Structured Cabling Systems for the Global Premises Distribution Market

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Advances in information technology have drastically altered the requirements of premises distribution systems. The advent of the personal computer has redefined the office environment and created a growing demand for high-speed local area networks. Accompanying that demand has been the need for open, standards-based, structured cabling schemes designed to handle traffic generated by the networks, no matter where they might be in the world. With these needs in mind, AT&T developed the Systimax® premises distribution system. This article describes how a structured cabling system, utilizing high-performance media and interconnection components designed within the context of open standards, has resulted in an increase of many orders of magnitude in the speed of signals carried over premises distribution systems.

Introduction

In 1881, the United States and England granted patents to Alexander Graham Bell for twisted pair copper cables. For almost 100 years after that, premises distribution systems carried only analog voice signals over cables based on Bell's original design.

During the past decade, more and more voice traffic has been moved from analog to digital systems. Concurrently, the commercial and industrial use of local area networks (LANs), links between mainframe computers and desktop terminals or personal computers, and other types of non-voice telecommunications, has resulted in a virtual explosion of digital data communications systems. In the 1970s, those systems were expected to transmit data traffic at kilobits-per-second speeds; in the '80s, speeds increased to megabits per second (Mb/s). Today, we see data transmission applications that require tens or hundreds of Mb/s.

As performance requirements increased, a stronger move toward a globalized market also became apparent. The growing number of transnational companies became aware that the many different approaches to premises cabling had to be replaced by more common, standardized implementations. To satisfy this need, AT&T developed the Systimax premises distribution system (PDS).

Structured Interconnections

The Systimax PDS connects buildings and building complexes (campuses) with unshielded twisted pair copper cables (UTP) and optical fiber. This approach provides an economical and flexible means for transporting the diverse voice and data applications in today's—and emerging—business communications environments.

Although premises distribution systems based on UTP cabling have been in existence for many years, they should not be considered outmoded or inefficient. UTP technology continues to evolve along with the communication systems it is designed to serve. Without exception, today's common data systems are supported on UTP. In fact, recent advances have led to universal support of a 100 Mb/s twisted pair-physical media dependent (TP-PMD) LAN, the UTP equivalent of the 100 Mb/s fiber-distributed data interface (FDDI).

Standards bodies are currently studying industry proposals for 155 Mb/s asynchronous transfer mode (ATM) protocols on UTP; research is under way at AT&T to determine the feasibility of 622 Mb/s ATM

Panel 1. Acronyms Used Often in This Paper

ANSI	American National Standards Institute
EIA	Electronic Industries Association
FDDI	fiber-distributed data interface
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
NEXT	near-end crosstalk
STP	shielded twisted pair
TIA	Telecommunications Industry Association
TP-PMD	twisted pair-physical media dependent
UTP	unshielded twisted pair

protocols on UTP. A graphic history of UTP applications appears in Figure 1.

As with all media, an increase in transmission speed causes a decrease in another aspect of performance. Figure 2 shows the distance supported on UTP for some common systems using simple coding schemes. As the figure shows, all applications work at 100 meters. This is important because international standards for building wiring require workstations to be located within 100 meters of a telecommunications closet. If necessary, the closet can be used to house electronics to refresh the signal from the workstation.

Some of the data systems shown in Figure 2 were designed to use media other than UTP, such as coaxial cables and shielded twisted pair (STP). Those systems are adapted with data BALUNs (BALanced to UNbalanced), passive devices that transform the balanced signal required for UTP into the unbalanced signal required for other media, such as coaxial cable. The curved line in Figure 2 shows the approximate distance-data rate tradeoffs for some common data applications on UTP, using simple data transmission encoding schemes. Token Ring 4 Mb/s is an example of a data system designed to use STP that doesn't take full advantage of UTP's capabilities. 10 BASE-T and the integrated-services digital network primary rate interface (ISDN PRI) are examples of systems designed specifically for UTP. The ISDN PRI is interesting in that it illustrates an important concept: distance-data rates exceeding the curved line are possible, but require an enhanced coding scheme. Based on Shannon's information theory[1], the channel capacity of voice-grade twisted pair wire would have an upper limit greater than 370 Mb/s at 100 meters. This is with a bandwidth limitation of 30MHz. Without bandwidth restriction, the capacity is close to 1Gb/s at 100 meters for data-grade UTP cables.[2] Although not shown in Figure 2, TP-PMD carrying 100 Mb/s is operating commercially on UTP at distances of 100 meters, using sophisticated coding schemes. This application will be discussed later in more detail.

