How can network managers deploy bandwidth-intensive applications over their local area networks (LANs) when they have tight budgets and must leverage their existing infrastructure? The latest Ethernet technology, 1000BASE-T (Gigabit Ethernet over Category 5 copper cabling), helps network managers boost their network performance in a simple, cost-effective way. 1000BASE-T is Ethernet that provides speeds of 1000 Mbps over Category 5 copper cabling, the most widely installed LAN cabling infrastructure. The IEEE Standards Committee formally ratified 1000BASE-T as an Ethernet standard in June 1999.

This article provides network managers with a technical understanding of the fundamentals of 1000BASE-T. It explains how the IEEE 802.3ab Task Force has designed 1000BASE-T to run over Category 5 cabling. In addition, it explains how to implement 1000BASE-T over existing Category 5 cable infrastructure and over Enhanced Category 5 (Cat 5e) in new sites.

**Why 1000BASE-T Gigabit Ethernet over Category 5 copper cabling?**

1000BASE-T Gigabit Ethernet over Category 5 copper cabling is an attractive option for network managers for several reasons. It addresses the exploding bandwidth requirements on current networks that are the result of implementation of new applications and the increasing deployment of switching at the edges of the network. Gigabit Ethernet leverages the organization’s existing investment in Ethernet and Fast Ethernet infrastructures, and it provides a simple, cost-effective performance boost while continuing to use the dominant horizontal/floor-cabling medium.

**Exploding bandwidth requirements**

New bandwidth-intensive applications are being deployed over Ethernet and Fast Ethernet networks. These applications include the following:

- Internet and intranet applications that create any-to-any traffic patterns with servers distributed across the enterprise, and users accessing web sites inside and outside the corporate network; these applications tend to make traffic patterns and bandwidth requirements increasingly unpredictable.
- Data warehousing and backup applications that handle gigabytes or terabytes of data distributed among hundreds of servers and storage systems.
- Bandwidth-intensive, latency-sensitive groupware applications, such as desktop video conferencing or interactive whiteboarding.
- Publication, medical imaging, and scientific modeling applications that produce multimedia and graphics files that are exploding in size from megabytes to gigabytes to terabytes.

Bandwidth pressures are compounded by the growing deployment of switching as the desktop connection of choice. Switching at the edge tremendously increases the traffic that must be aggregated at the work group, server, and backbone levels.

**Significant investment in Ethernet/Fast Ethernet infrastructure**

Ethernet is the dominant, ubiquitous LAN technology. According to industry analyst International Data Corporation (IDC) in Framingham, MA, more than 85 percent of all installed network connections were Ethernet at the end of 1997, representing more than 118 million interconnected PCs, workstations, and servers.

The deployment of Ethernet/Fast Ethernet networks involves investment in network interface cards (NICs), hubs, and switches, as well as in-network management capabilities, staff training and skills, and cabling infrastructure. In fact, cabling infrastructure is the longest-term networking investment, lasting at least two years.
and up to ten years. On average, almost half of the infrastructure is in place for more than five years, as indicated in the December 1998 Networking Cabling Market Study by Sage Research, Natick, MA.

A simple, cost-effective performance boost on existing Category 5 cabling

1000BASE-T offers a simple, cost-effective migration of Ethernet/Fast Ethernet networks toward high-speed networking and also has the following benefits:

- **1000BASE-T** scales Ethernet 10/100 Mbps performance to 1000 Mbps. Flexible 10/100 and 10/100/1000 connectivity will be offered and will enable the smooth migration of existing 10/100 networks to 1000 Mbps-based networks.
- **1000BASE-T** is the most cost-effective, high-speed networking technology available now. 1000BASE-T leverages existing, proven Fast Ethernet and V.90/56K modem technologies and will experience the same cost curve as the Ethernet/Fast Ethernet technologies. 1000BASE-T is in fact expected to be significantly more cost-efficient than 1000BASE-SX (Fiber Gigabit), which already has the lowest cost-per-data-transmitted per second among all LAN technologies (currently less than $1.5 per Mbps).
- **1000BASE-T** preserves Ethernet equipment and infrastructure investments, including the investment in the installed Category 5 cabling infrastructure. There is no need to undergo the time-consuming and high-cost task of replacing cabling located in walls, ceilings, or raised floors.

