Telecommunications Distribution Methods

MANUAL

13th Edition

Volume 1
TDMM 13th Edition Evolving With Our Industry

Welcome to the 13th edition of the Telecommunications Distribution Methods Manual (TDMM). While I have worked on many earlier versions of this manual, this is the first edition that I have had the privilege of releasing as Chair of BICSI’s Technical Information and Methods (TI&M) committee.

As you can imagine, there are countless people who selflessly gave of their time to help produce BICSI’s flagship manual. I would like to thank the hundreds of volunteers who spent thousands of hours contributing and shaping the technical information within these pages.

Thanks also to the hard working Technical Publications & Design staff at BICSI headquarters that go above and beyond in every phase of production. They have the unenviable job of motivating those volunteers (who have plenty of responsibilities from their paying jobs) into meeting deadlines, focusing on tasks, and getting jobs done, and they do all this in a positive and professional manner: they are truly BICSI.

There were many changes to the TDMM 13th edition that are far too numerous to list, but here are some of the significant changes:

- **Chapter 5: Horizontal Distribution Systems**
  - 12th edition Chapter 4: Work Areas, was updated and merged into this chapter
  - A new section, Passive Optical Networks (PON), was added
  - 12th edition appendix material related to the Americans with Disabilities Act (ADA) was merged into this chapter
  - Many new figures and tables were inserted into this chapter

- **Chapter 6: ITS Cables and Connecting Hardware**
  - Significant subject matter updates were incorporated
  - Many new tables and figures were inserted

- **Chapter 10: Telecommunications Administration**
  - Much of the information was updated to reflect new codes and standards

- **Chapter 13: Audiovisual Systems**
  - 12th edition Chapter 14: Private CATV Distribution Systems and 12th edition Chapter 15: Distributed Paging Systems, were merged into this chapter

- **Chapter 15: Data Networks**
  - Stripped down by almost 50 percent due to the removal of legacy technologies

- **Chapter 16: Wireless Networks**
  - A significant amount of new material concerning distributed antenna systems (DAS) was added
• **Chapter 21: Business Development and Project Management**
  – The Business Development section is new material
  – 12th edition Chapter 13: Design, Construction, and Project Management, was updated and merged into this chapter as its own section

• **All Chapters**
  – A significant amount of legacy technology information has been removed
  – More than 90 percent of all of the metric conversions now have the approximate symbol (≈) placed in front of the metric numbers as a result of the TI&M Committee Metric Conversion Task Force conclusions. This symbol has also been placed in more than 90 percent of the illustrations and tables that have metric conversions within them (this will be evident in all text, illustrations, and tables of all BICSI technical manuals going forward)
  – The chapter order and sequence between the 12th and 13th editions has changed significantly

Each new edition of the *TDMM* reflects the evolution of our association and the work of our volunteer members. The reorganization and addition of material in this 13th edition is indicative of the next phase of this evolution, which will come into focus with our manual modularization efforts in the *TDMM* 14th edition.

Before I close this preface, I would like to give a final thank you to a special person who is my biggest supporter. I could not do what I do, be who I am, or give what I give without the constant and unselfish gifts of my loving spouse Darlene.

Sincerely,

Robert Gross, RCDD, OSP
Chair, Technical Information and Methods (TI&M) Committee, BICSI
Please place the chapter tabs and appendix tabs in front of the title page for each chapter and appendix.
The section tabs should be inserted in front of the following pages:

Chapter 1: Principles of Transmission
1-1 Section 1: Metallic Media
1-83 Section 2: Optical Fiber

Chapter 5: Horizontal Distribution Systems
5-5 Section 1: Horizontal Cabling Systems
5-53 Section 2: Horizontal Pathways
5-103 Section 3: ADA Requirements

Chapter 21: Business Development and Project Management
21-1 Business Development
21-5 Project Management
WARNING

It is the responsibility of the user of this manual to determine the use of the applicable safety and health practices (e.g., in the United States, Occupational Safety and Health Administration [OSHA], National Electrical Code® [NEC®], National Electrical Safety Code [NESC®]) associated with ITS installation and design practices. BICSI shall not be liable to the purchaser or any other entity with respect to any liability, loss, or damage caused directly or indirectly by application or use of this manual. No project is so important nor any completion deadline so critical to justify nonconformance to ITS industry standards. This manual does not address safety issues associated with its use. It is the telecommunications professional’s responsibility to use established and appropriate safety and health practices and to determine the applicability of all regulatory issues.
About BICSI... Advancing Information Technology Systems

BICSI Vision Statement

BICSI® is the worldwide preeminent source of information, education, and knowledge assessment for the constantly evolving information technology systems (ITS) industry.

BICSI Mission Statement

BICSI’s mission is to:

• Lead the ITS industry with excellence in publications, education, and knowledge assessment.
• Advance our members’ ability to deliver the highest quality products and services.
• Provide our members with opportunities for continual improvement and enhanced professional stature.

Thank you for ordering the new thirteenth edition of BICSI’s Telecommunications Distribution Methods Manual (TDMM). The officers of BICSI are pleased to provide an up-to-date design reference manual that offers proven telecommunications design guidelines and methods accepted by the ITS industry. Volunteers outside the United States and Canada have provided valuable input to make the newest edition of the TDMM a valuable tool for an international audience.

BICSI provides information, education and knowledge assessment for individuals and companies in the ITS industry. We serve more than 23,000 ITS professionals, including designers, installers and technicians. These individuals provide the fundamental infrastructure for telecommunications, audio/video, life safety and automation systems. Through courses, conferences, publications and professional registration programs, BICSI staff and volunteers assist ITS professionals in delivering critical products and services, and offer opportunities for continual improvement and enhanced professional stature. Headquartered in Tampa, Florida, USA, BICSI membership spans nearly 100 countries.

BICSI 2012-14 Board of Directors

President: Jerry L. Bowman, RCDD, NTS, RTPM, CISSP, CDCDP
President-Elect: Michael Collins, RCDD, RTPM, CCDA, NCE
Secretary: Robert “Bob” Erickson, RCDD, NTS, OSP, WD, RTPM
Treasurer: Brian Ensign, RCDD, NTS, OSP, CSI
Canadian Region Director: Peter Levoy, RCDD
European Region Director: Brendan “Greg” Sherry, RCDD, NTS, WD
U.S. North-Central Region Director: Christy Miller, RCDD, RTPM
U.S. Northeast Region Director: Carol Everett Oliver, RCDD, ESS
U.S. South Central Region Director: Jeffrey Beavers, RCDD, OSP
U. S. Southeast Region Director: Charles “Chuck” Wilson, RCDD, NTS, OSP
U.S. Western Region Director: Larry Gillen, RCDD, ESS, OSP, CTS
BICSI Executive Director & Chief Executive Officer: John D. Clark Jr., CAE
International Credentials

BICSI’s professional registration programs are internationally recognized.

- **RCDD® Credential**
  - Registered Communications Distribution Designer (RCDD®) credential holders demonstrate expertise in the design, implementation, integration of telecommunications and data communications systems, and infrastructure components.

- **RITP Credential**
  - Registered Information Technology Professional (RITP) credential holders demonstrate non-design expertise in the ITS industry.

- **RTPM Credential**
  - Registered Telecommunications Project Management (RTPM) credential holders demonstrate proficiency in a vast collection of telecommunications project management principles, concepts, tools, and technology.

- **OSP Credential**
  - Outside Plant (OSP) design credential holders demonstrate proficiency in the ability to understand and apply a vast collection of OSP technology, including right-of-way, route design, media selection, cabling hardware, bonding and grounding (earthing), and electrical protection systems.

- **ESS Credential**
  - Electronic Safety and Security (ESS) design credential holders demonstrate the ability to understand and apply a vast collection of ESS technology, including principles of security, design process, access control, surveillance systems, intrusion detection systems, fire detection and alarm systems, notification, communication and display devices, special systems, network security, system integration, project management, and systems operation and commissioning.

- **DCDC Credential**
  - Data Center Design Consultant (DCDC) credential holders demonstrate proficiency in the knowledge and ability over multiple facets within data center design, including the planning, implementing and making of critical decisions regarding data centers.

- **BICSI ITS Installer 1; ITS Installer 2, Copper; ITS Installer 2, Optical Fiber; and ITS Technician**
  - BICSI ITS Installers and Technicians are proficient in the latest ITS industry standards and codes requirements and in various topics, including the pulling, terminating, testing, and troubleshooting of copper and optical fiber cable using BICSI global best practices as a guide.
This technical design reference manual is not a single source document but a compendium of many sources of ITS industry-related practices, processes, and procedures.

The information contained in this technical design reference manual includes, but is not limited to, national and international codes, de jure and de facto standards, and industry-accepted best practices. All source information can be found in Appendix A: Codes, Standards, Regulations, and Organizations and the Bibliography section of this manual.
Acknowledgments

BICSI’s Technical Information and Methods (TI&M) Committee serves to coordinate the information within all of BICSI’s technical publications. BICSI officers, membership, and Publications staff wish to thank the TI&M Committee and its many volunteer contributors who helped in the development of the thirteenth edition of BICSI’s Telecommunications Distribution Methods Manual (TDMM).

The following dedicated TI&M Subject Matter Expert Team Leaders (SMETLs) and Subject Matter Experts (SMEs) provided the key expertise required for the development of this manual’s technical content:

**TI&M Chair and TDMM 13th Edition SMETL:** Robert M. Gross, RCDD, OSP; GroTech

**TI&M Vice-Chair:**

**Chapter 1: Principles of Transmission**

**Chapter SMETL:** Paul Kish, ITS Consultant; Belden

**SME Contributors:** Richard S. Anderson, RCDD; Servamatic
Beatriz M. “Betty” Bezos, RCDD, NTS, OSP, WD, ESS, CT; Ross & Baruzzini
Robert Y. Faber Jr., RCDD, NTS; Snake Tray
Brent J. Lehmkuhl, RCDD; Black & Veatch
F. Patrick Mahoney, RCDD; Cannon Design

**Chapter 2: Electromagnetic Compatibility**

**Chapter SMETL:** Dr. Paulo Sérgio Marin, EE/BSc MSc, PhD; Paulo Marin Consulting Services

**SME Contributors:** Gordon J. Ash, RCDD, CTS; Leidos
Robert Y. Faber Jr., RCDD, NTS; Snake Tray
George M. Fewell, RCDD; NCI Information Systems Inc.
Paul Kish, ITS Consultant; Belden
Ken M. Michaels, RTPM; iGround
Igor G. Smirnoff, RCDD; Signamax Connectivity Systems
### Acknowledgments, continued

#### Chapter 3: Telecommunications Spaces

**SME Contributors:**
- **Richard S. Anderson**, RCDD; Servamatic
- **Gordon J. Ash**, RCDD, CTS; Leidos
- **George M. Fewell**, RCDD; NCI Information Systems Inc.
- **Shawna Irwin**, RCDD, WD; City of Overland Park, Kansas
- **F. Patrick Mahoney**, RCDD; Cannon Design
- **Dr. Paulo Sérgio Marin**, EE/BSc MSc, PhD; Paulo Marin Consulting Services
- **John Romanski**, OSP, WD, ESS, RTPM, DCDC; University of Central Florida
- **Ronald S. Timko**, PE, LEED AP; MDA Engineering, Inc.
- **Donald T. Wright**, RCDD; CH2M Hill

#### Chapter 4: Backbone Distribution Systems

**SME Contributors:**
- **John C. Adams**, RCDD, OSP; Adams Telecom Systems
- **Richard S. Anderson**, RCDD; Servamatic
- **Robert M. Gross**, RCDD, OSP; GroTech
- **Robert B. Hertling**, RCDD, OSP; Parsons Transportation Group
- **Joseph L. Leger**, RCDD; Syska Hennessy Group
- **Ken M. Michaels**, RTPM; iGround
- **John Romanski**, OSP, WD, ESS, RTPM, DCDC; University of Central Florida
- **Scott Smith**, RCDD, ITS Technician; Teletach Consulting
- **Donald T. Wright**, RCDD; CH2M Hill
Acknowledgments, continued

Chapter 5: Horizontal Distribution Systems

Chapter SMETL: Robert Y. Faber Jr., RCDD, NTS; Snake Tray

SME Contributors: John C. Adams, RCDD, OSP; Adams Telecom
Richard S. Anderson, RCDD; Servamatic
Dustin Bateman, PON Consultant; VT Group
Beatriz M. “Betty” Bezos, RCDD, NTS OSP, WD, ESS, CT; Ross & Baruzzini
James (Ray) Craig, RCDD, NTS, ITS Technician; Craig Consulting Services
Dave Cunningham, RCDD, PON Consultant; Corning Cable Systems
Robert S. “Bob” Erickson, RCDD, NTS, OSP, WD, RTPM; Communications Network Design
Robert M. Gross, RCDD, OSP; GroTech
Robert B. Hertling, RCDD, OSP; Parsons Transportation Group
Christopher A. Hillyer, OSP, RITP, ITS Technician; BICSI Master Instructor
Sean Kelly, RCDD, PON Consultant; TE Connectivity
Joseph L. Leger, RCDD; Syska Hennessy Group
F. Patrick Mahoney, RCDD; Cannon Design
Jeff Silveira, RITP, CAE, AStd; BICSI Director of Standards
Igor G. Smirnoff, RCDD; Signamax Connectivity Systems
Scott Smith, RCDD, ITS Technician; Teletach Consulting
Loni Le Van-Etter, 3M Communications
Michael Watts, PON Consultant; Verizon Federal Networking Systems
Michael Wilson, RCDD, PON Consultant; Tellabs

Chapter 6: ITS Cables and Connecting Hardware

Chapter SMETLs: Robert Y. Faber Jr., RCDD, NTS; Snake Tray
Igor G. Smirnoff, RCDD; Signamax Connectivity Systems

SME Contributors: John C. Adams, RCDD, OSP; Adams Telecom
Richard S. Anderson, RCDD; Servamatic
Shawna Irwin, RCDD, WD; City of Overland Park, Kansas
Philip W. Janeway, RCDD; tw telecom
Brent J. Lehmkuhl, RCDD; Black & Veatch
Jeff Silveira, RITP, CAE, AStd; BICSI Director of Standards
Scott Smith, RCDD, ITS Technician; Teletach Consulting
Acknowledgments, continued

Chapter 7: Firestop Systems

Chapter SMETL: 
James P. Stahl Jr., CFPS, CDT, Specified Technologies, Inc.

SME Contributors: 
Edward F. Coye, RCDD, NTS, OSP, WD, DCDC; Tyco AMP
Robert Y. Faber Jr., RCDD, NTS; Snake Tray
Philip W. Janeway, RCDD; tw telecom
Brent J. Lehmkuhl, RCDD; Black & Veatch
Julio Lopes, Specified Technologies, Inc.
Justin Pine, Specified Technologies, Inc.
John Romanski, OSP, WD, ESS, RTPM, DCDC; University of Central Florida

Chapter 8: Bonding and Grounding (Earthing)

Chapter SMETLs: 
Ken M. Michaels, RTPM; iGround
Mark S. Harger, B&G Consultant; Harger Lightning & Grounding

SME Contributors: 
Richard S. Anderson, RCDD; Servamatic
Edward F. Coye, RCDD, NTS, OSP, WD, DCDC; Tyco AMP
Robert Y. Faber Jr., RCDD, NTS; Snake Tray
Philip W. Janeway, RCDD; tw telecom
Justin Pine, Specified Technologies, Inc.
John Romanski, OSP, WD, ESS, RTPM, DCDC; University of Central Florida

Chapter 9: Power Distribution

Chapter SMETL: 
Brent J. Lehmkuhl, RCDD; Black & Veatch

SME Contributors: 
Richard S. Anderson, RCDD; Servamatic
John C. Adams, RCDD, OSP; Adams Telecom
Shawna Irwin, RCDD, WD; City of Overland Park, Kansas
John Romanski, OSP, WD, ESS, RTPM, DCDC; University of Central Florida
Vince Saturmo, PE, LEED AP, DCEP; Black & Veatch
Jeff Silveira, RITP, CAE, AStd; BICSI Director of Standards
Ronald S. Timko, PE, LEED AP; MDA Engineering, Inc.
John R. Turner, PE, LC, LEED AP; Wiley/Wilson
Acknowledgments, continued

Chapter 10: Telecommunications Administration

Chapter SMETL: Jonathan L. Jew, ITS Consultant; J&M Consultants, Inc.

