Field Operations Assessment

Development Guide

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Introduction

This Development Guide provides suggestions and information that will help you develop and improve knowledge needed the Field Operations Assessment. This Job Knowledge test must be passed to be considered for hire into certain job titles at Verizon. The Field Operations Assessment consists of 40 multiple-choice questions, covering five broad knowledge areas. The number of items devoted to each knowledge area on the test varies. Each multiple-choice question will have four possible responses, with one correct answer. These knowledge areas are described later in this Development Guide.

Using the Guide

1. Read the Test Information, Test-Preparation Tips, and Test-Taking Tips sections on pages 5-7. Then, review the section on Ways to Improve Your Score on the Test. Also, read the suggested activities that may help you further develop your knowledge, tailoring the suggestions to fit your specific work style and situation.
2. The knowledge areas measured on the test are each described in this Guide. First, a brief description of the knowledge area is provided. This description is not a complete tutorial on the knowledge area; it simply indicates what the knowledge area means for purposes of this test. Following the brief description, a number of relevant aspects of the knowledge area are listed. These are the things you should be sure to learn about when studying for the test. Then, suggested resources (primarily books and websites) are provided, where applicable, to help you learn about the knowledge area. Most of the books can be found at local libraries and bookstores.
3. You might want to read relevant portions of the books and websites listed in the suggested readings and resources. You do not need to read every book and website that is listed, nor do you necessarily need to read them in their entirety. The books and websites listed are just examples of the type of things that you should read. It is the content of these reference sources, not specific titles, that is important. You may therefore want to seek out other references that cover the content included in the test.
4. Included in the description of each knowledge area is a sample question from the practice test at the end of this Guide that represents the knowledge area, together with an explanation that indicates which of the four possible answers is correct, and why. You may also want to complete the practice test questions at the end of this Guide. Check your answers against the answers provided after the practice questions. An explanation of why the answers identified are correct is also provided for each question. Use this information to understand why the specified answers are correct and the other answers are incorrect.

Note: Using this Guide does not guarantee that you will pass the Field Operations Assessment. Your performance will depend on your initial knowledge and ability level, the effort you put into improving your knowledge, and the effectiveness of the knowledge development activities you undertake.

Test Information

The goals in developing the Field Operations Assessment were to ensure that the test is job-related, fair, and accurate. These goals were accomplished by working closely with a large number of subject matter experts (SMEs). Job-relatedness was established by asking the SMEs: (1) to identify the knowledge elements required to perform the targeted positions, (2) to review the test questions to make sure they tap those required knowledge elements, and (3) to evaluate whether they are relevant to the targeted positions. Fairness was established by asking SMEs to review all knowledge elements and test questions to ensure that they represent knowledge that is required on the job and is not specific to Verizon. Accuracy was established by asking SMEs to review each test question for technical accuracy and to make sure there is only one, clearly correct, answer.

As described above, all of the questions will be multiple-choice with four alternatives; there will be no “trick” questions. This test requires some knowledge of electronics and other technical topics as they relate to the telecommunications industry. The Field Operations Assessment does not, however, require any knowledge of specific Verizon policies, practices, instrumentation, or tools. The type of knowledge measured by this test can be acquired either inside or outside of Verizon. The number of items devoted to each knowledge element on the test will vary, according to its breadth and importance.

Test Preparation Tips

This section provides information about how to study effectively and how to apply your knowledge during the test.

General Suggestions

- Study to learn the key concepts now, permanently, rather than putting off the real learning for later.
- Don't focus simply on rote memorization; work on finding patterns in, drawing connections between, and understanding the principles underlying the information presented in the study materials.
- Cultivate interest in the material and confidence in your ability to master it; both improve learning.
- Avoid cramming just before you take the test; cramming will reduce your concentration and increase your confusion.
- Develop an organized "plan of attack" for learning the material that fits your learning style; for example, don't skip ahead to more advanced concepts until you've learned the more basic concepts (unless you've already learned the basic concepts).

Study Schedule and Study Environment Suggestions

- Set aside plenty of study time several weeks before the test.
- Devise a special study schedule by dividing material into organized units, each to be learned by a certain date before the test.
- Let your family and friends know how important it is that you stick to your study schedule.
- Arrange for a distraction-free place to study.

Review Suggestions

- Don't just skim your study materials; strive to understand the material as well as memorize for the test.
- Actively review material by writing things down as you study rather than just passively reading/re-reading the material.
- Remember that pattern-finding is very important to learning large amounts of information.
  - Try to impose a pattern on each topic you are studying.
  - Outline material by numbering or lettering important points.
  - Find relationships, concrete examples, and applications that will aid your memory of the study materials.
  - Use mnemonics (that is, memory aids such as using the sentence Every Good Boy Does Fine to remember the correct order of musical notes – EGBDF) when possible to help you learn information.

Test-Taking Tips

Before the Test

- If possible, get a good night's sleep before the test so that you're well rested and alert.
- Go into the test with a positive attitude, determined to do your best. Focus on what you know, rather than worrying about what you don't know.
- Reduce test anxiety and tension by breathing deeply and stretching before the test.

During the Test

- Read the instructions carefully. Be sure you understand the test instructions before you start.
- Read the entire question and all response alternatives before choosing your answer.
    - Read the question and response alternatives carefully to make sure you avoid accidentally adding or deleting words in your head.
    - Pay attention to critical words like NOT and EXCEPT.
    - Do not over-interpret questions or try to find hidden meanings; again, the questions are not designed to be tricky. Take the questions at face value.
- Try to stay relaxed during the test. If you have trouble concentrating or become tense, pause and take a few deep breaths.

Ways to Improve Your Score on Job Knowledge Tests

This section contains development suggestions that should help you improve your technical job-related knowledge. You may find these suggestions helpful in preparing for the Field Operations Assessment.

Developmental Suggestions

- Studying books and websites on basic electricity and electronics and basic telecommunications/telephony, including those suggested in this Guide. Relevant books are available in libraries and bookstores. Relevant websites can be found using standard search engines such as Google. If you don't have a computer with Internet access, many public libraries provide this service.
- Answering practice questions found in books and websites on basic electricity and electronics, and on basic telecommunications/telephony.
- Taking courses in basic electricity or electronics, and basic telecommunications/telephony at a community or vocational/technical school.
- Taking formal or self-study training courses in electricity and electronics, telecommunications/telephony, or safety practices in the telecommunications industry, if you work for an organization that offers them.

Knowledge Areas Covered in the Test

The Field Operations Assessment is made up of five knowledge areas:

1) Basic hardware and installation for outside plant
2) Basic safety procedures
3) Basic electrical principles and test equipment
4) Bonding and grounding principles
5) Basic computer knowledge

Each of these knowledge areas is described in the following pages. Reference materials are suggested for each knowledge area as appropriate. In addition, a sample question which represents the knowledge area is shown, along with an explanation for why the answer is correct.

1. Basic Hardware and Installation for Outside Plant

In telephony, the outside plant includes the cables and infrastructure that connect customers to the central office. This infrastructure includes the aerial plant, the buried plant, network terminations, protection devices, and all associated hardware. In this test, job candidates will be asked to demonstrate knowledge relevant to the installation and maintenance of the outside plant. This will include basic knowledge of drop locating procedures, cable pair and binder identification (color coding), sealing material techniques and associated safety practices, and buried plant installations. In addition, the test will cover knowledge of network interface devices (NIDs), installation tools, punch down blocks, aerial service terminals, and basic surge protectors. Knowledge of American Wire Gauge (AWG) and its application in the outside telephone plant will also be covered.

This knowledge area is made up of the following more specific knowledge elements:

- Basic drop locating procedures
- Buried drop installation
- How to install a network interface device (NID) and terminal drop wire
- Types of protectors and when to use
- Electrical hardware such as lugs, pins, wire gauges, and tools (e.g., punch blocks)
- Basic terminal types
- Wire sizes and gauges and how to use properly
- Proper sealing materials and techniques

Suggested Reference Materials

- Telecommunications Fundamentals
- Outside Plant Overview
- Telephone Cable Color Codes
- Verizon Service Offering
- Interfaces and Lightning Protectors
- Telephone Line Surge Protection
- Telecommunications Wiring
- Telephone Wire Sizes

Sample Question representing this knowledge area

1) In residential areas, buried services are normally placed at depths of ____, unless a local zoning ordinance specifies otherwise.
   a. 6-12 inches
   b. 12-18 inches
   c. 18-24 inches
   d. 24-36 inches

Explanation:

The correct answer is "b." Telecommunications industry standards in residential areas specify that buried lines are to be placed at a depth of 12-18 inches, unless a local zoning ordinance supersedes industry standards.

2. Basic Safety Procedures

Safety is a primary concern for employees in telephone industry field occupations. Maintaining a work environment that is free from hazards benefits both employees and employers. In this test, job candidates will be asked to demonstrate knowledge of basic safety procedures and practices for installation and maintenance of the telephone outside plant. This will include initial and final safety checks at work areas; the safe use of tools, equipment, and vehicles; avoidance of electrical, vehicular, and environmental hazards; and knowledge of safety codes relevant to the telephone industry.

This knowledge area is made up of the following knowledge element:

- Use of cable and safety test equipment

Suggested reference material

- Environmental, Health & Safety Communications Panel website (https://ehscp.org/)

Sample question representing this knowledge area

A telephone service technician should use traffic cones:

a. only when there is heavy traffic.
b. when there are children on site.
c. only when he/she needs to block a street.
d. when parking his/her service vehicle at a public area work site.

Explanation:

The correct answer is "d." When a telephone service technician performs an installation, maintenance, or repair activity at a public area work site, traffic cones are needed to: (1) provide a visible warning to other traffic, vehicular and pedestrian, that the service vehicle is parked and to stay clear of the work area; and (2) to serve as a reminder to the service technician to inspect the work area before departing or moving the service vehicle. As such, the use of traffic cones is limited neither to conditions involving only heavy traffic, nor to situations when a service technician needs to block a street. Moreover, the purpose of traffic cones is to ensure that not only children, but all pedestrians and vehicles, stay clear of the work area.

3. Basic Electrical Principles and Test Equipment

In this test, job candidates will be asked to demonstrate knowledge of fundamental concepts of AC and DC electricity and their applications in the telephony industry, including calculations using Ohm's Law. Job candidates will also be evaluated on their knowledge of commonly used analog and digital test and measuring equipment and its utilization to test for continuity, opens, shorts, and appropriate voltages on local loops. Knowledge of the basics of conducting and insulating materials as used in telephony will also be evaluated.

This knowledge area is made up of the following knowledge elements:

- Conductors and insulators
- Ohm's Law
- The use of testing equipment (e.g., multimeters, digital voltmeters)
- AC/DC theory
- Basic electrical principles (e.g., resistance – continuity, shorts, voltage)

Suggested reference materials

- The American Radio Relay League, Inc. (2002). Understanding basic electronics. ISBN: 0-87259-398-3
- McComb, G., & Boysen, E. (2005). Electronics for dummies. Hoboken, NJ: Wiley. ISBN: 0-7645-7660-7
- U.S. Bureau of Naval Personnel (1969). Basic electricity (2nd. Ed.). New York: Dover Publications. ISBN: 0486209733
- Van Valkenburgh, Nooger and Neville, Inc. (1993). Basic electricity (Rev. Ed.). Thomson Delmar Learning. ISBN 0790610418

Sample question representing this knowledge area

Which of the following is the best conductor of electricity?

a. Aluminum
b. Copper
c. Brass
d. Silver

Explanation:

The correct answer is "d." Of the four conductors listed, silver has the least resistance, followed by copper, aluminum, and brass. As such, silver is the best conductor. It is also, however, the most expensive. Because of the cost factor, copper is the most commonly used conductor.

4. Bonding and Grounding Principles

Grounding is the backbone of effective protection of all networked systems. Bonding is an integral component of effective grounding in that bonding keeps various pieces of conductive equipment at the same potential. In this test, job candidates will be asked to demonstrate knowledge of proper bonding techniques for conductors in outside plant telephony, including techniques relevant to the use of emergency and temporary power. Job candidates will also be asked to demonstrate knowledge of correct grounding procedures (for example, at network termination locations). Finally, candidates will be asked to demonstrate knowledge of appropriate safety procedures and notifications relevant to outside electrical hazards and working with power, both permanent and temporary.

This knowledge area is made up of the following knowledge element:

- Bonding and grounding principles and theories

Suggested reference materials

- PSI Grounding Tutorial
- NLSI Grounding Guidelines
- National Electric Code, Article 250
- Simmons, P. (2005). Electrical grounding and bonding: Based on the 2005 National Electric Code. Thomson Delmar Learning. ISBN: 1-4018-5938-0
- BICSI (2001). Telecommunications cabling installation. McGraw-Hill Professional. ISBN: 0-0714-0979-3

Sample question representing this knowledge area

A good ground is an important part of an installation for all of the following reasons EXCEPT:

a. It helps reduce damage in case of a lightning hit.
b. It eliminates any chance of personnel being electrocuted if a short occurs to a frame or cabinet.
c. It protects sensitive electronics from electrical static discharge during installation.
d. It is required by most manufacturers, industry practice, and electrical codes.

Explanation:

The correct answer is "c." A good ground will not protect sensitive electronics from electrical static discharge during installation. Static discharge can, for example, result from handling electronic components or using packaging material improperly, neither of which is related to grounding. By contrast, a good ground will reduce damage in a lightning hit during installation by shunting the voltage from the lightning strike to the ground (since the path to the ground has the least resistance). This will divert most of the energy away from regular wiring. A good ground will also eliminate the chance of electrocution if a short occurs during installation by diverting the stray voltage to the ground. Finally, most manufacturers, industry standards, and electrical codes require a good ground.

5. Basic Computer Knowledge

Verizon technical positions require new hires to rapidly become familiar with a number of computer systems/applications. It is therefore important that the job candidates possess the basic knowledge needed to learn these systems/applications. In this test, job candidates will be asked to demonstrate basic knowledge of the Windows operating system and the installation and use of common application software (e.g., Microsoft Excel, Word, Outlook). The purpose of these test questions is not to evaluate candidates' knowledge of specialized telecommunications industry software or advanced knowledge of computer hardware and software. Our purpose is simply to determine whether candidates have had some basic experience working with computers.

Suggested reference sources

None. To perform well on these questions, you should familiarize yourself with the basic functions and applications of computers.

Sample question representing this knowledge area

Today's laptop computers primarily use ___ operating systems:

a. DOS
b. UNIX
c. Windows
d. Excel

Explanation:

The correct answer is "c." The question asks which operating system is PRIMARILY used by today's laptop computers. DOS is sometimes used, but it is an older operating system used only on rare occasions for older programs that were created before the Windows Platform came out. UNIX is used in many engineering systems (and is the base of the MAC OS10 system), but it is not the primary operating system for today's laptop computers. Excel is not an operating system at all, but is instead an application used inside the operating system.

Appendix A. Practice Questions

The following questions are similar to those you will find on the Field Operations Assessment. The questions are grouped according to knowledge area.

Knowledge Area 1: Basic Hardware and Installation for Outside Plant

1. On an initial test, a telephone line reads 500 ohm tip-ring resistance. What is the most likely cause of this reading?
    a. The line is open
    b. The telephone is off the hook
    c. The line is grounded
    d. The meter isn't calibrated properly

2. In residential areas, buried services are normally placed at depths of ____, unless a local zoning ordinance specifies otherwise.
    a. 6-12 inches
    b. 12-18 inches
    c. 18-24 inches
    d. 24-36 inches

3. A technician is making an in-line splice as part of a buried drop installation. Approximately how much outer sheath should be removed from each end of the piece of service wire being added?
    a. 2 inches
    b. 4 inches
    c. 12 inches
    d. 24 inches

4. Which of the following statements about installation of protectors is true?
    a. Ground wires must not be spliced.
    b. Gas tube protectors should be mounted on the pole to protect the drop line.
    c. Wire with a gauge number of 22 or higher should be used to ground the protector.
    d. Protectors used with aerial drops should be mounted within 6 inches of where the drop attaches to a building.

5. When connecting telephone service to a mobile home, where should the protector be mounted?
    a. On the outside wall of the mobile home.
    b. At least six feet from the mobile home
    c. It is not needed because the mobile home is not grounded.
    d. On a post or pole about one foot from the mobile home.

6. Load coils:
    a. must be removed for digital circuits to function
    b. must be used on T-1 lines

c. must be used on ISDN BRI lines
d. Both b and c

7. In a buried wire environment, the choice of whether to take a plowing or trenching approach to cable installation should be made during the:
a. pre-survey.
b. inspection of tools.
c. notification of Central Office.
d. installation.

8. Which of the following is a disadvantage of standard twisted wire relative to coaxial cable?
a. It is more susceptible to electrical interference (noise).
b. It is very expensive.
c. It is more difficult to work with.
d. It takes longer to splice.

9. What is the best location for a 66 punch-down block?
a. On a pole
b. In a manhole
c. On the rear wall of a building
d. Inside an office building

10. At which of the following locations must telephone company-owned ducts be sealed at both ends?
a. Ducts connecting one pole to another
b. Ducts connecting one building to another
c. Ducts connecting one manhole to another
d. All of the above

Knowledge Area 2: Basic Safety Procedures

11. When must a telephone service technician wear a safety harness while working aloft on a telephone pole?
a. Only when the pole is shared by electric utility lines
b. Only when working under another employee
c. Only when climbing with “hooks”
d. A safety harness must be worn whenever a service technician works aloft on a telephone pole

12. A telephone service technician should use traffic cones:
    a. only when there is heavy traffic.
    b. when there are children on site.
    c. only when he/she needs to block a street.
    d. when parking his/her service vehicle at a public area work site.

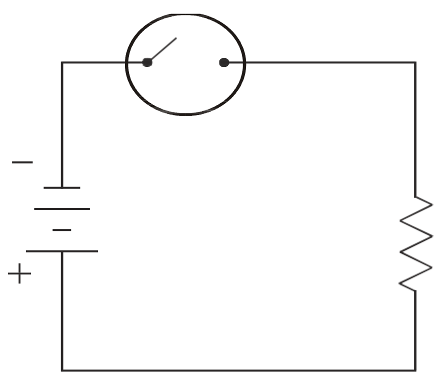
Knowledge Area 3: Basic Electrical Principles and Test Equipment

13. The United States standard for an alternating current is:
    a. 36 cycles per second.
    b. 48 cycles per second.
    c. 60 cycles per second.
    d. 72 cycles per second.

14. What four factors affect the resistance of a conductor?
    a. Length, weight, height, and size
    b. Temperature, length, size, and type of material
    c. Ground, weight, type of material, and length
    d. Voltage, size, length, and temperature

15. The unit of measurement for capacitance is the:
    a. ohm.
    b. farad.
    c. watt.
    d. volt.

16. In the schematic diagram below, the circled symbol represents a:



    a. capacitor
    b. battery
    c. switch
    d. resistor

17. Which of the following is used to measure the output of a battery?
   a. TDR
   b. Wattmeter
   c. Voltmeter
   d. Any of the above

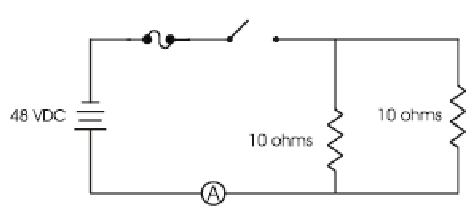
18. When using an Ohmmeter to measure a properly functioning component:
   a. a short will be measured across a ceramic capacitor.
   b. an open will be measured across a mylar capacitor.
   c. an open will be measured across a power transformer primary.
   d. an open will be measured across loud speaker terminals.

19. A zener diode is used to:
   a. regulate voltage
   b. amplify current
   c. filter audio
   d. switch circuits

20. One of the diodes in a full wave bridge rectifier opens. The DC output voltage will:
   a. increase.
   b. cease (no output).
   c. change polarity.
   d. be pulsing.

21. Which of the following is the best conductor of electricity?
   a. Aluminum
   b. Copper
   c. Brass
   d. Silver

22. What is the total current flow reading on the ammeter in this circuit?



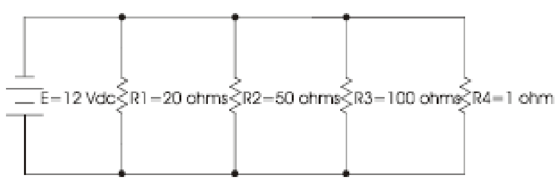
   a. 0 amps
   b. 4.8 amps
   c. 6.4 amps
   d. 9.6 amps

23. In a closed parallel circuit:
    a. the total current flow will be less than the sum of the individual loop currents.
    b. the total current flow will equal the sum of the individual loop currents.
    c. the total current flow will exceed the sum of the individual loop currents.
    d. None of the above

24. Assuming everything else is held constant, Ohm's law states that, as the current level of an electrical circuit increases:
    a. its voltage decreases.
    b. its resistance decreases.
    c. its inductance decreases.
    d. its capacitance decreases.

25. Which meter will be used when measuring the signal-to-noise ratio on a DSL circuit?
    a. Subscriber Loop Analyzer
    b. OTDR
    c. T-BERD
    d. Cable Hound

26. What type of circuit is depicted in the figure below?



    a. Series circuit
    b. Parallel circuit
    c. Solid state circuit
    d. Resonant circuit

Knowledge Area 4: Bonding and Grounding Principles

27. A B-temporary bond is used to:
    a. temporarily fix a ground in a telephone circuit.
    b. bond metallic fixtures while working aloft.
    c. ground a telephone circuit.
    d. remove excessive noise from a telephone line.

28. If an electrical fault develops on an electrical fixture while it is connected with a B-temporary bond to a direct path to ground, the B-bond will:

a. beep.
b. emit smoke.
c. light up.
d. break.

29. A good ground is an important part of an installation for all of the following reasons EXCEPT:
    a. It helps reduce damage in case of a lightning hit.
    b. It eliminates any chance of personnel being electrocuted if a short occurs to a frame or cabinet.
    c. It protects sensitive electronics from electrical static discharge during installation.
    d. It is required by most manufacturers, industry practice, and electrical codes.

Knowledge Area 5: Basic Computer Knowledge

30. Today's laptop computers primarily use ___ operating systems:
    a. DOS
    b. UNIX
    c. Windows
    d. Excel

Appendix B. Answers to Practice Questions with Explanations

Knowledge Area 1: Basic Hardware and Installation for Outside Plant

1. The correct answer is “b.” When a telephone is off-hook, it will have a resistance measured across the tip and ring of about 500 ohm. An open line is inconsistent with a reading of 500 ohm because there will be no connectivity between the tip and ring. A grounded line can result is a variety of readings depending on the location of the ground. Since a rating of 500 ohm signifies that the telephone is off-hook, and is therefore a plausible reading, it is unlikely that the meter has been improperly calibrated.

2. The correct answer is “b.” Telecommunications industry standards in residential areas specify that buried lines are to be placed at a depth of 12-18 inches, unless a local zoning ordinance supersedes industry standards.

3. The correct answer is “c.” The industry standard for splicing in-line buried drop cables is to remove 12 inches of the outer sheath before wrapping the splice to protect against water and moisture seepage into the splice. Four inches is too short and 24 inches is wasteful.

4. The correct answer is “a.” A good ground is necessary for a protector to function correctly. A spliced ground wire can, however, defeat the purpose of protectors. This is because exposed splices tend to degrade over time due to corrosion, resulting in failure of the ground. This failure occurs because corrosion causes resistance to form, which means the current will flow along a less resistant path than the one to the ground wire.

5. The correct answer is “d.” Protectors must be mounted on a rigid structure that is attached to the ground so that a ground wire can be securely attached to the protector. A mobile home is not structurally attached to the ground, so the protector must be mounted on a post or pole. The distance between the mounted protector and the mobile home should be about 12 inches, per industry standards.

6. The correct answer is “a.” Load coils (impedance matching transformers) are placed on POTS lines that exceed 6,000 feet. Load coils enhance the quality of analog voice signals by limiting the upper portion of the frequency spectrum, which is required by digital signals. Consequently, they interfere with the functioning of digital circuits.

7. The correct answer is “a.” A pre-survey is always done before any cable installation so that technicians know they have the proper materials (both type and amount). Tool inspection does not factor into the decision regarding plowing versus trenching. Once an approach has been selected, only then can the correct tools be chosen. The Central Office has nothing to do with how a wire is buried. And, of course, the choice should not be made during installation of the cable, since the technician may not have all of the appropriate tools and equipment. Moreover, if the choice were made during installation, the field drawings would have to be updated.

8. The correct answer is “a.” Twisted wire does not have a shield around it to block electrical interference, whereas coaxial cable does. As such, twisted wire is more susceptible to electrical interference. Twisted wire is less expensive to manufacture than coaxial cable because it is less complex and uses less material per foot. Twisted wire is easier to work with than coaxial cable because the braided shield that makes up coaxial cable (whether it is made of copper or another metal) is more difficult to connect or bond to than twisted wire. Finally, splicing coaxial cable takes longer than splicing twisted wire because splicing coaxial cable requires the shield around the cable to be completely bonded to the splice. This adds complexity to the splicing process, which consequently takes longer to complete.