The use of optical fiber instead of UTP provides a number of performance benefits. Examples include extending the distance between a computer host and its terminals, taking signals from many wires and multiplexing them onto a single pair of optical fibers, and providing an optical link immune to lightning, electromagnetic interference, and passive eavesdropping.

Combining the high-performance capabilities of optical fiber with inexpensive UTP copper in a single distribution system offers an ideal voice and data communications platform for a building or campus. Figure 3 shows the data from Figure 2 on a chart with enhanced coding schemes used in TP-PMD and multimode optical fiber with the 1300 nanometer light-emitting diode drivers in common use. This figure shows the advantage of fiber for long distances and/or high data rates. On the scale shown, the two copper curves approximate the data rate/distance trade-off for most data applications on any of the popular copper media, including UTP, STP and coaxial cable. Because UTP is universally accepted for voice applications, Systimax PDS simplifies building wiring by recommending it for voice and data whose applications fall within the copper limits. For data applications that call for higher speeds or longer distances than UTP can support, the guide recommends optical fiber cable. Introducing a copper medium in addition to UTP would greatly complicate maintenance and administration; at best, it would only provide a small improvement in performance.

International Standards

The design of Systimax PDS is based on an open architecture that is consistent with existing international standards. Recognition of cabling as the "fourth building utility," as it is sometimes called, has led to the development of national and international standards. Two of the best-known standards are the Electronic Industries Association/Telecommunications Industry Association-568 (EIA/TIA-568)[3] Commercial Building Wiring Standard, and the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) draft for the "Generic Cabling Standard for the Customer Premises."

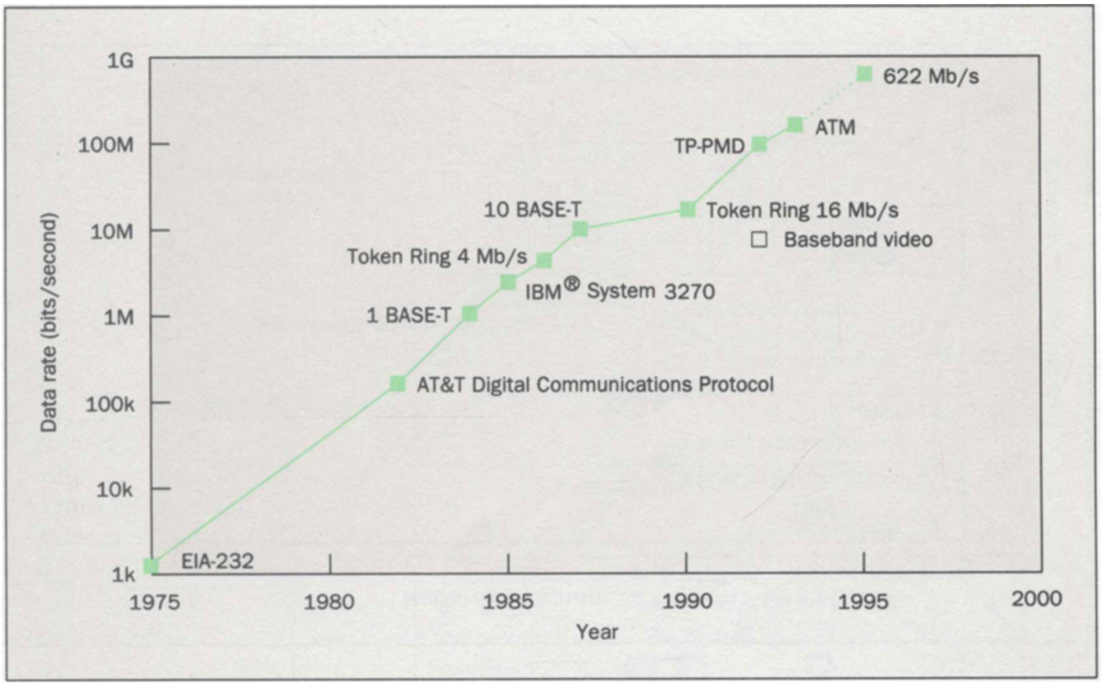


Figure 1. A graphic history of unshielded twisted pair (UTP) cabling. Although used for many years in premises distribution systems, UTP's usefulness persists: AT&T researchers are applying enhanced coding schemes to determine the feasibility of transmitting 622 megabits per second over UTP.

