

Sound Reproduction

The Acoustics and Psychoacoustics
of Loudspeakers and Rooms

Floyd E. Toole



AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Focal Press is an imprint of Elsevier



Contents

INTRODUCTION	xiii
ACKNOWLEDGMENTS AND DEDICATION	xix

Part One: Understanding the Principles

1	Sound Reproduction	3
1.1	A Philosophical Perspective	5
1.2	Recordings and the Music Being Recorded	8
2	Preserving the Art	11
2.1	Back to the Beginning: Capturing Sound Quality	13
2.2	Back to the Beginning: Direction and Space	15
2.3	A Circle of Confusion.....	18
2.4	Breaking the Circle: Professionals Hold the Key	19
2.5	Measuring the Ability to Reproduce the Art.....	24
3	Sound in Rooms—Matters of Perspective	27
3.1	Live Musical Performances	27
3.2	Sound Reproduction.....	32
3.3	Recording: Musical Instruments in Rooms	35
3.4	Hearing: Human Listeners in Rooms.....	37
3.5	Reflections: Conveyers, Integrators, and Differentiators of Sound	39
3.6	An Acoustical and Psychoacoustical Sense of Scale.....	39
4	Sound Fields in Rooms	43
4.1	Large Performance Spaces: Concert Halls	43
4.1.1	Reverberation Time and the Perception of Speech and Music.....	48
4.1.2	The Seat-Dip Phenomenon	49
4.1.3	The Effects of Early and Late Reflections.....	50
4.2	Offices and Industrial Spaces.....	51
4.3	Domestic Listening Rooms and Control Rooms	53
4.3.1	One Room, Two Sound Fields—The Transition Frequency.....	54
4.3.2	Above the Transition Frequency	59

4.3.3	Measuring the Lack of Diffusion in Small Rooms.....	60
4.3.4	What Is a “Small” Room?	62
4.3.5	Conventional Acoustical Measures in Small Listening Rooms.....	63
5	The Many Effects of Reflections.....	67
6	Reflections, Images, and the Precedence Effect.....	73
6.1	Audible Effects of a Single Reflection.....	73
6.1.1	Effects of a Single Reflection	77
6.1.2	Another View of the Precedence Effect.....	79
6.1.3	Reflections from Different Directions.....	80
6.2	A Reflection in the Presence of Other Reflections.....	82
6.2.1	Real Versus Simulated Rooms	84
6.2.2	The “Family” of Thresholds.....	85
6.3	A Comparison of Real and Phantom Images.....	85
6.4	Experimental Results with Music and Other Sounds	86
6.4.1	Threshold Curve Shapes for Different Sounds	88
6.5	Single Versus Multiple Reflections.....	89
6.6	Measuring Reflections	91
7	Impressions of Space.....	95
7.1	The Terminology of Spatial Perception.....	98
7.2	Listeners and Their “Preference” for Reflections.....	99
7.3	Some Reflections Are Better Than Others.....	102
7.4	Summarizing and Charting the Way Forward.....	109
8	Imaging and Spatial Effects in Sound Reproduction.....	113
8.1	First-Order Reflections.....	113
8.1.1	Some Thoughts about Loudspeaker Arrangements.....	119
8.1.2	Delayed Reflections and Reflections of Those Reflections	125
8.2	ASW/Image Broadening and Loudspeaker Directivity	126
8.2.1	Testing the Effects of Loudspeaker Directivity on Imaging and Space.....	128
8.2.2	The Audible Effects of Loudspeaker Dispersion Patterns—Other Opinions.....	138
9	The Effects of Reflections on Sound Quality/Timbre	141
9.1	The Audibility of Acoustical Interference—Comb Filtering	142
9.1.1	Very Audible Differences from Similar-Looking Combs.....	146

9.1.2	Binaural Hearing, Adaptation, and Comb Filtering.....	149
9.1.3	An Important One-Toothed Comb—A Fundamental Flaw in Stereo.....	151
9.2	Effects of Reflections on Timbre—The Audibility of Resonances	155
9.2.1	What Do We Hear—Spectral Bump or Temporal Ringing?	157
9.2.2	Where Do We Find Timbral Identity?.....	159
10	Reflections and Speech Intelligibility.....	161
10.1	Disturbance of Speech by a Single Reflection	161
10.2	The Effect of a Single Reflection on Intelligibility.....	161
10.3	Multiple Reflections, Noise, and Speech Intelligibility.....	162
10.4	The Effects of “Other” Sounds—Signal-to-Noise Ratio.....	163
10.5	Listening Difficulty—A New and Relevant Measure	167
10.6	A Real Center Loudspeaker Versus a Phantom Center	168
10.7	A Portable Speech-Reproduction Test.....	168
11	Adaptation	171
11.1	Angular Localization—The Precedence Effect.....	172
11.2	Perceptions of Distance.....	174
11.3	Sound Quality—Timbre.....	175
11.3.1	A Massive Test with Some Thought-Provoking Results	177
11.3.2	A Multichannel Test—And Something Is Learned.....	179
11.4	Summary.....	180
12	Adjacent-Boundary and Loudspeaker Mounting Effects	183
12.1	Solid Angles and the Radiation of Sound	183
12.1.1	Correcting for Adjacent-Boundary Effects	187
12.2	Loudspeaker Mounting Options	188
12.3	“Boundary-Friendly” Loudspeaker Designs	194
13	Making (Bass) Waves—Below the Transition Frequency	197
13.1	The Basics of Resonances	198
13.2	The Basics: Room Modes and Standing Waves	201
13.2.1	Optimizing Room Shape and Dimensions	203
13.2.2	Standing Waves in Real Rooms	208
13.2.3	Loudspeaker and Listener Positions, Different Rooms, and Manipulating Modes.....	213
13.3	Delivering Good Bass in Small Rooms	216
13.3.1	Reducing the Energy in Room Modes.....	217
13.3.2	Controlling the Energy Delivered from Loudspeakers to Room Modes	220

