Handbook Of Local Area Network Testing

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Handbook of LAN Testing

LAN HANDBOOK

WAVETEK WANDEL GOLTERMANN
Communications Test Solutions

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The purpose of this handbook is to provide the reader with a comprehensive resource for understanding and testing Local Area Network (LAN) cabling. In addition to addressing the detailed standards, tools and methodologies used for testing both copper and fiber optic physical cabling, this handbook also endeavors to provide the reader with a larger context for understanding LAN concepts and real-world network performance issues. The handbook is intended for use as both a learning tool and a field reference guide for professional cabling installers and corporate network administrators. Toward these objectives, the handbook has been segmented into clearly defined and indexed sections covering each of the key subject areas.

Handbook Overview

Section A provides a brief definition of data communications and a look at the current trends that are impacting data communications networks.

Section B looks at what constitutes a local area network and briefly explores the evolution of the different types of LAN topologies.

Section C examines the need for standards in data communications networks and looks at the role of international standards-setting organizations and committees.

Section D underscores the importance of documentation and discusses methods for documenting the various aspects of a network environment.

Section E provides an overview of current testing standards that govern the certification of structured cabling installations.

Section F defines the various types of physical layer tools that are used for testing copper cabling.

Section G describes in detail the physical layer testing methodologies that are needed to test and certify today's high performance copper cabling.

Section H provides a comprehensive overview of fiber optic cabling including definitions of how fiber cabling works, the key parameters and concepts used in fiber testing, and the various types of fiber testing equipment.

Section I takes a step back from the physical cabling media and looks at the higher level issues involved in Testing Beyond the Physical Layer, with special emphasis on tools for LAN traffic generation as well as comprehensive network traffic management software.

Appendix A provides a Glossary of Terms commonly used in LAN networking and data communications.

Appendix B provides a detailed LAN Cable Troubleshooting Guide.

What is Data Communications?

In the beginning, data communications was essentially a term used to encompass the various methods for the controlled transmission, reception and interpretation of information between separate computing systems. For the most part, it was also used to distinguish the relatively new arena of "data" communications from the well-established and highly structured arena of "voice" or "telecommunications".

For most of its early development, from the 1960's through the 1980's, data communications consisted of a diverse range of highly proprietary technologies for interconnecting specific types of computers to enable the sharing of rigidly formatted information. For example the dominant data communications technologies for many years came from IBM, the industry's most dominant computer systems provider. These included de facto "standards" such as the Systems Network Architecture (SNA) developed in the early 1970's for connecting IBM mainframe computers together. With the rise of personal computers, workstations, and client/server computing, IBM also addressed the need for a peer-based networking strategy with the creation of Advanced Peer-to-Peer Networking (APPN) and Advanced Program-to-Program Computing (APPC). In addition, over the years other proprietary networking methods have also been developed and offered as quasi-standards by companies such as Digital Equipment Corporation (DECnet), Apple Computer (AppleTalk), Xerox Corporation (Ethernet), etc.

Two of the key pivotal events that helped lay the groundwork for today's far-reaching, platform-independent, internetworking environment were:

- The invention of ARPAnet, which began in 1969 as a robust, fault-resistance networking technology intended to connect geographically distant military computers. Eventually, the ARPAnet project engendered the development of a widely-adopted extensible set of transport and information protocols that gave birth to today's global networking revolution known as the Internet.
- The creation of Ethernet by scientists at Xerox Corporation in 1973 as a platform-independent architecture for networking, which eventually has achieved widespread acceptance as the de facto protocol for Local Area Networks throughout the world.

During the 1990's the Internet has driven an explosion of data communications growth - going from a relatively obscure network of inter-linked resources used primarily by government, academics and technocrats, to a mainstream global communications infrastructure used by both consumers and businesses for everything from entertainment to research to commerce. In a parallel with increased traffic on the public Internet, there has also been a relentless expansion of private networks, such as Intranets, Extranets, etc., which in many cases are `linked to and/or partially carried across the Internet backbone.

In addition, the world of data communications has expanded to encompass much more than the traditional focus on sharing of computer data. The ubiquitous use of the Internet Protocol (IP) across a wide range of networks has laid the foundation for the convergence of many types of traffic in addition to data, including voice-over-IP (VoIP) applications. To a great extent, data communications networks have actually come full circle to usurp the dominant role that used to belong to traditional voice-oriented telecommunications. In fact, the lines of demarcation between datacom and telecom are now quite blurred, with many traditional telecommunications companies frantically pushing to become full-service data communications companies.

With the rise of these new bandwidth-hungry applications, such as multimedia, real-time e-commerce transactions, and latency-sensitive voice conversations, underlying network infrastructures are constantly being pushed to provide higher levels of performance and more consistent Quality of Service (QoS). As the dominant networking protocol, most Ethernet deployments have steadily evolved through 10Base-T at 10 Mbps up through 10/100Base-T at 100 Mbps and many backbone environments are now employing Gigabit Ethernet at 1000 Mbps.

In a parallel with the evolution of data communications networks, the physical transmission media has also undergone significant evolution and transformation. The various incarnations have included coax cabling such as that used for early 10Base-2 Ethernet, twisted pair copper wiring in both shielded (STP) and unshielded (UTP) versions, and even fiber optic cabling for many higher speed links and longer distances.

For the professional cabling installer and for the network administrator, the steadily increasing speed of modern networks makes it significantly more difficult to certify and maintain the underlying infrastructure for optimal performance. At the same time, the proliferation of additional mission-critical applications on to datacom networks is putting more pressure on the need for flawless performance and uninterrupted network availability.

In order to keep up with escalating performance and network criticality, installers and administrators need to continually stay abreast of the latest trends in physical layer testing tools and methodologies for copper wiring (Sections E, F and G). They must also understand the basics of fiber optic cabling and how to test it (Section H). In addition they need to explore the evolving opportunities for going beyond the physical layer and testing higher protocols to assess the overall performance of their LAN installations (Section I).

What is a Local Area Network?

A commonly accepted working definition of a LAN is "a computer network that spans a relatively small area" within which each individual computer node can execute its own programs locally while also being able to access data and devices anywhere on the LAN (subject to security/access parameters). For instance, use of workgroup LANs has been a major factor in improving the productivity and efficiency of individual users by enabling them to interactively exchange information and to share expensive resources, such as laser printers, disk arrays, etc. LANs are capable of transmitting data at very fast rates, much faster than data can be transmitted over a telephone line, but the distances are limited, and there is also a limit on the number of computers that can be attached to a single LAN.

Most LANs are confined to a single building or group of buildings. However, an individual LAN can also be connected to many other LANs over any distance via routers using telephone lines and radio waves. A system of LANs connected in this way is typically called a wide area network (WAN).

There are many different types of LANs, Ethernet being the most common for PCs. Most Apple Macintosh networks are based on Apple's AppleTalk network system, which is built into Macintosh computers.

Among the key characteristics that differentiate one LAN from another are:

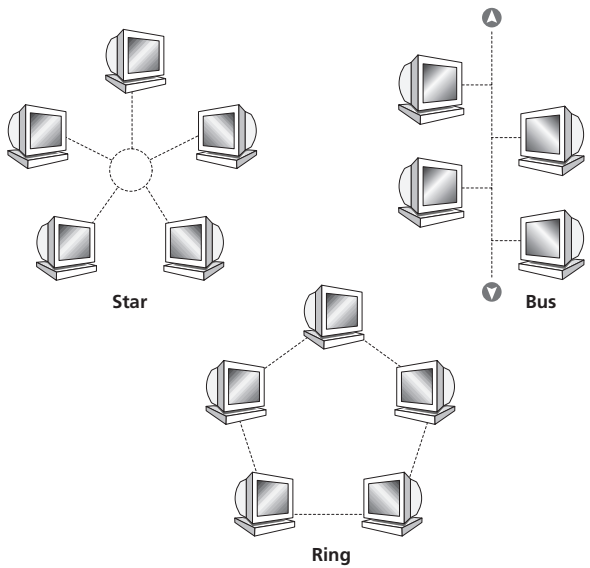
- Topology : The geometric arrangement of devices on the network. For example, devices can be arranged in a straight line, a ring or a star.
- Protocols : The rules and encoding specifications for sending data. The protocols also determine whether the network uses a peer-to-peer or client/server architecture.

LAN Topologies
There are three principal topologies used in LANs: Bus, Ring and Star.

Bus topology: All devices on the LAN are connected to a central cable, called the bus or backbone. Bus networks are relatively inexpensive and easy to install for small networks. Many smaller Ethernet LANs are implemented using a bus topology.

Ring topology: All devices on the LAN are connected to one another in the shape of a closed loop, so that each device is connected directly to two other devices, one on either side of it. Messages travel around the ring, with each node reading those messages addressed to it. Ring topologies are relatively expensive and difficult to install, but they offer high bandwidth and can also span large distances because each node regenerates messages as it passes them along the ring.

Star topology: All devices on the LAN are connected to a central hub. Star networks are relatively easy to install and manage, but bottlenecks can occur because all data must pass through the hub. More complex Ethernet LANs are generally implemented using Star shaped topologies, with multiple Ethernet LANs connected via inter-linked spokes for the various individual stars.



LAN Protocols

Basically a LAN protocol defines the agreed-upon procedures and formats for transmitting, receiving and acknowledging data between two devices. Generally the LAN's protocol specifies the following:

- The format of the data packets (e.g. data length, location of start & stop bits, etc.)
- The type of error checking to be used
- Data compression method, if any
- How the sending device will indicate that it has finished sending a message
- How the receiving device will indicate that it has received a message

In addition to a definition of data formats and handling procedures, a LAN also needs specified protocols to define the mechanisms whereby individual nodes can access the network and transmit data. This is a very important issue because uncontrolled transmission of data by multiple nodes can potentially result in errors or lost information.

For instance, in token ring networks, before any node can transmit, it must first obtain the "token" which gives it access to place data on the ring. The token is a special bit pattern that travels around the circle. To send a message, the transmitting node catches the token, attaches a message to it, and then lets it continue to travel around the network until the message is received by the addressee node. Because there is only a single token on the network, only one node can obtain permission to transmit at any point in time. The Token Ring specification originally developed by IBM has been standardized as the IEEE 802.5 standard.

In contrast to the token ring architectures, Ethernet uses a Carrier Sense Multiple Access / Collision Detection (CSMA/CD) methodology to handle network access by individual nodes. CSMA/CD is a set of rules determining how network devices respond when two devices encounter a "collision" by attempting to use a data channel simultaneously. The CSMA/CD standard enables devices to detect a collision, after which each device waits a random delay time and then attempts to re-transmit the message. If the device detects a collision again, it waits twice as long to try to re-transmit the message. This is known as exponential back off. While the requirement to routinely retransmit some messages does add a small amount of overhead to the network, the ability for all nodes to immediately contend for available bandwidth without waiting for permission has made Ethernet a very flexible and efficient protocol for use in data communications networks.

However, from the perspective of the network administrator, because excessive collisions can significantly degrade network responsiveness, it is very important to be able to simulate the impacts of different traffic patterns while measuring network performance. In addition, it can be vital to monitor the actual patterns of on going traffic usage in order to maintain optimal performance (See Section I for more detail).

Notes:

Why Standards Are Important

In a very real way, the definition and adoption of widely accepted standards represent the very bedrock upon which modern inter-operable networking systems are grounded. Without well specified and agreed upon standards at every level of the networking hierarchy there would be no way to ensure that networks would behave and perform as required to support critical applications and communications objectives.
One way to put the role of standards into an overall context is to take a quick review of the Open Systems Interconnection (OSI) model, defined in standard ISO/TEC 7498 and delineating seven layers as follows:.

- **Layer 1 - The Physical Layer** describes the media used to connect the systems, such as copper twisted pair, coax, or fiber, and defines the electrical, optical, mechanical, procedural and functional specifications for establishing the physical links between systems.

- **Layer 2 - The Data Link Layer** describes the actual presentation of bits and the format of messages on the physical media. The Data Link Layer is intended to provide reliable transit of data across the physical link by defining the specifications for physical addressing, network topology, line disciplines, error handling, frame sequencing, and flow control methods.

- **Layer 3 - The Network Layer** provides connectivity and path selection between end systems within the network by defining routing and methodologies and path selection criteria. The Network Layer is the point when higher level protocols come into play to provide the rules and conventions for internetworking.

- **Layer 4 - The Transport Layer** is responsible for reliable network communication between nodes, such as specifying mechanisms for establishing and terminating virtual circuits, detecting and recovering from transport faults, and passing flow control information between end points.

- **Layer 5 - The Session Layer** handles the management of specific network sessions between applications.

- **Layer 6 - The Presentation Layer** ensures interoperability of data between applications by negotiating high-level syntax for data transfer.

- **Layer 7 - The Application Layer** handles the interface to application processes that lie outside the OSI model, such as email, file transfer, terminal emulation, etc.

In today's networking environments, there are standards in place for every layer of a network, however, most of the time professional cable installers find themselves concentrating primarily on the specific cabling standards that lie beneath the Physical Media Layer in the OSI model. The PMD layer defines transceiver technology which provides the conversion between analog signals and digital information, thereby providing the foundation that allows all of the higher layers to operate in a purely digital domain. Typically, a PMD specification defines modulation, data rate, maximum acceptable Bit Error Rate (BER), ambient noise, etc. When specifying the medium, a PMD standard generally can just reference the applicable generic cabling standards, such as TIA-568-A, ISO11801, etc.

However, because cabling standards are application independent they are not necessarily designed to satisfy all of the channel requirements of all networks. For this reason, in addition to referencing a generic cabling standard, PMD standards may also define network specific channel characteristics such as ambient noise, insertion loss deviation, or signaling spectrum that might exceed the specified capabilities of the cabling standard.

As will be detailed in later sections of this handbook, it is very important for both professional installers and network administrators to understand the performance and reliability implications that can result from neglecting the interrelationships between physical layer issues and higher layer network requirements. For example, migrating 10/100Base-T functionality on to a cabling installation designed for 10Base-T operation could result in a network environment that appears to be operating properly under ideal conditions, while in reality it represents a latent data disaster in the making.

Section E and Section H provide more detailed information on the current state of cabling standards for copper and fiber optic installations, however it is also important to be aware of the various standards-setting organizations, as listed below. Because cabling and network standards tend to evolve with changing application and performance requirements, we have also included Web addresses for the organizations to aid in obtaining updates.

Standards-setting organizations:

Institute of Electrical and Electronics Engineers (IEEE). (www.ieee.org)
Most higher-level networking standards are developed and maintained by the IEEE, including the IEEE802.x series of standards, which define the following networking protocols.

- IEEE802.1 - Standards relating to network management
- IEEE802.2 - General standard for the Data Link Layer in the OSI model
- IEEE802.3 - Defines the Media Access Control (MAC) for Ethernet
- IEEE802.5 - Defines the MAC for Token Ring networks

Electronic Industries Alliance (EIA) (www.eia.org)

Telecommunications Industry Association (TIA) (www.tiaonline.org)

International Organization for Standardization (ISO) (www.iso.ch)

Additional useful information on the current status and trends in cabling standards can also be found at the BICSI web site at www.bicsi.org. or by regularly visiting the Wavetek Wandel Golterman site at www.wwgsolutions.com.

Notes:

The Importance of Documentation

In terms of capital outlay, documentation is the least expensive network troubleshooting tool. However, it can be the most powerful resource available to LAN service personnel when the system is down. The inherent maintainability of any network is only as good as the effort that is put into its documentation plan. For network administrators, one of the worst possible situations occurs when a simple upgrade or replacement turns into a "staff resource-sink" because of a lack of information, which requires "reinventing the wheel" to get each new device to function properly. By meticulously documenting each of the items outlined in the following sections upon initial installation and/or completion of each upgrade, the network can be kept in a robust, highly maintainable condition.

Documenting the Hardware

A professional data communications cable installer should provide the customer with complete documentation of the network topology, type(s) of cabling used, wiring map showing all cross-connects and end points, and labeling of each cable in a manner meaningful to both the installer and the client. The location of hubs, switches, concentrators, repeaters, patch panels, and any other active or passive interconnecting hardware should also be recorded. Cable certification printouts should be provided showing all relevant parameters for the specified Category level, such as length, impedance, connectivity (linemap), attenuation, and near-end crosstalk for all cabling components in a link.

Within the network design, all special devices such as gateways, routers, switches and bridges not only must be recorded as to their location but should also include detailed documentation regarding any unique setup information. This also applies to documentation of printers and printer sharing devices which can be the source of significant end user difficulties if not properly documented.

For the workstations, much time can be saved if all internal subsystems are known and well documented. This includes, but not limited to, network address, disk drives, tape drives, modems, fax boards, CRT boards, extra memory, processor type, or anything else that may lurk inconspicuously behind the generic AT-style casework. Once all of the subsystems are known, it is important to also record their hardware configuration parameters. Things like IRQ settings, memory base address, and DMA or SCSI channel ID will save tremendous amounts of time if they do not have to be rediscovered. Operating system type and revision level, as well as local applications information can prove invaluable in case of disk loss or damage.

In the server, all of the workstation parameters apply along with a few others. Operating system type and revision level is absolutely critical as well as any patches applied. Know the number and configuration of the Network Interface Cards (NICs), disk storage, and main memory. For server based applications, know the type, revision, and user licenses available.

Document Network Design Limitations

It is important to clearly define the limitations of the network design to provide a well-established baseline for both optimizing network performance, and for implementing future moves, adds, changes and upgrades. For example, the documentation needs to specify such details as the maximum number of nodes, the limitations of cable lengths, etc. In these days of heterogeneous service convergence and mixed-media networks, it is far easier to clearly document topological design rules and limitations than to expect to remember them or to assume your staff is completely familiar with all of your site's unique variations. Not knowing or following the rules may not result in immediate problems but could leave the network operating marginally, only to fail at a later time.

Careful Installation

It is always better to find a potential problem early, rather than have a user discover it during a critical situation. Therefore, it is good practice to take the extra effort at installation (or upgrade) to follow careful and thorough workmanship practices. For instance, double check cable continuity while jiggling connectors to ensure reliable mechanical connections. Make certain you or your installer avoid installing cable close to electrically noisy devices such as AC power lines, fluorescent lighting, motors, or transformers. From the AC power protection perspective, as a minimum, install surge protectors on each device for secondary surge protection. It is also highly recommended that you install uninterruptible power supplies (UPS) at least on file servers and backup equipment.

Anticipate Failures

Even the best designed and carefully installed networks are not going to always operate flawlessly, so it is important to plan for failures and to have contingency actions mapped out ahead of time. For example, educate yourself on what to expect in terms of failure rates, such as MTBF (mean time between failures) and MTTR (mean time to repair) for disk drives, major server components, hubs, concentrators, bridges and other key network components. Knowing which devices are likely to go first may not only assist you in problem prevention, but provide a starting point when failure does occur.

Develop a Benchmark

In order to know if a network is having problems, it is necessary to have adequately characterized it when it was healthy. Use network management tools and review network statistics regularly. By getting a "snapshot" of network activity, traffic, and behavior when the LAN is operating properly, the system manager can detect downward trends and trouble spots quickly and easily. Look for performance degradation and network or node-specific overload. Published performance specifications may not adequately apply to your unique site, necessitating the development of specific criteria for your own purposes. (Refer to Section I of this handbook for more information on network performance monitoring methods and tools.)

Overview of Testing Standards

The Evolution of Cabling Standards

Because the underlying cabling system infrastructure essentially forms the "highway" for handling all traffic on a network, the industry-accepted standards used for certifying a network highway have naturally undergone significant revisions as traffic levels and speeds have dramatically increased over recent years. Just as highway standards are critical to maintain the flow and safety of many types of vehicular traffic across different jurisdictional environments, cabling standards have evolved to ensure that customers can depend upon their certified installations to reliably support a variety of heterogeneous protocols and performance requirements.

Since the first establishment of broadly accepted industry standards, they have primarily focused on clearly defining two key parameters:

- Performance characteristics of components such as cabling and connecting hardware
- The transmission capabilities of the assembled and installed transmission link

Specific standards have evolved under the auspices of organizations, such as the Telecommunications Industry Association (TIA), the Electronic Industries Alliance (EIA), the American National Standards Institute (ANSI), the International Organization for Standardization (ISO), and the International Electrotechnical Commission (IEC). The development of standards have also provided the following benefits within increasingly complex network environments:

- Consistency of cabling design and installation
- Conformance to physical and transmission line requirements
- A basis for examining a proposed system expansion and other changes
- A consistent structure for uniform documentation of cabling installations
- Improved interoperability across mixed-vendor environments

Throughout their evolution, cabling standards have had to constantly balance the need for compatibility with existing technologies (connector form factors, punch blocks, etc.) with higher speed capabilities achievable through improved UTP characteristics and more accurate testing methods. In addition, the demands of different networking environments around the world have engendered two major classifications of standards, those developed by the TIA/EIA and by the ISO. TIA/EIA standards have provided the primary guidelines for installing and certifying North American cabling installations while ISO standards have been used throughout Europe.

The following sections provide a brief description of the key TIA/EIA and ISO standards that have formed the foundation for cable testing during the past few

years, plus a quick look at the status of new standards currently in development and/or under discussion.