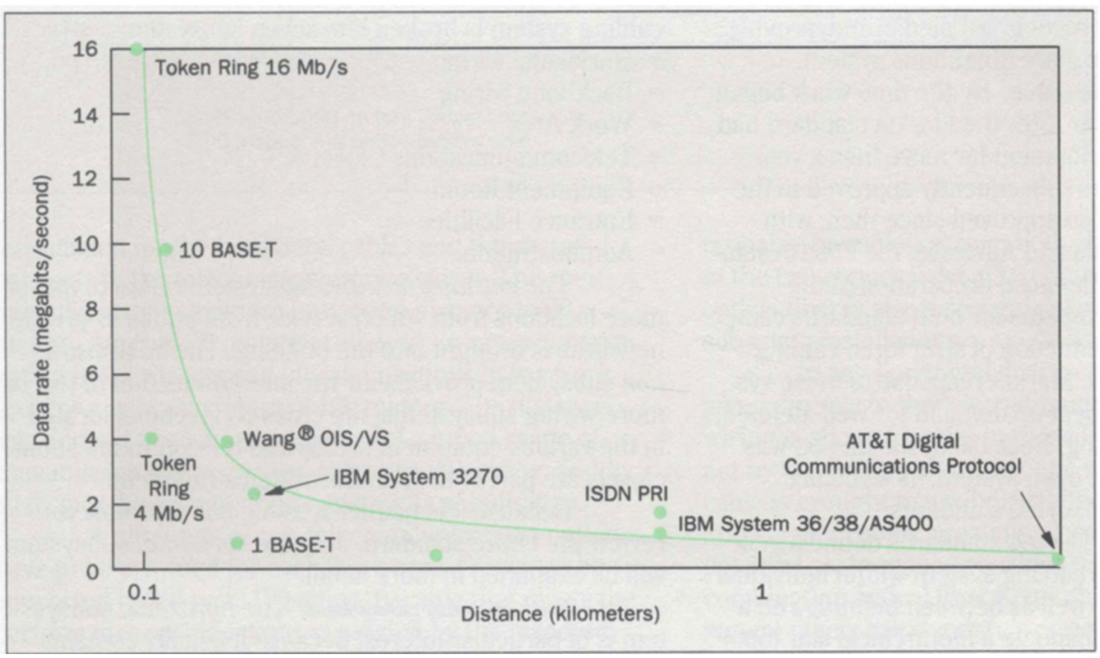
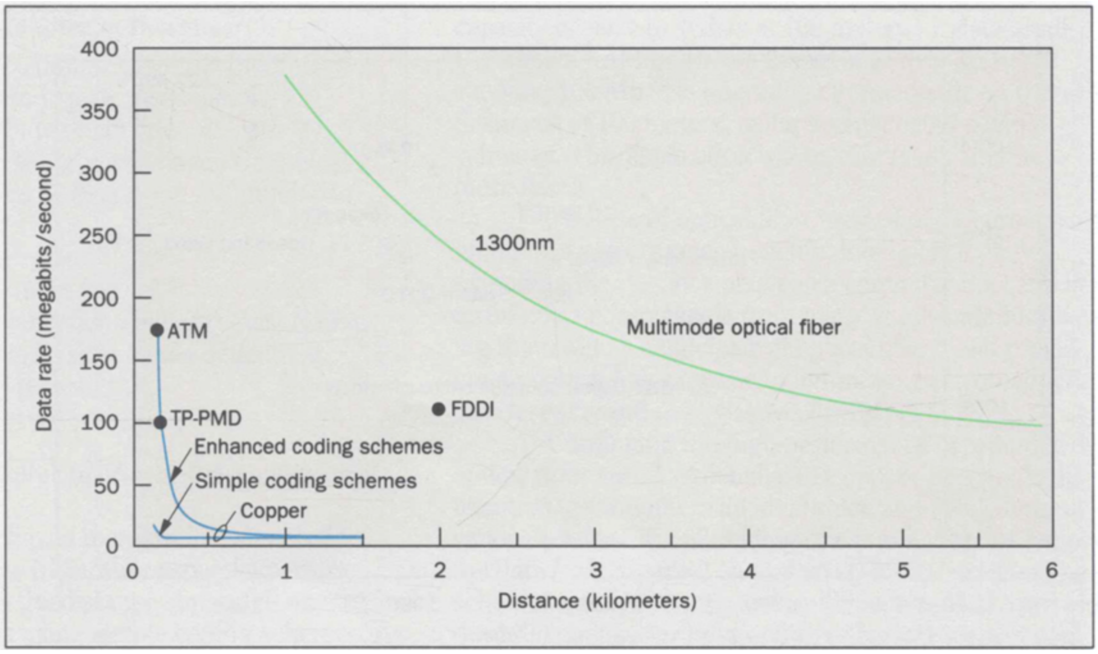


Figure 2. Distance supported on unshielded twisted pair wire for some common systems that use simple coding schemes. All applications work within the standards-mandated requirement that workstations and telecommunications closets to which they are wired must be within 100 meters of each other.