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 Ado 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	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	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	303
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

19.1.4	Basic Masking and the Auditory Reflex.....	437
19.1.5	Criteria for Evaluating Background Noises	439
19.1.6	The Boundaries of What We Can Hear.....	441
19.1.7	The Benefits of High-Resolution Audio	442
19.2	Hearing Tilts, Peaks, Dips, Bumps, and Wiggles.....	444
19.2.1	The Audibility of Resonances	445
19.2.2	Critical Bands, ERB _N 's and Timbre	450
19.3	Nonlinear Distortion	451
19.4	Power Compression	453
19.4.1	Any Port in a (Turbulent) Storm?	454
20	Closing the Loop: Predicting Listener Preferences from Measurements	457
20.1	The Klippel Experiments.....	457
20.2	The Olive Experiments.....	461
20.3	An Interim Summary	465
21	Acoustical Materials and Devices	471
21.1	Key Acoustical Variables and Measurements	472
21.2	The Mechanisms of Absorption.....	476
21.3	Acoustical Performances of Some Common Materials.....	477
21.3.1	Typical Domestic Materials.....	477
21.3.2	Engineered Acoustical Absorbers	482
21.3.3	Engineered Acoustical Diffusers.....	486
21.3.4	Acoustically "Transparent" Projection Screens and Fabrics.....	490
21.4	Flutters, Zings, and the Like	492
21.5	Summary.....	493
22	Designing Listening Experiences	495
22.1	Choosing the Multichannel Delivery System.....	496
22.2	Laying Out the Room.....	499
22.3	Loudspeaker Directivity and the Acoustical Treatment of Interior Surfaces	502
22.3.1	Side-Wall Reflections from Front L, C, and R Loudspeakers.....	503
22.3.2	The Surround Channels and Opposite-Wall Reflections.....	504
22.3.3	Treating the Interior of a Room	505
22.3.4	Other Surfaces—Reverberation Time.....	508
22.4	Subwoofers, Seating and Room Dimensions	509
22.5	Choosing the Loudspeakers.....	511
22.5.1	Front Loudspeakers	512

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
Absorption coefficients,
 audience, concert, 44f, 84, 474,
 479, 484, 493
 carpet, 478f
 defined and discussed, 472-476
 diffusers with and without
 fabric cover, 508
 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, 483f
 seats, 479f
 walls, 480f
AC-3, 290
Acoustical crossover, subwoofer/
 satellite 417, 500
Acoustical crosstalk, 120-121, 139,
 168
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
Acoustical materials
 absorbers. *See* Absorbers
 absorption coefficient, *See*
 Absorption coefficient
 carpet, 477
 origins of, 17, 251
 diffusers, 486-490
 domestic, 477-481
 drapes, 477-478
 engineered, 482-490
 fabrics, 486
 foam, 485
 upholstered seating, 478-479
Acoustical measurements in concert
 halls, 27-28, 43-51
Acoustical shadowing in binaural
 hearing, 149
Acoustical treatment of listening
 rooms, 505-508
Active absorbers, 220
Adaptation
 description of, 24, 150-151, 171,
 307
 summary of, 264-265
Adjacent-boundary effects
 computer modeling of, 186-187
 correction for, 187-188
 definition of, 183
 description of, 416
 loudspeaker placement for,
 187-188, 194-196
 summary of, 265
Age-induced hearing loss, 354
Algorithms
 Bass optimization/equalization,
 237
 Fosgate 6-axis, 287-288
 Harman/Lexicon logic 7, 288
 pitch-shifting, 283
Ambience extraction, 287
Ambiophonics, 277
Ambisonics, 285-286
Amplifiers, power
 constant voltage source, 421
 damping factor of, 421, 424
 loudspeaker interface with,
 421-425
 and loudspeaker sensitivity
 ratings, 425-426
 solid-state, 425
 tube, 425
Amplitude-panning in surround
 systems, 279
Analog tape recorder, phase shift in,
 420
Anechoic chambers
 low-frequency calibration of, 374
 absorbers used in, 485
 measurement setup in, 377f,
 491f
Anechoic loudspeaker
 measurements, 377-380
Angles
 loudness and, 437
 solid, 183-185
Angular dispersion requirements,
 321, 334-335f
Angular localization, 171-174
Apparent source width
 center channel potential for, 123
 definition of, 34, 50, 51f, 69,
 99, 113, 258

early spatial impression, 97
 generation of, 79, 88, 96-99, 120
 interaural cross-correlation and,
 104f, 106f, 294
 Klippel experiments, 458

