NETWORK MAINTENANCE AND TROUBLESHOOTING GUIDE

FIELD-TESTED SOLUTIONS FOR EVERYDAY PROBLEMS

SECOND EDITION

FLUKE networks.

Neal Allen

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Introduction

Network Maintenance and Troubleshooting Guide: Field-Tested Solutions for Everyday Problems is not about routers or operating systems. Fluke Networks specializes in network diagnostic and monitoring tools, so the focus this book provides is on those areas, which have not been as well served by other industry publications and training. Although I have noticed that many networking professionals have either forgotten or never knew much of the material, the book presents some of the knowledge and skills that are most needed by a network technician.

Here's an example: I was fortunate enough to be allowed to help support the 1996 Olympics in Atlanta. The network engineers who deployed the network were very knowledgeable about architecture, design, and equipment configuration, but seemed oddly unaware of some of the basics. The following incident marked the beginning of my suspicion that this was a common situation.

Several of the competition venues were experiencing exceptionally high levels of MAC Layer errors. Walking onto the grounds for one of the venues I observed that network cabling around the site was carefully placed up against walls and fences to protect it from being walked on. We went into the local wiring closet and looked at the errors being reported by the network infrastructure equipment. I left the network engineer checking the configuration of the routers and other gear, looking for clues to the problem.

I walked around the venue following the cables. For at least half of the cable path, I found the network cable lying on top of a considerable sprawl of 208-volt power lines that also followed the walls and fences to where they were needed. As I walked around the field I moved the network cables as far from the power lines as I could without placing them at risk for damage. When I returned from my walk, the engineer commented something about how the error level was pretty bad when we got there, but sort of faded away while he was troubleshooting. I related how the errors pointed to AC power or other noise source as a likely cause of the errors, and what I had done.

To my great surprise, I had to explain the characteristics of each of the reported errors, and how the errors suggested the power lines as a likely cause of the problem. I since came to realize that even when people I met had vastly more knowledge about many networking topics than I, it was still possible they had little or no knowledge about the basics presented in this book. Or just as likely, they learned this information a long time ago but have since forgotten it.

In order of appearance, this book is written for the following three purposes:

- Basic networking skills training textbook
- "Triage" guide for new network technicians or managers of a small network
- Reference for networking professionals

This book is an introductory-level text, which means "make it simple." This concept of "simple" has been challenged almost every time it was made. The most difficult job in writing the book was to decide what to condense to a few often overly simplistic statements or exclude altogether. Still, many readers will find the level of complexity to be a challenge with even what little was retained as "the simple version." Reading passages multiple times has been reported as an effective method for eventually grasping most of, if not all, the content. Still, be warned that although every effort was made to ensure accuracy, it is sadly true that anything printed undoubtedly has inadvertent errors, important omissions, and superseded facts. Your challenge is to learn enough to be capable of identifying them.

Knowing where to obtain accurate information about networking topics is a critical skill. References are provided for many details within this book as a starting point for further reading because it was so hard to locate them in the first place.

Boundaries

The majority of the information about troubleshooting OSI Layers 1–3 can be generic in nature. After you cross certain boundaries, the discussion requires that a problem be fully defined before the discussion can continue. For example, application troubleshooting requires a detailed description of the exact application, installation, configuration, and usage patterns before a troubleshooting discussion can commence. Troubleshooting data flow from a PC to a server on the same broadcast domain does not. Troubleshooting data flow between a PC and a server separated by a router might require some additional details, depending on whether advanced functions are enabled (such as access control lists [ACLs], firewalls, or load balancing).

Similarly, as soon as you depart from how data traverses a routed network and enter a discussion about how the routers should be configured, you must provide a detailed description of the routing protocols used, vendor router models and versions involved, and so on before you can effectively discuss the configuration or troubleshooting of the configuration.

The topics in this book tend to stop at those boundaries. This is for the reason stated (you have to define the problem first), and also because once you reach those boundaries there are existing vendor training courses and vendor or industry certifications that cover the topics more effectively. The lack of extensive details on 802.11 wireless is perhaps the most noteworthy example of what is omitted, but very good wireless certification courses are available.

Media Standards Development

This is a politically sensitive topic because the whole issue of cabling standards development is as much driven by politics as technology, but still bears mention. Analysis of the general evolution of cabling standards suggests that the following may be true:

- The research into emerging new cable technologies is arguably pushed forward more by the Telecommunications Industry Association (TIA) than the International Organization for Standardization (ISO) because the TIA working groups meet more frequently. The Institute of Electrical and Electronics Engineers (IEEE) plays an important role, too, because the new networking implementations often drive some of the changes to cabling standards.
- Other national standards appear to leverage the information found in the TIA and ISO standards bodies' results, and then apply additional research in specific areas or apply modifications suitable for the local in-country electrical codes and requirements.

As a result of this nonscientific determination, the cabling references in this book will be largely made using TIA cabling standard references. Also, Fluke Networks is more closely involved with the TIA standards and working group documents, and subject matter experts are readily available.

Terms

One of the more confusing things about learning networking is the way terms are always changing. Compound this with the common practice of incorrectly using terms for the topic of discussion, or using correct terms to describe related areas where the term is imprecise or inaccurate. Finally, acronyms have an amazing capability to look the same, despite having completely different meanings if the entire terms are given. There are many examples of a single networking acronym having multiple uses depending on the context.

If care is taken to stay with proper terminology use, the movement of data through the OSI Model is accompanied by changes in terms as the data passes between layers. In common speech, this would be somewhat confusing, especially to someone new to networking. Understanding that terms are used very casually will greatly assist your ability to follow the conversation without becoming confused. In general discussion, try to focus on the conversation topic and less on the terms. If the situation relates to training, hold the instructor accountable to present new information using the correct terminology and ask for clarification often.

As an example, the words *frame* and *packet* are perhaps the most common terms used to describe a unit of data sent over the network. The following are listed terms taken from the standards documents used to define networking, and are thus the "correct" term used at each stage at which the unit of data travels. In a discussion, *frame* and *packet* may be used loosely to describe a unit of data, and might not be being used specifically to identify the OSI layer at which the transfer is being discussed. It is easy to imagine that changing terms during a short discussion to maintain strict accuracy would likely prove more confusing than enlightening.

Physical Layer

The term *packet* describes an 802.3 Ethernet transmission event that includes all Ethernet fields from the Preamble to the Frame Check Sequence (FCS). The Preamble and Start of Frame Delimiter (SFD) fields are timing information and are discarded later, but are included in a *packet*.

Media Access Control (MAC) Layer Within the Data Link Layer

The term *frame* describes the portion of an 802.3 Ethernet transmission event after the timing information has been discarded. The fields from the destination address to the FCS are counted, and tested for errors and against minimum and maximum size limits at the MAC Layer, and are described as a *frame*.

Logical Link Control (LLC) Layer Within the Data Link Layer

The 802.2 standard uses *protocol data unit* (PDU) to describe a transmission handled by the LLC Layer.

Network Layer

Internet Protocol (IP) (see RFC 791 for more information) uses *datagram* to describe a transmission unit handled by the Network Layer.

Transport Layer

User Datagram Protocol (UDP) (see RFC 768) uses *datagram*, whereas Transmission Control Protocol (TCP) (see RFC 793) uses *segment* to describe a transmission unit handled by the Transport Layer.

A level of imprecision also appears in relation to terminology used to describe a device connecting to the network. It is not uncommon to have more than one term used in the same sentence and intended to apply to the same device.

At the Network Layer it is common to use *host* to describe any device participating in the IP protocol. At almost any layer it is just as likely to hear *device*, *station*, or a specific functional term such as *PC*, *router*, or *switch* to describe a device participating on the network. Again, understand that it is common to use these terms somewhat interchangeably in discussion, and that unless great precision is being used, any one of these terms (or others not mentioned) simply refers to a device connected to the network.

Another set of terms used in this book relates to the job performed. Job titles carry enormous significance in some organizations and little at others. The job descriptions that follow are used in this text and are based on routine tasks and network access. Adapt them to your organization as appropriate. (See the "What Tool to Start With" section at the beginning of Appendix H for more detailed descriptions.)

Help Desk

Daily routine involves helping users with the installed applications on their computer. A small amount of basic connectivity troubleshooting may be involved but is typically limited to obtaining link state from the network. Most activities are handled by telephone and by remote access sessions. If onsite support is appropriate, it is typically limited to the user's workspace and does not carry beyond the first switch port.

Network Technician

Daily routine involves interacting with Help Desk staff to carry problem resolution beyond the first switch port. The job responsibility of a technician is the network and not the user. Technicians may have the password to switches, but typically do not have router passwords. Responsibilities are typically restricted to a site.

Network Engineer

Daily routine involves configuration and maintenance of the routed infrastructure for a region or entire enterprise network. Some assistance is provided to technicians as problem escalation support. Network engineers are also involved in architecture design and planning for network expansion.

Network Manager

Daily routine involves liaison activities with the company management, collaboration with the network engineer at conceptual level, and policy development for all network support activities. Depending on personal technical qualifications, a network manager may or may not have switch and router passwords, but does not routinely change configurations even if passwords are available.

Organization

Other than the obvious adherence to how the OSI Model is organized, it might seem odd that the first eight chapters appear as a networking tutorial and the *good stuff* about troubleshooting and observed network behavior does not appear until close to the end of this book. There is a simple reason for this: The troubleshooting information will not be as effective unless the theory is understood first.

As a simple example, the Fluke Networks support line often receives calls that go something like this:

Caller: I have one of your (insert product name), and I would like some help finding the source of a broadcast storm.

Support: Would you start by describing the symptoms your (product) is displaying that indicate a broadcast storm?

Caller: (Product) is showing 100% broadcasts on my network.

Support: And what is the network utilization?

Caller: <pause> … That's odd. There is only 0.02% utilization.

Support: Are you connected to a switch?

Caller: Yes, but why do you ask?

The next few minutes are spent explaining how bridges operate. After reading this book, it is hoped that you will see humor in that support call. There are several common networking scenarios that appear in support calls and are similar in nature to the incident described—all of which are resolved by explaining basic networking principles to the caller. They tend to fall into two categories: a lack of understanding of the basic principles, which leads to incorrect conclusions; and a lack of understanding of the normal causes of observed symptoms, which prevents formulation of a troubleshooting plan. One follows the other.

The OSI Model presents a common framework for how similar or dissimilar networks may be described and interconnected. The model further provides boundaries where certain types of information is handed off under specific conditions. This model is a critical part of learning networking, although most beginning students see it as a boring waste of time. Because the OSI Model is the roadmap for all of networking, it is presented first. Without the OSI Model, it is particularly difficult to integrate networking theory and specific product information into an internally understood flow or process that will help you do your job.

Following the OSI Model you will find what amounts to the theory of operation for cabling, Ethernet, bridging and related protocols, and so on, up to OSI Layer 4. As mentioned earlier, it is not possible to cover everything. Look on this book as an introduction to networking, which uses TCP/IP and Ethernet operating over either twisted-pair or fiber optic cable systems as the example.

The troubleshooting section (Chapters 9–11) attempts to follow the same OSI Model order, although the material in Chapter 11 is separated into several different approaches or views. Troubleshooting is largely limited to ensuring that there was end-to-end delivery across the network infrastructure. Troubleshooting of higher-layer problems (OSI Layer 5 and higher), and modifications to end-to-end delivery, such as quality of service and security, are all outside the scope of this book.

At one time or another, most experts comment that "the more I learn, the more I realize I don't know." It is hoped that when you reach the end of a section or chapter you will realize that there is a lot which was not covered. When you reach the end of a chapter you should be full of unanswered questions. Enough references are cited that you should have an idea of where begin looking for answers.

Technical Details

There is a strong presence of protocol and frame detail in this book. There are two reasons for this substantial addition to the book: Most of the protocols listed in this book are unknown to the average user, and only a few fields are known to many technicians. Having a simplified summary makes reading the standards easier.

One of the ways to learn how things work and behave is to learn how various categories of devices talk to other categories of devices on the network. If you know how the conversation or negotiation is supposed to go, and which conversations are expected between like and unlike device categories, it is a lot easier to discover what is wrong when the conversation or negotiation is not producing the desired results.

Success with protocol analysis often comes down to knowing a lot about each specific protocol, and protocol analyzers are one of the four fundamental tool groups used to support networks. As a result, a lot of basic protocol and field details are presented in this text to serve as a reference for networking professionals, as well as a source of instruction for novices. These details are carefully presented in context and by the correct OSI Layer where they appear.

In at least one place in this text the level of detail far exceeds that which an average network technician or engineer would use in the course of supporting a network. The level of detail in the Ethernet implementations section was provided because it is not commonly described anywhere else (except the hard-to-read 802.3 standard), and it helps the reader to understand why the media test standards are as stringent as they are. There is a statement immediately prior to the excessively detailed section advising the casual reader to skip much of it.

Conventions Used in This Book

This book is straightforward, with just a few conventions to watch for:

- **See references.** Throughout many sections within each chapter, you'll see cross-references to other documentation, which look like this: [See 802.1D]. If the topic is of special interest, if ambiguity remains after reading the section (much was summarized or skipped), or if detailed questions remain, the cited standard or other document represents a good place for further reading about that topic. In most cases the cited reference provides either the most appropriate starting place or the most complete description for the topic located during my research.
- Each chapter closes with the section, "Chapter Review Questions," which give you hands-on practice with the chapter's content. Here is a general legend that indicates the anticipated difficulty of each question:


Concept reinforcement. This is supposed to be extremely easy.


The concepts were presented, but you must apply them to answer this question.


Challenge question. If you understood the information presented, it *is* possible to answer this question.

Supplemental Materials

Visit this book's website at www.informit.com/title/9780321647412 for supporting materials, including supplemental charts and graphs.

CHAPTER 2
Copper Media

This chapter describes issues related to installing and testing copper physical media for use in local area networks, primarily twisted-pair cabling. The OSI Model places the medium as being below the Physical Layer (see Figure 2-1). Each individual implementation of Ethernet specifies parameters for the intended medium, but usually references other cable related standards as part of that description. This chapter and Chapter 3, “Fiber Optic Media,” are about the medium itself (copper and fiber, respectively).