9. The correct answer is “d.” The 66 punch-down block is a device used to connect one group of wires to another. This device is not weatherproof and is used indoors rather than outdoors. Using it outdoors would cause the connections to corrode.

10. The correct answer is “d.” In this context, a duct is a pipe, tube, or conduit through which cables or wires are passed. Ducts must always be sealed on both ends to prevent moisture and foreign objects from entering. Location is irrelevant.

Knowledge Area 2: Basic Safety Procedures

11. The correct answer is “d.” OSHA regulations require the use of safety equipment to protect employees whenever they are working in situations in which injury or death could occur. The purpose of a safety harness is to protect employees from hazards associated with working in situations where a fall may injure or kill them. Working aloft on a telephone pole is one such situation. As such, a safety harness is required whenever a telephone service technician works aloft on a telephone pole.

12. The correct answer is “d.” When a telephone service technician performs an installation, maintenance, or repair activity at a public area work site, traffic cones are needed to: (1) provide a visible warning to other traffic, vehicular and pedestrian, that the service vehicle is parked and to stay clear of the work area; and (2) to serve as a reminder to the service technician to inspect the work area before departing or moving the service vehicle. As such, the use of traffic cones is limited neither to conditions involving only heavy traffic, nor to situations when a service technician needs to block a street. Moreover, the purpose of traffic cones is to ensure that not only children, but all pedestrians and vehicles, stay clear of the work area.

Knowledge Area 3: Basic Electrical Principles and Test Equipment

13. The correct answer is “c.” There are two worldwide standards that deal with the frequency of commercial alternating current (AC) electrical service: 50 Hz (Hertz, or cycles per second) and 60 Hz. North America, including the United States, is standardized on 60 Hz.

14. The correct answer is “b.” The resistance of a conductor: (a) decreases as the temperature decreases, (b) increases as the length of the conductor increases, and (c) decreases as the size (cross sectional area) of the conductor increases. Some types of materials are better conductors than others and, as such, have less resistance. For example, copper has less resistance than gold,

and gold has less resistance than aluminum. The weight of a conductor, the voltage run through a conductor, the grounding of a conductor, and the height of a conductor (without knowledge of its width) are unrelated to resistance.

15. The correct answer is "b." The unit of measurement for capacitance is farads (named for the 19th-century scientist Michael Faraday). The Ohm is a measure of resistance, the Watt is a measure of power, and the Volt is a measure of electrical potential.

16. The correct answer is "c." This question represents several electrical symbols, each with well-established meanings, according to telecommunications industry standards, and their use in a schematic diagram of a circuit. The circled symbol is used to represent a switch.

17. The correct answer is "c." A TDR (Time Domain Reflectometer) measures the length of a cable or the distance to a fault, a wattmeter measures power, and a voltmeter measures electrical potential (voltage). A battery's output is electrical potential, which is measured in volts.

18. The correct answer is "b." The Ohmmeter reading of properly functioning ceramic and mylar capacitors will indicate an open circuit. The Ohmmeter reading for both power transformer primaries and loud speaker terminals will show very low resistance, which does not indicate an open circuit.

19. The correct answer is "a." Zener diodes are widely used to regulate voltage across a circuit. A zener diode conducts once the voltage reaches the diode's reverse breakdown voltage (assuming it is connected in parallel with a variable voltage source so that it is reverse biased). The zener diode then maintains the voltage at that value.

20. The correct answer is "d." A full wave bridge rectifier is composed of four diodes configured to convert AC to DC. If one of the diodes should open, the DC output will lose part of the AC phase conversion to DC, resulting in a period of zero DC output during each cycle of the AC (as would be produced by a half wave rectifier circuit). This is observable on an oscilloscope as a pulsing output with the voltage falling to zero and remaining there for a half wave period.

21. The correct answer is "d." Of the four conductors listed, silver has the least resistance, followed by copper, aluminum, and brass. As such, silver is the best conductor. It is also, however, the most expensive. Because of the cost factor, copper is the most commonly used conductor.

22. The correct answer is "a." Since the switch is open, no current can flow and the ammeter measuring the total current flow in the circuit will read 0 amps. It is important to study a complete circuit before beginning to calculate voltages and current flows. If the switch were closed, Ohm's law could be used to calculate an answer.

23. The correct answer is "b." It is a fundamental law of electrical theory that, in a closed parallel circuit, the total current flow is equal to the sum of the individual loop currents.

24. The correct answer is "b." Ohm's law states that, for any circuit, the electric current is directly proportional to the voltage and is inversely proportional to the resistance. Ohm's law does not involve inductance or capacitance.

25. The correct answer is “a.” The subscriber loop analyzer is designed specifically to test the ratio of signal-to-noise on a DSL circuit. It does so using various test functions built into the equipment that compare the level of the signal to the level of the ambient noise on the circuit.

26. The correct answer is “b.” In the circuit above, all of the elements connect to the same two wires from the battery. The symbol used for the elements is that of a resistor. Since there are no capacitors or inductors shown, it cannot be a resonant circuit. Since there are no solid-state devices such as diodes or transistors, it cannot be a solid-state circuit. The resistors are arranged in parallel (that is, side-by-side with all elements connecting to the same upper and lower wires), not in series.

Knowledge Area 4: Bonding and Grounding Principles

27. The correct answer is “b.” The function of a B-temporary bond is to bond metallic fixtures to an earth ground. This is done to protect workers who might come into contact with potentially dangerous voltages while working in the vicinity of such fixtures. B-temporary bonds are used only on metallic fixtures. Response options “a,” “c,” and “d” all refer to communication circuits.

28. The correct answer is “b.” B-temporary bonds are designed to emit harmless smoke whenever an electrical fault occurs. This is done to alert workers to hazards so they can cease work until the fault can be resolved and it is safe to continue.

29. The correct answer is “c.” A good ground will not protect sensitive electronics from electrical static discharge during installation. Static discharge can, for example, result from handling electronic components or using packaging material improperly, neither of which is related to grounding. By contrast, a good ground will reduce damage in a lightning hit during installation by shunting the voltage from the lightning strike to the ground (since the path to the ground has the least resistance). This will divert most of the energy away from regular wiring. A good ground will also eliminate the chance of electrocution if a short occurs during installation by diverting the stray voltage to the ground. Finally, most manufacturers, industry standards, and electrical codes require a good ground.

Knowledge Area 5: Basic Computer Knowledge

30. The correct answer is “c.” The question asks which operating system is PRIMARILY used by today’s laptop computers. DOS is sometimes used, but it is an older operating system used only on rare occasions for older programs that were created before the Windows Platform came out. UNIX is used in many engineering systems (and is the base of the MAC OS10 system), but it is not the primary operating system for today’s laptop computers. Excel is not an operating system at all, but is instead an application used inside the operating system.

AN-6

COMMON MISTAKES IN LIGHTNING PROTECTION OF PHONE LINE INTERFACE CIRCUITS

By Joe Randolph

Introduction

Lightning protection of phone line interface circuits is a complicated topic. The specific protection circuit that will provide the best protection at the lowest cost will depend heavily on the type of interface being protected, the circuits used to implement that interface, and the type of equipment in which the interface is installed.

Despite this complexity, there are certain common considerations that typically apply for a wide range of applications. The purpose of this note is to provide a very basic description of the types of lightning surges that appear on phone lines, and a description of some of the common mistakes that designers make when trying to protect a phone line interface from these surges. This note is *not* intended to provide a comprehensive tutorial on lightning protection, but the basic principles described here should be helpful to any designer who is trying to develop a protection circuit, or to manufacturers who are experiencing lightning failures in the lab or in the field.

Terminology

In order to discuss lightning protection of phone line interface circuits, it is necessary to first define some terms that will be used frequently:

Phone Line Tip and Ring

A regular analog phone line consists of a single twisted pair of copper wires called tip and ring. Sometimes these are called the A and B leads. The discussion here will focus on this type of 2-wire phone line, although the same protection principles apply to 4-wire arrangements such as T1/E1, HDSL, and even Ethernet.

Terminal Equipment (TE)

In general, “terminal equipment” refers to equipment that terminates the phone line tip and ring leads at the customer’s premises. Examples include telephones, modems, fax machines, and PBXs. For the purposes of this discussion, we will also consider as “terminal equipment” any equipment provided by the phone company that terminates the other end of the phone line, such as a central office feed circuit. This is a slightly broader definition of TE than is commonly used in the industry.

Common Mode (Longitudinal) Surges

Most lightning surges appear “common mode” on tip/ring. This means that the surge voltage appears equally on both tip and ring with respect to earth ground. In other words, if you could measure the voltage from tip to ring during a 1000 volt common mode surge, you would measure zero volts tip-to-ring, but if you measured between tip/ring and ground, you would measure 1000 volts tip-to-ground and 1000 volts ring-to-ground. The telecom term for a common mode surge is “longitudinal.”

Differential (Metallic) Surges

Sometimes a common mode surge gets converted to a differential surge that appears as a voltage difference between the tip and ring leads. For example, if a common mode surge of 1000 volts is applied to tip/ring, and an SCR protection device triggers and shorts tip to ground, tip will be at ground potential while ring remains at 1000 volts. This is called a “common mode to differential conversion.” Whenever there are protection devices installed tip-to-ground and ring-to-ground, there exists the possibility of a common mode to differential conversion, since no two protection devices will trigger at the exact same moment. The telecom term for a differential surge is “metallic.”

Surge Waveform

Test waveforms for lightning surges are typically referred to by the rise time, fall time, open circuit voltage, and short circuit current. For example, a 10x1000 uS, 1000 volt, 100 amp surge has a nominal rise time of 10 uS, a decay to 50% peak value in 1000 uS, an open circuit voltage of 1000 volts, and a short circuit current of 100 amps.

The design of accurate, repeatable laboratory surge generators is very difficult, but the basic principle is deceivingly simple. A capacitor is charged up to the specified open circuit voltage, and then it is discharged into the phone line via a wave shaping network that includes a series limiting resistor. So, a surge generator for the above referenced 1000 volt, 100 amp surge will have an internal 10 ohm series resistor that limits its short circuit current output to 100 amps. As will be seen in the discussion that follows, it is important to consider both the open circuit voltage *and* the short circuit current when designing lightning protection circuits. In most situations, only one of these two parameters will dominate the failure mode for a particular surge.

DAA (FXO) and SLIC (FXS) Phone line Interfaces

There are two very different types of phone line interfaces used on regular analog phone lines. For TE such as telephones, modems, fax machines, and PBXs, the interface is typically called a DAA or FXO interface. These interfaces function as loads across the tip/ring leads, and they are typically *isolated from earth ground*. For the purposes of this discussion, we will call these DAA-FXO interfaces.

On the other end of the phone line, back at the phone company central office, there is a different interface called a SLIC or FXS interface. These interfaces provide DC power to the phone, and apply a high voltage AC ring signal to activate the ringer in the phone. These interfaces source power to the phone line, and they are typically *connected to earth ground*. For the purposes of this discussion, we will call them SLIC-FXS interfaces. The fundamental differences between DAA-FXO circuits and SLIC-FXS circuits call for very different protection schemes.

Primary Protector

Each end of the phone line is typically equipped with a “primary protector” at the point where the phone line enters the building. The job of the primary protector is to divert most of the lightning energy on the phone line to earth ground. Primary protectors have some form of crowbar overvoltage protection devices connected tip-to-ground and ring-to-ground. The devices used in primary protectors can be gapped carbon blocks, gas tubes, or SCR-type silicon devices.

In general, primary protectors that use gapped carbon blocks have the highest breakdown voltages. If the type of primary protector that will be present on a given phone line is unknown, it is customary to assume that it will be a carbon block protector. By industry convention, the maximum “let-through” of a carbon block primary protector is roughly 1000 volts differential and 1500 volts common mode. Most industry standards for lightning immunity of phone line TE assume that a primary protector is installed on the phone line. Thus, most industry standards focus on the “let-through” energy that gets past the presumed primary protector and can damage the TE.

How Lightning Appears On a Phone Line

Lightning almost never strikes phone lines directly. When it does, there is usually extensive damage including melted copper and scorched circuit boards. When a phone line gets a direct strike, there is pretty much no protection scheme that will protect the wiring and the equipment. None of the industry standard lightning test surges are intended to simulate a direct strike.

The vast majority of lightning surges on phone lines are *induced* on the phone line by lightning striking something nearby, such as a tree, a building, or the ground itself. The huge currents associated with the nearby strike generate intense electromagnetic fields that couple into the tip/ring leads by electromagnetic induction. Since the tip/ring wires are twisted together, the same voltage is typically induced in the tip lead as the ring lead, which is why lightning surges are typically induced as common mode surges.

Another mechanism by which lightning appears on phone line interfaces is called “ground potential rise.” When lightning strikes the ground, the huge currents flowing through the non-zero resistance of the ground will cause a momentary increase in the local ground potential. If the strike is near the point where the primary protector is connected to ground, this ground potential rise can effectively force current up the ground lead of the primary protector and onto the phone line, sort of like coming in the back door. Either way, a large common mode surge is induced on the phone line.

As mentioned earlier, if only one side of the primary protector triggers in response to a common mode surge, the surge will be converted from common mode to differential. This is why most telecom standards specify immunity to both common mode and differential surges.

Most industry standards for lightning immunity of phone line interfaces focus on how the TE will handle the let-through energy that gets past the primary protector. Lightning protection installed behind the primary protector is often referred to as the “secondary protection.” Secondary protection is typically included inside the TE near the point where the phone line enters the TE enclosure. Sometimes an external protector is installed near the TE, but if this protector is installed behind the primary protector it is still referred to as a secondary protector.

Some Common Mistakes

We have now defined the terminology we will use and have discussed how lightning gets induced on phone lines. The key role of the primary protector has been described, since assumptions about the primary protector affect the type of surge waveforms that the TE is likely to experience. We are now ready to discuss some of the common protection mistakes made by designers of phone line interface circuits.

1) Focusing on Voltage Instead of Current

Many designers focus their attention on the open circuit voltage of the surge, and do not give sufficient thought to the path that the surge current will take. Any time a voltage-limiting device is used for lightning protection, the dominant problem usually becomes one of managing the high peak currents that will travel through the protection device and return to the surge generator via some path through the TE.

It is very important to pay attention to the complete path that the surge current will take. For example, it is not a good practice to return lightning current through the logic ground plane of a circuit board. A current of 100 amps passing through the ground plane will develop significant voltage drops from one side of the board to the other, potentially causing upset or damage to sensitive circuits. While the digital ground usually must be tied to the chassis ground at some point, the location should be chosen in such a way that lightning return currents do not travel through sensitive circuitry.

One case where it is appropriate to focus on the open circuit voltage is for common mode surges on FXO interfaces. Since FXO interfaces are typically isolated from ground, it is possible to rely on the isolation barrier for protection against common mode surges. For example, an isolation barrier that provides 1000 VRMS (1414 volts peak) isolation when tested with a 50/60 Hz AC hipot test will usually handle a 1500 volt peak common mode surge without difficulty. In this case the protection strategy is to prevent any current at all from entering the TE during a common mode surge.

2) Using Undersized Components

The problem of undersized components is closely related to the need to study the path that the surge current will take as it passes through the TE.

Look carefully at every component that will carry lightning current, and confirm that it is capable of handling the current without damage. Of course, the surge protector itself is the first component to check, so study the data sheet carefully to confirm that the protector can handle the surge current it will see in the application. However, lightning return current typically also passes through other components on its way back to the surge generator. Every component in the lightning path should be evaluated, including connectors, diodes, resistors, relays, chokes, and ferrite beads.

For example, many designers mistakenly place small surface mount ferrite beads directly in the lightning path. Typically, these will blow off the board like popcorn when the first surge is applied.

Resistors in the surge path are a frequent problem, and must be carefully selected. A 10 ohm resistor with 50 amps passing through it will dissipate a peak power of (50)x(50)x(10) = 25,000 watts. While the entire surge event typically lasts less than 1 mS, this is still a lot of pulse power to handle.

Typically, a garden variety resistor can handle about ten times its steady state power rating for 1 mS. For example, just about any 10 ohm, 1 watt resistor can survive a 1 amp, 10x1000 uS surge (10 watts instantaneous peak). Beyond a peak-to-average ratio of about ten, it becomes important to use resistors that are specifically designed as “pulse withstand” resistors. Certain types of resistor construction, such as thick film and wire wound, are better suited to withstanding high pulse energy, especially if they are specifically designed for high pulse power. Determine the peak pulse power that the resistor will have to handle, and make sure that the specifications show that the resistor can handle that level of pulse power. When in doubt, request more information from the manufacturer.

3) Using Undersized Trace Width and Spacings in Board Layouts

There is much confusion among designers about what sort of trace widths and spacings are appropriate for handling lightning current. Sometimes the designer forgets to consider this at all, and an auto-routed circuit with 6 mil lines and 6 mil spacings suffers extensive lightning damage. On the other hand, some designers are more conservative than they need to be, and specify extremely wide trace width and spacings, causing excessive board area to be consumed.

In general, a minimum trace width of 15 mils in so called “one ounce copper” is required to handle a 10x1000 uS, 100 amp surge. For voltage breakdown, the spacing should be at least 25 mils for every 1000 volts of peak voltage that the spacing is intended to withstand. Note that depending on the protection scheme being used, the peak voltage differences in the circuit may be limited by the surge protectors.

4) Forgetting to Consider Both Common Mode and Differential Surge Events

Since lightning surges can be presented either common mode or differentially, it is important to consider how the circuit will respond to both types of surge. Some designers focus only on one type and forget to consider the other.

5) Forgetting That the Isolation Barrier Must be 3-Dimensional

In circuits such as DAA-FXO interfaces that rely on the isolation barrier for common mode protection, it is important to ensure that the barrier provides adequate spacing in three dimensions. Sometimes the designer will take great care to maintain the proper spacing in the board layout, but will forget to consider conductive parts that are mounted above, below, or next to the phone line interface. For example, the leads on a through-hole RJ-11 connector can protrude below the board and come close to the chassis or another circuit.

6) Neglecting Overshoot of Overvoltage Protectors

Most overvoltage protectors will limit at a lower voltage for a slow, low-current surge than for a fast, high-current surge. When analyzing the predicted behavior of an overvoltage protector, it is important to consider both the rise time and the peak current of the applied surge. For example, the actual trigger threshold of a GDT (Gas Discharge Tube) typically goes up significantly with faster rise times of the applied surge. The peak voltage across an MOV (Metal Oxide Varistor) will be much higher for high currents than for low currents. In general, all overvoltage protectors exhibit overshoot to some degree, and this overshoot should be factored into the design of the protection circuit.

7) Inadvertently Placing Two Overvoltage Protectors in Parallel

If two overvoltage protectors are placed in parallel, all of the surge current will flow through the device with the lower threshold. Sometimes this leads to unexpected results when different operational modes of the circuit create different surge paths. For example, when a DAA-FXO circuit is in the onhook idle mode, a 300 volt protector across tip/ring is usually adequate to protect the ring detector and switchhook relay without creating false triggering on the peaks of the AC ring signal.

However, when the circuit is in the offhook active mode, normal loop current flows through the DC hold circuit, generating a voltage drop of only ten volts or so between tip and ring. In this condition, a differential surge will cause excess current to flow through the DC hold circuit, and can overwhelm the low voltage protection (if any) provided in that circuit. Since excessive current can flow at voltages well under 300 volts, the 300 volt protector that works fine for the onhook condition provides no protection at all for the offhook condition.

8) Returning Surge Current to an Unreliable Ground

It is best to avoid returning surge currents to a “ground” that may not be grounded. For example, if the protection circuit in a fax machine or desk top terminal adapter has common mode overvoltage protectors installed tip-to-ground and ring-to-ground, the path to ground typically relies on a grounded AC mains connector. In many consumer applications the presence of a grounded AC power outlet can not be guaranteed. If surge currents are directed to a “ground” path that in fact is not grounded, the surge current will seek any other path to ground that it can find. Sometimes this might be through a USB cable or serial port connected to another piece of equipment that does have a ground. Surge currents traveling through such paths typically cause extensive damage.

9) Compromising Normal, Non-Surge Operation

Sometimes designers use protection devices that compromise the normal operation of the circuit. For example, an overvoltage protector that triggers on worst-case peak voltages experienced during normal operation can cause spurious behavior of the system. Also, most surge protectors present some amount of capacitance to the circuit. In some cases this capacitance is voltage-dependent and causes nonlinear distortion. Capacitance and nonlinearity are typically not an issue for conventional DAA-FXO circuits or SLIC-FXS circuits, but they can cause problems for high speed circuits such as T1/E1 and DSL modems.

10) Misunderstanding Balance Requirements

In phone line interfaces, the concept of balance refers to matching the impedance from tip-to-ground to the impedance from ring-to-ground. If these impedances are not well matched, induced

50/60 Hz common mode noise on the phone line can be converted to differential noise that is audible to the user.

The issue of balance is very important for interfaces that connect to long outside phone lines. Since outside lines are sometimes routed in parallel with AC power mains for long distances, there is considerable opportunity for induction of 50/60 Hz common mode voltages on the phone lines.

In general, SLIC-FXS interfaces are more difficult to balance than DAA-FXO interfaces. Since SLIC-FXS circuits are typically not isolated from earth ground, the impedance from tip-to-ground and from ring-to-ground is usually less than 100 ohms. If the designer adds a 10 ohm, 10% tolerance resistor in series with the tip lead and a 10 ohm, 10% tolerance resistor in series with the ring lead, the result could be a 111 ohm resistance tip-to-ground and a 109 ohm resistance ring-to-ground. This mismatch is enough to cause audible hum on an outside line. In SLIC-FXS circuits that interface to outside lines, any added impedances usually must be matched *to within a fraction of an ohm* in order to maintain good balance. This matching is hard to achieve with some protection schemes.

For SLIC-FXS interfaces that only connect to short loops within a building, the amount of induced common mode 50/60 Hz noise will usually be low. In these applications, a higher degree of unbalance can be tolerated without causing audible hum.

DAA-FXO circuits are typically much less sensitive to added resistance because they are isolated from ground. In general, adding 10, 20, or even 100 ohms in only the tip lead or only the ring lead is entirely acceptable for a DAA-FXO interface, since the inherent impedances from tip-to-ground and from ring-to-ground typically exceed one megohm. When the inherent impedances are already very high, adding a small amount of resistance in only one leg is not enough to materially affect the overall balance.

In summary, it is possible to either underestimate or overestimate the need for the protection circuit to provide well matched impedances in tip and ring. In general, extremely good matching is required for SLIC-FXS interfaces that connect to outside lines. Failure to provide this matching can introduce audible hum. On the other hand, matched impedances in tip and ring are generally less of an issue for SLIC-FXS interfaces that connect to short inside lines, or for DAA-FXO interfaces regardless of line length.

11) Assuming That the Primary Protector is Working

As noted earlier, most of the industry standard lightning surges used for compliance testing assume that the primary protector is properly installed and working. It turns out that a small percentage of primary protectors, especially in residential installations, are not functioning. This is usually because the primary protector’s connection to earth ground has been inadvertently disconnected by a plumber, electrician, or other contractor working on the house. Since a disconnected primary protector does not create any obvious problem with the phone service, these situations can remain undetected for a very long time.

When the primary protector is not functioning, common mode surges can reach 5000 volts or more, although the short circuit currents typically remain below 100 amps. For the best overall reliability in consumer applications, DAA-FXO interfaces that rely on the isolation barrier for common mode protection should withstand common mode surges of 5000 volts. Usually it is not difficult to enhance the isolation barrier to provide this level of protection.

12) Assuming That Inside Lines Never Experience Lightning Surges

As odd as it may seem, lightning surges can appear on phone lines that stay entirely within a building. Fortunately, the energy induced in inside lines is typically much lower than the energy induced in outside lines.

Recall that even for outside lines, the surge energy that appears on the phone line is typically induced by electromagnetic coupling from lightning that strikes a nearby object. In a tall office building with inside phone lines routed from the basement to the top floor, energy can be induced in the phone lines if lightning strikes the building and travels to ground through the steel frame of the building. The degree of risk for inside lines depends mostly on how long they are. In general, lines that are less than 100 meters long are probably at minimal risk, but the surge exposure grows as the length of the line increases.

Summary

Designing appropriate lightning protection for a phone line interface typically requires having detailed information about the circuit to be protected and the surges that it must survive. Without this information it is difficult to make general statements about what sort of protection circuit is best for a given application. Designers have available a wide variety of protection devices and protection strategies that can be combined for a successful solution.

In terms of general advice for designers, the important thing is to understand the expected surge events and then carefully analyze how the proposed protection scheme is likely to behave under surge conditions. Some designers underestimate the value of this type of analysis, and proceed directly to board layout and laboratory surge testing without doing the analysis first. This can lead to a long and expensive test-modify-retest cycle.

This note has provided some background on how lightning energy gets onto phone lines and what sorts of surge events typically appear at the phone line interfaces of terminal equipment. An effort has also been made to explain the differences between the various types of phone line interfaces, since these differences affect the available options for lightning protection.

With this background, several common mistakes in lightning protection have been described. Hopefully, readers can use this information to help them review their proposed circuits during the design phase. In addition, readers who are experiencing lightning failures that they do not presently understand may gain some insight from reviewing the above discussion.