Cabling standards can help preserve the investment of both vendors and consumers; standardization efforts are strongly supported by groups ranging from private companies to national governments. Ideally, a building's telecommunications distribution system should be as ubiquitous as its power distribution system. Such a system would probably be based on a single media/connector pair. A more pragmatic approach, given the huge number of existing connector interfaces and media, would be to limit the proliferation of new media and

Figure 3. Comparison of data rate/distance trade-offs between copper and optical fiber transmission media.



connectors that offer no significant advantages; establish performance criteria for recognized media; and, provide an evolutionary path to a more ubiquitous system.

The historical perspective. By the time work began on the ISO/IEC standard in 1988, the EIA/TIA standard had already been under development for more than a year. The EIA/TIA standard was subsequently approved in the United States in 1991. Also approved since then, with minor changes, in Canada and Australia, the EIA/TIA standard has significantly influenced preparation of the ISO/IEC document. The impetus for both standards came from the successful introduction of structured cabling systems such as AT&T's. Market response to these systems demonstrated the pent-up demand for well- defined, flexible, structured cabling. Because Systimax PDS was designed to be part of an open system, its structure inspired the EIA/TIA and ISO/IEC standards.

The EIA/TIA and ISO/IEC standards define a generic telecommunications cabling system within individual commercial buildings as well as between buildings on a campus. The standards mandate a hierarchical star topology and specify maximum distances for the associated segments. Building sites with a geographical span of up to 3,000 meters, up to 1,000,000 square meters of office space, and with a population of up to 50,000 individuals, fall within the scope of the standards.

Figure 4 shows how the telecommunications cabling system is broken into seven subsystems:
- Horizontal wiring
- Backbone wiring
- Work Area
- Telecommunications Closet
- Equipment Room
- Entrance Facilities
- Administration.

The *entrance facilities* subsystem refers to one or more locations from which service from public or private networks is brought into the building. The *administration* subsystem provides for the interconnection of two or more wiring subsystems; the cross-connections located in the various equipment rooms and telecommunications closets are part of the administration subsystem.

Because it is neither feasible nor desirable to review the entire standard, only the *horizontal* subsystem will be examined in more detail.

The horizontal subsystem. The horizontal subsystem is of particular interest because it usually contains the most cable. Changes to it cause the greatest disruption to users.

Horizontal wiring extends from the work area telecommunications outlet to the telecommunications closet. It includes the work area outlet, the mechanical