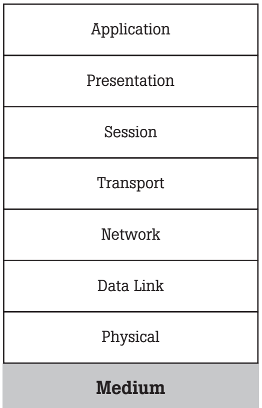


Figure 2-1. *Copper and fiber optic media in relation to the OSI Model*

Standards

Until the release of ANSI/TIA/EIA's Telecommunications Systems Bulletin 67 (TSB67), there were no standards for field testing the performance of installed twisted-pair LAN cable. All the older standards (prior to TIA/EIA-568-A TSB67, which was approved in October 1995) were designed to verify either raw cable or connecting hardware components—but did not apply to a cable assembly or an installed cable link.

Information about links in general, and information specific to twisted-pair LAN cables, is provided in the text that follows. Note that the term *link* is used to describe installed assemblies of cabling components; that is, connectors and cable.

As the networking industry matures, it is interesting to note which technologies emerge as dominant and to track which specifications and technologies are omitted. For example, one of the earlier documents that defined cable requirements for networking applications was the Underwriters Laboratories document "UL's LAN Cable Certification Program" (see Table 2-1). This document reviewed IBM's Cabling System Technical Interface Specification (GA27-3773-1) for 150 ohm cables, such as Type 1 and Type 3 cable. It also provided detailed performance requirements for the following cable types that have evolved into the current Category 3 and Category 5 cables referenced by TIA/EIA-568-A.

Table 2-1. *Early 1980s Underwriters Laboratories LAN cable grades (historical reference only)*

Cable Grade	Operating Frequency	Use
Level I	(No performance criteria found)	Telephone and power-limited circuits
Level II	Up to 1MHz	Similar to IBM Type 3
Level III	150kHz to 16MHz	Approximately the same as Category 3
Level IV	772kHz to 20MHz	Slightly better than Category 3, never widely adopted
Level V	772kHz to 100MHz	Approximately the same as Category 5

Category 3 and Category 5e are the only ones described by the 2001 release of TIA/EIA-568-B (see Table 2-2). Category 5 is explicitly described as a legacy cable specification. Depending on how cheap Category 5e becomes, and on how tenacious the low-speed protocols are (such as 10BASE-T), Category 3 is likely to disappear entirely, or may be used for technologies such as telephone and xDSL. TIA/EIA-568-B includes a statement to the effect that although 150 ohm (STP-A) cable is still mentioned, it is not recommended and is very likely to be removed from the next full release of the TIA standards entirely. An example of how cabling standards evolve is provided in Table 2-3.

Table 2-2. *ISO/IEC 11801 and TIA/EIA-568 cable grades for balanced cable as of March 2008*

ISO/IEC Cable Grade	Operating Frequency	TIA/EIA Cable Grade	Operating Frequency
Class A	Up to 100KHz	—	—
Class B	Up to 1MHz	—	—
Class C	Up to 16MHz	Category 3	Up to 16MHz
Class D	Up to 100MHz	Category 5e	Up to 100MHz
Class E	Up to 250MHz	Category 6	Up to 250MHz
Class E_A	Up to 500MHz is proposed	Category 6A	Up to 500MHz
Class F	Up to 600MHz	—	—
Class F_A	Up to 1000MHz is proposed	—	—

Table 2-3. *Evolution of high-speed twisted-pair link specifications as extracted from the obsolete TIA/EIA-568-A standard, the current TIA/EIA-568-B.2 and TIA/EIA-568-C.2 standards*

	TIA/EIA-568-A			TIA/EIA-568-B	TIA/EIA-568-C
	TSB67	TSB95	Addendum 5	TIA/EIA-568-B.2-1	TIA/EIA-568-C.2
	"Old" Cat 5	"New" Cat 5	Cat 5e	Cat 6	Cat 6A
Frequency Range	1–100MHz	1–100MHz	1–100MHz	1–250MHz	1–500MHz
Propagation Delay	Not Specified	Specified	Same as TSB95	Same as TSB95	Same as TSB95
Delay Skew	Not Specified	Specified	Same as TSB95	Same as TSB95	Same as TSB95
Attenuation	Specified	Same as Cat 5	Same as Cat 5	43 percent better	43 percent better
NEXT	Specified	Same as Cat 5	41 percent better	337 percent better	337 percent better
PS NEXT	Not Specified	Not Specified	Specified	216 percent better	216 percent better
ELFEXT	Not Specified	Specified	5 percent better	104 percent better	104 percent better
PS ELFEXT	Not Specified	Specified	Same as TSB95	95 percent better	95 percent better
Return Loss	Not Specified	Specified	26 percent better	58 percent better	58 percent better

The following list of standards is only a small part of what is available, but it represents some of the most likely standards of interest for a network support staff library.

International Standards

ISO/IEC 11801: IT—Cabling for customer premises

ISO/IEC 18010: Information technology—Pathways and spaces for customer premises cabling

ISO/IEC 14763-1: Information technology—Implementation and operation of customer premises cabling—Part 1: Administration, documentation, records

ISO/IEC 14763-2: Information technology—Implementation and operation of customer premises cabling—Part 2: Planning and Installation practices

ISO/IEC 61935-1: Testing of balanced communication cabling in accordance with ISO/IEC 11801—Part 1: Installed cabling

ISO/IEC 61935-2: Testing of balanced communication cabling in accordance with ISO/IEC 11801—Part 2: Patch cords and work area cords

United States Standards

ANSI/TIA/EIA-568-B.1: Commercial Building Telecommunications Cabling Standard

ANSI/TIA/EIA-568-B.2: 100 Ohm Twisted Pair Cabling Standard

ANSI/TIA/EIA-569-A: Commercial Building Standard for Telecommunications Pathways and Spaces

ANSI/EIA/TIA-570-A: Residential Telecommunications Cabling Standard

ANSI/TIA/EIA-606-B: Administration Standard for the Telecommunications Infrastructure of Commercial Buildings

ANSI/TIA/EIA-607-A: Commercial Building Grounding and Bonding Requirements for Telecommunications

ANSI/TIA-758-A: Customer-Owned Outside Plant Telecommunications Infrastructure

ANSI/TIA/EIA-862-A: Building Automation Systems Cabling Standard for Commercial Buildings

ANSI/TIA/EIA-942: Telecommunications Infrastructure Standard for Data Centers

ANSI/TIA-1005: Telecommunications Infrastructure Standard for Industrial Premises

ANSI/TIA/EIA-568-B, an update/replacement for ANSI/TIA/EIA-568-A (the Commercial Building Telecommunications Cabling Standard) requires better link performance by specifying much more stringent tests to support ever-faster networking demands, such as Gigabit and 10 Gigabit Ethernet (see Table 2-4). Unlike the earlier version, TIA/EIA-568-B was published in three sections. TIA/EIA-568-B was updated regularly following release.

- Part 1 (TIA/EIA-568-B.1, General Requirements) covers general requirements for planning and installing a structured cabling system. That is, everything from the configuration and requirements for the rooms that house the cable and equipment (see also ANSI/EIA/TIA-569-A), up through the electrical safety requirements (see also ANSI/TIA/EIA-607 and ANSI/TIA/EIA-758) and the actual network cable selection, installation, and testing requirements for both twisted-pair copper and fiber optic cables.
- Part 2 (TIA/EIA-568-B.2, Balanced Twisted-Pair Cabling Components) is mostly concerned with the connecting hardware and cable components used in 100 ohm twisted-pair copper cable networking applications. Several appendixes define the testing requirements for those components and for testing cable assemblies (patch cables and horizontal cabling). Updates have been released regularly, such as TIA/EIA-568-B.2-1, which was approved in June 2002 as Addendum 1 to the basic standard, and defines the performance specifications and test requirements for Category 6 cable and components. Addendum 10 defines Augmented Category 6 (Cat 6A) link performance requirements (approved February 2008).
- The TIA published Technical System Bulletin 155 (TSB-155) to define the cabling performance and field test requirements for the 10GBASE-T application as defined in IEEE standard 802.3an. Note that Category 6A demands a higher level of performance than TSB-155 in the frequency range from 250 to 500MHz and especially for "Alien Crosstalk."

The TIA/EIA-568-C standard update should be completely approved and published by Q3 2009. As with TIA/EIA-568-B, the document structure was reorganized. This text utilizes primarily TIA/EIA-568-B references and final test requirements because full approval for TIA/EIA-568-C had not occurred before the book went to press, and the requirements could still change.

- Part 0 (TIA/EIA-568-C.0) covers generic requirements for planning and installing a structured cabling system. Included are general requirements for architecture, length, grounding, bend radius, pulling tension, pin-out, and polarity. Also included are general testing requirements.
- Part 1 (TIA/EIA-568-C.1) covers requirements for cable systems in a commercial building, or between commercial buildings in a campus environment. Provides the configuration and requirements for the rooms that house the cable and equipment (see also ANSI/EIA/TIA-569-A), up through the electrical safety requirements (see also ANSI/TIA/EIA-607 and ANSI/TIA/EIA-758) and the actual network cable selection and installation requirements for both twisted-pair copper and fiber optic cables.
- Part 2 (TIA/EIA-568-C.2) covers the connecting hardware and cable components used in balanced twisted-pair cable networking applications. Provides the requirements and test specifications for components used to create an installed link, as well as the testing requirements for installed links.
- Part 3 (TIA/EIA-568-C.3) covers optical fiber topics. (See Chapter 3.)

Table 2-4. *Required test parameters for 10GBASE-T support for TIA and ISO cabling standards*

	TIA/EIA-568-B and TSB-155	ISO/IEC 11801 and TR -24750
Wiremap	M	M
DC Loop Resistance	I	M
Length	M	I
Propagation delay	M	M
Delay skew	M	M
Insertion loss	M	M
Return loss measured from both ends	M (1)	M (1)
Near-end crosstalk (NEXT) loss pair-to-pair measured from both ends	M	M (2)
Power sum near-end crosstalk loss (TIA) PSNEXT (ISO) PS NEXT calculated for both ends	MC	MC (2)
Attenuation to Crosstalk loss Ratio Near-end (TIA) ACRN, (ISO) ACR-N	NR	MC
Power Sum Attenuation to Crosstalk Loss Ratio Near-end (TIA) PS ACRN (ISO) PSACR-N	NR	MC
Attenuation to Crosstalk Loss Ratio Far-End (TIA) ACRF, (ISO) ACR-F (formerly ELFEXT) pair-to-pair	M	MC
Power Sum Attenuation to Crosstalk Loss Ratio Far-End (TIA) PSACRF (ISO) PS ACR-F (formerly PSELFEXT)	MC	MC
Alien Near-end Crosstalk (ANEXT) Loss	M	M
Power-Sum Alien Near-End Crosstalk Loss (TIA) PSANEXT (ISO) PS ANEXT	MC	MC
AFEXT loss	M	-
Power Sum Attenuation to Alien Crosstalk Ratio Far-End (TIA) PSAACRF (ISO) PS AACR-F	M	M
Average PSANEXT Loss	M	NR
Average PSAACRF	M	NR

I = Informational, M = Mandatory, MC = Mandatory (Calculated), NR = Not required by this standard

M (1) = If measured insertion loss value at the same frequency is less than 3dB, the value is not used for Pass/Fail criteria

M (2) = If measured insertion loss value at the same frequency is less than 4dB, the value is not used for Pass/Fail criteria

Note: Informational parameters are measured but not used for Pass/Fail criteria

Basic Cable Uses

It is important to know the fundamental differences between power, telephone, and LAN links. Power cables carry low-frequency signals (typically 50 or 60Hz) and are designed to minimize power loss. Standard telephone cables do not carry much power but use up to 4kHz of bandwidth. LAN cables carry high-bandwidth, low-power signals (the most widely adopted LAN protocols use bandwidths of 4MHz and higher) and are designed to allow correct decoding of signals that are transmitted over the cabling. The industry references for this type of cable are low-voltage, telco, or data communications cable, as opposed to the normal or high-voltage electrical power cables.

The actual bandwidth required by the media access standard being installed (Ethernet, Fiber Channel, and so on) determines the minimum parameters for selecting, installing, testing, and operating twisted-pair links for networking—not the raw throughput bit-rate. The existing LAN standards that carry raw throughput data rates of between 10Mbps and 1000Mbps across two or four pairs of copper conductors typically use bandwidths between 10MHz and 100MHz. Higher speed implementations may require components and workmanship that place their costs about equal to a fiber optic cable system. Although fiber has its own set of issues, it can also avoid some distance limitations, various forms of electrical interference, and other problems associated with higher speeds on copper.

Recent efforts to define ways to deliver DC power (Power over Ethernet [PoE]) across a point-to-point network cable link for operating an end station such as a wireless access point have added complexity to an already difficult topic. The cabling standards working groups are cooperating with the IEEE to discover what effect this will have in the workplace.

The primary concerns for PoE fall into two areas:

- Ensure that the power is supplied in an electrically safe way, both for the users and for the equipment.
- Monitor the installation to ensure that pushing current through closely grouped cables (loose, in cable trays, or in conduit) does not cause the temperature to rise above the working range of the cable plant (60°C or 140°F) and create a fire hazard. See TIA-TSB 184 for more details.

A single 48-port Ethernet switch with all ports supplying 15 watts would need a big UPS and would deliver a combined 720 watts to the cable plant. The cable, the switch, and the UPS will become warmer. In addition to fire hazard concerns about the cable raceways as the amount of PoE-delivered power increases, it may be necessary to install extra power circuits and air conditioning in the wiring closet.

Test Parameters

Many of the measurements are reported in decibels (dB) and are calculated by using the following formulas:

$$dB = 20 \log\left(\frac{Voltage\_Out}{Voltage\_In}\right) \text{ or } dB = 10 \log\left(\frac{Power\_Out}{Power\_In}\right)$$

The standard unit for the gain or loss of signals is the decibel (dB). When measuring cables, the voltage out is always less than the voltage in at the other end, so the results in dB for the preceding equations are negative, although the minus sign is generally left off in discussion.

Note: *The practice of using a mix of negative and unsigned numbers creates confusion but has become widespread.*

The following paragraphs provide a basic introduction to a number of important copper LAN link characteristics. Understanding this information can help ensure the proper operation of your LAN installation. Note also that some of the test parameters apply only to testing twisted-pair cable, such as Near-end Crosstalk (NEXT).

Recent cabling standards describe two groups of tests: in-channel and between-channel. The in-channel tests are all related to what takes place within a single cable jacket. The external tests relate to influences from outside that cable-under-test. The following list of test parameters is grouped along those lines, but starts with a simple grouping where frequency-based analysis is not a critical factor.

Basic Tests and Parameters Required for In-Channel Testing

These basic measurement parameters are available from a range of diagnostic and monitoring tools, primarily because they do not require much circuitry to implement.