Leveraging Category 5 copper cabling infrastructure is of significant importance for two reasons:

- Category 5 today is the dominant horizontal/floor cabling, providing connectivity to both desktops and work group aggregators (Figure 1). Fiber is the dominant cabling for connection of multiple buildings.
- Category 5 is one of the major options for building risers/backbone cabling for connection of different floor wiring closets (Figure 2).

### 1000BASE-T technical fundamentals

**Gigabit Ethernet media specifications**

Gigabit Ethernet cost-effectively leverages existing cabling infrastructure. It can be implemented in floor, building, and campus networks because it offers a wide range of connectivity media and connection distances. Specifically, Gigabit Ethernet is designed to run over four media:

- Single-mode fiber with connections up to at least 5 kilometers
- Multimode fiber with connections up to at least 550 meters
- Balanced, shielded copper with connections up to at least 25 meters
- Category 5 cabling with connections up to at least 100 meters

The IEEE 802.3z Gigabit Ethernet standard, approved in June 1998, specified three transceivers to cover three media: 1000BASE-LX for the installed base of single-mode fiber, 1000BASE-SX for the installed base of multimode fiber, and 1000BASE-CX for a balanced, shielded copper cable that could be used for interconnects in equipment rooms. 1000BASE-LX transceivers also can be used to reach at least 550 meters on multimode fiber.

Another task force, IEEE 802.3ab, has defined the physical layer to run Gigabit Ethernet over the installed base of Category 5 cabling. The IEEE Standards Committee approved the 1000BASE-T standard in June 1999. Figure 3 summarizes the various Gigabit Ethernet options and the standards that define them.

For more information on how Gigabit Ethernet is defined to support different media, see Sidebar on page 40.

### 1000BASE-T key specifications

The 1000BASE-T standard leverages the existing cable infrastructure as it is specified to operate up to 100 meters on Category 5 cabling.

The other key specifications of 1000BASE-T make it a cost-effective, non-disruptive, and high-performing technology. First, it supports the Ethernet MAC, and is thus backward compatible with a 10/100 Mbps Ethernet. Second, many 1000BASE-T products will support 100/1000 auto-negotiation, and therefore 1000BASE-T can be incrementally deployed in a Fast Ethernet network. Third, 1000BASE-T is a high-performing technology with less than one erroneous bit in 10 billion transmitted bits. This bit error rate of less than 10 – 10 is the same error rate as that of 100BASE-T.
**Detailed 1000BASE-T cable specifications**

1000BASE-T is specified to run over four pairs of Category 5 balanced cabling. The four pairs of Category 5 balanced cabling are specified in ANSI/EIA/TIA-568-A (1995). Additional link performance parameters (return loss and ELFEXT) are specified in TIA/EIA-TSB-95. Figure 4 details the standards of reference for the specification of 1000BASE-T cable performance parameters. For additional information, see Sidebar on page 40 and 41. Category 5 cabling is also specified in ISO/IEC 11801:1995, “Information Technology: Generic Cabling for Customer Premises.” The second edition of ISO/IEC 11801:1995 will include the additional cabling performance parameters specified to support Gigabit Ethernet.

![Figure 4](Image)

**1000BASE-T design**

1000BASE-T is designed to run over Category 5 copper cabling. The transmission of 1 Gbps is possible thanks to the use of four twisted-pair links with 250 Mbps of throughput on each pair (250 Mbps x 4 = 1 Gbps).

1000BASE-T transmits at the same clock rate as 100BASE-T, 125 MHz, but uses a powerful signaling and coding/decoding scheme that enables the transmission of double the amount of data as 100BASE-T. Following is a comparison of the two specifications:

- **1000BASE-T**: 125 MHz x 2 bits = 250 Mbps
- **100BASE-TX**: 125 MHz x 1 bit-symbol = 125 Mbit-symbol/s

Note: 125 Mbit-symbol/s is equivalent to 100 Mbps, since 100BASE-T uses a 4B/5B code – 4 bits of data are translated into 5 bit-symbols before transmission on the wire; the effective bits’ throughput is 125 x 4/5 = 100 Mbps.