TIA/EIA 568A & ISO 11801

TIA/EIA 568A and ISO 11801 constitute the primary Commercial Building Telecommunications Standards that are currently approved and finalized. While the TIA/EIA "Categories" and the ISO "Classes" do not have a perfect one-to-one correspondence on all details, in general they match up as follows:

- Category 3 and ISO Class-C
- TIA/EIA Category 4
- TIA/EIA Category 5 and ISO Class-D
- TIA/EIA Category 5e

As detailed in the sections below, a proposed Draft 5 revision to TIA/EIA 568A and the 2nd Edition of ISO 11801 will also provide for a uniform match up between TIA/EIA Category 6 and ISO Class-E

TSB-67

Technical Service Bulletin 67 supplements the TIA/EIA 568A specifications by providing detailed Transmission Performance Specifications for field testing UTP & STP cabling systems to meet 568A requirements. TSB-67 also defines accuracy requirements for cable testers, which define the maximum acceptable differences between the measured values reported by the tester and the actual values of the link's characteristics. Level II accuracy requirements for testers were initially established with the adoption of TSB-67. At the same time, a Level I category was created to grandfather in existing test equipment that could not meet TSB-67 Level II requirements. TSB-67 defines four measurements for certifying cables to Categories 3, 4, and 5: Line Map, Link Length, Attenuation and Crosstalk (defined as Near-end Crosstalk or NEXT). It also specifies the definitions for basic link and channel test configurations as well as the test methodologies for certifying cabling installations.

TSB-95 (CAT5) Gigabit

TSB-95 is a Draft-10 service bulletin that has been widely accepted as the basis for CAT5 testing and certification. TSB-95 augments TSB-67 and TIA/EIA 568A by defining the additional Category 5 measurement parameters of Return Loss and ELFEXT (Equal Level Far End Crosstalk). The new measurements of Return Loss and ELFEXT were incorporated at the request of the IEEE-802.3 a/b committee, which is responsible for defining the standards for transmitting Gigabit Ethernet over copper wiring (1000Base-T). These more stringent measures were needed because 1000Base-T requires a multi-transmit environment where all four pairs are used to transmit in both directions simultaneously.

TIA/EIA 568A Addendum 5 (CAT5e)

TIA/EIA 568A Addendum 5 enables existing Category 5 cabling to reliably carry 100 MHz traffic. The Category 5e specifications are supplemented by Level II-E

certification standards, which are defined in TSB 95. In addition to existing test parameters, Level II-E testing for CAT5e also incorporate Power Sum capabilities, which sum up the worst case measurements for all of the wiring pair combinations. Power Sum also provides a solid method for assessing Attenuation to Crosstalk Ratio (ACR) characteristics.

TIA/EIA 568A Draft 5 (CAT6) and ISO 11801 2nd Edition (Class-E)

TIA/EIA 568A Draft 5 represents a proposed revision and update of the entire 568A specification that incorporates all changes to date and also defines a new Category 6. Category 6 will be the nomenclature applied to cabling systems using RJ-45 style connectors and certified to carry 200 MHz traffic. Category 6 will also require testing to a new Level III accuracy. The adoption of CAT6 and Level III should also harmonize TIA Category 6 with ISO Class-E cabling. Level III accuracy will incorporate all of the existing tests used in TSB-95 at the CAT5e level. However, the movement from 100 MHz to 200 MHz traffic levels (250 MHz for the test suite) requires a significant improvement by as much as 10 dB in each of the critical RF parameters that characterize the test device's accuracy.

TIA/EIA 568B Proposed (CAT7) and ISO Class-F

TIA committee has also begun discussions on defining Category 7 that will likely provide 600 MHz transmission capabilities at some point in the future. However, because of the limitations of existing Unshielded Twisted Pair and RJ-45 connectors, it is projected that Category 7 will require both shielded wiring and a new connector design. Currently a leading candidate for the wiring media is PIMF (Pairs in Individual Metal Foil), which is already in use in many European countries. Potential connector designs for Category 7 are under discussion between the TIA, other standards groups, and the connector manufacturing industry.

Structured Cabling Concept

Beginning with the adoption of TIA/EIA 568-A, most international cabling standards have been predicated upon a hierarchical cabling infrastructure where all Work Area Outlets (WAOs) for individual desktop connections are "star-wired" back to a Main-Cross connect (MC) via horizontal cabling to the Telecommunications Closet (TC) where the cabling is terminated on the Horizontal Cross-Connect (HC). Backbone cable is used to support TC to MC connections, or TC to Intermediate Cross-Connect (IC) in some instances, and then back to the MC.

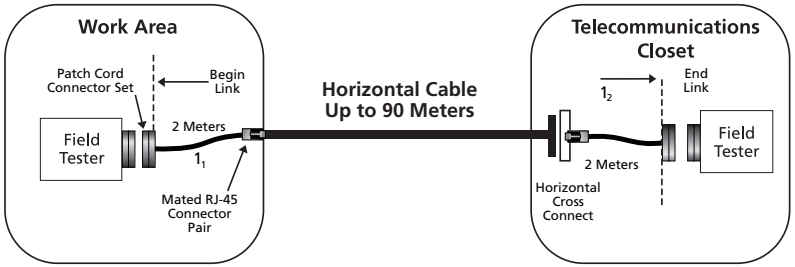
Under the Structured Cabling System (SCS) concept, the interconnection of the entrance facility (EF), service entrance (SE), MC and IC form backbone pathways routing cables to the HC in the TC and in turn along horizontal cabling to the WAO. All of these components are classified as the cabling infrastructure, which should be designed to support a building for 10 to 15 years. Installation in accordance to the industry's standards ensures operational capabilities for most popular network technologies in existence today, and should support migration to newer technologies.

Test Configurations

The horizontal cabling should be limited to 100 meters (90 meters plus a 10 meter allowance for the line cord at the device, patch cords, and patch cordage for cross-connects). Horizontal cabling segments generally fall into the three categories of Basic Links, Channel Links and Permanent Links, defined as follows.

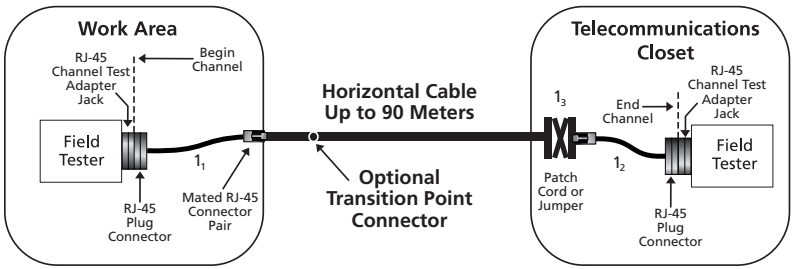
Basic Link

A Basic Link consists of up to 90 meters of horizontal cabling, with one connector at each end and no transition connectors. Up to 2 meters of equipment cord can be used at each end between the Basic Link connector and the test equipment.



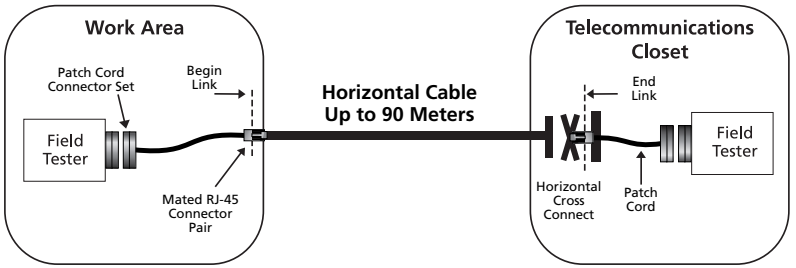
Channel Link

A Channel Link consists of up to 90 meters of horizontal cabling connecting to the Telecommunications Outlet, including allowance for an optional transition connector near the Work Area Outlet. A Channel Link can have up to two cross connections in the Telecom Closet. Total length of equipment cords, patch cords and jumpers is limited to 10 meters. Connections to equipment at each end are not included.



Permanent Link

There has been movement within the industry toward the widening use and adoption of an additional testing configuration that is defined in ISO/IEC 11801 as a "Permanent Link". This is a logical connection that runs from the RJ-45 connector on one end of the channel to the RJ-45 connector on the other end of the channel. Permanent Link assumes that test adapter cords will be used, but that the test equipment will have the ability to logically remove them from the channel measurements.



Overview of Test Requirements

As previously described, the evolution of TIA/EIA and ISO/IEC standards to encompass higher performance cabling links has also driven an expansion of test requirements to ensure reliable installation compliance at each level. The following table displays the various test suite components, such as Line Map, Link Length, Attenuation, Impedance, Crosstalk, ELFEXT, etc., and relates each test to the applicable TIA Categories and ISO Classes.

Applicable TIA/EIA, ISO/IEC Standard	Cable Type: TIA Category or ISO Class	Unshielded or Shielded	Field Tester Accuracy Level	Test Frequency	Test Configuration(s)	WireMap	Resistance	Length	Attenuation	NEXT	Capacitance	ELFEXT	Return Loss	Impedance	Delay-Skew	ACR	PS NEXT	PS ELFEXT	PS ACR	Headroom
TIA/EIA568A	CAT3	UTP	Level I	16 MHz	Channel	•		•	•	•										
TIA/EIA568A & TSB67	CAT5	UTP/STP	Level I/II	100 MHz	Basic/Channel	•		•	•	•										
TIA/EAI568A & TSB95	CAT5 (GBE)	UTP/STP	Level II	100 MHz	Basic/Channel	•		•	•	•		•	•		•					
TIA/EIA568A & TSB67	CAT5e	UTP/STP	Level IIe	100 MHz	Basic/Channel	•		•	•	•		•	•		•	•	•	•	•	•
TIA/EIA568A & TSB67/95 (Draft 5 Proposal)	CAT6	UTP/STP	Level III	250 MHz	Basic/Channel	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
ISO 11801	ISO Class-C	UTP/STP	Level I	Level I	Basic/Channel	•	•	•	•	•	•		•	•	•	•				
ISO (Proposal)	ISO Class-D	UTP/STP	Level I/II	100 MHz	Basic/Channel	•	•	•	•	•	•		•	•	•	•				
ISO (Proposal)	ISO Class-D 120	UTP/STP	Level I/II	100 MHz	Basic/Channel	•	•	•	•	•	•		•	•	•	•				
ISO (Proposal)	ISO Class-E	UTP/STP	Level III	250 MHz	Basic/Channel	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

Detailed definitions on each of the Test Suite Components are contained in Section G of the Cable Test Handbook (also published as a separate white paper on "Descriptions of Physical Layer Testing"). However, for resolution of actual cable certification issues, installation technicians should always refer to the most current edition of the applicable TIA/EIA or ISO/IEC standard as their final authority.

Category 3 is mostly used for telephone and low-speed data applications such as 10 BASE-T. (Category 4 has been omitted from the comparison table because it has essentially disappeared and has been replaced by Category 5 which currently has become the cable media of choice for horizontal cabling to the desktop.)

Category 5
Category 5 currently supports 100 Mbps (Fast Ethernet) and 155 Mbps Asynchronous Transfer Mode (ATM). It is also the goal of the IEEE 802.3ab committee to make Gigabit Ethernet (GBE) rated at 1000 Mbps backwards compatible to standard Category 5 cabling that was installed in accordance to the standards.

Category 5e
Category 5e provides somewhat better pair-to-pair performance and improved Return Loss, Near End Cross-talk (NEXT), and Equal Level Far End Cross-Talk (ELFEXT). From a test parameter standpoint, CAT5e and Level II-E accuracy essentially pushed each measurement category up by 3 dB over existing CAT5 requirements.

There is some concern in the industry that Category 5e did not go far enough because many existing installations of standard Category 5 cable and connectivity products are passing the Category 5e test parameters. This is likely a result of the highly competitive environment that has existed among cable manufacturers and the need for differentiation, which has led to the widespread design and manufacture of products with better than standard Category 5 capabilities.

Category 6 & Class E
Category 6 is intended to offer significant improvements in transmission capabilities with a frequency capability up to 200 MHz. The adoption of CAT6 and Level III is also intended to harmonize TIA Category 6 with ISO Class E cabling. Field test equipment for Category 6/ Class-E will be required to sweep to 250 MHz to cover any measurements in close proximity to the 200 MHz benchmark and will also have to test to a new Level III accuracy. Level III accuracy will incorporate all of the existing tests used in TSB-95 at the CAT5e level. However, the movement from 100 MHz to 200 MHz traffic levels (250 MHz for the test suite) requires a significant improvement by as much as 10 dB in each of the critical RF parameters that characterize the test device's accuracy. This is spawning a whole new generation of field testers to meet Level III requirements.

Category 6 / Class-E Implementation Issues
The clear objective of the currently proposed Category 6 and Class-E standards is to create an open 200/250 MHz standard that continues to allow the flexible mixing and matching of various vendor components, such as plugs, jacks and other connecting hardware, along with cabling from a variety of manufacturers. Cable installers have always enjoyed the benefits of such flexibility at the previous lower-speed Category/Class levels, thereby enabling them to easily manage heterogeneous inventories of parts without impact on overall installation reliability. Unfortunately, the migration to Category 6/Class-E is potentially eroding that overall mix-and-match flexibility due to the limitations of the RJ-45 connection.

As Category 6 and Class E draft specifications are being refined toward worldwide industry agreement, field test capabilities are closely tracking the draft requirements. In addition, there is available cable that clearly meets the Category 6 objectives along with a number of connector manufacturers that claim to have a total Category 6 solution. However, the weak point in overall Category 6 viability remains the RJ-45 connection.

Obviously, the goal of Category 6 is to specify a 200 MHz solution that is fully backward compatible with existing Categories 5 and 5e. However, squeezing Category 6 performance out of the RJ-45 without changing its form and function is requiring electrical tuning techniques as the sole avenue of improvement open to connector designers. As a result, the creation of higher performing CAT6-tuned "super plugs" may present significant backward-compatibility problems. The evidence indicates that tuned combinations of improved plug-and-jack connectors can effectively support Category 6 speeds. However, if a tuned RJ-45 plug is connected to an existing Category 5 jack, it can produce mismatched compensation and degraded NEXT performance that fail to even meet Category 5 requirements.

From an installer's standpoint, the lack of an industry wide standard for electrically tuning new Category 6 components means there is a definite risk of failure when attempting to mix RJ-45 plugs and jacks from different vendors. It is becoming increasingly important to consciously select and test for cross compatibility between connector components throughout a structured wiring implementation. These incompatibility issues can also pose a problem when it comes to the accepted practice of both installers and network administrators creating patch cords in the field. In addition, because the customer's equipment interfaces can cause incompatibility problems, the advent of Category 6 may require a higher level of customer hand holding and assistance well beyond the point of final cable certification.

Future Cabling Standards: Category 7 / Class-F
As previously described, the future definition and adoption of Category 7 / Class-F cabling standards is intended to push effective transmission speeds into the 600

MHz range. To achieve this objective will require going beyond the limitations of both unshielded cabling and the RJ-45 connector format. Most industry participants have accepted that the most likely cabling configuration will consist of individual shielded wire pairs, with an overall shield around all four pairs. Existing cabling such as the PIMF used in some European countries can potentially provide positive ACR values at 600 MHz, however, the high attenuation characteristics result in a relatively weak signal. In addition, the use of shielded cabling and the need for an entirely new connector design is likely to make the installation and certification of Category 7 / Class-F cabling a significantly more expensive proposition.

Because of the added expense and the uncertainties surrounding the CAT7/ Class-F situation, there is also a possibility that in the interim the emerging trend toward fiber optic cabling will subsume a significant portion of the market demand for higher speed copper solutions. Already fiber optic cabling has become a de facto choice for high-speed long-haul backbone implementations and the widening usage of fiber is helping to drive down its overall cost. In addition, most professional cabling installers are adding both the skills and equipment required for handling fiber cabling as well as traditional copper. (More detail on fiber optic testing equipment and procedures can be found in Section H)

Maintaining Effectiveness in an Environment of Evolving Standards

The relentless need for higher performance is destined to continue pushing the evolution of cabling standards and testing/certification requirements. It is therefore that professional installation companies and their customers maintain a constant awareness of the current state of all standards. Current versions of most cabling standards and draft versions of newly proposed standards can be obtained from organizations such as BICSI and official documents/specifications can also be purchased directly through the individual standards-setting organizations, such as TIA/EIA, ISO/IEC, etc.

In this changing standards environment, it is important that professional installers take advantage of the smooth migration paths offered by front-tier test equipment manufacturers. For new installation companies just entering the LAN market, a standards-based equipment migration path allows them to equip their initial teams with entry-level devices and then add higher-end systems as they grow, without the headaches and expense of wholesale retraining programs. For the large installer, the availability of many price/performance levels and support for on going upgrades enable them to efficiently equip and deploy more installer teams with targeted capabilities, while effectively managing their overall equipment investments. In addition, with cable installers and their customers both using equipment from a common family of devices and mutually staying abreast of changing standards, activities such as over-the-phone troubleshooting become much easier, thereby saving both parties significant time and expense.

Physical Layer Tools

Ohmmeter

Commonly referred to as a multimeter, VOM (Volt-Ohm-Milliampere-meter), or just meter, this is the most widely used type of cable test equipment today. The ohmmeter is used typically to measure continuity in a cable. A shorting device of some type is applied to the far end of the cable under test, the meter is attached, and hopefully something close to a short-circuit (very low resistance) is detected on the meter's display. For years, this was the predominant method of cable test, providing only bare-minimum open/short indications of cable quality. As more sensitive digital ohmmeters became prevalent, the cable's DC resistance value could be calculated and compared to a specification. In coaxial cable based systems, usually little more than this value and the length of the cable is necessary to validate the network's physical plant. Now that installations are shifting to various types of twisted pair media, however, much more information is required to be certain that the LAN will function properly on this new media.

Terminators

Terminators are used to end a particular cable segment or run. Typically two types are used, shorting and matching. Shorting terminators place a short circuit on either a pair of conductors or on all pairs of conductors in a given wire. When used in conjunction with the multimeter described above, shorting terminators provide a means to measure the DC loop resistance of the cable. They can also be used for a very basic form of station/cable identification by way of a short or open circuit measurement at the opposite end of a cable segment. Unfortunately, if there is a short circuit due to a problem, this could be a very frustrating test experience.

The other type of terminator is a matching terminator. This device provides the proper impedance match for the network cable during normal system operation, and is attached while the LAN is up and running. In conjunction with the multi-meter, basic wiring function can be measured. If the measured resistance of the matched line is very close to the matching terminator's value, the operator can judge that his cable segment is probably wired correctly. Another measurement technique using matching terminators is finding extraneous electrical noise. While matched, the cable segment under test can be monitored with a multimeter set to its AC mV range. Any voltage induced from outside sources will be measured. The user, however, will not receive any indication of the frequency of this noise, information that could help indicate possible sources of the noise so you could look closely at the cable path to determine if it is too close to noise inducing devices such as motors, power transformers and light ballasts.

Talk-sets

Installers and maintenance personnel require a method of communicating in those frequently encountered situations where it is impractical to walk back and forth between workstations and equipment rooms. Previous reliance on walkie

talkies presented problems because in many cases the walls of the structure were too thick and/or there was too much steel content in them. Slowly walkie talkies have been replaced with cost-effective talk sets built directly into the test equipment to allow communications on the media being tested, including talk sets that operate over fiber optic cabling. The WWG LT 8000 Series products offer talk sets that allow you to talk directly over the cables you are testing.

Time Domain Reflectometer

Probably the most effective tool for cable analysis in use today is the Time Domain Reflectometer (TDR), which measures cable length and impedance mismatching. Its output is typically an oscilloscope-like screen or a printout. It works by transmitting a fast rise-time pulse down the cable under test. It then monitors the cable for constant voltage, looking for reflections of the transmitted pulse. Impedance mismatches along the length of the cable cause reflections which are then displayed on the TDR's output. A significant reflection occurs at the end of the cable. Based on the cable's nominal velocity of propagation (NVP) dialed into the TDR prior to testing, the unit can measure the time it takes for the transmitted pulse to be reflected from the far end of the cable. By manipulating the instruments controls, the absolute length can be calculated quite accurately.

Impedance mismatches such as cable type changes, bad vampire taps (coax), pair splits and others will also be identified where they occur down the line. This is especially valuable for cable quality analysis since things like corrosion, stretching, crimping, incomplete shielding, and other defects that are visually undetectable can be easily identified with the TDR. Not only can their location be found, but the length of the defect itself can be recorded.

Noise Meter

A particularly vexing problem plaguing all types of cabling installed inside buildings is induced electrical noise. Because of its architecture, shielded cable is less susceptible to noise. Unshielded cable however, becomes an antenna when subjected to sufficient levels of induced electrical noise. To properly identify sources of noise, a wideband AC noise meter is used to not only measure the amount of unwanted signal, but to also analyze the frequency of the induced voltage to possibly isolate the offending device generating the disturbance. Typical sources of electrical noise include motors, fluorescent lighting, broadcast equipment, and microwave devices. Each of these sources has characteristic frequencies at which the generated noise is highest. By evaluating the frequency component of measured electrical noise, it is then possible, to a certain extent, to identify the source. We will discuss types of noise and how each relates to a typical source later in the text when we talk about noise testing.

Line Mapper

The proliferation of twisted pair cabling in LAN use has dictated the need for a device to verify all wires in a given modular plug are connected straight through to the same pins at the opposite end of the cable run. Since the cabling is very similar in appearance to telephone system wiring, but not connected in the same manner, this becomes an important test as the two are easily confused. Due to their small size and viewing angle, it is very easy to miswire or reverse conductors in a modular plug. In its most basic form, a line mapper may be simply a multimeter with various combinations of resistors and diodes to verify all lines and detect pair swaps. A more common version uses light emitting diodes (LED's) to display the status of each conductor. A loopback terminator is installed at the far end and the user simply monitors the LED's for the connectivity information. More advanced units not only provide this but will also indicate status such as open or shorted conductors, printouts showing both modular connector's conditions, and pin-to-pin wiring configuration.

High Frequency Signal Generator

To accurately measure parameters such as attenuation and crosstalk, a stable, preset signal source is needed. This source must be able to closely simulate and in some cases, even surpass the frequency bandwidth of a fully loaded network. This means applying signals up to 100 MHz to the Category 5 cable under test to get an accurate picture of that cable's characteristics under live conditions. Ideally, the output waveform will be a square wave to more closely simulate actual network traffic. For measurement purposes, however, a sine wave will stress the cabling system adequately and provide usable data defining the cable plant's capabilities. Since near end crosstalk (NEXT) is the key parameter defining the difference between grade levels of unshielded twisted pair cables, it is imperative that it be measured accurately for correct cable analysis.