Before qualitative frequency-based testing is possible, a link must be verified for simple pin-to-pin continuity and pairing of the wires according to a specific wiring standard. A wiremap test is used for this purpose. The specific requirements of the wiremap test are to evaluate all eight conductors (wires) in the four-pair cable for the following installation and connectivity errors. Each of the following is discussed in detail in this chapter:

- Continuity to the remote end
- Shorts between any two or more conductors
- Reversed pairs
- Split pairs

- Transposed pairs
- Any other miswiring

Wiremap

A wiremap test begins with a simple continuity test to ensure that each connector pin from one end of the link is connected to the corresponding pin at the far end, and is not connected to any other conductor or the shield. If the test signal does not reach the other end, the wire is open. If the DC voltage test signal crosses onto another wire because they are touching, it is shorted. Although this is enough for telephone and other low-frequency applications, simple continuity between pins from one end of the link to the other is not sufficient for typical networking applications.

Correct Pairing

A number of vendors and organizations have supplied their own pairing diagrams over the years, most of which are quickly fading into obscurity. The TIA/EIA-568-B standard describes two pairing diagrams intended for use with standard networking protocols T568A and T568B. The pairing schemes are electrically identical and differentiate only which pair is connected to specific pins in the 8-pin modular connections (see Figure 2-2 and Figure 2-3). Although the T568B arrangement is somewhat more widely installed, the standard identifies T568A as the preferred arrangement.

Installers are quick to learn to pair according to the wire colors marked on the jacks and punch-down blocks. Thus, mixed use of T568A and T568B components is likely to cause link faults. If a mix of components from both standard pinout arrangements is used in the same building, it is fairly certain that wiring faults will result through inattention to detail. Be sure to use the same wiring plan throughout the network.

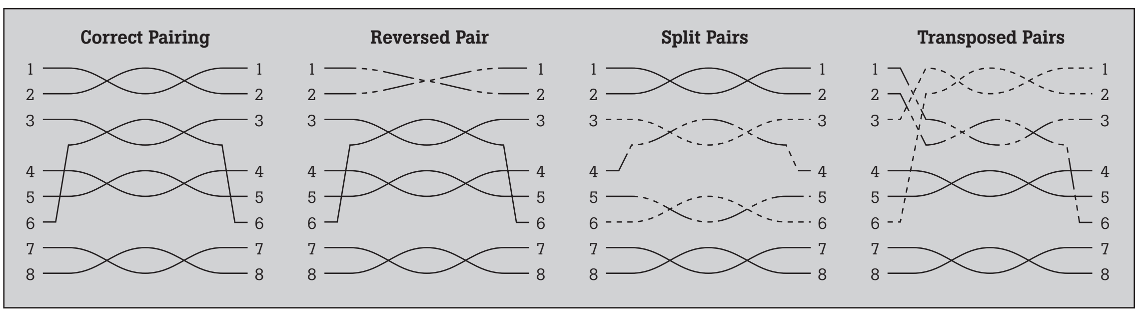
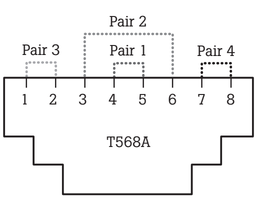


Figure 2-2. *TIA/EIA-568-B pinout for T568A*



Color Code Option 1

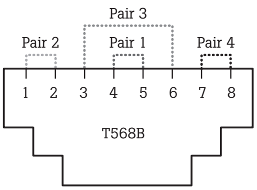
Pin	Wire Colors
1	White/Green
2	Green
3	White/Orange
4	Blue
5	White/Blue
6	Orange
7	White Brown
8	Brown

Color Code Option 2

Pin	Wire Colors
1	Blue
2	Orange
3	Black
4	Red
5	Green
6	Yellow
7	Brown
8	Slate

Figure 2-3. *TIA/EIA-568-B pinout for T568B*

Figure 2-4 shows how to count pin numbers on the 8-pin modular plug (RJ45).



Color Code Option 1		Color Code Option 2	
Pin	**Wire Colors**	**Pin**	**Wire Colors**
1	White/Orange	1	Black
2	Orange	2	Yellow
3	White/Green	3	Blue
4	Blue	4	Red
5	White/Blue	5	Green
6	Green	6	Orange
7	White Brown	7	Brown
8	Brown	8	Slate

Figure 2-4 *Position of pins in the 8-pin modular RJ45 plug*

The most common wiring faults are shown in Figure 2-5.

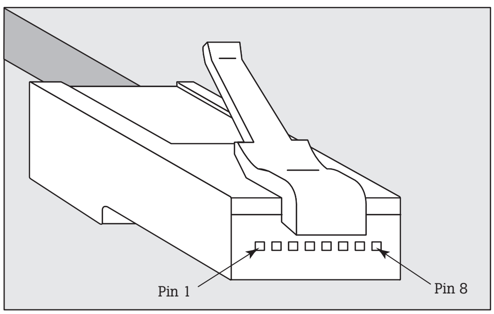


Figure 2-5 *Correct pairing and common link wiring faults*

Reversed Pairs

The reversed-pair cable fault is perhaps the simplest wiring fault. A pair reversal occurs when a twisted pair is not connected with straight-through pin-to-pin continuity. For example, if one wire of a twisted pair was connected to pin 1 at one end and pin 2 at the other, and from pin 2 to pin 1 for the second wire (see the example in Figure 2-2), then the pair is said to be reversed. As a carry-over from telephony, this is also sometimes called a *tip/ring reversal*.

Pair reversals can occur at any cable connection point, although they are most common at the RJ45 plug or jack.

Split Pairs

Using individual wires from two different twisted pairs to form a transmit or receive pair is called a *split pair*. Because the two wires are not twisted together as intended, the crosstalk cancellation effects are lost, and the two wire pairs usually begin acting as antennas to improperly hear the transmitted signal as noise on the receive pair. The effect is like a telephone circuit that is echoing whatever you say into the mouthpiece directly to the earpiece. If it is not very loud, you can sometimes continue, but if the echo gets too loud it disrupts the conversation. Although a link constructed this way exhibits correct pin-to-pin continuity, it causes errors in data transmission.

Split pairs occur most frequently from two causes: at punchdown blocks or at cable connectors, where not enough care was taken during cable installation or assembly; and from technicians not understanding the importance of the twisting of the wire pairs. The second problem is usually because the technician has taken the first twisted pair and used it for pins 1 and 2, the second twisted pair for pins 3 and 4, and so on. The result is shown in Figure 2-2, where the wires used to form a wire pair (3 and 6) come from two different twisted pairs. To someone not accustomed to building network cables, splitting apart a twisted pair to straddle the middle two pins might seem completely wrong.

Cable testers cannot literally test for a split pair using standard AC frequency-based tests. DC ohms tests by digital multimeters (DMMs) do not reveal split-pair problems either. There are several methods that cable testers use to infer that a split pair is present. One of the most common methods is to infer the presence of a split pair when the NEXT measurement fails badly. If a wire pair is split, or if a link is assembled with wire that is untwisted (such as ribbon cable or untwisted telephone cable), it will have a large NEXT problem. As a result, whenever a NEXT test fails with a significant margin, it is assumed that a split pair may exist.

Transposed Pairs

Transposed pairs occur when a twisted pair is connected to completely different pin pairs at both ends. Contrast this with a reversed pair, where the same pair of pins is used at both ends. This issue appears when color-coded punchdown blocks (for T568A and T568B) are mixed, and two different color codes are used at different locations in a single link.

Transposed pairs also commonly occur as the result of counting pin numbers from different sides of the connector or punchdown block at either end of the cable. This results in pin 1 connecting to pin 8, pin 2 to pin 7, and so on.

The cable shown in Figure 2-2 is transposed, but in a special way. When two Ethernet hubs or switches are connected together in series (cascading them), the transmit and receive pairs must be transposed; otherwise, receive is listening to receive and transmit is talking to transmit. This special cable is often called a *crossover cable*, and in this specific instance, the transposition is done on purpose. Note: Gigabit Ethernet requires that the interface be capable of correcting for transposed pairs, so use of this cable type might not be evident.

Propagation Delay

An electrical signal travels at uniform speed along a wire. The parameter used to describe this property is called the Nominal Velocity of Propagation (NVP). NVP expresses the speed at which a signal travels through a cable relative to the speed of light, and is expressed as a percentage. The actual speed of the electrical signal in a LAN cable is between 60 percent and 80 percent of the speed of light in a vacuum, or roughly 20cm (eight inches) per nanosecond. Signal speed is mainly affected by the composition of the cable insulation material (its relative permittivity).

Propagation delay is a simple measurement of how long it takes for the signal to travel down the cable being tested. This is measured on a per-pair basis on twisted-pair cable because of the physical difference in pair lengths caused by the different twist rates per pair in the cable.

Length (TDR)

Propagation delay measurements are the basis of the length measurement. TIA/EIA-568-B.1 specifies in paragraph 11.2.4.3.1 that the physical length of the link shall be calculated using the pair with the shortest electrical delay. Although the cable jacket may have length markings, testers usually measure the length of the wire based on the electrical delay as measured by the TDR function. The length of individual wire pairs inside a link may all be different, and may appear to be slightly longer than the measured length of the link being tested. This apparent discrepancy results primarily from different twist rates applied to the wire pairs within the cable, which changes the overall physical length of each pair, and thus the amount of delay measured. Another reason is that wire pairs may have different insulation material, which affects the velocity of the signal on that wire pair.

The Time Domain Reflectometry (TDR) test is used not only to determine length, but also to identify the distance to link faults such as shorts and opens. Other techniques for cable length measurement, such as capacitance and DC resistance, are unable to report the distance to a short or open.

When a cable tester makes a TDR measurement, it sends a pulse signal into a wire pair and measures the amount of time required for the pulse to return on the same wire pair. When the pulse encounters a variation in impedance, such as an open, short, or poor connection, some portion of the pulse energy is reflected back to the tester. The tester measures the elapsed time between when the pulse was sent and when the reflection was received. In addition to the comparatively large echo or reflection from the end of the cable (open circuit), smaller echoes may be detected that represent impedance changes in the link due to other forms of poor connections or defects in the cable.

The size of the reflected pulse is proportional to the change in impedance. Thus, a large change in impedance, such as a short, causes a large reflection; a small impedance change, such as a poor connection, creates a smaller reflection.

If a returning echo is larger than a threshold setting (the default is typically about 15 percent of the transmitted pulse), it displays the calculated distance to the echo source. These small echoes are called *anomalies* and are caused by cable faults of varying severity. Most testers display more than one distance: the distance to the end of the link as well as one or two anomalies along the way. Some of the faults that cause an echo reflection include poor connections, mixed-impedance cable segments, cable stubs, crushed cable, and severe kinks or over-tight tie-wraps. Cable test tools with high sensitivity are able to show a TDR plot that allows the user to see all anomalies along the length of the link.

Length measurements depend directly on knowing the NVP of the link under test. Most cable tester configuration screens enable users to choose from a range of cable types. For the length measurement, the primary purpose of choosing the cable type is to tell the tester what the approximate NVP value is for the cable being tested. For maintenance testing, you could leave the selection set at any cable type of the same impedance value as the cables you were testing all the time—providing you understood that the length measurement was not going to be precise. It is usually sufficient to learn that the problem is "a third of the way back from the end." With that information, you then look for a connection point (punch-down block, wall jack, etc.) in that general area. Almost all problems are found either at known connection points or in the user's workspace.

The choices for cable types are prepared using NVP values obtained from published specifications for each cable manufacturer and from worst-case values published in the standards. The variation in NVP from lot-to-lot of the same cable type from a specific manufacturer can be 5 percent or more, and may reach 10 percent between different manufacturers. Therefore, if length accuracy is critical to your situation, you must determine the true NVP of each cable batch installed in your network. Verify the tester's length measurement by testing a known-length sample of the same cable you will be installing or testing that is longer than 15 meters (50 feet). All cable analysis tools have a "calibrate" function that allows you to adjust the NVP value to match this cable sample. Very simple testers with a "length" function may not.

Delay Skew

Delay skew is calculated as the difference between the propagation delay for each of the four wire pairs. The fastest propagation delay among the four measurements is used as one extreme, and the slowest propagation delay measured is the other extreme. The difference between the two measurements becomes the delay skew. EIA/TIA-568-B permits no more than 44ns of delay skew between the fastest and slowest pairs in the cable for the Permanent Link configuration, and 50ns for the Channel Link. The high-throughput network applications such as 1000BASE-T and 10GBASE-T are most sensitive to delay skew; they also permit no more than 50ns of delay skew.

Some newer high-speed network implementations, such as 1000BASE-T, achieve very high data rates by simultaneously transmitting data on all the wire pairs of a four-pair cabling link. The encoded signal is sent simultaneously in four parts, one part on each wire pair, and all four parts must be received very close to the same time to be interpreted correctly.

One of the reasons delay skew was first included in several testing standards is because some Category 5 cables were constructed with different insulating materials around the copper conductors. This construction is referred to as *heterogeneous*. Homogeneous cable construction requires that all wire pairs be constructed with one and the same kind of insulating material. The insulating material has a significant influence on the NVP of the cable. There are two (then) relatively common instances of heterogeneous cables: the 2+2 cable and the 3+1 cable. In these cables the wires in two or three pairs are insulated using Teflon FEP, whereas the wires in the other pairs are insulated using a polyethylene compound. This heterogeneous construction method was used to meet the demand for category cable in view of a Teflon shortage that plagued the industry for a few years following a fire in a Teflon plant in 1995. The Teflon FEP insulated wire pairs exhibit the typical Category 5 NVP value of 69 percent, whereas the other pairs transmit the signals somewhat slower and have an NVP value that is several points lower (65 percent or 66 percent). Those 2+2 or 3+1 cables are unable to support technologies such as 1000BASE-T due to very poor delay skew performance.

Delay skew is a critical measure for 1000BASE-T, 10GBASE-T, and any other implementation where multiple pairs are used to transmit simultaneously in the same direction. The receiver

PHY must realign the received bits so that despite receiving the first data from one data unit transmission on one wire pair several time-slots away from the last data from the same data transmission on another wire pair, the whole transmission is reassembled and delivered to the next higher layer as if it were received at the same time.

Basic Frequency-Based Test Parameters Related to In-Channel Testing

The following test parameters depend largely on the frequencies used to perform the measurement. As a direct consequence of this dependence, the appropriate standards specify the maximum allowed frequency step rate or separation between tested frequencies. These tests require a substantial amount of very sensitive circuitry, and are thus rarely found in network diagnostic and monitoring equipment because of the additional bulk that would be required. Advanced cable analysis tools are usually separate testers, and are used only to test cable. Most such cable analysis tools consist of two identical test units—one bearing a display and the other nearly faceless. Both units offer the same full test and measurement capabilities and are placed at either end of the link being tested.

