

# Complete ERCES Handbook

with NICET In-Building Public Safety Communications (IB-PSC)  
Study Guide

**by Chief Alan Perdue (ret.), CFO, FM  
and John S. Foley**

**with Mike Brownson  
*Managing Editor and Contributing Writer***

SAFER BUILDING COALITION

# FOREWORD TO THE SAFER BUILDINGS COALITION'S COMPLETE ERCES HANDBOOK WITH NICET IB-PSC STUDY GUIDE

---

By Michael Desrochers, Vermont State Fire Marshal, President, National Association of State Fire Marshals (NASFM)

In the heart of every first responder and life-safety professional rests an inner calling to protect life, property and the environment from an all-hazards risk. Sadly, answering this call can result in the ultimate sacrifice that can be asked of anyone, as embodied in scripture: “Greater love has no one than this: to lay down one’s life for one’s friends.” (*Gospel of John, 15:13*). Public safety work involves skill, training, education, personal commitment, sacrifices, and a “Greater Love”. Love of learning, love of service, and love of community.

As the Executive Director for the Vermont Department of Public Safety, Division of Fire Safety and the President of the National Association of State Fire Marshals (NASFM), we share common core values targeted to protect the public and fire service with coordinated efforts in building partnerships, enhancing data collection, code enforcement, fire service training, public education, permitting, hazardous materials response, fire investigation, and urban search and rescue just to name a few. Within the core of protecting our first responders and the public, we must ensure that reliable communications during emergencies are part of the overall emergency planning strategy so we can enhance our response capability. The SBC team who authored this book shares this passion and dedication alongside the NASFM. Indeed, to perform our common mission, it is *critical* that our radios work inside buildings. If we can’t communicate during emergency incidents, we can’t protect ourselves or our community members. This book addresses that need head-on.

The technology deployed to ensure that critical communications are available inside buildings may be new and unfamiliar to many. The term most commonly used today for this technology is **Emergency Responder Communications Enhancement Systems (ERCES)**.

Note that the use of the word enhancement conveys the idea that when these systems are deployed within buildings, they do not work as stand-alone technology, but rather must be interwoven into the existing public safety communication networks that public safety agencies operate within their jurisdictions. The ERCES must perform its intended function but must also *enhance* and never *harm* the existing network.

This integration of ERCES and preexisting communication networks requires coordination, communication, codes and standards, best practices, and *agreement that everyone needs to be on the same page getting everyone on the same page*. And by everyone, I mean *all the stakeholders* with an interest in *in-building public safety communications*: first responders, building owners, code officials, public safety radio system operators, industry, elected officials, policy makers, codes and standards bodies, and more. This comprehensive handbook can help align and educate all of these stakeholders.

Life-safety professionals must explore and master many areas of study, some of which are technical and can involve time-consuming, sometimes dry, texts. These can be filled with jargon, arcane terms, and imprecise examples that can unintentionally make readers feel intimidated, or at the very least, unengaged. When an author is an advanced technical professional, it’s easy for them to forget what it’s like to be just starting out in the profession. The best authors find a way to present complicated concepts in accessible ways.

Chief Alan Perdue and his team at the Safer Buildings Coalition (SBC) had the daunting task of covering a set of extremely complex topics pertaining to math, science, technology, fire codes and standards, and many other highly detailed ERCES topics. This book could have easily turned into one of those dry, technical texts. But above all, Chief Perdue and his team at the Coalition are *teachers*. Their writing conveys the essential information to readers in a way that is both accurate and accessible to all professionals.

When Chief Perdue and the Coalition team first conceived of writing this book, they contacted NASFM for assistance to ensure that the work was articulated from a technical perspective while allowing users to learn about ERCES in a methodical manner. I, along with NASFM’s full Board of Directors, expressed enthusiasm in support of this important safety awareness project.

The subtitle of this book is “with NICET IB-PSC Study Guide”. The National Institute for Certification in Engineering Technologies (NICET) has for decades created and administered competency certification programs for fire alarm, fire sprinkler, and other engineering technologies. The Safer Buildings Coalition’s sound decision to collaborate with NICET to build the In-Building Public Safety Communications (IB-PSC) certification program leverages NICET’s widespread, pre-existing acceptance by code officials nationwide.

While there are many guideposts within this handbook to help prepare ERCES designers and technicians for NICET certification, the book does not “teach to the test.” Rather, it builds real competency step by step through teaching core concepts and best practices, and then relates these to the codes and standards that govern ERCES deployments.

---

The book begins with a full chapter telling *why* this subject is so essential (THE PURPOSE), followed by another chapter outlining what is to be done about the problem (THE OBJECTIVE). Every chapter and discussion for the remainder of the book, details not only *what* we need to know but *why* we should care about it.

From there, the book takes the reader through a logical progression of knowledge and understanding that builds toward ERCES competence. Building competence is an obvious essential goal of this book, but there is another objective that may be just as important.

The model code groups have implemented code requirements (standards) pertaining to ERCES; however, when considering the longevity of many codes and standards, the standards for ERCES are fairly new and are rapidly evolving requiring constant refining, standardizing, and continuing updates. As with any emerging technology, the ERCES domain is currently experiencing growing pains resulting in the need to establish a framework that provides education, training, technical support and resources on best practices to assist in implementing an Emergency Responders Communications Enhancement Systems by promoting effective communication between all stakeholders.

The authors set out to clarify code language and to offer best practices and interpretations to make it easier for code officials and industry to talk about project details as they pertain to ERCES codes and standards. The use of illustrations, examples, and code excerpts, presented from the perspective of a third-party authority are particularly useful in achieving this goal. Further, the book offers the perspective of an objective, virtual coach to facilitate discussion and agreement between code officials and industry professionals.

Chief Alan Perdue and the SBC are bona fide authorities in this domain and Chief Perdue has directly participated in writing much of the code in use today. This means he was at the table when each code detail was debated and whatever the final version of the language was, he was witness to the *intent* of each topic.

Perdue and his collaborators are well-informed by subject matter experts from the SBC's work groups comprising over a hundred volunteers with regular communication and collaboration with code officials and radio system administrators from across the country.

Turn to the *About the Authors* section of this book to read Chief Perdue's impressive biography and credentials, along with the backgrounds and credentials of his collaborators for this book (because no one person could have possibly covered every topic this book needed to address by themselves).

As the current President of NASFM, I am proud of our role in helping to bring this important handbook to all ERCES stakeholders, and I highly recommend this handbook as an essential guide for achieving in-building public safety communications competency. I encourage public safety and industry professionals alike to rely upon it as a trusted source of objective ERCES facts, and to incorporate it into their training programs.

Sincerely,  
Michael Desrochers  
Vermont State Fire Marshal, President - National Association of  
State Fire Marshals (NASFM)

## About Michael Desrochers



Michael Desrochers, Executive Director of Vermont Division of Fire Safety (DFS), was elected by his peers to lead as President of the National Association of State Fire Marshals (NASFM) in 2022. He is a 32-year veteran of the DFS.

Director Desrochers has served since 2012 as the Vermont State Fire Marshal and oversees fire service training, code enforcement, trade licensing and certification, USAR, Hazardous Material Response, Fire Investigation and represents Vermont on state boards, federal and national boards and committees. Previously, he served as Deputy Director of Vermont DFS, Regional Manager of DFS, Fire Prevention Officer, Certified Hazardous Materials Response Technician Team Member, and Certified Gas Technician.

NASFM membership comprises the most senior fire officials in the United States with the mission to protect human life, property, and the environment from fire and related hazards.

# CONTENTS

---

<b>Foreword: by Michael Desrochers</b> . . . . .	<b>xiv</b>
<b>How to Use this Handbook</b> . . . . .	<b>xvi</b>
<b>About the Authors</b> . . . . .	<b>xxxiii</b>
<b>1 THE PURPOSE: WHY WE CREATED THIS BOOK</b> . . . . .	<b>1</b>
1.1 The Impact of Building Materials on RF Penetration . . . . .	3
1.2 Higher Frequencies, Higher Attenuation . . . . .	4
1.3 The Importance of Location Accuracy . . . . .	4
1.4 Mobile Mass Notifications Must Reach Building Occupants . . . . .	5
1.5 Not Just Fire Departments, Not Just Radios . . . . .	6
1.6 First Responder Communications Must Work . . . . .	7
<b>2 THE OBJECTIVES: COMPETENCY, CONSISTENCY, AND RESOURCES</b> . . . . .	<b>9</b>
2.1 Stakeholders . . . . .	9
2.2 The Case for Competency . . . . .	10
2.3 NICET Certification Program and This Reference . . . . .	12
2.4 About NICET . . . . .	12
<b>3 THE STAKEHOLDERS</b> . . . . .	<b>19</b>
3.1 First Responders and The Communities They Protect . . . . .	20
3.2 Authority Having Jurisdiction (AHJ) . . . . .	20
3.3 Frequency License Holder (AKA The “Other” AHJ) . . . . .	21
3.4 Elected Officials and Community Leaders . . . . .	21
3.5 Federal Communications Commission (FCC) . . . . .	22
3.6 Fire and Building Code Organizations . . . . .	24
3.7 The System Integrators/Specialty Contractors . . . . .	24
3.8 Independent Testing Organizations . . . . .	25
3.9 Original Equipment Manufacturers (OEMs) . . . . .	25
3.10 Material Suppliers and Logistics (Distributors) . . . . .	25
3.11 UL Research Institutes . . . . .	25
3.12 Nationally Recognized Testing Laboratories (NRTL) . . . . .	26
3.13 Industry Associations and Media Partners . . . . .	26
3.14 Property Owners, Developers, and Managers . . . . .	27
3.15 Designers, Consultants, Professional Engineers . . . . .	29
3.16 General and Electrical Contractors . . . . .	30

3.17	Architects, Engineers . . . . .	31
3.18	Summary . . . . .	32
<b>4</b>	<b>THE RULES. . . . .</b>	<b>33</b>
4.1	FCC 47 CFR § 90.219 - Use of Signal Boosters. . . . .	35
4.2	47 CFR § 20.21 - Signal Boosters . . . . .	44
4.3	Summary . . . . .	45
<b>5</b>	<b>THE CODES AND STANDARDS . . . . .</b>	<b>47</b>
5.1	Access to Codes and Standards . . . . .	49
5.2	How to Determine What Codes and Standards Apply to a Particular Project . . . . .	51
5.3	Code and Standard Scope Statements . . . . .	53
5.4	Codes and Standards – What’s The Difference? . . . . .	56
5.5	Types of Codes and Standards . . . . .	58
5.6	Equivalency, Alternate Materials & Methods . . . . .	59
5.7	Consolidated Approach to Code Compliance . . . . .	60
5.8	Understanding the Key Components of the Codes and Standards . . . . .	61
5.9	Other Codes and Standards. . . . .	99
<b>6</b>	<b>RULES, CODES, AND STANDARDS REFERENCE TABLE . . . . .</b>	<b>.105</b>
<b>7</b>	<b>THE MATH. . . . .</b>	<b>.113</b>
7.1	Basics of RF Power Measurement . . . . .	.114
7.2	Linear Versus Logarithmic Scales . . . . .	.114
7.3	Basic Equations for Logs and Exponents . . . . .	.115
7.4	Using RF Math to Calculate the Link Budget . . . . .	.119
7.5	Allowed Decibel Math Operations . . . . .	.120
7.6	Calculating Composite Power . . . . .	.121
7.7	Free Space Path Loss . . . . .	.122
7.8	Indoor Environments Can Be Different – Enter the Path Loss Coefficient (or Exponent). . . . .	.124
7.9	The Link Budget . . . . .	.124
7.10	Practical Application of Our New-Found Understanding of dB Math. . . . .	.126
7.11	Is There a Solution to the In-Building Coverage Problem? . . . . .	.127
7.12	Summary . . . . .	.128
<b>8</b>	<b>THE SCIENCE . . . . .</b>	<b>.129</b>
8.1	What is Spectrum? . . . . .	.130
8.2	Frequency Bands . . . . .	.131
8.3	Channels . . . . .	.132