Capacitance Meter

In lieu of a TDR, a capacitance meter may be used to identify cable damage. Especially with PVC jacketed twisted pair (because it is easily stretched), a cable's mutual capacitance will change if it has been stressed during installation. The capacitance meter is attached to each conductor of a pair on an open cable to make this measurement. Nominal capacitance is typically specified by the manufacturer (usually in picofarads per foot) and normally does not vary. Specifications such as the TIA/EIA 568-A (Commercial Building Telecommunications Standard) also provide test values for various cable types.

Power Meter

The power meter is used in concert with the high frequency signal generator to make attenuation and crosstalk measurements on the cable under test. By injecting a signal of a known amplitude, cable attenuation can be calculated by installing the power meter at the opposite end of the test run. The result is usually expressed in negative decibels over the frequency range of the test. The signal

source is presumed to be 0 dB and the result will be somewhere in the range of -1 to -25 dB at the test end of the cable. We will expand upon interpreting the results in the Tests section of this document. NEXT can also be tested with the power meter by attaching it to the same end of a matched line as the signal source but to an adjacent pair. This way the amount of crosstalk can be directly associated with the frequency of the applied signal assuming that the amplitude is constant throughout the test bandwidth. NEXT results interpretation will also be detailed later in the book.

LAN Cable Tester
The growing sophistication of cabling test standards and the use of extensive test suites to certify new installations has made it important for both cable installers and end users to use new generation integrated LAN cable testers. These testers typically pull together all of the test requirements into combined AutoTest suites and provide outputs in easy-to-understand Pass/Fail formats.

For example, the WWG LT 8000 Series of LAN Cable Testers offers a complete family of high-performance solutions that deliver full CAT5e Level II cable testing, plus the option for cost-effective CAT6 testing with the new LT 8600. The entire LT 8000 family conforms to all internationally recognized test suite standards and enables users to quickly output test results in simple, easy-to-read, user-friendly formats.

High-end family members, such as the LT 8155 and the new LT 8600, can test cabling rated from 100 MHz up to 300 MHz at Level II, Level II-E and Level III accuracy, while supporting the cable installer's business requirement to store and manage large numbers of separate test results.

Key features common to all of the LT 8000 Series include:

- Compliance with all recognized international cable test standards (TSB-67, EN 50173 & 50174, ISO 11801, DIN 44312-1)
- Two-Way Return Loss (identifies problems that one-way cannot)
- Hardkeys for frequently used operations (e.g. Wire Map, Length, Cable Type)
- Delete Recovery of last operation (eliminates costly re-testing after erroneous deletes)
- Industry-leading Intuitive User Interface for overall ease of operation and reduced learning curves

By sharing a common set of features and the same intuitive user interface across the entire product line, the LT 8000 Series empowers both end users and professional installers to cost effectively test and troubleshoot virtually any cabling installation while maintaining a common basis for communicating and comparing test results.

Description of Physical Layer Testing

Overview of Tests for Copper Cabling
Since the first adoption of TIA/EIA 568A up through the currently proposed standards for Category 6 / Class-E cabling, a number of specific testing standards have been defined for checking and certifying horizontal cabling links. From the initially mandated tests for Line Map, Line Length, Attenuation and Near End Crosstalk (NEXT), the range of tests has been expanded to include DC Loop Resistance, Capacitance, ELFEXT, Return Loss, Impedance, Delay/Skew, Attenuation to Crosstalk Ratio (ACR) and PowerSum for NEXT, ELFEXT, and ACR. This document focuses primarily upon presenting descriptions of the various tests and should be used in conjunction with the separate white paper titled "Overview of Cable Testing Standards" to fully understand how the individual tests relate to each applicable TIA/EIA and ISO/IEC standard. Also, it should be noted that this document addresses only the tests for copper cabling. Fiber optic testing issues are dealt with separately in a white paper entitled "Tests for Fiber Optic Cabling".

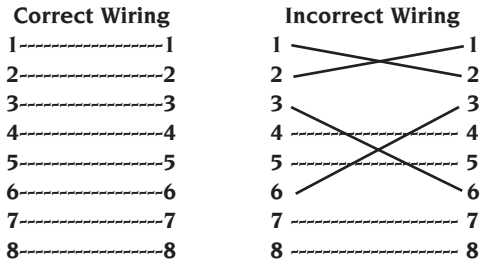
Line Map
Line mapping, also referred to as end-to-end connectivity, is a test that identifies the status of each wire in a twisted pair environment. Unlike telephone systems, which often reverse two or more conductors, LANs require that all lines are connected straight through from hub/concentrator to the workstation. The pairs are grouped as a transmit +/- pair and a receive +/- pair. It is very important that these lines are not crossed or shorted as the integrity of the network will suffer. Local area networks implemented on twisted pair wiring rely on active electronic devices to make the physically star-wired nodes appear logically as a ring or a bus depending on the topology. The integrity of the twisted pair wiring system enables any workstation connected, to be consistently recognized by the network operating system and network hardware/software drivers.

Testing end-to-end connectivity used to be a tedious process. Prior to the development of modern loop-back devices, this could only be accomplished using a multimeter and a semi-conductor PN junction component such as a diode. By placing diodes of differing values between the desired pairs, continuity and cable connect direction could be measured by reversing the polarity of the ohmmeter on each pair and comparing the resistance with recorded values. Using this method, an experienced technician might have qualified only 5-10 runs per hour.

A number of different test devices are now available, designed specifically to simplify this process. Their abilities range from simply identifying that wires are connected, to printing out the status of each individual conductor. These test devices use loopback plugs of various configurations to execute their testing.

Visual displays range from a panel of light emitting diodes (LEDs) to liquid crystal text (LCD) and printouts. The example below shows a comparison of correct and incorrect wiring for a LAN. The incorrect example has wire pairs 1,2 and 3,6 crossed.

Line Mapping



Test Results

Line Mapping:	**1 2 3 4 5 6 7 8**	**1 2 3 4 5 6 7 8**
Office Id: 5	**1 2 3 4 5 6 7 8**	**2 1 6 4 5 3 7 8**
Pass Criteria:	**1 2 3 4 5 6 7 8**	**1 2 3 4 5 6 7 8**

LAN Connectivity Examples with Test Results

The type of connectivity test equipment used will effect how the results of its tests are interpreted. For LED display testers, usually a lamp will light up indicating that the pair under test is connected (shorted) in the loopback connector at the far end. An open circuit will result in no illuminated LED for that pair. The drawbacks to this type of testing are that there is no indication of a short outside the loopback plug (at a cross-connect for example), and there is no way to determine if a wire reversal has occurred (i.e., 3,6 has become 6,3).

More advanced units incorporating LCDs and/or printers usually provide much more usable information. These devices not only indicate basic connection but will show wire reversals (or flips), open circuits, and short circuits and distance to fault information. Open or Short circuits are represented by an “o” or an “S” replacing that line’s number. Wire flips are easily detected by lining up near end and far end pin designators. Intelligent termination devices can also be used to provide different resistances on each pin as well as a variable value to facilitate quicker cable labeling and office identification.

DC Loop Resistance

All metallic cables insert a certain amount of DC resistance into a circuit, measured in ohms (Ω). Like the heating element in an electric oven, this resistance causes some of the electrical signal to be absorbed by the cable and dissipated as heat. As a general rule, data cabling has a very low resistance value that does not add a significant load to the transmission system or network. However, if there is too much resistance present, excessive signal loss will occur and will be observed as a transmission problem.

DC resistance is often confused with impedance, a term describing the dynamic resistance to signal flow, usually at a specified frequency. Both are measured in ohms because they define different types of opposition to electrical current flow. We will address impedance in more depth later. The main point here is that DC resistance increases proportionately with the length of cable being tested while (AC) impedance remains fairly constant regardless of length.

An ohmmeter is the most common tool used in DC resistance measurement. Alligator type test clips or some other shorting device is applied to two conductors at the far end of the cable under test (center to shield for coax, or between a pair for twisted pair). The loop resistance is then directly read from the ohmmeter. The table below provides some common DC resistance specifications.

COAXIAL	OHMS/SEGMENT	SEGMENT LENGTH
10BASE-5	5 Ω	500 m (1640')
10BASE-2	10 Ω	185 m (606')
TWISTED PAIR	**OHMS/100m SEGMENT**	**OHMS/1000'**
24 AWG	18.8 Ω	57.2 Ω
22 AWG	11.8 Ω	36.0 Ω

Common Cable Media Resistance Specifications

All pairs within the same cable should have nearly the same resistance. Variations in loop resistance can often be a quick indication of a cabling problem. Values at or below those shown in the table (measured with one end shorted) provide basic continuity information. For accurate measurement, an ohmmeter with a resolution of 0.1Ω or better is required.

Some of the common causes of excessive or inconsistent DC resistance include:

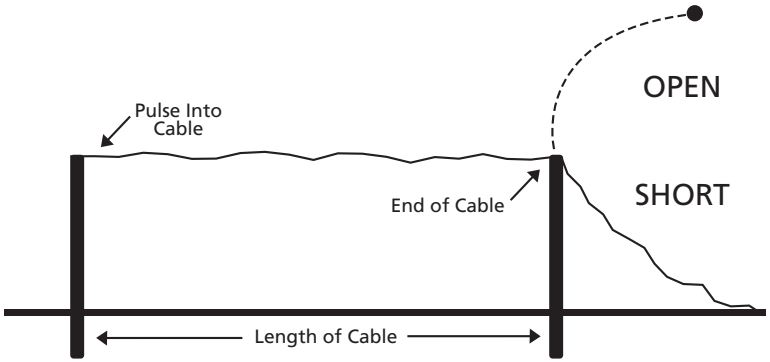
- Mis-matched cable types
- Poor punch block connections
- Poor RJ-45 termination connections
- Cable damage
- Shorted cable causing low DC resistance values
- Excessively long cabling runs

Cable Length Testing
All LAN topologies have inherent cable length limitations. For coaxial, shielded twisted pair and other high-grade cable plants, these limitations exist because of network timing considerations. That is, if the cable were any longer, it would take the signal too long to go from one end to the other and back. Thus, the originating node would think that its target didn't get the message and would re-transmit, causing collisions. For unshielded twisted pair applications, cable length is restricted due to signal degradation problems. This means, if the cables were longer, there might not be enough signal left for the receiver to detect reliably.

Cable length testing is almost always done with a test instrument called a Time Domain Reflectometer (TDR). It works very much like a radar, sending a pulse of energy down the cable. When that pulse encounters an impedance mismatch like a short-circuit or an open-circuit, reflections are generated which travel back up the cable to the transmitter. By knowing how fast electricity travels in the cable under test, the TDR can figure the cable's length by measuring the time it takes for the reflection to come back from the impedance mismatch.

(For discussion purposes, we will assume we are measuring a disconnected, or open cable with no other damage. In this case, the impedance mismatch is at the far end of the cable which is disconnected.)

Time Domain Reflectometry Sample Display



Basic TDR Function

The speed at which electricity travels in a cable is called the *propagation rate* of the cable. NVP, or Nominal Velocity of Propagation refers to the same thing. It is expressed as a percentage of the speed of light. The speed of light is designated by a lower case "c" (i.e., cable labeled 65%c or .65c means its NVP is 65 percent of the speed of light).

Almost all TDR's have the capability to adjust the NVP for different cable types; the propagation rate may vary slightly even between two batches of the same cable type from the same manufacturer! There is even more margin for error when dealing with multiple manufacturer's cables in a single segment. Testing for NVP is essential for accurate length measurements. Any TDR you choose will only be as accurate as the propagation rate entered into it.

If you don't know the NVP of the cable you are testing, there are several ways to determine it. The first method would be to go to the cable specification manual or directly to the manufacturer and ask. This is fine, except that the value obtained would be considered "nominal". That is, it would be a baseline from which the actual cable might vary up to ±2%. At that point it becomes an accuracy question and your length readings will vary based on the TDR's accuracy + the NVP error (which could end up being as much as ±10%.)

The second method minimizes the errors involved. It requires that you have a known length of the cable you wish to test. You should know its length to within ±1 foot. To avoid short link problems resulting in inaccurate measurements, TSB-67 recommends that you should have at least 15 meters of cable. The next step is to attach it to your TDR and look at the end of the cable on the display. Adjust the NVP until the TDR displays the length you know the cable to be. This will be the propagation rate for this cable. More sophisticated TDR-type testers have actual propagation rate tests which will calculate the NVP for you. These units also require that you know the length of the cable sample being evaluated.

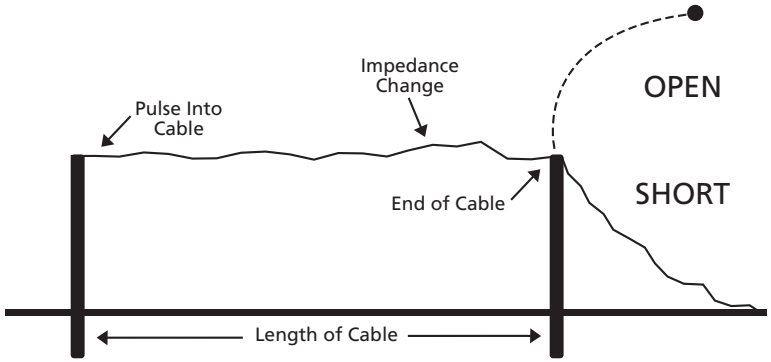
TDR's vary in their ease of use, sophistication, and type of display. The least expensive units on the market usually give only a numeric reading on an LCD indicating the distance to a severe short or open circuit. As price and sophistication increase, displays range from "raw" oscilloscope-type screens (no user reference points) to detailed graphic printouts giving average impedance and distance references for the entire length of the cable. We will look at cable impedance in more detail in the next section. Typically, the high-end TDR's have many adjustments for sensitivity and display interpretation may require a highly trained user. They are, however, able to detect impedance mismatches in a cable, which are much more subtle than a simple short or open circuit. These can include bad taps, poor punch downs, split cable pairs, internal cable water damage, and other defects.

Length test results will apply to the topology being tested. The primary factor is whether or not there is too much cable on a given segment. Occasionally, installation personnel leave a length of cable in a wall or ceiling in anticipation of a future move. This is fine as long as it is considered as part of the overall run. Depending upon the type of TDR used, results will be either a numeric value in feet or meters, or a trace on an oscilloscope-like screen.

Cable Impedance Testing

A Key analysis of a cable's quality throughout its length is a function of that cable's characteristic impedance. Impedance is defined as a measure of the total opposition to the flow of current in a given electrical circuit. It includes components of resistance, inductance, and capacitance. Impedance is often confused with DC loop resistance (described above) because both values are expressed in ohms. Impedance, however, is a more complex value that must remain constant regardless of the amplitude and frequency of the applied signal and independent of the cable's length. At a very basic level, the LAN cabling is part of the electrical circuit, which comprises the topology whether it is a ring, star or bus. Because of this, it is critical that the impedance of the cable not only be known on a baseline level (i.e., "characteristic", or the value published by the manufacturer and specified by the topology) but also relatively (that the published value is consistent throughout the length of the cable). If the impedance of the cable varies, it directly affects the performance of the electrical circuit of which it is a part.

In essence, average impedance measures the total opposition that each cable pair offers to the flow of a signal. Testing for average impedance can help identify physical damage to the cable, connector defects, or cable segments with incorrect characteristic impedance.



Cable Impedance Change at a Cross-Connect

Analysis of this measured impedance can provide quite a bit of qualitative information about the cable under test. Any disturbances to that cable's ability to carry signal can be easily pinpointed. Changes in relative impedance for a given segment can wreak havoc with the network packets transmitted on it. The impedance is inversely proportional to the speed of the signal traveling in the wire. That is, the higher the impedance, the slower the signal and vice versa. If there are several discontinuities in the cable, the signal speed will not be consistent. This speeding up and slowing down can produce excessive "jitter" on the transmitted pulses as well as framing errors and collisions or re-transmissions. Symptoms can be seen as sluggish workstation response, lockups, and possibly data corruption.

Some of the primary causes for the cabling that fails the Average Impedance Test are:

- Compression, stretching, or excessive bending that damages the cable
- Split wiring pairs within the cabling run
- Defective connectors
- Insulation damage at a connector
- Improperly chosen cable or patch cords
- Moisture in the cable

Capacitance Testing

The tendency for an electronic component to store energy is called capacitance. A capacitor is a device constructed of two electrically conductive pieces of material with an insulator sandwiched between them. One of its purposes is to store energy in an electronic circuit. When dealing with a transmission medium, such as a cable, capacitance becomes an undesirable attribute and needs to be minimized. Capacitance values for various cables are published in the manufacturers' catalogs and there is typically little variation from these specifications in actual measurement of the cable. The cables are rated normally in picofarads (pF) per foot. Unshielded twisted pair rates approximately 15-25 pF/ft. This value is called mutual capacitance. It is measured using a capacitance meter connected directly to the conductors of a pair with the far end terminated in an open circuit. The table below lists mutual capacitance maximums for the different UTP cable categories as defined by the TIA/EIA in the 568-A wiring specification.

TIA/EIA 568-A Mutual Capacitance Specifications

CABLE/CATEGORY	MAXIMUM MUTUAL CAPACITANCE
Category 3	20 pf/ft
Category 4	17 pf/ft
Category 5	17 pf/ft

Mutual Capacitance Levels for UTP

Measured with a capacitance meter, a given segment's reading will need to be divided by the length to give the proper pF/ft value. Unless there has been cable damage, it should be within 2% of the manufacturer's specification. Measuring mutual capacitance can quickly expose hidden damage that could not otherwise be detected except with the TDR and its scanning impedance capability.

Damaged cabling that exhibits a change in mutual capacitance can directly impair how a signal will be transmitted down the wiring segment. This becomes especially important with media such as UTP cable, which tends to stretch relatively easily.

Some of the primary causes of Capacitance Test failures include:

- Excessive bending or stretching damage to the cable
- Defective connectors
- Insulation damage at the connector
- Poor connections at punch-downs and wall plates
- Incorrect NVP settings
- Poor installation practices

Attenuation Testing

Attenuation is the amount of signal lost or absorbed in the cable itself. It is somewhat confusing because it is a negative term. The more attenuation you have, the less signal present at the receiver. Attenuation is also a dynamic measurement, it changes with respect to frequency. Most cables attenuate more as the frequency of the carried signal increases.

Attenuation is typically measured in decibels (dB). This type of measurement requires a known signal level as a reference from which to calculate the amount of loss. The reference signal is usually set to 0 dB. All subsequent measurements are then negative (i.e., -15 dB, -35 dB, etc.). By convention, the minus sign (-) is dropped or assumed in the reading display. Therefore, attenuation readings will generally be seen as 10 dB, 22 dB, etc. An important point to note is that decibel readings are logarithmic and not linear like resistance and voltage measurements. What that means is that for every 6 dB decrease, the signal strength is cut by 1/2. See the following table for some comparative voltage measurements and their decibel equivalents to provide a perspective on the impacts of attenuation on signal strength. The values shown are illustrative only. Our input signal is 500 mV. Since that is our reference, we calibrate our 0 dB to that value.

Reading Decibels

MILLIVOLTS (mV)	DECIBELS (dB)
500	0 dB
250	-6 dB
125	-12 dB
62.5	-18 dB
31.25	-24 dB
15.63	-30 dB
7.82	-36 dB

Decibels vs. Millivolts

As you can see, a measurement of - 20 dB would be a very significant amount of signal lost. Parameters such as DC resistance and characteristic impedance will affect a particular cable's attenuation performance. Just as with DC resistance,

more cable will cause more attenuation. The values obtained should be fairly additive with respect to the cable length; that is, twice the cable should cause twice the attenuation across the frequency spectrum you are testing. Remember though, since we are reading in decibels that would be only 6 dB more attenuation!

In the axial and shielded cable world, attenuation is not a particularly burning issue. Most of these types of cables are typically over-specified for the applications in which they function to allow for a large margin of performance error. It can become a significant factor, however, as topological length limitations are approached. This is especially true when the cable is of unknown or questionable origin.

For UTP (applications), however, the measurement of a particular segment's attenuation characteristics becomes more critical. UTP cabling exhibits far more loss than its axial counterparts, especially at high frequencies. This is one reason for tighter restrictions on segment length. Originally designed for voice use, UTP rarely carried frequencies greater than 5-10 kHz. At these levels, signals could travel several thousand feet before a repeater was needed. In a LAN, however, with transmission frequencies approaching 100 MHz and beyond, signals deteriorate beyond recognition within a few hundred feet. The typical LAN UTP length limit for ordinary cable is 100 meters (328 feet) between repeating devices. In their 802.3 (10BASET-supplement) document, the IEEE specifies that, including all patch and cross-connecting equipment, the maximum allowable attenuation for any segment at 10 MHz will be no greater than 11.5 dB. Although that sounds rather harsh, if you refer to Table 5, you will see that -11.5 dB is really only about 25% of the original signal! That is actually quite a large margin. In actual testing, most cables display what appears to be a linear behavior when attenuation is measured over increasing signal frequency and plotted on a logarithmic scale.

The most useful specifications as they apply to attenuation testing are those which pertain to a particular cable segment. Nominal numbers for cable, measured in thousand foot increments, are difficult to transfer to real segment lengths. The following table lists the values published in the TIA/EIA 568-A Building Wiring Standard (for Category 3 cable).