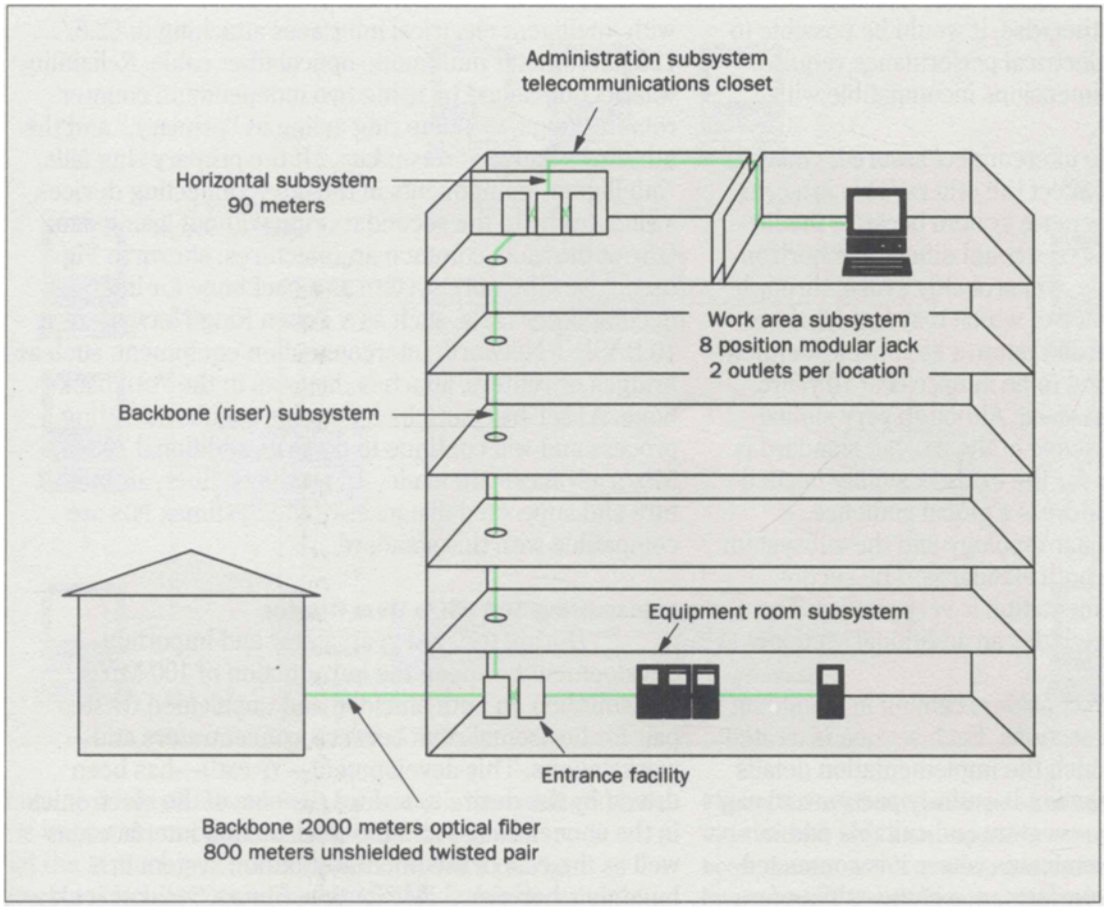


Figure 4. A characteristic telecommunications distribution system. Maximum distances shown are determined by international standards.

termination for the horizontal cables and the cross-connects in the telecommunications closet. The standards limit the maximum horizontal distance to 90 meters. Another 10 meters is allowed for cross-connect wiring in the closets and interconnections in the work area for a total maximum of 100 meters. The distance was derived from an examination of a broad range of transmission methods used in horizontal wiring, and by analyzing the architectural constraints of buildings.

A minimum of two telecommunications outlets have to be provided for each work area. One must be supported by a 4-pair, 100-ohm UTP cable that meets the performance specifications stipulated by the standard. The other outlet can be supported by one of the recognized copper horizontal media: 100-ohm UTP, 150-ohm STP and 50-ohm coaxial cable or 120-ohm twisted pair. The 120-ohm twisted pair is not allowed under the EIA/TIA-568 standard; the 50-ohm coaxial cable will probably be removed from both standards. In addition to the two copper links, 62.5/125 micrometer multimode optical fiber is also a recognized medium for horizontal subsytem installations.

In any horizontal distribution, all outlets are wired directly to the telecommunications closet. Zone wiring is allowed by the proposed ISO/IEC standard, but not by the Systimax PDS. In zone wiring, a multipair cable is brought to a subdistribution point and separated into smaller cables, creating a loss of flexibility and potential performance penalties. Hybrid cables, such as combination optical fiber/UTP cables in which each component meets the standard's performance requirements, may be used.

Electrical performance and relevant mechanical characteristics for all recognized components are specified by the EIA/TIA standard and the ISO/IEC draft standard to ensure end-to-end system performance and the ability to interconnect. Otherwise, it would be possible to have a cable that meets electrical performance requirements but has physical dimensions incompatible with cross-connect equipment.

With the ability to interconnect assured, changes to one subsystem cannot affect the others. This is a critical characteristic of any generic system because the lifetimes of individual subsystems could differ. The horizontal subsystem, for example, will probably evolve through several distinct phases, each of which may last for three to ten years, while an overall system's lifetime, as defined by the standard, is intended to be in excess of 10 years.

The ISO/IEC draft standard. Although very similar to that of EIA/TIA-568, the scope of the ISO/IEC standard is slightly broader. It allows for the extra flexibility needed for a document that will address a global audience.

The hierarchical star topology and the subsystem approach are common to both standards. The section devoted to specific implementation is very similar. The working draft of ISO/IEC includes an additional section called "Link Performance."