---

8.4	Modulation Techniques . . . . .	135
8.5	Multiple User Access Technologies . . . . .	138
8.6	RF Behaviors . . . . .	139
8.7	Noise . . . . .	140
8.8	Signal to Noise Ratio (SNR, S/N, SINR) and Bit Error Rate/Ratio (BER). . . . .	141
8.9	Thermal Noise Floor and Noise Power. . . . .	142
8.10	Noise Figure . . . . .	143
8.11	BDA Noise Power . . . . .	144
8.12	Uplink Noise Link Budget . . . . .	144
8.13	Multi-Stage Amplifier Operation. . . . .	145
8.14	Interference. . . . .	146
8.15	Interference Sources . . . . .	146
8.16	Summary . . . . .	150
<b>9</b>	<b>PROCESS OVERVIEW . . . . .</b>	<b>153</b>
9.1	ERCES Project Process Steps . . . . .	156
9.2	Initial Information Acquisition . . . . .	160
9.3	Initial Building Coverage Assessment – Is an ERCES Needed?. . . . .	166
9.4	Site Survey: Physical Facility and RF Coverage. . . . .	167
9.5	Perform Design. . . . .	168
9.6	Obtain Design Approval and Permits . . . . .	168
9.7	Acquire and Stage Materials . . . . .	168
9.8	Install Passive Components . . . . .	169
9.9	Install Active Equipment . . . . .	170
9.10	Commissioning and Optimization . . . . .	170
9.11	Inspection and Acceptance Testing. . . . .	171
9.12	As-Built Plans and Close-Out Package . . . . .	171
9.13	Registration with the FCC . . . . .	171
9.14	Ongoing Maintenance and Monitoring. . . . .	172
9.15	Summary . . . . .	172
<b>10</b>	<b>THE PUBLIC SAFETY COMMUNICATIONS SYSTEMS . . . . .</b>	<b>175</b>
10.1	Cellular Services . . . . .	176
10.2	Deeper Dive into Analog and Digital Public Safety LMR Networks. . . . .	176
10.3	P25 Standards and Applications Interoperability . . . . .	177
10.4	General P25 System Types . . . . .	178
10.5	Simplex, Half-Duplex, and Full-Duplex Operations . . . . .	180
10.6	Wide Area Networks . . . . .	181

---

10.7	Coverage Configurations . . . . .	181
10.8	Portable and Vehicle Mounted Repeaters . . . . .	183
10.9	Summary . . . . .	186
<b>11</b>	<b>ERCES ACTIVE COMPONENTS . . . . .</b>	<b>189</b>
11.1	Active Component Categories . . . . .	190
11.2	Signal Sources. . . . .	190
11.3	More About Bi-Directional Amplifiers . . . . .	193
11.4	Important Features and Specifications for BDAs . . . . .	198
11.5	Active DAS System Head End and Remotes . . . . .	205
11.6	Annunciator Panel. . . . .	208
11.7	Standby Power - Battery Backup Unit (BBU) . . . . .	209
11.8	FCC Rules for BDA Noise and Intermod . . . . .	211
11.9	FCC Required Label Requirements. . . . .	212
11.10	Summary . . . . .	213
<b>12</b>	<b>PASSIVE COMPONENTS . . . . .</b>	<b>215</b>
12.1	Antennas. . . . .	215
12.2	Splitters . . . . .	221
12.3	Filters . . . . .	223
12.4	Combiners . . . . .	226
12.5	Coaxial Cables . . . . .	227
12.6	Coax Cable Connectors . . . . .	231
12.7	Adaptors, Attenuators and Termination Loads . . . . .	232
12.8	Optical Fiber Cables. . . . .	232
12.9	Optical Connectors . . . . .	233
12.10	Summary . . . . .	234
<b>13</b>	<b>ERCES SYSTEMS. . . . .</b>	<b>237</b>
13.1	Active vs Passive Systems . . . . .	237
13.2	Public Safety Dedicated vs Combined PS/Cellular Active DAS . . . . .	239
13.3	Auxiliary Radio Communications System (ARCS). . . . .	241
13.4	Alternate Configurations . . . . .	242
13.5	Summary . . . . .	244
<b>14</b>	<b>TOOLS AND TEST EQUIPMENT. . . . .</b>	<b>245</b>
14.1	Required Hand Tools . . . . .	246
14.2	RF Test Equipment . . . . .	247
14.3	Electrical Test Equipment . . . . .	251
14.4	Coax Cable Prep and Testing Tools . . . . .	251

---

14.5	Optical Tools and Test Equipment . . . . .	256
14.6	Safety / Environmental Tools and Equipment . . . . .	259
14.7	Personal Protective Equipment [PPE]. . . . .	260
14.8	HEPA / Dust Control . . . . .	270
14.9	Man Lifts, Scissor Lifts, Scaffolding . . . . .	271
14.10	Site Material Handling (Gators, Carts) . . . . .	272
14.11	Software / Support Tools . . . . .	272
14.12	Summary . . . . .	275
<b>15</b>	<b>PROJECT ROLES AND SKILLS . . . . .</b>	<b>277</b>
15.1	Project Manager (PM). . . . .	277
15.2	Office Project Team . . . . .	278
15.3	Field Project Team . . . . .	279
15.4	NICET Level I, Technician Trainee . . . . .	280
15.5	NICET Level II, Associate Engineering Technician . . . . .	281
15.6	NICET Level III, Engineering Technician . . . . .	283
15.7	NICET Designer, Design Technician . . . . .	285
15.8	Summary . . . . .	286
<b>16</b>	<b>PROJECT MANAGEMENT. . . . .</b>	<b>289</b>
16.1	The Project Manager (PM) . . . . .	289
16.2	Project Communications . . . . .	290
16.3	Jurisdiction Requirements. . . . .	291
16.4	Define Project Scope . . . . .	292
16.5	Existing Building Considerations . . . . .	292
16.6	Government Building Considerations. . . . .	293
16.7	The Project Schedule . . . . .	293
16.8	Initial Design Phase . . . . .	294
16.9	Submittal Process . . . . .	295
16.10	Final Design . . . . .	295
16.11	Bulletins, Change Orders, & RFIs . . . . .	295
16.12	Pre-Installation Responsibilities . . . . .	298
16.13	Construction Site Management . . . . .	298
16.14	Installation Phase . . . . .	301
16.15	Billing . . . . .	301
16.16	Testing. . . . .	301
16.17	Final Submittals . . . . .	301
16.18	Summary . . . . .	302



---

<b>17 PHYSICAL FACILITIES AND RF SURVEYS . . . . .</b>	<b>.303</b>
17.1 The Pre-Design Survey . . . . .	304
17.2 Occupied Buildings . . . . .	304
17.3 The RF Survey . . . . .	305
17.4 The Physical Facility Survey . . . . .	309
17.5 Primary BDA Location . . . . .	310
17.6 Assess Staging Areas . . . . .	311
17.7 Distribution Antenna Systems. . . . .	311
17.8 Penetrations Required and Permitting. . . . .	312
17.9 Rooftop Donor Location . . . . .	314
17.10 Considerations for Special Facility Types. . . . .	316
17.11 Summary . . . . .	318
<b>18 THE DESIGN . . . . .</b>	<b>.321</b>
18.1 Project Stakeholders. . . . .	323
18.2 Starting a Design . . . . .	324
18.3 Designing . . . . .	327
18.4 Stages of the Design Process . . . . .	327
18.5 Using a Link Budget to Estimate Antenna Radius . . . . .	328
18.6 Product Selection Criteria. . . . .	330
18.7 Starting the Design . . . . .	334
18.8 Fine-Tuning . . . . .	340
18.9 Metrics to be Tuned to Match Real-World Conditions . . . . .	341
18.10 Propagation Types and Results . . . . .	341
18.11 Design Document Aesthetics . . . . .	342
18.12 Constructing a Link Budget. . . . .	344
18.13 Constructing a Bill of Materials. . . . .	345
18.14 Constructing a Project Data Submittal Package . . . . .	346
18.15 Summary . . . . .	347
<b>19 INITIAL PROJECT DOCUMENTATION AND SUBMITTALS . . . . .</b>	<b>.349</b>
19.1 Pre-Installation Design Submittals . . . . .	349
19.2 Requirement Documents from the AHJ. . . . .	352
19.3 Floorplans for the Designer . . . . .	354
19.3 RF Design Documents . . . . .	354
19.4 Submittals for AHJ Design Approval . . . . .	356
19.5 Submittals for FCC License Holder Approval . . . . .	357
19.7 Submittals for Building Engineer (New Construction) . . . . .	357

---

19.8	DAS Construction Drawings . . . . .	358
19.9	Commissioning Documentation. . . . .	359
19.10	Summary . . . . .	359
<b>20</b>	<b>THE INSTALLATION: MECHANICAL EXECUTION OF WORK. . . . .</b>	<b>361</b>
20.1	Overview . . . . .	361
20.2	BICSI and RCDDs . . . . .	362
20.3	Safety . . . . .	362
20.4	Pre-Installation Planning . . . . .	364
20.5	Pre-Construction Meetings and Site Walks . . . . .	369
20.6	Performing Rough-In Installation Activities . . . . .	369
20.7	Before Pulling Cable . . . . .	370
20.8	Cable Support . . . . .	370
20.9	Firestopping and Firestop Assemblies . . . . .	372
20.10	Termination and Testing of Installed Cables . . . . .	373
20.11	Installation of Passive Components . . . . .	377
20.12	Testing the Completed Passive Array . . . . .	379
20.13	Fiber Installation for Active DAS Systems . . . . .	379
20.14	Grounding and Lightning Protection for the Passive Array. . . . .	383
20.15	Installing Donor Antennas . . . . .	384
20.16	Donor Antenna Installation . . . . .	385
20.17	Active Equipment Location . . . . .	387
20.18	Active Equipment Installation . . . . .	389
20.19	Connections to the Fire Alarm . . . . .	390
20.20	Labeling . . . . .	390
20.21	As-Built Documentation . . . . .	391
20.22	Closeout Documentation . . . . .	391
<b>21</b>	<b>THE COMMISSIONING . . . . .</b>	<b>395</b>
21.1	ERCES Commissioning Pre-Checks . . . . .	396
21.2	Configuring Active System Components . . . . .	396
21.3	Active RF Equipment Validation . . . . .	397
21.4	Naming and Initial Commissioning . . . . .	397
21.5	Explanation of BDA Adjustments. . . . .	398
21.6	Identifying a Test Frequency . . . . .	399
21.7	Antenna Verification Testing . . . . .	399
21.8	Live Signal Integration Pre-Checks . . . . .	400
21.9	Donor Signal Measurement . . . . .	400

