houses, 49 optimum for piano in small room, 102 optimum for a listening room, 508-509 reflection-decay time and, 509 speech intelligibility affected by, 48, 509 Revised low-frequency B (RLB) curve, 347 Room(s). See also Listening rooms acoustics of large, 43-51 acoustics of offices and industrial spaces, 51-53 acoustic scattering and control rooms, 53-65 Room acoustics see also Rooms, Listening rooms classical music affected by, 30 historical investigations, 33-40 perceptual effects enhanced by, 68 religious services and, 30 Room correction, 180 Room correction criteria (RC Mark II), 441 Room curves anechoic data and, 375f, 383-384f description of, 186, 374 equalization of, 383, 517-519 house curves (large venue), 386 high-frequency roll-off, 386 X-curves for cinemas, 387-388f Measurement resolution, 55f, 248f predicting from anechoic data, 375f, 384f-385 transition frequency revealed by, 55f, 59f Room modes attenuation of, 237 calculation and display of, 203-205 damping with low-frequency absorbers, 217-220, 510 defined and described, 56, 199, 201-204-206 energy reduction in, 217-220 global equalization and, 223 manipulating the amplitude of, 220-223 minimum phase behavior, 200 standing waves definition of, 200 description of, 54, 57 effects of loudspeakers and listener locations, 255, 212f formation of, 201, 202f in real rooms, 208-213 Sound field management (SFM), 48, 509 "Roughness," 450 RPG Diffusor, 489, 508 S Sabine formula, 45, 508 Sahins, 45, 508 Samuel Goldwyn Theater, 312-313, 318f Scattering, See Diffusors, Diffusion Schroeder crossover frequency, 55f, 57-58f Schroeder diffuser, 488-489, 490f Schroeder frequency, 55f, 57-58f Seat-dip effect, 49-50, 50f, 253 Seats, 208-209, 517 absorption coefficients, 479f Sensitivity ratings of loudspeakers, 425-426 78 rpm record, 8 Share HTS, 281, 283, 331 Side walls Acoustical treatment of, 505-506f-508 reflections from, See First-order reflections Signal-to-noise ratio, 164-165 in listening tests, 347-348 in listening rooms, 439-440f-441 in cars, 440f Single reflections, See Reflections Single-stimulus method, 352 Small listening rooms, see Listening rooms definition of, 62-63 Spacial reverb., 54-55-56 Solid angles description of, 183-185 factor-of-two reduction of, 185 reduced by mounting of loudspeakers, 188-193 Solid-state amplifiers, 423 "Sonic Hologram," 277 Sound, See also All other topics in the index definition of, as perceptual event, 4 as physical event, 4 some basic dimensions of, 431f sound-absorbing materials, 471-486 Sound field management (SFM), 380, 432 Sound fields, See Concert halls, First-order reflections, Listening rooms, Reflections, Reverberation, Room modes in the acoustical spaces of interest, 39-40f-41f Sound-intensity vectors, 386 Sound power measurement in loudspeakers, 377-379 definition of, 379 Sound-pressure levels of common sounds, 431f Sound quality exaggerated claims regarding, 7, 13-15 culture intertwined with technology, 12, 337-338 separating the program from the technology, 12 personal taste, 337-338
interpreted as noise (historical), need for reverberation in recordings, 102 a requirement for live performance and recording, 18-31 speech intelligibility affected by, 48 summary of, 235-255 Reverberation chambers, 61, 474 Reverberation distance, see Critical distance Reverberation radius, see Critical distance Reverberation time calculation of, 44-45 description of, 18, 508-509 in listening rooms, 63, 311, 508-509 measurement of in small rooms, 63-64 effects of adding furnishings to empty room, 310 in concert halls and opera houses, 49 optimum for a listening room, 508-509 reflection-decay time and, 309 speech intelligibility affected by, 48, 509 Revised low-frequency B (RLB) curve, 477 Room(s). See also Listening rooms acoustics of large, 43-51 acoustics of offices and control rooms, 51-53 acoustics of listening and control rooms, 53-55 Room acoustic, see also Rooms, 53-56 classical music affected by, 30 historical investigations, 39-40 perceptual effects enhanced by, 65 religious services and, 30 Room correction, 180 Room correction curves (RC Mark II), 441 Room curves stochastic data and, 375a 383-384f description of, 186, 574 equalization of, 583, 517-519 house curves (large venue), 586 high-directivity loudspeakers, 586 X-curves for cinema, 387-388 Measurement resolution, 55, 248f predictions from psychoacoustic data, 375f, 248f-248f transition frequency revealed by, 55, 548, 591 Room modes attenuation of, 237 calculation and display of, 203-205 damping with low-frequency absorbers, 217-220, 510 defined and described, 56, 199, 201-204-208 energy reduction in, 217-220 global equalization and, 228 manipulating the amplitude of, 220-228 minimum phase behavior, 200 standing waves definition of, 200 description of, 54, 57 effects of loudspeaker and listener locations, 55, 212f formation of, 201, 202f in real rooms, 208-209 + Room resonances. See