Link performance considers cabling in a building to consist of one or more sections. Each section is treated as a "black box" within which the implementation details are not important. Each section is entirely passive and can be comprised of cables, connectors and suitable administration fields. A section terminates where it is connected to active equipment. The performance of the cabling for a particular type of medium is standardized at and between the interfaces to a cabling section. The performance requirements are relatively complex and require technical knowledge to exploit them fully. It is the intent of the standard that the cable, connector and administration field parameters specified in its implementation section will guarantee that every system will meet the performance section. The architecture and products of AT&T's Systimax PDS have been designed to meet the standard's implementation section.

100 Mb/s Systems

The ability of the Systimax PDS to handle new applications can be shown by studying the transmission of data at 100 Mb/s over copper and optical fiber.

The American National Standards Institute (ANSI) and ISO/IEC published system standards[4,5] for reliable transmission of 100 Mb/s data through an FDDI system.

The initially released standards defined a system with intelligent electrical interfaces attaching to 62.5/125 micrometer multimode optical fiber cable. Reliability was accomplished by using two independent, counter-rotating rings, with one ring acting as "primary," and the other as a backup "secondary." If the primary ring fails, "intelligent" components in the interconnecting devices switch traffic to the secondary ring without losing data. One of the most common architectures, shown in Figure 5, uses the FDDI system as a backbone for interconnecting other LANs, such as a Token Ring Network or a 10 BASE T Network. Interconnection equipment, such as bridges or routers, attaches the LANs to the FDDI backbone. AT&T has participated in this standards-setting process and will continue to do so as additional 100 Mb/s advances are made. All products, fiber, architecture and supported distances of the Systimax PDS are compatible with this standard.

Transmitting 100 Mb/s Over Copper

During the past year, a new and important development has been the introduction of 100 Mb/s transmission on both shielded and unshielded twisted pair for horizontal runs between concentrators and workstations. This development—TP-PMD—has been driven by the desire to reduce the cost of the electronics in the concentrators and the work station interfaces, as well as the cost of the fiber distribution system in a building's horizontal distribution. Figure 5 makes it clear that this activity applies only to horizontal runs. Optical fiber continues to be used for backbone and campus distribution. Installing twisted pair in the horizontal runs is possible because distances required are less than the 90-meter maximum defined by the building cabling standards. The 2-kilometer distance permitted for optical fiber by those standards is overkill for the 90-meter horizontal distance. Insight into this may be gained from Figure 3.

For copper media, two significant technical issues must be considered: high-quality transmission of data, and meeting electromagnetic compatibility requirements established to meet internationally accepted standards.[6] The standards deal with radiated emission, immunity to external noise, immunity to electrostatic discharge, and other items.

For TP-PMD, an important issue concerns the method used to transmit 100 Mb/s data on copper. The FDDI system, in fact, is a 125 Mb/s bit stream that