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, 314-321

Audio industry standards, 19-20,
 415-418

Auditory filter bandwidths,
 145-146f, 450-451

Auditory reflex, 437-439

Aural architects, 16, 24

Auratone 5C, 22f, 411-412, 413f

A weighting, 347f-348

B

Background noise, 163, 439-441

Backward masking, 437

Balanced noise criterion, 440f

Bass
 amplitude equalization of,
 240-248
 importance of in subjective
 ratings, 197, 462-464
 phase response in low bass,
 420-421
 pitch-shifting in, 244-245
 loudness growth of 433f
 phase equalization of, 420
 resonances in small rooms,
 201-216
 controlling resonances in small
 rooms, 197, 216-239
 rectangular rooms, subwoofer
 arrangements in, 222-238,
 509-511f
 stereo, 238-239
 summary of, 266-267

Bass efficiency matrix, 225

Bass management, 272

Bass-reflex ports, 454-455

"Bass traps," 237, 476-477

Benade paradox, 67, 68f, 95, 429,
 430f, 467

Bias in subjective judgments
 357-362

Bidirectional in-phase loudspeakers,
 126, 195, 399-407, 404f,
 502, 514-515

Bidirectional out-of-phase
 loudspeakers, 127, 285,
 327, 331, 399-407, 404f,
 406f, 514-515

Bidirectional surround loudspeakers,
see bidirectional in-phase,
 and bidirectional out-of-
 phase loudspeakers.

Bimodal (sight/sound) interactions,
 172, *See also*
 Ventriloquism effect.

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

Bipoles, *see* bidirectional in-phase
 loudspeakers

Blind listening tests, 349-352

Blind versus sighted listening tests,
 357-362

Blumlein-EMI patent, 273

Bolt "blob," 205, 207f

Bookshelf loudspeakers, mounting
 of, 189f-193f

"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,
 506f-507

Center channel loudspeaker, 120-
 123, 155, 259, 262, 323,
 399, 400f-401f,
 Acoustical perspective of, 475f

Center-rear loudspeaker, 305, 502

Central spectrum, 150

Channel(s)

Locations of, 302f-304f, 500f

Channel numbering, 298

Channel separation in stereo bass,
 239

Cinema

audio system calibration, X-curve
 385-389

audio system in, 313f

aural architecture applied to, 24

horizontal viewing angles in, 312

multichannel audio and, 273,
 280-281, 293f

picture resolution in, 313

seat-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

Codecs, 291-292

Comb filter, comb filtering
 audibility of, 145-151
 calculations, 144
 definition of, 142-143f
 description of, 69, 82, 88, 109,
 127, 262, 503

Compromise localizations, 409

Concert halls
 absorption coefficients, 44f
 acoustical measurements in,
 27-28f, 43-51
 fan-shaped, 32
 future trends in design of, 32
 "hi-fi," 32
 historical, 32, 40
 listening rooms vs., 29f-30
 modern trends, 32
 orchestra size matched with, 51
 rectangular-shaped (shoebox), 32
 room acoustics in, 27, 32
 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, 49-50, 50f
 summary of, 253-254