---

21.10	Live Signal Integration . . . . .	400
21.11	Live Signal Adjustment and Validation . . . . .	401
21.12	Adjustments for Multi-Stage Amplifier Operation . . . . .	401
21.13	Cellular DAS Commissioning . . . . .	402
21.14	Summary . . . . .	402
<b>22</b>	<b>RF TESTING AND BDA OPTIMIZATION . . . . .</b>	<b>405</b>
22.1	Three Categories of Tests . . . . .	406
22.2	Test Equipment Referenced . . . . .	406
22.3	Survey Tests Referenced in This Chapter . . . . .	407
22.4	Introduction to Tests During Project . . . . .	407
22.5	Information Preparation for Initial Testing . . . . .	410
22.6	A Note on Measuring RF Signal Quality . . . . .	410
22.7	Tests Done for Initial In-Building Coverage Assessment Prior to Construction . . . . .	411
22.8	Tests Done After the DAS is Constructed. . . . .	415
22.9	Downlink Testing and Optimization . . . . .	418
22.10	Uplink Testing and Optimization . . . . .	421
22.11	The BDA Optimization Excel Worksheet . . . . .	426
22.12	Uplink Testing and Optimization (Excel Worksheet) . . . . .	427
22.13	Near-Far Testing. . . . .	430
22.14	Adjusting Squelch Threshold . . . . .	432
22.15	Acceptance Testing . . . . .	434
22.16	Summary . . . . .	434
<b>23</b>	<b>THE ACCEPTANCE TEST . . . . .</b>	<b>437</b>
23.1	The Test Plan . . . . .	438
23.2	The Acceptance Test: RF Performance and Physical Infrastructure . . . . .	439
23.3	Acceptance Documentation . . . . .	445
23.4	Summary . . . . .	447
<b>24</b>	<b>FINAL SYSTEM DOCUMENTATION. . . . .</b>	<b>449</b>
24.1	Acceptance Phase Document Submittals . . . . .	449
24.2	Testing Documentation . . . . .	449
24.3	As-Built Drawings . . . . .	450
24.4	Registration of Repeaters with the FCC . . . . .	450
24.5	Close-Out Documentation. . . . .	450
24.6	Other Project Documentation . . . . .	451
24.7	Summary . . . . .	452

---

<b>25 MONITORING AND MAINTENANCE.</b>	<b>.453</b>
25.1 Fire Alarm Monitoring Basics.	.453
25.2 ERCES Code Monitoring Requirement Overview	.456
25.3 Maintenance and Annual Inspections	.458
25.4 Advanced DAS and BDA Monitoring	.459
25.5 Summary	.459
<b>26 CELLULAR SERVICES AND THE FUTURE OF PUBLIC SAFETY</b>	<b>.461</b>
26.1 Does the Code Recognize Cellular As a Public Safety Frequency for ERCES Purposes?	.462
26.2 National Public Safety Broadband Network (FirstNet)	.463
26.3 Cellular Frequency Bands.	.464
26.4 Differences Between Cellular and LMR Radio Networks	.465
26.5 Cellular and LMR Radio Networks Indoors	.465
26.6 Sharing Public Safety and Cellular on a DAS	.466
26.7 Interference Management	.467
26.8 Testing Parameters	.467
26.9 Cellular DAS Hardware Solutions	.468
26.10 Design Differences	.468
26.11 Carrier Coordination	.469
26.12 Excerpt From DHS Doc.	.469
26.13 Summary	.470
<b>Appendix A In-Building Public Safety Glossary.</b>	<b>.473</b>
<b>Appendix B Index.</b>	<b>.491</b>
<b>Appendix C Index of Specialized IB-PSC Skills</b>	<b>.505</b>
<b>Appendix D Working With Code Officials.</b>	<b>.512</b>
<b>Appendix E What FCC License Holders and Radio System Operators Want the Industry to Understand About ERCES</b>	<b>.515</b>
<b>Appendix F Building Owners' Toolkit.</b>	<b>.534</b>

Note: Page numbers followed by *f* and *t* indicate figures and tables, respectively.

- Absolute power, measurement of, 113, 115–117, 120–121
- Absorption, RF, 139, 139*f*
- Acceptance testing, 437–448
- codes and standards on, 96–97, 438, 445, 449
  - documentation of, 352, 445, 446*t*, 449
  - of fire alarm connections, 447, 447*f*
  - goals of, 437, 439
  - grid testing in, 407, 434, 441*f*, 442
  - of physical infrastructure, 442, 444*t*
  - planning for, 438
  - in project management, 301
  - in project process, 171
  - of RF performance, 439–442, 440*t*, 441*f*
  - timing of, 437–438, 439
  - types of tests in, 434, 438, 439, 441
- Access
- to annunciation and fire alarm panels, 389
  - to construction sites, 298
- Active components, 189–214. *See also specific types*
- vs. active systems, 189–190
  - categories of, 190
  - in commissioning phase, 396–398
  - definition of, 189
  - examples of, 189, 189*f*
  - installation of, 170, 170*f*, 387–389
  - monitoring of, 205
  - in project process, 170, 170*f*
- Active cooling, 389
- Active DAS, 237–241
- vs. active components, 189–190
  - definition of, 238, 238*f*
  - in design phase, 333
  - head-end of (*See* Head-end)
  - installation of, 379–383
  - vs. passive DAS, when to use, 239, 239*f*
  - public safety dedicated vs. combined public safety/cellular, 239–241, 240*f*
  - remotes of, 205, 207, 207*f*, 238
- Adaptors, 232, 232*f*, 255, 255*f*
- Adjacent channel interference, 148–149, 148*f*
- Administrative process, 153, 154*f*
- Aesthetics, design, 342–344, 343*f*, 344*f*
- AGC (Automatic Gain Control), 199, 199*f*
- AHJs. *See* Authorities having jurisdiction
- AIA (American Institute of Architects), 301
- ALC (Automatic Level Control), 200
- Alternatives, in codes and standards, 59, 242
- AM (amplitude modulation), 136, 136*f*
- American Institute of Architects (AIA), 301
- Amplifier circuits, 143
- Amplifier compression, 202, 202*f*
- Amplifiers, multi-stage, 145, 401–402
- Amplitude modulation (AM), 136, 136*f*
- Analog modulation, 135, 136, 136*f*
- Analog radio networks, 142, 176
- Annual inspections and testing, 96–97, 458–459, 459*f*
- Annunciator panels, 208, 389
- Annunciators. *See also* Dedicated annunciators
- configurations of, 208, 208*f*, 457, 457*f*
  - definition of, 91, 457
- ANSI/BICSI, 105, 107
- ANSI/TIA, 102, 106
- ANSI/UL, 111
- Antennas, 215–221. *See also specific types*
- codes and standards on density of, 94
  - in commissioning phase, 399
  - definition of, 215
  - in design phase, 328–329, 337–338, 337*f*
  - gain of, 216–217, 216*f*
  - installation of, 377–379
  - isolation testing of, 416–417, 416*f*
  - labeling of, 391
  - in physical facility surveys, 311–312
  - radiation patterns of, 216, 216*f*, 218, 218*f*, 219*f*
  - types of, 215
  - verification testing of, 379, 399, 415–416, 415*f*, 419–420, 419*f*
- APCO. *See* Project 25
- Architects, roles and responsibilities of, 31
- Architectural drawings, 354
- ARCS (Auxiliary Radio Communication Systems), 241–242, 241*f*
- Area coverage
- codes and standards on, 67–68, 68*f*
  - in free space path loss, 122–123
- As-built design documents
- in design process, 328
  - in final system documentation, 450
  - IFC on, 349
  - importance of, 294
  - in installation phase, 391
  - in project process, 168, 171
- Assessment. *See* Testing; *specific types*
- Associate Engineering Technicians (NICET Level II), 13, 281–282, 282*t*–283*t*
- Association of Public-Safety Communications Officials-International (APCO). *See* Project 25
- AT&T, 176, 463
- Attenuation
- by building material, 3, 3*t*, 116*t*, 329, 329*t*
  - definition of, 3, 116, 232
  - frequency bands and, 4

- 
- Attenuators, 232, 232*f*, 255, 255*f*
- Authorities having jurisdiction (AHJs)
- in acceptance testing, 438, 441
  - benefits of handbook for, 9
  - definitions of, 20, 51, 160
  - in design phase, 323
  - identifying, 51–52, 158–160
  - information provided by, 160–161, 291
  - in initial information acquisition, 160–161
  - NFPA 1225* on, 51, 159
  - preliminary submittals for approval of, 356–357
  - requirement documents from, 352–353, 353*t*–354*t*
  - roles and responsibilities of, 20–21, 33, 60, 160
  - technical criteria provided by, 83–85
- Authority to operate, FCC rules on, 37–40
- Automatic Gain Control (AGC), 199, 199*f*
- Automatic Level Control (ALC), 200
- Auxiliary Radio Communication Systems (ARCS), 241–242, 241*f*
- Backbone cables
- codes and standards on, 69–79
  - definition of, 70–71, 72*f*
- Backbone/distribution design, 381
- Background noise, 130, 141, 142
- Backup battery. *See* Battery backup
- Bandpass filters, 224, 224*f*
- Band reject filters, 224, 224*f*
- Bandwidth
- channel, 132–133
  - definition of, 132
  - thermal noise floor by, 143, 143*t*
- Baseband units (BBUs), 259
- Base stations, radio, 191, 191*f*
- Battery backup, 87, 209–211
- Battery backup units (BBUs), 209–211, 209*f*, 259
- BBUs. *See* Baseband units; Battery backup units
- BDAs (signal boosters), 193–205
- alternatives to, 33–34, 242
  - challenges of installing, 127
  - classes of, 193–198, 194*f*
  - codes and standards on, 40
  - in commissioning phase, 397–402
  - definition of, 190, 193
  - deployment rules for, 41–43, 42*f*, 63
  - in design phase, 330–331, 336
  - FCC database of, 42, 171, 172*f*, 450
  - FCC rules on, 22, 35–46, 63, 160, 211–212
  - features of, 198–205
  - labeling of, 43, 45*f*, 171*f*, 212, 212*f*, 459
  - mechanisms of, 193*f*, 194–196, 195*f*–196*f*
  - monitoring of, 459
  - noise figure of, 43, 143–144, 202–203
  - noise power of, 144
  - vs. other signal sources, 190
  - in physical facility surveys, 310–311, 310*f*
  - qualified installers of, 212
  - in solution to wireless coverage problem, 127
  - specifications for, 43, 198–205
  - spurious emissions from, 149–150
  - terms used for, 35, 37
- BDAs, optimization of, 405–435. *See also* RF testing equipment for, 406, 406*f*
- Excel worksheet for, 426–427, 426*f*
  - goals of, 405
  - in project process, 170
- Bel (B), 114
- Bench testing, 397
- BER. *See* Bit Error Rate; Bit Error Ratio
- BICSI, 102, 105, 107, 362
- Bi-Directional Amplifiers. *See* BDAs
- Bid walks, 303
- Billing, 301
- Bill of materials (BOM)
- in design phase, 345, 346*t*
  - in installation phase, 368, 369*t*
- Bit Error Rate (BER), 142, 421
- Bit Error Ratio (BER), 142
- Bits, definition of, 142
- Blueprints, in design phase, 326
- BOM. *See* Bill of materials
- Braided coaxial cables, 227, 229, 229*f*
- Branch circuits, dedicated, 85, 209–210
- Brick, impact on RF penetration, 3, 3*t*, 116, 116*t*
- Broadband, public safety, 42, 42*f*. *See also* Cellular services
- Building construction. *See* Construction
- Building materials, impact on RF penetration, 2, 3, 3*t*, 4*f*, 116*t*.  
*See also* Materials; *specific materials*
- Building owners
- in design phase, 323
  - in initial information acquisition, 162
  - in project process, 153, 162
  - roles and responsibilities of, 27–29, 60
- Bulletins, information, 295–296
- Bump caps, 263, 263*f*
- Cabinets, equipment
- codes and standards on, 87
  - installation of, 388–389
- Cable(s). *See also specific types*
- installation of (*See* Cable installation)
  - in physical facility surveys, 311–313
  - selection criteria for, in design phase, 331–334
  - tools for prepping and testing, 251–256, 373
- Cable connector prep tools, 252, 252*f*
- Cable entry points, 385, 385*f*, 387, 387*f*
- Cable hangers, 370, 371*f*
- Cable installation, 369–383
- avoiding sharp bends in, 378
  - fiber, 379–383
  - firestopping in, 372
  - labeling in, 390–391, 390*f*
  - planning for, 365
  - preparation for, 370
  - rough-in, 369
  - support in, 370–371
  - termination in, 373, 387
  - testing of, 373–377, 382, 387
- Cable pulling rigs and pulleys, 253, 253*f*
- Cable reel stands, 254, 254*f*
- Cable support, 370–371
- Cable testers/analyzers, 247, 374, 374*f*
- Cable trays, 371
- CAD software, 275, 275*f*, 366, 366*f*
- CAI (Common Air Interface), 177
- Calibration
- in cable testing, 375
  - in test equipment, 247, 256, 258, 374
  - propagation, 415
- Carrier coordination, 402, 469
- Carriers, use of term, 135
- CDMA (code division multiple access), 138, 138*f*