1000BASE-T cost-effectively leverages the design of proven existing Fast Ethernet and V.90/56K modem technologies. Signaling and coding/decoding methods already implemented in 802.3 Fast Ethernet transceivers and in V.90 or 56K modems using advanced DSPs are used to implement 1000BASE-T. Table 1 summarizes the 100BASE-T technologies and methods reused by 1000BASE-T. For additional information, see Sidebar on page 42 and 43.

---

**Preparing for deployment over existing cabling**

Preparing existing Category 5 copper cabling for running 1000BASE-T is a straightforward process. The first step is a simple test of the adequacy of the cable installation. In the unlikely event that an existing installation does not meet one of the performance parameters specified by 1000BASE-T, standard corrective actions can be implemented.

<table>
<thead>
<tr>
<th>Technology/Method</th>
<th>100BASE-T</th>
<th>100BASE-TX</th>
<th>100BASE-T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-level signaling</td>
<td>Five-level PAM</td>
<td>Five-level PAM</td>
<td>Yes Available</td>
</tr>
<tr>
<td>Symbol clock rate</td>
<td>125 MHz</td>
<td>125 MHz</td>
<td>125 MHz</td>
</tr>
<tr>
<td>Transmit spectrum</td>
<td>MLT-3-like</td>
<td>MLT-3</td>
<td>MLT-3</td>
</tr>
<tr>
<td>Digital signal processing</td>
<td>Yes Available</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Transmission</td>
<td>Bidirectional</td>
<td>Bidirectional</td>
<td>Bidirectional</td>
</tr>
</tbody>
</table>

**Table 1**

**Testing the installation of existing Category 5 cabling**

- Cable testing information is specified in the ANSI/TIA/EIA-TSB-67 standard, “Transmission Performance Specifications for Field Testing of Twisted-Pair Cabling Systems,” which has been used by cabling installers since 1995.
- The additional test parameters of return loss and ELFEXT for 100BASE-T are specified in the ANSI/TIA/EIA-TSB-95 bulletin, “The Additional Transmission Performance Guidelines for 100 Ohm 4-Pair Category 5 Cabling.”
- These additional tests are incorporated into the current versions of cable test tools. To view a list of them, refer to the Gigabit Ethernet Alliance web site. Field testing is performed by connecting the two handheld devices – one at each end of the cabling under testing (see Figure D-2 in Sidebar on page 42) with a field test cord and then activating the 1000BASE-T test function. A pass or fail will be indicated for the 1000BASE-T test and for the specific test parameters under testing. Many field testers include diagnostic functions to help identify the cause of failures. Corrective actions are described in Sidebar on page 42.

**Adjusting existing Category 5 cabling to run 1000BASE-T**

In the unlikely event that an existing Category 5 installation does not meet one of the performance parameters specified by 1000BASE-T, corrective actions are defined in a simple field procedure detailed in the ANSI/TIA/EIA-TSB-95. Three types of corrective measures can be applied:

- Use of high-performance Category 5e patch cables (see the following section for definition of Category 5e)
- Reduction in the number of connectors used in the link
- Reconnection of some connectors in the link

Sidebar on page 42 describes the corrective actions. In most cases in which an installation is not initially compliant, it is not necessary to perform all of the corrective actions.

**Preparing for deployment over new copper cabling: Category 5e**

The Gigabit Ethernet Alliance recommends that all new cable installations designed for 1000BASE-T deployment should be specified as Category 5e, enhanced Category 5. Category 5e cabling is manufactured to meet all 1000BASE-T transmission performance parameters. When field testing for Category 5e cabling performance is performed, specific field testing for 1000BASE-T is not required.

The Category 5e specification includes transmission parameters that are only informative recommendations for Category 5. These parameters are the measures for return loss and ELFEXT, as described in the sidebar on pages 40 and 41. Cable manufacturers, such as Mohawk/CDT (http://www.mohawk-cdt.com)
with its Mega LAN™ cable, can be held accountable for the transmission specifications of Category 5e. Category 5e also provides a further enhanced margin over the worst-case 1000BASE-T link requirements.

The 1000BASE-T standard specifies operation over the installed base of Category 5 cabling. 1000BASE-T will also run over Category 6 and Category 7 copper cabling systems as described below.

**Other cabling categories**

The ANSI/TIA/EIA TR-42.7.1 Copper Cabling Systems Working Group and the International Standard Committee ISO/IEC/SC25/WG3 are developing a Category 6 cabling standard, specified to 250 MHz. Network managers and cable system planners may want a cabling infrastructure that provides greater bandwidth or “headroom” to accommodate future high-speed technologies.