- speech intelligibility in, 48-49
variability of, 32
- Console reflection, 144
- Constant-beamwidth transducers, 370, 407
- Constructive interference, 143
- Critical bands, 145-146, 450-451
- Critical distance, 45f-47
- Crosstalk cancellation, binaural, 272, 277
- C-weighting, 347-348f, 517
- Cylindrical spreading, 368-372
- D**
- Damping, 225, 510
- Damping factor, 421, 424
- Dead acoustics, as a cultural norm, 17
- Destructive interference, 143f, 192f
- Detection threshold, 24, 433f, *see also*: hearing threshold
- Dialogue clarity, 165, 264, 323
- Dialogue intelligibility, *see* speech intelligibility
- Diaphragmatic absorbers, 219, 476-477
- Diffraction effect, 153, 367f
- Diffusers, 486-490, 504, 506f-507
- Diffuse sound fields, 44, 61-62, 114, 254, 317, 331, 474, 486
- Diffusion
description of, 60-61, 99, 254, 486
directional, 125-126
- Diffusivity, 61-62f, 114
- Digital audio, impact and reactions to, 7-8
- Dipole surround loudspeaker, *see* bidirectional out-of-phase loudspeaker
- Dipole radiator, ideal, 127f
- Direction
of sound fields, 33, 68
timbre and, 38
- Directional absorption coefficients, 483
- Directional diffusion, 61-62f, 125-126
- Directional microphones, 17
- Directivity,
of musical instruments, 27, 29, 36f
of loudspeakers, 126-140, 321-333
of human talker compared to loudspeakers, 169f
- Directivity index, 47f, 189, 377f-380, 384f-385, 411-412f, 459
- Defined, 379
- Direct sounds, 321-322, 326f, 373f, 375f
- Discrete multichannel audio, 290
- Distance of sound source, 33-34, 68, 294, 497
- Distance perception, 174-175
- Dolby Laboratories, 280, 303
- Dolby ProLogic, 273, 281, 287, 321
- Dolby Surround, 273, 281
- Domestic listening rooms. *See* Listening rooms
- Down-converter, 272-273
- Downmixer, 272-273
- Downwards conversion, 272-273
- Drapes, absorption coefficients 477-478
- Draw-away curves, 45f, 52f-53f, 60, 60f
- DSP effects, 277
- DTS, 292
- Dual bilateral light valve, 275
- DVD-Audio, 443
- E**
- Early reflections, 373, 373f, 377f, 378, 384f, 417
- Early spatial impression, 97
- Echo suppression effect, 76, 256
- Edison, Thomas, 13
- Eigenfrequencies, *See* Room modes
- Eigenmodes, *See* Room modes
- Electronic decorrelation in surround channels, 281, 283, 401
- Encoding matrix, 280, *See also* Down-converter, Downmixer
- "End corrections," 198
- Energy-time curve, 91, 93, 257
- "Enjoyment," 164-165
- Envelopment, 34, 50-51, 51f, 69, 99, 257, 294-298, 335-336, 497-498
- Equalization
acoustical versus electronic, 240-242
frequency response affected by, 519
large-venue sound systems, 387
loudspeaker transducers, 382
how to equalize, 517-519
measurements as an indicator of need for, 248, 381-382
multiple subwoofers and, 233, 236-238
room modes and, 223
surround channel timbre matching, 409-410
time and frequency domain behavior, 160 240, 241f, 243f, 248f
- Equal-loudness contours, 432-437
- Equivalent rectangular bandwidth (ERB), 146f, 450-451
- ERB_N, 146f, 450-451
- ETC. *See* Energy-time curve
- F**
- Far field, 366-367f
- "Feeling of space," 458, 460, 468
- Fidelity ratings, 354-357, 390-392
- First-order reflections
Comb filter effects, *See*, Comb filter
description of, 113-114
diffusivity affected by absorption of, 114, 115f
discussions of, 468, 502
effect on IACC, 104-106, 117
effect on spaciousness, 119-125
effect on directional diffusivity, 62f
from L, C, R, 322f-325
from surrounds, 326f
influence of directional absorption coefficient, 483f
recommendations for rooms, 503-508
relationship with loudspeaker directivity, 128-140
relationship with listener preferences, 99-109, 128-140
- Five-channel audio playback, 293f
- Flanking paths, 474
- Floor vibrations, 315-316
- F₁ statistic, 351
- Flush-mounted placement of loudspeakers, 189-194, 513, 516
- Flutter echo, 492-493
- Forward-temporal masking, 437
- Fosgate, 281
- Fosgate 6-axis algorithm, 287-288
- Fourier transform, 418