- Ceilings
  - omnidirectional antennas mounted on, 215–216, 215*f*, 216*f*, 219, 219*f*
  - in physical facility surveys, 312
  - radios mounted on, 192, 192*f*
  - spare tiles for, 378
- Cell phones, location accuracy with, 4–5
- Cellular boosters, 146, 468
- Cellular enhancement systems, 98, 239
- Cellular operators, 464, 469
- Cellular services for public safety, 461–471
  - codes and standards on, 192, 462–463
  - DAS, 402, 466, 466*f*, 468–469
  - designing, 322, 468–469
  - DHS on, 469–470
  - FCC rules on, 44
  - frequency bands for, 464, 465*t*
  - frequency license holders for, 21
  - future of, 469–471
  - interference management with, 467
  - vs. LMR radio networks, 322, 465–466, 470
  - prevalence of use, 461–462, 461*f*, 464
  - role of, 2, 176, 461–462
  - signal source for, 192, 192*f*
  - testing of, 467, 468*t*
- Certificate of Occupancy, Temporary, 20, 31, 441
- Certification. *See* NICET IB-PSC certification; Personnel qualifications
- Change orders, 295–297
- Channels, 132–135
  - bandwidth of, 132–133
  - physical vs. logical, 132, 132*f*
  - shared, advantages of, 134–135, 135*f*
- Checklists
  - physical infrastructure inspection, 444*t*
  - project, 291
  - RF inspection, 440*t*
  - system integrator qualifications, 29
- Close-out packages, 449–452, 450*f*
  - in installation phase, 391
  - in project process, 171
- Coax. *See* Coaxial cables
- Coaxial cable connectors, 231, 231*f*
- Coaxial cables, 227–231. *See also specific types*
  - definition of, 227
  - insertion loss for, 227, 228*t*
  - installation of, 369–377
  - ratings of, 229–231, 231*t*
  - selection criteria for, in design phase, 331–332
  - support for, 370–371
  - testing of, 373–377
  - tools for prepping and testing, 251–256
  - types of, 227–229
- Co-channel interference, 146–147, 146*f*
- Code division multiple access (CDMA), 138, 138*f*
- Code organizations, roles and responsibilities of, 24
- Codes, ERCES, 47–104. *See also specific codes*
  - consolidated approach to compliance with, 60, 60*f*
  - definition of, 56
  - determining applicability of, 51–53
  - development process for, 102–103, 103*f*
  - equivalency, alternatives, and modifications in, 59
  - key components of, 61–102
  - list of most important, 48
  - older vs. newer versions of, 48
  - online access to, 47, 47*f*, 49
  - origins and history of, 49
  - reference table of, 105–111
  - SBC reference card for, 61, 61*f*
  - scope statements of, 53–56
  - vs. standards, 56–58
  - types of, 58
- Combined public safety/cellular active DAS, 239–241, 240*f*
- Combiner modules, 206
- Combiners, 226–227
- Commissioning, 395–403
  - active components in, 396–398
  - of cellular DAS, 402
  - communications in, 291
  - documentation in, 359
  - goals of, 395
  - initial, 397–398
  - personnel qualifications for, 395
  - pre-checks in, 396, 400
  - in project process, 170
  - RF testing in, 409
- Common Air Interface (CAI), 177
- Common Public Radio Interface (CPRI), 259
- Communications
  - in fire alarm system monitoring, 454
  - in project management, 290–291, 290*f*
- Community leaders, roles and responsibilities of, 21–22
- Competencies
  - codes and standards on minimum, 96, 163
  - need for, 10–11, 14
- Composite power, 121, 200, 200*t*
- Compression, amplifier, 202, 202*f*
- Compression point, 1 dB, 202
- Computer aided design (CAD) software, 275, 275*f*, 366, 366*f*
- Conceptual design, 31, 168, 327
- Concrete, impact on RF penetration, 3, 3*t*, 116, 116*t*
- Connectivity diagrams, 368
- Connectors
  - coaxial cable, 231, 231*f*
  - installation of, 377–380
  - optical, 233–234, 234*f*, 379, 380*f*
  - selection of, in design phase, 332
- Construction. *See also* New buildings
  - codes and standards on types of, 76–78, 77*f*, 78*t*
  - substantially completed, 20, 31
- Construction drawings
  - CAD, 366, 366*f*
  - DAS, 358, 358*f*, 359*f*
- Construction sites
  - access rules for, 298
  - equipment for handling materials at, 272, 272*f*
  - management of, 298–299
  - offices at, 298
  - pre-construction walks at, 369
  - safety at, 298–299, 299*f*, 300*f*
- Consultants, roles and responsibilities of, 29
- Continuous wave (CW) test transmitters, 250, 250*f*
- Conventional repeater systems, 175, 178, 179*f*
- Cooling, active, 389
- Corner reflector antennas, 217
- Cosmic background radiation. *See* Thermal noise floor
- Coupling loss, of radiating cables, 220, 220*f*
- Coverage antennas. *See* Distribution antennas
- CPRI (Common Public Radio Interface), 259
- Crew supervisors, 279
- Crossband couplers, 226–227, 227*f*
- CW (continuous wave) test transmitters, 250, 250*f*

DAQ. *See* Delivered Audio Quality

DAS (Distributed Antenna Systems). *See also* Active DAS;  
 Passive DAS; *specific components*  
 cellular, 402, 466, 466f, 468–469  
 components of, 127f, 189, 189f  
 construction drawings of, 358, 358f, 359f  
 definition of, 127, 237  
 monitoring of, 459  
 in physical facility surveys, 310–312  
 RF testing after construction of, 415–418  
 roles and responsibilities of designers of, 29

Data collection tools, 274

dB. *See* Decibels

dBm. *See* Decibel-milliwatts

Decibel meters, 264, 265f

Decibel-milliwatts (dBm), 115–128  
 allowed math operations with, 120–121  
 vs. decibels, 115–117  
 definition of, 115  
 equivalencies in W and mW, 117, 117t, 119, 121

Decibels (dB), 113–128  
 allowed math operations with, 120–121  
 vs. decibel-milliwatts, 115–117  
 definition and origins of term, 114, 120  
 to fractions/multiples, 119, 119t  
 ratio of RF change in, 115–116

Dedicated annunciators  
 codes and standards on, 90–91, 91f, 208, 457, 457f  
 configurations of, 208, 208f, 457, 457f

Dedicated branch circuits, 85, 209–210

Dedicated public safety active DAS, 239–241, 240f

Dedicated radio consoles (DRCs), 241, 241f

Delivered Audio Quality (DAQ)  
 in acceptance testing, 441  
 rating scale for, 142, 142t  
 testing on digital radio networks, 411, 411f

Department of Homeland Security (DHS), 469–470

Deployment process. *See* Project process

Design, 321–348  
 aesthetics of, 342–344, 343f, 344f  
 art and science of, 327  
 as-built (*See* As-built design)  
 bill of materials in, 345, 346t  
 cellular, 322, 468–469  
 conceptual, 31, 168, 327  
 documentation of (*See* Design documents)  
 final, 168, 294, 295, 328  
 fine-tuning, 340–341  
 goals of, 321  
 obtaining approval for, 168, 295  
 preliminary, 168, 294, 328  
 product selection in, 330–334  
 in project process, 168, 171  
 propagation models in, 341–342, 342f  
 resources on, 321  
 RF testing during, 408  
 software in (*See* Design software)  
 stages of, 327–328  
 stakeholders in, 323–324  
 starting layout of, 334–339  
 submittal process for, 168, 295, 346  
 surveys before, 304

Design documents, 349–360. *See also* As-built design  
 documents  
 aesthetics of, 342–344, 343f, 344f  
 codes and standards on, 93, 349  
 needed before starting design, 324–326  
 pre-installation, 295, 349–352  
 preliminary phase, 352–360  
 RF, 354–356

Design engineering teams, 278–279

Design engineers, 279

Designers  
 benefits of handbook for, 9  
 roles and responsibilities of, 29

Design software, 274–275  
 CAD, 275, 275f, 366, 366f  
 design steps using, 334–335  
 documents exported by, 356  
 existing coverage surveys for, 413  
 in installation phase, 365–368  
 predictive, 274, 274f, 294f, 354–355, 355f, 366  
 RF, 367–368, 367f  
 training in, 321, 322f

Design Technicians, 13, 285, 285t–286t

Developers. *See* Property developers

DHS (Department of Homeland Security), 469–470

Diffraction, RF, 139, 139f

Digital cliff, 176

Digital multi-meters, 251, 251f

Digital radio networks, 142, 175–176, 411, 411f

Digital vehicular repeater systems (DVRS), 183–184, 184t

Diplexers. *See* Crossband couplers

Directional antennas, 215–219

Directional couplers, 221–223, 221f, 222f, 332, 339, 339t

Direct mode radios, 133, 175. *See also* Simplex communication  
 systems

Distance to fault (DTF) testing, 374–377

Distributed Antenna Systems. *See* DAS

Distribution antenna cables  
 codes and standards on, 69–79  
 definition of, 70–71, 72f