SME Contributors: John C. Adams, RCDD, OSP; Adams Telecom
Beatriz M. “Betty” Bezos, RCDD, NTS, OSP, WD, ESS, CT; Ross & Baruzzini
Robert S. “Bob” Erickson, RCDD, NTS, OSP, WD, RTPM; Communications Network Design
Robert Y. Faber Jr., RCDD, NTS; Snake Tray
Todd Fries; Hellermann Tyton
Steven R. Huffaker, RCDD; JPMorgan Chase
Alexander Jew, ITS Consultant; J&M Consultants, Inc.
F. Patrick Mahoney, RCDD; Cannon Design
Gene E. Malone, RCDD; TE Connectivity

Chapter 11: Field Testing of Structured Cabling

Chapter SMETL: Robert Jensen, RCDD, The University of Texas at Austin

SME Contributors: Richard S. Anderson, RCDD; Servamatic
Robert M. Gross, RCDD, OSP; GroTech
Robert B. Hertling, RCDD, OSP; Parsons Transportation Group
Ken M. Michaels, RTPM; iGround

Chapter 12: Outside Plant

Chapter SMETL: John C. Adams, RCDD, OSP; Adams Telecom

SME Contributors: Richard S. Anderson, RCDD; Servamatic
Robert M. Gross, RCDD, OSP; GroTech
Joseph L. Leger, RCDD; Syska Hennessy Group
Ken M. Michaels, RTPM; iGround
John Romanski, OSP, WD, ESS, RTPM, DCDC; University of Central Florida
Acknowledgments, continued

Chapter 13: Audiovisual Systems

Chapter SMETL: Gordon J. Ash, RCDD, CTS; Leidos

SME Contributors: John C. Adams, RCDD, OSP; Adams Telecom
Edward F. Coye, RCDD, NTS, OSP, WD, DCDC; Tyco AMP
Christopher A. Hillyer, OSP, RITP, ITS Technician; BICSI Master Instructor
Shawna Irwin, RCDD, WD;
City of Overland Park, Kansas
Philip W. Janeway, RCDD; tw telecom
Brent J. Lehmkuhl, RCDD; Black & Veatch
Dr. Paulo Sérgio Marin, EE/BSc MSc, PhD;
Paulo Marin Consulting Services
John Romanski, OSP, WD, ESS, RTPM, DCDC;
University of Central Florida

Chapter 14: Building Automation Systems

Chapter SMETL: Dr. Paulo Sérgio Marin, EE/BSc MSc, PhD;
Paulo Marin Consulting Services

SME Contributors: Gordon J. Ash, RCDD, CTS; Leidos
Edward F. Coye, RCDD, NTS, OSP, WD, DCDC; Tyco AMP
Robert Y. Faber Jr., RCDD, NTS; Snake Tray
George M. Fewell, RCDD;
NCI Information Systems Inc.
Jeff Silveira, RITP, CAE, AStd;
BICSI Director of Standards

Chapter 15: Data Networks

Chapter SMETL: Chris Scharrer, RCDD, NTS, OSP, WD;
DCS Technology Design, LLC

SME Contributors: Richard S. Anderson, RCDD; Servamatic
Cory Boon, RCDD; coryandsteve.com
Robert M. Gross, RCDD, OSP; GroTech
Shawna Irwin, RCDD, WD;
City of Overland Park, Kansas
Steve Kepekci, RCDD; coryandsteve.com
Ken M. Michaels, RTPM; iGround
Jeff Silveira, RITP, CAE, AStd;
BICSI Director of Standards
Acknowledgments, continued

Chapter 16: Wireless Networks

Chapter SMETL: Robert Y. Faber Jr., RCDD, NTS; 
Snake Tray

SME Contributors: Joseph A. Concepcion, RCDD, OSP; 
Physical Layer Telecommunications Consulting, LLC
Robert S. “Bob” Erickson, RCDD, NTS, OSP, WD, RTPM; 
Communications Network Design
Robert B. Hertling, RCDD, OSP; 
Parsons Transportation Group
Shawna Irwin, RCDD, WD; 
City of Overland Park, Kansas
Joseph L. Leger, RCDD; Syska Hennessy Group
Mike Patterson, RCDD, PE; 
Physical Layer Telecommunications Consulting, LLC
Timothy V. Peters, RCDD, WD; Tech Knowledge, Inc.
John Romanski, OSP, WD, ESS, RTPM, DCDC; 
University of Central Florida
Ward Sellars, RCDD, WD; 
Hidi Rae Consulting Engineers, Inc.

Chapter 17: Electronic Safety and Security

Chapter SMETL: Dr. Paulo Sérgio Marin, EE/BSc MSc, PhD; 
Paulo Marin Consulting Services

SME Contributors: Richard S. Anderson, RCDD; Servamatic
Edward F. Coye, RCDD, NTS, OSP, WD, DCDC; 
Tyco AMP
Robert Y. Faber Jr., RCDD, NTS; Snake Tray
Philip W. Janeway, RCDD; tw telecom
Dr. Paulo Sérgio Marin, EE/BSc MSc, PhD; 
Paulo Marin Consulting Services
Reese J. Miller Jr., RCDD, PE; Miller Engineering
John Romanski, OSP, WD, ESS, RTPM, DCDC; 
University of Central Florida
Acknowledgments, continued

Chapter 18: Data Centers

Chapter SMETL: Stephen Banks, RCDD; Nightlake

SME Contributors: Robert S. “Bob” Erickson, RCDD, NTS, OSP, WD, RTPM; Communications Network Design
Robert B. Hertling, RCDD, OSP; Parsons Transportation Group.
Steven R. Huffaker, RCDD; JPMorgan Chase
Alexander Jew, ITS Consultant;
J&M Consultants, Inc.
Jonathan L. Jew, ITS Consultant;
J&M Consultants, Inc.
Joseph L. Leger, RCDD; Syska Hennessy Group
Jeff Silveira, RTP, CAE, AStd;
BICSI Director of Standards

Chapter 19: Health Care

Chapter SMETL: Joseph L. Leger, RCDD; Syska Hennessy Group

SME Contributors: John C. Adams, RCDD, OSP; Adams Telecom
Gordon J. Ash, RCDD, CTS; Leidos
George M. Fewell, RCDD;
NCI Information Systems Inc.

Chapter 20: Residential Cabling

Chapter SMETL: Robert Jensen, RCDD;
The University of Texas at Austin

SME Contributors: John C. Adams, RCDD, OSP; Adams Telecom
Richard S. Anderson, RCDD; Servamatic
George M. Fewell, RCDD;
NCI Information Systems Inc.
Robert M. Gross, RCDD, OSP; GroTech
Ken M. Michaels, RTPM; iGround
### Acknowledgments, continued

**Chapter 21: Business Development and Project Management**

**Chapter SMETL:** Shawna Irwin, RCDD, WD; City of Overland Park, Kansas

**SME Contributors:**
- Richard S. Anderson, RCDD; Servamatic
- Gordon J. Ash, RCDD, CTS; Leidos
- Edward F. Coye, RCDD, NTS, OSP, WD, DCDC; Tyco AMP
- Robert S. “Bob” Erickson, RCDD, NTS, OSP, WD, RTPM; Communications Network Design
- Robert B. Hertling, RCDD, OSP; Parsons Transportation Group
- Philip W. Janeway, RCDD; tw telecom
- Joseph L. Leger, RCDD; Syska Hennessy Group
- F. Patrick Mahoney, RCDD; Cannon Design
- Kevin Seeley, RCDD, RTPM, ITS Technician; Kevin Seeley, LLC

**Appendix A: Codes, Standards, Regulations, and Organizations**

**Appendix SMETL:** Robert B. Hertling, RCDD, OSP; Parsons Transportation Group

**SME Contributors:**
- Beatriz M. “Betty” Bezos, RCDD, NTS, OSP, WD, ESS, CT; Ross & Baruzzini
- Robert Y. Faber Jr., RCDD, NTS; Snake Tray
- Anthony Frassetta, RCDD; A|E Works
- Jeff Silveira, RITP, CAE, AStd; BICSI Director of Standards
- Philip W. Janeway, RCDD; tw telecom
- Robert Jensen, RCDD; The University of Texas at Austin
- Peter Olders, RCDD, NTS, OSP, ITS Technician; Terra Communications, Inc.
### Acknowledgments, continued

**Appendix B:**
Network Interfaces and Demarcation Points in the United States

**SME Contributors:**
- John C. Adams, RCDD, OSP; *Adams Telecom*
- Robert B. Hertling, RCDD, OSP; *Parsons Transportation Group*
- Shawna Irwin, RCDD, WD; *City of Overland Park, Kansas*
- Brent J. Lehmkuhl, RCDD; *Black & Veatch*
- John Romanski, OSP, WD, ESS, RTPM, DCDC; *University of Central Florida*

**Appendix C:**
Regulations and Standards for Emissions and Immunity

**SME Contributors:**
- Edward F. Coye, RCDD, NTS, OSP, WD, DCDC; *Tyco AMP*
- Philip W. Janeway, RCDD; *tw telecom*
- John Romanski, OSP, WD, ESS, RTPM, DCDC; *University of Central Florida*

**Appendix D:**
Mechanical, Ingress, Climatic/Chemical, and Electromagnetic Considerations

**SME Contributors:**
- Beatriz M. “Betty” Bezos, RCDD, NTS, OSP, WD, ESS, CT; *Ross & Baruzzini*
- Robert Y. Faber Jr., RCDD, NTS; *Snake Tray*
- F. Patrick Mahoney, RCDD; *Cannon Design*
Acknowledgments, continued

Appendix E: Legal Considerations for the ITS Distribution Designer

Appendix SMETL: M. Georgia Gibson-Henlin, Attorney-at-Law; Nunes Schoefield Deleon & Co.

SME Contributors: Gordon J. Ash, RCDD, CTS; Leidos
George M. Fewell, RCDD;
NCI Information Systems Inc.
Robert M. Gross, RCDD, OSP; GroTech
Dr. Paulo Sêrgio Marin, EE/BSc MSc, PhD;
Paulo Marin Consulting Services

Bibliography:

SMETL: Robert B. Hertling, RCDD, OSP;
Parsons Transportation Group

SME Contributors: TDMM 13th Edition Revision Team

Master Glossary:

SMETL: Robert Y. Faber Jr., RCDD, NTS; Snake Tray

SME Contributors: Gordon J. Ash, RCDD, CTS; Leidos
Joseph A. Concepcion, RCDD, OSP;
Physical Layer Telecommunications Consulting, LLC
Mike Patterson, RCDD, PE;
Physical Layer Telecommunications Consulting, LLC

Index:

Jeff Silveira, RITP, CAE, AStd;
BICSI Director of Standards

John C. Adams, RCDD, OSP  
Richard S. Anderson, RCDD  
Gordon J. Ash, RCDD, CTS  
Edward F. Coye, RCDD, NTS, OSP, WD, DCDC  
Robert S. “Bob” Erickson, RCDD, NTS, OSP, WD, RTPM  
Robert Y. Faber Jr., RCDD, NTS  
George M. Fewell, RCDD  
Robert M. Gross, RCDD, OSP  
Robert B. Hertling, RCDD, OSP  
Shawna Irwin, RCDD, WD  
Philip W. Janeway, RCDD  
Joseph L. Leger, RCDD  
Brent J. Lehmkuhl, RCDD  
F. Patrick Mahoney, RCDD  
Dr. Paulo Sérgio Marin, EE/BSc MSc, PhD  
Ken M. Michaels, RTPM  
John Romanski, OSP, WD, ESS, RTPM, DCDC

BICSI staff attending:  
Nicole Anastasia Bryson  
John Ditzel  
Jeff Giarrizzo  
Clarke W. Hammersley  
Karen Jacob  
Jeff Silveira, RITP, CAE, AStd.  
Paul Weintraub, RCDD, ESS, RTPM, ITS Technician

Editorial Review Logistics:  
Lois Rosa
The following BICSI Professional Development staff members produced this manual at BICSI World Headquarters, Tampa, FL:

**Acting Vice President of Professional Development:**
John D. Clark Jr., CAE, BICSI Executive Director & CEO

**BICSI **TDMM 13th Edition Project Manager/ Director of Publications:**
Clarke W. Hammersley

**TDMM 13th Edition Lead Technical Editor:**
Karen Jacob

**TDMM 13th Edition Co-Technical Editors:**
Jeff Giarrizzo
Amy Woodland (under contract)

**TDMM 13th Design and Production:**
John Ditzel, Senior Publications Designer
Catherine Nold, Publications Designer

In fond memory of Nicole Anastasia Bryson, Publications Designer, who skillfully formatted much of this manual shortly before her passing.

1987-2013
BICSI Policy for Numeric Representation of Units of Measurement

BICSI technical manuals primarily follow the modern metric system, known as the International System of Units (SI). The SI is intended as a basis for worldwide standardization of measurement units. With the exception of conduit measurements, units of measurement in this manual are expressed in general and approximate SI terms, followed by an equivalent imperial (U.S. customary) unit of measurement in parentheses (see exceptions listed below):

- In general, approximate (soft) conversions are used in this manual and are denoted with the approximate symbol (≈) in front of the metric number. Approximate conversions are considered reasonable and practicable; they are not precise equivalents. In some instances, equivalents (hard conversions) may be used when it is a:
  - Manufacturer requirement for a product (e.g., conduit sizes).
  - Standard or code requirement.
  - Safety factor.

- In general, approximate SI units of measurement are converted to an imperial unit of measurement and placed in parentheses. Exception: When the reference material from which the value is pulled is provided in imperial units only, the imperial unit is the benchmark.

- For metric conversion practices, refer to SI 10-02 American Society for Testing and Materials (ASTM)/Institute of Electrical and Electronics Engineers® (IEEE®) SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System.

- Trade size is approximated for both metric and nonmetric purposes. Example: ≈ 100 mm (4 trade size).

- In some instances (e.g., optical fiber media specifications), the physical dimensions and operating wavelengths are designated.
Become a BICSI Member!

BICSI membership is your key to a successful career in the ITS industry. Member benefits extend into the technical, legislative, and even the financial realms of this competitive industry. Membership offers ample opportunities for professional networking and career development and advancement. Join BICSI and combine your expertise with your colleagues in the network of ITS professionals.

Corporate Connection Program

The Corporate Connection Program gives BICSI’s corporate members what they are looking for in one simple package. With six levels of membership to choose from, we are sure there is something that fits your corporate needs. Whether it’s training, conference, or company recognition, the Corporate Connection membership has something for your company needs. Want more information? Call our Membership and Customer Care Department at +1 813.979.1991 or e-mail us at bicsi@bicsi.org.

Member Benefits

Gain the Competitive Edge!

Combine all the benefits of BICSI membership into one complete package and you will understand why BICSI members hold a competitive advantage. BICSI keeps you ahead of your competition through a continuous flow of new information in the fast-changing field of low-voltage distribution systems. By prominently displaying your BICSI membership, you make known your professional ability to industry contacts.

Fast Access to Information

BICSI’s website (www.bicsi.org) is a quick way to find a wide variety of detailed BICSI information. While on the website, find answers to industry questions and communicate with members and colleagues through BICSI’s online forums or social media sites. Search for BICSI members, installers, design specialists, project managers, and RCDDs. Corporate Connection members also have the option of providing a brief company description and a link to their website.

Member Discounts

BICSI members receive substantial discounts on quality education—manuals, standards, design courses, and conferences. BICSI members also receive discounts with some of the BICSI partner organizations.

In addition, BICSI offers health, dental, vision, disability, term life, and accidental death and dismemberment insurance for individuals and companies.
Member Benefits, continued

Training

BICSI presents leading-edge technical training in all phases of ITS distribution design and installation. These vendor-neutral courses are offered at hundreds of locations across the country and around the world, including nearly 100 BICSI Authorized Training Facilities (ATFs) and several Authorized Design Training Providers (ADTPs).

In addition, BICSI can bring first-class training to your location. All BICSI courses are available for on-site training. BICSI credentialed members gain knowledge and continuing education credits (CECs) by attending BICSI courses, conferences, and classes.

BICSI CONNECT

BICSI CONNECT, BICSI’s interactive learning network, offers a flexible way to earn CECs and advance your ITS knowledge. BICSI CONNECT is available 24/7, 365 days a year from the convenience of any computer, accommodating your scheduling needs, while saving you travel and hotel expenses. Visit www.bicsiconnect.org/connect.aspx to view all of the current learning opportunities.

Educational Conferences

Each year, BICSI hosts conferences in North America as well as regularly scheduled conferences held in other BICSI Districts and Regions worldwide. Conferences include presentations by leaders in the ITS industry and opportunities to network with your peers. BICSI also offers a variety of other local educational opportunities in the form of Breakfast Clubs, Lunch and Learns and Pub Clubs. Visit www.bicsi.org for more information.

Technical Publications

Member Benefits, continued

Legislative and Standards Involvement

In the United States, the BICSI Governmental Relations Committee constantly monitors legislative, regulatory, and judicial activities and will advise you of any actions that affect BICSI and its membership. BICSI’s representatives take active roles in standards-setting panels and agencies worldwide.

BICSI Community UPLINK

*BICSI Community UPLINK* features news about upcoming conferences, workshops, and region meetings; training and exam schedules; announcements from the Board of Directors; new publications; and other newsworthy BICSI information.

Recruiting and Job Search Engine

BICSI’s ITS-jobs.com offers the ITS industry an effective tool to bring employers and job seekers together. ITS-jobs.com has an expanded number of resumes and jobs posted and offers an important service for BICSI members and the entire ITS industry.

The web-based resume posting, recruiting, and job search engine is truly an interactive tool. Using ITS-jobs.com, job seekers can post, edit, and update resumes. Areas of expertise can be identified so that employers can more easily find qualified candidates. Automatic notifications are sent when job postings match job seeker criteria.

If you are an employer seeking ITS talent, the extensive search capabilities of ITS-jobs.com help filter experience and background to search for the most qualified candidates. You also will have access to statistics such as number of views and number of applications for a job posting.

There is no cost to post and manage resumes and apply for jobs. For posting available jobs, employers pay a fee. A discounted rate applies to employers who are BICSI members.

Complete information can be found at http://careers.its-jobs.com.
Member Benefits, continued

Newsletters and Website

BICSI helps keep you in touch with industry news and association activities through The Journal of Information Technology Systems, BICSI Community UPLINK, ATF Insider, and targeted communications. BICSI’s website (www.bicsi.org) provides immediate information about BICSI activities around the world. The site offers members and visitors the opportunity to register for courses, conferences, and exams and participate in online forum discussion topics.

BICSI members also can view a listing of more than 15,000 BICSI credential holders, including RCDDs, specialty designations, and Registered Installers and Technicians. Promote your company online as a BICSI Corporate Connection Member and include a direct link to your website. Purchase manuals and receive “members-only” access to valuable documents.

Join BICSI Today!