Frequency	Maximum Attenuation/1000 ft.
64 kHz	2.8 dB
256 kHz	4.0 dB
512 kHz	5.6 dB
772 kHz	6.8 dB
1.0 MHz	7.8 dB
4.0 MHz	17 dB
8.0 MHz	26 dB
10.0 MHz	30 dB
16.0 MHz	40 dB

Table 6. TIA/EIA 568-A Category 3 Attenuation Specifications

Since the relationship is so linear between length and attenuation, simple division can provide ballpark values for estimation purposes. From the table, a 10 MHz signal can have no more than 30 dB attenuation per thousand feet. In actuality, the attenuation increases at approximately 3 dB per hundred feet. Since UTP is not supported at 1000-foot lengths at this time, attenuation specifications for that amount of cable are strictly reference. More than likely, your segment will be in the neighborhood of 80 - 250 feet. Using the 3 dB/100 ft guideline yields a target estimate from 2.4 dB to 7.5 dB. By adding some overhead for the cross-connects and wall plate connections (1-2 dB maximum), one can easily determine whether or not the segment under test will pass attenuation. Although the example is for Category 3, other higher speed frequencies exhibit similarly consistent linear relationships between line length and attenuation.

Near-End Crosstalk (NEXT) Testing

One of the most important test parameters in the UTP world is near-end crosstalk or NEXT. Crosstalk is the tendency for a portion of a signal traveling in a pair of wires to be induced into adjacent pairs. The term comes from the early telephone days when conversations carried on nearby wires could be overheard on other circuits. The principle is the same, although the "conversations" consist of digital signals being transmitted and received between network nodes. These induced signals can have sufficient amplitude to corrupt the original signal or be falsely detected as valid data. Excessive NEXT can cause problems ranging from intermittent workstation lockups to complete network attachment failure.

Like attenuation, NEXT is typically measured in decibels (dB). It is based on a reference signal of known value so as to determine the amount of that signal which has been induced over to the adjacent pair. As a general trend, NEXT increases with signal frequency as attenuation does. Recent studies have shown that NEXT on UTP is not totally linear with respect to frequency as previously thought. In fact, UTP exhibits "peaks" and "valleys" of NEXT susceptibility that is very dynamic and changes even when the cable is moved slightly. The following table shows an example of the NEXT values for a sampling of currently-released cabling standards.

Characteristics for 24 AWG Twisted Pair Wire

(Basic Link: 90 meters horizontal cable and 4 meters equipment cords)

Category	DC Resistance	Attenuation	NEXT
3	28.6 Ω/1000 ft.	6.1 dB @ 4 MHz 10 dB @ 10 MHz 13.2 dB @ 16 MHz	30.7 dB @ 4 MHz 24.3 dB @ 10MHz 21 dB @ 16 MHz
4	28.6 Ω/1000 ft.	4.3 dB @ 4 MHz 6.8 dB @ 10 MHz 8.8dB @ 16 MHz 9.9 dB @ 20 MHz	45.1 dB @ 4 MHz 38.6 dB @ 10 MHz 35.3 dB @ 16 MHz 33.7 dB @ 20 MHz
5	28.6 Ω/1000 ft.	4.0 dB @ 4 MHz 6.3 dB @ 10 MHz 8.2 dB @ 16 MHz 9.2dB @ 20 MHz 21.6dB @ 100 MHz	51.8 dB @ 4 MHz 45.5 dB @ 10 MHz 42.3 dB @ 16 MHz 40.7 dB @ 20 MHz 29.3dB @ 100 MHz

Table 7. UTP Cable Specifications*

*Values derived from TIA/EIA 568-A, TSB-67 (at 20°C)

These peaks and valleys only appear when the frequency band is swept during testing; instead of making measurements at fixed frequencies between 100 kHz to 100 MHz, the cable is monitored as the test frequency increases gradually and constantly from base to high end.

It is important to note that the location and amplitude of these peaks change relative to the cable's position. Test results for cable on a spool will be very different for an installed segment. For loosely twisted cable, the change will be much more dramatic as the cable is flexed and stressed. The length of the cable will also affect its crosstalk characteristics. As the segment gets longer, its immunity to NEXT is decreased. Crosstalk, therefore, is another parameter affecting the maximum length of UTP cable segments.

Paired cable's extent of immunity to NEXT is related to how tightly each conductor is twisted together with its other half. Flat cable would therefore have the least immunity to both NEXT and environmental noise because it is not twisted at all. Testing proves this to be true and is the primary reason that this type of cable is unacceptable as a data transmission medium. Flat cable makes an adequate telephone extension cord and should not be used for anything else. Even when high quality twisted cable is used to interconnect network devices, care should be taken to maintain the integrity of the cable twist during installation. As little as half inch of untwisted cable at a punch-down or a connector, can cause marginal performance with respect to crosstalk susceptibility. Untwisted patch cables as short as two feet can cause an entire cable segment to fail NEXT testing.

Similar to attenuation, NEXT test results are also read in negative decibels. Using the same signal level reference (0 dB), we are now interested in the amount of that signal that has been induced into the adjacent pair of wires. Proper testing procedures dictate that both the disturbing (signal source) and disturbed (tested) pairs be terminated in a matching impedance. For most UTP applications, this will be a 100-ohm resistor. Since near-end crosstalk is an undesirable characteristic, larger negative numbers are best. In essence, attenuation readings should be as close to zero as possible while NEXT readings should be as far away from zero as possible.

Because of their dynamic nature, crosstalk measurements should be taken after the installation is completely finished, so that all cable and interconnecting components can be evaluated as a system. This provides a more accurate picture of the transmission medium's capabilities under actual operating conditions.

NEXT should be measured between all pair combinations for complete compliance. As mentioned earlier, NEXT is a test whereby you inject a signal on one pair and measure the induced noise on the adjacent pairs. This is performed with the swept/stepped frequency generator and TSB-67 requires it to be done in both directions. Because we are measuring near-end crosstalk, and since networks transmit and receive from both ends, a dual NEXT test is required.

NEXT behavior is unpredictable and must be tested using a sweeping source with specified measurement increments. A typical NEXT test from 1 MHz to 100 MHz will include a minimum of 483 measurement points. Unlike attenuation which gradually and regularly increases with test frequency, NEXT exhibits "peaks and valleys" of performance throughout the measured frequency band. Category 5 testers measure NEXT and compare it against the suggested curve. It has been determined that within a four Pair cable sheath there are six different combinations of NEXT, and since the test should be performed from both ends, there are actually twelve NEXT combinations for a given link. The tester then gives a "pass/fail" indication of the installed link. If the link fails, the tester will default to the worst case measurement in the link. Keep in mind that you could have multiple incidences of NEXT failure and when you solve one, others will move up on the list. NEXT is also measured with respect to a 0 dB source signal, but since we are testing for induced signal onto an adjacent pair, the measured results should be as far from that reference as possible. For example, a measurement of 31.5 dB at 100 MHz (actually - 31.5 dB) is better than a result of 26.0 dB (-26.0 dB) at the same frequency.

When looking at the results for a NEXT sweep, be careful to evaluate the segment's performance over the range of frequencies. Some network systems, such as Ethernet, do not move data at a fixed frequency by virtue of their nature (i.e., CSMA/CD with Manchester encoded data). These systems operate over a range

of frequencies often far lower and occasionally higher than their common rating. For example, a 10BASE-T system is nominally rated at 10 Mbps. Actual data speed on the cable ranges from less than 4 Mbps during relatively idle moments to more than 10 Mbps during heavy file transfers. The Manchester encoding scheme contributes to these high frequencies because there is a state transition (0 to 1 and vice versa) for every data bit regardless of its value. Whenever possible, try to test the cable plant with signals approaching real data characteristics.

Attenuation to Crosstalk Ratio (ACR)

Absolute values for NEXT throughout the operating frequencies of the transmission medium are certainly important, however, equally important, is the relationship between NEXT and attenuation for the same frequency range. The attenuation to NEXT ratio (ACR), or signal-to-noise ratio (SNR), is a valuable indicator of cable performance. Essentially, it is the difference between the worst case attenuation and the worst case near-end crosstalk. It can be expressed as follows:

$$\mathbf{ACR = NEXT_{WC} - ATT_{WC}}$$

where

$\mathbf{NEXT_{WC}}$ **= Worst Case Near-end Crosstalk in decibels**

and

$\mathbf{ATT_{WC}}$ **= Worst Case Attenuation in decibels**

For example, a 223-foot UTP segment has an attenuation reading of - 6.5 dB at 16 MHz. Its NEXT is measured at - 29 dB at 16 MHz. By plugging the numbers into the above equation (and discarding the '-' sign) we get an ACR of (29 - 6.5) 22.5 dB. Typically, the larger the ACR, the better the noise immunity.

ACR becomes increasing important for higher speed cabling categories that must reliably perform across a wide range of frequencies. Therefore attenuation and crosstalk requirements must be specified in detail for a variety of distinct frequency levels. The following table provides maximum attenuation and minimum NEXT limits at specified frequencies for Category 5 cabling installations.

Limits for Attenuation and NEXT

	Maximum Attenuation (dB/100m)		Min. NEXT (dB)	
Frequency (MHz)	Basic Link	Channel Link	Basic Link	Channel Link
1.0	2.1	2.5	60.0	60.0
4.0	4.0	4.5	51.8	50.6
8.0	5.7	6.3	47.1	45.6
10.0	6.3	7.0	45.5	44.0
16.0	8.2	9.2	42.3	40.6
20.0	9.2	10.3	40.7	39.0
25.0	10.3	11.4	39.1	37.4
31.25	11.5	12.8	37.6	35.7
62.5	16.7	18.5	32.7	30.6
100.0	21.6	24.0	29.3	27.1

TIA/EIA 568-A - Attenuation & NEXT Limits

Attenuation to Crosstalk Ratio (ACR) is one of the best indicators of the bandwidth capability of a link because it is derived from the worst case NEXT measurements with attenuation subtracted to come up with a value considered to be a margin. This margin is sometimes called "overhead" because it indicates that the signal is better than the minimum specified values. The point where NEXT and Attenuation meet is considered to be "0" dB signal reference. It is this point where it becomes difficult to ascertain a "0" or "1" value in digital logic because the noise is the same value as the signal (the stronger will win). Most people want a high ACR value, and 10 dB is considered to be a strong signal, whereas 3 dB ACR is better than 0 dB, but marginally weak. Many cable and hardware connectivity manufacturers are rating their products with ACR margins because the higher the value, the more bandwidth capability of the product.

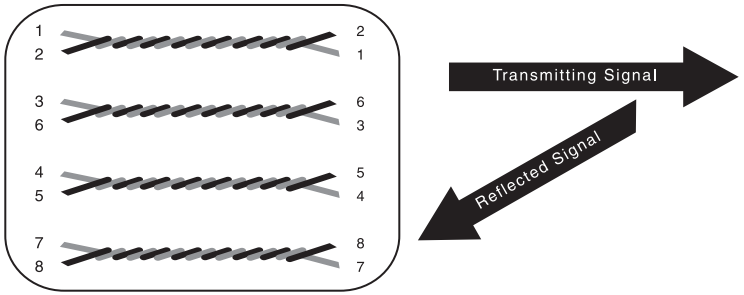
ELFEXT

ELFEXT is "Equal-Level Far End Crosstalk" and it is essentially a measure of crosstalk noise between pairs at the receive end of the transmission line. Simple FEXT measurements would not yield useful information because the amount of far end crosstalk varies significantly with the length of the cable. Therefore "equal level" FEXT is used to normalize for attenuation effects. Basically the amount of far end crosstalk is measured and attenuation is subtracted to get ELFEXT, with higher values representing a better result. In essence, ELFEXT can also be thought of as far end ACR because it combines the measurement of both attenuation and crosstalk at the far end of the link.

Return Loss

Return Loss is a measure of impedance mis match at the far end of the cable. The Return Loss test sends a signal from the near-end to the far-end of the link and then measures the amount of that signal that is reflected. Excessive Return Loss is indicated by a large reflection to the transmitting end. The smaller the

number, the greater the Return Loss. A higher level of reflected signal could indicate potential problems with impedance mismatch at the far-end, such as faulty termination, connector problems, etc. While Return Loss testing has been included in European specifications for some time, the adoption of two-way Return Loss testing will now become a more routine world-wide requirement to achieve the transmission efficiencies required for higher speed networks. Good Return Loss is extremely important in new high-speed full duplex LAN applications, such as Gigabit Ethernet.

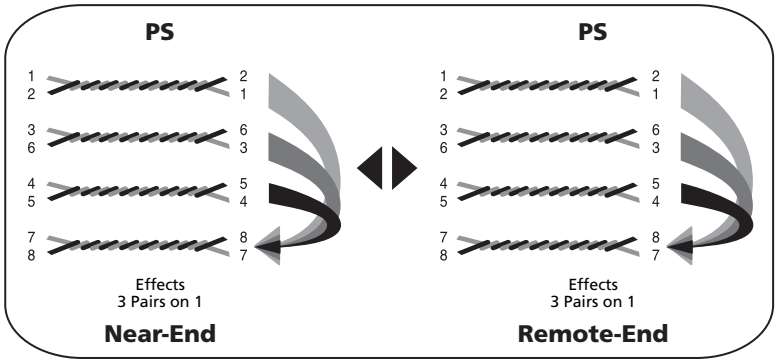


Some of the primary causes of Return Loss failures include:

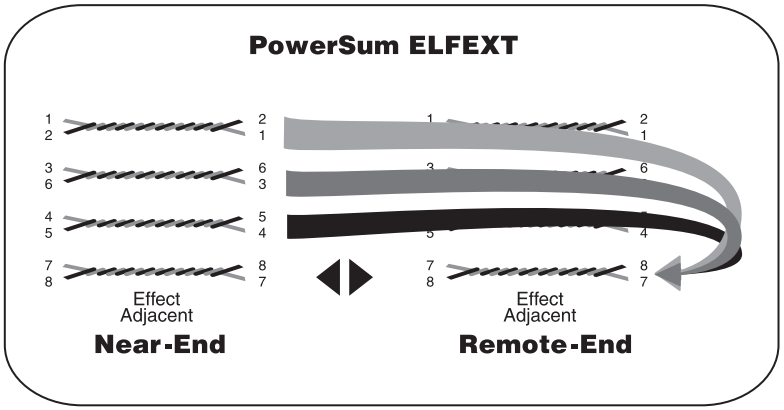
- Open, short or damaged cables or connectors
- Poor installation or poor cable quality
- Improper characteristics in installed cable, cable segments or patch cords
- Kinks in cable

PowerSum Measurements

PowerSum measurements perform an additional mathematical calculation to meaningfully aggregate the data for all of the wiring pairs within a cable. For instance, PowerSum NEXT measures the near-end crosstalk effects of three pairs on the fourth pair. By stepping through all four pairs, testing each against the other three, an aggregate PowerSum evaluation can be derived for any combination of simultaneous transmitting and receiving. Likewise, PowerSum ACR measures the aggregate attenuation to crosstalk ratios.

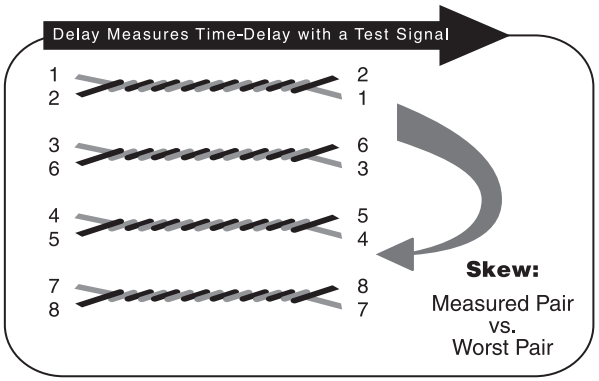


In contrast PowerSum ELFEXT performs a similar crosstalk test (three pairs at a time on each fourth pair), however it is conducted at the far-end of the structured wiring link. For speeds up to 100Base-T levels, this far-end crosstalk test has not been critical because typically only one pair would be transmitting and another receiving at any given point in time. The natural line attenuation occurring for any signal being received tended to make it too weak to have much crosstalk impact on the signal being transmitted. However, the high probability of as many as three signals being received simultaneously in higher speed networks certainly poses a real potential for a crosstalk impact on any transmission occurring over the fourth pair. This means that, in order to support the demands of Gigabit Ethernet or ATM, an enhanced CAT5 or a CAT6 installation must be tested for its susceptibility to far-end crosstalk problems



Delay and Skew Test

Delay and skew are measurements regarding the time that it takes for a test signal applied to one end of the cable to reach the other end. Delay measures the time delay on a specific pair, and skew relates that measured delay to the worst case pair within the cable.



Cable Structural Integrity

Today's data circuits are very sensitive to irregularities in the physical media caused by kinking, stretching, binding, and general rough handling. While tying a knot in a toaster cord is okay, in a LAN circuit it can cause a small impedance mismatch, that affects the clarity and timing of the transmitted signal. Wire pairs in a typical Category 5 cable are comprised of two insulated conductors very tightly twisted around each other. It is imperative that the integrity of this twist be maintained throughout the entire Category 5 link to ensure performance through 100 MHz.

Problems in Category 5 installations such as excessive attenuation or near-end crosstalk that can be attributed to the cable are usually because the structural integrity of the cable has been compromised. The transmission media's quality is based upon the complex interrelationship between the conductors, conductor pairs, pairs within the sheath, and the insulation material.

Stretching, a common issue, can actually cause the wire thickness to change, thus providing less available signal path and, therefore, increased attenuation. This change in thickness of the copper conductor is not a regular occurrence and results in irregular portions of the cable being alternately thin, then normal. When analyzed with a TDR, a trace resembling an offset sine wave is produced. Abnormal geometry caused by stretching reduces the cable's designed immunity to attenuation, Return Loss and ELFEXT.

Kinking of the cable is occasionally difficult to avoid, especially with some of the current plenum (fire-resistant, usually coated with Teflon or equivalent) varieties of Category 5 UTP. Tight radius bends cause similar problems. The TIA/EIA 568-A standard requires that all category 5 cable installations maintain a minimum bend radius of no less than one inch in diameter. Impedance mismatching and excessive NEXT are two situations that can arise from a kinked cable. An impedance mismatch occurs because the cable is so tightly bent that the relationship between the conductors is disturbed, resulting in fluctuating capacitive and inductive characteristics at that particular point.

Binding occurs when the cable is pulled tightly around a sharp object such as a support beam, hanging ceiling hardware, or ventilation equipment. Damage can range from a slight flattening of the cable pairs to complete sheath destruction and removal of individual conductor insulation. Since all installed cable runs are less than or equal to 100 meters, a good rule of thumb is to stop pulling and guide the cable around intrusive objects if you find yourself really leaning into a particular pull. Problems caused can range from mildly excessive crosstalk to open and shorted conductors.

Connecting Point Issues
Until recently, the cabling itself was thought to be the primary cause of NEXT interference. Current manufacturing techniques, however, are producing very consistent, tightly twisted media that are capable of handling extremely high frequencies with minimal NEXT coupling. At issue today are the modular connectors and termination facilities. These are the points in the link at which the cable structural integrity is compromised to allow an interface to active or passive interconnect hardware (i.e., patch panels or hub/concentrators). The cable will sometimes be untwisted and spread apart a certain amount to allow connection to a plug, jack or punch-down block causing minor impedance mismatches and structural variations at these points. These connecting points are normally implemented using IDC (Insulation Displacement Connectors) style connectors. As of this writing, designs have been verified on an improved version of the original "66" (vertical orientation) style punch-connect termination block that exhibits category 5 compliance. Most terminations, however, are connected to "110" (horizontal orientation) style IDC blocks or on the back of patch panels on "110" style IDC connections. Connecting block devices that comply with category 5 performance criteria are available from many manufacturers and in configurations that differ from the "66" and "110" styles mentioned above.

As mentioned earlier, the TIA/EIA 568-A requires pair twists to be 1/2" or less of the termination point for a Category 5 compliant link. Care must be taken to insure that this limit is observed to minimize the susceptibility to NEXT interference at higher frequencies. Since each mating connecting point (i.e., plug and jack) adds 1" of untwisted cable to the overall link, cross-connects must be limited to one only, and patch cables to a maximum of two per any one horizontal cable segment. Very simply put, the more connecting and termination points that exist, the more susceptible the system will be to interference and signal degradation.

It is recommended that the cable sheath be preserved as close to the connecting point as possible to maintain the inter-pair relationships (referred to as “cable lay") designed into the cabling. Previous installation practices where the sheathing was removed from several inches or feet of the cabling, severely impair the cable's ability to reliably transmit and receive high frequency signals.

Tests for Fiber Optic Cabling

Overview of Fiber Optic Cabling Technology
To meet constantly increasing demands for higher performance, fiber cabling has already become the de facto solution for long-haul backbone applications and is also making significant inroads into the horizontal cabling environment. Because of its significantly greater bandwidth capacity and better signal loss to distance characteristics, fiber optic cabling has quickly become the media of choice for higher traffic network links.

While copper links still carry most of the load for workgroup level LAN networks, optical links have already emerged as the preferred media for campus backbones, central office networks, Metropolitan Area Networks (MANs) and Wide Area Networks (WANs). As the carrying capacities of existing copper links approach their theoretical limits with Category 6 and a significant cost increment looms ahead for converting to Category 7, many companies are also looking seriously toward fiber as a viable alternative for the bulk of their LAN premises wiring applications.

In a fiber networking environment, optical pulses are generated from a fiber optic transmitter (light source), that is used to convert the network signal from a digital signal to light. These light pulses are transmitted along the fiber core and decoded at the receiving end (fiber to copper receiver) to complete the physical layer signal transmission. Fiber cable media used in a network must be capable of supporting the transmission from point-to-point or end-to-end. For normal LAN applications, each transmission link has a transmit (+) and receive (-) fiber strand that propagates the signal. Some very advanced systems also use wave division multiplexing (WDM) that allows multiple transmit and receive signals to be carried at different wavelengths on a shared fiber strand.