Standard Cable Color-Coding Reference

These are the standard color codings for telephone cables containing up to 26 pairs. For cables containing more than 26 pairs, a Binder Color Code wraps multiple bundles of 25 pairs with a colored binder thread. For cables containing more than 600 pairs, a Super Unit Binder Color code is used to separate multiple Binder bundles.

Insulation Band-Marked Color Code

Pair	Wire	T/R	Color Long/Short	Wire Markings
1	1	Tip	White - Blue	
	2	Ring	Blue - White	
2	3	Tip	White - Orange	
	4	Ring	Orange - White	
3	5	Tip	White - Green	
	6	Ring	Green - White	
4	7	Tip	White - Brown	
	8	Ring	Brown - White	
5	9	Tip	White - Slate	
	10	Ring	Slate - White	
6	11	Tip	Red - Blue	
	12	Ring	Blue - Red	
7	13	Tip	Red - Orange	
	14	Ring	Orange - Red	
8	15	Tip	Red - Green	
	16	Ring	Green - Red	
9	17	Tip	Red - Brown	
	18	Ring	Brown - Red	
10	19	Tip	Red - Slate	
	20	Ring	Slate - Red	
11	21	Tip	Black - Blue	
	22	Ring	Blue - Black	
12	23	Tip	Black - Orange	
	24	Ring	Orange - Black	
13	25	Tip	Black - Green	
	26	Ring	Green - Black	
14	27	Tip	Black - Brown	
	28	Ring	Brown - Black	
15	29	Tip	Black - Slate	

	30	Ring	Slate - Black
16	31	Tip	Yellow - Blue
	32	Ring	Blue - Yellow
17	33	Tip	Yellow - Orange
	34	Ring	Orange - Yellow
18	35	Tip	Yellow - Green
	36	Ring	Green - Yellow
19	37	Tip	Yellow - Brown
	38	Ring	Brown - Yellow
20	39	Tip	Yellow - Slate
	40	Ring	Slate - Yellow
21	41	Tip	Violet - Blue
	42	Ring	Blue - Violet
22	43	Tip	Violet - Orange
	44	Ring	Orange - Violet
23	45	Tip	Violet - Green
	46	Ring	Green - Violet
24	47	Tip	Violet - Brown
	48	Ring	Brown - Violet
25	49	Tip	Violet - Slate
	50	Ring	Slate - Violet
26	51	Tip	Red - White
	52	Ring	White - Red

Note: Some cable vendors only use a single color for the Tip wire, and mark the Ring wire with two colors. For example, for Pair 1, there would be a solid white Tip wire, and a White/Blue Ring wire twisted together as normal. Untwisted, there will be five identical Tip wires of the same color and this could cause confusion. Such cables require different handling than a cable with fully-marked wires.

Insulation Solid Color Code

Certain types of telephone wiring use solid color insulation markings rather than banded color codes. Solid color wiring is commonly used for jumper wire, distribution frame wire and station wire.

For sheathed station cables (pairs are usually not twisted) containing four to eight conductors, the following table is used. This includes "flat" cables, also known by the name "Satin Flex", regardless of outer insulator color. If a wire only has four or six conductors, it always uses the first four or six colors.

Pair	Wire	T/R	Wire Colors
1	1	Tip	Green
	2	Ring	Red
2	3	Tip	Black

	4	Ring	Yellow
3	5	Tip	Blue
	6	Ring	Orange
4	7	Tip	Brown
	8	Ring	White

For cables containing more than 8 conductors using solid colors, the pairs must be twisted together and the top color table is used.

Binder Color Code

For cables containing more than 25 pairs, the standard color sequence is repeated and each group of 25 pairs is wrapped in a Binder that is colored according to the table below. For cables of 100-pair or less, the White binder is optional.

Group	Pair Counts	Color Long/Short	Color Markings
1	1-25	**White - Blue**	
2	26-50	**White - Orange**	
3	51-75	**White - Green**	
4	76-100	**White - Brown**	
5	101-125	**White - Slate**	
6	126-150	**Red - Blue**	
7	151-175	**Red - Orange**	
8	176-200	**Red - Green**	
9	201-225	**Red - Brown**	
10	226-250	**Red - Slate**	
11	251-275	**Black - Blue**	
12	276-300	**Black - Orange**	
13	301-325	**Black - Green**	
14	326-350	**Black - Brown**	
15	351-375	**Black - Slate**	
16	376-400	**Yellow - Blue**	
17	401-425	**Yellow - Orange**	
18	426-450	**Yellow - Green**	
19	451-475	**Yellow - Brown**	
20	476-500	**Yellow - Slate**	
21	501-525	**Violet - Blue**	
22	526-550	**Violet - Orange**	
23	551-575	**Violet - Green**	
24	576-600	**Violet - Brown**	

Super-units Binder Identification Colors

It is desirable for manufacturing purposes to combine four 25-pair groups into "super units" when cables have 900-pair or more.

Pair Number	Group Number	Binder Color
1-600	1-24	White
601-1,200*	25-48	Red
1,201-1,800*	49-72	Black
1,801-2,400*	73-96	Yellow
2,401-3,000*	97-120	Violet
3,001-3,600*	121-144	Blue
3,601-4,200*	145-168	Orange

* Based on the Full Count binder color coding used in RDUP copper cable designs having 1,200-pair or more.

Telephone line surge protection

First version written by Tomi Engdahl at 1996, revised at June 1998

Why surge protection is needed ?

Telephone lines are long copper wires from central office to your apartment. Usually those wires are between few hundred meters to few kilometers. Those wires are connected in the central office to the telephone center/exchange. Normally there is only the 48V DC voltage from central office battery in the line, and when phone ring there is 70-130V AC voltage in the line. That's what in the line in normal operation.

But the situation in the thunderstorm is different. When the lightning hits the ground with it's millions of volts and thousands of ampreres strike every wire in the ground or hanging in the air will notice it. Near lightning strike gan generate a surge pulse of thousands of volts to telephone lines. If this can go to the electronics inside the telephone or modem, the electronics will destroy at the same moment.

What telecom operator has done to it ?

The surge can destroy electronics in both subscriber's and central office end, so you must think that telecom operator must have done something to this problem. Yes they have.

First they have installed surge suppression devices to their central office to make sure that small surges dos not damage it. They have usually also installed some sort of protection to subscriber's side of the line to the place where telephone cable enters the house or to the the telephone pole just next to the house. That type of protection devices are very common on rurals installations, where there are very long lines and they are usually hanging in the air from telecom poles so they are much more prone to lightning strike surges.

In bigger cities lightning protectors are not always used because different buildings are usually electrically so tightly connected to each other (though electric feed, plumbing etc.) and cables are in the ground so there is not possible to generate so big surge voltages because of potential differences between different points (central office and subscriber).

What types of voltage surges there are ?

There are two types of surges: differential and common mode. Differential surge is a voltage surge which is generated between the telephone wires. That is usually not great, because telephone wires are twisted pairs and is easy to stop by palacing suitable protection component between telphone line wires.

Other type of surge is common mode surge, in which the potential of the telephone wires raises thousands of volts from your ground potential. Usually the telephone wires are at potential quite near to the ground of your building. But if the lightning strike hits the central office (or some else place in telecom cabling near you), the potential of both of the telephone line wires can raise quite high (even thousands of volts). The common mode surges are usually bigger and more problematic than differential surges.

How telephone can handle surges ?

Telephones are devices sitting in the end of the telecommunication line electrically isolated from rest of the building. They are not very prone to common mode surges, unless they are special phones which are connected also to mains (for example those which have answering machine in them).

The thing which breaks ordinary telephone is differential surge, because it is the surge which can get to the electronics of the telephone. Modern telephones usually damage easier, because electronics will break down more easily than the transformers, carbon microphones and mechanical rotary dials used in older telephones. In cheap modern telephones there is usally not much done to protect them from surges, because good protection could easily cost more than the telephone itself. It is economically wise. If cheap telephone breaks down people go to shop and buy new one. If telephones are damaged often, then it migh be a good idea to install a good surge suppressor.

How about modems ?

Modems are more prone to lighting surges than telephones. There are two reasons for that: modems have more dedicate microelectronics in them than simple telephones and modems are connected to computers, which are connected to mains electricity. For those reasons modem electronics are prone to be damaged by both differential and common mode surges.

Differential surge easily can go through the modem line transfomer in the same way the normal modem signals go. To protect modem electronics, a good practice is to add protection to both sides of the line transformer: gas arrestor or VDR in the primary side of the transformer to take most of the surge and zener diodes to the secondary to take what goes through the primary protection and transformer. Quite typical circuit for modem line input protection is to put smal resistors (10 ohms or less) in resies with both lines coming to the modem. Then after those resistors there is the overvoltage protection device (gas arrestor and/or VDR, usually clamping at 130V). The resistors which are put in series with the telephone line work as sort of fuses for large surges and they are nonflammable type for fire safety.

The harder is the protection against common mode surges. The line transformer in the modem will keep the common mode voltage out of modem electronics, but it has limited isolation strength (few kilovolts). The telecommunication regulations demand that modem line transformer must withstand 1-2 kV of common mode voltage. This is enough for normal overvoltages, but large surges can easily have higher voltages. Overvoltage suppressors can't be generally used between phone line and modem case unless the modem is guaranteed to be properly grounded, because of user safety. So that's why they re not used in normal computer modems.

Why external surge suppressors are sometimes needed ?

The protection provided by telecom operator and the devices connected to telephone line are not always enough. The protection usually is designed so that it minimizes the costs. It is not worth to protect cheap telephones with expensive protectors, because strong lightning surge is quite rare and telephones are inexpensive to replace if such thing happens. Usually surge protection can be pretty sloppy is the electronics that are being protected are designed with surges in mind.

The situation migh be different, when there is something more expensive than ordinary telephone connected to line. For example expensive computer systems are usually worth to protect, because the damage caused by the lightning strike can cause very expensive damage. For example in PC case, lightning strike can not only destroy the modem (which is not usually very expensive), but also something else inside of the PC. That can become very expensive if valuable information is lost and the PC is very important at your business.

So sometimes extra protection is needed. The people which operate large computer systems know that sooner or later lightning strike will hit and break something. If there is enough protection, the damage is avoided or at least minimized.

Operation of the surge suppressors

To be able to get rid of surges the surge suppressors have to protect the equipments against two kinds of surge voltages:

- differential surge = surge voltage between line wires
- common mode surge = surge voltage between ground and line wires

To be able to do this the surge suppressors have to have good ground connection. If the circuit does not have a good ground connnection is can only protect against differential surges. The protector must also act quicly to be effective. A lightning surge has a typical rise time of 10 microseconds and a duration of about 1 millisecond.

When surge protectors are installed to a telephone/data communications room they are typically connected a common grounding bar which is connected to a good ground through a heavy grounding wire. The quality of the grounding (resistance and inductance) effect very much on how well the surge protector will protect against common mode surges. Even the best surge protector can't work well unless it is properly grounded. So it is recommended that you install the surge protector near the main grounding bar.

Some telephone line surge protectors sold in USA use the mains connector ground for grounding (those surge protectors which have mains surge and telehone line surge protectors in some case). The ground in the mains connector is not very good grounding point and using it as ground for surge protector can induce par of the surge also to the mains wiring.

The basic surge protectors use metal oxide varistor (MOV) to do the protection. This circuit below used one MOV between line wires for protection against differential surges and two MOVs from line wires to ground connection to protect against common mode surges.

The MOV between the line wire must be selected to have such voltage that it does not start to conduct at the normal telephone line voltages but stops the harmful higher voltages. Typica telephone line DC voltage is 48V and ring voltage is typically 90 vrms or 130V peak but can be upt to 130V RMS. Some modems use 130V RMS rated VDR which starts to conduct at about about 190V peak. Bell system Technical Reference #61100 mentions that a worst case telephone line voltage can be 105 VDC + 130 VAC= 289 V peak. If the MOV voltage is set too low the circuit will not pass "on-hook" requirments because it leaks too much current (for example FCC part 68 requirments demand 10 Mohm DC impedance in "on-hook" state).

```
                    |         |
                    |        MOV
  TELCO             |         |
                   MOV        o--- TO GROUND
  LINE              |         |
                    |        MOV
                    |         |
         ----------o---------o--------- to equipment
```

The MOVs form line to ground connection to line wires have typically somewhat higher voltage rating to make sure that they do not start to conduct at normal ground potential differences seen in the situation where the surge protector is used. For example one AT&T unit has 130 V RMS MOV's in SERIES to ground, so they won't clip until about 380V peak and one PATTON says it clips at 310V in 500 Ns.

Because MOVs have limited surge handling capacity some surge protectors use resistors between the line and the surge protector to somewhat limit the surge current and dissipate the surge energy. Because the surges can have high energy the resistors must be able to handle high power surges safely. By having enough powerful non-flammable resistors (0.5-2W) usually is a safe choice. The fuses in the circuit are ment to cut the connection if something hazardous happens. If big surge happens it will quite propably burn the fuse. The fuse itself does not usually help much in fighting against surge but it will make sure that if for some reason the ground potential is no longer ground, no damaging currents will flow to telephone line (for example mains current accidentally entering to thin telephone cable wire can burn it and start fire). So the fuses melting the phone wire in catastrophic failure.

```
          FUSE
TELCO  >----o/\o------/\/\/\----------o------------> OUT TO EQUIPMENT

                                      |

LINE
                                     MOV
                                      |---MOV--> TO GROUND
                                     MOV
          FUSE      20 OHMS 2W        |
       >----o\/o------/\/\/\----------o------------>
```

The MOV arrangemen in this circuit is somewhat special. In this arrangement the rurge voltage in which the MOVs start to conduct ia approximately double the voltage ratings of the MOVs used in this circuit. In any surge case the surge energy will flow through MOVs (so the energy is divided between them). This arrangement is shown here because it is used also on some commercial surge protectors. The MOV arrangement in this circuii equivalent to the first circuit if the first MOVs have half the voltage rating and twice the capacitance of the second MOVs.

Always just VDRs no not provide enough protoection. DVRs are quite fast, but have limited surge handling capacity. If nore capacity is needed it is quite common to use higher power but slower gas tube arrestors in front of the VDR surge protection circuit. This arrangement (when derigned correctly) gives high surge handling capacity and quitre fast operation. If even faster opration is needed then is possible to add some fast special semiconductor surge protection devices after MOVs (zener diodes, avalanche diodes, surgectors, TISPs etc.).

Non-commercial designs

The following non-commercial surge suppressor circuits are collected from various sources (BBSs, FTP-sites etc). I am only including those schematics here to make a good collection of surge suppression circuits. I have not tried those circuits myself, so I can't say if they are effective or not.

Circuit one

This circuit is designed by Reijo Salminen, who posted it to MITS BBS at spring 1991. The circuit is designed for protecting modems and telephones connected to telephone line. The circuit is designed for telephone lines used in rural areas. The protector is connected between modem and incoming telephone line. The ground connector is connected to main electricity ground of the building through good grounding wire.

```
     o---------------*----*----------RRRR-------*------
Line                 A    I                     V       ---> to modem
     o---------------*----I---*------RRRR-------*------
                          B   B
Ground--------------------*---*

A = 230V surge gas tube protector
B = 600V surge gas tube protector
RRRR = 10 ohm 1 W resistor
V = varistor 250V
```

The resistors in the circuit limit the surge energy passing through the circuit and they work as fuses in case of large surge. For safety, those resistors should be non flammable type.

Over voltage protectors B are rated so that in case of electricity grounding fault where ground pin becomes accidentally hot (220V AC), those surge protectors does not pass current to telephone line. If the surge protectors pass current to telephone line when electricity ground potential is raised against telephone line, there is apparent danger of fire.

In Finland modems are tested at 2000V voltage pulse and in USA with 1000V pulse, so the protection should be enough in both cases. It shold be mentioned that the circuit is not 100% proof, so the best protection is disconnect modem from telephone line connector when thunderstrom is coming.

Circuit two

This circuit was designed by Tim Jackson at 1990. It was presented in his article "TELEPHONE LINE SURGE ARRESTOR" found in telecommunication archives.

The trick is to install the unit in the line between the telephone jack and your modem (ie: not too far from the modem, like in another room) and connect the earth lead from the circuit to the earth pin on the SAME PLUG that feeds your PC.

```
                     10 ohm 5 Watt
      >----------+-----/\/\/\/------------------+------------->
Phone Line A     |                              |
                <=>300V Gas Arrester        ____|_____      To Modem
                 |                          |   A    |
                 |                          |TISP2290|
        |--------+--------------------------|C       |
      Earth      |                          |   B    |
                 |                          ----+-----
                <=>300V Gas Arrester            |
                 |                              |
                 |                              |           To Modem
Phone Line B     |                              |
      >----------+-----/\/\/\/------------------+------------->
                     10 ohm 5 Watt
```

Circuit drawn as best as possible with ASCII by Pat Verner.

The phone line has a gas arrestor from each leg to earth. In other words, two gas arrestors. One from A to earth and one from B to earth.

The line then has a resistor in series with each leg (A and B) before being connected to the TISP2290 (the Texas Instruments chip mentioned earlier). This chip has three pins. The outer two (A and B in the diagram) are connected to the resistors while the centre one (C) is connected to earth. The metal tag of this component is internally connected to the earth pin (C), just for the record. The modem is fed from the outer two pins of the TISP2290.

The bulk of the energy involved in a surge is dissipated by trusted (and slow as treacle) gas arrestors. The TISP2290 absorbs the high speed spike that the gas arrestors miss and is itself protected by the two resistors which provide a little current limiting. The modem, being fed from the same point as the TISP2290 is protected by the whole circuit.

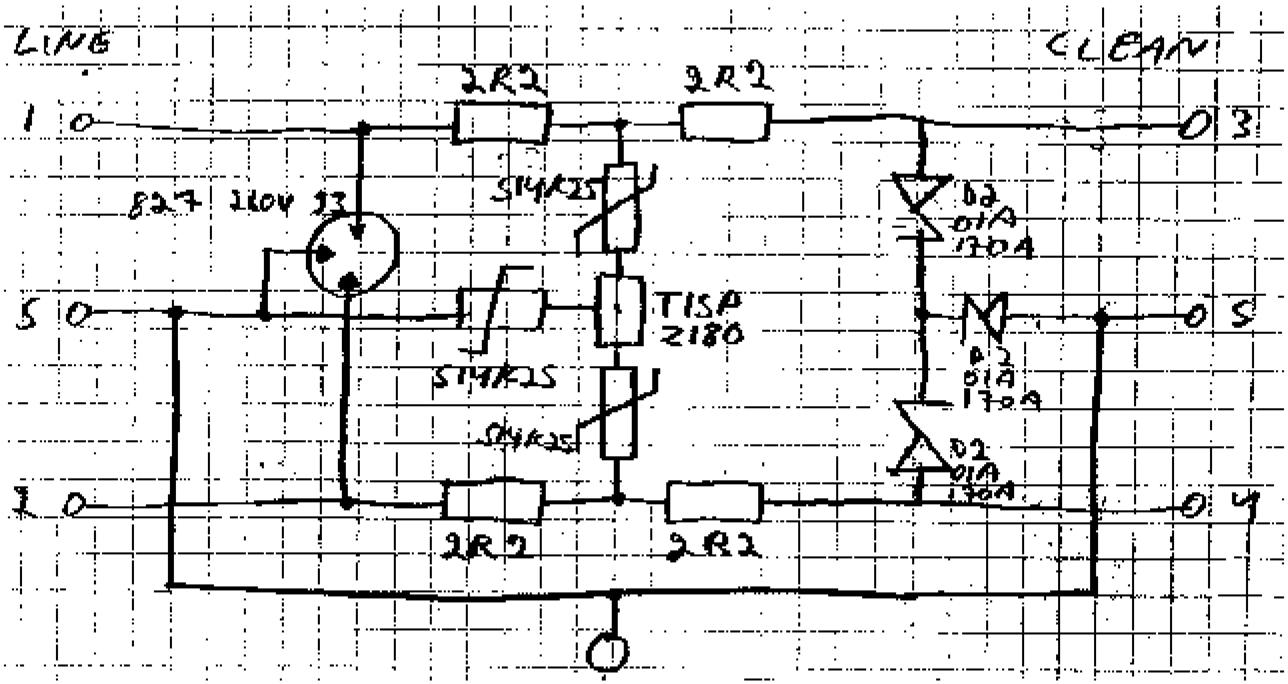
For those who have to know, the TISP2290 works in a manner similar to a zener array connected between the A and B wire and earth so as to limit the voltage between any of three points to about 200 Volts. As you know this is not entirely effective and so if the voltage rises to 290 Volts (hence TISP2*290*) then this crafty critter cuts in triacs to crowbar the offending points to earth until the surge has passed.

Commercial designs

The following circuit are the circuit used in two commercial units. The circuit diagram is drawn by looking inside those commercial units and drawing the circuit diagram. Those circuit diagrams are scanned from my memo I made when I examined those surge suppressors. Those circuit diagrams should be readable at most parts and the text should clear out the detais not easily readable from picture.

Furse ESP-TN

This circuit is a circuit diagram of commercial surge protector sold under name Furse ESP-TN for protecting normal telephone lines. The circuit is designed for protecting normal telephone lines and is packaged to metal box where there are connectors for telephone line and thick ground wire (the connector in the bottom of the circuit). The components were installed to circuit board where there is lots of copper thickened by lots of tin.



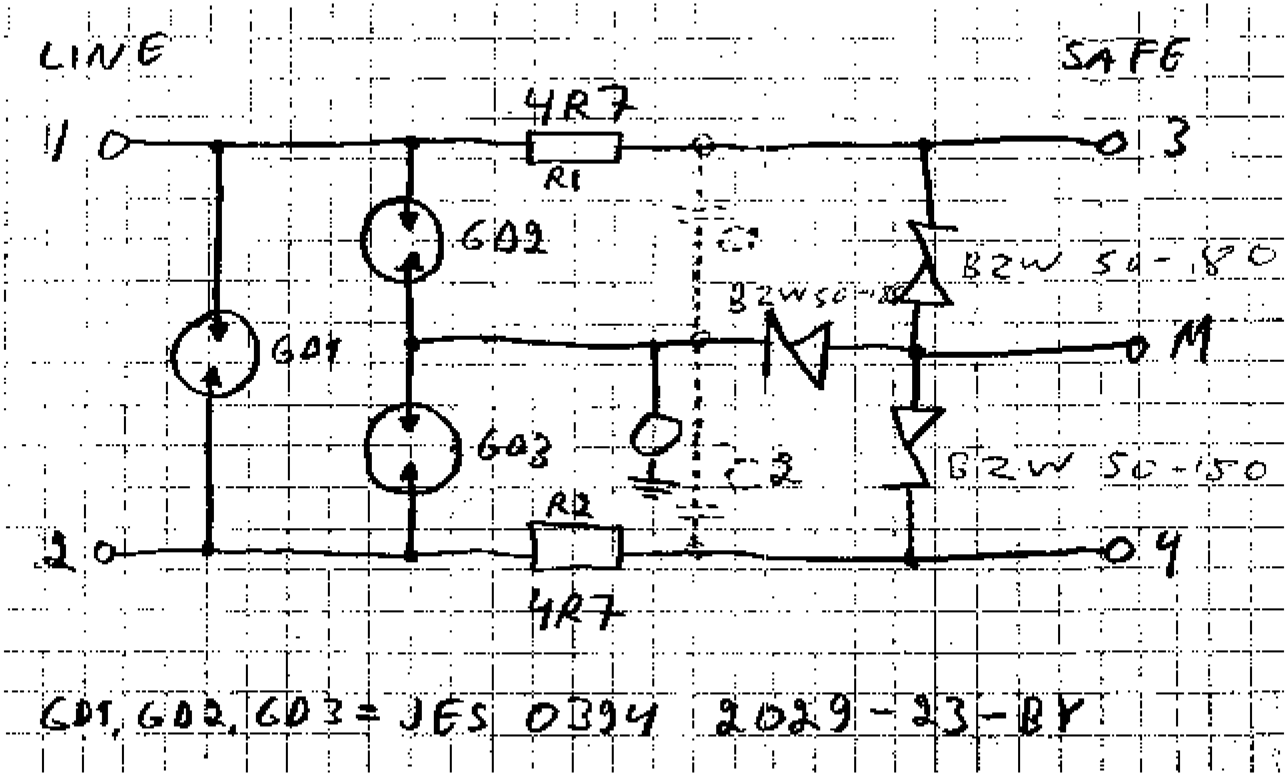
The circuit uses on 260 V doube gas arrestor as first protection. After that there is 2.2 ohm series resistors followed by surgesuppression network built from 180V TISP and three DVRs. After that there are two more serial resistors and network built from three 180V zener diodes. Wuite complicated circuit and no wonder why it costs quite much (about 100 US dollars).