BICSI membership is open to individuals and corporations serving the ITS and building industries. Join BICSI, and combine your expertise with your colleagues in the network of ITS professionals. Complete BICSI information is available upon request. For a membership application or other information, contact:

Membership and Customer Care
8610 Hidden River Parkway
Tampa, FL 33637-1000 USA
Tel.: 800.242.7405 (USA/Canada toll-free)
Tel.: +1 813.979.1991
Fax: +1 813.971.4311
E-mail: bicsi@bicsi.org
Website: www.bicsi.org

We welcome your comments about the TDMM. To do so, simply complete the Reader’s Comment Form on the last page of this Preface and return it to BICSI. Our goal is to make BICSI publications the most important design and reference tools in your office.
Comments? More Information?

For information on how to use this manual, see the following page.

To submit comments about the BICSI *Telecommunications Distribution Methods Manual (TDMM)* or for further information about BICSI, please complete the Reader's Comment Form in this section or contact:

**BICSI World Headquarters**  
8610 Hidden River Parkway  
Tampa, FL 33637-1000 USA  
Tel.: 800.242.7405 (USA/Canada toll-free)  
Tel.: +1 813.979.1991  
Fax: +1 813.971.4311  
E-mail: bicsi@bicsi.org  
Web site: www.bicsi.org
Chapter 1: Principles of Transmission

Section Heading

Part Heading

Part headings are used to discuss major areas of a topic.

- Bullet important terms and phrases.
  - Bullets are often followed by more detailed information.

Figures, examples, and tables are numbered sequentially in a given chapter. Each is followed by a brief descriptive title.

Figure 1.1
Title
Reader’s Comment Form

Telecommunications Distribution Methods Manual (TDMM), 13th edition

You may use this form to communicate your comments about this publication, its organization, or the subject matter. Your comments will be sent to BICSI’s Technical Information and Methods (TI&M) Committee for review and action, if any is deemed appropriate.

Comments (please include specific chapter and page reference; attach a marked-up page when a figure change is needed):

Please complete the following information:

<table>
<thead>
<tr>
<th>last name</th>
<th>first name</th>
<th>middle initial</th>
<th>date</th>
</tr>
</thead>
<tbody>
<tr>
<td>company name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mailing address</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>city</td>
<td>state/province</td>
<td>zip/postal code</td>
<td>country</td>
</tr>
<tr>
<td>daytime phone</td>
<td>fax</td>
<td>e-mail</td>
<td></td>
</tr>
</tbody>
</table>

Thank you for your comments.

Send to:  
Attn: TDMM User Response  
BICSI  
8610 Hidden River Parkway  
Tampa, FL 33637-1000 USA  
or fax to: +1 813.971.4311  
or scan and e-mail to: chammersley@bicsi.org

Office Use Only

Response from Technical Information and Methods Committee:

Class A ☐ Class B ☐ Class C ☐

TI&M Committee chair signature date

TI&M SME chair signature date
# Table of Contents

## Chapter 1: Principles of Transmission

### SECTION 1: METALLIC MEDIA
- Metallic Media .................................................. 1-1
- Electrical Conductors ........................................ 1-2
- American Wire Gauge (AWG) .............................. 1-5
- Insulation ......................................................... 1-5
- Balanced Twisted-Pair Cables ............................ 1-8
- Environmental Considerations .......................... 1-9
- Cable Shielding ............................................... 1-13
- Drain Wires ..................................................... 1-16
- Analog Signals ............................................... 1-17
- Telephony ........................................................ 1-24
- Digital Signals ............................................... 1-30
- Types of Transmission Circuits ....................... 1-42
- Asynchronous and Synchronous Transmission ...... 1-43
- Digital Hierarchy ............................................. 1-44
- Video Transmission ..................................... 1-50
- Transmission Line Concepts ........................... 1-53
- Balanced Twisted-Pair Performance ................ 1-64
- Balanced Twisted-Pair Channel Performance .... 1-65
- Balanced Twisted-Pair Permanent Link Performance 1-69
- Balanced Twisted-Pair Applications ................ 1-70

### SECTION 2: OPTICAL FIBER
- Optical Fiber .................................................. 1-83
- Optical Fiber Transmitters ................................ 1-84
- Optical Fiber Receivers .................................. 1-93
- Optical Fiber Medium ...................................... 1-94
- Bandwidth ....................................................... 1-96
- Optical Fiber Applications Support Information .... 1-108
- Verifying Optical Fiber Performance and Electronics Compatibility 1-110
- Selecting an Optical Fiber Core Size to Application or Original Equipment Manufacturer (OEM) Specifications 1-121
- Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH) Concepts 1-122
- Appendix ......................................................... 1-126
Chapter 2: Electromagnetic Compatibility

Electromagnetic Compatibility (EMC) ........................................... 2-1
Electromagnetics ...................................................................... 2-5
Overview of Electromagnetic Compatibility (EMC) ......................... 2-8
Electromagnetic Interference (EMI)—A Problem ......................... 2-12
Electromagnetic Compatibility (EMC)—The Solution ..................... 2-16
Electromagnetic Interference (EMI) and Cabling ......................... 2-20
Electromagnetic Qualification Parameters ................................. 2-21
Unwanted Signals .................................................................... 2-28
Grounding (Earthing) ................................................................. 2-31
Specific Telecommunications Electromagnetic Compatibility (EMC) Guidelines ......................................................... 2-40
Minimizing Electromagnetic Interference (EMI) ............................ 2-40
Considerations for Electromagnetic Compatibility (EMC) in Cabling Systems .............................................................. 2-42
Interference Reduction in Shielded Rooms ..................................... 2-49
Electromagnetic Interference (EMI) and Bandwidth of Balanced Twisted-Pair Cabling ............................................................ 2-49
Telecommunications Cabling Within Joint-Use Tunnel .................... 2-52

Chapter 3: Telecommunications Spaces

Telecommunications Spaces ......................................................... 3-1
Telecommunications Spaces Considerations ................................ 3-2
Telecommunications Rooms (TRs) and Telecommunications Enclosures (TEs) ............................................................. 3-22
Telecommunications Room (TR) and Telecommunications Enclosure (TE) Applications .......................................................... 3-23
Telecommunications Room (TR) Design ......................................... 3-25
General Requirements for All Telecommunications Enclosures (TEs) ................................................................. 3-30
Equipment Rooms (ERs) ............................................................... 3-32
Equipment Room (ER) Design ...................................................... 3-34
Locating the Equipment Room (ER) ............................................. 3-37
Space Allocation and Layout ........................................................ 3-43
Cable Installation and Pathways ................................................... 3-49
Electrical Power ....................................................................... 3-52
Heating, Ventilation, and Air-Conditioning (HVAC) Environmental Control ................................................................. 3-55
Miscellaneous Considerations ..................................................... 3-58
Design Approval, Buildout, and Final Inspection ............................. 3-59
Entrance Facilities (EFs) ............................................................... 3-61

Chapter 4: Backbone Distribution Systems

Backbone Distribution Systems .................................................... 4-1
Backbone Topologies ................................................................. 4-4
Hierarchical Star Campus Backbone Designs ................................ 4-5
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backbone Cable Lengths</td>
<td>4-12</td>
</tr>
<tr>
<td>Telecommunications Rooms (TRs) and Telecommunications Enclosures (TEs)</td>
<td>4-13</td>
</tr>
<tr>
<td>Building Backbones</td>
<td>4-16</td>
</tr>
<tr>
<td>Choosing Media</td>
<td>4-23</td>
</tr>
<tr>
<td>Backbone Building Pathways (Internal)</td>
<td>4-26</td>
</tr>
<tr>
<td>Miscellaneous Support Facilities</td>
<td>4-33</td>
</tr>
<tr>
<td>Bonding and Grounding (Earthing)</td>
<td>4-35</td>
</tr>
<tr>
<td>Backbone Planning</td>
<td>4-36</td>
</tr>
<tr>
<td>Indoor Hardware</td>
<td>4-38</td>
</tr>
<tr>
<td>Ethernet in the First Mile (EFM)</td>
<td>4-40</td>
</tr>
<tr>
<td>Chapter 5: Horizontal Distribution Systems</td>
<td></td>
</tr>
<tr>
<td>Horizontal Distribution Systems</td>
<td>5-1</td>
</tr>
<tr>
<td>SECTION 1: HORIZONTAL CABLING SYSTEMS</td>
<td></td>
</tr>
<tr>
<td>Horizontal Cabling Systems</td>
<td>5-5</td>
</tr>
<tr>
<td>Horizontal Cabling Media</td>
<td>5-18</td>
</tr>
<tr>
<td>Work Areas and Open Office Cabling</td>
<td>5-21</td>
</tr>
<tr>
<td>Centralized Optical Fiber Cabling</td>
<td>5-39</td>
</tr>
<tr>
<td>Passive Optical Networks (PONs)</td>
<td>5-43</td>
</tr>
<tr>
<td>SECTION 2: HORIZONTAL PATHWAYS</td>
<td></td>
</tr>
<tr>
<td>Horizontal Pathways</td>
<td>5-53</td>
</tr>
<tr>
<td>Types of Horizontal Pathways</td>
<td>5-58</td>
</tr>
<tr>
<td>Ceiling Distribution Systems</td>
<td>5-78</td>
</tr>
<tr>
<td>Other Horizontal Pathways</td>
<td>5-95</td>
</tr>
<tr>
<td>SECTION 3: ADA REQUIREMENTS</td>
<td></td>
</tr>
<tr>
<td>Americans with Disabilities Act (ADA) Requirements</td>
<td>5-103</td>
</tr>
<tr>
<td>Appendix: Disabled Access and the Americans with Disabilities Act (ADA)</td>
<td>5-111</td>
</tr>
<tr>
<td>Chapter 6: ITS Cables and Connecting Hardware</td>
<td></td>
</tr>
<tr>
<td>ITS Cables and Connecting Hardware</td>
<td>6-1</td>
</tr>
<tr>
<td>Balanced Twisted-Pair Cables</td>
<td>6-3</td>
</tr>
<tr>
<td>Optical Fiber Cables</td>
<td>6-15</td>
</tr>
<tr>
<td>Coaxial Cables</td>
<td>6-27</td>
</tr>
<tr>
<td>Balanced Twisted-Pair Connectors</td>
<td>6-36</td>
</tr>
<tr>
<td>Balanced Twisted-Pair Connecting Hardware</td>
<td>6-60</td>
</tr>
<tr>
<td>Balanced Twisted-Pair Connecting Blocks</td>
<td>6-66</td>
</tr>
<tr>
<td>Optical Fiber Connectors</td>
<td>6-82</td>
</tr>
<tr>
<td>Optical Fiber Connecting Hardware</td>
<td>6-95</td>
</tr>
<tr>
<td>Coaxial Connectors</td>
<td>6-101</td>
</tr>
<tr>
<td>Coaxial Connecting Hardware</td>
<td>6-110</td>
</tr>
</tbody>
</table>
# Table of Contents

## Chapter 7: Firestop Systems

- Firestop Systems .......................................................... 7-1
- Firestop and Disaster Avoidance .................................. 7-3
- Fire-Resistance Rated Construction ............................ 7-6
- Firestop Considerations .............................................. 7-8
- Testing and Guidelines for Firestops ......................... 7-11
- Types of Firestop Systems .......................................... 7-20
- Firestop for Brick, Concrete Block, and Concrete Walls  7-35
- Firestop for Framed Wall Assemblies .......................... 7-38
- Firestop for Lath and Plaster Walls ......................... 7-45
- Firestop for Combination Walls ................................. 7-45
- Firestop for Floor Assemblies ..................................... 7-46
- Firestop for Floor/Ceiling Assemblies ....................... 7-47
- Structural Steel Floor Units with Concrete Floor Fill without Suspended Ceiling Membranes ................. 7-51
- Firestop for Roof/Ceiling Assemblies ....................... 7-51
- Fire-Rated Vertical Shafts ........................................... 7-52
- Firestop for Curtain Wall Floor/Ceiling Seals ............ 7-52
- General Firestop Considerations ............................... 7-56
- Appendix A: Approved Firestop Methods .................. 7-58
- Appendix B: Testing and Guidelines for Firestops ........ 7-114

## Chapter 8: Bonding and Grounding (Earthing)

- Bonding and Grounding (Earthing) ............................... 8-1
- Alternating Current (ac) Grounding (Earthing) Electrode System ........................................... 8-5
- Equipment Grounding (Earthing) System ..................... 8-8
- Telecommunications Bonding Infrastructure ................. 8-13
- Lightning Exposure ..................................................... 8-29
- Appendix: Bonding and Grounding (Earthing) Standards ........................................................................ 8-33

## Chapter 9: Power Distribution

- Power Distribution ....................................................... 9-1
- Alternating Current (ac) Power .................................. 9-2
- American Wire Gauge (AWG) ....................................... 9-16
- Alternating Current (ac) Voltage Quality Problems .... 9-20
- Power Distribution ....................................................... 9-29
- Electrical Safety .......................................................... 9-33
- Power System Redundancy ......................................... 9-37
- Power Conditioning/Power Protection ....................... 9-43
- Direct Current (dc) Power ............................................. 9-62
- Installation of Direct Current (dc) Systems ..................... 9-73
# Table of Contents

- Batteries ......................................................... 9-75
- Power System Alarms ......................................... 9-85
- Power System Monitoring and Control .................. 9-88
- Conductor Identification .................................... 9-90

## Chapter 10: Telecommunications Administration

- Telecommunications Administration ...................... 10-1
- Identification Methods ...................................... 10-11
- Identification Systems ...................................... 10-24
- Labeling and Recordkeeping ............................... 10-28
- Administration of Large Spaces .......................... 10-36

## Chapter 11: Field Testing of Structured Cabling

- Field Testing of Structured Cabling ...................... 11-1
- Balanced Twisted-Pair Cabling Tests ..................... 11-3
- Balanced Twisted-Pair Cabling Acceptance Tests .... 11-12
- Coaxial Cabling Testing ...................................... 11-18
- Optical Fiber Cabling Tests ................................ 11-19
- Optical Fiber Cabling Acceptance Tests ............... 11-23
- Optical Fiber Cabling Field Testing ...................... 11-25
- Maintenance and Troubleshooting for Optical Fiber Cabling .................................................. 11-28
- Additional Optical Fiber Troubleshooting Tools and Equipment ................................................. 11-29

## Chapter 12: Outside Plant

- Outside Plant ..................................................... 12-1
- Types of Entrances ............................................. 12-4
- Underground Entrances ...................................... 12-5
- General Recommendations for Underground Entrances .................................................. 12-7
- Terminating Conduit at a Designated Property Line .................................................. 12-8
- Terminating Conduit Inside a Building ................. 12-9
- Bonding and Grounding (Earthing) ....................... 12-10
- Buried Entrances ............................................... 12-10
- Aerial Entrances .................................................. 12-11
- Aerial Cable at a Building .................................... 12-12
- Other Telecommunications Service Entrance Considerations .................................................. 12-18
- Terminating Space for Telecommunications Entrance Facilities ........................................... 12-23
- Outside Building Terminals (Pedestals and Cabinets) .................................................. 12-25
- Conduit Guidelines ............................................... 12-36
- Maintenance Hole Guidelines .............................. 12-41
- Cabling Placement ................................................. 12-45
- Aerial Plant Criteria .............................................. 12-48
**Chapter 13: Audiovisual Systems**

Audiovisual (AV) Systems ........................................... 13-1
Fundamentals ...................................................... 13-2
Types of Signals ................................................... 13-10
Environmental Considerations .............................. 13-34
Visual Display Systems ........................................ 13-42
Program Audio and Speech Reinforcement Systems .. 13-47
Signal Distribution Systems .................................. 13-57
Audioconferencing Systems .................................. 13-59
Videoconferencing Systems ................................... 13-74
Control Systems .................................................. 13-84
Overhead Paging Systems ...................................... 13-87
Sound Masking Systems ......................................... 13-97
Digital Signage Systems ....................................... 13-102
Cable Television Distribution Systems .................. 13-106

**Chapter 14: Building Automation Systems**

Building Automation Systems (BAS) ......................... 14-1
Building Automation Systems (BAS) Interfaces with Other Systems ............................. 14-4
Building Automation Systems (BAS) Communications Networks ................................... 14-16
Building Automation Systems (BAS) Electrical Characteristics .............................. 14-22
Planning Building Automation Systems (BAS) Distribution Cabling ......................... 14-24

**Chapter 15: Data Networks**

Data Networks .................................................... 15-1
Open Systems Interconnection (OSI) Reference Model ........................................... 15-4
Network Hardware ................................................. 15-8
Network Software ................................................ 15-14
Network Supported Systems ................................. 15-15
Network Design ................................................... 15-20
Computer Rooms .................................................. 15-22
Campus and Multisite Network Design .................. 15-34

**Chapter 16: Wireless Networks**

Wireless Networks ................................................. 16-1
Services and Applications ...................................... 16-2
Frequency and Wavelength .................................... 16-6
Electromagnetic Spectrum ...................................... 16-10
Wireless System Design ........................................ 16-20
Selection of Technology ......................................... 16-23
Components of a Wireless System .................................................. 16-26
Distributed Antenna Systems (DAS) .............................................. 16-34
Personal Area Networks (PANs) .................................................. 16-63
Wireless LAN (WLAN) Technology ............................................. 16-65
Wireless LAN (WLAN) Components ........................................... 16-67

Chapter 17: Electronic Safety and Security
Electronic Safety and Security (ESS) ........................................... 17-1
Locks and Electronic Access Control (EAC) ................................. 17-10
Video Surveillance ................................................................. 17-24
Intrusion Detection ................................................................. 17-34
Fire Alarm (FA) and Detection ................................................. 17-37
Notification Appliances .......................................................... 17-41
Control Units ........................................................................... 17-44
Digital Alarm Communicator System (DACS) ........................... 17-48