From an installation and testing standpoint, this widespread trend toward fiber cabling present a number of new challenges and opportunities for the LAN premises cabling installer. For example, because fiber cabling for premises wiring can be either multi-mode or single-mode supporting different distances and wavelengths, cable installers need to plan their test equipment investments to cover the whole spectrum of fiber types. In addition, it makes good sense to invest in lower cost options for quick-test verification of cabling before it is installed and for checking out raw unterminated cabling after installation. Most importantly, because copper is not going to go away overnight, installers need cost-effective options for sharing their tester investments across both copper and fiber installations for LAN cabling.

Differences between Single-mode and Multi-mode Fiber
There are many types of fiber used today in a variety of network environments. Multi-mode fiber is the type typically used in LANs with a 62.5/125 µm (micro meters = one millionth of a meter) core/cladding rating. Four multi-mode fibers have been used in datacom systems: 50/125, 62.5/125, 85/125 and 100/140 but 62.5/125 fiber has become dominant. It was chosen as the preferred fiber for FDDI and ESCON, and the US government is using 62.5/125 exclusively (FED STD 1070). Multi-mode fiber used in LANs typically operates in two basic wavelengths (850 nm & 1300 nm). Multi-mode fiber uses LED (light emitting diode) technology to transmit the optical signal allowing for significantly less expense and power consumption than with single-mode fiber. Multi-mode LEDs consume only tens of milliwatts of power as compared to the greater than 100 milliwatts required by single-mode lasers. In addition, the connector technology for multi-mode is significantly less expensive than for single-mode, because the parameters for launching the light into the fiber require less precision.

In multi-mode installations, the optical signal is transmitted along the length of the core and the cladding is an outer covering with a lower refractive index. The cladding redirects the fiber pulse towards the center, a process known as propagation. With multi-mode fiber, there are many different modes transmitted and this can be more easily understood if you think about light transmitted down the center, light transmitted (angled) towards the cladding (higher mode), and light transmitted towards the core (lower mode). These pulses are sent in a manner that the different modes of a signal actually arrive at the other end at different times and the maximum delay is limited to 15 to 30 ns (nanoseconds = one billionth of a second), hence the name multi-mode.

Once Light begins to reflect down a fiber, it will continue to do so.

Single-mode fiber has its application in backbones and inter/intra building connections for LANs. In single-mode the fiber core is so narrow that the light can take only a single path down the fiber, thereby increasing both the bandwidth and the difficulty with accurately launching the light into the fiber. Single-mode fiber core/cladding size is 8.33/125 µm, which greatly restricts modal dispersion and increases propagation efficiency. Coupled with the higher power of laser light sources, the efficiency of single-mode fiber can extend link distances up to 3000 km. Long haul carriers use single-mode fiber for the trunk lines connecting cities to one another and typically can go from 60 - 80 km without using repeaters. The bandwidth throughput is almost unlimited for single-mode and

many users pull single-mode fiber with the multi-mode and leave it disconnected until a future application can use its capabilities. One primary drawback for single-mode fiber is the cost of the electronics, mainly the requirements for expensive lasers. Another drawback is that the core is about seven times smaller than its multi-mode counterpart, so termination and splicing of single-mode require more training and proper tools.

The ANSI/TIA/EIA 568-A Standard recognizes single-mode fiber for backbones only and multi-mode fiber for both backbones and horizontal distribution. Single-mode fiber can easily perform in the horizontal distribution (patch panel to work area outlet) and future standards will most likely allow single-mode fiber for this application.

Budgeting
Fiber optic systems generally have three parameter budgets: bandwidth, power and loss.

Bandwidth Budget
Bandwidth budget is a factor of a specific light wavelength's ability to carry data signals. Bandwidth budget is of prime concern to the designers of transmit and receive equipment. Their goal is to produce equipment that best utilizes the available bandwidth for a specific light wavelength.

Power Budget
Power budget is expressed in dB and defines the difference between the transmitter's minimum power out and the receiver's minimum sensitivity. This budget is of concern to both the equipment designers and the system designers. The difference between these two will determine the limits of cable and connectors that can be installed between the transmit and receive ends of a fiber optic link. For a systems design engineer, the chosen equipment's limitations are a given specification that must be considered in the cable layout using a power budget. Power budgets also must consider room for future loss from factors like transmitter or receiver degradation over time and cable emergency splices that may be added to repair a cut fiber cable. Note the word "splices" is plural because cable repairs generally require one splice on either side of the point where the cable has been damaged. In fiber optic environments, every splice contributes an additional loss factor that must be considered in the overall power budget.

Loss Budget
Loss budget is the measured loss of the installed fiber link in both directions, summed and averaged. Primarily used by installers, this budget figure is compared to a computed maximum loss budget to determine the quality of the link. System designers then use the loss budget figure to compute their final margins of power budget. The original "paper calculations" and blueprint estimates for the system must then be updated with "real measurements" and

documented on "as-built drawings" in order to ensure that the deployed network system can live within the actual fiber links' loss budget.

Loss budget is the primary benchmark measurement for fiber optic cable installers. In some cases the maximum permissible loss budget is pre-calculated and specified in the drawings by the system designer. In this case, the maximum limit for loss only needs to be used by the installer as the pass/fail demarcation point. However, in many cases the installers must determine the loss budget themselves and then stay below the calculated maximum loss figure during the testing phase in order to verify a fiber optic link is satisfactory.

Standards for Optical Loss Budgets

Losses in fiber optic signals are measured in dB (decibels), and each component in a link (cable, connectors, splices, couplers, and patch cords) contributes to the overall loss. This overall loss is often referred to as the Optical Loss Budget (OLB).

Fiber testing methods and procedures are specified in (Annex H) ANSI/TIA/EIA 568-A, and is entitled "Optical Fiber Link Performance Testing". This Annex document is informative in nature and defines the minimum recommended performance testing criteria for an optical fiber cabling system installed in compliance with the standards. It provides users recommended field test procedures and acceptance values.

The fiber link is defined as the passive cabling network which includes cable, connectors, and splices (if present) between two optical fiber patch panels. The single primary performance parameter that is measured when testing fiber is link attenuation or power loss. Bandwidth and dispersion are important factors but because they cannot be affected by installation practices, they are tested by the fiber manufacturer and not in the field.

The ANSI/TIA/EIA 568-A Standard lists the following parameters as link attenuation coefficients, which are considered as the maximum allowed dB loss/km values.

	Wavelengths		
Fiber Type	**850 nm**	**1300 nm**	**1310 nm**
62.5/125 (m	3.75 dB/km	1.5 dB/km	0.50 dB/km

Note: the above coefficient values relate only to the fiber cable.

The standard also specifies connector and splice attenuation maximum loss values:

Connector Attenuation (dB) = number of connector pairs (connector loss (dB)
(Each mated connector pair = 0.75 dB loss)

Splice Attenuation (dB) = number of splices (splice loss (dB)
(Each splice loss allowance is 0.3 dB)

Based upon these values, each fiber type can support varying lengths (distances) because the link loss attenuation formula for the fiber cable can be referenced as a value of dB/km, with any length less than or more than one km being shown proportionately. For example, the following table shows calculated attenuation for various cabling lengths of 62.5/125 (m fiber (assuming two connector pairs).

Wavelength	500 meters	1000 meters	1500 meters	2000 meters
850 nm	3.2 dB	5.2 dB	7.1 dB	9.0 dB
1300 nm	2.3 dB	3.0 dB	3.8 dB	4.3 dB

Note: these values are approximate and extrapolated from TIA/EIA 568-A, *Annex* H *Optical Fiber Performance Testing; numbers do not include any splice loss. Add* 0.3 *dB for each splice in a link.*

Some networking protocols are less tolerant than others and require much lower loss limits. One should take care that respective design, installation and test parameters are correct. For instance, many users have been unaware of the importance of loss budget calculations because their systems have been operating with older technology, thereby allowing the higher link losses. Now that newer high-speed technologies such as Gigabit Ethernet and Fibre Channel allow for much less loss tolerance, system designers must be much more cognizant of their overall loss budget and the impacts of link attenuation factors.

For example, a report dated July 1998 from Cabling Standards Update (quarterly newsletter on standards committee meetings and results) states that 1000 BASE-SX (Gigabit Ethernet, Short Wavelength) requires a maximum channel insertion loss of 2.38 dB to operate effectively. This is a drastic change from current topologies such as Ethernet and FDDI, which allow for a 10 to 11 dB loss. In the past, with these lower speed protocols, it might have been fairly common for a system designer to allow for a 3 dB safety margin for an FDDI rated system, however today that same 3 dB loss factor represents the maximum allowable for Gigabit Ethernet.

Fiber Optic Test Tools

Fiber optic components are sensitive to physical stress that can actually induce additional loss factors. The mere physical movement of fiber optic cables and connectors can have measurable negative effects on fiber optic assemblies. For instance, a simple bend in single-mode fiber cable can induce several dB of

loss. Just handling fibers to make measurements can cause readings to vary by several tenths of dB. After installation, the cumulative effect of handling, splicing, adding connectors, etc. typically results in a very complex set of factors that impact the fiber link's overall transmission characteristics. Therefore installers need a full range of tools that efficiently support everything from conducting a quick test of fiber prior to installation to rigorously testing a variety of different long and short haul fiber links after installation.

Basic Fault Finders

Visual faultfinders provide a quick and inexpensive way to check cable prior to investing in the time and expense to install it. These instruments consist of a simple light source, such as a laser diode, that injects a highly visible red light into the cable, using either a continuous or pulsed mode. Because the light will "leak out" wherever there is a fault in the fiber jacketing due to kinks or breakage, the operator simply observes the cable for the presence of a steady or blinking red light in order to pin point the fault. Visual faultfinders can be used to check either multi-mode or single-mode cabling to lengths as long as 5km (3 miles). In addition to checking and verifying raw fiber cabling, visual faultfinders can also be helpful in locating faults for installed cabling when used with other test methods. Visual faultfinders can be especially effective at spotting the high percentage of breaks that typically occur within a few meters of the connectors.

Power Loss Meters

Equipment for measuring power loss essentially consists of an optical power source and a power meter. If relatively simple testing needs to be accomplished at a single wavelength, such as 850nm, an installer can simply invest in small, low-cost, pre-calibrated power sources and meters. These basic units typically provide a simple bar-graph readout of power loss, such as -2dBm increments, for quickly assessing the attenuation characteristics for a fiber link at the specified wavelength. For repetitive testing of a series of similar links, these devices can be a very cost-effective and easy-to-use alternative to higher end test capabilities, however they have the inherent disadvantage of lacking flexibility to test different wavelengths.

On the other end of the scale are full-featured programmable power loss meters and light sources that allow the operator to quickly switch between different wavelengths and to calibrate the meter reading precisely to the power output of the light source. The ability to stimulate and measure power loss for both multi-mode and single-mode fiber links at a variety of wavelengths and power levels make these instruments popular with installers that have to handle a wide range of fiber requirements. In addition, the ability to store many different readings and test settings in the device's local memory can be significantly helpful when testing a variety of different links.

Add-on Fiber Kits for Copper Test Equipment

Of course, the investment in standalone high-end dedicated fiber test instruments can sometimes be prohibitive for installation contractors who are incrementally migrating from copper to a mix of copper and fiber LANs for their customers. In these instances, the use of add-on fiber accessory kits for existing copper cable test sets has become a very cost-effective alternative that provides most of the capabilities of a high-end fiber test device at a fraction of the cost. For example, an inexpensive add-on fiber kit can provide power source and metering capabilities to test both multi-mode and single-mode fiber while leveraging the existing measurement capability, display and memory of a copper-based test device. In addition to minimizing incremental equipment expense, many installers also find that the use of add-on fiber accessory kits significantly cuts down on re-training costs because their technicians don't have to learn a whole new device.

OTDR Testers

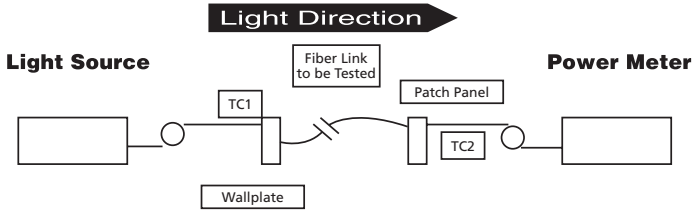
Optical Time Domain Reflectometers (OTDRs) can be very valuable devices for checking longer-haul fiber links and/or complex LAN configurations, especially those with a number of splices and connections. Essentially, an OTDR injects a pulse of laser light into the fiber link and then samples return signals from the pulse over a specified time domain. Because any optical fiber exhibits a certain degree of backscattering, the reflected signal can be analyzed in the OTDR to provide an accurate representation of the link's performance characteristics over given distances. Individual events on the link, such as end-points, splices and connectors, can be identified and located, based upon the return time required for their reflected signal from the originating light pulse.

Because the OTDR is operated from only one end of the fiber link, a single operator can efficiently use it, whereas typical power loss measurements require a source at one end and a meter at the other. It can readily measure splice loss, cable attenuation and optical return loss for the full link or any point along it, thereby identifying overall link length as well as the existence of and distance to any discontinuities, such as breaks, splices, kinks, etc. Because OTDR information can be displayed in a comprehensive graphical representation, it can visually identify anomalies along the link that might not be apparent with other testing methods. For example, a link might meet the overall specifications for link loss, continuity, etc. but might still contain a number of point discontinuities (e.g. 0.2 or 0.3 dB) that could degrade its actual performance. Most OTDR devices also include built-in software algorithms that automatically analyze the link to high-light and pin-point the location of any threshold optical discontinuities that can impact performance.

Optical Power Loss Measurement Procedures

Once the application's OLB has been determined and the fiber has been installed, the link must be tested for compliance. The standards are very specific in how a fiber link is to be tested and recommends use of the OFSTP-14-Method B for an insertion loss test.

Optical Fiber Systems Test Procedure (OFSTP)-14 Method B



Link Loss = link in the walls loss + two connector losses + Test Cable 2 loss (TC2 loss adds error of 0.002 dB @ 850 nm and 0.004 dB @ 1300 nm)

Current standards only require backbone fiber cabling to be tested in one direction at both operating wavelengths. Multi-mode links should be tested at 850 nm and 1300 nm and single-mode links should be tested at 1310 nm and 1550 nm in accordance with ANSI/TIA/EIA 526-14-7.

Horizontal fiber links (fiber cabling from the patch panel to work area outlet) only need to be tested at one fiber wavelength because of the short length of cabling allowed (90 meters - 295 ft or less). There are some exceptions and TSB-72 (Centralized Fiber Optic Cabling Guidelines) allows for 300m combined links of the fiber backbone and horizontal distribution, including patch cords. However it is important to note that going the extra step to test fiber strands at both wavelengths and both directions increases the predicted reliability of the link's performance. Remember, the standards are only minimum guidelines and by adding fiber testing in both directions, the installer can find all connections in a link that might be marginal.

Calculating Maximum Loss Budget

The calculated maximum loss budget is developed by summing the maximum expected losses for each connector, splice and the cable's loss by length and wavelength. All these maximum loss specifications are available from the component or cable manufacturers. Cable is generally specified in maximum loss per kilometer (3280 feet), and the specification is different for respective light wavelengths. In multi-mode applications for LAN this often is a very simple task. Most links will be made up of a single cable with one connector on either end.

An example calculation of this maximum loss budget is shown below for a 2000 ft link with connectors on each end.

Connector loss	0.6 dB	
Fiber Optic Cable loss @ 850nm	2.0 dB	= (2.9 dB /km specified)
Total loss budget expected @ 850nm		2.6 dB
Connector loss	0.6 dB	
Fiber Optic Cable loss @ 1300nm	0.7 dB	= (.9 dB / km specified)
Total loss budget expected @ 1300nm		1.3 dB

Note: The loss in the cable is extrapolated from the specification length to the actual length.

$$\frac{2000}{3280} = \frac{X}{2.9} = 2.0 \text{ dB}$$

Although not all cable and connector manufacturers provide loss budget figures as part of their datasheets, a reasonable "rule of thumb" for maximum loss budget calculations is as follows:

Cable @ 850nm, loss	**= 3.0 dB per kilometer (3280 feet)**
Cable @ 1300nm, loss	**= 1.0 dB per kilometer (3280 feet)**
Connectors, all types	**= 1.0 dB per full connection with coupling**
Splices, all types	**= 0.3 dB each**

Note: these values are more stringent than TIA/EIA *Standards*

Because these loss figures are acceptable for all type of connectors, splices and glass fiber optic multi-mode cable, they will yield a slightly larger maximum budget loss than if the manufacturer specifications are used. For example, the standard specifies 0.75 dB loss for a mated pair of connectors and the manufacturer specifications state 0.25 dB loss for each connector as typical. However, most LAN applications of multi-mode fiber are relatively short links without splices and only two connectors. This means the loss is often less than 3 dB, which leaves more than sufficient margin for most LAN application's power budget.

Measuring Link Loss

Once calculated, your maximum loss budget is now your PASS/FAIL demarcation point. Links measuring more loss budget than the amount calculated need troubleshooting to determine what is causing the excessive loss. Links with a measured loss budget lower than the requirement will pass, but need to be

as to their measured values. In some cases, the values may only signify a marginal pass margin over and above the specified loss budget. Once the values are known, one can keep a close watch over the ones that are marginal and post them for regular maintenance.

To obtain accurate test readings, the power meter's reference level must be checked and set prior to testing. Setting the reference level means establishing the zero dB reference on which all the measurements are based. The actual readings of light received by the power meter are in dBm. The "m" indicates this reading is referenced to one milliwatt of power. Since the light sources rarely output zero dBm, and there are losses in the launch cable(s) and connectors, a reference dBm level is subtracted from each reading to obtain the relative dB readings. To obtain accurate loss testing information the reference levels for the Light Source to Power Meter should be set daily, using the equipment manufacturer's guidelines. Reference settings should also be checked with every battery change or anytime the launch cables are changed.

With all the preliminaries out of the way (reference levels and setup complete), the fiber optic links can be physically tested by connecting the light source at one end of the link and the power meter at the other end of the link to take comparative measurements. It is important to remember that this measurement will include everything between the source and the meter. If additional launch cables and/or connectors are added that were not used during calibration (reference level setting) these are part of the system under test. Most test equipment uses ST type connectors and a hybrid ST to SC jumper may be required for those installations that use the SC connector recommended by TIA/EIA standards.

While there is no specific order for performing the tests, most technicians prefer starting with the shorter light wavelength (850nm for multi-mode or 1310 nm for single-mode), then measuring the longer wavelength. The logic behind this is that the shorter one is generally more forgiving and produces a passing result more easily. In either case, the cable should be measured at both it's rated light wavelengths and in both directions.

Why measure both light wavelengths?
Because different wavelengths react differently to bends, splices and connector gapping. As an example - an 850 nm light wave will go around a bend like a sports car, but a 1300 nm light wave corners more like a semi-tractor trailer rig. An excessive bend may not show any significant loss at 850nm, but could show unacceptable loss at 1300nm. The only way to be sure the fiber will work at both light wavelengths is to test it at both light wavelengths.

Why measure in both directions?
TIA/EIA Standards don't require bi-directional measurement for backbones, but

one must keep in mind the way light reacts across connectors. The fact that a light wave traveling from east to west through a connector exited on a polished end and entered the other with minimum loss does not guarantee it can cross this gap in the opposite direction equally well. The polished faces and alignment of the connectors is crucial to bi-directional performance. The only way to be sure the bi-directional performance is acceptable is to measure the fiber link in both directions. This will result in two measured values per strand, per wavelength. In addition, future technologies will most likely use the longer wavelengths because they support more bandwidth.

Most full-featured power meters, such as a Wavetek LANTEK PRO / PRO XL or LT8155/8600 series meter, will automatically compare the test results to the "Budget Loss" maximum entered earlier. If the measured loss is less than the maximum the instrument will immediately provide a PASSED or a FAILED indication.

Loss Measurement Test Results Documentation
Once the testing is completed there is always the paperwork to finish the job correctly. While requirements for documenting the test results will vary with different jobs, it is imperative to produce a clear record of how well each fiber optic link worked at the time of installation. All Wavetek FIBERKITs for either the LANTEK PRO / PRO XL or LT8155/8600 series instruments provide for storing, printing or PC uploading test results. In addition to this record, it is also strongly recommended that the original blueprints for the fiber link's installation be annotated with "As Built" notes including the loss measurement results. These records can prove invaluable at a later date for making moves, adds and changes (MACs) or repairing damaged cable. Refer to TIA/EIA's 606 Standards for full documentation references.

What Causes Failing Loss Measurements?
In essence, fiber links fail because too much of the light that has been injected at one end fails to reach the other end because it has been lost through either reflection or absorption. Reflected light never reaches its destination as it is reflected toward the source. Absorption of the light by the fiber optic cable reduces the amount of light at the destination.

While some absorption is normal and allowed for in the loss budget, excessive absorption can be caused by poor connector alignment, excessive bends in the cable, poor splice alignment, and/or cable manufacturing defects. On the other hand, the primary causes of reflection include poor connector polishing, poor connector alignment, dirty connector ends, and/or broken or cracked fiber cable.

One other cause for failing a loss measurement test is by gaining light. Since this is not possible under the laws of physics, it is normally attributed to a procedural error. The result is a test measurement value greater than the zero dB reference, which in most cases is caused by removing one or more launch cables that were

used during the calibration (reference setting) phase. Typically the cable that causes this error is the one attached to the light source because it is the most critical to set the amount of light transitioned from the source's LED into the fiber optic cable's cone of numerical acceptance (NA). If this cable is dirty, reversed after setting the reference levels, or disconnected and reconnected at the source, this can change the initial amount of light entering the cable and make the stored reference level invalid. Another error is setting the reference level too quickly after turning on the light source. As the LED warms up it increases the amount of light output. Most sources need only one to two minutes turned on for the LED to reach peak output. In either of these cases, re-calibrating the reference level will correct the problem.