Attenuation

Attenuation is signal loss or the decrease in signal amplitude over the length of a link (see Figure 2-6). The longer the cable and the higher the signal's frequency, the greater the attenuation or loss is. Therefore, be sure to measure attenuation using the highest frequencies that the cable is rated to support.

Attenuation needs to be measured only from one direction on the link (on all pairs) because attenuation of a specific wire pair is the same when measured in opposite directions.

In Figure 2-7, the signal amplitude decreases with distance to represent signal loss through attenuation and the related measurement of insertion loss.

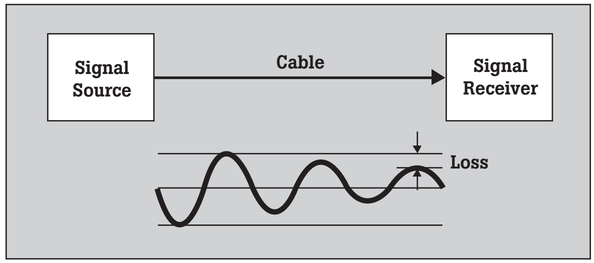


Figure 2-6. *Attenuation loss*

Attenuation is caused by a loss of electrical energy due to the resistance of the wire (converting the energy to heat), and when energy leaks through the cable's insulating material. This loss of energy (attenuation or insertion loss) is expressed in decibels (dB). Lower attenuation values are an indication of better link performance. For example, when comparing the performance of two links at a particular frequency, a link with an attenuation of 10dB (a factor of 3.16) performs better than a link with an attenuation of 20dB (a factor of 10). Link attenuation is determined by the cable's construction, length, and the frequencies of the signals sent through the link. In the 1 to 100MHz frequency range, the attenuation is dominated by the skin effect and is proportional to the square root of frequency. That is, the higher the frequency, the greater the attenuation.

Insertion Loss

The preceding discussion about attenuation assumes that the connection to the test instrument or end-user equipment and all intermediate connections in the link have a perfect impedance match. Because there is no such thing as a

Figure 2-7. *Attenuation (and the related measurement of insertion loss) results from the resistance of the transmission medium to the transmitted signal*

perfect connection, it is necessary to look at the severity of impedance discontinuities as they relate to the frequency ranges used in a local area network. Simple attenuation tends to be linear along the cable. The more cable you have, the greater the expected attenuation and that attenuation can be fairly accurately predicted because it is linear. At speeds covered by Category 5e cable (1 to 100MHz), the impedance discontinuities that result from good cable junctions have a nearly insignificant effect, and can be included in a simple attenuation measurement that ignores their contribution. At the speeds supported by Category 6 cable (1 to 250MHz), clear evidence emerges showing that these effects can be much more pronounced, and that their effect can easily reduce the performance of the link by 4 to 6dB (see Figure 2-8). Thus, TIA/EIA-568-B has changed the test parameter name from attenuation to insertion loss to include the effect of these reflections, which are separately measured as *return loss*.

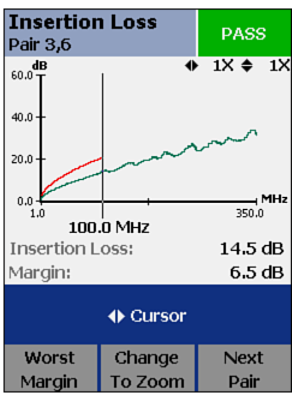


Figure 2-8. *DTX-1800 insertion loss test results example. The top line that extends only to 100MHz is the test results limit line for this Category 5e test. The irregular line below the limit line is the measured test result.*

In Figure 2-8, the top curved line is the test limit for Category 5e, and does not extend beyond 100MHz because that is the highest frequency specified for Category 5e. The wavy line below it is the current test result. The vertical line at 100MHz is the cursor, which shows the current measurement result of 14.5dB at 100MHz (a margin of 6.5 dB better performance than the test limit at that frequency). Test results for frequencies above 100MHz begin showing the echo effects of impedance discontinuities in the form of varying (nonlinear) test results—the wave in the line.

An impedance discontinuity on a link causes a reduction in the signal strength due to part of the energy being reflected. At the first discontinuity, a portion of the signal is reflected back toward the transmitter. The effect is compounded at the second (and each subsequent) discontinuity where an additional portion of the remaining signal is reflected backward, but part of the reflection is also reflected forward again by the first discontinuity. Multiple echo effects are created. By the time a signal has passed through several discontinuities, there is a clear drop in signal strength, and there is a growing set of echoes that both follow the original outbound signal and return to the transmission source.

The effects of the echoes are twofold. First, the effective cable length of the link is reduced because some percentage of the signal did not reach the end. The signal is not loud enough to be heard as far away as before. Second, because of echoes the receiver begins having difficulties properly sampling and decoding the signal, which results in corrupted data, and in turn results in more errors occurring on the network. This sampling or misclocking problem is called *jitter*. If you are curious about how much signal is reflected at a single impedance discontinuity try the following formula. Z is the symbol for impedance. The example shows the effect of connecting a 50 ohm and 75 ohm coaxial cable together, in that order (signal source, 50 ohm cable, 75 ohm cable). Twenty percent of the signal is reflected back toward the signal source at the junction of the two cables in the example. This is obviously an extreme example of an impedance discontinuity, but the problem is the same with large or small reflections on coax and twisted pair.

$$\left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right) = \left(\frac{75 - 50}{75 + 50}\right) = \left(\frac{25}{125}\right) = 20\%$$

As mentioned, this conspicuous behavior change at higher frequencies caused TIA/EIA-568-B to stop describing this as an attenuation test and is now calling it an insertion loss test. The only real difference between the two measurements is that insertion loss acknowledges the presence of jitter and its causes.

TIA/EIA-568-B defines the formulas to calculate the allowable insertion loss for an installed twisted-pair link for both link configurations the *permanent link* (formerly the basic link) and the *channel*. In addition, TIA/EIA-568-B shows a table of allowable values for these links. The allowable values of attenuation apply to an environment at 20°C. Attenuation increases as temperature increases: typically 1.5 percent per degree Celsius for Category 3 links, 0.4 percent per degree Celsius for Category 5e links, 0.4 percent per degree Celsius from 20°C to 40°C, and 0.6 percent from 40°C to 60°C for solid conductor Category 6 links, and so on. The network technician should remember to take temperature into consideration for both installation and testing purposes. TIA/EIA-568-B specifically permits adjustment of allowable attenuation for temperature. If the intended use environment is likely to be hotter than 60°C (140°F), another type of cable should be considered.

Cable analyzers may report the worst case attenuation test result value and the frequency at which it was measured. The testers are required to use attenuation results greater than 3dB only for Pass/Fail purposes.

Return Loss

Return loss is a measure of reflections caused by the impedance changes at all locations along the link and is measured in decibels (dB). Mismatches predominantly occur at locations where connectors are present, but they can also occur in cable where variations in characteristic impedance along the length of the cable are present.

The main impact of return loss is not on loss of signal strength (there is some, but generally it is not that much of a problem), but rather the introduction of signal jitter. An example of jitter was shown in Figure 2-8, where these reflections caused a visible impact on the attenuation measurement at higher frequencies. Attenuation tends to be linear (smooth line) along a cable. The measurement in Figure 2-8 shows how the echoes arrived at the receiver of the tester in phase with some frequencies and out of phase with others, resulting in a wavy line. Figure 2-9 shows possible sources of return loss along a cable link.

A simplified description of this type of jitter is that the edge of a signal representing a data bit is shifted slightly in time, such that when the receiver circuit samples the signal it incorrectly classifies the signal as either a binary 1 or 0 when it should have been the other value (see Figure 2-10). This jitter can vary the leading edge of the signal presented to the decoder in the receiver, or add to or subtract from the signal amplitude, and thereby cause decoding errors. The closer to a perfect match of characteristic impedance of the cabling to the output impedance of the transmitter, and to the input impedance of the receiver, the better the return loss measurement will be. A lab test called the "eye-pattern" is typically used to evaluate the degree of jitter present in a network, and the corresponding loss of signal strength (the amount of energy that fails to transfer from the signal source to the receiver due to impedance mismatches).

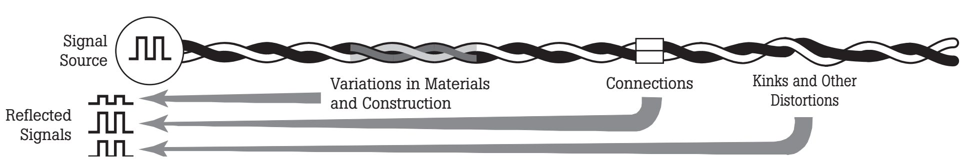


Figure 2-9. *Sources of return loss*

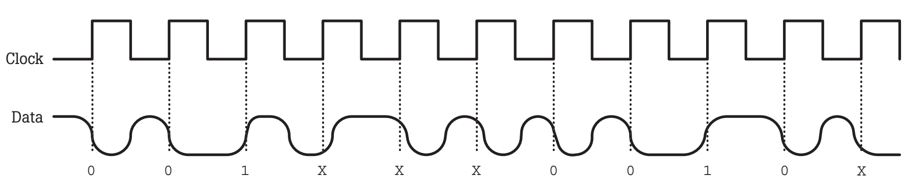


Figure 2-10. *Simplified illustration of sampling problems due to signal jitter*

Figure 2-10 assumes that the encoding scheme is edge sensitive. When the data signal becomes misaligned with reference to the clock, sampling errors take place. In the example, probable sampling errors are shown with an X in place of the binary value.

The return loss measurement varies significantly with frequency. Any variation in characteristic impedance of the cabling is one source of return loss. Another source is reflections from inside the link, mainly from connectors.

Figure 2-11 shows a typical return loss test result from a cable analyzer where the bottom curve is the limit for return loss, ending at 250MHz because Category 6 was selected for the test, and the irregular top line is the measured result for this test. The cursor is positioned at the frequency where the worst-case margin was detected. When a reported margin is positive, it indicates that the worst-case return loss is better than the limit (passed), whereas a negative margin indicates that the result exceeds the limit (failed). The cable analyzer also shows the wire pair and frequency where the worst-case return loss margin was measured.

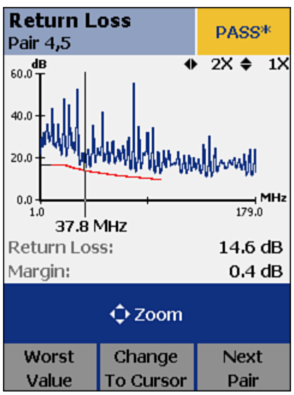


Figure 2-11. *Fluke Networks DTX-1800 return loss test results. The flat line below the irregular test result is the limit line for passing this test.*

Near-End Crosstalk (NEXT)

When it comes to overall twisted-pair link operation, crosstalk has the greatest effect on link performance. Crosstalk is the undesirable signal transmission from one wire pair to another nearby pair (see Figure 2-12). Unwanted crosstalk signals generally result from capacitive and inductive coupling between adjacent pairs. Crosstalk increases at higher frequencies and is very destructive to data signaling. Most low-speed LAN protocols need two pairs of twisted-pair cable, one pair for each direction of traffic. Higher-speed LAN protocols typically need multiple pairs, and typically operate simultaneously in both directions on each twisted pair.

Test devices measure crosstalk by applying a test signal to one wire pair and measuring the amplitude of the crosstalk signals received by other wire pairs. Near-end crosstalk (NEXT) is computed as the ratio in amplitude (in volts) between the test signal transmitted and the crosstalk signal received when measured from the same end of the link. This ratio is generally expressed in decibels (dB). Higher NEXT values (smaller received crosstalk signals) correspond to less crosstalk and better link performance. The NEXT test is also the most common method used to infer the presence of split pairs in twisted-pair links.

Although crosstalk is a critical performance factor for twisted-pair links, it is also difficult to measure accurately, especially at lower frequencies where many of the common LAN protocols operate. TIA/EIA-568-B specifies that NEXT must be measured at increments or intervals not greater than the maximum frequency step size increments shown in Table 2-5. For improved accuracy, a smaller step size is better, although this may take longer to measure. A Category 3 link needs to be tested to 16 MHz and a Category 5e link to 100MHz, because those are their maximum frequency ratings.

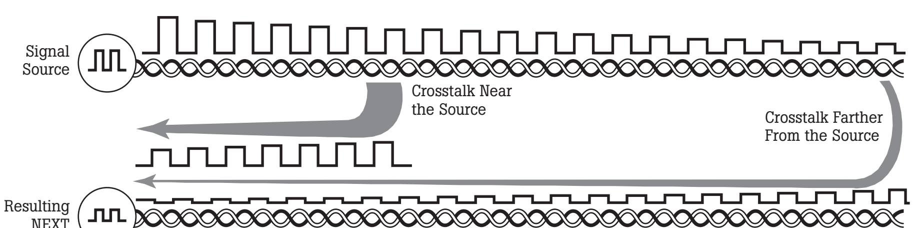


Figure 2-12. *Crosstalk is a measure of how much of the transmitted signal "leaks" onto an adjacent wire pair*

NEXT loss must be measured from every pair to every other pair in a twisted-pair link, and from both ends of the link. This equates to 12 pair combinations for the typical four-pair cabling link. To shorten test times, some older field testers allowed the user to test the NEXT performance of a link by using larger frequency step sizes. The resulting distance between measurements does not comply with TIA/EIA-568-B, and may overlook link crosstalk faults.

Table 2-5. *Maximum frequency step sizes allowed for compliance with TIA/EIA-568-B*

Frequency Range	Maximum Allowed Step Size
1 to 31.25MHz	150kHz (or 0.15MHz)
31.25 to 100MHz	250kHz (or 0.25MHz)
100 to 250MHz	500kHz (or 0.5MHz)
250 to 500MHz	1MHz

All signals transmitted through a link are affected by attenuation. The farther the signal travels, the smaller it becomes. Because of attenuation, crosstalk occurring farther down the link contributes less to NEXT than crosstalk occurring at the near end of the link (refer to Figure 2-12). If the signal that is crossing to another pair is smaller, the amount that is available to cross is correspondingly smaller too. Furthermore, the coupled signal still has to travel back to the source end and is further attenuated as it returns. Thus, near-end crosstalk is worse closest to a transmission source where the signal is the largest (greatest amplitude) and the attenuation in the return path is the shortest. To verify proper link performance, you should measure NEXT from both ends of the link; this is also a requirement for complete compliance with all the high-speed cable specifications.