Chapter 18: Data Centers
Data Centers ............................................................................. 18-1
Data Center Redundancy and Availability ................................. 18-4
Structured Cabling Hierarchy for Data Centers ......................... 18-10
Guidelines for Telecommunications Cabling, Cable Containment, Equipment Racks, and Cabinets ............................................................ 18-17
Data Center Security ............................................................... 18-24
Operation, Ownership Costs, Environmental Impact, and Efficiency .................................................................................. 18-30
Appendix: Data Center Planning Considerations ....................... 18-31

Chapter 19: Health Care
Health Care ................................................................................ 19-1
Space and Pathway Requirements and Considerations ................. 19-2
Nurse Call Systems ................................................................... 19-10
Code Call Systems ................................................................. 19-20
Hospital Security ...................................................................... 19-21
Wireless Networks .................................................................... 19-24
Audiovisual (AV) Systems ......................................................... 19-27
Picture Archiving and Communication System (PACS) ............ 19-29
Patient Monitoring ................................................................... 19-30
Radio Frequency Identification (RFID)–Based Systems ............. 19-33
Interactive Patient Entertainment and Education Systems ........ 19-37
Wayfinding and Signage ......................................................... 19-41
Regulatory Bodies and Organizations ......................................... 19-42

© 2014 BICSI®  vii  TDMM, 13th edition
# Table of Contents

## Chapter 20: Residential Cabling

- Residential Cabling ........................................... 20-1
- Components ....................................................... 20-4
- Planning the Cabling System ................................. 20-21
- Rough-In Cabling ............................................... 20-22
- Finish Cabling .................................................... 20-24

## Chapter 21: Business Development and Project Management

**SECTION 1: BUSINESS DEVELOPMENT**
- Business Development .......................................... 21-1

**SECTION 2: PROJECT MANAGEMENT**
- Telecommunications Project Management (TPM) ........... 21-5
- Building Information Modeling (BIM) ......................... 21-50

## Appendix A: Codes, Standards, Regulations, and Organizations

- Introduction ...................................................... A-1
- International Codes and Standards ......................... A-6
- Regional Codes and Standards ............................... A-29
- National Codes and Standards ............................... A-40
- Enforcement of United States (U.S.) Building Codes, Standards, and Regulations .................. A-69
- Regulations and Standards for Wireless Transmission ........ A-72
- United States (U.S.) Approval of Electrical Products and Equipment ........................ A-78
- Canadian Approval of Electrical Products and Equipment ............................... A-81
- European Approval of Electrical Products and Equipment ................ A-82

## Appendix B: Network Interfaces and Demarcation Points in the United States

- Network Interfaces and Demarcation Points in the United States .................. B-1
- Definitions ....................................................... B-1
- Classifications ................................................... B-1
- Groups ........................................................... B-2
- Types ............................................................ B-2
- Voice Connectors ............................................... B-3
- Data Connectors ............................................... B-23
- Network Channel Equipment Connectors ...................... B-41
- Optical Fiber Connector Interface ............................ B-43
Appendix C: Regulations and Standards for Emissions and Immunity
   Commercial Products Marketed in the United States (U.S.) ................. C-1
   Radiation Limits for Class A and Class B. ..................................... C-2
   Emission Limits for Class A and Class B ...................................... C-3
   Commercial Products Marketed Outside the United States (U.S.) .......... C-4
   Electrostatic Discharge (ESD) ..................................................... C-8

Appendix D: Mechanical, Ingress, Climatic/Chemical, and Electromagnetic Considerations
   Introduction .................................................................................. D-1
   Environmental Classification System .............................................. D-3
   Compatibility with MICE Environment ........................................... D-6

Appendix E: Legal Considerations for the ITS Distribution Designer
   Legal Aspects of Information Technology Systems (ITS) Design ....... E-1

Glossary

Bibliography

Index
Figures

Chapter 1: Principles of Transmission

Figure 1.1 Calculated attenuation values for cables insulated with FEP, ECTFE, and PVC from 1 MHz to 135 MHz at 22 °C (72 °F) ........................................... 1-10
Figure 1.2 Calculated and measured attenuation values for cables insulated with FEP, ECTFE, and PVC from 1 MHz to 135 MHz at 40 °C (104 °F) . . 1-11
Figure 1.3 Calculated and measured attenuation values for cables insulated with FEP, ECTFE, and PVC from 1 MHz to 135 MHz at 60 °C (140 °F) . . 1-12
Figure 1.4 Example 1 of a sinusoidal signal .................................................... 1-17
Figure 1.5 Example 2 of a sinusoidal signal .................................................... 1-19
Figure 1.6 Internet protocol telephony architecture ....................................... 1-28
Figure 1.7 Digital signal level one frame format ............................................ 1-33
Figure 1.8 E1 frame format . ........................................................................ 1-34
Figure 1.9 Polar non-return-to-zero level ...................................................... 1-38
Figure 1.10 Bipolar alternate mark inversion .................................................. 1-38
Figure 1.11 Biphase Manchester ................................................................. 1-38
Figure 1.12 Two binary bits encoded into one quaternary (2B1Q) ................. 1-39
Figure 1.13 Multilevel transition-3 (MLT-3, also referred to as non-return-to-zero inverted [NRZI-3]) ....................................................... 1-39
Figure 1.14 Composite video ..................................................................... 1-51
Figure 1.15 Two-conductor transmission line .............................................. 1-53
Figure 1.16 Resistive model ...................................................................... 1-54
Figure 1.17 Capacitance model .................................................................. 1-55
Figure 1.18 Inductive model ...................................................................... 1-56
Figure 1.19 Primary transmission line parameters ....................................... 1-57
Figure 1.20 General transmission model .................................................... 1-58
Figure 1.21 Example of a channel test configuration .................................... 1-65
Figure 1.22 Permanent link test configuration ............................................ 1-69
Figure 1.23 Spectral profile comparison of laser and light-emitting diode ..... 1-85
Figure 1.24 Spectral width of a light-emitting diode source showing full width half maximum ................................................................. 1-86
Figure 1.25 Numerical aperture .................................................................. 1-87
Figure 1.26 System bandwidth versus distance example ................................ 1-96
Figure 1.27 Pulse distortion because of rise time and data rate ................. 1-98
Figure 1.28 Link bandwidth at 1300 nanometers using 62.5/125 micrometer multimode optical fiber ................................................................. 1-102
Figure 1.29 Core and coating ................................................................. 1-105
Figure 1.30 Digital signal cross-connect optical multiplexing design .......... 1-123
Figure 1.31 Synchronous optical network multiplexing design .................. 1-124
Figure 1.32 Wavelength division multiplexing .......................................... 1-125
Chapter 2: Electromagnetic Compatibility

Figure 2.1 Electromagnetic spectrum .................................................. 2-2
Figure 2.2 Dependence of the safe distance to electromagnetic interference source on its power ................................................................. 2-9
Figure 2.3 Model T for a short wire channel ........................................... 2-24
Figure 2.4 Surge test voltage waveform sample ....................................... 2-27
Figure 2.5 Common mode versus differential mode ................................... 2-29
Figure 2.6 Ground loops in shielded cabling systems ................................ 2-32
Figure 2.7 Ground loop because of stray capacitance at high frequencies ...... 2-33
Figure 2.8 Common impedance coupling interference ................................ 2-34
Figure 2.9 Field-to-cable and ground loop .............................................. 2-35
Figure 2.10 Coupling reduction as function of grounding (earthing) practice .... 2-37
Figure 2.11 Higher frequency twist decrease ........................................... 2-38
Figure 2.12 Typical power line filter ..................................................... 2-46
Figure 2.13 Isolation transformer scheme .............................................. 2-47
Figure 2.14 Samples of ferrite toroids, beads, and sleeves ......................... 2-48
Figure 2.15 Balance concept .............................................................. 2-50
Figure 2.16 Electromagnetic interference susceptibility of circuits and systems connected through unshielded cables ................................. 2-53
Figure 2.17 Ground loop and electromagnetic interference immunity ........... 2-55

Chapter 3: Telecommunications Spaces

Figure 3.1 Typical telecommunications room layout ................................ 3-27
Figure 3.2 Typical sleeve/conduit ......................................................... 3-28
Figure 3.3 Typical shallow room layout ................................................ 3-29
Figure 3.4 Typical access provider equipment room .................................. 3-39
Figure 3.5 Typical equipment room layout ............................................ 3-44

Chapter 4: Backbone Distribution Systems

Figure 4.1 Typical backbone hierarchical star topology for multiple buildings on a campus (inside and outside distribution) ................................. 4-4
Figure 4.2 Example of a first level hierarchical star campus backbone ............ 4-5
Figure 4.3 Example of multiple hierarchical level campus backbone design .... 4-7
Figure 4.4 Levels of cross-connections .................................................. 4-8
Figure 4.5 Logical bus topology .......................................................... 4-9
Figure 4.6 Logical ring topology implemented using a physical star topology ... 4-10
Figure 4.7 Logical tree topology implemented using a hierarchical star topology 4-11
Figure 4.8 Buildings connected by a physical ring .................................... 4-14
Figure 4.9 Example of main backbone ring and redundant backbone star combined ................................................................. 4-15
Figure 4.10 Star building backbone ..................................................... 4-17
Figure 4.11 Hierarchical star building backbone ...................................... 4-18
Figure 4.12 Redundant routing for building backbone (HCs [FDs] not linked) .... 4-19
Table of Contents

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.13</td>
<td>Example of combined optical fiber/balanced twisted-pair backbone supporting voice and data traffic</td>
<td>4-20</td>
</tr>
<tr>
<td>4.14</td>
<td>Equipment rooms and access provider cabling system interface cabling</td>
<td>4-22</td>
</tr>
<tr>
<td>4.15</td>
<td>Typical office building pathway layout</td>
<td>4-29</td>
</tr>
<tr>
<td>4.16</td>
<td>Typical sleeve and slot installations</td>
<td>4-31</td>
</tr>
<tr>
<td>4.17</td>
<td>Ethernet in the first mile network boundaries</td>
<td>4-40</td>
</tr>
<tr>
<td>4.18</td>
<td>Point-to-multipoint optical topology</td>
<td>4-42</td>
</tr>
<tr>
<td>4.19</td>
<td>Point-to-point optical fiber</td>
<td>4-43</td>
</tr>
<tr>
<td>4.20</td>
<td>Point-to-point balanced twisted-pair topology</td>
<td>4-46</td>
</tr>
</tbody>
</table>

**Chapter 5: Horizontal Distribution Systems**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Typical horizontal cabling system elements</td>
<td>5-2</td>
</tr>
<tr>
<td>5.2</td>
<td>Horizontal cabling system channel</td>
<td>5-7</td>
</tr>
<tr>
<td>5.3</td>
<td>Horizontal cabling system channel model with four connection points</td>
<td>5-8</td>
</tr>
<tr>
<td>5.4</td>
<td>Horizontal cabling system channel model with three connection points</td>
<td>5-9</td>
</tr>
<tr>
<td>5.5</td>
<td>Horizontal cabling system permanent link model with three connection points</td>
<td>5-10</td>
</tr>
<tr>
<td>5.6</td>
<td>Example of connection by means of cross-connection</td>
<td>5-13</td>
</tr>
<tr>
<td>5.7</td>
<td>Example of connection by means of interconnection</td>
<td>5-14</td>
</tr>
<tr>
<td>5.8</td>
<td>Example of connection by means of cross-connection and interconnection</td>
<td>5-15</td>
</tr>
<tr>
<td>5.9</td>
<td>Example of connection by means of double cross-connection</td>
<td>5-16</td>
</tr>
<tr>
<td>5.10</td>
<td>Total cable length in the horizontal cabling system channel</td>
<td>5-19</td>
</tr>
<tr>
<td>5.11</td>
<td>Pin/pair assignments</td>
<td>5-22</td>
</tr>
<tr>
<td>5.12</td>
<td>Typical dimensions for furniture telecommunications outlet/connector</td>
<td>5-25</td>
</tr>
<tr>
<td>5.13</td>
<td>Example of multiuser telecommunications outlet assembly application</td>
<td>5-27</td>
</tr>
<tr>
<td>5.14</td>
<td>Consolidation points used in a combined furniture system and private office work area environment</td>
<td>5-27</td>
</tr>
<tr>
<td>5.15</td>
<td>Consolidation points located on all columns</td>
<td>5-31</td>
</tr>
<tr>
<td>5.16</td>
<td>Consolidation points located in a space between the columns</td>
<td>5-35</td>
</tr>
<tr>
<td>5.17</td>
<td>Consolidation points located in checkerboard order</td>
<td>5-36</td>
</tr>
<tr>
<td>5.18</td>
<td>Consolidation points located on columns close to the building core</td>
<td>5-37</td>
</tr>
<tr>
<td>5.19</td>
<td>Centralized optical fiber cabling</td>
<td>5-38</td>
</tr>
<tr>
<td>5.20</td>
<td>Traditional active Ethernet design compared with passive optical network-based architecture</td>
<td>5-40</td>
</tr>
<tr>
<td>5.21</td>
<td>Underfloor conduit extended to individual telecommunications outlet boxes</td>
<td>5-43</td>
</tr>
<tr>
<td>5.22</td>
<td>Typical underfloor conduit system</td>
<td>5-44</td>
</tr>
<tr>
<td>5.23</td>
<td>Conduit bodies recommended for telecommunications cables</td>
<td>5-58</td>
</tr>
<tr>
<td>5.24</td>
<td>Recommended pull box configurations</td>
<td>5-67</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>5.25</td>
<td>Stringered access floor system</td>
<td>5-72</td>
</tr>
<tr>
<td>5.26</td>
<td>Recommended clearance for access floor spaces</td>
<td>5-73</td>
</tr>
<tr>
<td>5.27</td>
<td>Typical zoned ceiling (plan view)</td>
<td>5-81</td>
</tr>
<tr>
<td>5.28</td>
<td>Conduit-based ceiling zone (elevation view)</td>
<td>5-82</td>
</tr>
<tr>
<td>5.29</td>
<td>Rules of installation for discrete cable support facilities</td>
<td>5-84</td>
</tr>
<tr>
<td>5.30</td>
<td>Raceways and fittings</td>
<td>5-86</td>
</tr>
<tr>
<td>5.31</td>
<td>Attaching various utility columns</td>
<td>5-88</td>
</tr>
<tr>
<td>5.32</td>
<td>Perimeter raceway</td>
<td>5-97</td>
</tr>
<tr>
<td>5.33</td>
<td>Molding raceway</td>
<td>5-98</td>
</tr>
<tr>
<td>5.34</td>
<td>Side-reach telephones</td>
<td>5-107</td>
</tr>
<tr>
<td>5.35</td>
<td>Forward-reach telephones</td>
<td>5-108</td>
</tr>
<tr>
<td>5.36</td>
<td>International teletypewriter/text telephone symbol and volume control telephone symbol</td>
<td>5-110</td>
</tr>
</tbody>
</table>

**Chapter 6: ITS Cables and Connecting Hardware**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Balanced twisted-pair cable construction types</td>
<td>6-7</td>
</tr>
<tr>
<td>6.2</td>
<td>Examples of balanced twisted-pair cables</td>
<td>6-8</td>
</tr>
<tr>
<td>6.3</td>
<td>Multimode optical fiber</td>
<td>6-18</td>
</tr>
<tr>
<td>6.4</td>
<td>Singlemode optical fiber</td>
<td>6-18</td>
</tr>
<tr>
<td>6.5</td>
<td>Side view of a loose-tube optical fiber cable</td>
<td>6-21</td>
</tr>
<tr>
<td>6.6</td>
<td>Loose-tube furcating harness</td>
<td>6-21</td>
</tr>
<tr>
<td>6.7</td>
<td>Loose-tube optical fiber cable</td>
<td>6-22</td>
</tr>
<tr>
<td>6.8</td>
<td>Tight-buffered optical fiber cable, distribution construction</td>
<td>6-24</td>
</tr>
<tr>
<td>6.9</td>
<td>Tight-buffered optical fiber cable, breakout construction</td>
<td>6-24</td>
</tr>
<tr>
<td>6.10</td>
<td>Series-6 quad shield (screen) coaxial cable</td>
<td>6-27</td>
</tr>
<tr>
<td>6.11</td>
<td>Classification of cables and wires according to the National Electrical Code</td>
<td>6-33</td>
</tr>
<tr>
<td>6.12</td>
<td>110-style insulation displacement contact connector design</td>
<td>6-37</td>
</tr>
<tr>
<td>6.13</td>
<td>Examples of 66-style connector designs</td>
<td>6-40</td>
</tr>
<tr>
<td>6.14</td>
<td>BIX-style insulation displacement contact connector design</td>
<td>6-43</td>
</tr>
<tr>
<td>6.15</td>
<td>Examples of LSA-style connector designs</td>
<td>6-46</td>
</tr>
<tr>
<td>6.16</td>
<td>8P8C unkeyed modular plug</td>
<td>6-49</td>
</tr>
<tr>
<td>6.17</td>
<td>8P8C modular plugs for stranded and solid conductors</td>
<td>6-50</td>
</tr>
<tr>
<td>6.18</td>
<td>8P8C modular jack</td>
<td>6-52</td>
</tr>
<tr>
<td>6.19</td>
<td>Modular jack design</td>
<td>6-53</td>
</tr>
<tr>
<td>6.20</td>
<td>Eight-position jack pin/pair assignments (front view)</td>
<td>6-54</td>
</tr>
<tr>
<td>6.21</td>
<td>50-position miniature ribbon connector</td>
<td>6-56</td>
</tr>
<tr>
<td>6.22</td>
<td>50-position miniature ribbon connector design</td>
<td>6-57</td>
</tr>
<tr>
<td>6.23</td>
<td>Telecommunications outlet/ connectors</td>
<td>6-60</td>
</tr>
<tr>
<td>6.24</td>
<td>Examples of work area telecommunications outlet designs</td>
<td>6-61</td>
</tr>
<tr>
<td>6.25</td>
<td>Rack-mount ≈483 mm (19 in) modular patch panel</td>
<td>6-62</td>
</tr>
<tr>
<td>6.26</td>
<td>Modular patch panel with cable management bar installed in an ≈483 mm (19 in) equipment rack</td>
<td>6-64</td>
</tr>
</tbody>
</table>
Table of Contents