Summary

In summary, the use of fiber optic cabling has already become a fact of life in the high speed backbone arena and is also rapidly proliferating into the horizontal interconnect and LAN environments. The need for accurate and cost-effective management of fiber optic testing has become a key on going success factor for most professional cabling installers. Fiber-based LANs are already becoming viable and many industry observers predict that fiber-to-the-desktop is not far over the horizon. According to industry analysts, the global consumption of fiber optic cable is increasing at an average of 19% per year and will reach approximately $14.9 billion by 2001. Although the bulk of new fiber being installed is for telecom applications, the private data LAN/WAN segment is projected to grow from 11% to 14% of the market, for a total of $2.17 billion (Source: ElectroniCast Corp.).

As a result, installation contractors must simultaneously stay abreast of the latest fiber optic testing standards and methods, while training their technical staff on new fiber procedures and transitioning their equipment investments across the evolving world of copper and the emerging world of fiber. In addition to the information contained in this document, installers can also obtain updates and new information on fiber testing by visiting the Wavetek Wandel Goltermann web site at www.wwgsolutions.com.

Testing Beyond the Physical Layer

Advanced Methods for Effective Traffic Generation, Analysis and Monitoring

Overview

In today's complex network environments, it is no longer sufficient to simply focus exclusively on the integrity of the Physical Layer media that provides the basic structured wiring links throughout the system. As the bandwidth specifications for various network protocols continue to escalate, the performance headroom margins are steadily being squeezed for even the highest classifications of physical media. Regardless of whether the media consists of twisted pair wiring, coax, or fiber optic cabling the ultimate test of its effectiveness will reside in the ability of the network to reliably transmit the required data under the stress of real-world operating conditions.

Importance of Higher Level Testing

Because of the growing requirement to assure that network cabling can effectively handle the higher speed protocols and traffic demands that will be required under actual operating conditions, many cable installers and their corporate customers are looking to more extensive performance testing methods.

For Cable Installers

In response to their corporate customers' need for assured performance levels, many professional cabling installers are beginning to offer some degree of performance testing as a value-added service, which can significantly enhance the installer's competitive position. By selectively deploying portable self-contained traffic generator/analysis devices within their installation operations, these forward-looking contractors are able to stress the newly installed cabling to simulate or exceed actual LAN traffic levels. As a result, they are able to give their customers an extra margin of confidence in the available performance headroom that the installation will be able to provide.

For follow-up evaluations, upgrades, warranty service and troubleshooting of installed networks, the ability to independently generate simulated traffic under controlled conditions can help to quickly distinguish between network cabling problems and customer equipment problems.

For Network Administrators

Relentless changes to the network and escalating performance demands have now become such a routine part of the daily challenge that most network administrators simply accept them as the routine facts of life in the IT business. In addition, the deployment of a myriad of new business critical applications across corporate LANs has dramatically raised the consequences of unanticipated network outages, performance slowdown, and/or traffic bottlenecks.

Although the proper installation and certification of the structured cabling environment can provide the foundation for a maintainable network, administrators also need easy to use, cost-effective solutions for the on going monitoring of actual traffic conditions. Instead of the field-oriented traffic generator/analyzer capabilities required by installers, network administrators generally need more in-depth traffic monitoring and analysis solutions that can see across the whole spectrum of network activity under actual operating conditions.

Review of the OSI Structure

The International Standards Organization, in standard ISO/TEC 7498, defines a 7 layer model for networking that is generally referred to as the Open Systems Interconnection (OSI) model. While the OSI model does not always have an exact one-to-one mapping to actual protocol implementations, such as Ethernet, it is a very useful construct for understanding the higher level protocol layers that need to be considered when analyzing a network's true performance capabilities.

The seven layers in the OSI model are defined as follows:

- **Layer 1** - The Physical Layer, which describes the media used to connect the systems, such as copper twisted pair, coax, or fiber. The Physical Layer defines the electrical, optical, mechanical, procedural and functional specifications for establishing the physical links between systems.
- **Layer 2** - The Data Link Layer describes the actual presentation of bits and the format of messages on the physical media. The Data Link Layer is intended to provide reliable transmission of data across the physical link by defining the specifications for physical addressing, network topology, line disciplines, error handling, frame sequencing, and flow control methods. For Ethernet implementations, which dominate today's network environments, the IEEE has further sub-divided Layer 2 into a MAC (Media Access Control) sub-layer and a LLC (Logical Link Control) sub-layer.
- **Layer 3** - The Network Layer provides connectivity and path selection between end systems within the network by defining routing methodologies and path selection criteria. The Network Layer is the point at which higher level protocols come into play to provide the rules and conventions for internetworking. As such, analysis of traffic behavior on Layer 3 can provide vital information for evaluating and predicting overall network performance. Internet Protocol (IP) has now emerged as the most ubiquitous Layer 3 protocol.
- **Layer 4** - The Transport Layer is responsible for reliable network communication between nodes, such as specifying mechanisms for establishing and terminating virtual circuits, detecting and recovering from transport faults, and passing flow control information between end points.
- **Layer 5** - The Session Layer handles the management of specific network sessions between applications.
- **Layer 6** - The Presentation Layer ensures interoperability of data between applications by negotiating high-level syntax for data transfer.

- **Layer 7** - The Application Layer handles the interface to application processes that lie outside the OSI model, such as email, file transfer, terminal emulation, etc.

In order to assess the real-world performance capabilities of a network, it is important to be able to selectively generate, capture, and analyze controlled traffic conditions for Layer 2 (link layer), Layer 3 (network layer), and Layer 4 (transport layer). To manage and optimize on going network performance, it is also important to continually monitor and analyze actual traffic conditions across the entire network topology.

Key Elements of LAN Performance Evaluation

Testing and documenting a network's performance necessitates being able to simulate a wide range of controlled traffic conditions and then capturing and analyzing the results. In addition the on going evaluation of real-world network performance and troubleshooting of problems require the ability to monitor actual network traffic.

Traffic Generation

In order to test the full range of capabilities of a network, one needs to be able to independently generate a broad spectrum of traffic conditions under tightly controlled conditions. This requires ability to quickly saturate the network with large volumes of standard packet traffic and to target various controlled traffic levels across a variety of bridged, switched and routed environments. When it comes to testing the performance of a complex network environment, it is helpful for the traffic generator to be relatively portable, thereby enabling the operator to simulate the effects of introducing traffic spikes and peaks from various points and sub-net segments within the overall topology.

Traffic Capture and Decode

After the simulated source traffic has been generated on to the network, the resultant destination traffic must be consistently captured, decoded and logged, before any analysis can take place. In a controlled performance-testing environment a separate physical device, connected in a remote location from the traffic generator, is generally required to perform the traffic capture function. Here again, for testing various aspects of a complex network it is helpful to have a self-contained, portable traffic capture device, that can be easily connected at various points in the network topology.

Traffic Monitoring

In addition to being able to simulate controlled conditions for assessing network performance parameters, network administrators also need to be able to monitor and analyze actual real-world traffic conditions in order to effectively manage and optimize network performance on an on going basis.

Traffic Analysis
Once the simulated or actual traffic has been captured, various levels of analysis are required to accurately assess network performance levels. For self-contained, field-oriented testers, the analysis should focus mainly on critical performance parameters such as collision frequency, packet errors, round-trip delays, etc. between specific points on the network, such as MAC and IP addresses. On the other hand, on going traffic monitoring solutions need to be able to accumulate and analyze in-depth statistics on overall network traffic levels, error rates, sub-net loads, node-by-node usage patterns, etc.

LAN Performance Testing and Monitoring Tools

As previously indicated, there are significant differences between the needs of professional cabling installers and network administrators when it comes to LAN performance testing and monitoring tools. For the most part, professional installers will require self-contained field equipment for targeted performance testing while network administrators will need more comprehensive software-based solutions for on going traffic monitoring and analysis. However, network administrators may also find it useful to have a portable field tester available for on the spot troubleshooting of specific LAN sub-nets by generating and analyzing known traffic conditions.

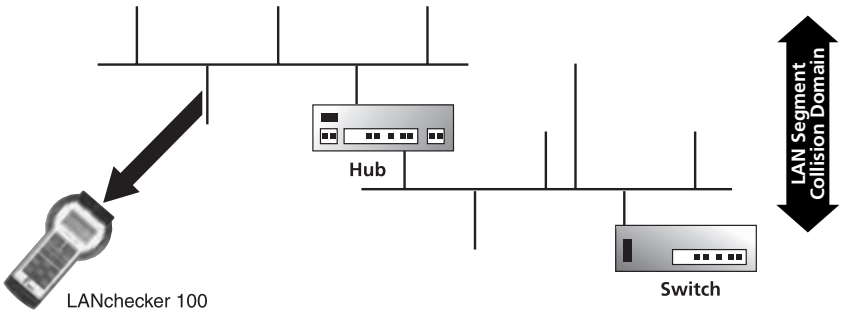
Portable Traffic Generation and Analysis Devices
Cable installers require field-ready portable devices, such as the LANChecker 100, that can provide all-in-one traffic generation and analysis capabilities and that can easily be attached between any points on the network, using standard connectors such as RJ-45.

In addition to being able withstand the rigors of field testing conditions, such devices also have to be small enough to fit within the professional installers' existing tool kits and flexible enough to complement existing methodologies. Installers need simple, easy-to-use test functions that rigorously exercise the protocol layers and provide clear understandable test results. Just as with Physical Layer field testers, it is important that LAN performance testers include the capacity to locally store a reasonable number of test results, as well as the ability to conveniently upload them at a later time.

For example, the LANChecker 100 is a handheld 10/100 Mbps Ethernet traffic generator/analyzer, consisting of near-end and remote end units, that can be used to test both new and existing LAN links, with or without actual traffic. When transmission is started from the measuring point, the remote end unit is found and configured automatically.
The LANChecker 100 is capable of the following performance tests and test management functions:

- Transmission tests to test links between terminals, in accordance with IEEE802.3
- Net load generation tests to simulate network traffic up to maximum transmission rates and to generate over-load scenarios to test the LAN's safety margins
- Cable tests to verify single cable length measurements
- Link testing to catalog the possible link combinations of a connected LAN
- Address Monitoring to discover and record MAC and IP addresses on the LAN and to monitor load conditions
- Network Statistics can be gathered in background mode while other specific tests are being conducted
- Data printout or export of test results via RS232 connection

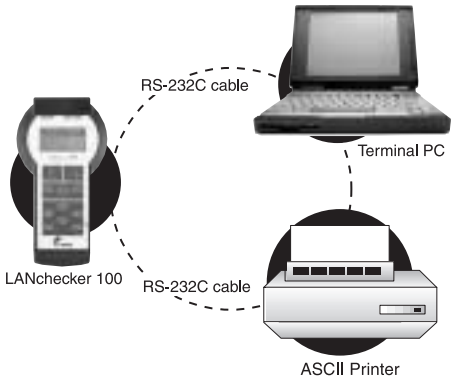
As demonstrated below, the LANChecker 100 can be interconnected directly into LAN hubs, switches or routers and supports analysis of bridged, switched or routed environments. The LANChecker 100 can automatically discover and record MAC and IP addresses as well as document the incidence of errors and traffic levels. The integrated network traffic load generator makes it possible to quickly simulate specific traffic load levels across the network environment and/or to even inject traffic errors.



Specific LAN transmission tests performed by the LANChecker 100 include:

- Echo test - to check the quality of the connection and LAN throughput between two end points, under specified traffic conditions
- Collision test - to simulate high-collision traffic conditions and record data loss statistics
- Round trip delay - to measure end-to-end delay conditions that are dependent upon cabling length and condition as well as the run times of intervening systems, such as switches and routers
- Ping test - to check and qualify bi-directional operation with installed IP-capable nodes

The LANChecker 100's network statistics function start automatically when the device is turned on, and runs permanently as a background process. As many as 512 auto tests of link performance can be conducted and stored in the local device, after which data can either be printed by connecting directly to a printer or uploaded via RS232 link to a PC.



While designed specifically to meet the needs of professional cabling installers, the LANChecker 100 also provides built-in versatility and statistical monitoring capabilities that make it useful as an ad hoc LAN troubleshooting tool for network administrators as well.

Comprehensive Software-based Traffic Analysis/Management Solutions

For more in-depth monitoring and analysis of network traffic on an on going basis, network administrators need to have comprehensive software-based solutions, that can be easily installed and run on any standard system on the network. After a network infrastructure has been certified and put into every day usage, network administrators must be able to continuously monitor network performance in order to identify potential problems before they become overt or catastrophic.

Because virtually no network environment remains static for even short periods of time, performance is constantly being impacted by escalating traffic levels, changes in user behaviors, increasing loads on routers/switches/bridges, reconfiguration of sub-nets or segments, and the introduction of bandwidth-hungry and latency-sensitive services, such as multi-media or voice-over-IP. Because of this environment of constant change, network administrators need continuous monitoring solutions that can go beyond just ad hoc troubleshooting or periodic performance evaluation.

For example, the LinkView PRO Network Analyzer provides a powerful but simple to use shrink-wrap software application that comprehensively monitors and analyzes a wide range of network conditions on an on going basis. Upon initial installation on a networked Windows 95/98/NT system, the LinkView PRO software automatically discovers the entire network topology and graphically displays it on the screen. The administrator can then easily customize the network map by assigning names and other information to each individual node or user station.

For performance monitoring, the administrator can select from a variety of screens and menus to hone in on specific network segments or nodes and/or to drill down for detailed load and usage statistics.
At the highest level, LinkView PRO's configurable user interface provides easy-to-interpret graphical representations of key network vital signs, such as LAN Frame Rates, Utilization Rates, Error Rates, etc. This enables the administrator to have an overview profile of network performance immediately available at all times, which can also be coupled with customized alarm settings to notify the administrator whenever pre-set parameters are violated.

LinkView PRO automatically captures statistical data from all frames sent by all stations in the network. Simply by selecting the appropriate menu choices, the administrator can quickly review many key factors, such as the types and distribution of protocols (IP, NetBIOS, IPX, etc.), the most active transmitting stations, the most active receiving stations, etc. In addition, the software package accumulates historic statistics according to user-defined time intervals so that further in-depth analysis can be conducted regarding trends and patterns as viewed over an extended period of time.

As a software-only application, relying on the host's existing NIC card, LinkView PRO is designed to meet all of the network administrators' requirements for real-time monitoring of actual data traffic and network load conditions. If necessary,

the software package can also be combined with an optional LinkView PRO Collision Expert adapter card that, when installed in the networked PC, can be used to capture greatly expanded detail on collision activity. By detecting and registering all collisions and jam signals in real-time at wire-speed, the Collision Expert card enables LinkView PRO to automatically calculate the available transmission bandwidth that is being lost to collisions. This allows network administrators to also employ LinkView PRO as a powerful tool for the in-depth analysis of congestive networks and the formulation of optimal network segmentation strategies.

Summary

The bottom line for both professional cabling installers and network administrators is the fact that simply testing the Physical Layer is no longer an adequate predictor of network performance. The increasing complexities of modern network topologies, coupled with constantly escalating bandwidth demands and higher-speed protocols, have virtually squeezed out all of the ample headroom that used to exist between the wiring plant's inherent capacity and the actual bandwidth requirements.

As a result, many installation contractors and their corporate customers are proactively turning to higher-level performance testing methods that allow them to better characterize the actual performance of individual links and the network as a whole. Whether the solutions consist of portable field testers for generating and analyzing simulated traffic, or comprehensive systems for on going monitoring of actual traffic, the ultimate goal is the same – to ensure that real-world network performance can consistently meet and exceed mission-critical application requirements.

Glossary of Terms and Abbreviations

AC - Alternating current. A signal that alternates its polarity between positive and negative with respect to a neutral which is commonly tied to earth ground. Dynamic signals such as audio, radio waves and utility power are typically AC.

ACK - Abbreviation for the Acknowledge response in data communications.

ACR - Attenuation to Crosstalk Ratio. ACR is a comparison of signal strength to noise interference and is used as a "bandwidth" indicator. The ratio is not a test but a comparison between two previous test results. It compares signal loss (attenuation) to noise interference (NEXT). The larger the ACR, the better the transmission will be.

ADDRESS - The destination of a message sent through a data communications system. A series of digits identifying a component or device attached to a network.

ANALOG - An electrical signal comprised of many different and constantly changing voltage levels.

ANSI - American National Standards Institute – an organization that develops standards for voluntary use in the United States.

APPLETALK - A proprietary network designed for Apple Computer Corp. Macintosh computers and peripherals. (See Topologies Section)

APPLICATIONS LAYER - The highest layer of the OSI network model. This is the level where the application, like email, would access the network.

ASCII - American Standard Code for Information Interchange. Developed by ANSI, it is a seven data bit code representing 128 different characters. Widely used as a common data exchange format between like and unlike computer systems.

ASYNCHRONOUS BALANCED MODE - Used in IBM's Token Ring Logical Link Control, it allows access to the data link by network attached devices.

ASYNCHRONOUS TRANSMISSION - Also called "start-stop transmission", it is a non-continuous data stream with each data element framed by tags called start and stop bits. This eliminates the need for precise clocking at both ends. Speed and bandwidth are sacrificed, however, due to excess information required. A seven-bit data element would typically have one start bit, one parity bit and one or two stop bits needing a maximum of 11 bits to get the original seven transmitted and properly received. This is the type of communication that personal computers most often use when they communicate via telephone lines.

ATM - Asynchronous Transfer Mode. A high speed form of packet switching being developed for the commercial sector and now used in LANs. High speed (155 Mbps) throughput can be achieved on Category 5 UTP. Most designers use ATM as a backbone technology connecting the switches and hubs with either Category 5 UTP (limited to 100 meters maximum) or fiber optic cable (up to 2000 meters distance).

ATTENUATION - Degradation of signal level along the cable due to losses in the cable. Attenuation is typically measured in decibels (dB) and represents the overall signal loss in the link. Excessive attenuation may cause a receiver to misinterpret electrical pulses and the larger the loss, the greater the attenuation. The dB values are expressed in negative numbers and by industry convention, the negative sign is omitted.

Attenuation is the measured loss of signal strength from one end of a cable to the other. A "Swept Frequency" measurement is taken to insure the cable's integrity. This measurement starts at a low frequency and incrementally steps, making measurements, up to the maximum frequency for the selected cable type.

AVERAGE IMPEDANCE - Testing that can be performed to identify physical damage to the cable (much like a capacitance test), connector defects, or cable segments with incorrect characteristic impedance.

AVERAGE NOISE - Detects rms voltage on each pair of wires using a broadband detector. Available only on the PRO-XL model.

AWG - American Wire Gauge. A method for measuring the thickness of the conductive portion of a piece of metallic cable. The numbers assigned are inversely proportional to the cable's size. A cable with a rating of 24 AWG will be much thinner than one rated 18 AWG.

BACKBONE - A term used to describe the main segment connecting several smaller subnetworks. This main segment is usually designed for maximum data throughput, sometimes at significantly higher speeds than the subnets.

BALUN - Balanced/Unbalanced. A passive line matching transformer designed to match the impedance of the transmission medium with that of the communicating device. Frequently used to implement communications on twisted pair media that would normally require coaxial cable.

BANDWIDTH - The range of electrical frequencies that an electronic device or transmission system can effectively handle. For LANs, it describes the maximum data rate for a given topology. The best bandwidth indicator of a cabling system is ACR, and one should strive for 7-10 dB ACR at the highest frequency level of transmission. The higher the ACR, the stronger the signal (see ACR).

BASEBAND - The use of the entire bandwidth of the network cable to transmit a single digital signal. The frames are applied directly to the cable in digital form without modulation or multiplexing. Ethernet and Token Ring are Baseband transmissions because they use only one protocol.

BAUD - The most basic unit of data transmission speed, one baud represents one signal state change per second. It is often confused with bits per second (bps) because they were at one time very similar. Using current data compression and modulation techniques, however, many times the baud rate in bits per second can be achieved.

BENDING RADIUS - The minimum allowed curvature of any piece of cable (fiber or metallic). Absolutely critical that this is maintained to not affect a cable's impedance (metallic) or refractive index (fiber optic).

BER - Bit Error Rate. The ratio of errored bits of data to the total number of bits transmitted.

BIT - Binary Digit. The smallest unit of data and most basic for data communications. It can have a value of a one (mark) or a zero (space).

BIT RATE - The number of bits passing a given point in a measured period of time. Usually expressed as bits per second (bps), thousands of bits per second (kbps), or millions of bits per second (Mbps).

BLOCK - A group of transmitted data, typically framed with control characters and having a fixed size, such as 256, 512, 4096, etc.

BNC - The Bayonet-Neill-Concelman connector. Widely used in 10BASE2 and other thin coaxial applications.

BPS - Bits Per Second (see also BIT RATE).

BRAID - The stranded shield found on most types of axial metallic media and some types of twisted pair, such as IBM type 1.

BRIDGE - In the LAN arena, it is a device used to connect two physically separate networks. They may or may not have the same topology.

BROADCAST - To send a message to two or more receiving devices at the same time.

BUS - An electrical connection tying two or more points together. A bus can be serial or parallel and can carry dynamic signals or DC voltage.

BUS NETWORK - A topology based on all communicating devices being attached to a common medium. Various access methods are used including CSMA/CD and Token Passing. Typically bus networks carry data in the millions of bits per second speed range.

BYTE - Eight data bits or two nibbles.

BYTE COUNT - The number of bytes in a given message or block of data.

c - Symbol representing the Speed of Light (See Propagation Rate and NVP).

CABLE - Metallic or fiber optic transmission medium used to interconnect electrical and data communications devices. Common metallic types used in LAN interconnects are axial (coaxial, twinaxial, triaxial, quadraxial), shielded twisted-pair (STP) and unshielded twisted-pair (UTP). Cable comes in many varieties and ratings for particular applications. See text for additional information.

CABLE RISER - Vertically installed cable connecting floors of a building. Cable tested to UL 1666 is "riser" rated. Typically multi-pair copper and fiber.

CABLE RUN - A horizontal installed cable segment with its unique path. The "Star Wired" cable run is the cable that is "home-run" from work outlet to cross-connect or patch panel.