Telematic Lighting Arrestor SAPN (Telematic Surge Barrier)

This is another telephone line surge arrestor sold under name Telmatic SAPN Line Barrier by Black Box. The protector has following specs:

- Clamping voltage: 200V+-10%
- Rise time: 15 ns
- Interface: 2-wire PSTN
- Connectors: Screw terminals
- Size: 2.5H x 2.1W x 14D cm
- Weight: 0.1 kg
- Protection mechanism: 5 kA gas discharge tube and high speed clamp diodes

This circuit is built using small circuit board fitted inside metal enclosure. The unit has 200V voltage rating, it has BAPT approval for connecting to public telephone network and it is NEMP tested. This protector model is also sold for a little less than 100 US dollars by Farnell Electronic Components.



The circuit is quite straighforward circuit made of gas arrestors, resistors and zener diodes. Firs protection for large surges are one gas arrestor connected between line leads and two other gas arrestors connected between line leads and ground connection. All gas arrestors are type JES 0394 2029-23-BY. After that there is 4.7 ohm resistors followed by surge suppression network built from zener diodes (type BWX50-180) which handle the surge which has passed those gas arrestors. There was a place and markings in the circuit board for capacitors C1 and C2, but those were not installed in the circuit.

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BASICS

The Basics of Structured Cabling

April 1, 2000

Do you have what it takes to become a certified telecom technician?

Paul Rosenberg

A structured cabling system is a complete system of cabling and associated hardware, which provides a comprehensive telecommunications infrastructure. This infrastructure serves a wide range of uses, such as to provide telephone service or transmit data through a computer network. It should not be device dependent.

We further define a structured cabling system in terms of ownership. The structured cabling system begins at the point where the service provider (SP) terminates. This point is the point of demarcation (demarc) or Network Interface Device (NID).

For example, in a telephone system installation, the SP furnishes one or more service lines (per customer requirements). The SP connects the service lines at the point of demarcation.

Every structured cabling system is unique. This is due to variations in:

- The architectural structure of the building, which houses the cabling installation;
  The cable and connection products;
- The function of the cabling installation;
- The types of equipment the cabling installation will support -- present and future;
- The configuration of an already installed system (upgrades and retrofits); Customer requirements; and Manufacturer warranties.

The methods we use to complete and maintain cabling installations are relatively standard. The standardization of these installations is necessary because of the need to ensure acceptable system performance from increasingly complex arrangements.

The U.S. cabling industry accepts the American National Standards Institute (ANSI), in conjunction with TIA/EIA, as the responsible organization for providing and maintaining standards and practices within the profession. It has published a series of standards to design, install, and maintain cabling installations. These help to ensure a proper cabling installation.

The benefits of these standards include:

- Consistency of design and installation;
- Conformance to physical and transmission line requirements;
- A basis for examining a proposed system expansion and other changes; and
- Uniform documentation.

The industry standard term for a network installation that serves a relatively small area (such as a structured cabling installation serving a building) is a local area network (LAN). There are also metropolitan area networks (MANs) and wide area networks (WANs).

Structured cabling installations typically include: entrance facilities; vertical and horizontal backbone pathways; vertical and horizontal backbone cables; horizontal pathways; horizontal cables; work area outlets; equipment rooms; telecommunications closets; cross-connect facilities; multi-user telecommunications outlet assemblies (MUTOA); transition points; and consolidation points.

The entrance facility includes the cabling components needed to provide a means to connect the outside service facilities to the premises cabling. This can include service entrance pathways, cables, connecting hardware, circuit protection devices, and transition hardware.

An entrance facility houses the transition outside plant cabling to cabling approved for intrabuilding construction. This usually involves transition to fire-rated cable. The entrance facility is also the network demarc between the SP and customer premises cabling (if required). National and regional electrical codes govern placement of electrical protection devices at this point.

The location of the entrance facility depends on the type of facility, route of the outside plant cabling (e.g. buried or aerial), building architecture, and aesthetic considerations. The four principal types of entrance facilities include underground, tunnel, buried, and aerial. (We will cover only aerial entrances in this article.)

In an aerial entrance, the SP cables provide service to a building via an overhead route. Aerial entrances usually provide the lowest installation cost, and they're readily accessible for maintenance. However, they're subject to traffic and pedestrian clearances, can damage a building's exterior, are susceptible to environmental conditions (such wind and ice), and are usually joint-use installations with the power company, CATV company, and telephone or data service providers.

Backbone cabling. From the entrance facility, the structured cabling network branches out to other buildings, as well as from floor to floor within a building on the backbone cabling system. We use the term backbone to describe the cables handling the major network traffic.

The ANSI/TIA/EIA-568-A standard defines backbone cabling as follows: "The function of the backbone cabling is to provide interconnections between telecommunications closets, equipment rooms, and entrance facilities in the telecommunications cabling system structure. Backbone cabling consists of the backbone cables, intermediate and main cross-connects, mechanical terminations, and patch cords or jumpers used for backbone-to-backbone cross-connection. Backbone cabling also includes cabling between buildings."

Interbuilding and intrabuilding are two types of backbone cables. Interbuilding backbone cable handles traffic between buildings. Intrabuilding backbone cable handles traffic between closets in a single building.

This standard identifies two levels of backbone cabling. First-level backbone is a cable between a main cross-connect (MC) and intermediate cross-connect (IC) or horizontal cross-connect (HC). Second-level backbone exists between an IC and HC.

The main components of backbone cabling are:

- Cable pathways: shafts, conduits, raceways, and floor penetrations (such as sleeves or slots) that provide routing space for the cables.
- The actual cables: optical fiber, twisted-pair copper, coaxial copper, or some combination of these. (Note: You should avoid areas where potential sources of EMI or electromagnetic interference may exist when planning the routing and support structure for copper cabling.)
Connecting hardware: connecting blocks, patch panels, interconnections, cross-connections, or some
- combination of these components, and Miscellaneous support facilities: cable support hardware, firestopping and grounding hardware. Note: The terms horizontal and backbone (previously called riser)
- evolved from the orientations typical for functional cables of these types. However, the physical orientation of the cabling has no bearing on classifying the cable as horizontal or backbone.

The useful life of a backbone cabling system consists of several planned growth periods (typically three to 10 years). This is shorter than the life expectancy of the premises cabling system.

Cabling connectors. A connector is a mechanical device you use to interface a cable to a piece of equipment or one cable to another. The role of the connector is to provide a coupling mechanism that keeps loss to a minimum.

In the case of fiber, it allows light impulses to transfer from one connector to another. For copper, it allows electrical signals to transfer from one connector to another.

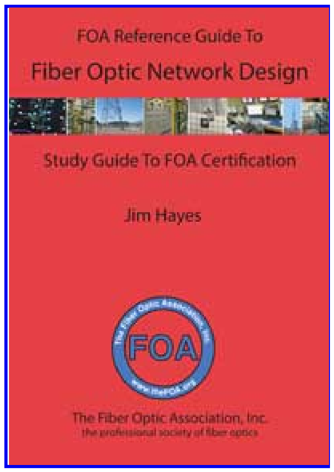
A good connection requires aligning the connectors, preventing the connectors from unintentional separation, and efficient transferring of light or electricity from one connector to the other.

A connector demonstrates durability by withstanding hundreds of insertion and withdrawal cycles without failing. We calculate this as mean time between failures (MTBF).

Connectors are as essential to the integrity of the entire telecommunications network as is the cable itself. Connectors align, attach, and decouple the media to a transmitter, receiver, another media of same or similar type, an active telecommunications device, or a specified passive telecommunications device.

Outside Plant Fiber Optic Network Design

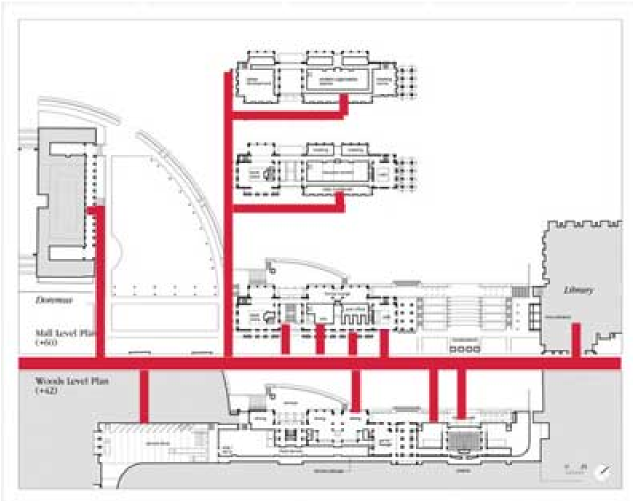
Learn more about Fiber Optic Network Design from the FOA Fiber Optic Network Design textbook:



Fiber optic network design refers to the specialized processes leading to a successful installation and operation of a fiber optic network. It includes determining the type of communication system(s) which will be carried over the network, the geographic layout (premises, campus, outside plant (OSP, etc.), the transmission equipment required and the fiber network over which it will operate. Designing a fiber optic network usually also requires interfacing to other networks which may be connected over copper cabling and wireless.

Next to consider are requirements for permits, easements, permissions and inspections. Once we get to that stage, we can consider actual component selection, placement, installation practices, testing, troubleshooting and network equipment installation and startup. Finally, we have to consider documentation, maintenance and planning for restoration in event of a future outage.

The design of the network must precede not only the installation itself, but it must be completed to estimate the cost of the project and, for the contractor, bid on the job. Design not only affects the technical aspects of the installation, but the business aspects also.



Campus network design

Working With Others

Designing a network requires working with other personnel involved in the project, even beyond the customer. These may include network engineers usually from IT (information technology) departments, architects and engineers overseeing a major project and contractors involved with building the projects. Other groups like engineers or designers involved in aspects of project design such as security, CATV or industrial system designers or specialized designers for premises cabling may also be overseeing various parts of a project that involves the design and installation of fiber optic cable plants and systems. Even company non-technical management may become involved when parts of the system are desired to be on exhibit to visitors.

Qualifications For Fiber Optic Network Designers

It's the job of the designer to understand not only the technology of communications cabling, but also the technology of communications, and to keep abreast of the latest developments in not only the technology but the applications of both.

Designers should have an in-depth knowledge of fiber optic components and systems and installation processes as well as all applicable standards, codes and any other local regulations. They must also be familiar with most telecom technology (cabled or wireless), site surveys, local politics, codes and standards, and where to find experts in those fields when help is needed. Obviously, the fiber optic network designer must be familiar with electrical power systems, since the electronic hardware must be provided with high quality uninterruptible power at every location. And if they work for a contractor, estimating will be a very important issue, as that is where a profit or loss can be determined!

Those involved in fiber optic project design should already have a background in fiber optics, such as having completed a FOA CFOT certification course, and may have other training in the specialties of cable plant design and/or electrical contracting. It's also very important to know how to find in-depth information, mostly on the web, about products, standards, codes and, for the OSP networks, how to use online mapping services like Google Maps. Experience with CAD systems is a definite plus.

Copper, Fiber or Wireless?

While discussions of which is better – copper, fiber or wireless – has enlivened cabling discussions for decades, it's becoming moot. Communications technology and the end user market, it seems, have already made decisions that generally dictate the media and many networks combine all three. The designer of cabling networks, especially fiber optic networks, and their customers today generally have a pretty easy task deciding which media to use once the communications systems are chosen.

The Communications System

Before one can begin to design a fiber optic cable plant, one needs to establish with the end user or network owner where the network will be built and what communications signals it will carry. The contractor should be familiar with premises networks, where computer networks (LANs or local area networks) and security systems use structured cabling systems built around well-defined industry standards. Once the cabling exits a building, even for short links for example in a campus or metropolitan network, requirements for fiber and cable types change. Long distance links for telecommunications, CATV or utility networks have other, more stringent requirements, necessary to support longer high speed links, that must be considered.

But while the contractor generally considers the cabling requirements first, the real design starts with the communications system requirements established by the end user. One must first look at the types of equipment required for the communications systems, the speed of the network and the distances to be covered before considering anything related to the cable plant. The communications equipment will determine if fiber is necessary or preferable and what type of fiber is required.

Outside Plant Networks

Telephone networks are mainly outside plant (OSP) systems, connecting buildings over distances as short as a few hundred meters to hundreds or thousands of kilometers. Data rates for telecom are typically 2.5 to 10 gigabits per second using very high power lasers that operate exclusively over singlemode fibers. The big push for telecom is now taking fiber directly to a commercial building or the home, since the signals are now too fast for traditional twisted copper pairs.

CATV also uses singlemode fibers with systems that are either hybrid fiber-coax (HFC) or digital where the backbone is fiber and the connection to the home is on coax. Coax still works for CATV since it has very high bandwidth itself. Some CATV providers have discussed or even tried some fiber to the home, but have not seen the economics become attractive yet.

Besides telecom and CATV, there are many other OSP applications of fiber. Intelligent highways are dotted with security cameras and signs and/or signals connected on fiber. Security monitoring systems in large buildings like airports, government and commercial buildings, casinos, etc. are generally connected on fiber due to the long distances involved. Like other networks, premises applications are usually multimode while OSP is singlemode to support longer links.

Metropolitan networks owned and operated by cities can carry a variety of traffic, including surveillance cameras, emergency services, educational systems, telephone, LAN, security, traffic monitoring and control and sometimes even traffic for commercial interests using leased bandwidth on dark fibers or city-owned fibers. However, since most are designed to support longer links than premises or campus applications, singlemode is the fiber of choice.

For all except premises applications, fiber is the communications medium of choice, since its greater distance and bandwidth capabilities make it either the only choice or considerably less expensive than copper or wireless. Only inside buildings is there a choice to be made, and that choice is affected by economics, network architecture and the tradition of using copper inside buildings. Next, we'll look at the fiber/copper/wireless choices in more detail.

Premises Networks

Premises cable systems are designed to carry computer networks based on Ethernet which currently may operate at speeds from 10 megabits per second to 10 gigabits per second. Other systems may carry security systems with digital or analog video, perimeter alarms or entry systems, which are usually low speeds, at least as far as fiber is concerned. Premises telephone systems can be carried on traditional twisted pair cables or, as is becoming more common, utilize LAN cabling with voice over IP (VoIP) technology.

Premises networks are usually short, often less than the 100 meters (about 330 feet) used as the limit for standardized structured cabling systems that allow twisted pair copper or fiber optic cabling, with backbones on campus networks used in industrial complexes or institutions as long as 500 m or more, requiring optical fiber.

Premises networks generally operate over multimode fiber. Multimode systems are less expensive than singlemode systems, not because the fiber is cheaper (it isn't) nor because cable is cheaper (the same), but because the large core of multimode fiber allows the use of cheaper LED or VCSEL sources in transmitters, making the electronics much cheaper. Astute designers and end users often include both multimode and singlemode fibers in their backbone cables (called hybrid cables) since singlemode fibers are very inexpensive and it provides a virtually unlimited ability to expand the systems.

Premises networks will include a entrance facility where outside plant and premises communications systems meet. This facility must include not only cabling connections but compatible communications equipment. Since it is indoors, it must consider issues for building and electrical codes, such as the common requirement that bare OSP cables can only come 50 feet (about 15 meters) before being terminated in fire-rated cables unless it is in conduit.

Cabling Design

Long Distance and Outside Plant Cabling
Other than telco systems that still use copper for the final connection to the home, practically every cable in the telephone system is fiber optic. CATV companies use a high performance coax into the home, but it connects to a fiber optic backbone. The Internet backbone is all fiber. Most commercial buildings in populous areas have direct fiber connections from communications suppliers. Cities use SM fiber to connect municipal buildings, surveillance cameras, traffic signals and sometimes offer commercial and residential connections, all over singlemode fiber. Even cellular antenna towers along highways and on tall buildings usually have fiber connections. Remote areas such as central Africa depend on satellite communications since cables are too expensive to run long distances for the small amounts of traffic involved.

Designing long distance or outside plant applications generally means choosing cabling containing singlemode (SM) fiber over all other media. Most of these systems are designed to be used over distances and speeds that preclude anything but SM fiber. Occasionally other options may be more cost effective, for example if a company has two buildings on opposite sides of a highway, a line-of-sight or radio optical wireless network may be easier to use since they have lower cost of installation and are easier to obtain relevant permits.
The choice of the actual singlemode fiber, however, can depend on the application. Depending on the length of the link, the wavelength of the transmitters, data rate of the transmission and if CWDM or DWDM are planned, different types of fiber may be optimal. Refer to Chapter 5 on fiber for more details.

Premises Cabling
The desire for mobility, along with the expansion of connected services, appears to lead to a new type of corporate network. Fiber optic backbone with copper to the desktop where people want direct connections and multiple wireless access points, more than is common in the past, for full coverage and maintaining a reasonable number of users per access point is the new norm for corporate networks.

Most building management systems use proprietary copper cabling, for example thermostat wiring and paging/audio speaker systems. Security monitoring and entry systems, certainly the lower cost ones, still depend on coax copper cable, although high security facilities like government and military installations often pay the additional cost for fiber’s more secure nature.

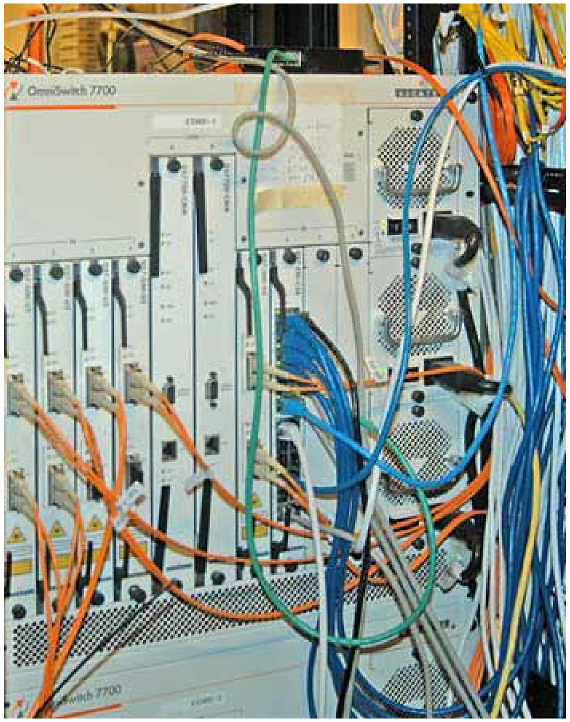
Surveillance systems are becoming more prevalent in buildings, especially governmental, banking, or other buildings that are considered possible security risks. While coax connections are common in short links and structured cabling advocates say you can run cameras limited distances on Cat 5E or Cat 6 UPT like computer networks, fiber has become a much more common choice. Besides offering greater flexibility in camera placement because of its distance capability, fiber optic cabling is much smaller and lightweight, allowing easier installation, especially in older facilities like airports or large buildings that may have available spaces already filled with many generations of copper cabling.

When these premises communications systems connect to the outside world, it is generally to singlemode optical fiber. The entrance facility and equipment room must accommodate the equipment needed to make those connections.

Use of Cabling Standards
Many documents relating to cable plant design focus on industry standards for both communications systems and cable plants. US standards come from the TIA or Telcordia while worldwide standards may come from ISO/IEC or ITU.

It is important to realize why and by whom these standards are written. These standards are written by manufacturers of products to ensure that various manufacturers’ products work together properly. Whenever users specify standards for any project, it is important that the contractor/installer understand what standards are being referenced and ensure that such standards are relevant to the job being done.

Choosing Transmission Equipment



Choosing transmission equipment is the next step in designing a fiber optic network. This step will usually be a cooperative venture involving the customer, who knows what kinds of data they need to communicate, the designer and installer, and the manufacturers of transmission equipment. Transmission equipment and the cable plant are tightly interrelated. The distance and bandwidth will help determine the fiber type necessary and that will dictate the optical interfaces on the cable plant. The ease of choosing equipment may depend on the type of communications equipment needed.

Telecom has been standardized on fiber optics for 30 years now, so they have plenty of experience building and installing equipment. Since most telecom equipment uses industry conventions, you can usually find equipment for telecom transmission that will be available for short links (usually metropolitan networks, maybe up to 20-30 km), long distance and then really long distance like undersea runs. All run on singlemode fiber, but may specify different types of singlemode.

Shorter telecom links will use 1310 nm lasers on regular singlemode fiber, often referred to as G.652 fiber, it's international standard. Longer links will use a dispersion-shifted fiber optimized for operation with 1550 nm lasers (G.653 or G.655 fiber). For most applications, one of these will be used. Most telco equipment companies offer both options.

Most CATV links are AM (analog) systems based on special linear lasers called distributed feedback (DFB) lasers using 1550 nm operating on regular singlemode fibers. As CATV moves to digital transmission, it will use technology more like telecom, which is already all digital.

The choices become more complex when it comes to data and CCTV because the applications are so varied and standards may not exist. In addition, equipment may not be available with fiber optic transmission options, requiring conversion from copper ports to fiber using devices called media converters.

In computer networks, the Ethernet standards, created by the IEEE 802.3 committee, are fully standardized. You can read the standards and see how far each equipment option can transmit over different types of fiber, choosing the one that meets your needs. Most network hardware like switches or routers are available with optional fiber optic interfaces, but PCs generally only come with UTP copper interfaces that require media converters. An Internet search for "fiber optic media converters" will provide you with dozens of sources of these inexpensive devices. Media converters will also allow the choice of media appropriate for the customer application, allowing use with multimode or singlemode fiber and may even offer transceiver options for the distance that must be covered by the link.

CCTV is a similar application. More cameras now come with fiber interfaces since so many CCTV systems are in locations like big buildings, airports, or areas where the distances exceed the capability of coax transmission. If not, video media converters, usually available from the same vendors as the Ethernet media converters, are readily available and also inexpensive. Again, choose converters that meet the link requirements set by the customer application, which in the case of video, not only includes distance but also functions, as some video links carry control signals to the camera for camera pan, zoom and tilt in addition to video back to a central location.

What about industrial data links? Many factories use fiber optics for its immunity to electromagnetic interference. But industrial links may use proprietary means to send data converted from old copper standards like RS-232, the ancient serial interface once available on every PC, SCADA popular in the utility industry, or even simple relay closures. Many companies that build these control links offer fiber optic interfaces themselves in response to customer requests. Some of these links have been available for decades, as industrial applications were some of the first premises uses of fiber optics, dating back to before 1980.

Whatever the application, it's important for the end user and the cabling contractor to discuss the actual application with the manufacturer of the transmission hardware to ensure getting the proper equipment. While the telecom and CATV applications are cut and dried and the data (Ethernet) applications covered by standards, it is our experience that not all manufacturers specify their products in exactly the same way.

One company in the industrial marketplace offered about fifteen different fiber optic products, mainly media converters for their control equipment. However, those fifteen products had been designed by at least a dozen different engineers, not all of whom were familiar with fiber optics and especially fiber jargon and specifications. As a result, one could not compare the products to make a choice or design them into a network based on specifications. Until their design, sales and applications engineers were trained in fiber optics and created guidelines for product applications, they suffered from continual problems in customer application.

The only way to make sure you are choosing the proper transmission equipment is to make absolutely certain the customer and equipment vendor – and you – are communicating clearly what you are planning to do.

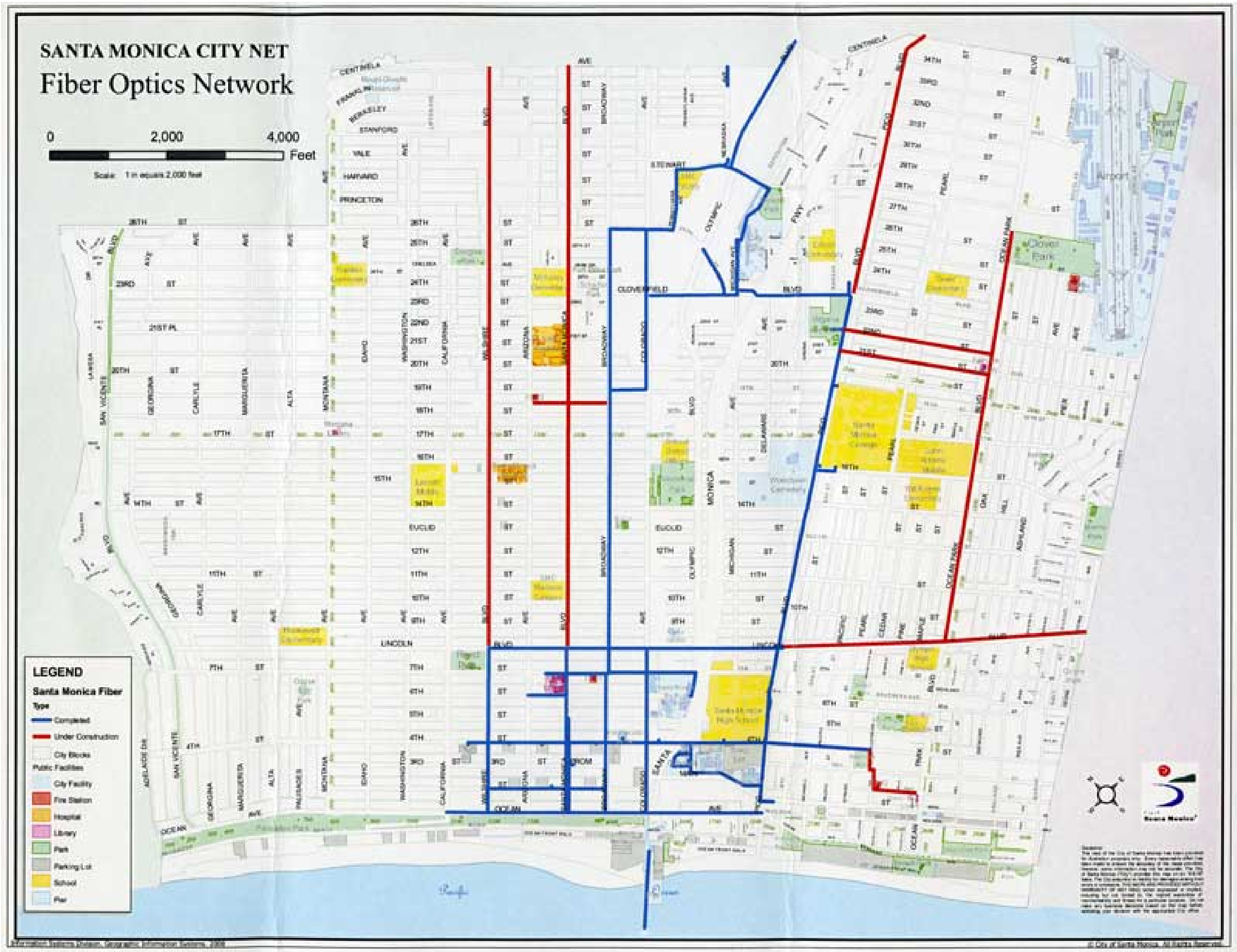
Planning The Route

Having decided to use fiber optics and chosen equipment appropriate for the application, it's time to determine exactly where the cable plant and hardware will be located. One thing to remember – every installation will be unique. The actual placement of the cable plant will be determined by the physical locations along the route, local building codes or laws and other individuals involved in the designs. As usual, premises and outside plant installations are different so we will consider them separately.