Figure 6.27 66-style block, 89-style mounting brackets, and a distribution frame with installed 66-style blocks ................................................. 6-66
Figure 6.28 110-style wiring blocks .............................................................. 6-68
Figure 6.29 BIX-style connecting blocks mounted in a distribution frame .......... 6-71
Figure 6.30 25-pair BIX-style connecting strip ................................................. 6-72
Figure 6.31 LSA-style connecting blocks ......................................................... 6-73
Figure 6.32 10-pair LSA-style connecting block .................................................. 6-74
Figure 6.33 Hybrid equipment cord assembly or hybrid patch cord assembly. .... 6-76
Figure 6.34 Example of MS2 and Type 710 insulation displacement connector splicing contacts ................................................................. 6-78
Figure 6.35 Example of single-pair splice connectors and modules .................... 6-79
Figure 6.36 Example of multipair splice connectors and modules ....................... 6-80
Figure 6.37 LC-style optical fiber adapters and connectors .................................. 6-85
Figure 6.38 Subscriber connector-style optical fiber adapters and connectors ...... 6-87
Figure 6.39 Straight tip-style optical fiber connector ........................................... 6-88
Figure 6.40 Array-style optical fiber connector and adapter (example of Type-A multifiber push-on configuration) ............................................. 6-89
Figure 6.41 Array-style optical fiber connector and adapter (example of Type-B multifiber push-on configuration) ............................................. 6-90
Figure 6.42 Fusion splicer ................................................................................. 6-91
Figure 6.43 Mechanical splice open position ..................................................... 6-92
Figure 6.44 Optical fiber pigtail splicing ............................................................ 6-94
Figure 6.45 Cross-connection of optical fiber cabling segments (first- and second-level backbone) .............................................................. 6-96
Figure 6.46 Interconnection of equipment to backbone cabling ............................ 6-97
Figure 6.47 Hybrid optical fiber patch cord assembly .......................................... 6-98
Figure 6.48 BNC-style connector ..................................................................... 6-102
Figure 6.49 BNC-style connector components .................................................. 6-102
Figure 6.50 BNC-style connector plug and jack .................................................. 6-103
Figure 6.51 50-ohm and 75-ohm bayonet BNC-style connectors .......................... 6-103
Figure 6.52 One-piece crimp-style F-style connector .......................................... 6-106
Figure 6.53 N-style coaxial connector ............................................................... 6-108
Figure 6.54 Standard wall-mount multimedia and modular furniture multimedia outlets featuring F-style coaxial connectors .................................. 6-110
Figure 6.55 BNC-style bracket mount and F-style ≈483 mm (19 in) rack-mount coaxial patch panels ............................................................... 6-112

Chapter 7: Firestop Systems

Figure 7.1 Standard time/temperature curves ..................................................... 7-10
Figure 7.2 Elastomeric modules (within frames) ................................................... 7-21
Figure 7.3 Mechanical firestop system ............................................................... 7-22
Figure 7.4 Example of fire-rated pathway device ............................................... 7-23
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5</td>
<td>Typical plastic pipe device</td>
<td>7-25</td>
</tr>
<tr>
<td>7.6</td>
<td>Typical cast-in-place firestop device</td>
<td>7-26</td>
</tr>
<tr>
<td>7.7</td>
<td>Examples of poke-thru</td>
<td>7-27</td>
</tr>
<tr>
<td>7.8</td>
<td>Continuous conduit penetration through concrete</td>
<td>7-35</td>
</tr>
<tr>
<td>7.9</td>
<td>Cable penetration in concrete wall or floor</td>
<td>7-36</td>
</tr>
<tr>
<td>7.10</td>
<td>Polyvinyl chloride innerduct penetration in concrete wall</td>
<td>7-36</td>
</tr>
<tr>
<td>7.11</td>
<td>Polyvinyl chloride innerduct penetration in concrete floor</td>
<td>7-37</td>
</tr>
<tr>
<td>7.12</td>
<td>Qualified cable tray seal system in concrete wall</td>
<td>7-37</td>
</tr>
<tr>
<td>7.13</td>
<td>Qualified steel pipe system in framed wall</td>
<td>7-38</td>
</tr>
<tr>
<td>7.14</td>
<td>Telecommunications cable seal system for framed wall</td>
<td>7-39</td>
</tr>
<tr>
<td>7.15</td>
<td>Nonmetallic innerduct penetration of framed wall</td>
<td>7-40</td>
</tr>
<tr>
<td>7.16</td>
<td>Sleeve systems for retrofit over existing cables</td>
<td>7-41</td>
</tr>
<tr>
<td>7.17</td>
<td>Sleeve system with cable tray</td>
<td>7-42</td>
</tr>
<tr>
<td>7.18</td>
<td>Sleeve system with cable support</td>
<td>7-43</td>
</tr>
<tr>
<td>7.19</td>
<td>Expansion joint or slot in a floor</td>
<td>7-54</td>
</tr>
<tr>
<td>7.20</td>
<td>Expansion joint or slot in a wall</td>
<td>7-54</td>
</tr>
<tr>
<td>7.21</td>
<td>Perimeter gap</td>
<td>7-55</td>
</tr>
<tr>
<td>7.22</td>
<td>Seal system in a curtain wall</td>
<td>7-55</td>
</tr>
<tr>
<td>7.23</td>
<td>Typical label for all firestops</td>
<td>7-57</td>
</tr>
<tr>
<td>7.24</td>
<td>Concrete floor or wall</td>
<td>7-59</td>
</tr>
<tr>
<td>7.25</td>
<td>Typical framed wall penetration</td>
<td>7-60</td>
</tr>
<tr>
<td>7.26</td>
<td>Typical concrete wall penetration</td>
<td>7-61</td>
</tr>
<tr>
<td>7.27</td>
<td>Concrete wall or floor (metallic pipes)</td>
<td>7-62</td>
</tr>
<tr>
<td>7.28</td>
<td>Concrete wall or floor (no penetrating item)</td>
<td>7-63</td>
</tr>
<tr>
<td>7.29</td>
<td>Concrete wall or floor (electrical power, telecommunications, and building signaling cables)</td>
<td>7-64</td>
</tr>
<tr>
<td>7.30</td>
<td>Concrete floor (electrical power and telecommunications cables)</td>
<td>7-65</td>
</tr>
<tr>
<td>7.31</td>
<td>Framed wall (steel pipes or conduit)</td>
<td>7-66</td>
</tr>
<tr>
<td>7.32</td>
<td>Framed wall (cable)</td>
<td>7-67</td>
</tr>
<tr>
<td>7.33</td>
<td>Framed wall (steel or aluminum cable trays)</td>
<td>7-68</td>
</tr>
<tr>
<td>7.34</td>
<td>Concrete wall (cable)</td>
<td>7-69</td>
</tr>
<tr>
<td>7.35</td>
<td>Concrete floor or wall (bus duct)</td>
<td>7-70</td>
</tr>
<tr>
<td>7.36</td>
<td>Concrete floor or wall (steel pipe)</td>
<td>7-71</td>
</tr>
<tr>
<td>7.37</td>
<td>Framed wall (cables)</td>
<td>7-72</td>
</tr>
<tr>
<td>7.38</td>
<td>Framed wall (polyvinyl chloride pipe [closed or vented])</td>
<td>7-73</td>
</tr>
<tr>
<td>7.39</td>
<td>Floor or wall (PVC, CPVC, or PB pipe [closed or vented] or RNC)</td>
<td>7-74</td>
</tr>
<tr>
<td>7.40</td>
<td>Wood joist floor (steel or copper pipe)</td>
<td>7-76</td>
</tr>
<tr>
<td>7.41</td>
<td>Concrete floor or wall (electrical power, building signaling, control, and telecommunications cables)</td>
<td>7-77</td>
</tr>
<tr>
<td>7.42</td>
<td>Concrete floor or wall (steel or aluminum cable tray)</td>
<td>7-78</td>
</tr>
<tr>
<td>7.43</td>
<td>Framed wall (steel or aluminum cable tray)</td>
<td>7-79</td>
</tr>
<tr>
<td>Figure 7.44</td>
<td>Floor or wall (steel or aluminum cable tray)</td>
<td>7-80</td>
</tr>
<tr>
<td>Figure 7.45</td>
<td>Floor or wall (pipes and cable tray)</td>
<td>7-81</td>
</tr>
<tr>
<td>Figure 7.46</td>
<td>Head of wall joint (framed wall or concrete fluted deck)</td>
<td>7-82</td>
</tr>
<tr>
<td>Figure 7.47</td>
<td>Head of wall joint (concrete wall or concrete fluted deck)</td>
<td>7-83</td>
</tr>
<tr>
<td>Figure 7.48</td>
<td>Concrete floor or wall (telecommunications cable)</td>
<td>7-84</td>
</tr>
<tr>
<td>Figure 7.49</td>
<td>Framed wall (telecommunications cable)</td>
<td>7-85</td>
</tr>
<tr>
<td>Figure 7.50</td>
<td>Framed wall (telecommunications cable)</td>
<td>7-86</td>
</tr>
<tr>
<td>Figure 7.51</td>
<td>Framed wall (telecommunications cable)</td>
<td>7-87</td>
</tr>
<tr>
<td>Figure 7.52</td>
<td>Concrete floor or wall (telecommunications cable)</td>
<td>7-88</td>
</tr>
<tr>
<td>Figure 7.53</td>
<td>Concrete floor or wall (telecommunications cable)</td>
<td>7-89</td>
</tr>
<tr>
<td>Figure 7.54</td>
<td>Framed wall stud cavity (electrical outlet box)</td>
<td>7-90</td>
</tr>
<tr>
<td>Figure 7.55</td>
<td>Concrete floor or wall (no penetrating item)</td>
<td>7-91</td>
</tr>
<tr>
<td>Figure 7.56</td>
<td>Concrete floor or wall (PVC innerduct or ENT with optical fiber cables)</td>
<td>7-92</td>
</tr>
<tr>
<td>Figure 7.57</td>
<td>Concrete floor or wall (PVC innerduct or ENT with optical fiber cables)</td>
<td>7-93</td>
</tr>
<tr>
<td>Figure 7.58</td>
<td>Framed wall (nonmetallic conduit)</td>
<td>7-94</td>
</tr>
<tr>
<td>Figure 7.59</td>
<td>Framed wall (electrical power, building signaling, control, or telecommunications cable steel sleeve system)</td>
<td>7-96</td>
</tr>
<tr>
<td>Figure 7.60</td>
<td>Framed wall (electrical power, building signaling, control, or telecommunications cable split sleeve system)</td>
<td>7-98</td>
</tr>
<tr>
<td>Figure 7.61</td>
<td>Plenum-rated wrap system for combustible pipe</td>
<td>7-100</td>
</tr>
<tr>
<td>Figure 7.62</td>
<td>Intumescent blocks</td>
<td>7-101</td>
</tr>
<tr>
<td>Figure 7.63</td>
<td>Framed wall (electrical power, building signaling, control, or telecommunications cable steel sleeve system)</td>
<td>7-102</td>
</tr>
<tr>
<td>Figure 7.64</td>
<td>Concrete floor or wall (electrical power, building signaling, control, or telecommunications cable steel sleeve system)</td>
<td>7-103</td>
</tr>
<tr>
<td>Figure 7.65</td>
<td>Framed wall (power, building signaling, control, or telecommunications split cable pathway system)</td>
<td>7-104</td>
</tr>
<tr>
<td>Figure 7.66</td>
<td>Framed wall (power, building signaling, control, or telecommunications cable sleeve device system)</td>
<td>7-105</td>
</tr>
<tr>
<td>Figure 7.67</td>
<td>Concrete floor (power, building signaling, control, or telecommunications cable sleeve system)</td>
<td>7-107</td>
</tr>
<tr>
<td>Figure 7.68</td>
<td>Framed wall (telecommunications cable steel sleeve membrane penetration system)</td>
<td>7-108</td>
</tr>
<tr>
<td>Figure 7.69</td>
<td>Framed wall (telecommunications cable firestop grommet membrane penetration system)</td>
<td>7-109</td>
</tr>
<tr>
<td>Figure 7.70</td>
<td>Framed wall (telecommunications cable firestop grommet penetration system)</td>
<td>7-110</td>
</tr>
<tr>
<td>Figure 7.71</td>
<td>Typical perimeter fire barrier system exterior insulation glass panel curtain wall</td>
<td>7-111</td>
</tr>
<tr>
<td>Figure 7.72</td>
<td>Typical framed wall heating, ventilation, and air-conditioning duct</td>
<td>7-112</td>
</tr>
<tr>
<td>Figure 7.73</td>
<td>Concrete floor (power, building signaling, control, or telecommunications cable pathway system)</td>
<td>7-113</td>
</tr>
</tbody>
</table>
# Chapter 8: Bonding and Grounding (Earthing)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Caption</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>Typical supplementary bonding grid</td>
<td>8-12</td>
</tr>
<tr>
<td>8.2</td>
<td>Small systems</td>
<td>8-15</td>
</tr>
<tr>
<td>8.3</td>
<td>Recommended large system arrangement</td>
<td>8-17</td>
</tr>
<tr>
<td>8.4</td>
<td>Typical telecommunications main grounding busbar</td>
<td>8-18</td>
</tr>
<tr>
<td>8.5</td>
<td>Typical telecommunications grounding busbar</td>
<td>8-20</td>
</tr>
<tr>
<td>8.6</td>
<td>Equipment rack bonding and grounding (earthing)</td>
<td>8-27</td>
</tr>
<tr>
<td>8.7</td>
<td>Zone of protection</td>
<td>8-30</td>
</tr>
<tr>
<td>8.8</td>
<td>Cone of protection</td>
<td>8-31</td>
</tr>
<tr>
<td>8.9</td>
<td>Extending zone of protection</td>
<td>8-32</td>
</tr>
</tbody>
</table>

# Chapter 9: Power Distribution

<table>
<thead>
<tr>
<th>Figure</th>
<th>Caption</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1</td>
<td>Measuring amplitude</td>
<td>9-2</td>
</tr>
<tr>
<td>9.2</td>
<td>Measuring phase difference in a three-phase system</td>
<td>9-4</td>
</tr>
<tr>
<td>9.3</td>
<td>Delta configuration</td>
<td>9-5</td>
</tr>
<tr>
<td>9.4</td>
<td>Wye configuration</td>
<td>9-5</td>
</tr>
<tr>
<td>9.5</td>
<td>Center-tapped single-phase configuration</td>
<td>9-6</td>
</tr>
<tr>
<td>9.6</td>
<td>Typical electrical power system</td>
<td>9-7</td>
</tr>
<tr>
<td>9.7</td>
<td>Typical electrical power system</td>
<td>9-7</td>
</tr>
<tr>
<td>9.8</td>
<td>Calculation chart</td>
<td>9-8</td>
</tr>
<tr>
<td>9.9</td>
<td>Voltage and current in phase (resistive load)</td>
<td>9-10</td>
</tr>
<tr>
<td>9.10</td>
<td>Current lags voltage (inductive circuit)</td>
<td>9-10</td>
</tr>
<tr>
<td>9.11</td>
<td>Current leads voltage (capacitive load)</td>
<td>9-11</td>
</tr>
<tr>
<td>9.12</td>
<td>Panelboard connection to equipment</td>
<td>9-30</td>
</tr>
<tr>
<td>9.13</td>
<td>Power distribution unit connection to equipment</td>
<td>9-31</td>
</tr>
<tr>
<td>9.14</td>
<td>Sample Class 1 electrical system topology</td>
<td>9-39</td>
</tr>
<tr>
<td>9.15</td>
<td>Sample Class 2 electrical system topology</td>
<td>9-40</td>
</tr>
<tr>
<td>9.16</td>
<td>Sample Class 3 electrical system topology</td>
<td>9-41</td>
</tr>
<tr>
<td>9.17</td>
<td>Class 4 electrical system topology</td>
<td>9-42</td>
</tr>
<tr>
<td>9.18</td>
<td>Uninterruptible power supply module with maintenance bypass cabinet</td>
<td>9-50</td>
</tr>
<tr>
<td>9.19</td>
<td>Series configured rotary uninterruptible power supply system</td>
<td>9-51</td>
</tr>
<tr>
<td>9.20</td>
<td>Elevation of modular uninterruptible power supply system</td>
<td>9-53</td>
</tr>
<tr>
<td>9.21</td>
<td>Single module uninterruptible power supply system</td>
<td>9-56</td>
</tr>
<tr>
<td>9.22</td>
<td>Parallel redundant uninterruptible power supply system</td>
<td>9-57</td>
</tr>
<tr>
<td>9.23</td>
<td>Isolated redundant uninterruptible power supply system</td>
<td>9-58</td>
</tr>
<tr>
<td>9.24</td>
<td>Distributed redundant uninterruptible power supply system</td>
<td>9-59</td>
</tr>
<tr>
<td>9.25</td>
<td>Communications link uninterruptible power supply system</td>
<td>9-60</td>
</tr>
<tr>
<td>9.26</td>
<td>Typical direct current power system</td>
<td>9-63</td>
</tr>
<tr>
<td>9.27</td>
<td>Identification by color, letter, or marking</td>
<td>9-91</td>
</tr>
</tbody>
</table>
# Table of Contents