- Fractional-octave bandwidth
analyzers, 247-248f
- Frequency-dependent interaural
cross-correlation, 297
- Frequency response
anechoic measurements of
loudspeakers, 377f-379
audibility of variations in,
445-451
description of, 372-373
steady-state vs. transient state in
rooms, 240-246f
- Frequency shifting of room modes,
243-244f
- Frequency-weighting curves, 347f,
347-348
- Full space, 184
- Fusion zone, fusion interval, 73,
79-80f
- G**
- Glass fiber, 471, 476, 482
- "Great debate" issues in subjective
audio, 345
- Group delay, 420
- Gypsum board, 479-480
- H**
- Haas effect, 73-76, *see also*,
Precedence effect
- Haas equal-loudness experiment,
74-75, 75f
- Haas fusion zone, 76, *see also*
fusion zone, fusion interval
- Harman International
data-gathering system at,
377-378
Harman/Lexicon logic 7
algorithm, 288
- Harmonic distortion, 452
- HDTV, 314
- Headphone reproduction, 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,
434-437
hierarchical levels of, 24-25
influence in listening tests,
353-357
loss, damage to, 166-167, 353-
357, 430-431f, 434-437
occupation-induced loss of,
430-431f
thresholds, 433f, 435f, 441
Heisenberg's uncertainty principle,
245
Helmholtz absorbers, 220, 477
Helmholtz resonances, 198
"Hi-fi concert halls," 32
High fidelity, 14, 141
High-Q resonances, *see* resonances
High-resolution audio, 442-444
Home cinemas, *see* Home theaters,
Listening rooms
Home theaters, *see* Listening rooms
as a reference for movies,
520-521
Home THX, 282-285
Homogeneous sound field, 61
Horizontal dispersion requirements
for loudspeakers, 319f,
326f, 334f
Horizontal viewing angle, in
cinemas, 312
Horn-loaded loudspeakers, 381f,
399f, 513
House curves, 386, *See also* Room
curves
Human talker directivity index, 168
- I**
- IACC, *see* interaural
cross-correlation
- IEC room, 83
- Image broadening, *See also* Apparent
source width, 79, 95, 97,
99, 116, 118, 174, 311,
323
image quality,
effect of lateral reflections,
128-134f-140
phantom versus real image, 86,
86f, 151-152f-155,
120-123
Image shift, 79, 97
Image-shift thresholds, 78f, 80f, 83f,
85f
Impedance, loudspeaker, 421-422,
425
In-ceiling loudspeakers, 516
Industrial spaces
characteristics of, 51
sound fields in, 51-53, 62
Infinity Prelude MTS, 423
- In-head localization, 135(defined),
401
- Institute for Research in
Construction, 474-475
- Interaural cross-correlation
apparent source width and, 294
as a function of reflection
angle, 106
as a correlate of preference, 104f
as a correlate of spatial
impression, 104f
as a function of delay, 108f
definition of, 102, 105, 106f, 317
generated by multiple
loudspeakers, 295f, 296f,
299f
envelopment and, 294-298, 317
frequency-dependent, 297
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
ITU-R BS.775-2 recommendation,
302
- J**
- Jazz
early recordings of, 8
sound reproduction effects on,
8-9
JBL Professional, 389, 411
- K**
- KEF Concord, 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, 62f
Late reflections, 373, 373f
Law of the first wavefront, 73,
see also, Precedence effect
Legendre contour, 372

- 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* Room(s), 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, 509-511f
 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
 a variable in listening tests, 346
 video considerations in, 314-316
- Listening tests, *see* Loudspeaker evaluations
- Listening window, 377f-378
- Live musical performances
 acoustical contexts of, 15-16
 characteristics of, 28f
 interaction with halls, 30-32
 sound reproduction vs., 29f
 "Liveness" vs. "pure" music," 17
- Live vs. reproduced demonstrations, 5-6, 14
- Localization
 angular, in rooms, 37-38, 171-174
 "blur", 113
 definition of, 68, 497
 distance, 174-175
 imperfection of, 113
 in-head, 135, 401
 summary of, 258
 of surround loudspeakers, 328-331, 515
 ventriloquism effect, 113, 172, 294, 318, 497
- Logic 7 algorithm, 288
- Loudness
 of common sounds, 431
 compensation, 432-434
 effect of direction, 107f, 437, 438f
 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, 183-188
 amplifier interface with, 421-426
 arrangements of, description of, 119-125, 266, 292-298, 300, 499
 designing a theater floor plan, 316-321, 499-502
 audible effects of dispersion, 126-140
 bidirectional in-phase, 126, 195, 399-407, 404f, 502, 514-515
 bidirectional out-of-phase, 127, 285, 327, 331, 399-407, 404f, 406f, 514-515
 bookshelf, mounting options 188-194
 "boundary-friendly" designs of, 194-196
 "breaking in," 353
 center channel, real vs. phantom images, 120-121f, 123f, 151-154, and first lateral reflections, 323, horizontal center designs, 399, 400f-401f, view of listening room, 475f
 reflections from room boundaries, 119-126,
 center-rear, 305, 502
 control-room monitor, 20-24, 196, 411-418
 dipole (true) description and directivity pattern, 127f
 frequency response, 130f, 341f
 dipole surround, *see* bidirectional out-of-phase
 directivity requirements of, 321-327, 334f, 503f
 energy coupling to room modes, 220-221
 far-field, 366, 367f
 flush-mounted placement of, 194-195, 513
 free-standing, 194, 396-399, 500
 frequency response, early schools of thought, 342-343
 guidelines for choosing, 511-516
 high-end, 393-395, 394f, 399f
 horn-loaded, 381f, 399f, 513
 impedance of, 421f (defined), 424, 425f
 in-ceiling, 516
 in-wall, 513, 516
 ITU-R BS.775-2 recommendation, 302
 limited vertical dispersion of, 284
 line source, *see* Line sources
 at low frequencies, 365
 measuring the properties of data gathering and processing, 376-380