Premises and campus installations can be simpler since the physical area involved is smaller and the options fewer. Start with a good set of architectural drawings and, if possible, contact the architect, contractor and/or building manager. Having access to them means you have someone to ask for information and advice. Hopefully the drawings are available as CAD files so you can have a copy to do the network cabling design in your computer, which makes tweaking and documenting the design so much easier.

If the building is still in the design stage, you may have the opportunity to provide inputs on the needs of the cable plant. Ideally, that means you can influence the location of equipment rooms, routing of cable trays and conduits, availability of adequate conditioned power and separate data grounds, sufficient air-conditioning and other needs of the network. For pre-existing buildings, detailed architectural drawings will provide you with the ability to route cabling and network equipment around the obstacles invariably in your way.

Outside plant (OSP) cabling installations have enormous variety depending on the route the cable must take. The route may cross long lengths of open fields, run along paved rural or urban roads, cross roads, ravines, rivers or lakes, or, more likely, some combination of all of these. It could require buried cables, aerial cables or underwater cables. Cable may be in conduit, innerduct or direct buried, aerial cables may be self-supporting or lashed to a messenger. Longer runs often include crossing water, so the cable may be underwater or be lashed across a bridge with other cables.



GIS (Geographic Information Systems)

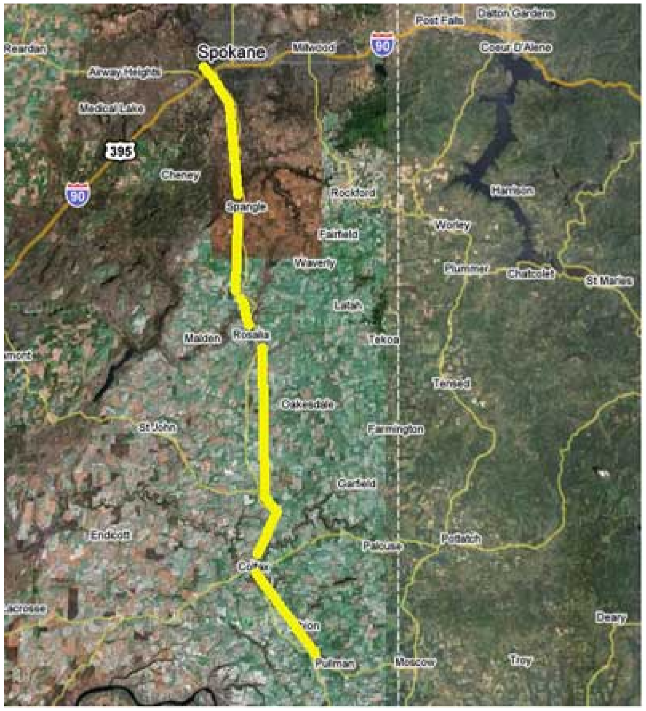
Outside plant installations depend heavily on maps and data about the cable plant route. This can include basic data on the local geology, locations of road, buildings, underground and aerial utilities, and much more. GIS (Geographic Information Systems) are generally used to create very detailed maps of the routes of OSP cable plants during the design phase. It is beyond the scope of this book to examine GISs in detail but the designer should learn how to utilize a GIS to create the design to facilitate not only the design of the cable plant but also create documentation for the network.

It is important to understand the limitation of GIS. For example the type of ground along the route can determine the methods of underground installation, with deep soil permitting direct burial, other soils requiring trenching and conduit and rocky areas precluding underground installation of any type. Aerial installations must be based on knowledge of the owners of the poles and the processes necessary to gain permission to use the poles and make ready for new cable installations.

Do not use GIS alone. It is just one tool that can assist the designer but is not a replacement for traditional processes including site visits to evaluate the route.

Site Visits

And as soon as possible, you must visit the site or route where the network will be installed. Outside plant routes need to be driven or walked every foot of the way to determine the best options for cable placement, obstacles to be avoided or overcome, and to determine what local entities may have input into the routing. Often cities or other governments will know of available conduits or rules on using utility poles that can save design time and effort.



OSP network route on satellite map

For installations inside current buildings, you should inspect every area to be absolutely certain you know what the building really looks like and then mark up drawings to reflect reality, especially all obstacles to running cabling and hardware and walls requiring firestopping that are not on the current drawings. Take pictures if you can. For buildings under construction, a site visit is still a good idea, just to get a feeling of what the final structure will be like and to get to know the construction managers you will be working with. They may be the best source of information on who the local authorities are who will be inspecting your work and what they expect.

With all those options on OSP installations, where do you start? With a good map. Not just a road map or a topographical map, but satellite images overlaid on roads is much better, like “Google Maps” can provide. Creating a route map is the first step, noting other utilities along the route on that map, and checking with groups that document the current utilities to prevent contractors from damaging currently installed pipes and cables.

Once you have marked up maps, the real “fun” begins: finding out whose permission you need to run your cabling. OSP installs are subject to approval by local, state and federal authorities who will influence heavily how your project is designed. Some cities, for example, ban aerial cables. Some have already buried conduit which you can use for specific routes. Since many municipalities have installed city-owned fiber networks, they may have fiber you can rent, rather than go through the hassle of installing your own.

Unless you are doing work for a utility that has someone who already has the contacts and hopefully easements needed, you may get to know a whole new set of people who have control over your activities. And you have to plan for adequate time to get approval from everyone who is involved.

Dig Once

Governments and other organizations that control rights-of-way face a difficult problem in the Internet age - the continual digging up of their properties for cable plant installation. It's not uncommon for roads to be dug up multiple times for different cable plant owners and operators. This is expensive and disruptive. A simple solution is what is generally referred to as "Dig Once," a process where the cable plant installer who digs up rights-of-way installs excess conduits or ducts for future cable plant installation.

When installing one cable with its associated ducts or conduits, the installer adds in several extra ducts for future use on the route. The number and type of ducts is based on projected future uses but is probably a minimum of 2 to 5. The requirement for additional ducts is specified in the contract with the cable plant owner and/or installer and the local authority generally owns the installed ducts. Future users lease duct space from the local authority and pull in their own cables.

This "dig once" policy is especially useful in metropolitan areas where digging is most disruptive and cities looking at becoming "smart cities" find themselves in need of large fiber optic backbones to support desired services.

Call Before You Dig (OR DESIGN)

Digging safely is vitally important. The risk is not just interrupting communications, but the life-threatening risk of digging up high voltage or gas lines. Some obstacles may be found during site visits, where signs like these are visible. There are several services that maintain databases of the location of underground services that must be contacted before any digging occurs, but mapping these should be done during the design phase and double-checked before digging to ensure having the latest data.

If all this sounds vague, it is. Every project is different and requires some careful analysis of the conditions before even beginning to choose fiber optic components and plan the actual installation. Experience is the best teacher.

Choosing Components

Choosing Components For Outside Plant Installations

The choice of outside plant fiber optic (OSP) components begins with developing the route the cable plant will follow. Once the route is set, one knows where cables will be run, where splices are located and where the cables will be terminated. All that determines what choices must be made on cable type, hardware and sometimes installation methodology.

Cables

When choosing components, most projects start with the choice of a cable. Cable designs are optimized for the application type. In OSP installations, cables may be underground, direct buried, aerial or submarine (or simply underwater.)

Underground cables are generally installed in conduit which is usually a 4 inch (10 cm) conduit with several innerducts for pulling cables. Here cables are designed for high pulling tension and lubricants are used to reduce friction on longer pulls. Automated pulling equipment that limits pulling tension protects the cables. Very long runs or those with more bends in the conduit may need intermediate pulls where cable is pulled, figure-8ed and then pulled to the next stage or intermediate pulling equipment is used. Splices on underground cables are generally stored above ground in a pedestal or in a vault underground. Sufficient excess cable is needed to allow splicing in a controlled environment, usually a splicing trailer, and the storage of excess cable must be considered in the planning stage.

Direct buried cable is placed underground without conduit. Here the cable must be designed to withstand the rigors of being buried in dirt, so it is generally a more rugged cable, armored to prevent harm from rodent chewing or the pressures of dirt and rocks in which it is buried. Direct burial is generally limited to areas where the ground is mostly soil with few rocks down to the depth required so trenching or plowing in cable is easily accomplished. Splices on direct buried cables can be stored above ground in a pedestal or buried underground. Sufficient excess cable is needed to allow splicing in a controlled environment, usually a splicing trailer, and the storage of excess cable must be considered.

Microtrenching is another method used for underground installation, generally on roadways or in private yards for fiber to the home connections. Microtrenching involves digging a narrow and shallow trench about 25mm (1 inch) wide and 200-250mm (8-10 inches) deep using a special tool. Tools are available that can cut through asphalt or concrete roadways or sidewalks or for cutting in bare ground. After cutting the trench, one can install a special cable or microducts in which cables can be installed by blowing. A typical trench can accommodate a microduct with up to six ducts providing for future expansion.

Aerial installations go from pole to pole, but the method of securing cables can vary depending on the situation. Some cables are lashed to messengers or other cables, such as CATV where light fiber cables are often lashed to the heavy coax already in place. Cables are available in a “8” configuration with an attached steel messenger that provides the strength to withstand tension on the cable. Some cables are made to directly be supported without a messenger, called all-dielectric sefl-supporting cables that use special hardware on poles to hold the cables. Optical ground wire is used by utilities for high voltage distribution lines. This cable is an electrical cable with fibers in the middle in a hermetically-sealed metal tube. It is installed just like standard electrical conductors. Splices on aerial cables can be supported on the cables or placed on poles or towers, Most splices are done on the ground, although it is sometimes done in a bucket or even on a tent supported on the pole or tower. Hardware is available for coiling and storing excess cable.

Sometime OSP installations involve running cables across rivers or lakes where other routes are not possible. Special cables are available for this that are more rugged and sealed. Even underwater splice hardware is available. Landings on the shore need to be planned to prevent damage, generally by burying the cable close to shore and marking the landing. Transoceanic links are similar but much more complex, requiring special ships designed for cable laying.

Since OSP applications often use significant lengths of cables, the cables can be made to order, allowing optimization for that particular installation. This usually allows saving costs but requires more knowledge on the part of the user and more time to negotiate with several cable manufacturers.

To begin specifying the cable, one must know how many fibers of what type will be included in each cable. It’s important to realize that fiber, especially singlemode fiber used in virtually all OSP installations, is cheap and installation is expensive. Installation of an OSP cable may cost a hundred times the cost of the cable itself. Choosing a singlemode fiber is easy, with basic 1300 nm singlemode (called G.652 fiber) adequate for all but the longest links or those using wavelength-division multiplexing. Those may need special fiber optimized at 1500-1600 nm (G.653 or G.654). For premises and campus cable plants, OM3 type laser-optimized 50/125 multimode fiber is probably the best choice for any multimode OSP runs, as its lower attenuation and higher bandwidth will make most networks work better.

Including more fibers in a cable will not increase the cable cost proportionally; the basic cost of making a cable is fixed but adding fibers will not increase the cost much at all. Choosing a standard design will help reduce costs too, as manufacturers may have the cable in stock or be able to make your cable at the same time as others of similar design. The only real cost for adding more fibers is additional splicing and termination costs, still small with respect to total installed cost. And remember that having additional fibers for future expansion, backup systems or in case of breaks involving individual fibers can save many future headaches.

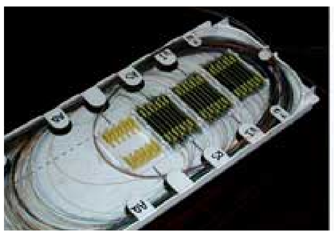
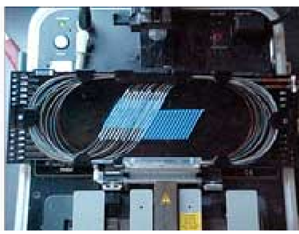
Common traits of all outside plant cables include strength and water or moisture protection. The necessary strength of the cable will depend on the installation method (see below.) All cables installed outdoors must be rated for moisture and water resistance. Until recently, most people chose a gel-filled cable, but now dry-water blocked cables are widely available and preferred by many users. These cables use water-absorbing tape and power that expands and seals the cable if any water enters the cable. Installers especially prefer the dry cables as it does not require the messy, tedious removal of the gel used in many cables, greatly reducing cable preparation for splicing or termination.

OSP cable construction types are specifically designed for strength depending on where they are to be direct buried, buried in conduit, placed underwater or run aerially on poles. The proper type must be chosen for the cable runs. Some applications may even use several types of cable. Having good construction plans will help in working with cable manufacturers to find the appropriate cable types and ordering sufficient quantities. One must always order more cable than route lengths, to allow for service loops, preparation for termination and excess to save for possible restoration needs in the future.

Like cable types, cable plant hardware types are quite diverse and should be chosen to match the application type and cable types being used. With so many choices in hardware, working with cable manufacturers is the most expeditious way to chose hardware and ensure compatibility. Besides cable compatibility, the hardware must be appropriate for the location, which can be outdoors, hung on poles, buried, underwater, inside pedestals, vaults or buildings, etc. Sometimes the hardware will need to be compatible with local zoning, for example in subdivisions or business parks. The time consumed in choosing this hardware can be lengthy, but is very important for the long term reliability of the cable plant.

Splicing And Termination Hardware

Splicing and termination are the final category of components to be chosen. Most OSP singlemode fiber is fusion spliced for low loss, low reflectance and reliability. Multimode fiber, especially OM2, 3 and 4, is also easily fusion spliced, but if only a few splices are necessary, mechanical splicing may provide adequate performance and reliability.



Finished splices are placed in a splice tray and placed in a splice closure outdoors or optionally in trays on patch panels indoors. They are sealed to prevent moisture reaching the splices and are designed to be re-entered for repair or re-routing fibers. Splice closures are available in hundreds of designs, depending on the placement of the closure, for example underground in a manhole or vault, above ground in a pedestal, buried underground or mounted on a pole. Closures must also be chosen by the number and types of cables being spliced and whether they enter at both ends or only one. The numbers of cables and splices that a closure can accommodate will determine the size of the closure, and those for high fiber count cables can get quite large.

Splice trays generally hold twelve single fiber fusion splices but may hold fewer ribbon or mechanical splices. Each splice tray should securely hold the splice and have a cover to protect the fibers when stacked in the closure.

Singlemode fibers are best terminated by fusion spicing factory-made pigtails onto fibers in the cable and protecting the splices in a closure or patch panel tray. If termination is done directly on multimode OSP cables, breakout kits will be necessary to sleeve fibers for reliability when connectors are directly attached. This takes more installation time than splicing pre-terminated pigtails on the cables, as is common with singlemode fiber cables, and may not save any costs. Even complete preterminated outside cable plant systems are becoming available, reducing the time necessary for termination and splicing. Talk to the cable manufacturers to determine feasibility of this option.

Outdoor terminations are sometimes housed in pedestals or equipment housings such as those used for local phone switches or traffic control systems. Some of these closures may not be fully sealed from dust and moisture, in which case it is recommended that the fiber connections be inside a more protective housing to prevent future unreliability.

Choosing the proper components for OSP installations can take time, but is important for system operation. Once components are chosen, the materials lists are added to the documentation for purchase, installation and future reference.

Choosing Components For Premises Installations
Premises cabling and outside plant cabling will coexist in the entrance facility or the equipment room where the two are connected. The choice of premises fiber optic components are affected by several factors, including the choice of communications equipment, physical routing of the cable plant and building codes and regulations. If the design is a corporate network (LAN), the design will probably include a fiber optic backbone connecting computer rooms to wiring closets. The wiring closets house switches that convert the fiber backbone to UTP copper for cable connected desktops and either copper or fiber to wireless access points. Some desktops, especially in engineering or design departments, may require fiber to the desktop for it's greater bandwidth. Extra cables or fibers may be needed for security systems (alarms, access systems or CCTV cameras) and building management systems also.
Design of the fiber optic cable plant requires coordinating with everyone who is involved in the network in any way, including IT personnel, company management, architects and engineers, etc. to ensure all cabling requirements are considered at one time, to allow sharing resources.

As in OSP design, consider the fiber choice first. Most premises networks use multimode fiber, but many users now install hybrid cables with singlemode fibers for future expansion. The 62.5/125 micron fiber (OM1 fiber) that has been used for almost two decades has mostly been superceded by the new 50/125 laser-optimized fiber (OM3), as it offers substantial bandwidth/distance advantages.

Virtually all equipment will operate over 50/125 OM3 fiber just as well as it did on 62.5/125 OM1 fiber, but it's always a good idea to check with the equipment manufacturers to be sure. Remember in the design documentation to include directions to mark all cables and patchpanels with aqua-colored tags, indicative of OM3 and OM4 fiber.

Cable in premises applications is generally either distribution or breakout cable. Distribution cables have more fibers in a smaller diameter cable, but require termination inside patch panels or wall mounted boxes. Breakout cables are bulky, but they allow direct connection without hardware, making them convenient for industrial use. Fiber count can be an issue, as backbone cables now have many fibers for current use, future expansion and spares, making distribution cables the more popular choice. The cable jacket must be fire-retardant per the NEC, generally OFNR-rated (Riser) unless the cable in air-handling areas above ceilings, where OFNP (plenum) is needed. Cable jacket color for OM3 cables can be ordered in aqua for identification as both fiber optics and OM3 50/125 fibers.

If the cable is going to be run between buildings, indoor/outdoor designs are now available that have dry water-blocking and a double jacket. The outer jacket is moisture-resistant for outdoor use but can be easily stripped, leaving the fire-rated inner jacket for indoor runs.

Fiber optic connector choices are also changing. STs and even SCs are succumbing to the success of the smaller LC connector. Since most fast (gigabit and above) equipment uses LC connectors, using them in the cable plant means only one connector needs to be supported. The LC offers another big advantage for those users who are upgrading to OM3 fiber. The LC connector is incompatible with SC and ST connectors, so using it on 50/125 fiber cable plants prevents mixing 50 and 62.5 fibers with high fiber mismatch losses.

Premises fiber optic cables need to be run separately from copper cables to prevent crushing. Sometimes they are hung carefully below copper cable trays or pulled in innerduct. Using innerduct can save installation time, since the duct (which can be purchased with pull tapes already inside) can be installed quickly without fear of damage and then the fiber optic cable pulled quickly and easily. Some applications may require installing fiber optic cables inside conduit, which requires care to minimize bends, provide intermediate pulls to limit pulling force or use fiber optic cable lubricants.

The hardware necessary for the installation will need to be chosen based on where the cables are terminated. Premises runs are generally point-to-point and are not spliced. Wherever possible, allow room for large radii in the patch panels or wall-mounted boxes to minimize stress on the fibers. Choose hardware that is easy to enter for moves, adds and changes but lockable to prevent intrusion.

In premises applications, it's worth considering a preterminated system. These use backbone cables terminated in multifiber connectors and preterminated patch panel modules. If the facility layout is properly designed, the cable manufacturer can work with you to create a "plug and play" system that needs no on-site termination and the cost may be very competitive to a field-terminated system.

Creating A Materials List
For every installation, a complete materials list must be created listing each component needed and quantities required. This list will be used by the installation crew, but first it will be used to estimate the cost of the project.

It is very important to list every component. Some components can be estimated based on other quantities. Ducts for example will be ordered in lengths similar to the cable pulled into them. Each fiber needs termination on both ends of the cable plant. Splice trays and closures must be ordered according to the numbers of fibers in the cables.

You should include extra quantities for installation. Every splice point, for example, needs 10-20 meters extra cable for splicing in a splice trailer, stripping for the splice and service loops. Extra cable should also be ordered to be kept for possible future restoration. Extra connectors or pigtails are needed to replace those improperly installed during installation. Some contractors routinely order 2-5% more than they estimate is necessary for the job.

While ordering more components than necessary can be costly, it’s less expensive than being short during the actual installation, especially for special order items like cables or patchcords. Excess components should be packed and stored as part of a restoration kit.

Cable Plant Link Loss Budget And Power Budget Analysis

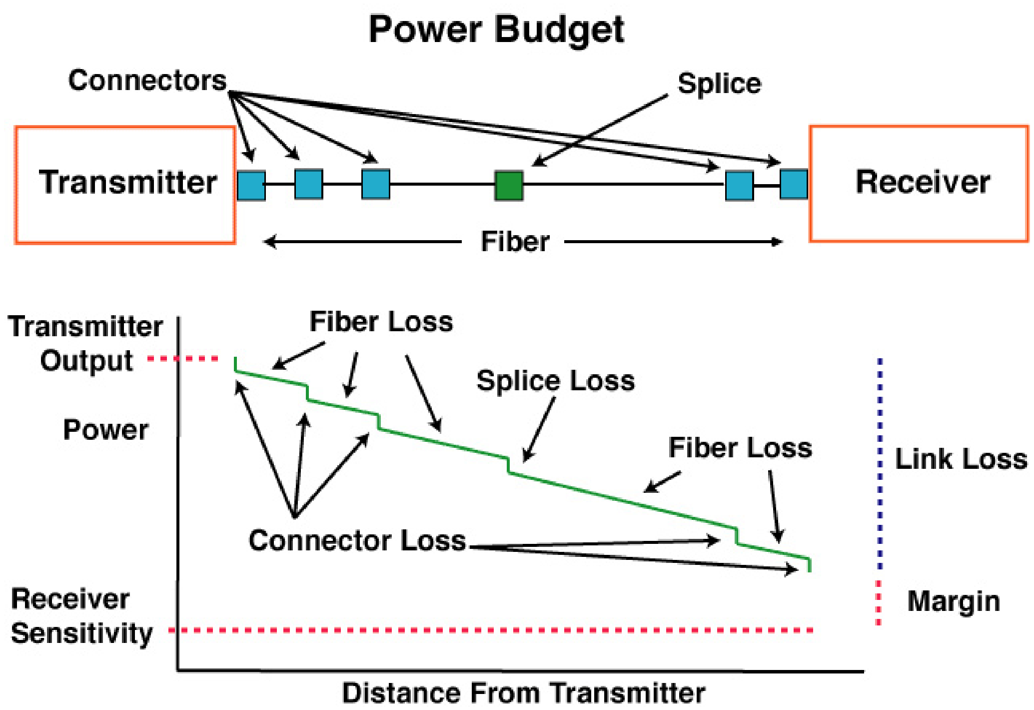
The idea of a loss budget is to insure the network equipment will work over the installed fiber optic link.

Loss budget and power budget analysis involves the calculation and verification of a fiber optic system's operating characteristics. This involves items such as cable plant routing, electronics, wavelengths, fiber type, and circuit length. Attenuation and bandwidth are the key parameters for budget loss analysis. The designer should analyze link loss early in the design stage prior to installing a fiber optic system to make certain the system will work over the proposed cable plant.

The passive components of the circuit are included in the loss budget calculation. Passive loss is made up of fiber loss, connector loss, and splice loss. Don't forget any couplers or splitters in the link, such as those used in passive optical networks like FTTH. If the system electronics are already chosen, active components such as wavelength, transmitter power, receiver sensitivity, and dynamic range are used to calculate a power budget for the communications system that is compared to the loss budget to ensure the cable plant and communications system will work together properly. If the electronics are not known, industry generic or standard loss values can be used for the loss budget. Prior to system turn up, test the insertion loss of the cable plant with a source and power meter to ensure that it is within the loss budget.

It is normal to be conservative over the specifications. Don't use the best possible specs for fiber attenuation or connector loss to allow some margin for installation and component degradation over time.