## Chapter 10: Telecommunications Administration

- Figure 10.1 Telecommunications administration systems ........................................ 10-1
- Figure 10.2 Numbering telecommunications rooms ................................................. 10-12
- Figure 10.3 Numbering cable trays ......................................................................... 10-14
- Figure 10.4 Labeling example .................................................................................. 10-18
- Figure 10.5 Example of equipment identification ..................................................... 10-23
- Figure 10.6 Recordkeeping system example .............................................................. 10-32
- Figure 10.7 Room grid coordinate example .............................................................. 10-37
- Figure 10.8 Sample rack and cabinet nongrid identifiers ........................................ 10-38

## Chapter 11: Field Testing of Structured Cabling

- Figure 11.1 Wire map testing .................................................................................... 11-3
- Figure 11.2 Pair electrical lengths .......................................................................... 11-5
- Figure 11.3 Propagation delay/delay skew ............................................................... 11-5
- Figure 11.4 Return loss ........................................................................................... 11-6
- Figure 11.5 Near-end crosstalk .............................................................................. 11-7
- Figure 11.6 Attenuation-to-crosstalk ratio–far-end .................................................... 11-8
- Figure 11.7 Power sum near-end crosstalk ............................................................. 11-9
- Figure 11.8 Coaxial time domain reflectometer test .................................................. 11-11
- Figure 11.9 Typical work area three-connector channel ......................................... 11-12
- Figure 11.10 Typical work area four-connector channel ......................................... 11-13
- Figure 11.11 Typical data center four-connector channel ....................................... 11-13
- Figure 11.12 Work area three-connector permanent link ........................................ 11-14
- Figure 11.13 Work area four-connector permanent link ......................................... 11-14
- Figure 11.14 Data center four-connector permanent link ....................................... 11-15
- Figure 11.15 Optical time domain reflectometer display .......................................... 11-22

## Chapter 12: Outside Plant

- Figure 12.1 Underground pathway plan ................................................................. 12-3
- Figure 12.2 Installing underground entrances ......................................................... 12-7
- Figure 12.3 Examples of building attachment ......................................................... 12-13
- Figure 12.4 Vertical conduit mast ............................................................................ 12-16
- Figure 12.5 Cable entrance sleeve through a wall ..................................................... 12-17
- Figure 12.6 Direct-buried pathway plan .................................................................. 12-28
- Figure 12.7 Typical joint trenching dimensions (section view through trench) ....... 12-33
- Figure 12.8 Positioning conduit on poles ................................................................. 12-40
- Figure 12.9 Typical maintenance hole diagram ....................................................... 12-41
- Figure 12.10 Typical maintenance hole on private property .................................... 12-42
- Figure 12.11 Basic maintenance hole configurations ............................................... 12-45
- Figure 12.12 Typical cable maintenance hole ......................................................... 12-46
- Figure 12.13 Maintenance hole racking .................................................................. 12-47
Chapter 13: Audiovisual Systems

Figure 13.1 Measuring wavelength ........................................... 13-2
Figure 13.2 Different amplitudes of equal frequency sine waves .......... 13-3
Figure 13.3 Equal amplitudes of different frequency sine waves .......... 13-3
Figure 13.4 Two waves offset by 180 degrees ............................. 13-4
Figure 13.5 Frequency .......................................................... 13-5
Figure 13.6 Complex waveform .............................................. 13-6
Figure 13.7 Building complex waveforms .................................. 13-7
Figure 13.8 Electromagnetic spectrum ...................................... 13-8
Figure 13.9 Sample rate the size of the signal frequency .................. 13-13
Figure 13.10 Sample rate double the size of the signal frequency ........ 13-14
Figure 13.11 Video signal building blocks ................................ 13-17
Figure 13.12 Video signal bandwidth ...................................... 13-18
Figure 13.13 Analog video signals .......................................... 13-22
Figure 13.14 Radio frequency (RF) signal .................................. 13-23
Figure 13.15 Examples of digital visual interface connectors .......... 13-24
Figure 13.16 Example of high-definition multimedia interface (HDMI) connector 13-25
Figure 13.17 Example of a DisplayPort connector ....................... 13-26
Figure 13.18 Optimum and acceptable viewing areas ........................ 13-36
Figure 13.19 Sightlines .......................................................... 13-37
Figure 13.20 Flat floor—seats aligned ...................................... 13-38
Figure 13.21 Tiered floor—seats staggered ................................. 13-39
Figure 13.22 Chain of typical audio components......................... 13-47
Figure 13.23 Example of horn installation ................................ 13-49
Figure 13.24 Potential versus needed acoustic gain measurements .... 13-51
Figure 13.25 Loudspeaker dispersion polar plot .......................... 13-54
Figure 13.26 Loudspeaker coverage formula .............................. 13-55
Figure 13.27 Typical audioconferencing system.......................... 13-60
Figure 13.28 Conference room microphone pickup pattern ............. 13-63
Figure 13.29 Two connected rooms and their acoustic echo cancellers 13-66
Figure 13.30 Telephone hybrid .............................................. 13-68
Figure 13.31 Line echo canceller ............................................ 13-68
Figure 13.32 Loudspeaker coverage angle ................................ 13-70
Figure 13.33 Microphone pickup and loudspeaker coverage patterns ... 13-72
Figure 13.34 Field of view ...................................................... 13-77
Figure 13.35 Camera bright-to-dark ranges ................................ 13-78
Figure 13.36 Videoconference light setup ................................ 13-80
Figure 13.37 Hexagonal loudspeaker pattern ............................... 13-90
Figure 13.38 Square loudspeaker pattern ................................ 13-91
Figure 13.39 70 Volt loudspeaker line loss ................................ 13-94
Figure 13.40 Distributed amplifier system .................................. 13-96
### Table of Contents

**Chapter 13: Data Networks**

- Figure 13.41 Collaboration of component technology ..................................... 13-103
- Figure 13.42 Home run network design ............................................................... 13-109
- Figure 13.43 Trunk and tap design ................................................................. 13-110
- Figure 13.44 Video over balanced twisted-pair cabling .................................... 13-111
- Figure 13.45 Video over optical fiber cabling .................................................... 13-112
- Figure 13.46 Dividing the optical signal ............................................................ 13-112
- Figure 13.47 Signal tilt for ≈12.7 mm (0.50 in) hardline .................................. 13-113

**Chapter 14: Building Automation Systems**

- Figure 14.1 Building system changes ............................................................... 14-3
- Figure 14.2 Example of fire alarm, security, and access control interfaces with building automation systems ................................................................. 14-4
- Figure 14.3 Heating, ventilation, and air-conditioning system in a small commercial building ................................................................. 14-8
- Figure 14.4 Hierarchical configuration of processor and controller levels ........... 14-17
- Figure 14.5 Cabling system elements and channel .............................................. 14-29
- Figure 14.6 Single-point and chained branch devices ......................................... 14-31
- Figure 14.7 Cabling system topologies for building automation systems ........... 14-37
- Figure 14.8 Devices bridged at horizontal cross-connect (floor distributor) or horizontal connection point ................................................................. 14-38
- Figure 14.9 Devices chained at the horizontal cross-connect (floor distributor) or horizontal connection point ................................................................. 14-39
- Figure 14.10 Building automation systems equipment cabling .......................... 14-42
- Figure 14.11 Traditional distributed building automation system with multiple horizontal pathways ................................................................. 14-43
- Figure 14.12 Integrated distributed building automation system with single horizontal pathway ................................................................. 14-44
- Figure 14.13 Separate and consolidated cabling systems .................................... 14-46
- Figure 14.14 Reducing quantity and costs of building automation systems controllers ................................................................. 14-48

**Chapter 15: Data Networks**

- Figure 15.1 Example of a LAN ................................................................. 15-2
- Figure 15.2 Example of a wide area network .................................................... 15-3
- Figure 15.3 Open Systems Interconnection Reference Model ............................ 15-5
- Figure 15.4 Message transfer described using the Open Systems Interconnection Reference Model ................................................................. 15-7
- Figure 15.5 Multiple routers in an internetwork ................................................. 15-11
- Figure 15.6 Integrated voice over Internet protocol infrastructure ....................... 15-16
- Figure 15.7 Types of network video communications ....................................... 15-17
- Figure 15.8 Functional (top-down) design ....................................................... 15-20
- Figure 15.9 Physical (bottom-up) design ........................................................... 15-21
Table of Contents

Chapter 16: Wireless Networks

Figure 16.1 Frequency, amplitude, and wavelength .......................... 16-6
Figure 16.2 Propagation velocity through free space. ......................... 16-7
Figure 16.3 Fresnel zone ......................................................... 16-8
Figure 16.4 Electromagnetic spectrum ........................................ 16-11
Figure 16.5 Amplitude modulation ........................................... 16-12
Figure 16.6 Frequency modulation ........................................... 16-13
Figure 16.7 Phase modulation ................................................ 16-14
Figure 16.8 Pulse modulation techniques ..................................... 16-15
Figure 16.9 Harmonic distortion ............................................... 16-17
Figure 16.10 Typical distributed antenna system environments ........... 16-36
Figure 16.11 Omnidirectional antennas ....................................... 16-39
Figure 16.12 Directional antennas ............................................ 16-40
Figure 16.13 Radiating cable standoff mount .................................. 16-43
Figure 16.14 Headend and backend .......................................... 16-47
Figure 16.15 Optical to radio frequency coupling power relationship .... 16-49
Figure 16.16 Extended service set using a wireless distribution system .... 16-68
Figure 16.17 Extended service set using a cable distribution system .... 16-69
Figure 16.18 Point-to-point bridging .......................................... 16-72
Figure 16.19 Point-to-multipoint bridging .................................... 16-73
Figure 16.20 Repeating bridge .................................................. 16-74
Chapter 17: Electronic Safety and Security
Figure 17.1 Elements of a security program .................................. 17-2
Figure 17.2 Threat, risk, and vulnerability assessments ....................... 17-4
Figure 17.3 Security quandary ......................................................... 17-5
Figure 17.4 Single-connector modified permanent link with one connection point .......................................................... 17-15
Figure 17.5 Electric strikes ................................................................. 17-18
Figure 17.6 Magnetic locks ................................................................. 17-20
Figure 17.7 Electric locksets ............................................................... 17-21
Figure 17.8 Electric latch and mechanical operation ............................. 17-22
Figure 17.9 Electrified exit hardware ............................................... 17-23
Figure 17.10 Grid display layouts ....................................................... 17-30
Figure 17.11 Typical fire alarm pull station ........................................ 17-40
Figure 17.12 Enhanced annunciator panel ........................................... 17-52

Chapter 18: Data Centers
Figure 18.1 Relationship of spaces in a data center ............................... 18-2
Figure 18.2 Hierarchical structure of a data center from CENELEC EN 50173-5 and ISO/IEC 24764 ......................................................... 18-15
Figure 18.3 Example of TIA-942-A data center topology ....................... 18-16
Figure 18.4 Cabling cross-sectional area comparison ........................... 18-17
Figure 18.5 Example of equipment cabling using overhead infrastructure .. 18-19
Figure 18.6 Example of overhead communications cabling with power and bonding conductors beneath raised access floor ............................... 18-21
Figure 18.7 Example of communications, power, and earth conductors installed in raised access floor ......................................................... 18-22
Figure 18.8 Layering ........................................................................ 18-26

Chapter 19: Health Care
Figure 19.1 Technology distribution room .......................................... 19-5
Figure 19.2 Redundancy option 1 ....................................................... 19-6
Figure 19.3 Redundancy option 2 ....................................................... 19-7
Figure 19.4 Redundancy option 3 ....................................................... 19-8
Figure 19.5 Redundancy option 4 ....................................................... 19-9
Figure 19.6 Typical nurse call staff emergency station .......................... 19-12
Figure 19.7 Typical nurse call bedside station ..................................... 19-13
Figure 19.8 Typical nurse call code call station ................................... 19-14
Figure 19.9 Typical nurse call staff station ......................................... 19-15
Figure 19.10 Nurse call system traditional one-line diagram ................ 19-18
Figure 19.11 Typical physiological monitor remote wiring diagram ......... 19-31
Figure 19.12 Typical radio frequency identification tag ......................... 19-34
Figure 19.13 Typical interactive patient TV infrastructure system .......... 19-40
Chapter 20: Residential Cabling

Figure 20.1 Residential cabling layout ........................................ 20-4
Figure 20.2 Media room with one balanced twisted-pair and three coaxial cable runs to a telecommunications outlet ...................... 20-10
Figure 20.3 Example of a residential premises cabling system .......... 20-12
Figure 20.4 Multi-dwelling unit cabling layout ............................. 20-14
Figure 20.5 Telecommunications backbone and distribution cabling layout for an apartment building with a central backbone ......... 20-15
Figure 20.6 Telecommunications backbone and distribution cabling layout for an apartment building with multiple backbones .......... 20-16
Figure 20.7 Example of conduit distribution for a seven-unit townhouse 20-17
Figure 20.8 Cabling distribution for a side-by-side duplex residence 20-18
Figure 20.9 Example of cable distribution for frame apartment projects 20-19
Figure 20.10 Example of an apartment complex with backbone cable 20-20
Figure 20.11 Telecommunications outlets/connectors .................... 20-25

Chapter 21: Business Development and Project Management

Figure 21.1 Simple organizational breakdown structure ................. 21-16
Figure 21.2 PERT or network logic diagram using the precedence diagram method ......................................................... 21-21
Figure 21.3 Milestone chart ...................................................... 21-21
Figure 21.4 Gantt chart ............................................................ 21-21
Figure 21.5 Calendar of schedule .............................................. 21-22
Figure 21.6 Example of budgeted cost of work schedules ............... 21-25
Figure 21.7 Example of plotted BCWP, BCWS, and ACWP ........... 21-25
Figure 21.8 Client/supplier model ............................................. 21-28
Figure 21.9 United States National CAD Standard® layer name format 21-44

Appendix A: Codes, Standards, Regulations, and Organizations

Figure A.1 Conformité européenne (CE) mark .......................... A-82

Appendix B: Network Interfaces and Demarcation Points in the United States

Figure B.1 RJ11C/RJ11W connector configuration ...................... B-4
Figure B.2 RJ15C connector configuration .................................. B-5
Figure B.3 RJ16X connector configuration ................................. B-6
Figure B.4 RJ17C connector configuration .................................. B-8
Figure B.5 RJ18C, RJ18W connector configuration ...................... B-9
Figure B.6 RJ31X connector configuration .................................. B-10
Figure B.7 RJ14C/RJ14W connector configuration ...................... B-11
Figure B.8 RJ14X connector configuration .................................. B-12
Figure B.9 RJ25C connector configuration .................................. B-13
Figure B.10 RJ61X connector configuration ............................... B-14
Table of Contents

Figure B.11 RJ2DX connector configuration ........................................... B-15
Figure B.12 RJ2EX connector configuration ........................................... B-16
Figure B.13 RJ2FX connector configuration ........................................... B-17
Figure B.14 RJ2GX connector configuration ........................................... B-18
Figure B.15 RJ2HX connector configuration ........................................... B-19
Figure B.16 RJ21X connector configuration ........................................... B-20
Figure B.17 RJ2MB connector configuration ........................................... B-21
Figure B.18 RJ71C connector configuration ........................................... B-22
Figure B.19 RJ41S single-line data connection ..................................... B-24
Figure B.20 RJ45S single-line data connection ..................................... B-25
Figure B.21 RJ4MB single-line data connection ..................................... B-26
Figure B.22 RJ41M single-line data connection ..................................... B-28
Figure B.23 RJ45M single-line data connection ..................................... B-30
Figure B.24 RJ26X single-line data connection ..................................... B-31
Figure B.25 RJ27X single-line data connection ..................................... B-32
Figure B.26 RJ48S connector configuration ........................................... B-33
Figure B.27 RJ48T connector configuration ........................................... B-34
Figure B.28 RJ48C connector configuration ........................................... B-35
Figure B.29 RJ48M connector configuration ........................................... B-36
Figure B.30 RJ48X connector configuration ........................................... B-37
Figure B.31 RJ48H connector configuration ........................................... B-38

Appendix C: Regulations and Standards for Emissions and Immunity
Figure C.1 Emission limits at 10 m (≈33 ft) .......................................... C-4
Figure C.2 IEC CISPR 22 conducted disturbance limits (main ports) .......... C-5
Figure C.3 IEC CISPR 22 conducted disturbance limits (telecommunications ports) . C-5

Appendix D: Mechanical, Ingress, Climatic/Chemical, and Electromagnetic Considerations
Figure D.1 Industrial floor area described by MICE classification 1, 2, or 3. .... D-2
### Tables