- data interpretation, 380–383
 - overview of, 372–373
 - requirements, 373–376
 - as minimum-phase devices, 382
 - midrange-tweeter-midrange
 - arrangement, 180, 334, 399, 400f
 - monitor, 20–24, 196, 411–418
 - mounting options, 188–194, 265
 - near-field, 366, 367f
 - near-field monitors, 154, 368
 - (defined), 410–413
 - on-wall placement of, 191, 194, 195f, 500, 513
 - point source, 329, 330f
 - professional monitor, 20–24, 196, 411–418
 - rear, 305, 502
 - selection of, 511–516
 - surround, *See* Surround loudspeakers
 - Loudspeaker evaluations
 - “Great debate” issues in
 - subjective audio, 345
 - listening environment for, 362–363
 - objective, 365–427
 - subjective, 337–363,
 - subjective/objective correlations, 390–395, 457–469
 - stereo versus mono, 126–137
 - Low-cutoff frequency, importance of, 392
 - Low-frequency absorbers, *see* Absorbers
 - Low-frequency effects channel, 272, 316
 - Low-Q resonances, *see* resonances
 - LP master tapes, 8
- M**
- Masking, 172, 437, 451–452
 - Mastering engineers, 22–23, 521
 - Matrixed surround systems, 278
 - Mean output level (MOL), 225–226
 - Mean spatial variance, 225, 228
 - Mechanically resonant absorbers, *see* Absorbers
 - Medium-Q resonance, *see* resonances
 - Membrane absorbers, *see* Absorbers
 - Membrane absorption, *see* Absorbers
 - Microphones
 - Directional, 17
 - frequency response problems, 348
 - origin of close-miking, 14, 16
 - multichannel, 122
 - placement of, 33, 35–37
 - Middle-ear reflex, 438
 - Midrange-tweeter-midrange
 - arrangement, 180, 334, 399, 514
 - Mineral wool, 471, 476, 482
 - Minimum-phase devices,
 - rooms at low frequencies, 200
 - transducers, 382, 419
 - Monaural, 271 (defined)
 - Monitor loudspeakers, 20–24, 196, 411–418
 - Monophonic
 - definition of, 272
 - history of, 13–18, 273
 - Monopole surround loudspeaker 404f
 - Mounting of loudspeakers, 188–194, 265
 - Movie industry statistics, 521
 - Multichannel audio
 - Ambisonics, 285–286
 - in automobiles, 289
 - cinema and, 280–281
 - center-channel discussions, 119–123
 - channel numbering scheme, 298
 - codexs, 291–292
 - configurations for best
 - envelopment, 297f, 299f
 - definition of, 272
 - digital discrete, 290–292
 - history of, 273–275
 - Home THX embellishments, 282–285
 - in music video concerts, 320
 - quadraphonics, 278f–279, 297f, 299f
 - recommended configurations, 300–305, 496–499
 - tests, 179–180
 - Multifilter graphic equalizers, 247
 - Multiple reflections, 82–85, 89–91, 162–163
 - Multiple reflections, loudness
 - summing, 90–91, 91f
 - Music
 - artistic nature of, 11
 - choosing for listening tests, 348
 - experimental results with, 86–89
 - Musical instruments
 - frequency-dependent directional patterns, 35
 - radiating of sound by, 35, 36f
 - in rooms, 35–37
 - sound power output, an
 - important attribute, 31
- N**
- Narrow-band smoothness, 464
 - near-field, 366, 367f
 - near-field monitors, 154, 368
 - (defined), 410–413
 - Noise, background, criteria for
 - evaluating, 439–441
 - Noise-induced hearing loss,
 - 166–167, 353–357, 430–431f, 434–437
 - Noise reduction coefficient, 473
 - Nonlinear distortion, 451–453
 - NS-10M, 411–412, 413f
- O**
- Occupational-induced hearing loss,
 - see* Hearing, Noise-induced hearing loss
 - 1/3 octave resolution, 247–248f, 416
 - Office spaces
 - characteristics of, 51
 - sound fields in, 51–53
 - Olive experiments, 461–465
 - Omnidirectional radiation, 27, 46, 184, 366–367f
 - 1080p images, 314
 - Onset transients, timbral
 - information in, 159–160
 - On-wall placement of loudspeakers, 194, 195f, 265, 500, 513
 - Opera houses, 49
 - Opposite-wall reflections of surround
 - channels, 124f, 326f, 504–505
- P**
- Panorama mode, 277
 - Paradox, central, 68, 430
 - Parametric equalizer, equalization, 248, 518
 - Particle velocity, 202, 219
 - Perceptual adaptation, 150, 171–181
 - Performance and reproduction
 - spaces
 - historical types of, 39–40
 - range of, 40f–41
 - amount of research in, 41f
 - Phantom center
 - center channel vs., 119–123, 168, 399