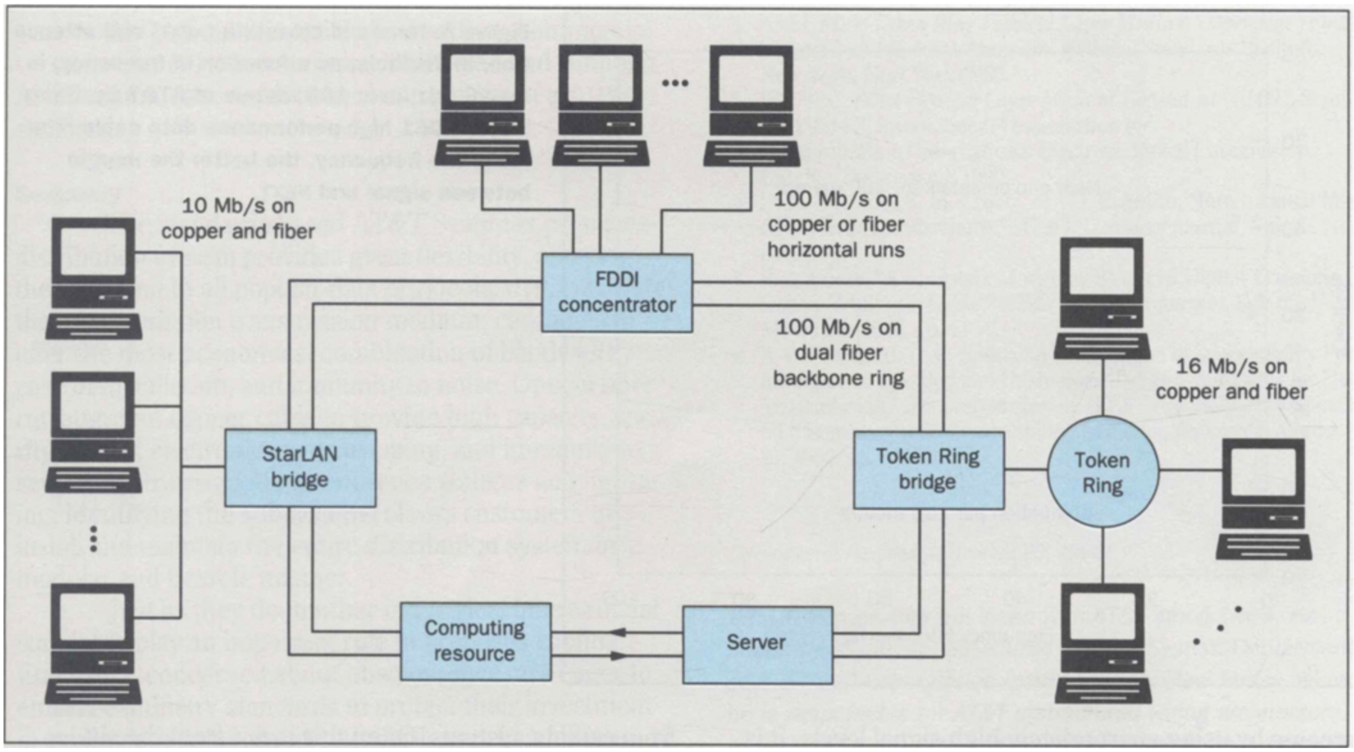


Figure 5. Reliable transmission of horizontally distributed data at 100 Mb/s on copper is connected to an FDDI backbone system with counter-rotating rings. Bridges or routers interconnect the system to other LANs.

contains 4 bits of information for every 5 transmitted bits. It is important to continue to use the "4 out of 5" code so that the FDDI chip sets can be used without change. Interface circuitry converts the 125 Mb/s bit stream into a form that matches the characteristics of the media.

Transmission considerations. Whenever a TP-PMD copper-based system is developed, it is necessary to maintain performance at the very low error rate required by the existing FDDI standard. To do this requires a good signal-to-noise ratio at the receiver in a TP-PMD system. In any two-pair system, the signal transmitted from a piece of equipment is at an appropriately high energy level. This energy can hop from the transmitting pair to the receiving pair near the equipment and appear as unwanted noise[7]. The noise, called *near-end crosstalk* (NEXT), is measured in decibels of isolation between pairs in a cable. This is measured as a function of frequency, and the crosstalk increases with frequency. NEXT is measured on what could be considered an inverse scale: the larger the NEXT isolation, the better the cable.

The level of a signal as it arrives at the receiver depends on the attenuation characteristics of the cable and the length of the cable. Attenuation describes how much a signal is reduced: the lower the attenuation, the better the cable. Attenuation is also measured as a function of frequency, and increases with frequency.

Figure 6 shows NEXT and attenuation plotted as a function of frequency for the AT&T Systimax 1061/2061 high-performance data cable. A measure of signal-to-noise margin for a two pair data transmission system is the difference between these two curves. In Figure 6, the cable shows a significant signal-to-noise margin for 100 Mb/s transmission. An important point to remember is that the lower the frequency, the better the margin, so that coding methods that use signals confined to lower frequencies will have better margin. Increasing the signal level will not improve the margin of signal relative to NEXT because the NEXT level increases proportionally to the increase in the signal level.

A second possible source of noise is interference from outside sources.[8] The effect of this can be