#### Chapter 1: Principles of Transmission

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1.1</td>
<td>Conductor descriptions</td>
<td>1-2</td>
</tr>
<tr>
<td>Table 1.2</td>
<td>Solid conductor properties</td>
<td>1-3</td>
</tr>
<tr>
<td>Table 1.3</td>
<td>Electrical characteristics of common insulation types</td>
<td>1-6</td>
</tr>
<tr>
<td>Table 1.4</td>
<td>Explanations of insulation electrical characteristics</td>
<td>1-7</td>
</tr>
<tr>
<td>Table 1.5</td>
<td>Types of cable shields</td>
<td>1-15</td>
</tr>
<tr>
<td>Table 1.6</td>
<td>Common units of frequency measurement</td>
<td>1-18</td>
</tr>
<tr>
<td>Table 1.7</td>
<td>Spectrums of standard frequency bands</td>
<td>1-21</td>
</tr>
<tr>
<td>Table 1.8</td>
<td>Power ratios from 0 to 60 decibels</td>
<td>1-22</td>
</tr>
<tr>
<td>Table 1.9</td>
<td>Transmission data rates</td>
<td>1-30</td>
</tr>
<tr>
<td>Table 1.10</td>
<td>Coding methods</td>
<td>1-37</td>
</tr>
<tr>
<td>Table 1.11</td>
<td>Asymmetric digital subscriber line standards</td>
<td>1-46</td>
</tr>
<tr>
<td>Table 1.12</td>
<td>Asymmetric digital subscriber line performance</td>
<td>1-47</td>
</tr>
<tr>
<td>Table 1.13</td>
<td>Very high bit-rate digital subscriber line data rate and target range</td>
<td>1-48</td>
</tr>
<tr>
<td>Table 1.14</td>
<td>Propagation delay/delay skew</td>
<td>1-61</td>
</tr>
<tr>
<td>Table 1.15</td>
<td>Balanced twisted-pair cabling channel performance</td>
<td>1-71</td>
</tr>
<tr>
<td>Table 1.16</td>
<td>Applications supported using 100-ohm balanced twisted-pair cabling</td>
<td>1-72</td>
</tr>
<tr>
<td>Table 1.17</td>
<td>Media selection</td>
<td>1-74</td>
</tr>
<tr>
<td>Table 1.18</td>
<td>Transmission, speed, distance, and pair requirements</td>
<td>1-76</td>
</tr>
<tr>
<td>Table 1.19</td>
<td>Characteristics of typical light-emitting diode sources</td>
<td>1-88</td>
</tr>
<tr>
<td>Table 1.20</td>
<td>Characteristics of typical short wavelength laser</td>
<td>1-89</td>
</tr>
<tr>
<td>Table 1.21</td>
<td>Characteristics of typical vertical cavity surface emitting laser sources</td>
<td>1-90</td>
</tr>
<tr>
<td>Table 1.22</td>
<td>Characteristics of typical laser diode sources</td>
<td>1-91</td>
</tr>
<tr>
<td>Table 1.23</td>
<td>Comparison of transmitters</td>
<td>1-92</td>
</tr>
<tr>
<td>Table 1.24</td>
<td>Optical fiber cable performance by type</td>
<td>1-95</td>
</tr>
<tr>
<td>Table 1.25</td>
<td>Summarized comparison of core sizes of multimode and singlemode optical fiber cable</td>
<td>1-103</td>
</tr>
<tr>
<td>Table 1.26</td>
<td>Typical characteristics of multimode optical fiber</td>
<td>1-104</td>
</tr>
<tr>
<td>Table 1.27</td>
<td>Characteristics of 50/125 μm multimode optical fiber</td>
<td>1-105</td>
</tr>
<tr>
<td>Table 1.28</td>
<td>Characteristics of 62.5/125 μm multimode optical fiber</td>
<td>1-106</td>
</tr>
<tr>
<td>Table 1.29</td>
<td>Typical characteristics of singlemode optical fiber</td>
<td>1-107</td>
</tr>
<tr>
<td>Table 1.30</td>
<td>Maximum cable attenuation coefficient</td>
<td>1-109</td>
</tr>
<tr>
<td>Table 1.31</td>
<td>Mismatch of core size and power loss</td>
<td>1-112</td>
</tr>
<tr>
<td>Table 1.32</td>
<td>Calculating optical fiber performance</td>
<td>1-113</td>
</tr>
<tr>
<td>Table 1.33</td>
<td>System gain, power penalties, and link loss budget calculations</td>
<td>1-116</td>
</tr>
<tr>
<td>Table 1.34</td>
<td>Calculating losses</td>
<td>1-117</td>
</tr>
</tbody>
</table>
Table 1.35 Splice loss values in decibels .............................. 1-118
Table 1.36 Minimum system loss ...................................... 1-120
Table 1.37 Common synchronous optical network and synchronous digital
hierarchy transmission rates ......................................... 1-122
Table 1.38 Levels of multiplexing and carrier transmission in North America .......................... 1-128
Table 1.39 Levels of multiplexing and carrier transmission in Europe .......................... 1-130

Chapter 2: Electromagnetic Compatibility
Table 2.1 Factors that can affect electromagnetic interference in
telecommunications equipment .................................... 2-12
Table 2.2 Factors that can affect electromagnetic interference in sites ................................. 2-14
Table 2.3 Four levels of immunity ........................................ 2-22
Table 2.4 Electrostatic discharge susceptibility ranges ......................... 2-23
Table 2.5 Mutual capacitance ranges for telecommunications cables ................. 2-25
Table 2.6 Minimum separation distances from possible sources of
electromagnetic interference exceeding 5 kilovolt-amperes ............... 2-44
Table 2.7 Separation requirements between metallic cabling and specific
electromagnetic interference sources ............................... 2-45

Chapter 3: Telecommunications Spaces
Table 3.1 Size guidelines ....................................................... 3-14
Table 3.2 Smaller buildings ..................................................... 3-15
Table 3.3 Allocating termination space ..................................... 3-17
Table 3.4 Layout considerations .............................................. 3-26
Table 3.5 Environmental control systems standards for equipment rooms .................. 3-56

Chapter 4: Backbone Distribution Systems
Table 4.1 Backbone distribution system components .............................. 4-2
Table 4.2 Length and data rates for choosing optical fiber type ....................... 4-25
Table 4.3 Common conduit sizes with vernacular .................................. 4-26
Table 4.4 Summary of Ethernet in the first mile physical layer signaling
systems ............................................................................. 4-41
Table 4.5 Ethernet in the first mile installed singlemode optical fiber .............. 4-44

Chapter 5: Horizontal Distribution Systems
Table 5.1 Maximum allowable cable lengths with the use of multiuser
telecommunications outlet assemblies .................................. 5-29
Table 5.2 Comparison of consolidation point locations .................................... 5-34
Table 5.3 Primary passive optical network variations and their source
standards ............................................................................ 5-44
Table 5.4 Maximum channel attenuation and supported distance for passive
optical network versions .................................................... 5-47
Table 5.5 Typical electrical metallic tubing conduit fill rate for varying cable diameters ........................................ 5-62
Table 5.6 Bend radii guidelines ................................................... 5-65
Table 5.7 Adapting designs ......................................................... 5-66
Table 5.8 Typical space requirements for pull boxes having conduit enter at opposite ends of the box ............................................ 5-68
Table 5.9 Slip sleeves and gutters ............................................... 5-69
Table 5.10 Coverings ............................................................... 5-75
Table 5.11 Load capacity ......................................................... 5-75
Table 5.12 Guidelines for recommending ceiling panels ................... 5-79
Table 5.13 Common types of cable trays ..................................... 5-90
Table 5.14 Common cable tray dimensions ................................. 5-92
Table 5.15 Americans with Disabilities Act height requirements ........ 5-106

**Chapter 6: ITS Cables and Connecting Hardware**

Table 6.1 Comparison of the terms class and category within ISO/IEC and TIA standards ........................................... 6-3
Table 6.2 Balanced twisted-pair cabling channel performance ........ 6-4
Table 6.3 Balanced twisted-pair cable designations ..................... 6-5
Table 6.4 Balanced cable designs ............................................. 6-6
Table 6.5 Optical fiber cable transmission performance parameters ... 6-16
Table 6.6 Typical distances supported by optical fiber cabling ......... 6-20
Table 6.7 Examples of regional fire safety standards ..................... 6-30
Table 6.8 Communications cable types ..................................... 6-31
Table 6.9 Optical fiber cable types ........................................... 6-32
Table 6.10 Interclass relativity of National Electrical Code and International Electrotechnical Commission fire safety specifications .... 6-34
Table 6.11 Comparison between National Electrical Code CM ratings and Canadian Standards Association FT requirements .......... 6-35
Table 6.12 Connecting hardware transmission performance categories for 110-style connector-based connecting hardware .................. 6-38
Table 6.13 Connecting hardware transmission performance categories .... 6-41
Table 6.14 Connecting hardware transmission performance categories for BIX-style connectors ........................................... 6-44
Table 6.15 Connecting hardware transmission performance categories for LSA-style connector-based connecting hardware ................. 6-47
Table 6.16 Modular plug transmission performance categories ........ 6-51
Table 6.17 Modular jack transmission performance categories .......... 6-55
Table 6.18 50-position miniature ribbon connector transmission performance categories .............................................. 6-58
Table 6.19 Optical fiber link transmission performance calculations worksheet ...................................................... 6-83
Table 6.20 Splice insertion loss guidelines and objectives ................ 6-93
Table of Contents

Chapter 7: Firestop Systems
Table 7.1 Barrier standards ................................................................. 7-6
Table 7.2 European test standards ....................................................... 7-12
Table 7.3 Rating classifications, standards, and definitions .................. 7-13
Table 7.4 Limiting temperature for each test standard .......................... 7-16
Table 7.5 Pipes, conduits, sleeve systems, innerducts, cable trays, and cable penetration firestop methods (in ceilings) ......................... 7-47
Table 7.6 Electrical apparatus, boxes, and access panels firestop methods in ceilings ................................................................. 7-48
Table 7.7 Pipes, conduits, sleeve systems, innerducts, cable trays, and cable penetration firestop methods (in floors/ceilings) ................. 7-49
Table 7.8 Underfloor pipe, conduit, sleeve system, and innerduct firestop methods (in floors) .......................................................... 7-50
Table 7.9 Pipe sizes and fire ratings .................................................... 7-75
Table 7.10 Sizes of pipe chokes, wrap strip layers, and fire ratings .......... 7-95
Table 7.11 United States firestop standards ......................................... 7-115
Table 7.12 Canadian firestop standards .............................................. 7-117
Table 7.13 International firestop standards ......................................... 7-118

Chapter 8: Bonding and Grounding (Earthing)
Table 8.1 Basic guide to calculating bonding conductor resistance values .......................... 8-24

Chapter 9: Power Distribution
Table 9.1 Circular mils of standard American wire gauge conductors .......... 9-17
Table 9.2 Electrical formulas ............................................................ 9-19
Table 9.3 Voltage and current fluctuations ......................................... 9-20
Table 9.4 K-rating based on load makeup .......................................... 9-25
Table 9.5 Calculating maximum input current ..................................... 9-70
Table 9.6 Calculating voltage ............................................................ 9-71
Table 9.7 Major alarms (direct current) .............................................. 9-85
Table 9.8 Minor alarms (direct current) ............................................. 9-86
Table 9.9 Major alarms (uninterruptible power supply) ......................... 9-86
Table 9.10 Color code for conductors in the United States ...................... 9-90
Table 9.11 Color code for conductors in the United Kingdom and Ireland ... 9-92

Chapter 10: Telecommunications Administration
Table 10.1 Required identifiers by class ............................................. 10-5
Table 10.2 Minimum and optional administration system elements ........ 10-7
Table 10.3 Color codes ................................................................. 10-16
Table 10.4 Identifying pathways ....................................................... 10-29
Table 10.5 Required records by class ................................................. 10-34

Chapter 11: Field Testing of Structured Cabling
Table 11.1 Determining worst-case attenuation coefficient .................. 11-24
Chapter 12: Outside Plant
Table 12.1 Service diversity ................................................. 12-21
Table 12.2 Terminating space ............................................. 12-23
Table 12.3 Vertical/horizontal separations .............................. 12-32
Table 12.4 Metallic conduit types and sizes used in telecommunications .......... 12-37
Table 12.5 Direct-bury polyvinyl chloride (PVC) conduit types and sizes used in telecommunications ................................................................. 12-38
Table 12.6 Nonmetallic conduit types and sizes used in telecommunications .... 12-39

Chapter 13: Audiovisual Systems
Table 13.1 Color temperature ranges ..................................... 13-9
Table 13.2 Typical audio signal units of measurement .................. 13-11
Table 13.3 Common bit resolutions ......................................... 13-15
Table 13.4 Supported video formats ......................................... 13-27
Table 13.5 Standard-definition TV versus high-definition TV. ......... 13-29
Table 13.6 Front and rear projection advantages and disadvantages. .... 13-45
Table 13.7 Area covered by horns ............................................. 13-92
Table 13.8 Articulation index speech intelligibility ....................... 13-100
Table 13.9 Example of loss values per \( \approx 30 \text{ m (100 ft)} \) of the coaxial cable for the lowest and highest channels in a 60-channel system .......... 13-114

Chapter 14: Building Automation Systems
Table 14.1 Typical work and building automation systems coverage area sizes... 14-33

Chapter 16: Wireless Networks
Table 16.1 Transceiver types and application ............................ 16-27

Chapter 18: Data Centers
Table 18.1 Comparison of the standards .................................. 18-11

Chapter 20: Residential Cabling
Table 20.1 Recognized tenant area residential cabling by grade ............ 20-3
Table 20.2 Guidance in planning the wall space allocated for distribution device and associated equipment .......................... 20-8
Table 20.3 Telecommunications outlets/connectors for residences ........... 20-11
Table 20.4 Minimum space for a multi-dwelling unit common telecommunications room ............................................................. 20-13

Chapter 21: Business Development and Project Management
Table 21.1 MasterFormat® 2012 numbering .............................. 21-38

Appendix A: Codes, Standards, Regulations, and Organizations
Table A.1 Relationship between series EN 50174 and other design standards .... A-30
Table A.2 Sections of the Canadian Electrical Code ........................ A-44
Table A.3 Federal Communications Commission documents .................. A-52
Table A.4  *NESC®* parts, sections, and rules applicable to telecommunications distribution requirements ............................................... A-54
Table A.5  *NEC®* 2011 chapters, articles, and sections that impact telecommunications installation .................................................. A-59
Table A.6  Federal safety and health standards .................................................. A-71
Table A.7  Federal Communications Commission Regulations .......................... A-75

**Appendix B: Network Interfaces and Demarcation Points in the United States**

Table B.1  RJ11C/RJ11W connector configuration .............................................. B-3
Table B.2  RJ15C connector configuration .......................................................... B-5
Table B.3  RJ16X connector configuration .......................................................... B-6
Table B.4  RJ17C connector configuration .......................................................... B-7
Table B.5  RJ18C, RJ18W connector configuration .............................................. B-9
Table B.6  RJ31X connector configuration .......................................................... B-10
Table B.7  RJ14C/RJ14W connector configuration .............................................. B-11
Table B.8  RJ14X connector configuration .......................................................... B-12
Table B.9  RJ25C connector configuration .......................................................... B-13
Table B.10 RJ61X connector configuration ......................................................... B-14
Table B.11 RJ2DX connector configuration ......................................................... B-15
Table B.12 RJ2EX connector configuration ......................................................... B-16
Table B.13 RJ2FX connector configuration ......................................................... B-17
Table B.14 RJ2GX connector configuration ......................................................... B-18
Table B.15 RJ2HX connector configuration ......................................................... B-19
Table B.16 RJ21X connector configuration ......................................................... B-20
Table B.17 RJ2MB connector configuration ......................................................... B-21
Table B.18 RJ71C connector configuration ......................................................... B-22
Table B.19 RJ41S single-line data connection .................................................... B-23
Table B.20 RJ45S single-line data connection .................................................... B-25
Table B.21 RJ4MB single-line data connection ................................................... B-26
Table B.22 RJ41M single-line data connection ................................................... B-27
Table B.23 RJ45M single-line data connection ................................................... B-29
Table B.24 RJ26X single-line data connection ................................................... B-31
Table B.25 RJ27X single-line data connection ................................................... B-32
Table B.26 RJ48S connector configuration ......................................................... B-33
Table B.27 RJ48T connector configuration ......................................................... B-34
Table B.28 RJ48C connector configuration ......................................................... B-35
Table B.29 RJ48M connector configuration ......................................................... B-36
Table B.30 RJ48X connector configuration ......................................................... B-37
Table B.31 RJ48H connector configuration ......................................................... B-38
Table B.32 Intermixable services at network-provided standard connectors ........ B-39
Table B.33 Facility interface code translator ................................................... B-42
Appendix C: Regulations and Standards for Emissions and Immunity

<table>
<thead>
<tr>
<th>Table C.x</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.1</td>
<td>Class A radiation limits</td>
<td>C-2</td>
</tr>
<tr>
<td>C.2</td>
<td>Class B radiation limits</td>
<td>C-2</td>
</tr>
<tr>
<td>C.3</td>
<td>CENELEC EN 61000-6-1 and CENELEC EN 61000-6-2 generic standards</td>
<td>C-6</td>
</tr>
</tbody>
</table>

Appendix D: Mechanical, Ingress, Climatic/Chemical, and Electromagnetic Considerations

<table>
<thead>
<tr>
<th>Table D.x</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.1</td>
<td>List of applicable International Electrotechnical Commission test procedures</td>
<td>D-4</td>
</tr>
<tr>
<td>D.2</td>
<td>Ingress protection codes</td>
<td>D-7</td>
</tr>
<tr>
<td>D.3</td>
<td>Enclosure ratings and ingress protection codes</td>
<td>D-8</td>
</tr>
<tr>
<td>D.4</td>
<td>Comparison of specific applications of enclosures for indoor nonhazardous locations</td>
<td>D-9</td>
</tr>
</tbody>
</table>

Examples

Chapter 1: Principles of Transmission
Example 1.1 Optical fiber performance calculations example .................................... 1-114

Chapter 14: Building Automation Systems
Example 14.1 Scope of work checklist ............................................................................. 14-25

Chapter 21: Business Development and Project Management
Example 21.1 Work breakdown structure .......................................................................... 21-19
Example 21.2 Work breakdown structure in a text outline format ..................................... 21-20
Chapter 1
Principles of
Transmission

Chapter 1 focuses on the main concepts related to
signal transmission through metallic and optical fiber
transmission media. Among those concepts, this chapter
discusses types of signals and their properties, types
of transmission, and performance of different types of
transmission media. The appendix provides additional
information about signals provided in North America
and Europe.