- creation of, 120
description of, 38, 119
sound quality of, 151-152f-155
speech intelligibility diminished in, 168
- Phantom images
sensitivity to reflections, 85-86f
distinctive sound and spatial character of, 120-121f
- Phase linear transducers, 420
Phase response audibility, 418-421
at low bass frequencies, 420-421
- Phons, 432
Pink noise, 446-447, 517
Pitch-shifting algorithm, 283
Plausibility, in localization, 172
Playback sound levels, 101, 347
Point source
definition of, 367f-368
loudspeakers, 329-330f
Port compression, 454-455
Power amplifiers, 421-427
Power compression, 453-455f
Precedence effect
angular localization in rooms, 172-174
cognitive level of, 172
definition of, 73, 75f, 173f
description of, 68, 79-80, 317
fusion interval,
for speech, 80f
for other sounds, 89-90f
ignoring of, 173
illustration of, 75f, 173f
- Preference
levels of reflections for speech, 100f
levels of reflections for music, interaural cross-correlation and, 104f, 109
spatial impression and, 104, 109
- Presbycusis, 354, 435f
Professional audio standards, 415-418
Professional monitor loudspeakers, 20-24, 196, 411-418
Projection screens, 490-492
Propagation loss, 317, 328-333, 336
Psychoacoustics, 429-455
- Q**
Q, 199 (definition), 220
QD-1 Quadrapter, 277
Quad ESL Mark 1, 341f
Quad ESL 63, 130f
Quadraphonics, 278-280
- R**
Random-incidence sound absorption coefficient, 474
Ray acoustics, 43, 113
RCA, live vs. reproduced demonstrations, 14
Recording control rooms, 20-21, *see also* Listening rooms
Recordings
alter the music being recorded, 5-9
binaural, 271
not like live concerts, 35-36
sweetening the mix with reflections, 156
Rectangular rooms, subwoofer arrangements in, 222-238, 509-511f
Re-equalization, 284
Reference axis, 378
Reference sound, 15
Reflection-decay time, 309
"Reflection-free zone," 261
Reflections, *See also* First-order reflections
as an aid to hearing, 37-39
Comb filter effects, *See*, Comb filter
console, 144
distance determined using, 68, 174-175
early reflections, defined, 373, 373f
effects overview, 67-71
effects on
audibility of resonances, 155-160
image quality, 128-134f-140
real and phantom images, 85-86
single reflections, 73-82
spatial effects, 95-99
speech intelligibility, 161-163
differences between speech and musical sounds, 86-89
first-order. *See* First-order reflections
from loudspeakers in a multichannel system, 322-328
late reflections, defined, 373, 373f
lateral. *See* Lateral reflections
listener preferences for, 99-109
loudness summing of multiple, 90-91, 91f
measuring levels of, 91-93
multiple reflections, 82-85, 90-91, 91f
a reflection among other reflections, 82-85
spectral smoothing from, 150, 152
summary of, 255-257, 261-264
timbre changes caused by, 141, 155-160
Repetition pitch, 69
Reproduced sound
evaluation criteria for, 12
liberating nature of, 41
live sounds vs., 5-6, 14
subjectivity of, 12, 337-338
Reproduction, 3-4. *See also* Speech reproduction
Resistive absorbers, 17, 217, 219, 476-477, 482, 494
Resonances
audibility of, 69, 155-160, 199, 445-451
damping of, *See* Room modes
controlling resonances in small rooms, 197, 216-239
detection thresholds for, 445
explanations of different kinds of, 198-201
Helmholtz, 198
in small rooms, 201-216
in transducers, 380
Minimum-phase types of, *See* Minimum-phase devices
Q, 199 (definition), 220
high-Q, 155, 157, 193, 199-200, 262, 416, 446, 448
low-Q, 157, 200, 262, 380, 447, 449
medium-Q, 448
room modes, *See* Room modes
room resonances, *See* Room modes
spectral bump vs. temporal ringing, 157-159
standing waves in rooms, *See* Room modes
Resonant modes, *See* Room modes
Reverberation
definition of, 43-44
in listening rooms, 176

- interpreted as noise (historical),
 17
 need for reverberation in
 recordings, 102
 a requirement for live
 performance and recording,
 35-37
 speech intelligibility affected by,
 48
 summary of, 253-255
 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, 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, 309
 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
 acoustics of listening and control
 rooms, 53-65
 Room acoustics *see also* Rooms,
 Listening rooms
 classical music affected by, 30
 historical investigations, 39-40
 perceptual effects enhanced by,
 68
 religious services and, 30
 Room correction, 180
 Room criterion curves (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
 explanations, 386
 X-curve for cinemas, 387-388f
 Measurement resolution, 55f,
 248f
 predicting from anechoic data,
 375f, 384f-385
 transition frequency revealed by,
 55f, 58f, 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,
 201-204f-208
 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 loudspeaker and
 listener locations, 55f, 212f
 formation of, 201, 202f
 in real rooms, 208-213
 Room resonances. *See* Room modes
 "Roughness," 450
 RPG Moddiffuser, 489, 508

S
 Sabine formula, 45, 508
 Sabins, 45, 508
 Samuel Goldwyn Theater, 312-313,
 313f
 Scattering, *See* Diffusers, 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, 308-309, 517
 absorption coefficient, 479f
 Sensitivity ratings of loudspeakers,
 425-426
 78 rpm record, 8
 Shure HTS, 281, 283, 331
 Side walls
 Acoustical treatment of,
 505-506f-508
 reflections from, *See* First-order
 reflections
 Signal-to-noise ratio,
 in speech intelligibility, 163-
 167
 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 a small room,
 62-63
 Spectral smoothing, 54-55f-56
 Solid angles
 description of, 183-185
 factor-of-two reduction of, 185
 reduced by mounting of
 loudspeakers, 188-193
 Solid-state amplifiers, 425
 "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),
 230-236, 308, 510
 Sound fields, *See* Concert halls,
 First-order reflections,
 Listening rooms,
 Reflections, Reverberation,
 Room modes in the
 acoustical spaces of
 interest, 39-40f-41
 Sound-intensity vectors, 286
 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