The International Standard Committee ISO/IEC/SC25 is developing a Category 7 cabling standard, specified to 600 MHz. Category 7 cable is constructed with individually shielded pairs with an additional shield over the pairs. Category 7 cabling requires termination to a shielded connector. The Category 7 standard is still in the early stages of development.

1000BASE-T will operate on the cabling specified in the current draft 5 of ANSI/TIA/EIA-Cat 6 (estimated release, late 2000) and the current draft of the Category 6 specifications proposed for the second edition of ISO/IEC 11801:1995 (estimated release, late 1999), as well as Category 7 (estimated release, late 2000).

Migrating Ethernet/Fast Ethernet Networks toward high-speed networking 1000BASE-T allows a simple performance boost to support exploding bandwidth requirements on today’s networks. 1000BASE-T is best suited for unclogging network bottlenecks that occur in three main areas:

- Work group aggregation
- Connections to high-speed servers
- Desktop connections

The following scenario describes a typical migration of an Ethernet/Fast Ethernet network to Gigabit Ethernet. As shown in Figure 5, the initial building backbone is 10/100 Mbps Ethernet/Fast Ethernet. Several Ethernet or Fast Ethernet segments are aggregated into a 10/100 Mbps switch, which in turn has several 10/100 Mbps Ethernet/Fast Ethernet server connections. Some users have dedicated 10/100-switched connections to their end stations. In this configuration, users are starting to experience slow response times, and power users are experiencing bottlenecks.

![Figure 5](image)

The first upgrade phase is implemented in three areas (Figure 6):

- Upgrading the backbone with a 100/1000 Mbps Fast Ethernet/Gigabit Ethernet switch
- Upgrading the work group switches that support power users or large work groups with Gigabit Ethernet downlink modules
- Implementing 100/1000 Mbps Fast Ethernet/Gigabit Ethernet NICs in key servers

![Figure 6](image)

As a result of these measures, the speed of the backbone increases tenfold to accommodate the overall increase in network band-
width demand while the investment in existing work group switches end-station NICs, and existing cabling is preserved.

The second migration phase is the upgrading of power users to 100/1000 Mbps Fast Ethernet/Gigabit Ethernet NICs (Figure 7). Fast Ethernet and, over time, Gigabit Ethernet to the desktop are now supported, giving power users full access to the resources of the network.

**Figure 7**

**Conclusion**

1000BASE-T, Gigabit Ethernet over Category 5 copper cabling, helps network managers boost their network performance in a simple, cost-effective way while enabling migration of today’s Ethernet/Fast Ethernet networks toward high-speed networking. Following is a summary of Gigabit Ethernet characteristics:

- 1000BASE-T is Ethernet, providing speeds of 1000 Mbps.
- 1000BASE-T is designed to run over Category 5 copper cabling, the most widely installed LAN cabling infrastructure.
- 1000BASE-T leverages the design of proven, cost-effective existing Fast Ethernet and modem technologies.
- 1000BASE-T can be progressively deployed in a Fast Ethernet network since 100/1000 auto-negotiation will be supported in many 1000BASE-T products.

**Christopher T. Di Minico** is Director of Network Systems Technology with the Cable Design Technologies Corporation (CDT). Christopher has over 30 years of experience in the telecommunication industry. Prior to his current position with CDT, he was employed at Digital Equipment Corporation with responsibility for the development and delivery of telecommunication connectivity products and services. Christopher plays an active role in the development of Telecommunication Standards as a Member of Institute of Electrical and Electronic Engineers (IEEE), the Telecommunications Industry Association (TIA), and the US advisory group for international cabling standards development. He is the elected liaison for the TIA TR42 committee to IEEE 802.3. Christopher received an award of recognition from both IEEE 802.3 and the Gigabit Ethernet Alliance for his contributions to the development of the Gigabit Ethernet Standards. A native of Massachusetts, Christopher holds a Bachelor of Science Degree in Electrical Engineering from Northeastern University.