This chapter has been updated to reflect current best
practices, codes, standards, and technology.
# Table of Contents

## SECTION 1: METALLIC MEDIA

**Metallic Media** .................................................. 1-1  
Overview .......................................................... 1-1

**Electrical Conductors** ........................................... 1-2  
Overview .......................................................... 1-2  
Description of Conductors ....................................... 1-2  
Comparison of Solid Conductors .................................. 1-3  
Solid Conductors versus Stranded Conductors ............... 1-4  
Composite Conductor ............................................... 1-4

**American Wire Gauge (AWG)** .................................... 1-5  
Overview .......................................................... 1-5

**Insulation** ........................................................ 1-5  
Overview .......................................................... 1-5  
Electrical Characteristics of Insulation Materials .......... 1-6

**Balanced Twisted-Pair Cables** .................................. 1-8  
Overview .......................................................... 1-8  
Pair Twists ....................................................... 1-8  
Tight Twisting .................................................... 1-8

**Environmental Considerations** ................................ 1-9  
Electromagnetic Interference (EMI) .............................. 1-9  
Temperature Effects ............................................... 1-9

**Cable Shielding** .................................................... 1-13  
Description ......................................................... 1-13  
Shielding Effectiveness .......................................... 1-13  
Types of Shields ................................................... 1-14  
Solid Wall Metal Tubes .......................................... 1-14  
Conductive Nonmetallic Materials ............................... 1-14  
Selecting a Cable Shield ......................................... 1-14  
Comparison of Cable Shields .................................... 1-15

**Drain Wires** ........................................................ 1-16  
Overview .......................................................... 1-16  
Applications ....................................................... 1-16  
Specifying Drain Wire Type ...................................... 1-16
## Chapter 1: Principles of Transmission

### Analog Signals

- Overview ................................................. 1-17
- Sinusoidal Signals ........................................ 1-17
- Standard Frequency Bands .......................... 1-21
- Decibel (dB) ........................................... 1-22
- Echo and Delay ........................................... 1-23
- Phase and Delay ........................................... 1-23

### Telephony

- Overview ................................................. 1-24
- Telephone Line Impedance ....................... 1-25
- Telephony Echo ......................................... 1-25
- Telephony Distortion ................................. 1-26
- Trends ....................................................... 1-26
- Internet Protocol (IP) Telephony ............... 1-27
  - Overview ................................................. 1-27
- Internet Protocol (IP) Telephony Devices .... 1-27
- Internet Protocol (IP) Telephony Architecture 1-27
- Power Over Balanced Twisted-Pair ............ 1-29
- Mission-Critical Data Network .................. 1-29

### Digital Signals

- Definition .................................................. 1-30
- Transmission Data Rates ...................... 1-30
- Converting an Analog Signal to a Digital Signal .................. 1-30
  - Filtering .................................................. 1-30
  - Sampling ............................................... 1-31
  - Quantizing/Companding ......................... 1-31
- Pulse Code Modulation (PCM) .................... 1-31
- Time Division Multiplexing (TDM) .......... 1-32
- Converting Digital Data to Digital Signals .... 1-35
  - Encoding Techniques .............................. 1-35
- Quadrature Amplitude Modulation (QAM) .... 1-40
- Discrete Multitone (DMT) ....................... 1-40
- 8B/1Q4 PAM5 Encoding .............................. 1-40
- Digital versus Analog .......................... 1-41

### Types of Transmission Circuits

- Overview ................................................. 1-42
- Simplex ................................................. 1-42
- Half-Duplex .............................................. 1-42
- Full-Duplex .............................................. 1-42
Chapter 1: Principles of Transmission

Asynchronous and Synchronous Transmission. ......................... 1-43
  Overview ........................................... 1-43
  Asynchronous Transmission .................................. 1-43
  Synchronous Transmission .................................. 1-43

Digital Hierarchy .................................................. 1-44
  Overview ........................................... 1-44
  Integrated Services Digital Network (ISDN) .................. 1-44
  Digital Subscriber Line (DSL) .................................. 1-45
  High Bit-Rate Digital Subscriber Line (HDSL) .............. 1-45
  Symmetrical Digital Subscriber Line (SDSL) .................. 1-45
  Asymmetric Digital Subscriber Line (ADSL) Technologies .... 1-46
  Rate-Adaptive Digital Subscriber Line (RADSL) ............. 1-47
  Very High Bit-Rate Digital Subscriber Line (VDSL) ......... 1-48

Video Transmission ................................................. 1-50
  Baseband Analog ........................................ 1-50
    Composite Format ...................................... 1-51
    Component Format ..................................... 1-51
  Broadband Video ......................................... 1-52
  Balanced Twisted-Pair Media Implementation ................. 1-52

Transmission Line Concepts ........................................ 1-53
  Overview ........................................... 1-53
  Characteristic Impedance .................................... 1-59
  Attenuation ........................................... 1-59
  Crosstalk ............................................. 1-60
  Nominal Velocity of Propagation (NVP). ...................... 1-60
  Propagation Delay ....................................... 1-60
  Delay Skew ............................................ 1-61
  Reflection Coefficient .................................... 1-61
  Return Loss ........................................... 1-62
  Signal-to-Noise Ratio (SNR) ................................ 1-62
  Attenuation-to-Crosstalk Ratio (ACR) ......................... 1-62
  Power Sum Attenuation-to-Crosstalk Ratio (PSACR) ......... 1-62
  Power Sum Attenuation-to-Alien-Crosstalk Ratio at the Near End (PSAACRN) ...................... 1-63
  Power Sum Attenuation-to-Alien-Crosstalk Ratio at the Far End (PSAACRF) ...................... 1-63

Balanced Twisted-Pair Performance ................................. 1-64
**Chapter 1: Principles of Transmission**

### Balanced Twisted-Pair Channel Performance 1-65
- Channel Model 1-65
- Performance Parameters 1-65
- Insertion Loss Performance Limits 1-66
- Near-End Crosstalk (NEXT) Loss Limits 1-66
- Power Sum Equal Level Far-End Crosstalk (PSELFEXT) Loss Limits 1-66
- Return Loss Limits 1-66
- Power Sum Attenuation-to-Crosstalk Ratio (PSACR) 1-67
- Concept of Bandwidth 1-67
- Summary 1-68

### Balanced Twisted-Pair Permanent Link Performance 1-69
- Permanent Link Model 1-69
- Balanced Twisted-Pair Patch Cords and Cross-Connect Jumpers 1-69

### Balanced Twisted-Pair Applications 1-70
- Design Considerations 1-70
- 100-Ohm Balanced Twisted-Pair Performance Category 1-71
- Media Selection 1-74
- Distances and Pair Requirements 1-76
- Shared Sheath Applications and Compatibility 1-79
- Media Conversion 1-80
- Impedance-Matching Devices (Baluns) 1-80
- Signal Converters 1-80
- Media Filters 1-81
- Transceivers 1-81
- Conclusion 1-81

### SECTION 2: OPTICAL FIBER

#### Optical Fiber 1-83
- Overview 1-83

#### Optical Fiber Transmitters 1-84
- Overview 1-84
- Light-Source Characteristics that Influence Optical Fiber Selection 1-84
  - Center Wavelength 1-84
  - Spectral Width 1-85
  - Average Power 1-86
  - Modulation Frequency 1-88
- Transmitter Light Sources 1-88
  - Light-Emitting Diode (LED) 1-88
  - Short Wavelength Lasers 1-89
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Cavity Surface Emitting Laser (VCSEL)</td>
<td>1-90</td>
</tr>
<tr>
<td>Laser Diodes (LDs)</td>
<td>1-91</td>
</tr>
<tr>
<td>Comparison of transmitters</td>
<td>1-92</td>
</tr>
<tr>
<td><strong>Optical Fiber Receivers</strong></td>
<td>1-93</td>
</tr>
<tr>
<td>Overview</td>
<td>1-93</td>
</tr>
<tr>
<td>Characteristic Parameters</td>
<td>1-93</td>
</tr>
<tr>
<td>Sensitivity and Bit Error Rate (BER)</td>
<td>1-93</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>1-93</td>
</tr>
<tr>
<td><strong>Optical Fiber Medium</strong></td>
<td>1-94</td>
</tr>
<tr>
<td>Optical Fiber Core Size Selection Parameters</td>
<td>1-94</td>
</tr>
<tr>
<td>Active Equipment</td>
<td>1-94</td>
</tr>
<tr>
<td>Transmission Media</td>
<td>1-95</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>1-96</td>
</tr>
<tr>
<td>Overview</td>
<td>1-96</td>
</tr>
<tr>
<td>Transmitters and Rise Time</td>
<td>1-97</td>
</tr>
<tr>
<td>Optical Fibers</td>
<td>1-99</td>
</tr>
<tr>
<td>Singlemode System</td>
<td>1-99</td>
</tr>
<tr>
<td>Multimode System</td>
<td>1-99</td>
</tr>
<tr>
<td>Chromatic and Modal Dispersion in Multimode Systems</td>
<td>1-100</td>
</tr>
<tr>
<td>Chromatic Dispersion</td>
<td>1-100</td>
</tr>
<tr>
<td>Modal Dispersion</td>
<td>1-100</td>
</tr>
<tr>
<td>Measurement and Specification of Multimode Systems.</td>
<td>1-100</td>
</tr>
<tr>
<td>Calculation</td>
<td>1-101</td>
</tr>
<tr>
<td>Classification of Optical Fiber</td>
<td>1-103</td>
</tr>
<tr>
<td>Multimode Optical Fiber</td>
<td>1-104</td>
</tr>
<tr>
<td>Wavelength Windows</td>
<td>1-106</td>
</tr>
<tr>
<td>Singlemode Optical Fiber</td>
<td>1-107</td>
</tr>
<tr>
<td><strong>Optical Fiber Applications Support Information</strong></td>
<td>1-108</td>
</tr>
<tr>
<td>Overview</td>
<td>1-108</td>
</tr>
<tr>
<td>Supportable Distances and Channel Attenuation</td>
<td>1-109</td>
</tr>
<tr>
<td><strong>Verifying Optical Fiber Performance and Electronics Compatibility</strong></td>
<td>1-110</td>
</tr>
<tr>
<td>Overview</td>
<td>1-110</td>
</tr>
<tr>
<td>Key Parameters</td>
<td>1-111</td>
</tr>
<tr>
<td>Verification Theory and Methodology</td>
<td>1-111</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1-112</td>
</tr>
<tr>
<td>Attenuation</td>
<td>1-113</td>
</tr>
<tr>
<td>A. Calculating the Link Loss Budget</td>
<td>1-115</td>
</tr>
<tr>
<td>B. Calculating the Passive Cable System Attenuation</td>
<td>1-117</td>
</tr>
<tr>
<td>C. Verifying Performance</td>
<td>1-119</td>
</tr>
</tbody>
</table>
Chapter 1: Principles of Transmission

Selecting an Optical Fiber Core Size to Application or Original Equipment Manufacturer (OEM) Specifications ............... 1-121

Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH) Concepts ........................................ 1-122

System Example .................................................................................. 1-123

Appendix ............................................................................................... 1-126

North American Digital Signal (DS) .................................................... 1-126
  Digital Signal Level Zero (DS0) ......................................................... 1-126
  Digital Signal Level One (DS1) ......................................................... 1-126
  Digital Signal Level One C (DS1C) .................................................... 1-127
  Digital Signal Level Two (DS2) ......................................................... 1-127
  Digital Signal Level Three (DS3) ....................................................... 1-127
  Higher Levels .................................................................................. 1-128

European E ......................................................................................... 1-129
  B Channel ...................................................................................... 1-129
  E1 Level ......................................................................................... 1-129
  E2 Level ......................................................................................... 1-129
  E3 Level ......................................................................................... 1-129
  Higher Levels .................................................................................. 1-130
### Figures

| Figure 1.1 | Calculated attenuation values for cables insulated with FEP, ECTFE, and PVC from 1 MHz to 135 MHz at 22 °C (72 °F) | 1-10 |
| Figure 1.2 | Calculated and measured attenuation values for cables insulated with FEP, ECTFE, and PVC from 1 MHz to 135 MHz at 40 °C (104 °F) | 1-11 |
| Figure 1.3 | Calculated and measured attenuation values for cables insulated with FEP, ECTFE, and PVC from 1 MHz to 135 MHz at 60 °C (140 °F) | 1-12 |
| Figure 1.4 | Example 1 of a sinusoidal signal | 1-17 |
| Figure 1.5 | Example 2 of a sinusoidal signal | 1-19 |
| Figure 1.6 | Internet protocol telephony architecture | 1-28 |
| Figure 1.7 | Digital signal level one frame format | 1-33 |
| Figure 1.8 | E1 frame format | 1-34 |
| Figure 1.9 | Polar non-return-to-zero level. | 1-38 |
| Figure 1.10 | Bipolar alternate mark inversion | 1-38 |
| Figure 1.11 | Biphase Manchester | 1-38 |
| Figure 1.12 | Two binary bits encoded into one quaternary (2B1Q) | 1-39 |
| Figure 1.13 | Multilevel transition-3 (MLT-3, also referred to as non-return-to-zero inverted [NRZI-3]) | 1-39 |
| Figure 1.14 | Composite video | 1-51 |
| Figure 1.15 | Two-conductor transmission line | 1-53 |
| Figure 1.16 | Resistive model. | 1-54 |
| Figure 1.17 | Capacitance model | 1-55 |
| Figure 1.18 | Inductive model | 1-56 |
| Figure 1.19 | Primary transmission line parameters | 1-57 |
| Figure 1.20 | General transmission model | 1-58 |
| Figure 1.21 | Example of a channel test configuration | 1-65 |
| Figure 1.22 | Permanent link test configuration | 1-69 |
| Figure 1.23 | Spectral profile comparison of laser and light-emitting diode | 1-85 |
| Figure 1.24 | Spectral width of a light-emitting diode source showing full width half maximum | 1-86 |
| Figure 1.25 | Numerical aperture | 1-87 |
| Figure 1.26 | System bandwidth versus distance example. | 1-96 |
| Figure 1.27 | Pulse distortion because of rise time and data rate | 1-98 |
| Figure 1.28 | Link bandwidth at 1300 nanometers using 62.5/125 micrometer multimode optical fiber | 1-102 |
| Figure 1.29 | Core and coating. | 1-105 |
| Figure 1.30 | Digital signal cross-connect optical multiplexing design | 1-123 |
| Figure 1.31 | Synchronous optical network multiplexing design | 1-124 |
| Figure 1.32 | Wavelength division multiplexing | 1-125 |
Table 1.1  Conductor descriptions ................................................. 1-2
Table 1.2  Solid conductor properties ........................................... 1-3
Table 1.3  Electrical characteristics of common insulation types ......... 1-6
Table 1.4  Explanations of insulation electrical characteristics ........... 1-7
Table 1.5  Types of cable shields .................................................. 1-15
Table 1.6  Common units of frequency measurement ......................... 1-18
Table 1.7  Spectrums of standard frequency bands .......................... 1-21
Table 1.8  Power ratios from 0 to 60 decibels ................................ 1-22
Table 1.9  Transmission data rates ................................................ 1-30
Table 1.10 Coding methods .......................................................... 1-37
Table 1.11 Asymmetric digital subscriber line standards ..................... 1-46
Table 1.12 Asymmetric digital subscriber line performance .................. 1-47
Table 1.13 Very high bit-rate digital subscriber line data rate and target range 1-48
Table 1.14 Propagation delay/delay skew ....................................... 1-61
Table 1.15 Balanced twisted-pair cabling channel performance .......... 1-71
Table 1.16 Applications supported using 100-ohm balanced twisted-pair cabling 1-72
Table 1.17 Media selection ............................................................ 1-74
Table 1.18 Transmission, speed, distance, and pair requirements .......... 1-76
Table 1.19 Characteristics of typical light-emitting diode sources ........ 1-88
Table 1.20 Characteristics of typical short wavelength laser ............... 1-89
Table 1.21 Characteristics of typical vertical cavity surface emitting laser sources ....................................................... 1-90
Table 1.22 Characteristics of typical laser diode sources .................... 1-91
Table 1.23 Comparison of transmitters .......................................... 1-92
Table 1.24 Optical fiber cable performance by type ......................... 1-95
Table 1.25 Summarized comparison of core sizes of multimode and singlemode optical fiber cable ......................................... 1-103
Table 1.26 Typical characteristics of multimode optical fiber ............. 1-104
Table 1.27 Characteristics of 50/125 μm multimode optical fiber .......... 1-105
Table 1.28 Characteristics of 62.5/125 μm multimode optical fiber ....... 1-106
Table 1.29 Typical characteristics of singlemode optical fiber .......... 1-107
Table 1.30 Maximum cable attenuation coefficient ............................ 1-109
Table 1.31 Mismatch of core size and power loss .............................. 1-112
Table 1.32 Calculating optical fiber performance .............................. 1-113
Table 1.33 System gain, power penalties, and link loss budget calculations 1-116
Table 1.34 Calculating losses ....................................................... 1-117
Table 1.35 Splice loss values in decibels ........................................ 1-118
Chapter 1: Principles of Transmission

Table 1.36 Minimum system loss ........................................ 1-120
Table 1.37 Common synchronous optical network and synchronous digital hierarchy transmission rates. ........................................ 1-122
Table 1.38 Levels of multiplexing and carrier transmission in North America .... 1-128
Table 1.39 Levels of multiplexing and carrier transmission in Europe .......... 1-130

Examples

Example 1.1 Optical fiber performance calculations example .................. 1-114