- determined in large part by a non-standardized industry, 19-24
summary of, 260-263
- Sound reproduction
definition, 3-5
defining characteristics of, 29f, 32-35
live versus reproduced
 comparisons, 13f-14
 modifies the music itself, 8-9
 listener preferences in
 loudspeakers, 391-395, 457-469
 the importance of space in,
 15-18
 optimizing the delivery of
 envelopment, 294-298
 taking liberties with the ideal,
 5-8
 summary of, 249-251
- Sound-scattering devices, *See*
 Diffusers, Diffusion
- Soundstage illusions, described, 110
- Sound transmission class (STC),
473
- Space, *See* Spaciousness
 perceptions of, 329, 458
 subjective evaluations of, 362
- Spaciousness
 apparent source width. *See*
 Apparent source width,
 Image broadening, Early
 spatial impression
 definitions of, 50-51f, 95-99,
 envelopment, 34, 50-51, 51f, 69,
 99, 257, 294-298, 335-
 336, 497-498
 listeners especially sensitive to,
 119, 173
 listener preference and, 99-105,
 457-461
 loudspeaker directivity effects on,
 128-138
 recording technique effects on,
 136
 summary of, 252, 257-261
- Spatial-effect balloon, 106f, 116,
303, 327
- Spatial impression, *See* Spaciousness
- Spectral adaptation, 151 *See also*
 Spectral Compensation
- Spectral compensation, 150,
175-176, 262
- Spectral tilt, audibility of, 444
- Speech intelligibility
 description of, 48-49, 69, 503
 reduced in stereo phantom
 image, 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, 521
 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
 capabilities of, 275
 a fundamental flaw in, 151-155
 as a factor in listening tests,
 133f, 349, 357f
 definition of, 272, 276f
 history of, 18, 272-278
 loudspeaker directivity and,
 128-140
 potential for creating
 envelopment, 295-300
 seat, 277
 upmix opportunities, 288-290f
- Stereo bass, 238-239
- Subjective measurements, 344-362,
See also Loudspeaker
 evaluations
- Subwoofers, *See also* Bass, Room
 modes
 Solutions for rectangular rooms,
 222-238, 509-511f
 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,
 ITU, 302
 Dolby, 304
 Toole composite, 304
 summary recommendations,
 500f, 501
 equalization of, 409-410
 horizontal dispersion
 requirements, 325-328,
 503f
 illusions that they must create,
 327, 496-497, 505
 localization of, 515
 multidirectional,
 bidirectional in-phase (bipole),
 126, 195, 399-407, 404f,
 502, 514-515
 bidirectional out-of-phase
 (dipole), 127, 285, 327,
 331, 399-407, 404f, 406f,
 514-515
 opposite-wall reflections, 124f,
 326f, 504-505
 problems with propagation loss,
 328-333
 selection of, 514-515
- Surround processor, 273
 "Surround-sound" upmixing,
 288-289, 290f
- Sweetening the mix, 156
- T**
- Tannoy, monitor gold, 341
- T-bar ceiling, 226
- THX, 282-285, 305, 331, 401
- Tight bass, 197, 239, 420,
424-425
- Timbral identity, 159-160
- Timbre
 acoustical interference effects on,
 142-143
 association with direction, 38
 audibility of resonances,
 445-450
 definition of, 141
 description of, 36
 information in onset transients,
 159-160
 reflections effect on, 69, 141-
 160
 repetition effects on, 143
 resonances have a dominant
 effect on, 155
 summary of, 261-263

Timbre matching of loudspeakers in
a surround system, 38,
283-284, 409-410

Time and frequency domains,
239-248

Tinnitus, 436

"Tone tests," Edison 13-14

Transition frequency, 54-60,
59f, 144, 518

Tube amplifiers, 425

U

Up-converter, *See* Upmixer

Upholstered seating, 478-479

Upmixer, 127, 273, 287-289-290f,
301, 305

Upwards conversion, *See* Upmixer
UREI 811B, 23f

V

Velocity, particle, 202, 219

Velour drapes, absorption of,
477-478f

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

Video, factors in room layout
312-321

Violin, directivity of, 36

W

Walls, acoustical treatment of,
505-508

Wharfedale

Live vs. reproduced
demonstrations, 14

W-90, 341

Waterfall diagrams,
of comb filters, 146-147f-149
of room resonances, 239-248

Waveform fidelity, 37, 418-420

Wide-dispersion loudspeakers, 136,
160, 325, 356, 459

Wire resistance, 423t

X

"X" curve, 385-389, 465

Y

Yamaha NS-10M, 411-412, 413f