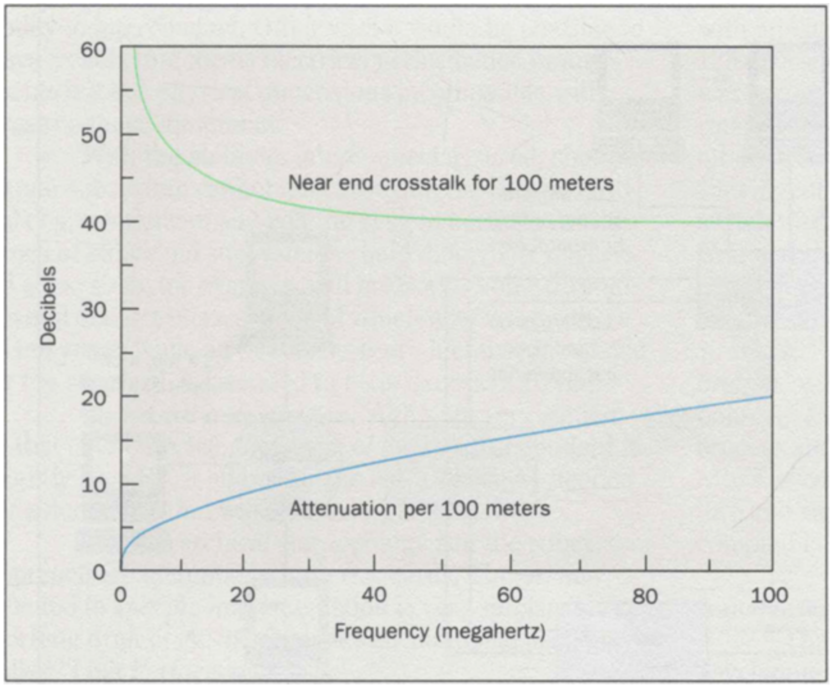


Figure 6. Near-end crosstalk (NEXT) and attenuation, in decibels, as a function of frequency, in megahertz, over 100 meters of AT&T Systimax 1061/2061 high-performance data cable. The lower the frequency, the better the margin between signal and NEXT.

overcome by using appropriately high signal levels. It is also controlled by using cable and electronic design techniques. The Systimax 1061/2061 cable uses tight-twist geometries to minimize outside interference. Coupled with balanced transmission schemes and appropriate signal levels for the electronics, it has been possible to develop robust transmission of data at 100 Mb/s on high-quality twisted pair cable. Attempts to resolve radiated energy issues by reducing the signal level has a negative effect on the quality of the transmitted data. This is true because the noise level from outside interference will remain constant as the signal level is reduced, leading to a poorer signal-to-noise ratio.

Electromagnetic compatibility considerations. Perhaps the most critical challenge facing designers of copper-based transmission system products is to satisfy electromagnetic radiation limits imposed by the Federal Communications Commission in the United States and the IEC's International Special Committee on Radio Interference (CISPR) in Europe. Both agencies have established maximum allowable radiated energy, starting at 30 MHz and extending beyond 1000 MHz. Radiated energy from equipment sometimes leaks directly onto the cabling system in the form of common mode signals. These signals account for most of the radiated energy from cabling systems. Often this is not from the signal drivers directly but from clocks and other signal-generating components within the equipment. This can usually be controlled by careful design of the equipment or by installing common mode filters. When the signal energy itself is above 30 MHz, the cabling system can convert signal voltages to common mode voltages. AT&T Systimax 1061/2061 cables minimize this conversion process because of their superior balance. The balance is controlled by a tight-twist design, patented by AT&T, and careful fabrication to improve the cables' mechanical tolerances. Also, the bit stream format proposed in the standard was scrambled so that there are no single frequency components during idle patterns.

In addition to standards concerning electromagnetic radiation *emission* from a wire, the European Community also has standards concerning the wire's *immunity* to electromagnetic radiation. One of the most stringent requirements is based on the IEC 801.4 test. Premises distribution systems undergoing the test are bombarded with fast transient pulses. The test requires the systems to recover from this bombardment. The tight twists and superior balance of the Systimax 1061/2061 cable rejects these transient pulses.

At the time this article was written, commercial versions of a TP-PMD system were installed and running; ANSI continues to work toward completion of a TP-PMD standard.

Summary

The standards-based AT&T Systimax premises distribution system provides great flexibility, allowing the evolution to all popular data protocols. UTP, currently the most common transmission medium, continues to offer the most economical combination of bandwidth, ease of installation, and immunity to noise. Optical fiber can augment copper cable to provide high capacity, security against electronic eavesdropping, and immunity to severe electromagnetic interference sources and lightning. Identifying the subsystems allows customers to install and maintain the entire distribution system in a modular and flexible manner.

Just as they do in other industries, international standards play an important role in premises cabling. End users, concerned about obsolescence, are eager to embrace industry standards to protect their investment in cabling and interconnecting hardware. In addition, large multinational corporations are interested in adopting a cabling system based on a global standard so that a consistent cabling infrastructure will be found in all their office locations.

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