Crosstalk can be minimized by twisting wire pairs more, so that the signal coupling is "evened out." Twisted-pair wiring for LANs have more twists per unit length than telephone wiring. LANs use TIA/EIA Category 3 or better cable. Telephone wiring is typically comparable to the old UL Level 1 (see Table 2-1), and might not seem to be twisted at all. The higher the category, the more twists per unit length in the cable are necessary, and the higher the frequency rating will be. To ensure reliable LAN communications, cable pairs must not be left untwisted even for short distances. For this same reason, cables with parallel conductors (ribbon type or "silver satin" type cables) should never be used in LAN applications.

Signals from twisted-pair wiring may "leak" to the outside world and to other adjacent cables. The principle behind balanced twisted-pair cables is that, at every location along the cable, the voltage in one wire of a wire pair is equal in amplitude but opposite in phase to the voltage in the other wire of the wire pair. In addition to some other undesirable side effects, imbalance creates the effect of an antenna and receives external signals—thereby disrupting data with electromagnetic interference (EMI) and radio frequency interference (RFI). Substantial improvements have recently been made to cabling components—connectors in particular—which has had a positive impact because the majority of link problems occur at connectors, and the new connectors reduce these effects. To minimize the antenna effect, shielding the cable is a possible solution. When shielded cabling is used, however, a new set of potential problems is introduced, such as ground loops due to differences in the ground (earth) potential at opposite ends of the link. The ground-loop problem is often more serious than the EMI/RFI problem.

Generally, the problem of NEXT is worse in shielded cabling. The reason for this is that crimping the plugs to the shield of the cable enhances capacitive imbalance, one of the sources of NEXT. Also, shielded twisted-pair wiring is harder to install correctly, making it more prone to this sort of problem. Shielded twisted-pair cable comes in two basic types: 1) shielded twisted pair (STP), which has a foil shield around each individual pair and another shield around the four pairs, and 2) foil-screened twisted pair (FTP) or screened twisted pair (ScTP), which has a shield around the outside of the group of four pairs only, and is usually 100 ohm cabling. Some legacy cables could be either 120 ohm or 150 ohm cabling. With the advent of the 10GBASE-T application and the concerns over alien crosstalk, many manufacturers are promoting shielded or screened cable types. New terminology has been introduced to emphasize the cabling construction. The name F/UTP has been introduced to designate the foil around the four unshielded wire pairs. Proper grounding procedures must be followed when using these cable types. Screened cable types have been widely used in Europe because of strict laws intended to limit EMI/RFI emissions. As a side effect, they reduce external noise from interfering with the signals on the link. If proper balance is maintained, however, UTP cabling can provide EMI/RFI performance levels that also satisfy the European requirements.

Figure 2-13 shows typical NEXT test results. In both figures, the bottom curve is the TSB67 limit for NEXT and the top lines are the results for this test. When a reported margin is positive, this indicates that the worst-case NEXT is better than the limit, whereas a negative margin indicates that the results are worse than the limit. The cursor is positioned at the frequency where the worst-case margin was detected. The irregular shape of the top curve demonstrates that unless NEXT is measured at many points along the frequency range, low points (points of worse NEXT loss) could easily go undetected. Therefore, TIA/EIA-568-B defines a maximum frequency step size for NEXT measurements, as shown in Table 2-5.

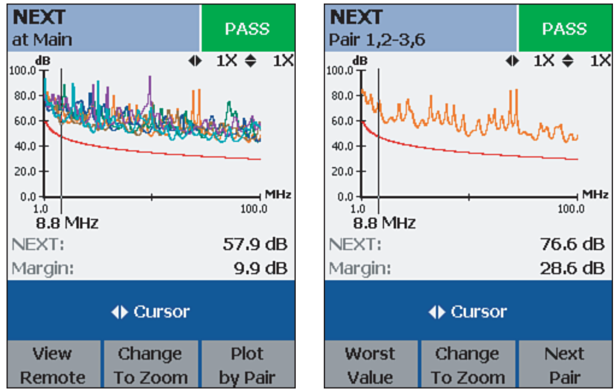


Figure 2-13. *Fluke DTX-1800 Near-end Crosstalk (NEXT) test results example. The left example shows the results for all pair combinations together. The right example shows only one pair combination. Each pair combination may be viewed separately. The cursor is at 8.8MHz, where the worst NEXT test result (smallest margin) was found.*

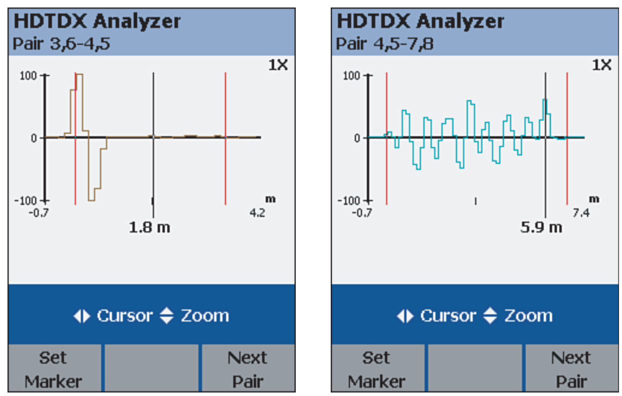


Figure 2-14. *Fluke DTX-1800 HDTDX test result. Left screen shows connector problem, right screen shows poor quality cable. The test was made with the Permanent Link test adapter, so the cable under test begins 0.7m from the tester as indicated by the vertical red lines.*

If a NEXT failure is detected, it is possible to use other tests to pinpoint where along the length of the link the failure is occurring. One such test is called Time Domain Crosstalk (TDX), which is displayed in the same graphic format as a Time-Domain Reflectometry (TDR) test. The difference between TDR and TDX is that, in the case of a TDR, the signal is applied at one wire pair and the reflections are measured on the same wire pair. TDR reflections occur because of impedance anomalies. TDX applies a signal to one wire pair and measures the coupled signal on an adjacent wire pair.

Figure 2-14 shows two typical high-definition TDX test results. The vertical measurement spikes represent sources and magnitude of crosstalk. The vertical red lines are positioned at locations where the tester has determined the cable-under-test ends to be, and distance is shown at the bottom of the graph accordingly. The black vertical line is the user moveable cursor used to determine distance from the local tester end. The left graphic shows the point-source impact of a bad connection, either due to poor workmanship or poor connecting hardware. The right graphic shows crosstalk all along the cable-under test, which indicates that the cable itself is not good quality.

Attenuation-to-Crosstalk Ratio (ACR or ACRN)

ACR is calculated in an attempt to answer the question: While a transmission is taking place,

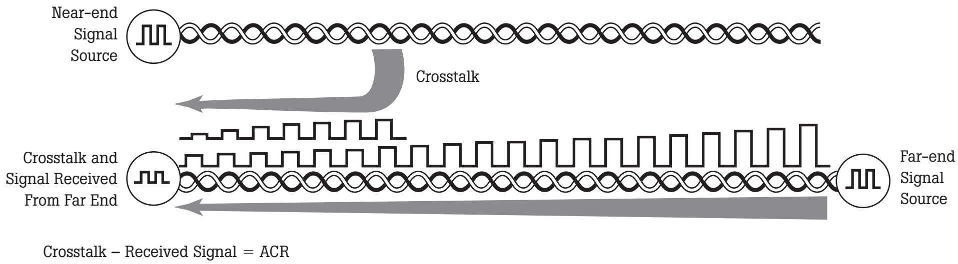
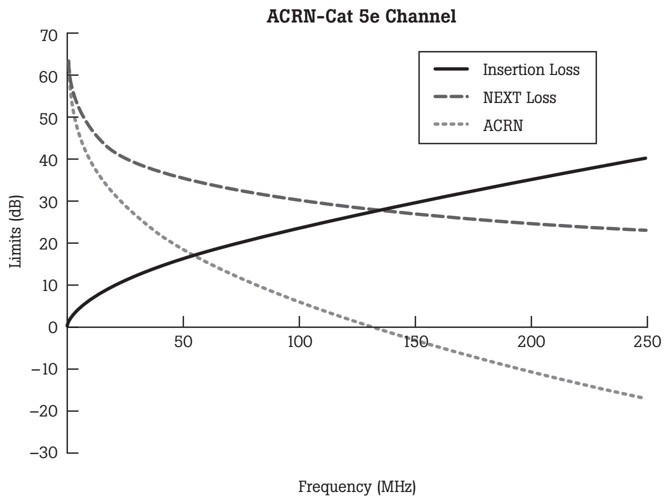


Figure 2-15. *ACR is calculated from attenuation and NEXT measurements*

how much does the noise from crosstalk disrupt the (attenuated) signal I am listening to? (See Figure 2-15.) ACR has been renamed ACRN (to indicate near-end crosstalk) in TIA/EIA-568-B.2-10 (the Augmented Category 6 standard), and is named ACR-N in the ISO 11801 standard.

The attenuation-to-crosstalk ratio affects the bit-error rate (BER) directly and thereby the need for retransmissions. The noise consists of both externally induced noise and self-induced noise (which is NEXT). Self-induced noise usually dominates externally induced noise. The ACR is the same as the signal-to-noise ratio measurement when you deem that external noise is insignificant. The two factors considered in the calculation are NEXT and attenuation, as indicated in the name of the parameter. When insertion loss and NEXT loss measurements are expressed in dB, you can subtract the NEXT loss measurement from the insertion loss measurement to obtain the ratio. The closer the ACR result comes to zero dB, the less likely your link is going to work (see Figure 2-16).

In Figure 2-16, the top graph is based on limit value calculations for a 100-meter Category 5e "channel" configuration specified in TIA/EIA-568-B.2, and the bottom graph shows the same calculation for Category 6 as specified in TIA/EIA-568-B.2-1. Category 5e and Category 6 only offer verified performance calculation formulas out to 100MHz and 250MHz, respectively. The formulas in the standard should not be extended beyond the specified frequency values. However, for the purpose of illustration the graph for Category 5e in Figure 2-18 has been extended beyond 100MHz using the Category 5e formulas. The graphs show calculated worst-case limits and plot three values: NEXT Loss, Insertion Loss (attenuation) and the derived ACR.



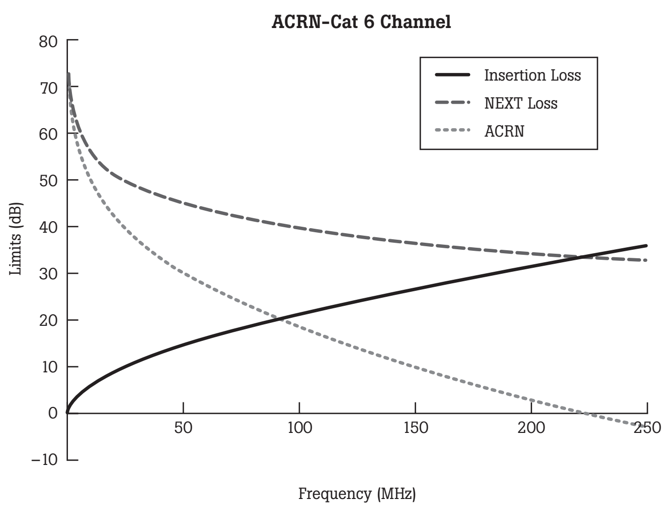


Figure 2-16. *ACRN Category 5e (TIA-568-B.2) and Category 6 (TIA-568-B.2-1) conformance*

The limit for the ACRN value can also be viewed as the difference between the Insertion Loss and NEXT Loss limit lines in Figure 2-18.

In Figure 2-16, at the point where the plot lines for Insertion Loss and NEXT Loss intersect, the desired data signal will be exactly equal to the amount of noise contributed by NEXT at this frequency and the ACR limit value crosses the zero mark. Notice that the crosstalk will begin to be louder than the data signal at around 132MHz for Category 5e, and 226MHz for Category 6. To transfer data reliably, links used in LAN applications typically must perform at least 6dB better than the noise floor. For Category 6, the IEEE asked the TIA to extend the specification beyond the point where ACRN = 0 because of noise cancellation and error correction techniques it intended to apply to the appropriate Ethernet implementation.

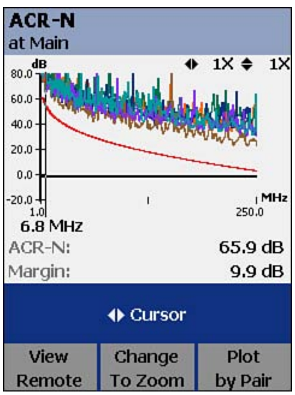


Figure 2-17. *DTX-1800 Category 6 ACRN test results example. The curve below the test results is the limit line for ACRN and extends to 250MHz as specified for Category 6.*

This test is important for technologies such as 10BASE-T and 100BASE-TX, where only one pair is used in each direction. It does not mean as much for technologies that operate in parallel, such as 1000BASE-T, where power sum measurements are far more important.

In Figure 2-17, the bottom curved line is the Category 6 limit for NEXT, and the irregular stacked test results lines above are the per-pair results for this test. The cursor is positioned at the frequency where the worst-case margin was detected. When a reported margin is positive, this indicates that the worst-case ACRN is better than the limit, whereas a negative margin indicates that the result falls below the limit and the test fails. The cable analyzer permits results to be viewed for each cable pair combination separately.

Signal-to-Noise Ratio (SNR)

The signal-to-noise ratio is the combination of all disturbances generated within a cabling link plus the noise that penetrates the cable from external sources compared to the attenuated signal that transmits the information (see Figure 2-18). The internal disturbances that affect a wire pair within a cabling link consist of PSNEXT and PSACRF (both described later) contributed from the other three wire pairs in the cabling and return loss on the pair of interest. PSACRN and PSACRF calculate only a portion of the combined disturbance. No single test parameter has been defined that represents the true internal portion of the signal-to-noise ratio. With the advent of 10GBASE-T, the noise coupling from adjacent cabling links must be added to the SNR budget of every cabling link.

An example of external noise might include the residual noise floor of the measuring instrument itself (for example, when you turn the volume on your music player equipment up very loud but don't press play—the hissing, crackly noise you hear is noise from the circuits themselves). The only problem with this measurement is being certain that you have included all the possible noise sources.