The best way to illustrate calculating a loss budget is to show how it's done for a typical cable plant, here a link with 5 connections (2 connectors at each end and 3 connections at patch panels in the link) and one splice in the middle. See the drawings below of the link layout and the instantaneous power in the link at any point along it's length, scaled exactly to the link drawing above it.



Cable Plant Passive Component Loss

Step 1. Calculate fiber loss at the operating wavelengths (length times standard estimates of loss at each wavelength)

Cable Length (km)	25	25
Fiber Type	Singlemode	Singlemode
Wavelength (nm)	1310	1550
Fiber Atten. (dB/km)	0.4	0.2
Total Fiber Loss (dB)	10.0	5.0

(All specifications in brackets are maximum values per EIA/TIA 568 standard. For singlemode fiber, a higher loss is allowed for premises applications, 1 dB/km for premises, 0.5 dB/km for outside plant.)

Step 2. Connector Loss
Multimode connectors will have losses of 0.2-0.5 dB typically. Singlemode connectors, which are factory made and fusion spliced on will have losses of 0.1-0.2 dB. Field terminated singlemode connectors may have losses as high as 0.5-1.0 dB. Let's calculate it at both typical and worst case values.

Connector Loss	0.3 dB (typical adhesive/polish connector)
Total # of Connectors	5

Total Connector Loss	1.5 dB

(All connectors are allowed 0.75 max per EIA/TIA 568 standard)
Many designers and technicians forget when doing a loss budget that the connectors on the end of the cable plant must be included in the loss budget. When the cable plant is tested, the reference cables will mate with those connectors and their loss will be included in the measurements.

Step 3. Splice Loss
Fusion splicing of singlemode fiber will typically have lower loss than 0.15 dB.

Splice Loss	0.15 dB
Total # splices	1
Total Splice Loss	0.15 dB

Step 4. Total Cable Plant Loss
Add together the fiber, connector and splice losses to get the total link loss of the cable plant.

	Best Case [TIA 568 Max]	
Wavelength (nm)	1310	1550
Total Fiber Loss (dB)	10.0	5.0
Total Connector Loss (dB)	1.5	1.5
Total Splice Loss (dB)	0.15	0.15
Other (dB)	0	0
Total Link Loss (dB)	11.65	6.65

These values of cable plant loss should be the criteria for testing. Allow +/- 0.2 -0.5 dB for measurement uncertainty and that becomes your pass/fail criterion.

Equipment Link Loss Budget Calculation
Link loss budget for network hardware depends on the dynamic range, the difference between the sensitivity of the receiver and the output of the source into the fiber. You need some margin for system degradation over time or environment, so subtract that margin (as much as 3dB) to get the loss budget for the link.

Step 5. Data From Manufacturer's Specification for Active Components (Typical 100 Mb/s multimode digital link using a 1300 nm LED source.)

Operating Wavelength (nm)	1310 or 1550
Fiber Type	SM
Receiver Sensitivity (dBm@ required BER)	-8 max, -20min
Average Transmitter Output (dBm)	0.0
Dynamic Range (dB)	20
Recommended Excess Margin (dB)	3

Step 6. Loss Margin Calculation

	1310nm	1550nm
Dynamic Range (dB) (above)	8 to 20 dB	8 to 20 dB
Cable Plant Link Loss (dB @ 1300 nm)	11.65	6.65
Link Loss Margin (dB)	8.35	13.35* (Overloaded, needs attenuator)

Note the system at 1550nm has only 6.65dB loss estimated while it needs at least 8dB loss to not be overloaded. So if the cable plant is used at 1550nm, it needs at least a small attenuator at the receiver to reduce power to acceptable levels at the receiver. For more details, see the FOA Guide pages on Datalinks and Attenuators.

As a general rule, the Link Loss Margin should be greater than approximately 3 dB to allow for link degradation over time. Connectors or splices may degrade or connectors may get dirty if opened for rerouting or testing. If cables are accidentally cut, excess margin will be needed to accommodate splices for restoration.

More on link loss budgets.

Project Documentation

Documentation of the cable plant is a necessary part of the design and installation process for a fiber optic network that is often overlooked. Documenting the installation properly during the planning process will save time and material in the installation. It will speed the cable installation and testing since the routing and terminations are already known. After component installation, the documentation should be completed with loss test data for acceptance by the end user. During troubleshooting, documentation eases tracing links and finding faults. Proper documentation is usually required for customer acceptance of the installation.

The documentation process begins at the initiation of the project and continues through to the finish. It must begin with the actual cable plant path or location. OSP cables require documentation as to the overall route, but also details on exact locations, e.g. on which side of streets, which cable on poles, where and how deep buried cables and splice closures lay and if markers or tracing tape is buried with the cable. Premises cables require similar details inside a building in order for the cable to be located anywhere in the path.

Most of this data can be kept in CAD drawings and a database or commercial software that stores component, connection and test data. Long outside plant links that include splices may also have OTDR traces which should be stored as printouts and possibly in computer files archived on disks for later viewing in case of problems. A computer with proper software for viewing traces must be available, so a copy of the viewing program should be on the disks with the files. If the OTDR data is stored digitally, a listing of data files should be kept with the documentation to allow finding specific OTDR traces more easily.

The Documentation Process

Documentation begins with a basic layout for the network. A sketch on building blueprints may work for a small building but a large campus, metropolitan or long distance network will probably need a complete CAD layout. The best way to set up the data is to use a facility drawing and add the locations of all cables and connection points. Identify all the cables and racks or panels in closets and then you are ready to transfer this data to a database.

Fiber optic cables, especially backbone cables, may contain many fibers that connect a number of different links which may not all be going to the same place. The fiber optic cable plant, therefore, must be documented for cable location, the path of each fiber, interconnections and test results. You should record the specifications on every cable and fiber: the manufacturer, the type of cable and fiber, how many fibers, cable construction type, estimated length, and installation technique (buried, aerial, plenum, riser, etc.)

It will help to know what types of panels and hardware are being used, and what end equipment is to be connected. If you are installing a big cable plant with many dark (unused) fibers, some will probably be left open or unterminated at the panels, and that must be documented also. Whenever designing a network, it's a very good idea to have spare fibers and interconnection points in panels for future expansion, rerouting for repair or moving network equipment.

Documentation is more than records. All components should be labeled with color-coded permanent labels in accessible locations. Once a scheme of labeling fibers has been determined, each cable, accessible fiber and termination point requires some labeling for identification. A simple scheme is preferred and if possible, explanations provided on patch panels or inside the cover of termination boxes.

Protecting Records

Cable plant documentation records are very important documents. Keep several backup copies of each document, whether it is stored in a computer or on paper, in different locations for safekeeping. If a copy is presented to the customer, the installer should maintain their own records for future work on the project. One complete set on paper should be kept with a “restoration kit” of appropriate components, tools directions in case of outages or cable damage. Documentation should be kept up to date to be useful so that task should be assigned to one on-site person with instructions to inform all parties keeping copies of the records of updates needed. Access to modify records should be restricted to stop unauthorized changes to the documentation.

Planning for the Installation

Once the design of a fiber optic project is complete and documented, one might think the bulk of the design work is done. But in fact, it’s just beginning. The next step is to plan for the actual installation. Planning for the installation is a critical phase of any project as it involves coordinating activities of many people and companies. The best way to keep everything straight is probably to develop a checklist based on the design during the early stages of the project.

The Project Manager

Perhaps the most important issue is to have a person who is the main point of contact for the project. The project manager needs to be involved from the beginning, understands the aims of the project, the technical aspects, the physical layout, and is familiar with all the personnel and companies who will be involved. Likewise all the parties need to know this person, how to contact them (even 24/7 during the actual install) and who is the backup if one is needed.

The backup person should also be involved to such a degree that they can answer most questions, may even be more technically savvy on the project, but may not have full decision-making authority. The backup on big jobs may well be the person maintaining the documentation and schedules, keeping track of purchases and deliveries, permits, subcontractors, etc. while the project manager is more of a hands-on manager.

Design Checklist

Planning for a project is critical to the success of the project. The best way is to develop a checklist before beginning the design process. The checklist below is comprehensive but each project will have some of its own unique requirements that need to be added. Not all steps need be done serially, as some can be done in parallel to reduce time required for designing the project. The designer must interface with many other people and organizations in designing a project so contacts for outside sources should be maintained with the design documentation.

Design process

Link communications requirements
Link route chosen, inspected, special requirements noted including inspections and permits
Specify communications equipment and component requirements
Specify cable plant components
Determine coordination with facilities, electrical and other personnel
Documentation completed and ready for installation
Write test plan
Write restoration plans

Contractor package for the install

Documentation, drawings, bills of materials, instructions
Permits available for inspection
Guidelines to inspect workmanship at every step, test plan
Daily review of progress, test data
Safety rules to be posted on the job site(s) and reviewed with all supervisors and installation personnel

Requirements for completion of cable plant installation

Final inspection

Review test data on cable plant
Instructions to set up and test communications system
Final update of documentation
Update and complete restoration plan, store components and documentation

Developing A Project Checklist

The final project checklist will have many items, all of great importance. Each item needs a full description, where and when it will be needed and who is responsible for it. See Chapter 10 for a recommended project installation checklist. Components like cables and cable plant hardware should indicate vendors, delivery times and where, when and sometimes how it needs to be delivered. Special installation equipment needs to be scheduled also, with notes of what is needed to be purchased and what will be rented. If the jobsite is not secure and the install will take more than a day, security guards at the jobsite(s) may need to be arranged.

A work plan should be developed that indicates what specialties are going to be needed, where and when. Outside plant installations (OSP) often have one crew pulling cable, especially specialty installs like direct burial, aerial or underwater, another crew splicing and perhaps even another testing. OSP installers often do just part of the job since they need skills and training on specialized equipment like fusion splicers or OTDRs and installation practices like climbing poles or plowing-in cables. Inputs from the installation crews can help determine the approximate time needed for each stage of the installation and what might go wrong that can affect the schedule.

And things will go wrong. All personnel working on the project should be briefed on the safety rules and preferably be given a written copy. Supervisors and workers should have contact numbers for the project manager, backup and all other personnel they may need to contact. Since some projects require working outside normal work hours, for example airports or busy government buildings where cabling is often done overnight, having a project manager available – preferably onsite – while the work is being done is very important.

During the installation itself, a knowledgeable person should be onsite to monitor the progress of installation, inspect workmanship, review test data, create daily progress reports and immediately notify the proper management if something looks awry. If the project manager is not technically qualified, having someone available who is technical is important. That person should have the authority to stop work or require fixes if major problems are found.

Facilities and Power/Ground issues

This chapter primarily focuses on the unique aspects of fiber optic cable plant design and installation, but this process cannot be done in a vacuum. Cable plants may require municipal permits, cooperation from other organizations to allow access through their property and construction disruptions. Any communications system requires not only the cable plant but facilities for termination at each end, placing communications equipment, providing power (usually uninterruptible data quality power) and a separate data ground. Inside the facility, connections must be made to the end users of the link.

The large number of options involved in almost every project make it impossible to summarize the issues in a few sentences, so let’s just say you must consider the final, complete design to gain cooperation and coordinate the final installation. One of the most valuable assets you can have when designing and installing a fiber optic project is an experienced contractor.

Developing A Test Plan

Every installation requires confirmation that components are installed properly. The installer or contractor wants to ensure the work is done properly so the customer is satisfied and callbacks for repair will not be necessary. Customers generally require test results as well as a final visual inspection as part of the documentation of a proper installation before approving payment.

In our experience, however, there is often confusion about exactly what should be tested and how documentation of test results is to be done on fiber optic projects. These issues should be agreed upon during the design phase of the project. Project paperwork should include specifications for testing, references to industry standards and acceptable test results based on a loss budget analysis done during the design phase of the project.

The process of testing any fiber optic cable plant may require testing three times, testing cable on the reel before installation, testing each segment as it is installed, including verifying every splice as it is made using an OTDR and finally testing complete end to end loss of every fiber in the cable plant. Practical testing usually means testing only a few fibers on each cable reel for continuity before installation to ensure there has been no damage to the cable during shipment. Then each segment is tested as it is spliced and/or terminated by the installers. Finally the entire cable run is plugged together and tested for end-to-end loss for final documentation.

One should require visual inspection of cable reels upon acceptance and, if visible damage is detected, testing the cable on the reel for continuity before installing it, to ensure no damage was done in shipment from the manufacturer to the job site. Since the cost of installation usually is high, often much higher than the cost of materials, it only makes sense to ensure that one does not install bad cable, which would then have to be removed and replaced. It is generally sufficient to just test continuity with a fiber tracer or visual fault locator. However, long spools of cable may be tested with an OTDR if damage is suspected and one wants to document the damage or determine if some of the cable needs to be cut off and discarded (or retained to get credit for the damaged materials.)

After cable installation, splicing and termination, each segment of the cable plant should be tested individually as it is installed, to ensure each splice, connector and cable is good. One should never complete splicing cables without verifying the splices are properly done with an OTDR before sealing the splice closure. Finally each end to end run (from equipment to equipment connected on the cable plant) should be tested for loss as required by all standards. Remember that each fiber in each cable will need to be tested, so the total number of tests to be performed is calculated from the number of cable segments times the number of fibers in each cable. This can be a time-consuming process.

Required vs. Optional Testing

Testing the complete cable plant requires insertion loss testing with a source and power meter or optical loss test set (OLTS) per TIA standard test procedure OFSTP-14 for multimode or OFSTP-7 for singlemode. The test plan should specify the “0 dB” reference method option (one, two or three reference cables) as this will affect the value of the loss. TIA 568 calls for a one cable reference, but this may not be possible with all combinations of test sets and cable plant connectors. The required test methods need to be agreed upon by the contractor and user beforehand.

OTDR testing is generally done on outside plant cables, but OTDR testing alone is not acceptable for cable plant certification. Long lengths of outside plant cabling which include splices should be tested with an OTDR to verify splice performance and look for problems caused by stress on the cable during installation.

While there are advocates of using OTDRs to test any cable plant installation, including short premises cables, it is not required by industry standards nor is it recommended for premises cabling. The shorter lengths of premises cabling runs and frequent connections with high reflectance often create confusing OTDR traces that cause problems for the OTDR autotest function and are sometimes difficult for even experienced OTDR users to interpret properly.

Coordinating Testing and Documentation

The Test Plan should be coordinated with the cable plant documentation. The documentation must show what links need testing and what test results are expected based on loss budget calculations. The Test Plan should also specify how the test data are incorporated into the documentation for acceptance of the installation and for reference in case of future cabling problems that require emergency restoration.

Planning for Restoration

About once a day in the USA, a fiber optic cable is broken by a contractor digging around the cable, as this photo shows. Premises cables are not as vulnerable, except for damage caused by clumsy personnel or during the removal of abandoned cables. Any network is susceptible to damage so every installation needs a restoration plan.

Efficient fiber optic restoration depends on rapidly finding the problem, knowing how to fix it, having the right parts and getting the job done quickly and efficiently. Like any type of emergency, planning ahead will minimize the problems encountered.

Documentation for Restoration

Documentation is the most helpful thing you can have when trying to troubleshoot a fiber network, especially during restoration. Start with the manufacturer's datasheets on every component you use: electronics, cables, connectors, hardware like patch panels, splice closures and even mounting hardware. Along with the data, one should have manufacturer's "help line" contact information, which will be of immense value during restoration.

During installation, mark every fiber in every cable at every connection and keep records using cable plant documentation software or a simple spreadsheet of where every fiber goes. When tested, add loss data taken with an optical loss test set (OLTS) and optical time domain reflectometer (OTDR) data when available. Someone must be in charge of this data, including keeping it up to date if anything changes.

Equipment For Restoration

Testing and Troubleshooting

You must have available proper test equipment to troubleshoot and restore a cable plant. An OLTS should also have a power meter to test the power of the signals to determine if the problem is in the electronics or cable plant. Total failure of all fibers in the cable plant means a break or cut in the cable. For premises cables, finding the location is often simple if you have a visual fault locator or VFL, which is a bright red laser coupled into the optical fiber that allows testing continuity, tracing fibers or finding bad connectors at patch panels.

For longer cables, an OTDR will be useful. Outside plant networks should use the OTDR to document the cable plant during installation, so during restoration a simple comparison of installation data with current traces will usually find problems. OTDRs can also find non-catastrophic problems, for example when a cable is kinked or stressed, so it only has higher loss, which can also cause network problems.

Tools and Components

Once you find the problem, you have to repair it. Repair requires having the right tools, supplies and trained personnel available. Besides the test equipment needed for troubleshooting, you need tools for splicing and termination, which may include a fusion splicer for outside plant cables. You also need components necessary for restoring the cable plant.

For every installation, a reasonable amount of excess cable and installation hardware should be set aside in storage for restoration. Some users store the restoration supplies along with documentation in a sealed container ready for use. Remember that the fiber optic patchcords that connect the electronics to the cable plant can be damaged also, but are not considered repairable. Just keep replacements available.

One big problem in restoring damaged cables is pulling the two cable ends close enough to allow splicing them together. You need several meters of cable on each end to strip the cable, splice the fibers and place them in a splice closure. Designing the cable plant with local service loops is recommended. If the cable ends are too short , or the damaged cable is underground or buried, you will have to splice in a new section of cable. Since the restoration cable must match the damaged cable or at least have a greater nuber of fibers, the best source of cable for restoration is cable leftover from the original installation. Manufacturers also can supply cable restoration kits that include cable and splice closures.

What else besides cables and cable plant hardware should be in a restoration kit? You should have a termination or mechanical splice kit and proper supplies. For splices, you need splice closures with adequate space for a number of splices equal to the fiber count in the cable. All these should be placed in a clearly marked box with a copy of the cable plant documentation and stored in a safe place where those who will eventually need it can find it fast.

Preparing Personnel

Personnel must be properly trained to use this equipment and do the troubleshooting and restoration. And, of course, they must be available on a moments notice. The biggest delay in restoring a fiber optic communications link is often the chaos that ensues while personnel figure out what to do. Having a plan that is known to the responsible personnel is the most important issue.

Major users of fiber optics have restoration plans in place, personnel trained and kits of supplies ready for use. It’s doubtful that most premises users are ready for such contingencies. Users may find that the cost of owning all this expensive equipment is not economic. It may be preferable to keep an inexpensive test set consisting of a VFL and OLTS at each end of the link and having an experienced contractor on call for restoration.

Managing A Fiber Optic Project

Managing a fiber optic project can be easiest part of the installation if the design and planning have been done thoroughly and completely, or, if not, the hardest. But even assuming everything has been done right, things will still probably go wrong, so planning for the unexpected is also very important. Here are some guidelines for managing the project that can minimize the problems and help in their speedy solution.

Application of Standard Project Management Processes in Fiber Optic Cable Plant Project Management
Organizations in the communication industry are proving that adopting proven project management practices reduces risks, cuts costs, and improves success rates of projects. The present article demonstrates how standard project management processes apply to fiber optic cable plant project management.

The article compares the Project Management Institute (PMI)'s standards and guidelines to the FOA's best practices in terms of fiber optic cable plant project management. PMI is the world's leading not-for-profit professional association for the project, program, and portfolio management profession. PMI strives to mature the profession of project management through standards, certifications, resources, tools, academic research, publications, professional development courses, and networking opportunities.

The PMI's Guide to the Project Management Body of Knowledge (PMBOK ® Guide) defines the project lifecycle as a combination of the following three (3) main phases: Project Initiation, Project Execution, and Project Closing. This article shows that the FOA's fiber optic cable plant project management lifecycle phases, which include the Design, Installation, and Testing, fit with PMI's recommended project lifecycle.

On Site Management and Supervision
First, someone has to be in charge, and everyone involved must know they are the boss, including them. During the project, they must be readily available for consultation and updates. While this may sound obvious, sometimes the network user's representative has other responsibilities (like managing an IT department) and may not be able or willing to direct full attention to the project. Whoever is assigned the task of managing the project must be involved and available, preferably on the job site, full time. If necessary, delegate responsibility to the contracting construction supervisor with requirements for daily reports and personal updates.

Make certain that everyone responsible for parts of the project have appropriate documentation and have reviewed the installation plan. Everyone should have toured the relevant job sites and be familiar with locations. They must also know who to contact about questions on the sites, within the network user, the contractor and any outside organizations such as local governments or utilities. Everyone needs to have contact information for each other (cell phones usually, since email may be too slow and instant messaging will probably not be available to field workers.) The onsite supervisor should have a digital camera and take plenty of photos of the installation to be filed with the documentation for future reference and restoration.

Locations of components, tools and supplies should be known to all personnel. On larger jobs, managing equipment and materials may be a full time job. Special equipment, like splicing trailers or bucket trucks, should be scheduled as needed. Rental equipment should be double checked with the suppliers to ensure delivery to the job site on time. Contacts for vendor technical support should be noted on documentation for the inevitable questions arising during installation.

Contacts with Local Authorities
Outside plant installs may require local authorities to provide personnel for supervision or police for protection or traffic management on public job sites, so they must also become involved in the scheduling. If job inspections are required, arrangements should be made so that the job interruptions for inspections are minimized. Supervisory personnel must be responsible for job site safety and have appropriate contact information, including for public services like police, fire and ambulance.

If the project is large enough to last several days or more, daily meetings to review the day's progress are advisable. At a minimum, it should involve the onsite construction supervisor and the network user's person in charge of the project. As long as things are going well, such a meeting should be short. On longer projects, overnight security personnel at job sites should have contact information for the job manager who must be available 24/7 as well as public service contacts.

Continuous Inspection, Testing and Corrections
Inspection and testing of the installed cable plant should not be left until after the job is completed. Testing continually during installation can find and fix problems such as cable stresses or high termination losses before those problems become widespread. Each installer doing testing should have documentation with loss budget calculations and acceptable losses to use for evaluating the test results. Installers should be double-checking each other's work to ensure quality.

What do you do when (not if) things go wrong? Here judgment calls are important. When something happens, obviously it is the responsibility of the onsite supervisor to decide quickly if they can take care of it. If not, they must know who needs to be brought in and who needs to be notified. By reviewing progress regularly, disruptions can be minimized. Equipment failures, e.g. a fusion splicer, can slow progress, but other parts of the project like cable laying can continue, with splicing resumed as soon as replacement equipment is available. Problems with termination should be reviewed by an installer with lots of experience and the cure may require new supplies or turning termination over to more experienced personnel. Never hesitate to call vendor support when these kinds of questions or problems arise.

Following the completion of the install, all relevant personnel should meet, review the project results, update the documentation and decide if anything else needs to be done before closing the project.

References and Training

References for the fiber optic designer's bookshelf include the FOA texts,The FOA Online Reference Guide to Fiber Optics , The FOA Reference Guide to Outside Plant Fiber Optics, The FOA Reference Guide to Fiber Optics, The FOA Reference Guide to Premises Cabling, and the FOA Tech Bulletins or NECA/FOA-301 installation standard. When it comes to the NEC, Limited Energy Systems, a textbook published by the NFPA, is very useful. There are dozens of books on communications system design, but unfortunately, the fast pace of development in communications technologies means that many textbooks are hopelessly out of date unless it's updated frequently. Better to rely on the web, especially the FOA Reference site and websites of well-established manufacturers, if you ignore the obvious hype in most white papers. (Hype is becoming so blatant and obvious that avoiding it is getting easier!)

Getting trained specifically in fiber optic network design is available through some FOA-Approved schools. The material is covered in part in some advanced fiber optic courses offered by the FOA-approved schools and by large manufacturers who help you understand how to build networks using their products. The FOA has a new FOA design certification (CFOS/D.)

More on fiber optic network design.

Test Your Comprehension

Table of Contents: The FOA Reference Guide To Fiber Optics

Reference Guide

Outside Plant Construction Guide

Introduction

Introduction

This is a description of the processes used in outside plant (OSP) or outdoor fiber optic cable construction, basically what happens before and during the process of installing the fiber optic cable plant. The FOA has extensive material available in our textbooks and online FOA Guide on what is involved in the fiber installation process (cable installation, preparation, splicing, termination and testing), so consider this the textbook for the construction processes that occur before the typical FOA CFOTÒ certified techs begin their work.

The audience for this includes the management of organizations owning or installing fiber optic cable plants, designers or estimators of the cable plant, as well as the actual CFOTÒ certified techs doing the installation work. It is intended to provide background information on the entire project and in conjunction with the other FOA information on basic fiber, OSP fiber, design and testing, provide complete information on all stages of a fiber optic communications project.

It is important to remember that every fiber optic cable plant project is unique! FOA provides these guidelines for understanding the processes involved in construction but it is the responsibility of the project managers and workers to interpret these guidelines appropriately for the cable plant being built.

Other References

As with any fast-moving technology, keeping abreast of the latest technology, techniques and products can be a daunting task. Here are some references that will assist you.

FOA Websites

The FOA website, www.thefoa.org, has a special section of the Online Fiber Optic Guide with almost 1000 pages on technical information on fiber optics. It is an up to date reference to all topics related to fiber optic communications and is a study guide for FOA Certifications as well as a reference for those interested in refreshing or increasing their knowledge of fiber optics. The FOA Guide is so large we provide a Custom Search for the site to help you find specific topics of interest.