**About Mohawk/CDT**

Cable Design Technologies (CDT) is a worldwide, recognized resource in the design, development, and manufacturing of both fiber optic and copper cables, structured wiring systems, and cable management solutions. Mohawk/CDT, a division of CDT, manufactures high-performance network cabling solutions. Referred to as Mohawk Accredited Contractors, Mohawk/CDT has a network of certified contractors accredited through a formal training process including the design, installation, and field test verification of infrastructure cabling. In cooperation with 3Com, Mohawk/CDT offers a service to verify installed Category 5 cabling for 1000BASE-T operation.

For more information on 1000Base-T, the company and its products, contact:

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Gigabit Ethernet specifies technology covering the bottom two layers of the OSI model:

- The data link layer, which controls access to the physical medium of transmission
- The physical layer, which controls the actual transmission over the physical medium

Gigabit Ethernet implements data link layer functionality by supporting the Ethernet Media Access Control (MAC) sublayer. The MAC sublayer transforms data sent by the upper layers of communication into Ethernet frames and determines how data is scheduled, transmitted, and received. The Gigabit Ethernet MAC is the Ethernet/Fast Ethernet MAC, which ensures backward compatibility between Ethernet/Fast Ethernet and Gigabit Ethernet frames.

Frames are sent or received by the MAC layer through the Gigabit Media Independent Interface (GMII). Because the GMII is designed to enable Gigabit Ethernet MAC devices to hook up in a standard way to any of the physical layers defined by the Gigabit Ethernet standards, the IEEE 802.3ab committee was able to concentrate its effort on designing a physical layer for Gigabit Ethernet over Category 5 copper. The IEEE 802.3ab Task Force specified 1000BASE-T at the same time the IEEE 802.3z Task Force designed and standardized the overall Gigabit Ethernet standard and physical implementation over fiber and shielded copper.

The physical layer defines the electrical signaling, link states, clocking requirements, data encoding, and circuitry needed for data transmission and reception. There are several sublayers to perform these functions.

- The physical coding sublayer (PCS): codes/decodes the data transmitted by the GMII to a form suitable for transmission over the physical medium.
- The physical medium attachment (PMA) sublayer: generates and receives the signal to and from the wire.
- The physical medium dependent (PMD) sublayer: provides physical connections to the wire.

Table A-1 details the specifications for Gigabit Ethernet media, the associated cabling specifications, and the minimum range certified by the IEEE.

<table>
<thead>
<tr>
<th>Gigabit Ethernet Transceivers</th>
<th>Fiber Type</th>
<th>Modal Bandwidth (MHz*km)</th>
<th>Minimum Range Specified by IEEE (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000BASE-LX</td>
<td>62.5 μm MM MM</td>
<td>500</td>
<td>2–550</td>
</tr>
<tr>
<td></td>
<td>50 μm MM MM</td>
<td>400</td>
<td>2–550</td>
</tr>
<tr>
<td></td>
<td>50 μm MM MM</td>
<td>500</td>
<td>2–550</td>
</tr>
<tr>
<td></td>
<td>10 μm SM</td>
<td>N/A</td>
<td>2–8000*</td>
</tr>
<tr>
<td>1000BASE-SX</td>
<td>62.5 μm MM MM</td>
<td>160</td>
<td>2–220</td>
</tr>
<tr>
<td></td>
<td>62.5 μm MM MM</td>
<td>200</td>
<td>2–275</td>
</tr>
<tr>
<td></td>
<td>50 μm MM</td>
<td>400</td>
<td>2–500</td>
</tr>
<tr>
<td></td>
<td>50 μm MM</td>
<td>500</td>
<td>2–550</td>
</tr>
<tr>
<td>1000BASE-CX</td>
<td>N/A</td>
<td>N/A</td>
<td>25</td>
</tr>
<tr>
<td>1000BASE-T</td>
<td>N/A</td>
<td>N/A</td>
<td>100</td>
</tr>
</tbody>
</table>

MM = multimode
SM = single-mode
* = 3Com certifies 1000BASE-LX Gigabit Ethernet connectors (GBICs) to distances of up to 1000 meters.