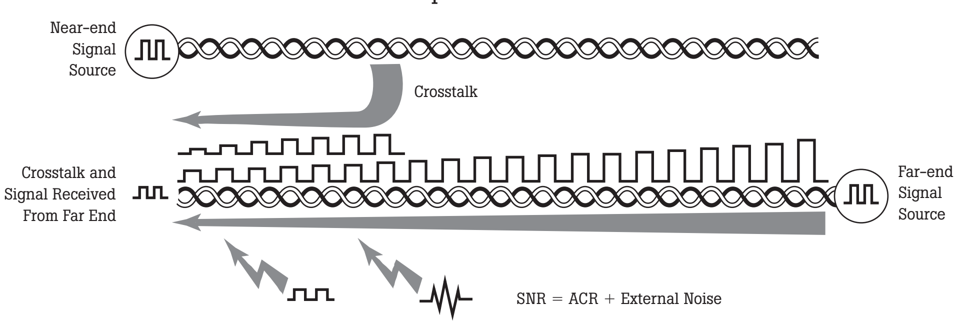


Figure 2-18. *SNR is the same as ACRN plus external noise influences*

Advanced Frequency-Based Test Parameters Related to In-Channel and External Testing

The preceding test parameters were satisfactory for Ethernet implementations up through Fast Ethernet, as they were largely limited to low speed signaling (comparatively speaking) and the use of a single pair for transmit in each direction.

The parameters shown in Table 2-6 became necessary with the introduction of Gigabit Ethernet and higher signaling implementations. In these schemes, there are multiple pairs transmitting simultaneously in each direction, and therefore the effects of signals crossing over from adjacent wire pairs or from adjacent cables becomes significant.

More of the complex measurements are calculated rather than measured, unlike most of the simpler measurements previously described.

Table 2-6. *Measured and calculated test parameters*

Measured Test Parameter	Calculated Test Parameter
Propagation Delay, Length	Delay Skew
Insertion Loss	
NEXT (pair-to-pair)	PSNEXT, ACRN, PSACRN
ANEXT, AFEXT (pair-to-pair)	
FEXT (pair-to-pair)	ACRF (ELFEXT), PSACRF
Return Loss	

Far-End Crosstalk (FEXT)

The other kind of crosstalk is *Far-End Crosstalk* (FEXT). In this case, the signal coupled into the disturbed wire pair travels to the end of the link opposite the transmission source. In Figure 2-19, observe that any FEXT travels the same distance on an adjacent pair as the transmitted signal on the original pair. All crosstalk occurring as FEXT is subject to an amount of attenuation equal to the attenuation of the link, because it always travels the full distance of the link.

Compare this with NEXT, which as discussed previously is attenuated in direct relation to the distance traveled to the point of coupling. The transmitted signal is attenuated on its way to the far end, and at any point that a portion of the signal crosses to an adjacent pair it must travel (and be attenuated) an equal distance before it arrives back at the source end.

The FEXT measurement compares the original signal to the signal coupled in an adjacent wire pair and arriving at the far end. NEXT is mostly a result of capacitive coupling along the cable, while FEXT is mostly the result of inductive coupling at connectors. For implementations that transmit on one pair in each direction, such as 10BASE-T and 100BASE-TX, FEXT is largely irrelevant. However, for technologies such as 1000BASE-T that transmit on multiple pairs in the same direction, FEXT is a very important property to test. FEXT represents another disturbance for a receiver. Consider the receiver at the right side of the bottom wire pair in Figure 2-19. This receiver is also affected by the NEXT from transmissions on the adjacent wire pair from right to left.

Because of attenuation, FEXT on longer cables is less than FEXT on shorter cables of the same type.

Attenuation to Crosstalk Ratio Far-End (ACRF)

Attenuation to Crosstalk Ratio Far-End (ACRF) is the ratio of FEXT to the attenuated signal over the affected wire pair (see Figure 2-20). Compare the

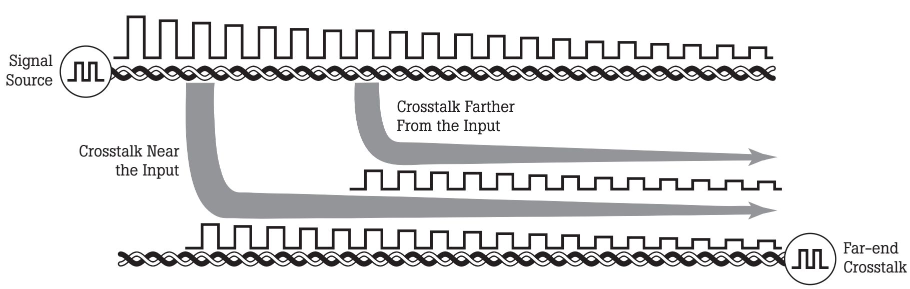


Figure 2-19. *Far-end Crosstalk (FEXT)*

FEXT disturbance to the attenuated signal arriving from the sender at the opposite end of the wire pair to assess the impact of the FEXT crosstalk on the signal transmission.

This test parameter used to be called ELFEXT, or equal level far-end crosstalk, but is renamed as the test parameter ACRF (TIA) or ACR-F (ISO) in the new versions of the standards.

Like ACRN, ACRF represents a signal-to-noise ratio for the cabling. Higher ACRF values (in dB) mean that data signals received at the far end of the cabling are much larger than the far end crosstalk signals received. Higher ACRF values correspond to better cabling performance.

NEXT and FEXT coupling mechanisms tend to be similar in cable but can differ greatly in connecting hardware. Some connectors achieve good NEXT performance by balancing the inductive and capacitive currents that cause crosstalk. Because these currents are 180° out of phase at the near end of the cabling, they cancel out, which eliminates crosstalk at the near end. However, currents that cancel at the near end add up at the far end, causing far-end crosstalk and poor ACRF performance.

In Figure 2-20, a signal is transmitted on one wire pair. A signal transmitted on an adjacent pair crosses to the first wire pair, traveling in the same direction as the "good" signal. The FEXT electrons accompany the good signal electrons to the remote receive inputs of the LAN equipment. To properly decode the desired signal the amount of FEXT crosstalk must be smaller than the desired signal.

Power Sum Near-End Crosstalk (PSNEXT)

Power Sum NEXT loss is concerned with the combined effect of NEXT from all other pairs in the cable simultaneously. TIA/EIA standards use PSNEXT, whereas ISO standards use PS NEXT. Compare this with NEXT, where the amount of a transmitted signal from one pair is measured as crosstalk on one adjacent pair.

For each wire pair in the four-pair cable, PSNEXT loss is computed from three pair-to-pair NEXT loss test results (see Figure 2-21). Statistical theory indicates that a good assumption for the intensity of the total crosstalk in a link is a power sum. The value is calculated by taking the square root of the sum of the square of each crosstalk amplitude.

For implementations that receive from only one pair in each direction, such as 10BASE-T and 100BASE-TX, PSNEXT is not relevant. However, for technologies such as 1000BASE-T that receive simultaneously from multiple pairs in the same

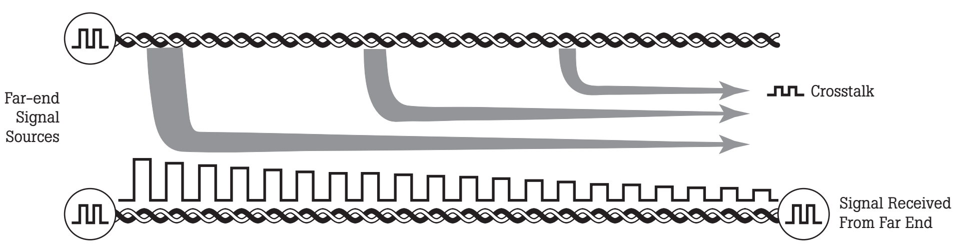


Figure 2-20. *ACRF*

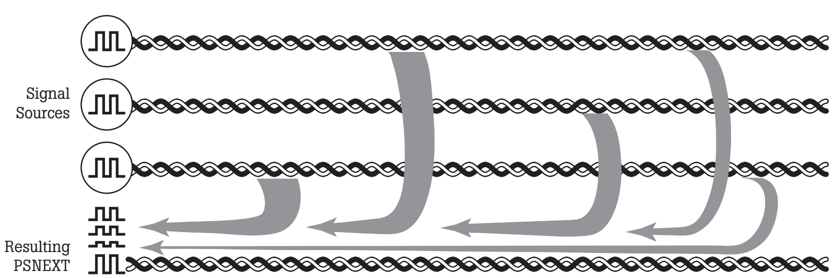


Figure 2-21. *Power sum near-end crosstalk (PSNEXT)*

direction, power sum measurements can be very important tests. The cumulative effect of crosstalk from multiple simultaneous transmission sources can be very detrimental to the signal you are trying to receive. In the case of 1000BASE-T, the requirements for pair-to-pair NEXT loss as specified are such that PSNEXT loss is always satisfied if the pair-to-pair NEXT loss requirements are satisfied, so PSNEXT calculations were not required. TIA/EIA-568-B certification requires this test.

Power Sum Attenuation to Crosstalk Ratio, Near-End (PSACRN)

Power Sum Attenuation to Crosstalk Ratio, Near-End (PSACRN) was previously called PSACR. The addition of *Near-End* was recently made to distinguish it from PSACRF for the far-end measurement. PSACRN values indicate how the amplitude of signals received from a far-end transmitter compares to the combined amplitudes of crosstalk produced by near-end transmissions on the other cable pairs. TIA/EIA standards use PSACRN, while ISO standards use PS ACR-N.

PSACRN is the difference (in dB) between each wire pair's attenuation (insertion loss) and the combined crosstalk received from the other pairs. Measured PSNEXT and Insertion Loss test results are used to calculate PSACRN values. Higher PSACRN values mean received signals are much larger than the crosstalk from all the other cable pairs. Higher PSACRN values correspond to better cabling performance.

Power Sum Attenuation to Crosstalk Ratio, Far-End (PSACRF)

Power Sum Attenuation to Crosstalk loss Ratio, Far-End (PSACRF) was previously defined as Power Sum Equal Level Far-End Crosstalk (PSELFEXT). PSACRF takes into account the combined crosstalk on a receive pair at the far end from signals transmitted simultaneously on the three adjacent pairs at the near end (see Figure 2-22). PSNEXT and PSACRN are for the near end; PSACRF is for the far end. TIA/EIA standards use PSACRF, whereas ISO standards use PS ACR-F.

The affect of attenuation, measured as insertion loss, is taken into account when the FEXT for the other three pairs in the link is calculated as a sum affecting the wire pair being measured. PSACRF results show how much the far end of each cable pair is affected by the combined far-end crosstalk from the other pairs.

PSACRF is the difference (in dB) between the test signal and the crosstalk from the other pairs received at the far end of the link. PSACRF results are typically a few dB lower than worst-case FEXT results.

Alien Crosstalk

All the electronic influences thus far described have occurred within a single cable sheath. Alien crosstalk is any external influence, typically NEXT and FEXT, that is measured between adjacent cables. The influence does not project very far, and separation of between 1cm and 2cm reduces the influence to insignificant levels. Cable bundles and cable piled in conduit or cable trays is easily close enough together to suffer from this effect

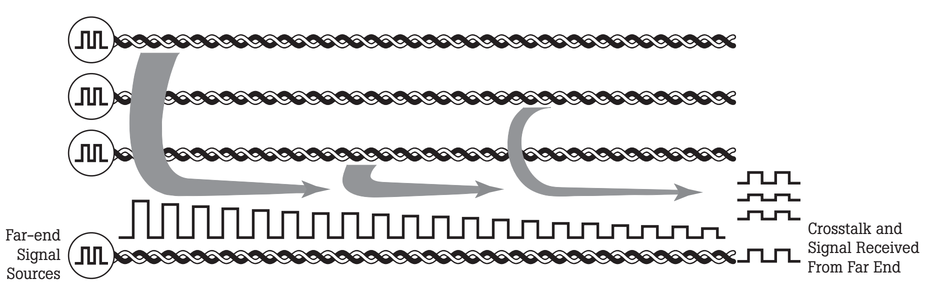


Figure 2-22. *Power Sum Attenuation to Crosstalk Ratio, Far-End (PSACRF)*

(see Figure 2-23). The effect is mitigated if the cable is placed loosely together so that no section of one cable is touching another cable for a significant distance. "Dressing" the cables for neatness by aligning them using cable ties and otherwise joining long runs together for extended distances causes alien crosstalk to increase.

This crosstalk is worst between wire pairs with the same twist rate. The effect is greater for pairs with a lower twist rate. Impact increases with the distance over which the cables run in parallel, and with the frequency of the transmitted signals.

Alien crosstalk is also affected by "ambient noise" caused by RF signals (various radio communications or noise sources) and electromechanical disturbances. Noise from these other uncorrelated sources cannot be canceled out, and is included in alien crosstalk measurements.

Virtually all the previous frequency-based measurements are repeated for alien crosstalk, with the addition of some average values. A full suite of alien crosstalk measurements is made after all the in-channel measurements have been made (and pass). Then a cable in a given bundle is selected as the *victim link* (officially it is the *disturbed link*), and signals are transmitted on all adjacent links in the bundle called the *disturber links*. A complete test suite for a 48-cable bundle could take many hours because each cable must be the victim link in turn, and all disturber links must be used for each victim link. Because this extensive testing is simply too time-consuming, a process for sampling the most likely worst-case victim and disturber links has been laboratory validated. This process is a resource available from the Fluke Networks web site at www.flukenetworks.com/10gig in support of TIA TSB-155 testing.

Alien Near-End Crosstalk (ANEXT)

Alien Near-End Crosstalk loss (ANEXT) is the amount of unwanted signal coupling from a disturber pair in an adjacent cable measured on a victim pair in the measured cable. ANEXT is measured at the near end—the same end as the transmission source. In the same manner that NEXT is worst closest to the transmission source, ANEXT is worst nearest the adjacent transmission source.

Average Alien Near-End Crosstalk (Average ANEXT)

Average Alien Near-End Crosstalk (Average ANEXT) is the average amount of unwanted signal coupling at the near end measured for each of the four victim pairs in one victim cable at the near end.

Alien Far-End Crosstalk (AFEXT)

Alien Far-end Crosstalk loss (AFEXT) is the amount of unwanted signal coupling from a disturber pair in an adjacent cable measured on a victim pair in the disturbed (victim) cable. AFEXT is measured at the far end, the end away from the transmission source.

Attenuation to Alien Crosstalk Ratio Far-End (AACRF)

Attenuation to Alien Crosstalk Ratio Far-end (AACRF) is the difference (in dB) between the Alien FEXT from a disturber pair in an adjacent cable and the insertion loss of the victim pair in the disturbed cable at the far end.