Distribution antennas, 219, 384

Distributors, roles and responsibilities of, 25

Dixie cup design, 327, 341

Documentation, 349–360. *See also* Design documents  
 acceptance phase, 352, 445, 446t, 449  
 in administrative process, 153, 154f  
 of cable testing, 377, 377f  
 commissioning, 359  
 final system, 449–452  
 of firestop assemblies, 372  
 needed before starting design, 324–326  
 pre-installation, 349–352  
 preliminary phase, 352–360

Dominance, designing for, 341

Donor antennas, 217–218  
 in commissioning phase, 400  
 definition of, 217  
 in design phase, 326  
 grounding and lightning protection for, 383, 383f, 386  
 installation of, 383–387  
 isolation of, 86, 316  
 mounting of, 94, 217–218, 314, 386–387  
 in physical facility surveys, 314–316, 315f  
 in RF surveys, 306–307, 307f  
 testing of, 387  
 types of, 217, 217f–218f

Donor cables  
 grounding and lightning protection for, 383  
 installation of, 385–386, 385f, 386f

Donor signal  
 measurement of, 400, 413–414, 413f  
 verification test for, 418–419, 418f



- Donor towers, in donor antenna installation, 384
- Downlink (DL) adjustment, initial, 401
- Downlink (DL) testing and optimization, 418–421
- Drawings. *See* Design; *specific types*
- DRCs (dedicated radio consoles), 241, 241f
- Drills, cordless, 252, 252f
- DTF (distance to fault) testing, 374–377
- Duplexers, 224
- Dust control, 270, 270f
- DVRS (digital vehicular repeater systems), 183–184, 184f
- Effective radiated power (ERP), 42, 217
- Elastomeric respirators, 263
- Elected officials, roles and responsibilities of, 21–22
- Electrical contractors
- in design phase, 323–324
  - in initial information acquisition, 162
  - roles and responsibilities of, 30
- Electromagnetic spectrum, 130, 130f
- Elevator shafts, radiating cables in, 221
- Emergency Responder Communication Enhancement Systems. *See* ERCES
- EMS, 9–1–1 calls routed to, 6
- Energy efficient building materials, 2, 3
- Engineering Technicians (NICET Level III), 13, 283–284, 284f
- Engineers
- in office project teams, 278–279
  - preliminary submittals for, 357
  - in project process, 166
  - roles and responsibilities of, 29–31, 278–279
- Environmental noise, testing for, 417–418, 417f
- Equal power dividers, 221
- Equations
- for free space path loss, 123
  - Friis noise, 145, 145f
  - for logs and exponents, 115–119
- Equipment. *See also* Test equipment
- codes and standards on listing of, 65–66
  - for material handling on sites, 272, 272f
  - safety, 259–271
  - staging of, 298, 311
- Equivalency, in codes and standards, 59
- ERCES
- future of, 469–471
  - history of regulation of, 6, 10–11, 437
  - need for, 1–8, 237
  - types of systems, 237–244
- ERP (effective radiated power), 42, 217
- Estimators, in operations teams, 279
- Excel worksheets
- for BDA optimization, 426–427, 426f
  - for BDA uplink squelch optimization, 433
  - for near-far testing, 432
  - for uplink testing and optimization, 427–429
- Existing buildings, ERCES in
- advantages and disadvantages of, 292–293
  - codes and standards on, 63, 155
  - vs. new buildings, 31
  - project management with, 292–293
  - project process for, 155, 158
  - surveys of, 304, 310
- Exponents, basic equations for, 115–119
- Exterior leakage testing, 420–421, 420f, 442
- Exterior performance testing, 421
- External references, in codes and standards, 66
- Eye safety, 256, 261, 262f
- Face protection, 261
- Facilities, initial information acquisition on, 162. *See also* Physical facility surveys
- Fall protection systems, 267–269, 267f
- F/B. *See* Front-to-back
- FCC. *See* Federal Communications Commission
- FCC license holders. *See* Frequency license holders
- FDMA (frequency division multiple access), 138, 138f, 178–180, 179f, 180t
- Federal Communications Commission (FCC)
- on competencies, 11
  - license search with, 161, 162f
  - on 9-1-1 response times, 4–5
  - roles and responsibilities of, 22
  - signal booster database of, 42, 171, 172f, 450
  - on spurious emissions, 149–150
- Federal Communications Commission (FCC) rules, 33–46
- codes and standards on compliance with, 97
  - on frequency license holders, 35
  - on maximum uplink gain, 422–423
  - overview of, 107–108
  - on signal boosters, 22, 35–46, 63, 160, 211–212
- Feeder cables, definition and use of term, 69–70. *See also* Distribution antenna cables
- Fiber DAS, 238, 238f
- Fiber optic (optical fiber) cables, 232–233, 232f, 233f
- installation of, 379–383
  - selection of, in design phase, 333, 333f
  - splicing of, 256f, 257, 381, 381f
  - testing of, 382, 382f
  - tools for prepping and testing, 256–259, 256f–259f, 382
  - types of, 379–380, 380f
- Field engineers, 278, 279
- Field project teams, 279
- communications with, 290–291
  - members of, 279, 289
  - roles and responsibilities in, 279
- Field testing, codes and standards on, 64–65
- Filters, 223–225
- Final design, 168, 294, 295, 328
- Final system documentation, 449–452
- Fire Alarm and Signaling Code. *See* NFPA 72
- Fire alarm contractors
- in design phase, 324
  - qualifications of, 455
- Fire alarm panels and systems
- access to, 389
  - codes and standards on, 89–90, 453, 456–457
  - installing connections to, 390, 455
  - monitoring of ERCES by, 89–90, 453–457, 453f, 455f
  - testing connections to, 447, 447f
- Fire Code Officials, use of term, 20, 51. *See also* Authorities having jurisdiction
- Fire departments, 6
- Fire phones, 73–74
- Fire rating, codes and standards on, 75–78, 78t
- Firestop assemblies, installation of, 372, 372f
- Firestopping, installation of, 372, 372f
- Firewalls, in physical facility surveys, 312
- FirstNet, 463–464
- development of, 176, 463–464
  - frequency allocations to, 42, 42f, 463–464, 463f–464f
  - prevalence of use, 464
- First Responder Network Authority. *See* FirstNet
- Five-year testing, codes and standards on, 96–97

Flat panel antennas, 217, 218f  
 FLHs. *See* Frequency license holders  
 Floor plans  
   in pre-installation planning, 365  
   in preliminary documentation, 354  
 Flowcharts, of administrative process, 153, 154f  
 FM (frequency modulation), 136, 136f  
 Foot protection, 265, 265f  
 4-port BDAs, 195–196, 195f  
 Fractions  
   adding and subtracting, 115  
   converting dB to, 119, 119t  
 Free space path loss (FSPL), 122–123  
   definition of, 120, 122, 139  
   in design phase, 328–329, 330t  
   by distance, 116t, 122–123, 122f–123f  
   equation for calculating, 123  
   in maximum uplink gain, 426, 426t  
 Frequencies. *See also* Channels  
   additional, codes and standards on, 92–93, 462–463  
   in design phase, 326, 331  
 Frequency bands  
   cellular, 464, 465t  
   definition of, 131  
   divided into channels, 132–135  
   for public safety communications, 4, 4t, 131, 131f, 131t  
 Frequency division multiple access (FDMA), 138, 138f, 178–180, 179f, 180t  
 Frequency license holders (FLHs)  
   in acceptance testing, 438  
   benefits of handbook for, 9–10  
   for cellular services, 21  
   in design phase, 323  
   FCC rules on, 35–45  
   FCC search tool for, 161, 162f  
   identifying, 52–53, 158–160  
   in initial information acquisition, 161  
   NFPA 1225 on, 34, 159  
   other terms for, 21  
   overview of codes and standards on, 87  
   preliminary submittals for approval of, 357  
   roles and responsibilities of, 21, 33, 60, 161  
   use of term, 53  
 Frequency modulation (FM), analog, 136, 136f  
 Frequency shift keying (FSK), 136, 136f  
 Friis noise equation, 145, 145f  
 Front-to-back (F/B) ratios, of antennas, 217  
 FSK (frequency shift keying), 136, 136f  
 FSPL. *See* Free space path loss  
 Full duplex BDAs, 195  
 Full duplex communication systems, 134, 134f, 180  
 Fusion splicers, 257, 381, 381f  
 Future ready systems, designing for, 334

Gain  
   antenna, 216–217, 216f  
   BDA, 198–199, 198f  
   uplink, 422–426, 429  
 General contractors (GCs)  
   in design phase, 323  
   in initial information acquisition, 162  
   roles and responsibilities of, 30  
 General Radiotelephone Operator License (GROL), 11, 164  
 Gloves, 266, 267f  
 Government buildings, project management with, 293

Grid testing, 407, 411–413  
   in acceptance testing, 407, 434, 441f, 442  
   in Initial In-Building Coverage Assessment, 407, 411–413, 412f  
   procedure for, 412–413, 412f, 442  
 Grips, cable, 253, 253f  
 GROL (General Radiotelephone Operator License), 11, 164  
 Grounding, in installation phase, 383–384, 386, 389, 389f  
 Group delay, 203  
 Guard bands, 399  
 Guide pulleys, 253, 253f

Half duplex communication systems, 133, 134f, 180  
 Hand protection, 265–266, 265f, 267f  
 Hand tools, 246–247  
 Hard hats, 263, 263f  
 Hardline coaxial cables, 227–229  
 Harmonic emissions, 149  
 Head-end of active DAS, 205–207  
   cable management in, 381  
   in design phase, 336, 336f  
   functions of, 206–207  
   mechanisms of, 206f, 238, 238f  
   in physical facility surveys, 310–311  
   public safety dedicated vs. combined public safety/cellular, 241  
 Head protection, 263, 263f  
 Hearing protection, 264, 264t, 265f  
 Heat maps, 274, 294f, 341, 354, 365–366. *See also* Predictive software  
 HEPA, 270, 270f  
 High-pass filters, 225, 225f  
 Home run design, 381  
 Hybrid combiners, 226, 226f

IAFC (International Association of Fire Chiefs), 4  
 IBC. *See* International Building Code  
 IB-PSC certification. *See* NICET IB-PSC certification  
 iBwave, 321, 322f  
 ICC. *See* International Code Council  
 IEBC (International Existing Building Code), 102, 108  
 IFC. *See* International Fire Code  
 In-building coverage. *See* ERCES  
 In-building coverage problem. *See* Wireless dead zones  
 In-Building Public Safety Communications (IB-PSC). *See* ERCES  
 In-Building Public Safety Communications (IB-PSC) certification. *See* NICET IB-PSC certification  
 Independent testing organizations, roles and responsibilities of, 25  
 Indoor environmental noise, testing for, 417–418, 417f  
 Industry associations, 26–27  
 Information acquisition, initial, in project process, 160–166  
 Information bulletins, 295–296  
 Infrastructure  
   physical inspection of, 442, 444t  
   telecommunications, master plan for, 29  
 Initial design phase, 294  
 Initial In-Building Coverage Assessment, 411–415  
   chicken and egg problem with, 155  
   codes and standards on, 63–65, 97  
   existing coverage surveys in, 413  
   goals and scope of, 406, 408, 411  
   grid testing in, 407, 411–413, 412f