Table A-1

Key performance parameters for 1000BASE-T cabling

<table>
<thead>
<tr>
<th>Performance parameters specific to 1000BASE-T cabling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return loss is a measure of the reflected energy caused by impedance mismatches in the cabling system. Echo is countered by echo cancellation. Echo cancellation is proven in established phone technologies.</td>
</tr>
<tr>
<td>FEXT is the noise induced by a transmitter at the near-end into a far-end receiver due to unwanted signal coupling. FEXT can be a factor in multi-pair, bidirectional signaling such as 1000BASE-T. It is countered by the use of cancellation.</td>
</tr>
<tr>
<td>Equal level far-end cross talk (ELFEXT) is defined as the measure of the unwanted signal coupling from a transmitter at the near-end into a neighboring pair measured at the far-end relative to the received signal level measured on that same pair (Figure B-3).</td>
</tr>
</tbody>
</table>

Figure B-1

Bidirectional transmission on the same wire results in echo (Figure B-2). Echo is the combined effect of the cabling return loss and the hybrid function.

Figure B-2

Return loss is a measure of the reflected energy caused by impedance mismatches in the cabling system. Echo is countered by echo cancellation. Echo cancellation is proven in established phone technologies.

FEXT is the noise induced by a transmitter at the near-end into a far-end receiver due to unwanted signal coupling. FEXT can be a factor in multi-pair, bidirectional signaling such as 1000BASE-T. It is countered by the use of cancellation.

Equal level far-end cross talk (ELFEXT) is defined as the measure of the unwanted signal coupling from a transmitter at the near-end into a neighboring pair measured at the far-end relative to the received signal level measured on that same pair (Figure B-3).

Table A-1
Performance parameters for 10BASE-T, 100BASE-TX, and 1000BASE-T cabling

The transmit signal is subject to impairments introduced by the cabling and external noise sources (Figure B-4). In order for the receiver to operate reliably, the impairments to the transmit signal need to be controlled. The signal-to-noise ratio (SNR), the ratio between the impairments (typically referred to as noise) and the transmit signal, is maintained in order to achieve an acceptable bit error rate (BER).

The following key cabling performance parameters characterize the signal impairments.

- **Attenuation** is a reduction in signal power due to cabling losses expressed in decibels (Figure B-5). Attenuation is a function of frequency and is proportional to the cable length; that is, at a given frequency, the attenuation of 50 meters is one-half of the attenuation of 100 meters. The effect of attenuation is countered at the receiver by the equalization of the signal, which compensates for the cabling losses. Ethernet, Fast Ethernet, and Gigabit Ethernet signals are subject to cabling attenuation.

- **Near-end cross talk (NEXT)** is the noise induced by a transmitter to a neighboring receiver due to unwanted signal coupling (Figure B-6). NEXT can impair both Ethernet/Fast Ethernet and Gigabit Ethernet. It is countered by the use of NEXT cancellation. Gigabit Ethernet technology employs the use of NEXT cancellation, while Fast Ethernet does not. The addition of NEXT cancellation to 1000BASE-T is an enhancement to Ethernet/Fast Ethernet because it provides additional immunity to noise.

- **Delay** is the time it takes for a signal to travel through a medium compared to the speed of light. Delay skew is the difference in delay between pairs (Figure B-7). The delay skew specification ensures that the transmit signals divided across the four pairs can be reassembled in Ethernet/Fast Ethernet and Gigabit Ethernet.

**Note on performance margins:** It is important to realize that 1000BASE-T has been designed to operate under worst-case conditions at the maximum distance. That is, 1000BASE-T has been designed to work when the performance characteristics of each and all of the components in the link (cable and connecting hardware) are worst case. It is highly unlikely in a real network that the installed infrastructure would contain multiple or all worst-case components. Additionally, the attenuation of the cable scales by distance, that is, 50 meters of cable, has half the attenuation of 100 meters. Therefore, most installed cabling and the average installation will enjoy a significant performance margin or “headroom.”

**Summary**

All Ethernet twisted-pair technologies are subject to signal impairment. But in the case of 1000BASE-T, these disturbances are cancelled. For example, 1000BASE-T echo cancellation uses established, proven technologies leveraged from telecommunications. In addition, 1000BASE-T cross talk cancellation uses digital signal processing (DSP) technology that has been used by many advanced modems and digital subscriber line (DSL) devices. Table B-1 summarizes the signal impairments and corrective actions implemented in 1000BASE-T.