Fiber U - Free Online Training

The FOA has also created an online learning site, Fiber U at www.fiberu.org, that offers free online courses for self-study. At Fiber U, you will find self-study programs for many topics related to fiber optic communications including fiber optic network design. Courses at Fiber U offer a Fiber U Certificate of Completion for those completing the classes and passing an online exam.

FOA Textbooks

The FOA has published other Reference Guides that are the references for FOA certifications. These books are the reference books you should have on your bookshelf.

The FOA Outside Plant Construction Guide is a concise reference for the installation of fiber optic cables, including the construction involved in underground, direct-buried and aerial cables. This book is the printed version of the material in this section of the FOA Guide.

The FOA Reference Guide to Fiber Optics is a general reference guide for fiber optics and the basic study guide for the CFOT certification.

The FOA Reference Guide to Premises Cabling is a reference guide for copper and fiber optic cabling and wireless as used in indoor applications and the basic study guide for the CPCT certification.

The FOA Reference Guide to Outside Plant Fiber Optics is a reference guide for fiber optic cabling as used in outdoor applications and the basic study guide for the CFOS/O certification.

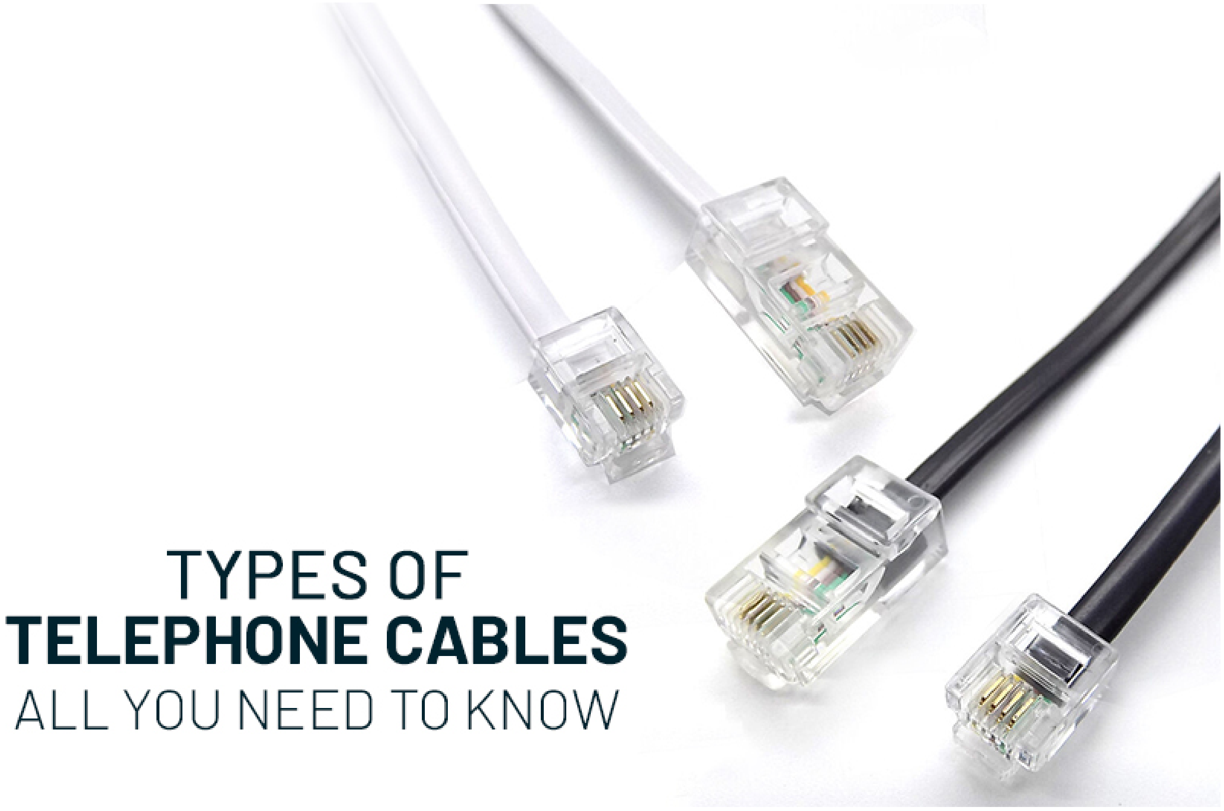
The FOA Reference Guide to Fiber Optic Network Design is a reference guide for designing fiber optic cabling networks, both OSP and premises.

The FOA Reference Guide to Fiber Optic Testing is a comprehensive reference guide for testing fiber optic cabling and networks.

All FOA textbooks are available for purchase from Amazon and most booksellers.

Disclaimer: This information is provided by The Fiber Optic Association, Inc. as a benefit to those interested in teaching, designing, manufacturing, selling, installing or using fiber optic communications systems or networks. It is intended to be used as an overview and/or basic guidelines and in no way should be considered to be complete or comprehensive. These guidelines are strictly the opinion of the FOA and the reader is expected to use them as a basis for learning, as a reference and for creating their own documentation, project specifications, etc. Those working with fiber optics in the classroom, laboratory or field should follow all safety rules carefully. The FOA assumes no liability for the use of any of this material.

Return to the OSP Construction Guide Index



20/ 06, 2019

Telephones are an important invention that have the ability to connect people all over the world. They consist of numerous pairs of copper insulated wires having a diameter that ranges from 0.3 to 0.9 and are either twisted into two or four pairs. These pairs of wires are then connected to each phone jack in your house. There are many different cables that serve different purposes and vary in configuration, size and performance. Here are the most common types of telephone cables.

1. Coaxial cable

One of the most common telephone cables is called the coaxial cable. It is called coaxial because it has one physical channel, which is an insulated layer that is a woven shield of copper. This inner layer carries the signal and is surrounded by another physical channel that is created out of a plastic sheath. The outer channel is considered the 'ground' where many of the pairs of coaxial tubes are placed and transmit information over a great distance. It is essential that you take proper precautions to maintain your home electrical wire (https://finolex.com/fool-proof-tips-to-maintain-your-home-electrical-wiring/) to ensure they are in perfect working condition. Coaxial cables come in many different sizes and have various performance and power-handling capabilities. In addition to serving as a telecommunication connection, they can also be used to connect audio and video equipment, LAN and television networks. A few coaxial cables include twin-axial, bi-axial and RG/6 cables.

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2. Twisted pair cable

Another type of telephone cable is the twisted pair cable which contains a pair of copper wires- usually colour coded – that are twisted around each other. These cables have a diametre in the range of 0.4 to 0.8 mm. In each twisted pair cable, the number of twisted pairs can vary. In most cases, the higher the number of wire pairs, the better, because it reduces the risk of cross talk and any external noise. However, it is important to note that although twisted pair cables are incredibly cost-effective when compared to other telephone cables, they have a high attenuation and low bandwidth. There are essentially two types of twisted cables:

a. Unshielded twisted pair (UTP)

These twisted cables do not rely on a physical shield to block any connectivity issues or interference. This is the most common type of twisted pair cable used for both business and residential (https://finolex.com/a-guide-to-electrical-essentials-for-your-household/)use. There are various UTPs that differ in their bandwidth as you go up the scale. Like a CAT1 scale has 1Mbps and CAT2 has a bandwidth of up to Mbps.

b. Shielded twisted pair

The second type of twisted cable is the shielded twisted pair (STP). Unlike the unshielded twisted pair (UTP), the STP blocks external interference with foil jacket. This type of twisted cable is used on a larger scale for big enterprises and high-end applications that may be exposed to environmental elements.

3. Fiber optic cables

One of the latest telephone cables out there is the fiber optic cable. Unlike traditional telephone cables that transmit data over copper wires, this cable uses optical fibers to transmit data with light rather than electricity. For added protection, each of these optical fibers has a plastic layer that is contained in a protective tube. This layer makes it resistant to external interference resulting in an incredibly fast internet connection that around 26,000 times faster than the connectivity provided by twisted pair cables. There are two types of fibre optic cables

a. Single mode fibre optic cable

This cable has a small core and only allows one mode of light to enter at any given time. This reduces the number of light reflections as they pass through the core of the cable. This allows the data to travel faster and a low attenuation rate. This type of fibre optic cable is commonly used in telecommunications.

b. Multimode fiber optic cable

This cable has a larger diameter and allows more modes of light and data to enter through its core. Since the light is more dispersed in a multi-mode cable, there is a lower attenuation rate and reduced bandwidth. The connection with a multimode fiber optic cable can only be used for communication over a short distance like telecommunications, LAN and security systems.

4. Jelly-filled telecom cable

A cable that is filled with petroleum jelly which is water resistant is a jelly filled cable. This cable is an underground cable that uses the material polythene as insulation on the conductors. The spaces between the conductors is filled with petroleum jelly. This jelly has numerous benefits, for one it prevents the entry of moisture or water from entering the core of the cable in the event that the cable is damaged. They are suitable for both hot and cold climates.

5. Ribbon cable

This cable is also known as a flat twin cable or a multi-wire planar cable and it is made of numerous insulated wires that are parallel to each other. These parallel cables are beneficial as they allow the transmission of data to occur simultaneously. These types of cables are used in interconnected network devices. Telephone lines are connected by numerous cables that come in many different types and each has its own purpose and function. Telephone cables like power cables perform the function of carrying sound signals. Each of the cables discussed above has comes with its own bandwidth and configuration so it is up to each person to decide which telephone cable will meet their needs best. It is also important to have the essential safety accessories (https://finolex.com/top-safety-accessories-to-consider-for-your-next-home-wiring/) before you wire your home. If you are looking for a brand that can provide you with high-quality, durable telephone cables (https://finolex.com/products/telephone-cables/), look no further. Keeping a customer-centric focus as our prime motto, Finolex (https://finolex.com/)provides exclusive after-sales repair and maintenance services on their wires and cables (https://finolex.com/5-reasons-you-need-to-switch-to-finolex-wires-and-cables/). Additionally, our well-established warranty and exchange policies makes Finolex one of the most customer-friendly electrical companies in India.

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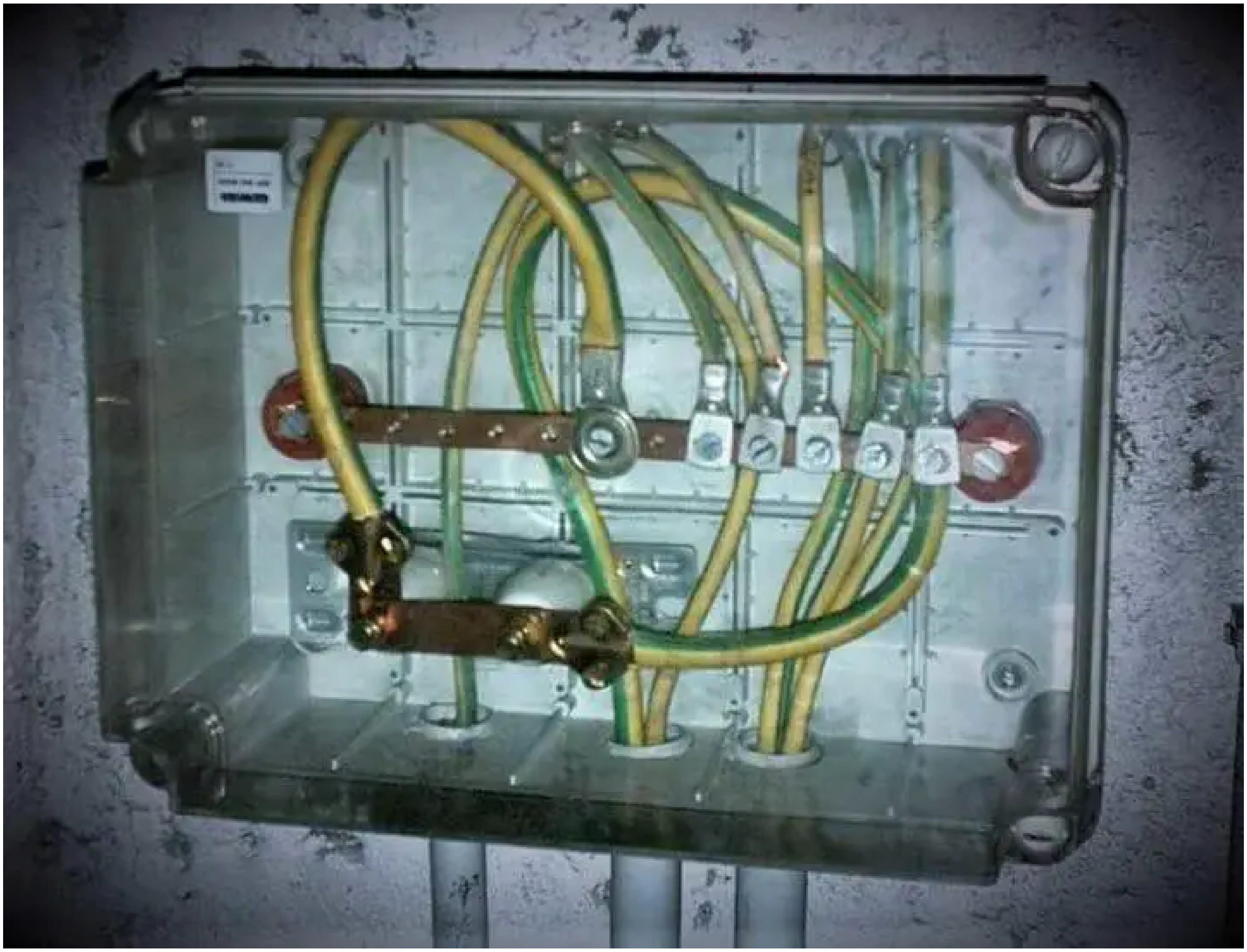
Testing and Inspection of Bonding and Grounding Systems

by Editorial Staff

Bonding and grounding are very effective techniques for minimizing the likelihood of ignition from static electricity.

A **bonding** system connects various pieces of conductive equipment and structures together to keep them at the same potential. Static sparking cannot take place between objects which are at the same potential.

Grounding is a special form of bonding in which the conductive equipment is connected to the facility grounding system in order to prevent sparking between conductive equipment and ground.



In potentially flammable locations, all conductive objects that are electrically isolated from ground by nonconductors such as nonconductive piping or hoses, flexible hoses, flexible connections, equipment supports or gaskets should be bonded.

An isolated conductive object can become charged sufficiently to cause a static spark. Objects that can become isolated include screens, rims of nonconductive drums, probes, thermometers, spray nozzles and high pressure cleaning equipment.

In order to successfully achieve the objective of the same ground potential for all materials and their containers when there are additional and/or redundant grounding systems, and particularly when there are supplementary grounding electrodes, all such grounding electrodes and systems must be interconnected as required by the NEC and NFPA Lightning Protection Code.

Bonding and grounding conductors must be durable and of a low resistance. Connections of bonding conductors to equipment must be direct and positive for portable equipment. Clamps must make contact with metal surfaces through most paint, rust and surface contaminates. Single point clamps are superior to battery type and “alligator” type clamps for making direct contact.

Caution must be exercised in the installation of static grounding systems so that no part of the electrical currentcarrying system is used as a ground. Fires have occurred in plants where static-control grounds were tied into the electrical system neutrals. These neutrals must never be part of the ground system except at the service entrance or other approved common bonding point.

Testing and Inspection of Bonding and Grounding Systems

The proper installation of bonding and grounding devices is important in the protection of personnel and equipment. At the time of installation, a resistance test is needed to confirm electrical continuity to ground. In addition, an effective inspection and periodic maintenance program is needed to ensure that continuity exists throughout the system.

In evaluating maintenance requirements, the bonding and grounding requirements can be divided into three categories:

1. The point type clamps equipped with flexible leads used for temporary bonding of portable containers to the facility grounding system.
2. The fixed grounding conductors and busbars used to connect the flexible leads and fixed equipment to ground.
3. The facility grounding system.

The flexible leads are subject to mechanical damage and wear, as well as corrosion and general deterioration. For this reason, they usually should be uninsulated and should be inspected frequently. This inspection should evaluate cleanliness and sharpness of clamp points, stiffness of the clamp springs, evidence of broken strands in the conductor and quality of the conductor connections.

A more thorough inspection should be made regularly using an approved ohmmeter to test electrical resistance and continuity. One lead of the ohmmeter is attached to a clean spot on the container, the other lead is connected to the facility grounding system. The measured resistance should be less than 25 ohms and will usually be about 1 ohm. Shake the leads to make sure that the contact point and the leads are sound. Do not rely on contact through dirt or rust.

The fixed leads and the busbar are not usually subject to damage or wear but should be annually checked with an ohmmeter. They are checked between the leads or bus and the facility ground. The measured resistance should be less than 1 ohm.

Conductive hoses should be checked regularly and after any repairs are made. The conductive segments may break or may not be properly repaired. Nonconductive hoses with an internal spiral conductor should be installed so that the spiral conductor makes contact with the adjacent metallic fittings. Shake the hose whenever possible when making the measurements.

Facility Ground System

The final component of the static bonding and grounding system is the facility ground system. The facility ground must conform to the rules of the NEC. Underground piping equipped with cathodic protection should not be used as the grounding system.

Do you face any problems with Bonding and Grounding? Share with us.

Reference: erico

Service Offering: Buried Wire

Overview

Buried Service Wire (BSW) is defined as a cable installed underground from a telephone terminal to a CLEC's Network Interface Device (NID) that brings dial tone to the premises. Verizon is not responsible for digging the trench and laying the conduit when the CLEC requests BSW. There may be occasions when a CLEC requests Verizon to place BSW before the service is installed. If the CLEC/contractor has provided the trench, Verizon will place the BSW in the trench. It is Verizon's responsibility to place and maintain it. This wire does not belong to the CLEC/end user.

A Network Interface Device (NID) is a point of interconnection between Verizon communication facilities and terminal equipment, protective apparatus or wiring at the CLEC/end user's premises. The NID will be located on the CLEC/ end user's side of the Verizon protector or its equivalent at or near point of entry and accessible to both Verizon and the CLEC. Only one (1) NID per dial tone line can be installed in a CLEC/end user's premises. All inside wires, jacks, telephone(s), alarm, meter readings, or other terminal devices must be connected through the NID.

In Verizon West , CLECs can request that the DEMARC or DROP at an end user's location be moved or relocated on the same premises. The DEMARC, DEMARCATION POINT or DROP is the terminal box located where Verizon's facilities (aerial or buried cable) comes into the end user's house or building.

Verizon will move wire for the following reasons

- Renovations to home or business Demolition of the building Construction
- where service exists
-

Buried Drop/Wire may refer to the following

- The movement and/or relocation of the Network Interface Device (NID) Changing
- Aerial Wire to Buried Wire
- Move or change Outside Drop Wire or Protector

CLECs are not permitted to

- Access the network side of a NID
- Disconnect a Verizon NID
- Request the move of a NID if an address, location (Ex: FLR, APT, etc) or facility change is required

Requesting Buried Service Wire or Requesting a New or Move of a Network Interface Device

Required Forms
- Local Service Request (LSR)
- End User Form (EU)
- Service Specific Form (Resale, Loop Service, etc)

For assistance in completing your Local Service Request (LSR), see our Order Sample (W89).

The "REQTYP" (Request Type) will depend on the type of service.

When requesting a new or move of a Network Interface Device (NID), review Verizon's Business Rules for the appropriate usage and value of the "NIDR" (NID Request) Field.

East USOCs

- Platform* - RWW
- Resale* - RWW

NW1 (Standard Network Interface) NW2 (Network Interface)

*New York - Information for NID moves are submitted via a Maintenance Ticket

West
Populate the "ACT" (Activity) field on the LSR form with a "C," the "DSPTCH" (Dispatch) field with a "Y," and the "REMARKS" field with the move or relocation being requested. NOTE: For Platform service, the "REMARKS" field is used in place of the "NIDR" field. Effective October 10, 2005 with the scheduled release of LSOG 9, the NIDR field will be available for use.

Grounding

Ten years ago it would have been rare for anyone to talk about the importance of low resistance grounding and bonding except where mainframe computer systems, telecommunications equipment or military installations were being discussed. Today, we live in a world controlled by microprocessors so low resistance grounding is now critical and is a popular topic of conversation.

The electrical grounding system in most facilities is the electrical service entrance ground. In the past it was often "OK" to just meet the minimum requirements of the National Electrical Code (NEC). Today, the requirements of the NEC should only be the starting point for grounding systems and bonding.

The primary focus of the NEC is life safety and proper equipment operation. The NEC and most local codes call for the installation of one or two 8- 10’ ground rods with the intention of the ground rods net total resistance being no more than 25 Ohms. The NEC does not address the grounding or bonding requirements of sensitive networked systems or the testing of grounding systems. The NEC does not call for what is known as "low resistance electrical grounding". These specifications are most often those of equipment manufacturers, power quality consultants or electrical engineers familiar with sensitive equipment’s grounding requirements.

The evolution of microprocessors and networking is the root cause of today’s keen interest in grounding. The continued growth of networked systems and equipment is the focus of the need for low resistance grounding as well as the associated power quality issues. The microprocessor has evolved from the transistor to integrated circuits with millions of transistors in packages considered impossible only a few years ago. These new packaged transistors commonly known as computer chips operate on 3 or 5 volts DC (direct current) and are very sensitive to the problems resulting from high resistance or bad grounds. The problems associated with grounds is better left to other areas of this report, but remember, for the proper operation of networked microprocessors a low resistance "clean" ground is required.

Ground, by most electrical or electronic definitions, is "0" reference. More formal definitions are: The position or portion of an electric circuit that is at zero potential with respect to earth, and, A large conduction body, such as the earth, used as a return for electric currents which has an arbitrary zero potential.

Ground to an electrical system should "0" potential and be designed to be a highly conductive path for electrical energy. The resistance of the path to this "0" reference must be low, of sufficient ampacity and capable of handling a broad frequency spectrum of energy.

Today, the most common specification where sensitive equipment is involved is for the ground field (rods, grids, plates, etc.) to be a maximum of 5 Ohms of resistance or lower. Many military and critical communications sites specify substantially below 1 Ohm. If sensitive equipment is to be installed it is very important for the grounding system to be compatible with the equipment requirements.

Most commercial buildings are specified with a NEC or other code ground and not to low resistance standards. The resistance of this code ground is intended to be 25 Ohms or less, but is rarely tested. To verify the resistance of ground, it is most often tested with instruments using the fall-of-potential method by a trained technician.

In lightning prone areas ground should be tested more frequently than most commercial installations that require only annual testing. Location of electrical panels, equipment to be grounded and other factors must enter into the calculation of the required wire size. The calculation of conductor size and installation method is best left to engineers or professionals in the field of grounding.

Grounding is the backbone of effective protection of all networked systems. AC power, security, life safety, computer, video, satellite, telecommunications, etc. systems all rely on ground for operation. In addition, the protective devices used to protect these systems such as UPS systems, power conditioners, voltage regulators, surge suppressors, etc., will be rendered ineffective if connected to improper wiring or defective grounding.

Electrical distribution systems are solidly grounded to limit voltage to ground during normal operation and to prevent excessive voltage due to lightning, line surges or unintentional contact with higher voltage lines during normal operation. In all cases, the grounding electrode system is required to be common and solidly bonded to each system per the NEC.

National Electrical Code (NEC) Grounding Requirements

Code requires the grounding of one current carrying conductor in a distribution system where voltages are between 50 and 1000 volts or where one of the service conductors in not insulated. The grounded conductor is identified either by a white or light gray color at termination points and is typically referred to as the neutral conductor. The equipment-grounding conductor is a non-current carrying conductor *whose primary function is safety*. The conductor must have adequate ampacity and low enough impedance to actuate over current protection devices (circuit breakers or fuses), on the supply side of a circuit should an ungrounded conductor come in contact with any exposed metal part of the distribution system or equipment. *Both the neutral and equipment-grounding conductor is bonded together at a single point* via a bonding jumper. (Most often this is the main disconnect or the neutral/ground service entrance bonding buss bar.) This point is also bonded to Earth via the grounding electrode conductor that bonds the system to the grounding electrode system. The panel that houses the bonding jumper (or bonding buss bar) is called the main panel (main distribution panel) or can be the service entrance main disconnect. All subsequent panels and disconnects fed from this point are referred to as sub-panels, distribution panels or disconnects.

Single point bonding at the service entrance is critical to life safety and is required by code (NEC). It can occur more than once between a service entrance and the first panel housing a disconnecting device such as a fuse or circuit breaker; however, this is still considered a single location. Neutral and ground can only be re-bonded on the outputs of separately derived systems such as transformers, generators, and some UPS systems. The most important aspect of a single point of bonding is that it keeps current off the equipment-grounding conductor.