- in project process, 155–156, 166–167
- system integrators in, 156
- walk path testing in, 414, 414f
- Injuries, hand, 265, 265f
- Innerduct, 380, 380f
- Insertion loss, 220, 225, 227, 228t
- Inspections
  - annual, 96–97, 458–459, 459f
  - physical infrastructure, 442, 444t
  - in project process, 171
- Installation, 361–393. *See also specific parts*
  - of active components, 170, 387–389
  - activities by NICET technician levels, 361, 361t
  - of cables (*See Cable installation*)
  - codes and standards on approval prior to, 94–95
  - design details needed for, 344
  - of donor antennas, 383–387
  - grounding in, 383–384, 386, 389, 389f
  - labeling in, 390–391, 390f
  - of lightning protection, 383–384, 387, 387f
  - of passive components, 377–378
  - pre-construction meetings on, 369
  - pre-installation planning for, 364–368
  - project management during, 301
  - in project process, 169–170
  - resources on, 361–362
  - rough-in, 369
  - safety in, 362–364
- Interference, 146–150
  - in BDAs, 197
  - with cellular and ERCES sharing networks, 467, 467f
  - codes and standards on, 97, 98
  - definition of, 146
  - in RF surveys, 306–307, 307f
  - science of, 146–150
  - sources of, 146–150
- Intermodulation interference, 149, 149f, 211
- International Association of Fire Chiefs (IAFC), 4
- International Building Code (IBC), 102
  - overview of, 108
  - prescriptive requirements in, 58
  - scope statement of, 102
- International Code Council (ICC). *See also specific codes*
  - code development process of, 102–103, 103f
  - NFPA compared to, 49
  - online access to, 47, 47f, 49
  - origins and history of codes of, 49
  - overview of codes of, 108
  - roles and responsibilities of, 24
- International Existing Building Code (IEBC), 102, 108
- International Fire Code (IFC)
  - on AHJs, 20
  - changes to language of, 6
  - on competencies, 10
  - on design documents, 93, 349
  - first appearance of ERCES in, 6, 10, 437
  - key components of, 61–98
  - on maintenance, 458
  - on mounting of donor antennas, 94, 314
  - overview of, 108
  - on permits, 65, 349
  - on qualifications of personnel, 10, 96, 163, 212–213
  - references to NFPA standards in, 68
  - scope statement of, 54–55
- Invoicing, 301
- Isolation testing, 416–417, 416f
- J-hooks, 370, 371f
- Jumpers, 255, 332, 378, 378f
- Jurisdiction. *See also Authorities having jurisdiction*
  - in design phase, 324–325
  - in project management, 291
  - in project process, 153
- KN95 masks, 262, 262f
- Knowledge base, 160
- Labeling
  - in annual inspections, 458–459, 459f
  - of BDAs, 43, 45f, 171f, 212, 212f, 459
  - in installation phase, 390–391, 390f
- Land Mobile Radio. *See LMR*
- Leakage maps, 341–342, 342f
- Leakage testing, exterior, 420–421, 420f, 442
- Leaky coax cables. *See Radiating cables*
- Life safety drawings, 354
- Light fixtures, interference from, 146
- Lightning protection
  - codes and standards on, 53–55, 82–83
  - installation of, 383–384, 387, 387f
- Light sources, optical, 258, 258f
- Light spectrum, 130
- Linear scales, 114–115
- Line of Duty Death (LODD) studies, 7
- Link budget, 124–126
  - calculating, 119–120
  - definition of, 113, 124, 130
  - in design phase, 328–329, 344
  - examples of, 113f, 124–125, 125f, 345t
  - uplink noise, 126, 144–145, 144t
- Live signal
  - adjustment and validation of, 401
  - antenna verification with, 419–420, 419f
  - integration of, 400–401
- LMR (Land Mobile Radio), 176
  - vs. cellular, 322, 465–466, 470
  - channel bandwidths of, 132–133
- Loads. *See Termination loads*
- Location accuracy, 4–5
- LODD (Line of Duty Death) studies, 7
- Logarithmic scales, 114–116, 115f, 120
- Logical channels, 132, 132f
- Logs, basic equations for, 115–119
- Low-e glass, 3, 4f
- Low-pass filters, 225, 225f
- Macro systems, 242
- Maintenance, 453–460
  - codes and standards on, 453, 458–459
  - periodic, 458–459
  - in project process, 172
- Man lifts, 271, 271f
- Manufacturer training, 372, 373, 397
- Masks, 262, 262f
- Mass notifications, mobile, 5
- Materials
  - acquisition of, 168–169, 298
  - bill of, 345, 346t, 368, 369t
  - building, attenuation by type of, 3, 3t, 116t, 329, 329t
  - equipment for handling, 272, 272f

Materials (*continued*)

- roles and responsibilities of suppliers of, 25
- selection criteria for, in design phase, 330–334
- staging of, 168–169, 298, 311

Math. *See* RF math

Maximum composite power, 121

Mechanical protection, 79

Mechanical fiber splicing, 381

Media partners, roles and responsibilities of, 26–27

Megohmmeters (Meggers), 251

Mesh networking, 470, 470*f*

MEWP (mobile elevated work platforms), 271

Middle-Class Tax Relief and Job Creation Act of 2012, 463

Milliwatts (mW), 114–120, 117*t*

MIMO antennas, 219

Mobile elevated work platforms (MEWP), 271

Mobile mass notifications, 5

Model codes and standards. *See* Codes; Standards; *specific codes and standards*

Modifications, in codes and standards, 59

Modulation, 135–137

Monitoring, 453–460

- of active components, 205
- of BDAs, 459
- codes and standards on, 90, 453
- of DAS, 459
- of ERCES by fire alarm systems, 89–90, 453–456, 453*f*, 455*f*
- in project process, 172
- of signal sources, 90

Monitoring services, 454

Motorola R56 standards and guidelines, 111

Multi-carrier DAS, 27–28, 207, 401, 466

Multicast networks, 182, 182*f*

Multipath effect, 124

Multiples, converting dB to, 119, 119*t*

Multiple user access technologies, 138, 138*f*

Multi-stage amplifier operation, 145, 401–402

mW. *See* Milliwatts

  

Naming, in initial commissioning, 397–398

Narrowband, public safety, 42, 42*f*

National Electrical Manufacturers Association (NEMA), 87

National Electric Code (NEC). *See* NFPA 70

National Emergency Number Association (NENA), 4

National Fire Alarm and Signaling Code. *See* NFPA 72

National Fire Protection Association. *See* NFPA

National Institute for Certification in Engineering Technologies. *See* NICET

National Institute for Occupational Safety and Health (NIOSH), 7, 20

Nationally Recognized Testing Laboratories (NRTLs), 26, 99–100

National Public Safety Broadband Network (NPSBN). *See* FirstNet

National Society of Professional Engineers (NSPE), 12

Near-far effect, 94

- BDAs and, 197
- in design phase, 331, 340
- testing of, 430–432, 442

NEC (National Electric Code). *See* NFPA 70

NEMA enclosures, codes and standards on, 87

NENA (National Emergency Number Association), 4

Neutral host operators, 27–28

New buildings, ERCES in

- codes and standards on, 63
- vs. existing buildings, 31
- project process for, 155, 158

NFPA

- on AHJs, definition of, 20, 51
- ICC compared to, 49
- key components of codes of, 61–98
- online access to, 47, 47*f*, 49
- origins and history of codes of, 49
- overview of codes of, 108–110
- roles and responsibilities of, 24
- scope statements of, 53–55
- sprinkler installation rules by, 10

NFPA 1

- equivalencies, alternatives, and modifications in, 59
- first appearance of ERCES in, 10, 167, 437
- key components of, 62–65
- overview of, 108
- performance-based requirements in, 58
- scope statement of, 54

NFPA 13, 69

NFPA 70

- other codes and standards on, 100–101
- overview of, 109
- scope statements of, 55, 100–101

NFPA 72

- on branch circuits, 85, 210
- on cellular services, 462
- first appearance of ERCES in, 437
- key components of, 62–98
- other codes and standards on, 101
- overview of, 109
- scope statement of, 55

NFPA 101, 55, 109

NFPA 780, 53, 55, 109

NFPA 790, 110

NFPA 791, 110

NFPA 1221

- on annual testing, 458
- on dedicated branch circuits, 85, 210
- equivalency in, 59
- on frequency license holders, 34
- key components of, 62–98
- on monitoring by fire alarm systems, 89–90, 456
- overview of, 110
- scope statement of, 53, 54

NFPA 1225

- on acceptance testing, 96, 438, 445, 449
- on AHJs, 51, 159
- on annual testing, 458
- on cellular services, 192, 462–463
- on dedicated annunciators, 90–91, 457
- on frequency license holders, 34, 159
- on grid testing, 442
- key components of, 62–98
- on monitoring by fire alarm systems, 89–90, 456–457
- on monitoring of signal sources, 90, 456
- on mounting of donor antennas, 94, 217
- on oscillation control, 88, 201
- overview of, 110
- on permits, 65, 350
- on RF system designers, 11, 14
- scope statement of, 54
- on signal boosters, 40