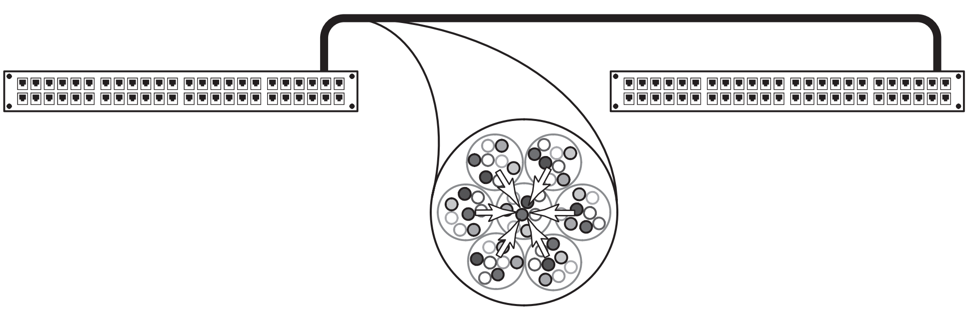


Figure 2-23. *Alien crosstalk is mostly a problem related to adjacent cables. This problem is exhibited whenever cables are in close proximity for any distance, such as a cable bundle between patch panels.*

Power Sum Alien Near-End Crosstalk (PSANEXT)

Power Sum Alien Near-End Crosstalk loss (PSANEXT) is the power sum of the unwanted crosstalk loss from adjacent disturber pairs in one or more adjacent disturber cables measured on a victim pair at the near end—the same end as the transmission source.

Power Sum Alien Far-End Crosstalk (PSAFEXT)

Power Sum Alien Far-End Crosstalk loss (PSAFEXT) is the power sum of the unwanted signal coupling from adjacent disturber pairs in one or more adjacent disturber cables measured on a victim pair at the far end—the end away from the transmission source.

Power Sum Attenuation to Alien Crosstalk Ratio Far-End (PSAACRF)

Power Sum Attenuation to Alien Crosstalk Ratio Far-End (PSAACRF) is the difference (in dB) between the Power Sum Alien Far End Crosstalk from multiple disturber pairs in one or more adjacent cables and the insertion loss of the victim pair in the measured cable at the far end.

Average Power Sum Attenuation to Alien Crosstalk Ratio Far-End (Average PSAACRF)

Average Power Sum Attenuation to Alien Crosstalk Ratio Far-End is the average of the Power Sum Attenuation to Alien Crosstalk Ratio Far End (Average PSAACRF) measurements for the four pairs in the victim cable.

The alien crosstalk evaluation of a disturbed or victim link requires that the PSANEXT and PSAACRF test parameters pass for all its wire pairs and the average of these four pairs after including the contribution by all disturber links. The disturber links must include all links bundled in the same bundle as the victim link, and links terminated in adjacent jacks in the panel if not already included because they are also part of the bundle.

Other Commonly Referenced Test Parameters

These next four test parameters are interesting, but are not usually part of a cable certification test. The problems related to these parameters are easily detected by other tests.

Capacitance

The TIA/EIA-568-B standard does not list capacitance as a required test for an installed link. To further support this, section 4 of TIA/EIA-568-B-2 states, "Mutual capacitance recommendations are provided for engineering design purposes" in several locations. If mutual capacitance is out of specification, characteristic impedance, return loss, and/or NEXT are directly affected, and field testing detects the problem accordingly with these tests.

From a troubleshooting perspective (not an engineering perspective), the goal of testing for capacitance problems is to identify the location of a link or installation fault. Rather than actually testing capacitance, it is far simpler and more accurate to use a TDR test to find the location of this sort of problem. Capacitance is also one of the test technologies used to infer the presence of split pairs in a twisted-pair cable.

Characteristic Impedance

When a high-frequency electrical signal is applied to a cable, the signal source experiences impedance. Impedance is a type of resistance that opposes the flow of alternating current (AC)—and network data is a type of high-frequency AC. A cable's characteristic impedance is a complex property, resulting from the combined effects of the cable's inductive, capacitive, and resistive values. These values are determined by physical parameters such as the size of the conductors, the distance between conductors, and the properties of the cable's insulation material.

Proper network operation depends on a constant characteristic impedance throughout the system's cables and connectors. Abrupt changes in characteristic impedance (called *impedance discontinuities* or *impedance anomalies*) cause signal reflections. Such changes in characteristic impedance can cause a high incidence of bit errors, as discussed previously.

The impact of characteristic impedance problems are more practically represented by the effect called return loss (see the description of return loss). Return loss tells you directly how bad the total effect of all reflections is.

Termination impedance present at the link ends must be equal to the characteristic impedance. Frequently, this termination impedance is included in the interface of equipment to be connected to the LAN. A good match between characteristic impedance and termination impedance provides for a good transfer of power to and from the link and minimizes reflections.

Complex high-speed LAN encoding methods, such as the 4D-PAM5 scheme used with 1000BASE-T, are even more sensitive to changes in characteristic impedance. The faster and more complex the signaling, the more sensitive the scheme is to this sort of problem. Lengths of untwisted wires must be kept to the absolute minimum, and lengths of cable with different characteristic impedance should never be mixed. If the characteristic impedance suddenly changes as a signal travels along a link, a reflection occurs that causes the signal (or a portion thereof) to bounce back toward the source. Such a reflected signal may again bounce back at another impedance anomaly and continue along the path of the originally transmitted signal. This combination of possible reflections may cause problems for the receiver (it creates signal jitter).

The characteristic impedance is almost always disturbed at connections or terminations. A LAN can tolerate some disturbance. However, it is critically important for the installer to untwist a twisted-pair cable to the minimum extent possible, particularly when installing links for high-speed LANs. In fact, for Category 5e cable, a link is permitted to have a *maximum* of 13 millimeters (0.5 inches) of untwisted wire at each termination point (TIA/EIA-568-B-1, paragraph 10.2.3). Installing an older or unrated RJ45 coupler to connect two cables normally exceeds this limit. Older RJ45 couplers often have particularly bad NEXT performance, and unless they are clearly marked with Category 5e or better ratings they should never be used in a Category 5e or better installation (the effect of poor quality couplers is shown in Figure 2-24). Rated couplers are typically larger than older poor quality couplers, and are much more expensive.

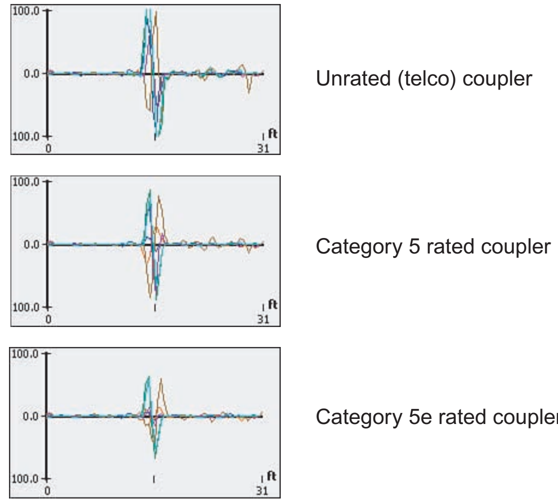


Figure 2-24. *DTX 1800 HDTDX test results for two 5-meter (15 ft) Category 6 patch cables joined with an RJ45 coupler. The top graphic depicts the link with an older (unrated) RJ45 coupler, the middle has a Category 5 coupler, and the bottom has a Category 5e coupler.*

Reflected signals are attenuated as they travel back, so the effect of reflections is reduced as the distance from the receiver increases. Sharp bends or kinks in LAN cable can also alter the cable's characteristic impedance. Poor electrical contacts, improper cable terminations, improper cable pairing, mismatched cable types (cables with different characteristic impedance values), and manufacturing defects in the cable all cause impedance discontinuities, resulting in degraded link performance.

An impedance measurement is sometimes used to infer the presence of split pairs in twisted-pair cable. When there is a split pair, the characteristic impedance measurement usually exhibits significantly different impedances for the pairs that were split.

Noise

Noise problems on a LAN link include impulse noise and continuous wideband noise. Noise does not include signals from other wire pairs, which are measured as forms of crosstalk.

Impulse noise is measured by counting the number of voltage spikes that exceed a certain threshold. A low impulse count is desirable for good network performance. However, an impulse noise test is not always sensitive enough for LANs that use higher levels of encoding than the common 10BASE-T networks. Wideband noise is a continuous presence of noise over a wide frequency band; it is not a part of the data transmission signal but potentially corrupts this signal. The lower the wideband noise voltage, the better the LAN performance will be. To resolve problems related to noise, it might be necessary to use other categories of tools, such as high-speed digitizing sampling oscilloscopes and spectrum analyzers with variable measurement bandwidths.

As mentioned during the discussion of NEXT, due to imbalance, LAN links also act as antennas. They can pick up noise signals from fluorescent lights, electric motors, photocopiers, and other similar devices that are located in proximity to the LAN cable. Also, when a transmitter of a radio or TV station is in the vicinity, significant noise can be picked up by the cable. Remember that the lower FM and TV bands are within the 1MHz to 100MHz range at which nearly all LAN protocols operate. Be sure to consider these external noise signal influences when you are planning your installation and route links as far away as possible or use shielded cable.

The LAN is a wideband system, meaning that all frequencies between 1MHz and 100MHz for Category 5e, or up to as high as 500MHz for Category 6A, make up the signal that is to be transmitted.

Resistance

The DC loop resistance test is a basic resistance test used to detect the presence of termination resistor(s) on coax cable and to detect poor-quality connections on twisted-pair links.

A simple coax resistance test should show one of three expected results for Ethernet: open (no termination present), 50 ohms (one terminator present), or 25 ohms (two terminators present, one at each end of the cable). For RG-59 used with WAN links and wireless the measurements would reveal 75 ohms, or 37.5 ohms. If the test result deviates much from one of those three options, a cable fault is likely. 802.3 Ethernet specifies that termination resistors shall be 50 ohms with variations of only ±1 percent. However, the network *usually* continues to operate with variations of up to several ohms, although this introduces reflections of the data and reduces the effective maximum link length accordingly.

If the center conductor is shorted to the shield at the far end, thick coax should measure around 5 ohms at 500 meters, and thin coax should measure around 2 ohms at 185 meters (maximum lengths for Ethernet). If there are poor-quality connections along the path, each additional poor connection adds some amount of resistance. Similar tests may be made for RG-59.

For UTP, the DC loop resistance test is more significantly affected by link length. A typical DC loop resistance test on a 100-meter cable should provide results in the range of 9 ohms to 12 ohms. The TIA/EIA-568-B maximum limit is 9.38 ohms of resistance per 100 meters of UTP (at 20°C). The test on twisted pair is performed by shorting the two wires from a twisted pair together at the far end, and then measuring the resistance of the entire wire path. The quickest way to tell whether there is a problem is to compare the results from all four pairs. If one pair shows 25 ohms, and the other three are between 11 ohms and 14 ohms, it is highly probable that the 25 ohms pair has a link fault. The TIA/EIA-568-B limit for ScTP is 14 ohms per 100 meters (at 20°C).

Any problems with DC resistance show up as attenuation problems as well; therefore, DC resistance is not very important for field testing. Note that the TIA/EIA standards do not include the DC resistance test, whereas the ISO 11801 standard includes this as a pass/fail test. When deploying Power over Ethernet (PoE), it might be advisable to take note of the DC measurement results. An excessive resistance gives rise to heat and a greater than expected voltage drop.

Test Configurations

A horizontal cable run consists of up to 90 meters of solid conductor cable, plus not more than 10 meters of stranded conductor patch cables in the equipment room, the user's work area, and any intermediate cross-connect or consolidation points.

Basic Link

The basic link was obsoleted by TIA/EIA-568-B when it superseded the TIA/EIA-568-A edition of that standard. The basic link was used by installers for testing the cable "in the wall" before the network was deployed, and often before power was available in new construction. The test required better performance than the channel link because there would be additional patch cables added later.

The basic link configuration does not permit any extra connectors in the tested link, but the point of measurement starts near the field tester and ends near the field tester remote unit at the other end of the link (see Figure 2-25). Therefore, the cable that is part of the basic link adapter is included in the test results each time.

Permanent Link

The permanent link replaces the basic link in TIA/EIA-568-B. The test is still used primarily by installers for testing the cable "in the wall," before the network is deployed.

The permanent link excludes the cable portions of the test adapters but includes the mated connection at each end (see Figure 2-26). The permanent link also allows for a consolidation point, which is desirable for open office cabling installations, and therefore more practical.

The significant difference between the basic and permanent link configurations is that the reference point for the measurements was moved from the tester interface to the plug end of the test adapter cable. This new test definition requires field testers to remove or subtract all measured effects of the test cord from each test result, but the mated connection with the link jacks is still included in the test results. From an installer's perspective, the change from basic to permanent link also means a loss of approximately 2dB of NEXT margin at 250MHz, which can lead to more failures and marginal results on Category 6/Class E links.

Channel Link

The channel link test is intended for the complete end-to-end or point-to-point cable path between two network devices, including the actual patch cables that will be used (see Figure 2-27). If a single common set of patch cables is used with the tester for each successive link tested instead of the end user's patch cables, the test does not comply with the requirements.

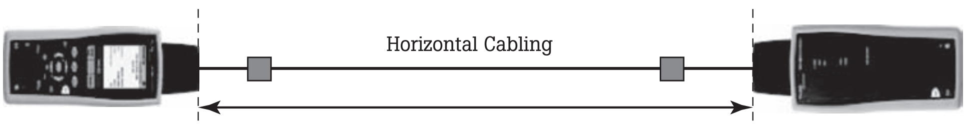


Figure 2-25. *Obsolete basic link test configuration*

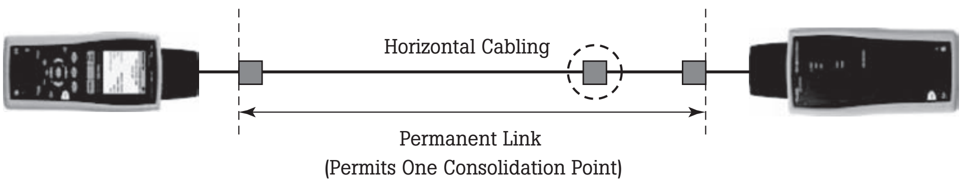


Figure 2-26. *Permanent link test configuration*

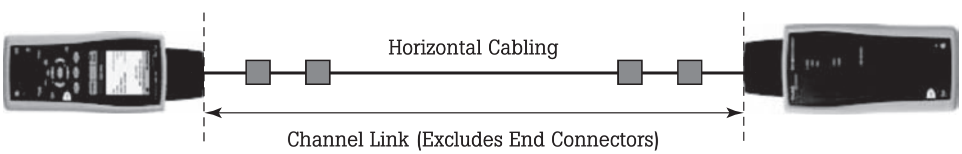


Figure 2-27. *Channel link test configuration*

Patch cords can make a significant difference, particularly because of a different mating of plugs and jacks (the cable of a patch cord rarely has much of an impact unless it is severely damaged, and that is usually quite evident and detectable by a visual inspection). The end user wants the performance of the complete cabling link verified, which must include the end user's patch cables and not the instrumentation patch cables. The tested patch cable used in the channel test must be left as part of the tested link. Changing patch cables invalidates the test results, and would require a retest to recertify.