Electrical panels are typically supplied with a bonding jumper in the form of a screw that bonds the neutral bus to the panel case. If the electrician installing the panel fails to remove the screw prior to completion of the installation, the equipment-grounding conductor on the supply side of the panel will carry objectionable neutral current. Accidental bonding within building distribution or branch circuitry will cause neutral current to flow in the grounding system. Building steel, water piping and most other metal conductive systems that are required by code to be bonded to the ground will also carry this current. (Reference: Intersystem Ground Noise)

Inter-system ground noise results from current flow on the ground conductor. This ground noise occurs because of the impedance differences in the different components of ground within the building. Accidental neutral to ground bonding also makes it impossible to predict and/or defend against the effects of lightning induced currents within a building. Any current on ground will divide into the lowest impedance path back to the service entrance ground placing different parts of the ground system at different voltage potentials. (Reference: Ground loops)

Grounding Requirement

The NEC requires the path back to ground from circuits, equipment and exposed metal enclosures:

1. be permanent, reliable, and continuous.
2. have sufficient capacity to conduct safely any fault current likely to be imposed on it: and
3. have sufficient low impedance to limit voltage to ground and:
4. to facilitate the operation of the circuit protective devices in the circuit.

All the components that form a ground conductor for a given circuit; i.e.: panels, raceway, conduit, wires, clamps, fittings, brackets, etc., must be able to carry fault currents capable of tripping the circuit protective devices (breakers or fuses) feeding the ungrounded conductors in that circuit without causing significant heating in any of those components.

It is very common for problems to arise over time with all of the above requirements. These potential problems can be divided into five areas.

1. <u>Materials</u>: Ground continuity must be maintained through what can be hundreds or thousands in large buildings, of components that may be of many types of material. i.e.: Steel raceway, electrical panels,

disconnects, transformers, conduit, flexible conduit, fittings, connectors, bushings, etc. In addition many of these have coatings which can be made of dozens of different materials.
2. Initial Workmanship: Depending on the quality, initial design, material selection and workmanship the trouble free life of the buildings electrical distribution system can vary dramatically.
3. Subsequent Work or Equipment Additions: Modifications and additions to the electrical distribution system are common several years after a building has been completed. Modifications that do not follow the guidelines of the NEC and good grounding principles can impose problems to the properly installed portion.
4. Age: Without preventive maintenance and testing an electrical distribution system will deteriorate dramatically. Over time, components will wear out, fail, overheat, etc. If appropriate corrective action is not taken the result is system deterioration, rust, corrosion, painting, and inappropriate circuit usage which will all take their toll. Renovations and improper maintenance of internal systems such as heating ventilation and air conditioning equipment can cause significant electrical distribution system problems. i.e.: If the building does not have adequate and positive ventilation of conditioned air, then condensation can form on the metallic portions of the electrical distribution system and cause significant corrosion. This will result in continuity loss and lowered ampacity of the electrical distribution system.
5. Not directly related to the NEC, but significant none the less, is building usage. It is common for a building to have several owner or tenants over its normal life. The usage of these tenants is likely to have changed from the initial construction. i.e.: Microprocessor usage today vs. the use of typewriters and adding machines in 1970. The needs and requirements of the electrical distribution system have changed dramatically, but has the system been updated to meet the needs of these devices? Has the grounding ever been tested or updated?

Sufficient capacity (ampacity) can only be ensured via testing, however, there is no requirement in the code with respect to testing the adequacy of a ground circuit after the initial installation. It may only take a single faulty joint in a long circuit to eliminate the ability for a breaker or fuse to trip during a fault. It may only take one lightning strike to "glaze" the ground rod(s) and render them ineffective or increase their resistance significantly. The safety issue is that faulty joints can burn open and leave the exposed parts of the equipment at this short at a high voltage with respect to Earth. This leaves a shock hazard for operators of equipment and renders equipment protective devices useless. Remember, impedance will also be affected by the composition, length of the different components, the quality of the hardware and the workmanship to join them, maintenance issues aside.

Surge suppression technology installed on a defective circuit may not only fail to perform as expected, but can also redirect harmful energy into the protected load. At a minimum, high impedance ground will negatively affect surge suppression technology to some degree.

Grounding Electrodes and Grounding Electrode Conductors

A low impedance connection to Earth is necessary to prevent excessive voltages due to lightning. This connection to Earth is provided by a grounding electrode system.

Where available, all of the following must be bonded together to form a grounding electrode system:

1. Metal underground water pipe that is in direct contact with earth for ten feet or more.
2. The metal frame or structural members of the building.
3. Concrete encased electrodes. Reinforcing bars or rods not less than 20 feet long and not less than ½ inch in diameter.
4. Ground Ring. A copper conductor, not smaller than No. 2 copper and at least 20 feet long that is buried not less than 30 inches deep, which encircles the building.

When none of the above electrodes are available, or when only a water pipe is available, made electrodes such as copper clad ground rods must be driven to supplement the grounding electrode system. *Multiple electrodes must be bonded together regardless of their distance apart.*

Once the individual components of the grounding electrode system have been bonded together, a single grounding electrode conductor serves to bond the electrical system to the ground conductor (neutral) and the equipment grounding conductor of one or more services feeding a building. (It is important to note that neutral is utility ground.) *Individual services for a single building cannot reference different grounds.* Size and requirements for all grounding components are specified in sections 250 and 800-820 in the NEC.

A common mistake in both the computer and telecommunications industries is to drive separate ground rods as an attachment point to earth for an "isolated ground" with no connection back to the building service entrance neutral to ground bond point. This lack of bonding is a clear violation of the NEC and actually significantly increases the risk of damage due to lightning.

Telephone communication lines and CATV coax cable (cable TV) lines are required by code to make connections to the building grounding electrode system. Phone systems require primary lightning protection equipment at the service entrance. (FCC required) If a separate ground rod is driven for convenience during the installation of the discharge equipment, this rod must be bonded to the building electrode system with an adequate conductor. Cable and satellite coax cable shields, as well as metal support structures, must also be bonded to the building electrode system at their point of entry into the building. Again, any separate ground rods driven for the purpose of grounding this equipment must be bonded to the building electrode system with a minimum of a No.6 copper wire. When determining Bonding and grounding, always refer to sections 250 and 800-820 in the NEC.

Supplemental Ground Rods

Equipment installers are allowed by code to supplement the existing ground system by driving additional ground rods and bonding these rods via a supplemental grounding electrode conductor to the chassis of the equipment. This is very common for phone switching equipment. Several references state that this can be done to help reduce noise, however, Code demands that this can only be done when the existing circuit, which feeds that device, is properly grounded.

The reason for this allowance in the code is to provide for the installation of supplemental ground rods for outside structures that are electrically connected to the AC power supply of a building. A good example of where supplemental ground rods can help a facility would be parking lot lights. The supplemental ground rods dissipate to Earth a direct lightning strike rather than have it migrate to the building ground. If a supplemental rod is driven for a piece of equipment that is housed within the building, the existing circuit ground serves as the bond between the supplemental rod and the building grounding electrode system. This would seem to be in conflict with the section of the NEC that states that any additional rods be bonded with a minimum of a No. 6 copper conductor. In the case of the supplemental rod, the existing equipment grounding conductor for the circuit serves as the bond between the two ground systems and need not be a No. 6 copper conductor. The risk here is that the supplemental rod can be a source of lightning energy rather than an aid. Ground loops can develop between different ground potentials. While meeting the letter of the code, it is still a formula for disaster for the connected networked equipment. (Reference: Ground Loops) All ground rods should be bonded properly to form a single reference, as you don’t want to develop a voltage potential across the building as a result of a lightning hit.

The reason for and the necessity to bond individual grounds or ground electrodes is simple. Soil is an extremely poor conductor and lightning energy that is conducted into it generates rings of voltage potentially around the point where the lightning strikes the Earth. Ground rods in different locations can be thousands of volts apart from each other. If these rods are not solidly bonded, this voltage potential may attempt to equalize in the piece of equipment where there are two grounds, or over the conductors between them. In the most basic installation, the most common examples of this are phone and modem damage or cable TV tuner damage. In the world of microprocessors, this is damage to networked equipment coming in on the data ports. This action is referred to as a *difference in potential* or a *ground loop*.

Network and Communications Cables

The installation configuration of network and communications cables and the quality of workmanship used to install them relate directly to the connected equipment’s ability to survive severe transients. The relationship between these cables and ground is also critical to the survival of the connected equipment as well. Different cabling platforms have different characteristics and different levels of immunity to disturbances on ground.

1. Unshielded twisted pair Ethernet cable and network cards has no ground connections and a 1500-volt isolation specification between any cable pin and any part of the card.
2. Coax Ethernet has no physical connection between the cable and the card unless a grounded terminator makes an intentional connection. Coax also has a 500-volt isolation specification between both the center pin and any part of the card that comes into contact with the motherboard of the computer.
3. Token ring cabling has no isolation specification and may or may not make any direct connection with the computer chassis depending on whether a shielded cable is used.
4. RS-232, 422, 432, AUI, serial and parallel cables all carry one or more ground pins and consequently have no isolation between the cabling and computers or peripherals that interconnect.

There is always a risk of bridging two branch circuits with the ground on one of these cables. Any significant difference in the impedance of the two AC grounds can induce current flow in network cable ground that, at the least, can potentially destroy the cards at either end. For this reason fiber optic cables are preferred when the possibility of difference in ground impedance (ground loop) may be present. Optical isolation often will not carry the data line transmission speed, but in installations were it will, optical isolators are an inexpensive solution to difference in ground impedance.

Grounding & Soil Conditions

Ground grids are installed in soil and the composition of the soil (soil type, salt content and moisture content) will effect the resistance of the ground grid. In addition the life of the ground grid will be determined by the pH factor of the soil. Soil pH is a measure of the acidity or alkalinity of the soil.

Most ground grid materials are composed of copper, copper plated steel, and zinc plated steel, steel, stainless steel or aluminum. Acidic soils will easily eat away both copper and zinc, yet they will be are stable in alkaloid soils. Aluminum is unaffected by acidic soils; but it is etched by alkaloids. A very basic soil test can be performed using some soil with distilled water (equal parts) in a pool/spa water strip pH tester. It is simple yet effective test and the equipment cost is minimal.

Aside from the pH of the soil, its water and salt content determine the conductivity. The more salts, the less water required to reach a specific conductivity. Like all partial conductors, the resistance value is measured in ohmmeters or ohm-cm.

Soil resistively can be measured using four-point fall of potential equipment. This testing is best left to a trained, experienced technician with calibrated equipment.

Grounding Verification and Testing of Proper Grounding

There is no verification process required by NEC for checking the quality of a grounding system during or after installation. At best the code specifies adequate materials and encourages good workmanship with phrases like "connections must be wrench-tight". The inspection process involved in obtaining a sign-off to achieve an occupancy permit for a building is typically a visual inspection only. Inspection after walls have been closed in can be almost impossible; depending on the material employed to build a ground system.

The proper testing of a grounding electrode system for resistance involves two steps. The ground grid (ground rods, bonding, etc.) is tested for resistance to Earth. The branch circuits are tested for resistance at the outlets.

The ground grid (rods) should be tested using the fall-of-potential method by a trained, experienced, skilled technician. The equipment used must be in current calibration and the equipment manufacturer instructions must be followed. A professional should be contracted to perform this testing.

Standards for the "net" resistance of the ground grid will vary. The preferred specification for sensitive equipment is less than 5 Ohms and a lower resistance is better. The NEC call for a 25-Ohm resistance but does not require testing or take into consideration the needs of sensitive equipment.

Branch circuit resistance testing can be completed using a SureTest® branch circuit analyzer model ST-1D or ST-THD. These testers will also perform a number of other tests to analyze the circuit's ability to carry a load properly. One such test is that for an isolated ground circuit, very often critical for sensitive equipment. The advantage of these testers is their ability to test a live circuit. Most other testing of circuits require they be disabled and the equipment disconnected.

In older (pre microprocessor) buildings conduit was often used as the ground conductor. This method of ground is completely unacceptable for sensitive equipment. The joint work, age, corrosion and dozens of other factors render these ground systems ineffective. Current NEC does not allow conduit ground as an acceptable practice. Using a copper wire as a conductor for ground is infinitely more desirable due the fact that terminations of the copper wire occur inside the metal or plastic work boxes that house receptacles and switches, making the joints assessable.

Standards for branch circuits are clear and have been defined by IEEE (Institute of Electrical & Electronic Engineers) and the NEC.

Measuring a Ground Connection

Ground connections have to be good connections and measuring them can be accomplished with standard low range meters. One such instrument is a Fluke Model 8012A with option 01 can measure down to .001 ohm, (one milliohm). This meter provides the capability to zero out the lead resistance with a front panel control.

> *Note: Sites with phone system batteries use +48 volts to ground and you may experience a slight problem in making resistance measurements. It is not uncommon for the meter to read negative ohms. This is due to the return currents causing a voltage drop across the ground connection being measured. Reversing the meter leads will make the reading positive. The true reading is the algebraic sum of the two readings.*

Grounds and Frequency

The true resistance of a ground connection in an AC power system is the most important measurement, but the inductive value of the ground path can play a critical role. Radio frequency energy and the fast rise time of a lightning strike event require low inductance ground paths. Cellular Phone and radio towers are struck more often than most structures, as they are tall and made of conductive metal. The energy in a lightning strike is broad-spectrum energy. When high frequency energy travels on a conductor it travels on or near the surface of the conductor. This is called the "skin effect" and is the tendency of high frequency energy to only be conducted on or near the surface of the conductor. Below this surface, the majority of the conductor material is not used. This means that connections or conductors that do not have a large surface area will be more inductive and have higher impedance (resistance) to the flow of high frequency currents.

Ground Conductor Size and Type

The NEC outlines ground conductor requirements to meet code. The size of the conductor is outlined in detail and the ampacity of the conductor is a function of size. The type of conductor is not outlined in the NEC. Where ever possible when high frequency energy is to be handled it is preferable to use stranded conductor vs. solid conductor. The surface area of a stranded conductor is greater than that of a solid conductor and therefore it is better able to handle high frequency energy. A ground conductor can not be too large and in the case of ground conductors, bigger is better.

Grounding and Dissimilar Metals

The use of dissimilar metals should be avoided if possible. Where it is not possible to avoid their connection it is important to take steps to prevent corrosion or electrolysis between the dissimilar metals.

When making low impedance connections which could be of dissimilar metals it is important to use a joint compound such as T&B's Kopr-shield CP-8 (for copper joints) or Alumashileld (for aluminum joints). This will prevent corrosion and should also be practiced when connections will be exposed to moisture.

Shared Neutral & Ground Conductors

Neutral is the drain to the phase conductor just as the phase is like the water faucet is the supply pipe in a water system and the drain is the disposal pipe. That means that neutral is the power (utility) company ground.

Shared neutrals in branch circuits meets the NEC, but not recommended when sensitive equipment is used. It is also not recommended when the circuit is powering non-linear loads. Non linear loads are "switch mode power supplies" as found in computers and other microprocessor products.

The theory behind using shared neutrals is valid only with linear loads. Linear loads have a unity power factor while switch mode loads do not. In theory a three-phase system is balanced as each phase voltage is 120 degrees behind (lagging) the phase before it. Phase currents are separated by 120 degrees as well. If each phase is carrying equal current (10 amps as an example), the equivalent currents will cancel each other as they combine at the neutral for return to the source. The result can be mathematically and algebraically shown to result in no (0 amps) of neutral current.

In reality the previous example assumes the electrical system is powering linear loads that the system is resistive in nature, that it is operation at unity power factor, and further, that the system operates in a state of equilibrium. In the real world, three phase systems are never in this state even though electricians do their best to balance loads. Elevators, compressors, and air handlers cycle in their operation. Computers, lights, copy machines, etc. are constantly being turned on or off. These changing conditions create natural imbalances in the three-phase distribution system. As soon as currents become unbalanced cancellation of neutral currents cease. As neutral current begins to flow, physical laws take over and the flow through the impedance of the neutral conductor creates a voltage drop that can be measured with reference to ground. The amplitude of the voltage will be directly proportional to the amount of neutral current flow and the impedance of the neutral conductor. Result, Neutral to ground voltage often called common mode voltage.

Branch circuit length, induced and conducted voltages all impact neutral to ground voltages, but the most common cause is outlined above. Sharing neutrals where switch mode power supplies are involved is not recommended because they are such a contributor to the imbalance. Neutral to ground (common mode) events can cause significant disruption to the operation of microprocessor based equipment. These devices constantly measure logic voltage against the "zero voltage reference" of life safety ground. The microprocessor expects to see less than .5 volts between neutral and ground.

It is common practice and meets the NEC to have shared ground and neutral conductors in 120-volt branch circuits (most cases). It is not good practice to have shared conductors for several reasons. Those that relate to the neutral and ground conductor will be explained briefly.

The ground conductor (not neutral) is the life safety and equipment chassis ground reference for the standard (120-volt) branch circuit. Other equipment uses ground as the "neutral" or drain wire is for the 120-volt branch circuit. Single-phase (208 & 240 volt) equipment is often wired; phase (hot), phase (hot) & ground. The efficiency of the equipment will determine how much of the energy is not used by that equipment. The unused energy uses the ground wire as the drain. This resulting energy dumped on the ground wire can have a very negative effect on sensitive equipment relying on the same ground. Noise, stray voltages and other anomalies are not good for sensitive networked equipment.

Isolated Ground Circuits

The below standards should be a guide to the proper installation of branch circuits. The wire size, outlet type, etc., should be selected to meet the NEC and the equipment requirements. The below standards are for 120VAC 15 ampere and 20-ampere branch circuits. All low voltage circuits should meet the grounding requirements below.

Branch Circuit Standards		
Description	*Normal Range*	*Comments*
Line Voltage	108 – 132	Low or high voltage will harm equipment.
% Voltage Drop@ 15 Amp. Load	<5.0%	NEC Part. 210-19, FPN 4. Excessive voltage drop can cause fires. (test for 15 amp. Circuit)
% Voltage Drop@ 20 Amp. Load	<5.0%	NEC Part. 210-19, FPN 4. Excessive voltage drop can cause fires. (test for 20 amp. Circuit)
Voltage between neutral and ground	< .5 Volts	Higher voltages upset microprocessor operation. Can

		often be noise.
Phase Conductor Impedance	<.25 Ohms	IEEE recommends less than .25 Ohms from any outlet to the building entry.
Neutral Conductor	<.25 Ohms	IEEE recommends less than .25 Ohms from any outlet to the building entry.
Ground Conductor Impedance	<.25 Ohms	IEEE recommends less than .25 Ohms. Critical for proper operation of surge protection devices.

This information in Microsoft Word 97 format is availiable for download (55kb)

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~ National Lightning Safety Institute ~

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Section 5.3.1

Recommended Grounding Guidelines

Prominent lightning engineers and major technical codes and standards agree as to proper grounding guidelines. We present summaries of those generally accepted designs.

1. From *Golde, Lightning, Academic Press, NY, 1977, vol. 2, chapter 19 by H. Baatz, Stuttgart, Germany, p. 611:*

> "Equalization of potentials should be effected for all metallic installations. For lightning protection of a structure it is of greater importance than the earthing resistance...
>
> The best way for equalization of potentials utilizes a suitable earthing system in the form of a ring or foundation earth. The downconductors are bonded to such a ring earth; additional earth electrodes may be unnecessary…"

2. From *Sunde, Earth Conduction Effects in Transmission Systems, Van Nostrand, NY, 1949, p. 66:*

> "Adequate grounding generally requires that the resistance of the ground , at the frequency in question, be small compared to the impedance of the circuit in which it is connected. By this criterion, it may be permissible in some instances to have a ground of high resistance, several thousand ohms, as in the case of "electrostatic" apparatus ground, the impedance to ground of insulated apparatus cases being ordinarily quite high. In other [situations], however, a resistance of only a few ohms may be required for effective grounding."

3. From *Horvath, Computation of Lightning Protection, Research Studies Press, London, 1991, p. 20:*

> "The earthing of the lightning protection system distributes the lightning current in the soil without causing dangerous potential differences. For this purpose the most effective earthing encloses the object to be protected. The potential increases on the earthing and on all earthed metal parts of the object relative to the zero potential at a distant point. It may reach a very high value but it does not cause any danger if the potential differences inside the object to be protected are limited. Potential equalization is realized by the bonding of all extended metal objects."

4. From *Hasse, Overvoltage Protection of Low Voltage Systems, Peter Peregrinus Press, London, 1992, p. 56.*

> ''Complete lightning protection potential equalization is the fundamental basis for the realization of internal lightning protection; that is the lightning overvoltage protection for the electrical and also the electronic data transmission facilities and devices in buildings. In the event of a lightning stroke, the potential of all installations in the affected building (including live conductors in the electrical systems with arrestors) will be increased to a value equivalent to that arising in the earthing system -- no dangerous overvoltages will be generated in the system…

Nowadays lightning protection potential equalization is considered indispensable. It ensures the connection of all metal supply lines entering a building, including power and communication cables, to the lightning protection and earthing system by direct junctions across disconnection spark gaps, or arrestors in the case of live conductors."

5. From *IEEE Emerald Book, Powering and Grounding Sensitive Electronic Equipment, IEEE Std 1100-1992, IEEE, NY, 1995, p. 216:*

"It is important to ensure that low-impedance grounding and bonding connections exist among the telephone and data equipment, the ac power system's electrical safety-grounding system, and the building grounding electrode system. This recommendation is in addition to any made grounding electrodes, such as the lightning ground ring. Failure to observe any part of this grounding requirement may result in hazardous potential being developed between the telephone (data) equipment and other grounded items that personnel may be near or might simultaneously contact."

6. From *International Standard IEC 1024-1, Protection of Structures Against Lightning, International ElectroTechnical Commission, Geneva, 1991, p. 23:*

"In order to disperse the lightning current into the earth without causing dangerous overvoltages, the shape and dimensions of the earth-termination system are more important than a specific value of the resistance of the earth electrode. However, in general, a low earth resistance is recommended.

From the viewpoint of lightning protection, a single integrated structure earth termination is preferable and is suitable for all purposes (i.e. lightning protection, low voltage power systems, telecommunication systems).

Earth termination systems which must be separated for other reasons should be connected to the integrated one by equipotential bonding…"

7. From *FAA-STD-019b, Lightning Protection, Grounding, Bonding, and Shielding Requirements for Facilities, Federal Aviation Administration, Washington DC, 1990, p. 20:*

"The protection of electronic equipment against potential differences and static charge build up shall be provided by interconnecting all non-current carrying metal objects to an electronic multi-point ground system that is effectively connected to the earth electrode system."

8. From *MIL-STD-188-124B, Grounding, Bonding and Shielding, Department of Defense, Washington DC, 1992, p. 6 and p. 8:*

"The facility ground system forms a direct path of known low voltage impedance between earth and the various power and communications equipments. This effectively minimizes voltage differentials on the ground plane which exceed a value that will produce noise or interference to communications circuits." (p.6)

"The resistance to earth of the earth electrode subsystem should not exceed 10 ohms at fixed permanent facilities." (p. 8)

9. From *MIL-STD-1542B (USAF), Electromagnetic Compatibility and Grounding Requirements for Space Systems Facilities, Department of Defense, Washington DC, 1991, p. 19:*

"This Standard, MIL-HDBK-419, and MIL-STD-188-124 do not recommend the use of deep wells for the achievement of lower impedance to earth. Deep wells achieve low dc resistance, but have very small benefit in reducing ac impedance. The objective of the earth electrode subsystem is to reduce ac and dc potentials between and within equipment. If deep wells are utilized as a part of the earth electrode subsystem grounding net, the other portion of the facility ground network shall be connected to them."

10. From *National Electrical Code, NEC-70-1996, National Fire Protection Association, Quincy MA, 1996, Article 250 - Grounding, p. 120 & p. 144:*

"Systems and circuit conductors are grounded to limit voltages due to lightning, line surges, or unintentional contact with high voltage lines, and to stabilize the voltage to ground during normal operation. Equipment grounding conductors are bonded to the system grounded conductor to provide a low impedance path for fault current that will facilitate the operation of overcurrent devices under ground-fault conditions." (p. 120)

"Metal Underground Water Pipe. A metal underground water pipe in direct contact with the earth for 10 ft. (3.05 m) or more (including any metal well casing effectively bonded to the pipe) and electrically continuous (or made electrically continuous by bonding around insulating joints or sections or insulating pipe) to the points of connection of the grounding electrode conductor and the bonding conductors. Continuity of the grounding path or the bonding connection to interior piping shall not rely on water meters or filtering devices and similar equipment. A metal underground water pipe shall be supplemented by an additional electrode of a type specified in Section 250-81 or in Section 250-83. The supplemental electrode shall be permitted to be bonded to the grounding electrode conductor, the grounded service-entrance conductor, the grounded service raceway, or any grounded service enclosure." (p. 145)

11. From *MIL-HDBK-419A, Grounding, Bonding, and Shielding for Electronic Equipments and Facilities, Department of Defense, Washington DC, 1987, p. 1-2, p. 1-6, p.1-102 and p. 1-173:*

"The value of 10 ohms earth electrode resistance recommended in Section 1.2.3.1a represents a carefully considered compromise between overall fault and lightning protection requirements and the estimated relative cost of achieving the resistance in typical situations." (p. 1-2)

"At fixed C-E facilities, the earth electrode subsystem should exhibit a resistance to earth of 10 ohms or less." (p.1-6)

"All metallic pipes and tubes (and conduits) and their supports should be electrically continuous and are to be bonded to the facility ground system at least at one point." (p. 1-102)

"Water pipes and conduit should be connected to the earth electrode subsystem to prevent ground currents from entering the structure." (p. 1-173)