- NICET IB-PSC certification, 9–18  
 development of, 12  
 as evidence of competency, 163, 212–213  
 four levels of, 13, 15*t*–17*t*, 280–285  
 installation activities by level of, 361, 361*t*  
 need for, 9–12, 14  
 performance measures in, 16*t*–17*t*, 281*t*–286*t*  
 purpose of, 9  
 requirements for, 14, 15*t*  
 roles and skills of personnel with, 277–286, 281*t*–286*t*
- NICET Level I (Technician Trainees), 13, 280, 281*t*  
 NICET Level II (Associate Engineering Technicians), 13, 281–282, 282*t*–283*t*  
 NICET Level III (Engineering Technicians), 13, 283–284, 284*t*
- NIOSH (National Institute for Occupational Safety and Health), 7, 20
- N95 masks, 262, 262*f*
- Noise. *See also* Interference; *specific types*  
 definition of, 140  
 examples of impacts of, 140–141, 140*f*  
 indoor environmental, testing for, 417–418, 417*f*  
 science of, 140–150  
 sources of, 140–141
- Noise exposures, permissible, 264, 264*t*
- Noise figure, 43, 143–144, 202–203
- Noise floor  
 codes and standards on, 83  
 definition of, 141  
 maximum uplink gain without raising, 423–425  
 science of, 141–145  
 thermal, 142–145
- Noise power, 144–145  
 definition of, 144  
 uplink, 427–428, 427*f*
- Non-interference, codes and standards on, 98
- No Noise Task Force, 45
- Notch filters, 223, 224*f*, 225, 226*f*
- NPSBN. *See* FirstNet
- NRTLs (Nationally Recognized Testing Laboratories), 26, 99–100
- NSPE (National Society of Professional Engineers), 12
- Occupational Safety and Health Administration (OSHA)  
 on NRTLs, 26  
 on safety tools and equipment, 259–271
- Occupied buildings. *See* Existing buildings
- OEMs (original equipment manufacturers), 25
- OFDMA (Orthogonal FDMA), 138, 138*f*
- Office project teams, 278–279  
 communications with, 290–291  
 members of, 278–279, 290  
 roles and responsibilities in, 278–279
- Omnidirectional (omni) ceiling mounted antennas, 215–216, 215*f*, 216*f*, 219, 219*f*
- One-line diagrams, 368
- Operations managers, 279
- Optical connectors, 233–234, 234*f*, 379, 380*f*
- Optical fiber cables. *See* Fiber optic cables
- Optical light sources, 258, 258*f*
- Optical power meters, 258, 258*f*
- Optical time delay reflectometers (OTDRs), 258, 259*f*, 382, 382*f*
- Original equipment manufacturers (OEMs), 25
- Orthogonal FDMA (OFDMA), 138, 138*f*
- Oscillation, 88, 200–201, 201*f*
- OSHA. *See* Occupational Safety and Health Administration
- OTDRs (optical time delay reflectometers), 258, 259*f*, 382, 382*f*
- Owners. *See* Building owners; Property owners
- Parasitic oscillation, 200
- Parking, 298, 298*f*
- Passbands  
 of class A vs. class B BDAs, 197, 197*f*  
 definition of, 42  
 FCC rules on, 41–42
- Passive components, 215–235. *See also specific types*  
 in commissioning phase, 399  
 definition of, 169, 189, 215  
 examples of, 189, 189*f*, 215  
 installation of, 170, 377–378  
 labeling of, 391  
 vs. passive systems, 189–190  
 in project process, 169  
 selection of, in design phase, 332  
 testing, 379
- Passive DAS, 237–239  
 vs. active DAS, when to use, 239, 239*f*, 242  
 definition of, 237, 237*f*  
 vs. passive components, 189–190
- Passive intermodulation (PIM), 149, 221  
 testing of, 252, 253*f*, 255, 376
- Path loss. *See also* Free space path loss  
 calculating, 123–124, 124*t*  
 in design phase, 328–329, 329*f*  
 factors contributing to, 124  
 in maximum uplink gain, 426, 426*t*
- Path loss coefficient, 123–124, 124*t*
- Pathway survivability  
 codes and standards on, 72–79  
 definition of, 73  
 fire rating in, 75–78  
 mechanical protection in, 79
- Penetrations, wall, in physical facility surveys, 312–313, 313*f*
- Performance-based requirements, 58
- Permits  
 codes and standards on requirements for, 65, 349–350  
 in design phase, 343–344  
 in project process, 168
- Personal fall protection systems, 267–269, 267*f*
- Personal protective equipment (PPE), 260–269  
 during installation, 363, 363*f*  
 OSHA rules on, 260–261  
 types of, 260–269, 260*f*
- Personnel, 277–287. *See also specific positions*  
 in project process, 157*t*, 163–166  
 roles and skills of, 277–287
- Personnel qualifications, 10–11, 163–165  
 for BDA installation, 212  
 for commissioning, 395  
 FCC on, 11, 164, 212  
 for fire alarm contractors, 455  
 for GROL, 164  
 IFC on, 10, 96, 163, 165, 212–213  
 need for improvement of, 11  
 NFPA on, 11, 96  
 state, county, and local requirements for, 165–166, 165*f*  
 for system integrators, 29
- PEs. *See* Professional engineers

Phones  
 cell, location accuracy with, 4–5  
 fire, 73–74

Physical channels, 132, 132*f*

Physical facility surveys, 303–319. *See also* RF surveys  
 BDA location in, 310–311, 310*f*  
 DAS in, 310–312  
 in design phase, 326  
 donor antennas in, 314–316, 315*f*  
 in existing buildings, 304, 310  
 goals of, 303  
 pre-bid vs. post-award, 303  
 pre-design, 304  
 preparation for, 309  
 in project process, 167–168  
 for special facility types, 316–317  
 staging areas in, 311  
 tools for, 274

Physical infrastructure inspection, 442, 444*t*

PIM. *See* Passive intermodulation

Planning, pre-installation, 364–368

Plenum rated cables, 228–231  
 codes and standards on, 79–81, 81*f*, 228, 229  
 in design phase, 332  
 illustration of, 228*f*, 251*f*  
 vs. riser cables, 229–231, 231*t*

Plenum spaces, definition of, 79, 229, 229*f*

PMI (Project Management Institute), 363

PMs. *See* Project managers

POEM principle, 29

Portable repeaters, 183–185, 184*f*–185*f*, 469–470

Power  
 absolute, measurement of, 113, 115–117, 120–121  
 composite, 121, 200, 200*t*  
 effective radiated, 42, 217  
 for fire alarm systems, 454  
 noise, 144–145, 427–428  
 standby, 85–86, 86*f*, 209–211  
 sufficient, in installation, 389  
 testing during installation, 389, 390

Power dividers, 221

Power meters, optical, 258, 258*f*

PPE. *See* Personal protective equipment

Precision loads, 375, 375*f*

Predictive software, 274, 274*f*, 294*f*, 354–355, 355*f*, 366

Preliminary design, 168, 294, 328

Preliminary phase document submittals, 352–360

Prescriptive requirements, 58

Primary structural frame, 75–78

Process. *See* Project process

Product selection, in design phase, 330–334

Professional engineers (PEs)  
 in project process, 166  
 roles and responsibilities of, 29–30

Project coordinators, 279

Project documentation. *See* Documentation

Project management, 289–302  
 acceptance testing in, 301  
 billing in, 301  
 bulletins, change orders, and RFIs in, 295–297  
 checklists in, 291  
 communications in, 290–291  
 at construction sites, 298–299  
 in existing buildings, 292–293  
 final submittals in, 301  
 goals of, 289  
 in government buildings, 293  
 in initial design phase, 294  
 key elements of, 289*f*  
 pre-installation responsibilities in, 298  
 schedules in, 293–294, 298  
 scope definition in, 292  
 submittal process in, 295

Project Management Institute (PMI), 363

Project management software, 273, 294

Project managers (PMs). *See also* Project management  
 benefits of handbook for, 9  
 roles and skills of, 277–278, 289–290

Project process, 153–173. *See also specific phases*  
 administrative, 153, 154*f*  
 close-out package in, 171  
 commissioning and optimization in, 170  
 design in, 168  
 facility and RF surveys in, 167–168  
 FCC registration in, 171, 172*f*  
 identifying AHJs and FLHs in, 158–160  
 Initial In-Building Coverage Assessment in, 155–156, 166–167  
 initial information acquisition in, 160–166  
 inspection and acceptance testing in, 171  
 installation of passive and active components in, 169–170  
 maintenance and monitoring in, 172  
 materials acquisition and staging in, 168–169  
 overview of steps in, 156–157, 157*t*  
 personnel requirements in, 157*t*, 163–166  
 technical, 153, 155, 157*t*

Project roles and skills. *See* Personnel

Project schedules, 293–294, 298

Project scope, defining, 292

Project teams. *See* Personnel; Teams

Project 25 (P25), 175–183  
 architecture of, 175–183  
 benefits of, 176  
 channels in, 132, 132*f*  
 coverage configurations for, 181–183  
 definition of, 175, 177  
 interference in, 147–148, 147*f*  
 model of, 177, 178*f*  
 modulation techniques in, 136–137  
 multiple user access technologies in, 138  
 signal to noise ratio in, 141–143, 142*t*  
 types of systems, 178–180  
 wide area networks in, 181, 181*f*

Propagation calibration, 415

Propagation delay, 203

Propagation models, in design phase, 341–342, 342*f*

Property developers  
 benefits of handbook for, 10  
 roles and responsibilities of, 27–29

Property managers  
 benefits of handbook for, 10  
 categories of, 27  
 roles and responsibilities of, 27–29

Property owners. *See also* Building owners  
 benefits of handbook for, 10  
 categories of, 27  
 roles and responsibilities of, 27–29

Protected contours. *See* Service contours

P25. *See* Project 25

Public safety communications systems, 175–187. *See also*  
 Radio networks  
 cellular services in, 2, 176  
 frequency bands used in, 4, 4*t*, 131, 131*f*, 131*t*

Pulling rigs, 253, 253*f*

Quadrature amplitude modulation (QAM), 137, 137f  
 Quadrature phase shift keying (QPSK), 137, 137f  
 Qualified installers, 212–213

Racks, installation of, 388–389  
 Radiated power, effective, 42, 217  
 Radiating (leaky) cables, 219–221, 219f, 220f, 229, 331, 331f  
 Radiation patterns, antenna, 216, 216f, 218, 218f, 219f  
 Radio amplification units (RAUs), 241, 241f  
 Radio base stations, 191, 191f  
 Radio frequency. *See* RF  
 Radio network operators. *See* Frequency license holders  
 Radio networks. *See also specific types*  
   architecture of, 175–187  
   cellular vs. LMR, 322, 465–466  
   initial information acquisition on, 161, 161f, 162f  
   science of, 130–138  
   types of, 133–135, 175  
 RadioReference.com, 46, 161, 326  
 Radio spectrum, 130–138  
   allocation of frequency bands of, 131, 131f, 464, 465t  
   definition of, 130–131  
   science of, 130–138  
 RAUs (radio amplification units), 241, 241f  
 RCDDs (Registered Communications Distribution Designers), 107, 362  
 Reactive splitters, 221, 221f  
 Received Signal Strength Indicator (RSSI), 67, 142, 467, 468t  
 Reel stands, 254, 254f  
 Reference Signal Received Power (RSRP), 467, 468t  
 Reference Signal Received Quality (RSRQ), 467, 468t  
 Reflected ceiling drawings, 354  
 Reflection, RF, 139, 139f  
 Refraction, RF, 139, 139f  
 Registered Communications Distribution Designers (RCDDs), 107, 362  
 Rejection, 225  
 Remotes, of active DAS, 205, 207, 207f, 238  
 Renovations, major, project process for, 155  
 Repeaters, portable and vehicle mounted, 183–185, 184f–185f, 469–470. *See also specific types*  
 Requests for information (RFIs), 295–296, 325  
 Requests for proposal (RFPs), 325  
 Requirement documents, from AHJs, 352–353, 353t–354t  
 Respiratory protection, 262–263, 262f  
 Retransmit applications and authorizations, 38–40, 38f–39f, 87, 88f, 97, 156, 396, 406  
   for cellular, 469  
 Return loss testing, 374–377, 375f. *See also* Sweep testing  
 RF (radio frequency)  
   behaviors of, 139–140, 139f  
   impact of building materials on, 2, 3, 3t, 4f  
 RF Characterization, 140, 256  
 RF design documents, in preliminary documentation, 354–356  
 RF Design Software, 334, 335, 354  
   in installation, 367, 368, 367f  
 RFIs (requests for information), 295–296, 325  
 RF math, 113–128  
   allowed operations in, 120–121  
   application of, 126–127, 126f, 127f  
   calculating composite power, 121  
   calculating free space path loss, 122–123  
   calculating link budget, 119–120, 124–126  
   calculating path loss, 123–124, 124t  
   equations for logs and exponents in, 115–119  
   how to simplify, 118–119  
   logarithmic scales in, 114–116, 115f, 120  
   units of measurement in, 114–115  
 RF noise. *See* Noise  
 RFPs (requests for proposal), 325  
 RF Signal Booster Systems. *See* BDAs  
 RF signal generators, 247, 250, 250f  
 RF surveys, 303–309  
   exterior (donor), 306–307, 307f  
   goals of, 303  
   interior, 305–306, 306f  
   pre-bid vs. post-award, 303  
   pre-design, 304  
   in project process, 167–168  
   tools for, 249, 274, 305, 307–309  
 RF testing, 405–435. *See also specific types*  
   in acceptance phase, 439–442, 440t, 441f  
   categories of, 406  
   after DAS construction, 415–418  
   equipment for, 247–250, 406, 406f  
   goals of, 405  
   information preparation for, 410  
   near-far, 430–432  
   overview of, 407–409, 408f  
   uplink, 421–429  
 RF to optical conversion modules, 206  
 Riser cables, 229–231. *See also* Backbone cables  
   codes and standards on, 69–70, 79–81, 80t, 81f  
   definition and use of term, 69–70  
   vs. plenum cables, 229–231, 231t  
 Riser plans, 343, 344f, 368, 368f  
 Roll-off slope, 225  
 Rough-in installation activities, 369  
 RSRP (Reference Signal Received Power), 467, 468t  
 RSRQ (Reference Signal Received Quality), 467, 468t  
 RSSI (Received Signal Strength Indicator), 67, 142, 467, 468t  
 Rule of 3s and 10s, 118, 120, 121  
 Rules, ERCES, 33–46  
   diversity of sources of, 33  
   reference table of, 105–111