CABLE SHIELD - A conductive layer of material located just under the cable's outer sheath which is designed to increase the cable's immunity to outside interference. It may be constructed of metal foil or braided strands.

CAMPUS ENVIRONMENT - A relatively large geographical area encompassing multiple buildings and involving the interconnections between all devices therein.

CAPACITANCE - The measured ability of an electronic component to store an electrical charge. Capacitance is rated in units called FARADS. Common divisions of farads include microfarads (mF = X 10^6), nanofarads (nF = X 10^9) and picofarads (pF = X 10^{12}).

CARRIER SENSE MULTIPLE ACCESS/COLLISION DETECTION - CSMA/CD. The most common form of access control found in an Ethernet environment. It is used to detect data collisions in a logical bus topology, like Ethernet.

CARRIER SIGNAL - A continuous signal, upon which is modulated the data or other signal that is to be transmitted.

CAT3 - "Category three" 4 Pair UTP cable and associated connecting hardware whose transmission characteristics are specified up to 16 MHz. (EXISTING TIA/EIA; SEE ISO 11801 CLASSES A, B, C)

CAT4 - "Category four" 4 Pair UTP cable and associated connecting hardware whose transmission characteristics are specified up to 20 MHz. (EXISTING TIA/EIA; SEE ISO 11801 CLASSES A,B,C)

CAT5 - "Category five" 4 Pair UTP cable and associated connecting hardware whose transmission characteristics are specified up to 100 MHz. (EXISTING TIA/EIA; SEE ISO 11801 CLASS D)

CAT5e - "Category five e" 4 Pair UTP cable and associated connecting hardware whose transmission characteristics are specified up to 100 MHz (RATIFIED TIA/EIA) Has approximately 3dB stronger signal strength than standard CAT5.

CAT6 - "Category six" 4 Pair UTP cable and associated connecting hardware whose transmission characteristics are specified up to 200 MHz.(FUTURE PROPOSED TIA/EIA; SEE ISO 11801 CLASS E)

CAT7 - "Category seven" 4 Pair STP cable and associated connecting hardware whose transmission characteristics are specified up to 600 MHz.(FUTURE PROPOSED TIA/EIA; SEE ISO 11801 CLASS F)

CATV - Community Antenna Television or Cable Television. CATV is Broadband transmission effected by multiplexing multiple channels on one medium.

CAU - Controlled Access Unit. A type of semi-intelligent central wiring concentrator for the Token Ring environment. Used in conjunction with LAMs.

CCITT - International Telephone and Telegraph Consultative Committee. An international standards setting body for the telecommunications industry. In 1985, the CCITT chartered the TIA/EIA with drafting the 568 Standards we use today.

CDDI - Copper Distributed Data Interface. A standard describing 100 Mbps data transmission on metallic cable.

CPU - Central Processing Unit. The portion of a computer which performs all arithmetic and logic manipulation in addition to instruction interpretation and processing.

CHARACTER - A combination of binary digits representing an alphanumeric value.

CHARACTERISTIC IMPEDANCE - 1. The measure of a transmission medium's impedance throughout its length and over a swept frequency spectrum. Often conversion is done to the frequency data to put it in the time domain. 2. A resistive termination matching that of the transmission medium being used to effectively minimize reflections due to structural variations in the medium.

CHARACTER ORIENTED PROTOCOL - A communications protocol that responds to special control characters as opposed to individual bit values for function control.

COAXIAL CABLE - A cable constructed of an insulated center conductor surrounded by a shield. 10 BASE-5 and 10 BASE-2 require different types of 50 ohm coax cables.

COLLISION - When data from two devices attached to a common bus is placed on the bus at the same time. In Ethernet, this typically generates a re-transmission.

COMMUNICATIONS PROTOCOL - Rules governing the behavior and attributes of both hardware and software as they apply to data communications.

COMMUNICATIONS SERVER - A device that acts as a gateway to communications lines outside normal building boundaries or to a different communicating device. The server may allow access to several lines by any number of users on a network. Sometimes called a modem pool.

CONCENTRATOR - A device used in LAN applications to attach several nodes to one AUI or bus attachment point. Often this term is used mistakenly in place of hub.

CONNECTING BLOCK - An interconnecting device used in telecommunications and LAN applications consisting of multiple points for wire attachment. Some common connecting blocks are the 66 block, 110 block, the BIX block and the Krone block (see Cross-Connect).

CPS - Characters Per Second.

CRC - Cyclic Redundancy Check. A common form of error checking for data communications and other situations where blocks of data are moved from one location to another. All bits in a block are divided by a predetermined binary number and the result is compared with what the actual number should be.

CROSS-CONNECT - A block or patch panel used to cross-connect or patch (make changes) to a network backbone or a user's horizontal cable run.

CROSSTALK - Crosstalk is the measure of a signal induced to one pair by another pair of conductors. Crosstalk measured from the near end is "NEXT" and crosstalk measured from the far end is "FEXT". Crosstalk is expressed in dB and the smaller the number, the greater the inductive noise effect. TSB-67 requires bi-directional NEXT measurements to verify performance in both directions.

CSMA/CD - See Carrier Sense Multiple Access/Collision Detection (an Ethernet Media Access Mechanism).

D TYPE - A description for the 9, 15 and 25 pin connectors widely used for data communications and microcomputer peripherals. It looks very loosely like a "D" when viewed vertically.

DATA GRADE CIRCUIT - A telephone line capable of carrying high speed data. The line is specially conditioned to accommodate this.

dB - or decibel. A unit of measurement to compare an output signal to an input signal. A relative term. (see text on ATTENUATION for more information)

DC - Direct Current. A steady state voltage, either positive or negative with respect to ground, but not both. Batteries are a source of DC.

DC RESISTANCE - Provides an effective check on cable and connector integrity. Both cabling and connectors have inherent DC resistance. Loop resistance is the combined resistance of each individual wire in a two-wire pair. It is tested for each pair by placing a known DC voltage on one wire in the pair, shorting the Remote Handset and reading the voltage loss at the Display Handset. DC loop resistance testing is essential to isolating poor connector punch downs, cable damage and shorts.

DIGITIZE - The conversion of an analog or continuous signal into a data stream of binary digits.

DISTRIBUTED PROCESSING - A system or network where the processing is done at each individual workstation and not at a central device. A LAN is an example of distributed processing. A network of computers sharing the calculations, or processing data, instead of just one computer.

DOMAIN - All peripherals and nodes under control of a single computer or server in a network.

DRAIN WIRE - In a cable, it is an uninsulated wire included in the sheath with the insulated wires. Typically used for grounding.

DROP CABLE -A cable connecting a workstation or peripheral to the main network cable.

EIA - Electronic Industry Alliance. A trade organization of manufacturers that sets and defines standards for its members. This group works with the TIA on standards pertaining to both industries. The originator of the "RS" series of interfaces (RS-232C, RS-449, etc.)

ELFEXT - Equal Level Far End Crosstalk, is a measure of crosstalk noise between pairs at the receive end of the transmission line, adjusted for attenuation. This noise measurement is important to the performance of newer applications which will transmit on multiple pairs (Gigabit Ethernet).

EMI - Electro-Magnetic Interference.

ETHERNET - A LAN operating under the guidelines of the IEEE 802.3 document defining physical and data link layer behavior.

FANOUT - A device similar to a concentrator in that it provides multiple access to a single backbone tap.

FARAD - A unit for measuring capacitance. One farad is a one coulomb charge with one volt potential difference between the plates. A 50 volt, one farad capacitor is roughly the size of a quart milk container. (see also CAPACITANCE)

FAR-END CROSSTALK - A less accurate measurement of the amount of a signal that is induced into an adjacent pair of wires. (see also CROSSTALK)

FAULT FIND - A diagnostics feature on the PRO XL that allows you to determine where in a link a fault is located. (see DOWNLINE IMPEDANCE)

FCC - Federal Communications Commission.

FCS - Frame Check Sequence. An error checking field found in bit oriented protocols.

FDDI - Fiber Distributed Data Interface. A dual counter-rotating ring topology based on fiber optics operating at 100 Mbps.

FDM - Frequency Division Multiplexing. A technique in which several signals are transmitted on the same cable simultaneously at different frequencies. Used in Broadband.

FDX - Full Duplex transmission. Gigabit Ethernet will use full duplex transmission on all four pairs.

FOUR-WIRE CIRCUIT - A transmission circuit using a transmit pair and a receive pair, or four wires altogether.

FREQUENCY - The rate at which an electrical current alternates, usually measured in Hertz, or cycles per second, which are the same.

FTP - File Transfer Protocol. A file sharing protocol often used in conjunction with TCP/IP. It operates in layers 5 through 7 of the OSI network model.

FULL DUPLEX - The ability of a circuit to carry signals in two directions simultaneously. (see FDX & GIGABIT ETHERNET)

GATEWAY - A connection between two dissimilar networks, i.e. 10BASET & 3270.

GROUND LOOP - Undesirable condition that occurs when a segment is grounded at more than one point. It creates a situation for a potential voltage difference between the grounds, causing the network cable to conduct unwanted electricity.

GUI - Pronounced "gooey", it's the abbreviation for Graphical User Interface.

HALF DUPLEX - The ability of a circuit to carry signal in one direction at a time.

HEADROOM - Headroom is the sum of the natural margin, or ACR, of the cabling and the additional margin between the worst case NEXT and the limit for NEXT. Headroom is calculated using a power sum ACR on the worst pair after the attenuation for that pair has been normalized to 100 meters (328 ft).

HERTZ - An equivalent to cycles per second for defining frequency.

HOME RUN - A cable run going from a workstation or office directly back to a wiring closet with no other connections. Physical star topologies consist exclusively of home runs.

HUB - 1. A central point of connection for several circuits. 2. A device that electrically converts a logical topology to a different physical topology. An ARCNET hub enables physically star-wired nodes to be seen as a logical, token-passing bus. Hubs can be active (powered), or passive (non-powered). Active hubs sometimes are capable of allowing longer cabling lengths than passive units.

IBM TOKEN RING - A token passing network topology that conforms to the IEEE 802.5 definition and documents. Operating at 4 Mbps or 16 Mbps, at one time it was the chief topology used to interconnect small and mid-size equipment from IBM and other vendors. See TOPOLOGIES section for specifications.

IDC - Insulation Displacement Connector. A type of connector in which the insulated wire is pushed down between two sharp bladelike pieces of metal so that the conductor touches the connector and there is no exposed bare wire. Modular telephone plugs (RJ series) are examples of insulation displacement connectors.

IDF - Intermediate Distribution Frame as it was called previous to being changed to "IC" or intermediate cross-connect in TIA/EIA 568-A. Also known as a wiring closet, the IDF is a cross connection point for horizontally attached

devices to riser media. Provides the wiring interface between the end-user and the Main Distribution Frame. The MDF was change to "MC", which stands for main cross-connect.

IEEE - Institute of Electrical and Electronic Engineers. A standards setting and publishing body responsible for such guidelines as the 802 series for LANs.

IEEE 802.X - Guidelines describing the physical and data link layers of the OSI network model for various topologies. See TOPOLOGIES Section for a description of each.

IMPEDANCE - The complex opposition to current flow dynamically in a transmission medium. Including components of resistance, capacitance and inductance. See IMPEDANCE for more detailed information.

IMPEDANCE MATCHING - The verification that all elements of a transmission system exhibit very similar impedance characteristics at operating frequency. A properly impedance matched system introduces very little signal distortion.

IMPULSE NOISE - Intermittent, high frequency (short), high amplitude pulses that are induced into a transmission line. Can cause data corruption and in some cases hardware damage. (see also ELECTRICAL NOISE TESTING Section)

INDUCTANCE - The tendency for an electrical current to build a magnetic field around a conductor and cause a portion of that current to be induced or generated on an adjacent conductor. (see also ELECTRICAL NOISE TESTING and NEAR-END CROSSTALK TESTING Sections)

INSULATION - A non-conductive material used to separate conductors to prevent electrical short circuits. Cables are insulated and rated for different applications. Plenum rated cables can be used anywhere inside a building and riser rated cables are used between floors and horizontally and cannot be used in a plenum unless it is in conduit.

INTERNET PROTOCOL - IP. Used at OSI Level 3 and above to connect networks through gateways and routers.

INTERNETWORKING - The connection of multiple networks for data interchange. This is normally accomplished with interface devices such as bridges, routers and gateways.

ISO - International Standards Organization. Based in Geneva, this body develops open industry standards for the world. A key standard is the Open Systems Interconnection Network Model (OSI model) which forms a general definition for all LANs. ISO 11801 is similar to TIA/568-A but uses different terms and values. (see NETWORK TROUBLESHOOTING TOOLS for a copy of the OSI model)

JABBERING, JABBER - The continuous transmission of meaningless data, usually due to a failure of some sort. The network slows tremendously when burdened with this excess traffic.

JITTER - The skewing of a transmitted pulse to cause its edge to become poorly defined and its width to be variable, causing data errors.

LAN - Local Area Network. A distributed processing environment usually located within the confines of a single building.

LENGTH - The distance of a communications link measured by a tester with a TDR. For TIA/EIA 568-A, the basic link is limited to 90 meters of horizontal cabling embedded in the walls and ceiling plenum, plus 2 meters of test equipment cords on each end. Length is one of the TSB-67 required tests for a Category 5 UTP cable limited to a total distance of 100 meters including the basic link of 90 meters + 10 meters allowance of line cords, patch cords and up to two cross-connects in a link. (see NOMINAL VELOCITY OF PROPAGATION)

LINEMAP - A term referring to the termination pinout pairs of cable. (see CONTINUITY & WIREMAP)

LLC - Logical Link Control. A protocol developed by the IEEE for end-system addressing and error checking. Operates in Layer 2 of the OSI model.

LOCAL DISTRIBUTION FRAME - LDF. Another name for an Intermediate Distribution Frame or "IC" as the TIA/EIA 568-A standard specifies.

MAC - Media Access Control. A control protocol designed for specific media with variations for different media. Works in conjunction with LLC.

MAIN DISTRIBUTION FRAME - the MDF has been changed to "MC" (main cross-connect) in the TIA/EIA 568-A 1995 revision. The MC is the point at which outside service lines interface to inside service and then to IC's or to TC's.

MAN - Metropolitan Area Network. A Network operating within the confines of a single city or community.

MANCHESTER ENCODING - An encoding method that involves a digital state change (0 to 1 or vice versa) for every bit representation occurring in the middle of the transmitted bit. Useful in local area networks because it is self-clocking. The receiver can develop the data clock from the transmitted data stream. Used in Token Ring and Ethernet systems.

MAU - Media Access Unit. Another name for an Ethernet transceiver. Was also the abbreviation for a Token Ring Multi-station Access Unit. This has been changed to MSAU to avoid confusion.

MDF - Main Distribution Frame, which has been changed to "MC" (main cross-connect) by the TIA/EIA 568-A Standard. The connecting point in a building where outside services interface to internal services. All networking components are "star-wired" back to the MC.

MEDIUM - Material used for the transmission of signals.

MICROFARAD - One millionth of a farad.

MJ - Modular Jack. A term describing plug-in IDC connectors used in telephone and data communications. The connectors usually are configured with 4, 6 or 8 pins.

MODEM - MOdulator DEModulator. A device that converts digital data to a modulated form which can be transmitted over telephone lines, and reverses the process when receiving.

MODULAR PLUG - A series of connectors designed for ease of use and flexibility. They are characterized by locking plastic tabs on the bottom and typically appear in three configurations: RJ-11 (4 conductor), RJ-12 (6 conductor) and RJ-45 (8 conductor).

MSAU - Multi-Station Access Unit. The new abbreviation for a Token Ring wiring center. The units can be active or passive. They typically have eight ports (or lobes) for device attachment and a RI (ring-in) and RO (ring-out) port for network attachment.

MULTIPLEXER - A device that causes two or more signals to use the same communications medium. Multiplexing can occur in either the frequency or the time domain.

MUTUAL CAPACITANCE - The capacitance between two conductors with all other conductors shorted to ground.

MUX - A short form slang of multiplex. Also MUXED, MUXING.

NAK - No Acknowledgment. A data communications negative response.

NEAR-END CROSSTALK - The induction of transmitted signal onto another pair at the transmitting end of the medium (NEXT). (see also NEAR-END CROSSTALK TESTING)

NETWORK ADDRESS - A number giving a specific identification to a network attached device.

NETWORK INTERFACE CARD NIC - A circuit card providing the hardware interface between a network device and the transmission medium.

NETWORK OPERATING SYSTEM (NOS) - The software component of a network. The NOS contains all instructions pertinent to data transfer, file manipulation and services and interfacing routines.

NETWORK TOPOLOGY - The physical layout and interconnection of a network. See TOPOLOGIES Section for examples.

NODE - A connection point into a network. The node may perform several functions (i.e., file server, workstation, print server, bridge, etc.).

NOMINAL VELOCITY OF PROPAGATION - "NVP" is the relative speed that a signal travels on a conductor that is proportionate to the speed of light in a vacuum. Length measurements are determined by sending a signal down a line and measuring the reflected signal that comes back and factoring in the amount of time it took to make the return trip. (see "c" and LENGTH)

OCTOPUS - A cable adapter that transforms a 25-pair feeder into individual modular plugs.

ODD PARITY - An error checking method in which binary ones or zeroes are added to a character so that the number of one is always odd.

OHMS - A measure of resistance. One ohm (Ω) allows one ampere of current to flow across a one volt potential.

OPEN CIRCUIT - An incomplete circuit. A cable connected at one end only is an example of an open circuit. The opposite of a short circuit.

OSI - Open Systems Interconnect. A seven layer model defining the different levels of data communications in a network environment. Developed by the International Standards Organization.

PACKET - A group of data in an organized form with a distinct header, control information and a destination address.

PACKET SWITCHING - The transmission of packetized data through a network. Each packet has information linking it to the rest of the total message or file as well as the destination address. This form of communication is efficient because each packet can take a different route if necessary to maximize throughput.

PACKET SWITCHING NETWORK - A network constructed to move data packets. An X.25 network is an example of a packet switching network.

PAIR - Two wires, usually twisted around each other.

PAIRED CABLE - Cable in which all conductors are arranged in color-coded pairs, usually twisted around each other and then surrounded by a sheath.

PARITY CHECK - The addition of a bit to a character to aid in error checking.

PATCH PANEL - A board with multiple jacks installed for the purpose of connecting devices with modular jacks and cables.

PDN - Public Data Network.

PDS - Premise Distribution system.

PEER-TO-PEER NETWORK - A network where all devices have equal status and abilities for file transfer, printer sharing, etc.

PHYSICAL LAYER - The bottom layer of the OSI model, concerning physical interconnect hardware and electrical interface between devices.

PICO - 1×10^{-12}. Used as a prefix for capacitance (pF).

PICOFARAD - One trillionth of a farad. A common unit used in measuring mutual capacitance in cable.

PLENUM CABLE - Cable that can meet the UL 910 (Steiner Tunnel) test by using fire retardant insulation that inhibits fire propagation and toxic fumes. These cables can be used in horizontal runs in open air ceiling returns and will be clearly indicated with a "P" suffix (such as CMP) as certified by UL, ETL or other third party testing firms. It is typically coated with Teflon.

POLL - In LAN applications, it is a query to a node looking for information to be transferred on the network.

POTS - Plain Old Telephone Service. Slang term to describe unknown, older, generic telephone wire.

POWER SUM - Pair-to-Pair measurements are used to measure one pair against another. Power Sum measurements select a pair and then measures the disturbing pairs within the same sheath. This can be used in a 4-Pair or other high pair count (25, 50, 100 and up) to determine the effects of all the cables (of course testers only test 4-Pair at a time). Power Sum ACR, ELFEXT (equal level FEXT), and bi-directional NEXT measurements are made with the LT 8000 Series Testers. In general, this results in an approximately 3 dB loss limit when compared to pair-to-pair test values.

PROPAGATION RATE - The speed at which electricity travels in a transmission medium. Expressed as a percentage of the speed of light which is represented as a lowercase "c". (see also CABLE LENGTH TESTING Section)

PROTCOL - A set of rules governing all aspects of communicated data.

PROTOCOL ANALYZER - A device capable of capturing, monitoring, decoding and analyzing various communications protocols. A high level troubleshooting and analysis tool.

PUNCH-DOWN BLOCK - A device used to terminate and cross-connect premises wiring. (see also CONNECTING BLOCK)

RACEWAY - A metal or plastic trough used to guide and carry installed cabling.

RECEIVER - Any device that receives communications. The opposite of a transmitter.

RESISTANCE - The blockage or obstruction of current flow. A property of all conductors, it is measured in ohms.

RETURN LOSS - A measure of impedance mismatch indicated by a return echo signal reflection. It is often referred to as "RL" and it measures the ratio between the transmitted signal strength and the signal reflected to the transmitting end. Like attenuation, excessive return loss indicates reduced signal strength at the receiver end and it can indicate a mismatched impedance at some point along the cable link. Return Loss is reported as a dB value for each pair, from each end. A value of 20 dB or higher for UTP is very good and a value below 10 dB causes a large reflection of signal back to the source and is not good. The WWG LT8155/8600 will provide this measurement.

RISER - The path between floors of a building carrying cables that interconnect the floors.

ROUTER - A device used to connect LANs utilizing different communications protocol. It directs traffic within networks and offers security by restricting access to those that don't belong. Routers require intensive programming instructions and are used mostly for WAN (wide area network) interface to outside services.

RS-232-C - A standard developed by the EIA defining signal levels and pin assignments for serial data communications. Misused and modified, it no longer represents a standard, but a general guideline to follow when interfacing DTE and DCE.

SAG - The downward curvature of a wire or cable due to its weight. The TIA/EIA 569 Pathways and Spaces Standard requires Category 5 cable to be supported at 48" to 60" intervals and the sag cannot exceed 12" between supports.