The channel configuration may include the optional consolidation point as well as a cross-connect. Often there is just a patch panel in the equipment room. The connection at the tester end is not included in the test results.

The permanent link test offers an important advantage to the network owner. Patch cords may be changed a number of times during the life of the cabling installation. A passing permanent link test ensures that adding "good" patch cords automatically provides a passing channel. This advantage can be claimed only if two important conditions are met:

- The RJ45 plug at the end of the tester permanent link adapter is a test reference plug—a plug that operates in the very center of the plug specification range for all frequency-dependent parameters. The performance requirements of the centered test (reference) plug are defined in the TIA Category 6 and Category 6A standards. Typical commercial patch cords seldom if ever meet this stringent requirement and should not be used to perform the permanent link test. The test reference plug at the end of the permanent link test adapter guarantees that the jack meets the category specification.
- The patch cords you use to complete the channel must meet the category rating of the permanent link or better. You should either purchase patch cords for the high-performance links (Category 5e/Class D or above) from reputable manufacturers, or test patch cords with the proper adapters and against the appropriate standard to confirm their performance. Some manufacturers include the test results data with their patch cords to confirm their compliance with the standards. Be sure that a patch cord test was performed (for short cables), and not a channel test for up to 100 meters.

What Should Be Tested?

TIA/EIA-568-B contains specifications for the testing of installed twisted-pair cabling links. The primary field test parameters for such a link include

- Wiremap
- Length
- Insertion loss
- Near-End Crosstalk (NEXT) loss
- Power Sum Near-End Crosstalk (PSNEXT) loss
- Attenuation to Crosstalk Ratio at the Far-End (ACRF)
- Power Sum Attenuation to Crosstalk Ratio at the Far-End (PSACRF)
- Return loss
- Propagation delay
- Delay skew

Table 2-4 listed the test requirements for certification of Augmented Category 6 (Category 6A), as described in TIA/EIA-568-B Addendum 10. The ISO standard will publish the performance requirements for Augmented Class E (Class E_A) in a future edition of standard 11801.

You should always test to the maximum rating for the grade of cable you are installing. If you are specifying an installation that will be contracted out, require the contractor to submit electronic test results showing certification to the maximum rating for that grade of cable. A draft template for contracting a cable installation is available from the Fluke Networks web site. Look for "Field Test Specification" in the Knowledge Base. The template is kept current per the evolving standards requirements, and should help you avoid most of the typical installation problems. There are templates for both twisted-pair copper and for fiber.

Grounding and Shielding Cable

Although the primary purpose of requiring Screened Twisted Pair (ScTP) or Shielded Twisted Pair (STP) throughout most of Europe is to prevent network signals from leaking *out* of the cable, most people think of shielding as a way to prevent signals from leaking *into* the cable. Although the use of shielding is a good way to meet both requirements, there are some potential problems.

Figure 2-28 shows one style of shielded metallic connection box. Part A shows the parts of an ScTP cable. Part B shows one type of wall jack where the shielding fully encloses the end of the cable, with an arrow indicating the point where the cable shield connects to the jack shield. Part C shows a cutaway of a correctly terminated fully enclosed ScTP 8-pin modular plug (RJ45), with an arrow indicating the point that the cable shield connects to the plug shield over 360 degrees (full circle). Below that is an incorrectly terminated ScTP cable, where the cable shield does not enclose the wire pairs completely into the shield of the plug.

The fundamental purpose of a shield is to *fully enclose* a signal so that no radiated field can enter the cable and disturb the signal lines, and equally important, so that no field is radiated out of the cable, where it could interfere with other electronic devices. Note that it is absolutely essential that shields fully enclose the signals in every regard. Extending a drain wire even a short distance past the shield of a cable to make a connection defeats the quality of the shield significantly (see part C in Figure 2-28). Proper installation requires mounting clamps that are located inside enclosed metal spaces, so that openings are absolutely minimal. Coaxial cabling systems and connecting hardware lend themselves well toward this goal.

Generally speaking, a connection to ground is made for personal safety reasons. To meet current safety requirements, almost all powered equipment must have a third wire safety connection to ground. The issue then becomes where (at what locations) connections have to be made between the earth ground (chassis) and the shield.

All earth ground connections eventually lead to a building ground location. Voltage potentials in the earth ground lead are caused by leakage currents in the various pieces of electrical equipment. The leakage current times the resistance of the ground wires cause voltage potentials, which easily can exceed several volts. Voltage potentials between buildings are generally very significant.

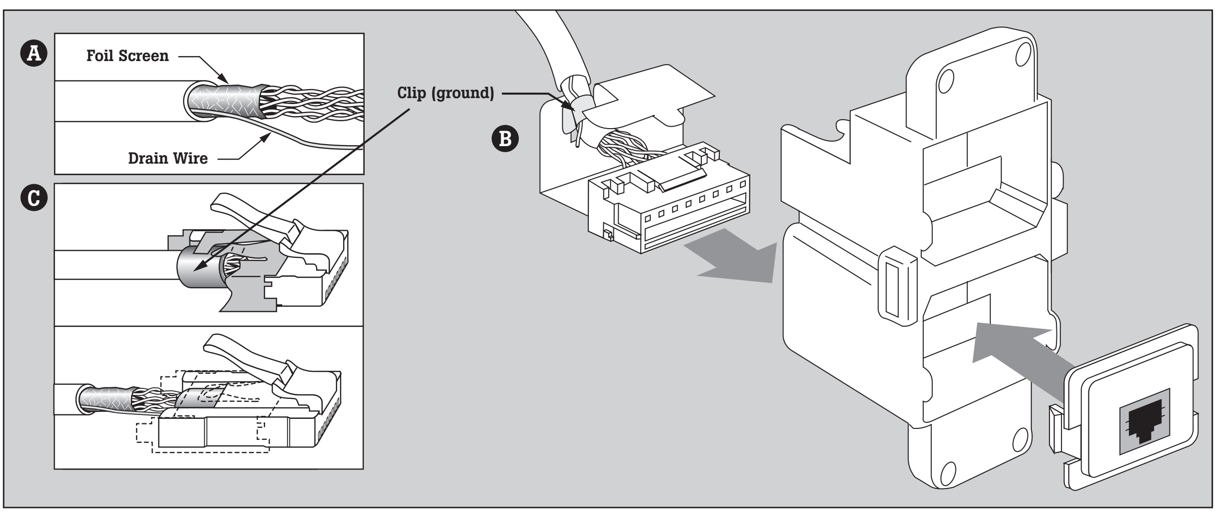


Figure 2-28. *One style of Screened (ScTP) connection*

Lightning is another important consideration when connecting buildings. For data communication between buildings, fiber optic connections are the only practical and safe solution.

You do not want to have a cable shield become a ground return path. This can be avoided in one of two ways:

- Permit only a single connection between earth ground and the shield. The recommended end for grounding an ScTP or STP permanent link is at the wiring closet end, where the ground should be bonded to the building earth ground.
- Make certain that there is no substantial voltage potential between the earth ground connections of the equipment and any connection to data communications systems. If there is no voltage, there will be no current, and therefore no problem. This is the solution that is followed for shielded twisted-pair cabling systems (STP and ScTP).

In coaxial cable systems (10BASE2 and 10BASE5), the connection between earth ground and the shield is made at one location in the cable system. This is typically done at one end of the coax run. At all other locations there is isolation between tap connections and any earth ground source. For 10BASE2, protective plastic caps are often used to prevent accidental contact between the BNC "Tee" connector and the PC chassis. Most WAN and wireless coax use is point-to-point with little opportunity for shorts, unlike coaxial Ethernet.

Coax may be tested by measuring the current flow between the shield of the cable and the shield mating connection on the end equipment. Disconnect the cable and measure between the shield connections with a digital multimeter. Less than 20mA is unlikely to disrupt data.

When using shields with twisted-pair cabling systems (ScTP, STP), you can verify the absence of ground loop potentials by testing for them after all non-LAN electrical equipment has been installed and is operational. Then activate the LAN equipment and measure the voltage potential between the shield of the other end and the chassis of the equipment to be connected (see Figure 2-29).
If the voltage is less than 1 volt AC, you may be reasonably assured that there will be no ground loop effect.

If the voltage is substantially higher, you must locate the source of the leakage. This normally involves working with a qualified electrician to correct the problem that is creating the voltage potential. This is not always easy to do, and if not possible, you should convert the connection from copper to fiber optic cable.

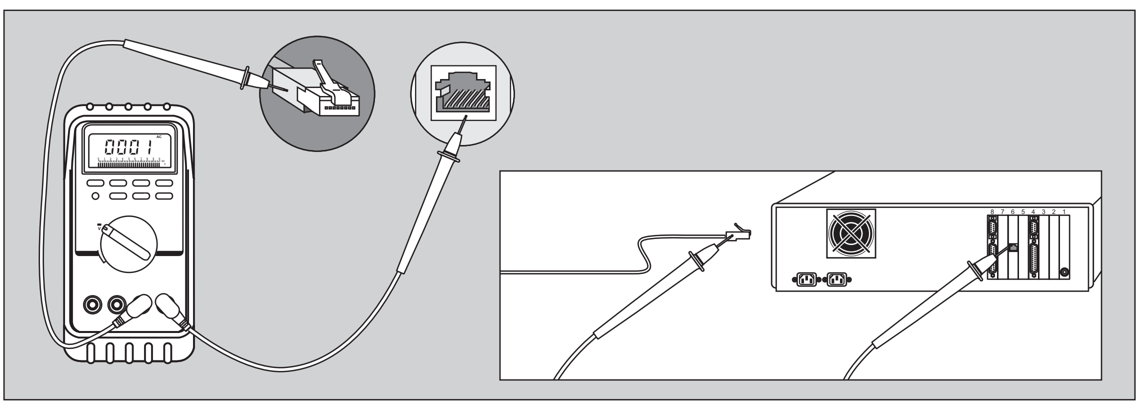


Figure 2-29. *Measuring a cable shield for AC voltage with a digital multimeter*

Summary

This chapter described copper cabling test standards, the test parameters required for compliance with those standards, and test configurations.

- Cabling standards continue to evolve. To be certain that the test results obtained certifying a new cable installation are reliable, it is important to keep the cable tester updated with the latest performance specifications.
- Testing cable to the requirements of the technology you are deploying is acceptable, but a better practice would be to test to the performance specifications of the installed cable type.

  If testing is performed to ensure that a specific technology operates, it is likely to be a less stringent test than if the performance specifications of the installed cable type were tested. Also, knowing that the installed cable performed according to the labeling of the cable instead of a lesser standard would allow a different technology to be used on the same cable plant without requiring a full retest of the cable plant. For example, if a Category 5e cable plant had been tested for use with 100BASE-TX, which requires testing to 80MHz and uses only two pairs, the entire cable plant would have to be retested before 1000BASE-T is deployed. 1000BASE-T requires all four pairs to be tested to 100MHz, plus some additional tests required by Category 5e but not for 100BASE-TX. If the cable plant is certified for Category 5e performance specifications at the time of installation, either Ethernet implementation could be deployed over the cable plant without further testing.
- Understanding what is tested will help you with both installation and testing. Knowing the operational characteristics of cable test parameters is particularly helpful in understanding the purpose for the installation guidelines (such as not untwisting pairs more than absolutely necessary), and also in understanding what to look for when troubleshooting a failed cable performance test.
- Selecting the correct test configuration is an important part of certifying a cable, but abiding by the requirements of the test configuration is just as important. If the channel test configuration is used, but the same patch cables are used to test the entire installation instead of leaving the tested patch cables in place after each test, the testing performed is invalidated. It is important to understand what is required for each test configuration.

Chapter Review Questions

To aid in your comprehension of important concepts, the following questions are provided. Refer to this book's Introduction for a general legend that indicates the anticipated difficulty of each question. For answers to these review questions, see Appendix I, "Answers to Chapter Review Questions."

1. Which cable classifications are currently supported by the media standards? List both ISO and TIA cable types.

2. What is the minimum cable test standard that the cable test standard must meet to support 10GBASE-T?

3. In addition to general electrical safety, what is the primary concern for delivering power over twisted-pair cabling?

4. What types of cable fault does a wiremap test reveal?

5. What is the difference between a reversed pair and a transposed pair?

6. What is the difference between TIA/EIA-568-B and T568B?

7. What is the difference between T568A and T568B?

8. In addition to comparing wire insulation colors used for each pair at both ends of a cable, what test infers the presence a split pair? Name three test techniques.

9. What special type of Ethernet cable is created when T568A and T568B are used on the same cable?

10. Approximately how far does an Ethernet signal travel in 10 nanoseconds on a typical Ethernet cable?

11. Describe the principle or process behind a TDR measurement.

12. What is delay skew?

13. What does the attenuation test measure?

14. Up to approximately what frequency does insertion loss generally appear to be linear?

15. At what location along a typical cable is return loss most frequently introduced?

16. How is the influence of crosstalk typically reduced by the cable manufacturer?

17. What is the measurement difference between ACR and SNR?

18. How is NEXT different from FEXT?

19. If ACRF fails, where is the problem most likely to be found?

20. How is a power sum measurement different from the nonpower sum equivalent (such as NEXT and PSNEXT)?

21. What characteristic identifies Ethernet implementations where power sum measurements could be important?

22. How is alien crosstalk different from other forms of crosstalk, such as NEXT versus ANEXT?

23. What typically results from a change of impedance along a cable link?

24. How is impulse noise measured?

25. What measurement, other than DC resistance, would likely detect a DC resistance fault in a cable?

26. What is the difference between a *permanent* link and a *channel* link?

27. How low must current flowing over a cable shield be to avoid disrupting data communications?

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