Safety  
   at construction sites, 298–299  
   culture of, 298–299, 364  
   during installation, 362–364  
   tools and equipment for, 259–271  
   training in, 299, 362–363  
 Safety margins, 126–127, 141  
 Safety vests, 263–264, 264f  
 Scaffolding, 271, 271f  
 Scanning receivers, 249, 249f, 307–308, 308f  
 Scattering, RF, 139, 139f  
 Schedules, project, 293–294, 298  
 Science, 129–151  
   core concepts of, 129–130  
   of noise/interference, 140–150  
   of radio spectrum, 130–138  
   of RF behaviors, 139–140, 139f  
 Scissor lifts, 271, 271f  
 Scope, project, 292  
 Scope statements, in codes and standards, 53–56  
 Segment testing, 373, 375–376  
 Semi-rigid cables. *See* Hardline coaxial cables  
 Service antennas. *See* Distribution antennas  
 Service contours, 21  
 Shared channel organization, 134–135, 135f, 178

SI. *See* System integrators

Signal boosters. *See* BDAs

Signal generators, portable, 250, 399*f*

Signal leakage  
 maps of, 341–342, 342*f*  
 testing of, 420–421, 420*f*, 442

Signal power, uplink, 428–429

Signal quality  
 in acceptance testing, 439–442  
 codes and standards on, 67–68  
 measurement of, 410–411  
 in signal to noise ratio, 142

Signal sources  
 codes and standards on monitoring of, 90, 456  
 types of, 190–192

Signal strength  
 in acceptance testing, 441–442  
 codes and standards on, 67–68  
 requirements for two-way radios, 126–127, 126*t*

Signal to interference plus noise ratio (SINR), 140–142, 140*f*

Signal to noise ratio (SNR, S/N, SINR), 140–142  
 with cellular networks, 467, 468*t*  
 definition of, 141  
 exterior performance testing using, 421  
 illustrations of, 140–141, 141*f*, 142*f*  
 in noise figure, 143, 143*f*

Simple channel organization, 134–135, 135*f*, 178

Simplex BDAs, 196, 196*f*

Simplex communication systems, 133, 133*f*, 175, 180

Simulcast networks, 182, 182*f*

Single-line diagrams, 368

SINR. *See* Signal to interference plus noise ratio; Signal to noise ratio

SISO antennas, 219

Site plans, in design phase, 326

Sites. *See* Construction sites; Facilities

Site surveys. *See* Physical facility surveys

Site walks, pre-construction, 369

Smoke dampers, 313, 313*f*

SNR. *See* Signal to noise ratio

Software, 272–275, 294. *See also* Design software

Special environments  
 in design phase, 331  
 physical facility surveys for, 316–317

Specialty contractors, roles and responsibilities of, 24, 27

Specification documentation, 325

Spectrum, definition of, 130–131. *See also* Radio spectrum

Spectrum analyzers, 247–248, 247*f*, 385

Splitters, 221–223  
 in design phase, 338–339  
 installation of, 377–378, 377*f*, 378*f*  
 types of, 221–223, 221*f*

Spot testing, 411

Sprinkler systems, 10, 69–70, 69*f*

Spurious emissions (spurs), 149–150, 150*f*

Squelch circuits, 399, 432–433, 433*f*

Staffing. *See* Personnel

Staging, of materials and equipment, 168–169, 298, 311

Stakeholders, 19–32. *See also specific types*  
 in acceptance testing, 439  
 benefits of handbook for, 9–10  
 in design phase, 323–324  
 roles and responsibilities of, 19–32, 60

Standards, ERCES, 47–104. *See also specific standards*  
 vs. codes, 56–58  
 definition of, 56  
 determining applicability of, 51–53  
 development process for, 102–103, 103*f*  
 equivalency, alternatives, and modifications in, 59  
 key components of, 61–102  
 list of most important, 48  
 older vs. newer versions of, 48  
 online access to, 47, 47*f*, 49  
 origins and history of, 49  
 reference table of, 105–111  
 scope statements of, 53–56  
 types of, 58

Standby power, 209–211. *See also* Battery backup  
 codes and standards on, 85–86, 86*f*

Submittals, 349–360. *See also* Documentation  
 acceptance phase, 352, 445, 446*t*, 449  
 final, 301, 449–452  
 pre-installation, 295, 349–352  
 preliminary phase, 352–360

Subscriber Units (SUs), 178

Subtraction, 114–117, 120–121

Supervising stations, 454

Surveys. *See* Physical facility surveys; RF surveys

SUs (Subscriber Units), 178

Sweep testing, 254, 254*f*, 370, 374–377

System commissioning. *See* Commissioning

System integrators (SIs). *See also* Project process  
 qualifications checklist for, 29  
 roles and responsibilities of, 24, 32, 33  
 roles and skills of teams of, 277–287  
 signal boosters under, 39  
 sub-categories of, 24

System testing, 406  
 codes and standards on, 96–97  
 in installation phase, 373, 376

Talk-around radios, 133, 175. *See also* Simplex communication systems

Talk groups, 135

Tappers, 221–223, 221*f*, 223*f*  
 in design phase, 332, 339, 339*f*

TDI interference, 147–148, 147*f*–148*f*, 197

TDMA (time division multiple access), 132, 138, 138*f*, 180, 180*f*, 180*t*

Technical criteria, codes and standards on, 83–85

Technical process, 153, 155, 157*t*

Technicians. *See also specific types*  
 benefits of handbook for, 9  
 in field project teams, 279

Technician Trainees (NICET Level I), 13, 280, 281*t*

Telecommunications Grounding Bus Bars (TGGBs), 389, 389*f*

Telecommunications Industry Association (TIA), codes and standards of, 102, 106, 110

Telecommunications infrastructure, master plan for, 29

Temporary Certificate of Occupancy, 20, 31, 441

Tens, rule of, 118, 120, 121

Termination loads, 232, 232*f*, 255, 255*f*

Termination tools, 373

Test antennas, 256, 256*f*

Test equipment, 245–276. *See also specific types*  
 coax cable, 251–256  
 electrical, 251  
 list of, 245–246  
 optical, 256–259, 382  
 RF, 247–250, 406

Test frequencies, in commissioning, 399



- Testing. *See also specific components and tests*  
 annual, 96–97, 458–459, 459f  
 of cellular services, 467, 468t  
 field, codes and standards on, 64–65  
 five-year, 96–97  
 overview of, 407–409  
 radio network types in, 175  
 system (*See* System testing)  
 by third-party testing organizations, 25
- TETRA systems, 175
- TGBBs. *See* Telecommunications Grounding Bus Bars
- Thermal noise floor  
 calculating, 142–143  
 definition of, 142  
 science of, 142–145
- Third-party management, 27–28
- Third-party operators (3PO), 27–28
- Third-party testing organizations, roles and responsibilities of, 25
- Three-radio testing, 430–431, 430f
- Threes, rule of, 118, 120, 121
- TIA. *See* Telecommunications Industry Association
- Time delay interference (TDI), 147–148, 147f–148f, 197
- Time division multiple access (TDMA), 132, 138, 138f, 180, 180f, 180t
- Tools, 245–276. *See also specific types*  
 cable prep and testing, 251–256, 373  
 dust control, 270  
 electrical test, 251  
 hand, 246–247  
 lifts and scaffolding, 271  
 list of, 245–246  
 optical, 256–259  
 in project process, 157, 157t  
 RF survey, 249, 274, 305, 307–309  
 RF test, 247–250, 406  
 safety, 259–271  
 software/support, 272–275
- Torque wrenches, 252, 378
- Training  
 BICSI, 362  
 design software, 321, 322f  
 manufacturer, 372, 373, 397  
 safety, 299, 362–363
- Transmission mask, 148
- Transportable repeaters, 183–185, 184f–185f
- Trunked radio systems  
 P25, 179–180, 179f, 180f  
 science of, 133–135, 135f  
 testing of, 175
- TSB-88-B, 102, 110
- Tunnels  
 designing for, 331, 331f  
 radiating cables in, 219, 219f, 221
- Two-radio testing, 430–432, 431f
- Two-way radios  
 signal strength requirements for, 126–127, 126t  
 as testing tools, 250, 250f
- UL 2196 standard, 111
- UL 2524 standard, 99–100  
 active vs. passive components under, 190  
 key components of, 25–26, 99
- on listing of equipment, 65–66  
 need for, 99  
 origins and development of, 99  
 other codes and standards on, 99–100  
 overview of, 111  
 scope of, 99
- UL 60950-1 standard, 111
- UL Research Institutes  
 overview of standards of, 111  
 roles and responsibilities of, 25–26
- Underwriters Laboratory. *See* UL
- Uplink (UL)  
 initial adjustment, 401  
 testing and optimization of, 421–429
- Uplink gain  
 maximum, 422–426  
 optimization of, 429
- Uplink noise link budget, 126, 144–145, 144t
- Uplink noise power, measurement of, 427–428, 427f
- Uplink signal power, optimization of, 428–429
- Validation  
 of active components, 397  
 of live signal, 401  
 of passive components, 399
- Vehicle mounted repeaters, 183–185, 184f–185f, 186t
- Verification testing  
 antenna, 379, 399, 415–416, 415f, 419–420, 419f  
 donor signal, 418–419, 418f  
 system, 406
- Vests, safety, 263–264, 264f
- Voltage standing wave ratio (VSWR), 254, 254f
- Voting receivers, 183, 183f
- Walk path testing, 407  
 in Initial In-Building Coverage Assessment, 414  
 procedure for, 414, 414f  
 tools for, 307–309, 308f, 309f  
 use and timing of, 407, 414
- Walks  
 bid, 303  
 site, pre-construction, 369
- Wall mounting, installation of, 387–388
- Wall penetrations, in physical facility surveys, 312–313, 313f
- Warning labels, 43, 45f, 171f, 212, 212f
- Watts (W), 114–119, 117t, 121
- Waveguiding effects, 124
- Wide area networks, 181, 181f
- Wilkinson splitters, 221, 221f
- Wind ratings, antenna, 217
- Wireless dead zones, in-building, 1–8  
 definition of, 1  
 overview of problem of, 1–8, 2f  
 solution to problem of, 127, 127f
- Worker safety. *See* Safety
- Yagi antennas, 215, 215f, 217–219, 217f–219f, 256
- Zip ties, 371