SERIAL TRANSMISSION - The sending of multiple data bits down a single line in a stream.

SERVER - A network device that provides a service to other network devices. Services include file, printer, communications or gateway.

SESSION LAYER - The fifth layer of the OSI model dealing with network processing, linking and unlinking users from their chosen service.

SHEATH - The outermost covering of a cable, usually an insulating material applied to protect the cable from environmental effects.

SHIELD - A conductive material installed between the insulated center conductor(s) and the sheath. Designed to provide increased immunity to interference caused by outside electrical noise. Usually constructed of metal foil or braided, stranded wire.

SHIELDED PAIR - A pair of wires, twisted together and covered with a conductive material to provide any potentially induced noise a quick path to ground.

SHORT CIRCUIT - A condition that exists when two conductors are connected ahead of where they normally should be in a circuit. This causes reduced resistance and sometimes the undesirable side effects.

SIGNAL GROUND - A common point of reference for all other signals in a communications interface.

SIGNAL TO NOISE RATIO - (SNR) The ratio of received signal to existing system noise. In LAN applications it is the attenuation to NEXT ratio. Both are expressed in decibels.

SNMP - Simple Network Management Protocol. A popular network management protocol being incorporated into many intelligent hubs and concentrators. Originally designed for TCP/IP, it now functions independently and with most topologies and NOS's.

SONET - Synchronous Optical NETwork.

SPLIT PAIR - A situation that occurs when a twisted pair is misconnected so that it becomes 1/2 of two separate pairs. The noise immunity of the twists is lost and an impedance mismatch is created. This wiring error will not show up as an error on wiremap, but will be indicated by very high NEXT.

STAR TOPOLOGY - A physical layout in which each device is wired back to a central point. (see also TOPOLOGIES Section)

START BIT - In asynchronous communications, each character is delimited by a start bit and a stop bit to indicate to the receiver the character's location.

START/STOP TRANSMISSION - Another term for Asynchronous Communication.

STOP BIT - The trailing bit in an asynchronous character sequence.

STP - Shielded Twisted Pair. Cable constructed of pairs of insulated wire twisted around each other surrounded by shielding material made of foil or braid or both. The entire group of wires may have a common shield or each pair may be shielded individually with another shield around the entire group just under the sheath.

STRANDED CONDUCTOR - A wire or cable constructed of several small strands of conductor instead of one larger solid piece. This configuration provides for more flexibility in certain applications. Patch cords are made out of stranded conductors and the NEXT values are degraded up to 20% to allow for them in a link.

SWITCH - Multi-port device used to connect a quasi-exclusive 10/100/1000 Mbps connection between any two end systems using the source and destination addresses of the packet via the internal bus. Switches work at the MAC (Media Access Control) Layer and above and use either "store and forward" or "cut-through" technology. Switches are "plug-and-play " devices that can be used to segment a network when it starts to slow down. Each port can function at the rated speed of the switch and some are auto-sensing for 10/100 Mbps. Ethernet switches are offered as standalone systems or as modules for existing hubs.

SYNCHRONOUS TRANSMISSION - Transmission between devices with a common clock. Data can be sent at a much higher speed because there is no need to frame each character.

T CONNECTION - A connector fanning three directions and looking like a "T". Commonly used is a BNC T connector for 10BASE2 applications.

TAP - An electrical connection to a bus to enable access. A tap may be invasive (requiring a cable splice), or non-invasive (a "vampire" tap).

TCP/IP - Transmission Control Protocol/Internet Protocol. A suite of protocols designed by the Department of Defense to enable communications between dissimilar computer systems. Now widely used by the commercial and academic sectors.

TDR - Time Domain Reflectometer. A piece of test equipment used to measure metallic cable length and impedance. (see also CABLE LENGTH TESTING and IMPEDANCE TESTING Sections)

TERMINAL SERVER - A device that allows connection of several terminals and multiplexes them onto a LAN cable.

TERMINATE - To connect a wire or wires to a device or a matching impedance connection.

THICKNET - Another term for IEEE 802.3 10BASE-5 systems.

THIN ETHERNET - Normally describes a 10BASE-2 system. Also called Cheapernet. (see also TOPOLOGIES Section for specifications)

TIA - Telecommunications Industry Association.

TOKEN - A unique combination of bits that passes from station to station in a token passing network. When a station has the token, it may communicate with the network.

TOKEN BUS - A bus topology that uses token passing as its contention method.

TOKEN PASSING - Moving a special combination of bits from station to station in a ring or bus when there is no traffic. When a workstation has the token, it may then use the network channel for communications.

TOKEN RING - A logical ring topology that passes a token in one direction around the ring. A given device must possess the token to communicate with any other device. If it does not gain control of the token as it passes, it must wait until the token goes around the ring.

TOPOLOGY - The geometric form describing a network's logical and physical layout.

TRAFFIC - A measure of the activity on a network at a given time. Network analyzers can monitor traffic, and when Ethernet segments start to exceed 30% to 40% utilization, they run much slower and need to be segmented with switches.

TRANSCEIVER - A device that can transmit and receive information, typically to a workstation from a network connection.

TRANSPORT LAYER - Level 4 of the OSI model, this layer deals with end-to-end control of the transmitted information and provides results to the session layer.

TSB-67 - Technical Service Bulletin released by TIA/EIA 568-A. It is entitled "Transmission Performance Specifications for Field Testing of Unshielded Twisted-Pair Cabling Systems." TSB-67 specifies the electrical characteristics of field testers, test methods and minimum transmission requirements for UTP cabling. It describes the different categories of cable, four basic test requirements: wiremap, length, attenuation, and bi-directional crosstalk.

In addition, tester accuracy limits are specified with Level II being the most accurate.

TSB-95 - Technical Service Bulletin coming from TIA, "Additional Transmission Performance Specifications for 100 ohm 4-Pair Category 5 Cabling". This TSB governs the pass/fail requirements for Gigabit Ethernet over installed Category 5. It defines additional parameters -- return loss, ELFEXT, delay and delay skew – for installed Category 5 cabling. Every cable link will need to be tested to TSB-67 and TSB 95 to guarantee that it will support Gigabit Ethernet. TSB-95 also specifies Level II-E field tester requirements to measure these new parameters. Field re-certification using a Level II-E instrument will insure proper operation of 1000 BASE-T.

TWINAXIAL CABLE - Cable constructed of two insulated center conductors surrounded by a braided shield. Widely used in midrange IBM systems (AS 400's).

TWISTED PAIR - Two insulated wires twisted around each other at regular intervals. May be shielded or unshielded.

UL - Underwriter's Laboratories. A testing body formed primarily to certify fire safety of electrical equipment dealing with voltages greater than 48 VAC or DC. UL has assumed the responsibility for certification of data grade unshielded twisted pair media for conformance to EIA/TIA and NEMA specifications. The cable categories III through V from the EIA/TIA TSB 36 document serve as the basis for UL cable LEVELS 2 through 5. Cable certified by the UL to meet these standards will bear a marking indicating such.

UTP - Unshielded Twisted Pair. Cable constructed of typically multiple twisted pairs of wires, unshielded in a PVC or plenum rated sheath.

uV - Microvolt. One millionth of a volt.

µm - A "micro-meter" equals one millionth of a meter. 70 um is the approximate width of a human hair and the most common multi-mode fiber uses 62.5/125 µm core/cladding.

VAMPIRE TAP - A tap system for 10BASE5 systems that does not require cutting and splicing the cable. This system uses a sharp pin which pierces the insulator and contacts the center conductor of the thick 10BASE5 cable.

VOICE GRADE - A designation for a facility capable of carrying signals with a frequency range of 200 - 4000 Hertz.

WAN - Wide Area Network. A network typically spanning a continent or the globe and connected by routers.

WIRING CLOSET - Typically called a telecommunications closet (TC). It is a central point for horizontal floor wiring to connect to vertical riser cable or to backbones running to an IC or MC.

WIREMAP - A test performed in the suite of TSB-67 requirements that determines the pinout configuration of the wiring pairs. This is the first test a Category 5 tester runs and it looks for opens, shorts, reversals, split pairs and any other miswires. TIA/EIA 568-A specifies that all four pairs be terminated for Category 5 UTP. Each respective protocol has different pinouts as shown by the WIREMAP test results. Ethernet uses pins 1,2 and 3,6 and Token Ring uses 3,6 and 4,5. (see LINEMAP)

WORD - A collection of related data bits whose length is dependent upon the bus width of the computer doing the processing. For example, an 8-bit computer would use an 8-bit word, a 32-bit computer would use 4X8 bits or a 32 bit word.

X-ON/X-OFF - A basic form of information flow control for data communications, the receiving device would issue an X-OFF to the transmitter while it emptied its buffer to disk or performed another operation. When the receiver was ready for more data, it would then issue an X-ON.

XC - Abbreviation for cross-connect.

LAN Cable Troubleshooting Methodologies

If the cabling is in question or it has been conclusively determined that the fault is there, then the testing process begins. We will look at a series of steps to take first on an "alien" or unknown segment, and secondly on a familiar cable segment about which we already have some information. The format of this discussion is based upon a logical step-by-step process with several tools to troubleshoot different types of cable (from coax to UTP). If you have a Category 5 tester and you are testing UTP, you are in luck. After selecting the cable type, all you will need to do is push the AUTOTEST button and the tester will automatically perform the tests. If an error is detected, the tester will indicate to you what failed and you can focus on the problem.

Find the Cable
The first thing to do is to attempt to find both ends of the suspicious segment. If your cables are accurately labeled and mapped, proceed to Step 2. If not, there are a few things that can be done to find any given cable.

It is assumed that you already have a general idea of where the cable goes; at least to an intermediate closet. A basic continuity or loop resistance test from the station end will tell whether or not the segment is properly terminated. If it is not terminated (reads as an open or short circuit), a length test can then be run to determine how far down the line it is to the apparent end (open) or damage (short). If the cable is properly terminated and reads a few ohms higher than a matching resistance (i.e. 100Ω terminator + 6Ω loop resistance = 106Ω) proceed to the active device for that group of nodes. If you are fortunate enough to have some type of activity indicator on your active device, look for an inactive node to disconnect. Once disconnected, your loop resistance should now read an open circuit. This will give you the impedance mismatch necessary to determine the cable length. If there is more than one inactive node, you may need to experiment a bit until the right one is found.

For a coaxial system, the procedure is similar, however there usually are fewer cables to choose from at the point where the segment joins the backbone. In the case of a multi-port repeater, again look for the segment, which is inactive to begin the identification process.

When troubleshooting twisted-pair systems where baluns are used, it becomes more difficult to identify cables using the above method. A balun displays a DC short circuit under normal circumstances. If the near-end balun is removed, the cable should measure just the loop resistance of itself plus an insignificant (<2Ω) amount for the balun at the far end. Unfortunately, finding a particular segment amidst a panel full of unlabeled, balun attached twisted-pair wires quickly becomes a hit and miss situation without documentation of any sort. TIA/EIA 568-A is very specific about what is allowed in a link. The cable, cross-connect

hardware or patch panels, patch cord or a line cord at the device. Accessories like baluns and adapters are not allowed in a test link.

Your cable test equipment might also have the capability to assist you in labeling your cables. Typically this is accomplished in one of two ways. The first method involves using a specialized transmitter to broadcast a tone down the cable and also a separate receiver to trace the cable through walls and ceilings to its final destination. Drawbacks to this method are loss of signal through a firewall, densely packed cable conduit, or cable just too far away physically, or once the wiring closet is located, the receiver cannot distinguish between several cables close together. The other method uses variable resistances between the conductors to identify the cables with a number or a specific measurement. This is particularly helpful if there are a large number of cables to label. Drawbacks to this method are the need to know location of both ends of the cable, and typically a minimum of three conductors are needed for this type of test. Depending upon your particular installation, one or both of these methods may be the best.

Once you have located the cable that requires testing, DOCUMENT IT! You will probably never have to look for this cable again, however, you also don't want to go through Step 1 every time a cable problem or question rears its ugly head.

Is it Alive?

Once you know which segment to run tests on, the next step is to determine if it is active, and the extent of the damage present. If you completed Step 1, you have already determined a basic loop resistance of the cable in question. For those bypassing Step 1, use your test equipment to monitor the line for noise. This will indicate whether or not this segment is active. Large readings (> 300 mV) in the active frequency band for your topology probably mean that this segment is connected and is transmitting and receiving to a certain extent. If activity is indicated, the cable segment will need to be shut down for meaningful results on further tests. This measurement applies to all types of wiring systems, coaxial, twisted pair, and balun based as well. Once the segment is identified as inactive, the noise measurement should again be run to determine that the questionable cable is not inducing any signals from outside sources which could be contributing to a perceived network problem.

Connectivity Testing

You have identified the segment, it is not active, but it still may be causing some trouble or be suspect in your mind. The next step is to check the pin-to-pin connectivity of the cable. The object is to find wiring reversals and short and/or open circuits. Typically this is accomplished using a specialized termination along with your test equipment. You should get either a visual or hard copy indication of your interconnection identifying each conductor and its status.

Length and Impedance

At this point, you are ready to assess the cable for physical damage. A scan of the cable's absolute impedance and a resulting plot of impedance over the cable's length will reveal the most practical information at this point. If a Time Domain Reflectometer is used, it will give both of these measurements simultaneously. By evaluating the results, it can be determined whether or not the cable is contiguous from end to end. Keep in mind when using the TDR that a properly terminated cable segment will absorb the energy pulse transmitted for cable analysis. This will make the TDR think that the cable has no end. For best results, either short the opposite end of the cable's conductors together or unplug them from any active or passive device. The ideal TDR impedance plot is a flat line from the source to the end of the cable under test indicating consistent impedance throughout the segment's length. This is typical for coaxial cables and any deviations are easily spotted. By its nature, unshielded twisted pair will not yield as consistent a reading and faults will be more difficult to discern from actual normal cable fluctuations. Usually, any reflections $\geq \pm 10\%$ should be considered a fault worthy of investigation. If the twisted pair cable being analyzed is very old or of known questionable quality, a larger tolerance may be more appropriate. If the TDR does not have impedance measuring capability, the cable's mutual capacitance can be measured to assess cable damage. Undamaged cable's capacitance will be as specified by the manufacturer. If the cable was stressed or damaged during installation or remodeling, its capacitance will have changed (usually increased) beyond acceptable levels.

If your test cable passes through length and impedance, you can be confident that it is connected correctly and the proper distance exists between end points. The next series of tests will determine how susceptible the segment is to outside and internally generated interference.

Noise Testing

Problems caused by noise induction can unfortunately exhibit the same symptom even though the source of the problem may be different in different circumstances. Since you know your test cable is already run and connected correctly, now it's time to check for induced noise from some outside source. Using a wideband AC voltmeter, look at all frequencies up to 100 MHz for an activity. Make sure your test cable is properly terminated into its characteristic impedance for this test. There may exist a background level of up to 70 mV of existing noise depending upon your current wiring plant. This is negligible in its effect and should basically be ignored. For anything over 70 mV, try to narrow down the frequency of the signal so as to determine its source (see Noise Testing section).

If you're having intermittent problems, the cause could be an induced impulse of some sort. Put a timed recording voltmeter on the line that will capture and record fast pulses. By adjusting the trigger threshold of the voltmeter above 260 mV, you can record incidents other than normal network traffic.

So your cable is connected properly, is the right length, and isn't inducing noise from any outside source - what else could it be?

Attenuation
Maybe the cable is just too old or weathered to effectively handle LAN speeds reliably. Test the cable's loss characteristics with a signal injector and a power meter.

See just how much signal is getting to the receiver at the frequencies you normally operate at. By testing through all patch panels, patch cables, cross connects, etc., you will be able to tell if you really have a local area network or just a telephone system in disguise. Look at the section on Attenuation testing for some typical response curves that one might expect to see. Remember that cable attenuates more at longer lengths and at higher frequencies.

Shielded twisted pair cable can cause some real nightmares in this arena. Normally you would think that because a cable is shielded, it just has to be better, right? Not always. I'm not talking about IBM Type 1 or any of its derivatives (type 2,6 or 9). I mean the cable that some people hook terminals to their mainframe or minicomputer with. Typically 4-6 pairs with a foil shield. For mainframe attached terminals operating at 9600 bps, it provides quite a bit of noise immunity from outside sources. At network speeds of 4-100Mbps, however, the extra capacitance added by the foil shield causes a tremendous amount of excess attenuation which can then cause LAN nodes to fail or generate errors. Before you connect your twisted pair network with shielded cable, test it at the speed you will be using.

Crosstalk
If you've come this far, the problem is probably excessive errors, and/or random disconnects, or intermittent log-on failures. There should be some amount of signal transmission if all tests pass up to this point. It may not be clean or error free, but activity should exist on the cable segment being tested.

Excessive NEXT (near end crosstalk) could be the cause of the problem. If the cable plant is older, or existing wire was used, it may not be twisted tightly enough to cancel out the inductive tendencies of unshielded cable. Again using a signal injector and power meter, test to see how much of your transmitted signal is induced on your receiving pair. Both pairs (called disturbing pair and disturbed pair) should be properly terminated into the characteristic impedance of the cable being tested (i.e., 100().

Due to the high data rates and passive nature of many of its interconnecting devices, Token Ring on UTP cabling is especially susceptible to NEXT interference.

Problem/Solution Guide
Problems associated with the cabling plant often exhibit similar symptoms to defects in other layers of the network. Diagnosing these difficulties requires specialized test equipment designed for the various areas of system functionality. As with any system related failure, the intermittent type of problem is the most difficult to isolate and troubleshoot.

The initial system diagnosis must start from the top of the network model and work downwards until the solution is found. This "Top Down" approach allows the user to qualitatively analyze the network for proper performance and see from an overall operations standpoint where a source of trouble could be located. The primary goal of the troubleshooter is to break the problem down to the lowest common denominator. Symptoms, which manifest themselves in one particular application or function, can usually be quickly ruled out of a cabling issue. Exceptions would be if that function were logon, or network access. Also, localized hardware issues such as floppy drive access, monitor distortion, or keyboard failures can be attributed to the local node rather than a systemic problem.

When it comes down to the cable plant, there are a few common situations, which will be discussed here as well as a proposed course of remedial action. The distinction between symptom and problem will be maintained because many symptoms could be indicative of similar or different problems. In other words, different causes can make the same things look bad. Intermittent and consistent failures will be distinguished. While consistent troubles are more easily repaired, the intermittent ones seem to be more prevalent in the real world.

Symptom: Unable to log onto the network.

Type: Consistent (An easy one to start with!)

Problem: Moving the node around has broken a connection to one of the transmit wires.

Solution: Since the workstation does not recognize being attached to the network, the first test would be for end-to-end connectivity (Line Map) from the concentrator, through the patch and station cables out to the workstation. After the connection has been re-established, all functions normally.

Symptom: Unable to log onto the network, station freezes.

Type: Intermittent

Problem: Difficult to determine, it never happens when I go to test it out.

Solution: Now, this is more like what happens in the networks I know! The first thing to do would be to check the connectivity. If it passes, wiggle the wires and run it a few times to pick up a possible marginal connection. A DC loop resistance test on both pairs would be advisable next to determine a poor punch down or bad end connector. If all looks good to this point, there is probably an impedance mismatch or induced noise present. The average noise should be measured next, followed by an impulse noise test. If possible, try to correlate the symptom's occurrences with a specific time frame so as to catch an elusive noise spike. The next measurement should be impedance of the line. If there are any cable type changes or split-pairs, it will show up here. For good measure, perform also attenuation and near-end crosstalk tests to rule out those issues. Try taking your measurements at different times to account for heating and cooling.

Symptom: Disk errors on network drive, sluggish performance, station freezes.

Type: Intermittent

Problem: Induced electrical noise from an outside source.

Solution: Measure average noise and breaks the reading down by frequency. Low frequency sources include lighting, AC power lines and motors. Mid-band sources could be medical equipment, computer switching power supplies, light dimmers. High frequency sources include radio, TV, or microwave broadcast, or network traffic (near end crosstalk).

Symptom: At 3:00 PM every day, my computer indicates a network access error and it must be rebooted.

Type: Consistent

Problem: A common induced noise problem. An electrical noise spike is upsetting the network information going to that node.

Solution: Place an impulse noise recorder on the line shortly before 3:00 PM and set it to record any impulses over a 250 mV threshold. If they exist, examine the routing of that node's cable segment. Look for things such as proximity to large motors, elevators or other heavy equipment.

Symptom: On my coax network, one workstation fails to attach to the network. Nodes ahead of and behind this one work fine. Even a different computer that worked well somewhere else doesn't work in this location.

Type: Consistent

Problem: A phenomenon called a standing wave has been created because the cable portion is just long enough to coincide with the wavelength of the signal it is carrying or a harmonic of that signal.

Solution: First measure the entire cable segment's impedance to insure there are no changes or discontinuities in the entire run which may be aggravating the problem. Then obtain a length for the segment to determine if additional cable can be added. Finally, replace the cable portion leading into the workstation with another, slightly longer piece. The distance requirements for Ethernet coax are 18" (0.5 meters) minimum for thin and 7.5' (2.5 meters) for thick coax. Tees and/or taps should not be located more closely than these minimums or at multiples of them.

Symptom: A newly installed workstation can access the network but response time is extremely slow.

Type: Intermittent

Problem: Existing wiring was used to attach this node. The wire was leftover from an obsolete telephone system dating back to the early 1970's.

Solution: Older telephone wiring or POTS (Plain Old Telephone Stuff) may not be adequate for high speed data communications or local area networks. The best course of action here would be to run a complete set of tests, paying particular attention to line impedance, capacitance, and crosstalk parameters. It is possible that this cable may be used, but when cross-connected to newer cable an impedance mismatch is created resulting in excessive transmission errors.

While these problems are by no means all-inclusive of those you will be encountering, they are a sample of the kind of symptoms that may be experienced by the end users and which may have a cable-based solution.