Room modes "Roughness," 450 RPQ Modulator, 489, 508 Sabine formula, 45, 508 Sabins, 45, 508 Samuel Goldwyn Theater, 312-313, 313f Scattering, see Diffusers, Diffusion Schroeder crossover frequency, 54-55f Schroeder diffuser, 488-489, 490f Schroeder frequency, 55, 57-58f Schroeder dip, effect of, 49-50, 50, 253 Sears, 308-309, 517 Schroeder, 488-489, 490f Schroeder frequency, 55, 57-58f sensitivity ratings of loudspeakers, 432-426 78 rpm record Shure HTS, 281, 283, 311 Side walls Acoustical treatment of, 505-506f speech intelligibility determined in large part by a non-standardized industry, 17-19 summary of, 260-263 Sound reproduction definition, 9-5 defining characteristics of, 29f, 32-33 live versus reproduced comparison, 138-144 modifies the music itself, 8-9 listener preferences in loudspeakers, 391-395, 457-460 the importance of space in, 15-16 optimizing the delivery of envelopment, 298-299 taking liberties with the ideal, 5-8 summary of, 245-251 Sound-scattering devices, see Diffusers, Diffusion Soundstage illusions, described, 110 Sound transmission class (STC), 473 Space, see Spaciotemporal perceptions of, 329, 458 subjective evaluations of, 362 Spaciotemporal apparent source width. See Apparent source width, image broadening. Early spatial impression definitions of, 50-51, 95-99, 204f, 205f, 206f, 208f, 209f, 210f, 248f-248f, 355-356, 457-458f, 459-460f listeners especially sensitive to, 319, 117, 173 listener preference, and 99-105, 457-461 loudspeaker directivity effects on, 128-138 recording technique effects on, 126 summary of, 252, 257-261 Spatial-effect balloon, 106f, 116, 203, 327 Spatial impression, see Spaciotemporal Spectral compensation, 151, see also Spectral Compensation Spectral scission, 150, 175-176, 262 Spectral tilt, audibility of, 444 Speech intelligibility description of, 48-49, 69, 503 reduced in stereo pianos, 154, 168 multiple reflections effect on, 162-163 reflections effect on, 69, 161-163 reverberation time and, 48, 509 signal-to-noise ratio effects on, 163-167 single reflections effect on, 161-162 summary of, 263-264 versus listening difficulty, 167-168 Speech-reproduction test, 168-169 Spherical spreading, 366-368, 367f Standards, 19-20, 251 a wish list for, 415-418 Standing waves, see Room modes Steady-state sound field, in concert halls, 44, 45f, in small rooms, 60f Stereo capabilties of, 275 s a fundamental flaw in, 151-155 as a factor in listening tests, 133f, 439, 437f, 466-466, 469f, 470f history of, 18, 272-278 loudspeaker directivity and, 120-129 potential for creating envelopment, 225-203 seat, 377 Spatial opportunities, 288-289f Stereo bass, 238-239f Subjective measurements, 344-362, 362f See also Loudspeaker evaluations Subwoofers, see also Bass, Room 377f modes Solutions for rectangular rooms, 233-238, 509-511 solutions for non-rectangular rooms, 230-236 multiple subs manipulate modes, 220-221f equalization algorithms for, 237 optimal arrangements and rooms, 509-511f Summing localization, 74-75f Surround illusions, described, 110-111 Surround loudspeakers arrangements of, 172, 302 Dolby, 304 Too many brightness, 304 summary recommendations, 500f, 501 equalization of, 449-450 horizontal dispersion requirements, 325-328, 328f illusions that they must create, 327, 496-497, 505 localization of, 515 multidirectional, biferential, in-phase biferential out-of-phase, 127, 283, 327, 331, 399-407, 404f, 406f, 514-515 oppositional reflections, 124f, 536, 504-505 problems with propagation loss, 328-333 selection of, 514-515 Surround processor, 273 "Surround-sound" upmixing, 84-86f Sweetering the mix, 196 T Tammy, monitor gold, 341 T-bar ceiling, 282f, 285, 305, 351, 401f Thin bas, 197, 239, 420f Timbral identity, 159-160 Timber acoustical interference effects on, 142-143 association with direction, 38 audibility of resonances, 445-446f definition of, 141 description of, 36 information in onet transients, 159-160 reflections effect on, 69, 141-143 repetition effects on, 143 resonances have a dominant effect on, 155 summary of, 261-265
Timbre matching of loudspeakers in a surround system, 38, 283–284, 409–410

Time and frequency domains, 239–248

Timissin, 436

"Tone tests", Edison 13–14

Transition frequency, 54–60, 594, 144, 518

Tube amplifiers, 425

U

Up-converter, See Upmixer

Upholstered seating, 478–479

Upmixer, 23, 273, 287–289–290f, 301, 305

Upwards conversion, See Upmixer

UREI 811B, 23f

V

Velocity, particle, 202, 219

Velour drapes, absorption of, 477–478

Ventriloquism effect, 113, 172, 294, 318, 497

Video, factors in room layout, 315–321

Violin, directivity of, 35

W

Walls, acoustical treatment of, 505–508

Wharfedale

Live vs. reproduced demonstrations, 14

W-90, 341

Waterfall diagrams, of comb filters, 146–147–149

of room resonances, 239–248

Waveform fidelity, 37, 418–420


Wire resistance, 423f

X

"X" curve, 385–389, 465

Y

Yamaha NS-10M, 411–412, 413f