<table>
<thead>
<tr>
<th>Signal Disturbance</th>
<th>Signal Integrity Restoration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attenuation</td>
<td>Adaptive equalizers</td>
</tr>
<tr>
<td>NEXT</td>
<td>NEXT cancelers</td>
</tr>
<tr>
<td>FEXT</td>
<td>FEXT cancellers</td>
</tr>
<tr>
<td>Return Loss</td>
<td>Echo cancellers</td>
</tr>
</tbody>
</table>

**Table B-1**
Category 5 cabling field mitigation procedures

ANSI/TIA/EIA-568-B.3 (1998) defines corrective actions that can be taken to improve return loss and ELFEXT performance. These corrections apply to the different elements of the Category 5 cabling systems as specified by ANSI/TIA/EIA-568-A (see Figure D-1). The cross-connect is a facility, generally a type of patch panel that allows a connection between the horizontal cable and the equipment cable using a patch cord or jumper. Cross connections are not generally used for high-speed data communication cabling solutions. 1000BASE-T recommends an interconnect cabling solution as illustrated in Figure D-2. The interconnect cabling predominates in data communication cabling. The interconnection patch panel provides for the direct connection of the horizontal cable to the equipment cable. The following five steps are to reduce the maximal configuration to the minimal configurations. They reference the elements in Figures D-1 and D-2.

1. Replace the patch cord with a cord constructed from a Category 5e patch cable, a patch cable designed to comply with the return loss and ELFEXT parameters.
2. Reconfigure the cross-connect as an interconnect.
3. Replace the transition point or consolidation point connector with a Category 5e transition point or consolidation point connector.
4. Replace the work-area outlet connector with a Category 5e work-area outlet connector.
5. Replace the interconnect with a Category 5e interconnect.

A retest for compliance is recommended after each option is implemented. In practice, some flexibility in the order of implementation of these options is possible. For example, it may be more convenient to substitute a new patch cord as a first step while the tester is at that location.

1000BASE-T physical layer implementation

As described earlier, the 1000BASE-T physical layer is composed of various sublayers.

From the MAC layer, frames of eight bits are transmitted to the physical coding sublayer (PCS) through the Gigabit Media Independent Interface (GMII). To encode eight GMII bits, 2^8 = 256 codes are needed. A two-level signal used on each of the four pairs of transmission would enable the coding of 2^2 = 16 data codes. Similarly, a three-level signal would give 3^2 = 81 codes. A five-level signal gives 5^2 = 25 potential codes and has been chosen by the IEEE for implementation. The specific five-level signal used by 1000BASE-T is Pulse Amplitude Modulation 5 (PAM-5), which was already implemented in 100BASE-T2 (Fast Ethernet over two pairs of Category 3).

By comparison, 100BASE-T uses three-level signaling (MLT-3). Figure C-1 shows the eye patterns of 100BASE-T and 1000BASE-T signaling. The eye pattern illustrated was produced by a modulated random-data waveform, with each symbol period tracing from left to right and starting in the same place on the left. The figure shows that 1000BASE-T provides closer consecutive levels of signals and therefore a greater sensitivity to transmission distortions – that is, it has a reduced signal-to-noise margin compared to 100BASE-T.

The reduced noise margin lost at the level of PAM-5 is recovered, thanks to the use of convolution coding. Convolution coding implemented by 1000BASE-T (called Trellis coding)
allows error detection and correction by the receiver (through Viterbi decoding). These are established, proven technologies defined and used in modems for more than ten years. In comparison, 100BASE-TX uses block coding (4B5B coding, four bits coded by five symbols). Block coding uses simple codes that do not offer error detection or correction.

In fact, the use of Trellis coding and Viterbi decoding makes 1000BASE-T even more resilient to external noise than 100BASE-T. The 1000BASE-T transmits uncorrelated symbols in the transmitted symbol stream; no correlation is allowed between symbol streams traveling in both directions on any pair combination, and no correlation is allowed between symbol streams on each pair. External noise pickup is generally correlated (common) to each pair. External noise can be cancelled statistically providing improvements in noise immunity that are not available in 100BASE-TX.

Summary
1000BASE-T is designed to run reliably on the same Category 5 cabling as Fast Ethernet because it implements powerful digital signaling and coding/decoding methods that maintain the integrity of the signal when transmitted over Category 5 cabling. Figure C-2 shows the architecture of a 1000BASE-T transceiver, which implements the various technologies detailed earlier.